<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VENUSIAN CORONA-NOVAE WITH ARCUATE GRABEN: EVIDENCE FOR LAVA-FLOW MODIFICATION</td>
<td>MS002</td>
</tr>
<tr>
<td>Aittola M. and Kostama V.-P.</td>
<td></td>
</tr>
<tr>
<td>METEORITE ABLATION BASED ON COSMIC RAY TRACK STUDIES</td>
<td>MS003</td>
</tr>
<tr>
<td>Alexeev V.A.</td>
<td></td>
</tr>
<tr>
<td>DEFINITION OF PARAMETERS OF NUCLEUSES OF GALACTIC COMETS BY MEASURE-MENT OF DIAMETERS OF CRATERS ON THE MARS AND THE MOON</td>
<td>MS004</td>
</tr>
<tr>
<td>Barenbaum A.A.</td>
<td></td>
</tr>
<tr>
<td>VARIATIONS OF ELASTIC ENERGY IN EARTH-MOON SYSTEM AND THEIR CORRELATIONS WITH EARTHQUAKES AND MOONQUAKES</td>
<td>MS005</td>
</tr>
<tr>
<td>Barkin Yu.V., Ferrandiz J.M., and Navarro J.</td>
<td></td>
</tr>
<tr>
<td>MONITORING MARS LOD VARIATIONS FROM A HIGH ALTITUDE CIRCULAR EQUATORIAL ORBIT</td>
<td>MS006</td>
</tr>
<tr>
<td>Barriot J.-P.</td>
<td></td>
</tr>
<tr>
<td>AIRFALL CRATER DEPOSITS ON THE SURFACE OF VENUS</td>
<td>MS007</td>
</tr>
<tr>
<td>Basilevsky A.T. and Head J.W.</td>
<td></td>
</tr>
<tr>
<td>EJECTA OUTFLOWS OF VENUSIAN IMPACT CRATERS: CORRELATION WITH THE DARK HALO PRESERVATION DEGREE</td>
<td>MS008</td>
</tr>
<tr>
<td>Basilevsky A.T. and Setytaeva I.V.</td>
<td></td>
</tr>
<tr>
<td>THE TERRA ARABIA LOW EPITHERMAL NEUTRON FLUX ANOMALY: POSSIBLE CORRELATION WITH PRESENCE OF LAYERED DEPOSITS</td>
<td>MS009</td>
</tr>
<tr>
<td>THICKNESS OF CRATER-RELATED MANTLES ON VENUS</td>
<td>MS010</td>
</tr>
<tr>
<td>Bondarenko N.V. and Head J.W.</td>
<td></td>
</tr>
<tr>
<td>THE GEOLOGIC EVOLUTION OF THE URAL MOUNTAINS: A SUPPOSED EXPOSURE TO A GIANT IMPACT</td>
<td>MS011</td>
</tr>
<tr>
<td>Burba G.A.</td>
<td></td>
</tr>
<tr>
<td>ARRANGEMENT OF LAVA CHANNELS ON THE SURFACE OF VENUS: A POSSIBLE EVIDENCE OF THE INTERIOR DYNAMICS</td>
<td>MS012</td>
</tr>
<tr>
<td>Burba G.A.</td>
<td></td>
</tr>
<tr>
<td>SEARCH OF CORRELATION BETWEEN NUCLEAR LINES MEASURED BY GRS AND NEUTRON DATA FROM HEND ONBOARD 2001 MARS ODYSSEY</td>
<td>MS013</td>
</tr>
<tr>
<td>Charyshnikov S.V., Litvak M.L., Mitrofanov I.G., Kozyrev A.S., Sanin A.B., Tretyakov V., Boynton W.V., Hamara D.K., Shinohara C., Saunders R.S., and Drake D.</td>
<td></td>
</tr>
<tr>
<td>WHEN MARS WAS SIMILAR TO JUPITER</td>
<td>MS014</td>
</tr>
<tr>
<td>Dmitriev E.V.</td>
<td></td>
</tr>
<tr>
<td>MARS: MOVEMENT OF GEOGRAPHICAL POLES AND DEFORMATION OF ITS SURFACE</td>
<td>MS015</td>
</tr>
<tr>
<td>Dolitsky A.V., Rodionova J.F., Kochetkov R.M., Ainetdinova A.F.</td>
<td></td>
</tr>
<tr>
<td>CHARACTERISTICS OF VALLEYS ON CERAUNIUS THOLUS AND THEIR FORMATION: PART I</td>
<td>MS016</td>
</tr>
<tr>
<td>Fassett C.I. and Head J.W.</td>
<td></td>
</tr>
<tr>
<td>CHARACTERISTICS OF VALLEYS ON CERAUNIUS THOLUS AND THEIR FORMATION: PART II</td>
<td>MS017</td>
</tr>
<tr>
<td>Fassett C.I. and Head J.W.</td>
<td></td>
</tr>
<tr>
<td>HIGH DENSITY PHASES AS AN ATTRIBUTE OF IMPACT STRUCTURES. CONDITIONS OF FORMATION AND PRESERVATION IN SHOCK PROCESSES</td>
<td>MS018</td>
</tr>
<tr>
<td>Feldman V.I., Sazonova L.V., and Kozlov E.A.</td>
<td></td>
</tr>
</tbody>
</table>
Microsymposium 38 Abstracts
Table of Contents

ESA SMART-1 MISSION TO THE MOON

COMPARATIVE DEGASSING HISTORY OF EARTH AND VENUS
Franck S. and Bounama C.

SPHERICAL ANALYSIS OF GEOMETRY OF EARTH STRUCTURES
Garcia Ferrandez M., Ferrandiz J.M., and Barkin Yu.V.

IMPACTS OF LARGE METEORITES AS A POSSIBLE SOURCE OF ORGANIC COMPONENTS ON TITAN
Gerasimov M.V. and Sañonova E.N.

ON THE EVAPORATIVE CHEMICAL DIFFERENTIATION OF IMPACT-PRODUCED MELTS
Gerasimov M.V., Yakovlev O.I., Dikov Yu.P., and Ivanov B.A.

SEARCH FOR SEASONAL VARIATIONS OF MARTIAN GAMMA-RAY FLUX BASED ON HEND/ODYSSEY DATA

VENUS SURFACE PANORAMAS: HYPOTHESES FOR THE ORIGIN OF SURFACE FEATURES
Head J.W. and Basilevsky A.T.

THE MARTIAN HYDROLOGICAL CYCLE AND LATE NOACHIAN HYDROLOGY: TERRESTRIAL BACKGROUND 1
Head J.W., Carr M., Russell P., Fassett C.I.

THE MARTIAN HYDROLOGICAL CYCLE AND LATE NOACHIAN HYDROLOGY: TERRESTRIAL BACKGROUND 2
Head J.W., Carr M., Russell P., Fassett C.I.

LATE NOACHIAN HYDROLOGICAL CYCLE: GROUNDWATER SAPPING TERRESTRIAL ANALOGS AND LABORATORY EXPERIMENTS 3
Head J.W., Carr M., Russell P., Fassett C.I.

LATE NOACHIAN HYDROLOGICAL CYCLE: THEATER-HEADED VALLEYS, FRETTED CHANNELS AND LARGE VALLEY NETWORKS 4
Head J.W., Carr M., Russell P., Fassett C.I.

LATE NOACHIAN HYDROLOGICAL CYCLE: THE DICHTOTOMY BOUNDARY 5
Head J.W., Carr M., Russell P., Fassett C.I.

LATE NOACHIAN HYDROLOGICAL CYCLE: THE DICHTOTOMY BOUNDARY 6
Head J.W., Carr M., Russell P., Fassett C.I.

MARTIAN HYDROLOGY: SUMMARY OF THE LATE NOACHIAN HYDROLOGICAL CYCLE 7
Head J.W., Carr M., Russell P., Fassett C.I.

GEOLOGY AND HYDROLOGY OF THE ARGYRE BASIN, MARS BASED ON MOLA AND MOC DATA
Hiesinger H. and Head J.W.

LUNAR SOUTH POLE-AITKEN IMPACT BASIN: CLEMENTINE TOPOGRAPHY AND IMPLICATIONS FOR THE INTERPRETATION OF BASIN STRUCTURE AND STRATIGRAPHY
Hiesinger H. and Head J.W.

BIOGENIC RINGED DARK DUNE SPOTS ON MARS?
Horvath A., Ganti T., Berczi Sz., and Szathmary E.

SOME FEATURES OF THE CRATERING OF ISIDIS BASIN
Iluhina J.A., Lagutkina A.V., and Rodionova J.F.
<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL MODEL OF MARTIAN POLAR CAPS: POSSIBLE IMPLICATIONS FOR ORBITAL RADAR SOUNDING</td>
<td>Ilyushin Ya.A.</td>
<td>MS036</td>
</tr>
<tr>
<td>DEMONSTRATION OF POLYGONAL ICE-WEDGES TERRAINS ON THE WEASTERN SIBIREA AND THEIR COMPATIBILITY WITH SAME PATTERNS ON THE MARS</td>
<td>Isaev V.S., Abramenko O.N.</td>
<td>MS001</td>
</tr>
<tr>
<td>STRATIGRAPHY OF SMALL SHIELDS ON VENUS: CRITERIA FOR DETERMINING STRATIGRAPHIC RELATIONSHIPS AND ASSESSMENT OF THE RELATIVE AGE</td>
<td>Ivanov M.A. and Head J.W.</td>
<td>MS037</td>
</tr>
<tr>
<td>GEOLOGIC MAP OF THE MYLITTA FLUCTUS QUADRANGLE (V-61), VENUS</td>
<td>Ivanov M.A. and Head J.W.</td>
<td>MS038</td>
</tr>
<tr>
<td>THE MAGMATIC TRANSPORT OF CARBON AND HYDROGEN CONSTITUENTS FROM REDUCED PLANETARY INTERIORS</td>
<td>Kadik A.A.</td>
<td>MS040</td>
</tr>
<tr>
<td>TO THE PROBLEM OF SEARCH FOR SUPER-HEAVY ELEMENT TRACES IN THE METEORITES: PROBABILITY OF THEIR DISCOVERY BY THE NUCLEAR SPONTANEOUS FISSION TRACKS</td>
<td>Kashkarov L.L., Kravtsov L.I., Kalinina G.V., and Kniazeva G.P.</td>
<td>MS042</td>
</tr>
<tr>
<td>MAPS OF MATURITY-CORRELATED PARAMETERS OF THE LUNAR REGOLITH</td>
<td>Kaydash V., Shkuratov Yu., Pieters C., Omelchenko V., and Stankevich D.</td>
<td>MS043</td>
</tr>
<tr>
<td>ARKHYS-DISTURBED METEORITE CRATER IN NORTH CAUCASUS</td>
<td>Krjjanina L.P.</td>
<td>MS044</td>
</tr>
<tr>
<td>TECTONICALLY AND CHEMICALLY DICHTOMIC MARS IS THE LEAST OUTGASED OF TERRESTRIAL PLANETS</td>
<td>Kochmasov G.G.</td>
<td>MS045</td>
</tr>
<tr>
<td>STRUCTURES OF THE WAVE PLANETOLOGY AND THEIR PROJECTION ONTO THE SOLAR PHOTOSPHERE: WHY SOLAR SUPERGRANULES ARE 30000 KM ACROSS</td>
<td>Kochmasov G.G.</td>
<td>MS046</td>
</tr>
<tr>
<td>POST-IMPACT DEPRESSIONS ON MARTIAN CRATER FLOORS: PRELIMINARY RESULTS AND A CASE STUDY OF THE GREATER HELLAS REGION</td>
<td>Korteniemi J., Kostama V.-P. and Raitala J.</td>
<td>MS048</td>
</tr>
<tr>
<td>TEMPERATURE MODE IN COLD TRAPS ON THE MOON</td>
<td>Kozlova E.A.</td>
<td>MS049</td>
</tr>
<tr>
<td>SUBSURFACE WATER DISTRIBUTION IN MARTIAN EQUATORIAL REGIONS FROM HEND/ODYSSEY DATA</td>
<td>Kozyrev A.S., Mitrofanov I.G., Litvak M.L., Sanin A.B., Tretyakov V., Boynton W.V., Hamara D.K., Shinozara C., Saunders R. S., and Drake D.</td>
<td>MS050</td>
</tr>
<tr>
<td>CALDERAS ON VENUS AND EARTH (I). PLANET EARTH: OVERVIEW OF CALDERAS</td>
<td>Krassilnikov A.S. and Head J.W.</td>
<td>MS051</td>
</tr>
<tr>
<td>Title</td>
<td>Authors</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>CALDERAS ON VENUS AND EARTII (II): COMPARISON AND MODELS OF FORMATION</td>
<td>Krassilnikov A.S. and Head J.W.</td>
<td>MS052</td>
</tr>
<tr>
<td>POSSIBLE ROLE OF MAGNETIC MATERIALS IN RADIOPHYSICS OF VENUS SURFACE</td>
<td>Kreslavsky M.A. and Starukhina L.V.</td>
<td>MS053</td>
</tr>
<tr>
<td>CRATERS AND OTHER CIRCULAR FEATURES IN NORTHERN CIRCUMPOLAR AREA, MARS</td>
<td>Kreslavsky M.A., Kostama V.-P., and Head J.W.</td>
<td>MS054</td>
</tr>
<tr>
<td>AN INTERNAL LIQUID-WATER OCEAN IN CALLISTO</td>
<td>Kronrod V.A. and Kuskov O.L.</td>
<td>MS055</td>
</tr>
<tr>
<td>PREPARATION OF THE LUNAR SURFACE SURVEYING RESULTS ON THE PROGRAM &quot;Zond&quot; FOR REPRESENTATION IN INFORMATION SYSTEM</td>
<td>Kurpichev A.V.</td>
<td>MS056</td>
</tr>
<tr>
<td>THE CRATER LAKES AND OTHER IMPLICATIONS FOR STANDING BODIES OF WATER IN HELLAS REGION, MARS</td>
<td>Lahtela H., Kostama V.-P., Aittola M., Ohman T., and Raitala J.</td>
<td>MS057</td>
</tr>
<tr>
<td>AUBRITES: TRACE ELEMENT ABUNDANCES IN SEPARATED PHASES AND PETROGENESIS</td>
<td>Lavrentjeva Z.A., Lyul A.Yu., and Kolesov G.M.</td>
<td>MS058</td>
</tr>
<tr>
<td>SOME PROBLEMS OF THE EVOLUTION OF ASTEROID - RUBBLE PILE</td>
<td>Leikin G.A. and Sanovich A.N.</td>
<td>MS059</td>
</tr>
<tr>
<td>THE CONCEPT ON FORMATION OF THE TERRITORIAL - SPATIAL DATA BASE DEVELOPMENT AS A TOOL TO REPRESENT THE CARTOGRAPHIC INFORMATION OF SOLAR SYSTEM BODIES</td>
<td>Leonenko S.M.</td>
<td>MS060</td>
</tr>
<tr>
<td>OBSERVATIONS OF MARS SEASONAL CAPS FROM HEND/ODYSSEY DATA</td>
<td>Litvak M.L., Mitrofanov I.G., Kozylev A.S., Sanin A.B., Tretyakov V., Boynnton W.V., Hamara D.K., Shinohara C., Saunders R.S., and Drake D.</td>
<td>MS061</td>
</tr>
<tr>
<td>POSSIBLE REASONS OF LOW Fe3+/Fe2+ RATIOS IN TEKTITES IN COMPARISON WITH THAT OF INITIAL TARGET MATTER INVOLVED IN THE IMPACT PROCESS</td>
<td>Lukanin O.A and Kadik A.A.</td>
<td>MS062</td>
</tr>
<tr>
<td>FORMATION OF HYDRATED SILICATES IN EDFGOWORTH-KUIPER BELT OBJECTS</td>
<td>Makalkin A.B., Dorofeeva V.A., and Busarev V.V.</td>
<td>MS063</td>
</tr>
<tr>
<td>LUNAR CRATERS HAVE ENDOGENIC NATURE</td>
<td>Makarenko G.F.</td>
<td>MS064</td>
</tr>
<tr>
<td>VOLCANIC FESTOON DEPOSITS ON VENUS: FRACTAL ANALYSES AND IMPLICATIONS FOR EMPLACEMENT</td>
<td>McColley S.M. and Head J.W.</td>
<td>MS066</td>
</tr>
<tr>
<td>SURVEY OF MARS CRATER TOPOGRAPHY FROM MOLA DATA</td>
<td>Michael G.G.</td>
<td>MS067</td>
</tr>
<tr>
<td>VERTICAL DISTRIBUTION OF SHALLOW WATER IN MARS SUBSURFACE FROM HEND/ODYSSEY DATA</td>
<td>Litvak M.L., Kozylev A.S., Sanin A.B., Tretyakov V., Boynnton W.V., Hamara D.K., Shinohara C., Saunders R. S., and Drake D.</td>
<td>MS069</td>
</tr>
<tr>
<td>MAPS OF LUNAR PYROXENES</td>
<td>Omelchenko V., Shkuratov Yu., Pieters C., Stankevich D., and Kaydash V.</td>
<td>MS070</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>MICROSTRUCTURE PROPERTIES OF THE REINER GAMMA FORMATION AS DEDUCED FROM EARTH-BASED PHOTOMETRY AND POLARIMETRY</td>
<td>MS071</td>
<td></td>
</tr>
<tr>
<td>Opanasenko N. and Shkuratov Yu.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOURCES OF WATER RELATED TO THE EXCAVATION OF THE SHALBATANA VALLEY SYSTEM, MARS</td>
<td>MS072</td>
<td></td>
</tr>
<tr>
<td>Palmero A., Sasaki S., Kuzmin R.O., and Greeley R.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THE CASTALIA MACULA REGION: A PLATE RECONSTRUCTION MODELLING TEST CASE</td>
<td>MS073</td>
<td></td>
</tr>
<tr>
<td>Patterson G.W. and Head J.W.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARLY EARTH AND XE-MISSING PROBLEM SOLUTION</td>
<td>MS074</td>
<td></td>
</tr>
<tr>
<td>Pechernikova G.V., Vityazev A.V., and Bashkirov A.G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ON A PROBLEM FOR SEARCHING OF EXO-PLANET SATELLITES</td>
<td>MS075</td>
<td></td>
</tr>
<tr>
<td>Perov N.I. and Nahodneva A.A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHOTOMETRY OF REGOLITH-LIKE SURFACES: ALBEDO AND SURFACE ROUGHNESS EFFECTS</td>
<td>MS076</td>
<td></td>
</tr>
<tr>
<td>Petrov D.V. and Shkuratov Yu.G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SYSTEMATIC GLOBAL MIXING AND MELTING IN LUNAR SOIL EVOLUTION</td>
<td>MS077</td>
<td></td>
</tr>
<tr>
<td>Pieters C. M. and Taylor L. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VENUS: GLOBAL MAPPING OF RIDGE BELT PATTERNS</td>
<td>MS078</td>
<td></td>
</tr>
<tr>
<td>Pivchenkova E.V. and Kryuchkov V.P.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ON THE BASIS OF TERRESTRIAL ANALOGUE SITE STUDIES ARE THE DARK DUNE SPOTS REMNANTS OF THE CRYPTO-BIOTIC-CRUST OF MARS?</td>
<td>MS079</td>
<td></td>
</tr>
<tr>
<td>Pocs T., Horvath A., Ganti T., Berczi Sz., and Szathmary E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHYSICAL AND MINERALOGY CHARACTERISTICS OF THE LUNAR REGOLITH IN THE AREAS OF THE THERMAL ANOMALIES</td>
<td>MS080</td>
<td></td>
</tr>
<tr>
<td>Pugacheva S.G. and Shevchenko V.V.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAVONIS MONS FAN-SHAPED DEPOSIT - A COLD-BASED GLACIAL MODEL</td>
<td>MS081</td>
<td></td>
</tr>
<tr>
<td>Shean D.E. and Head J.W.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVALUATING THE STRUCTURE OF THE SURFACE LAYER OF MERCURY</td>
<td>MS082</td>
<td></td>
</tr>
<tr>
<td>Shevchenko V.V.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MERCURY: LOCAL VARIATIONS OF THE PHOTOMETRIC RELIEF</td>
<td>MS083</td>
<td></td>
</tr>
<tr>
<td>Shevchenko V.V.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REMOTE DETERMINATION OF LUNAR SOIL MATURITY</td>
<td>MS084</td>
<td></td>
</tr>
<tr>
<td>Shevchenko V.V., Pinet P., Chevrel S., Daydou Y., Skobeleva T.P., Kvaratkhelia O.I., and Roseenberg C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REMOTE METHOD OF IDENTIFICATION OF THE EJECTA LUNAR TERRAINS AND THEIR COMPOSITION FITURES</td>
<td>MS085</td>
<td></td>
</tr>
<tr>
<td>Shevchenko V.V., Pinet P., Chevrel S., Pugacheva S.G., and Daydou Y.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIMULATION OF SOME SPACE WEATHERING EFFECTS IN PHOBOS REGOLITH BY LASER IRRADIATION OF CARBONACEOUS CHONDRITE MIGHEI</td>
<td>MS086</td>
<td></td>
</tr>
<tr>
<td>Shingareva T.V., Basilevsky A.T., Fisenko A.V., Semjonova L.F., Chistyakova N.I., and Nechelyustov G.N.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOME RESULTS BY USING OF NONLINEAR ALGORITHM FOR CALCULATION OF TRANSFORMATION PARAMETERS BETWEEN PLANET COORDINATE SYSTEMS</td>
<td>MS087</td>
<td></td>
</tr>
<tr>
<td>Shirenin A.M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REGULARITIES OF THE &quot;MERCURY BREATH&quot; OF THE EARTH. II. AMPLITUDES OF MERCURY VAPOR FLOW AND THEIR SENSITIVITIES TO EARTH-CRUST TIDES</td>
<td>MS088</td>
<td></td>
</tr>
<tr>
<td>Stakheev Yu.I.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS089</td>
<td>NUMERICAL SIMULATION OF VERTICAL DISTRIBUTION OF NEUTRONS BORNED BY COSMIC RAYS IN A MODEL MARTIAN SOILS FOR PROCESSING OF HEND/ODYSSEY DATA</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Tretyakov V., Litvak M.L., Mitrofanov I.G., Kozyrev A.S., Sanin A.B., Boynton W.V., Hamara D.K., Shinohara C., Saunders R.S., and Drake D.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS090</th>
<th>THE MORPHOMETRIC ANALYSIS OF THE FEATURES OF MARTIAN CRATERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ushkin I.A., Michael G.G., Kozlova E.A.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS091</th>
<th>TECHNIQUE, ALGORITHMS AND THE SOFTWARE OF DYNAMIC REGRESSION MODELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeev S.G. and Sergeyev E.S.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS092</th>
<th>MODELLING OF MOVEMENT OF THE EARTH POLES ON THE BASIS OF THE DRM-APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeev S.G. and Sergeyev E.S.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS093</th>
<th>PERSPECTIVES OF APPLICATION OF METHODOLOGY OF DRM-APPROACH FOR MODELLING OF SOLAR ACTIVITY (SA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeev S.G. and Sergeyev E.S.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS094</th>
<th>RECENT RESULTS OF UKRAINIAN SHIELD ASTROBULSES STUDY AND THEIR POSSIBLE SIGNIFICANCE TO GEOLOGY AND PLANETOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valter A.A.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS095</th>
<th>SOUTH-POLAR POLYGONAL PATTERNS - PHENOTYPES AND LOCAL GEOMORPHOLOGIC CONTEXT</th>
</tr>
</thead>
<tbody>
<tr>
<td>van Gasselt S., Reiss D., and Neukum G.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS096</th>
<th>ON ABILITY OF STUDY OF NATURE OF CELESTIAL BODIES UNDER POLARIZATION MEASUREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vid'machenko A.P. and Morozhenko A.V.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS097</th>
<th>GEOLOGY AND STRATIGRAPHY OF IMPACT CRATERS ON CALLISTO - RESULTS FROM HIGH-RESOLUTION IMAGES OF THE GALILEO SSI CAMERA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagner R. and Neukum G.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS098</th>
<th>STRATIGRAPHY AND AGES OF LUNAR VOLCANIC DOMES: HANSTEEN AND HELMET REGIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagner R.J., Head III J. W., Wolf U., and Neukum G.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS099</th>
<th>GIANT POLYGONS IN MARTIAN LOWLAND PLAINS AND THE EXISTENCE OF AN OCEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Werner S. C., van Gasselt S., and Neukum G.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS100</th>
<th>THE ROLE OF SINGLE SCATTERING IN SHAPING OF NEGATIVE POLARIZATION BRANCHES OF DARK REGOLITH-LIKE SURFACES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zubko E., Ovcharenko A., Shkuratov Yu., and Videen G.</td>
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</tr>
</tbody>
</table>
Abramenko O.N. MS001
Ainetdinova A.F. MS015
Aittola M. MS002, MS057, MS065
Alexeev V.A. MS003
Barenbaum A.A. MS004
Barkin Yu.V. MS021, MS005
Barriot J.-P. MS006
Bashkirov A.G. MS074
Basilevsky A.T. MS007, MS008, MS025, MS009, MS086
Berczi Sz, MS034, MS079
Bondarenko N.V. MS010
Bounama C. MS020
Boynton W.V, MS009, MS013, MS024, MS050, MS061, MS069, MS089
Burba G.A. MS011, MS012
Busarev V.V. MS063
Carr M, MS026, MS027, MS028, MS029, MS030, MS031, MS032
Charyshnikov S.V. MS013, MS024
Chevrel S, MS084, MS085
Chicarro A.F. MS007, MS008
Chistyakova N.I. MS086
Daydou Y. MS084, MS085
Dikov Yu.P. MS023
Dmitriev E.V. MS014
Dolitsky A.V. MS015
Dolnikov G.G. MS047
Dorofeeva V.A. MS063
Drake D. MS013, MS024, MS050, MS061, MS069, MS089
Fassett C.I. MS016, MS017, MS026, MS027, MS028, MS029, MS030, MS031, MS032
Feldman V.I. MS018
Ferrandiz J.M. MS005, MS021
Fisenko A.V. MS086
Foing B.H. MS019
Franck S. MS020
Ganti T. MS034, MS079
Garcia Ferrandez M. MS021
Gerasimov M.V. MS022, MS023, MS047
Grande M. MS019
Greeley R. MS072
Grinkov V.Y. MS024
Hamara D.K. MS013, MS024, MS050, MS061, MS069, MS089
Head J. W. MS007, MS009, MS010, MS016, MS017, MS025, MS026, MS027, MS028, MS029, MS030, MS031, MS032, MS033, MS037, MS038, MS051, MS052, MS054, MS066, MS073, MS081, MS098, MS101
Hiesinger H. MS033, MS03
Horvath A. MS034, MS079
Huovelin J. MS019
Iluhina J.A. MS068, MS035
Ilyushin Ya.A. MS036
Isaev V.S. MS001
Ivanov B.A. MS023
Ivanov M.A. MS037, MS038
Ivliev A.I. MS039, MS041
Josset J.-L. MS019
Kadik A.A. MS040, MS062
Kalinina G.V. MS039, MS041, MS042
Kashkarov L.L. MS039, MS041, MS042
Kaydash V. MS070, MS043
Keller H.U. MS019
Khlanina L.P. MS044
Klingelhofer G. MS047
Kniazeva G.P. MS042
Kochmasov G.G. MS045, MS046
Kochetkov R.M. MS015
Kolesov G.M. MS058
Korchuganov B.N. MS047
Korteniemi J. MS048
Koschney D. MS019
Kostama V.-P. MS002, MS048, MS065, MS054, MS057
Kozlov E.A. MS018, MS049, MS068, MS090
Kozyrev A.S. MS009, MS013, MS024, MS050, MS061, MS069, MS089
Krassilnikov A.S. MS051, MS052
Kravets L.I. MS042
Kreslavsky M.A. MS053, MS054
Kronrod V.A. MS055
Kryuchkov V.P. MS078
Kurpichev A.V. MS056
Kuskov O.L. MS055
Kuyunko N.S. MS039
Kuzmin R.O. MS072
Kvaratskhelia O.I. MS084
Lagutkina A.V. MS035
Lahtela H. MS057
Lavrentjeva Z.A. MS058, MS039
Leikin G.A. MS059
Leonenko S.M. MS060
Litvak M.L. MS013, MS024, MS050, MS061, MS069, MS089
Lukanin O.A MS062
Lyul A.Yu. MS039, MS058
Makalkin A.B. MS063
Makarenko G.F. MS064
Malki A. MS019
Manso Rogeiro I. MS065
Marini A. MS019
McColley S.M. MS066
Michael G.G. MS019, MS067, MS068, MS090
Mitrofanov I.G. MS009, MS013, MS024, MS050, MS061, MS069, MS089
Morozhenko A.V. MS096
Nahodneva A.A. MS075
Nathues A. MS019
Navarro J. MS005
Nechelyustov G.N. MS086
Neukum G. MS095, MS097, MS098, MS099, MS009
Ohman T. MS057
Omelchenko V. MS043, MS070
Opanasenko N. MS071
Ovcharenko A. MS100
Palmero A. MS072
Patterson G.W. MS073
Pechenikova G.V. MS074
Perov N.I. MS075
Petrov D.V. MS076
Pieters C. M. MS077, MS043, MS070
Pinet P. MS084, MS085
Pivchenkova E.V. MS078
Pocs T. MS079
Prlutskyi O.F. MS047
Pugacheva S.G. MS080, MS085
Racca G.R. MS019
Raitala J. MS048, MS057, MS065
Reiss D. MS095
Rieder R. MS047
Rodionova J.F. MS015, MS035, MS068
Rosenberg C. MS084
Russell P. MS026, MS027, MS028, MS029, MS030, MS031, MS032
Safronova E.N. MS022
Sanin A.B. MS009, MS013, MS024, MS050, MS061, MS069, MS089
Sanovich A.N. MS059
Sasaki S. MS072
Saunders R. S. MS050, MS069, MS009, MS013, MS024, MS061, MS089
Sazonova L.V. MS018
Semjonova L.F. MS086
Sergeyev E.S. MS091, MS092, MS093
Setytaeva I.V. MS008
Shean D.E. MS081
Shchekhov V.V. MS068, MS080, MS082, MS083, MS084, MS085
Shingareva T.V. MS086
Shinohara C. MS013, MS024, MS050, MS061, MS069, MS089
Shirenin A.M. MS087
Shkuratov Yu. MS043, MS070, MS071, MS076, MS010
Skobeleva T.P. MS084
Skripnik A.Ya. MS039, MS041
Stakheev Yu.I. MS088
Stankevich D. MS043, MS070
Starukhina L.V. MS053
Szathmary E. MS034, MS079
Taylor L. A. MS077
Tretyakov V. MS013, MS024, MS050, MS061, MS069, MS089
Ushkin I.A. MS090
Valeev S.G. MS091, MS092, MS093
Valter A.A. MS094
van Gasselt S. MS095, MS099
Vid’machenko A.P. MS096
Videen G. MS100
Vityazev A.V. MS074
Wagner R. MS097, MS098
Werner S. C. MS099, MS009
Wolf U. MS098
Yakovlev O.I. MS023
Zubko E. MS100
DENOMINATION OF POLYGONAL ICE-WEDGES TERRAINS ON THE TAZOVSKY PENINSULA IN THE WEASTERN SIBIREA AND SOME POLYGONAL PATTERNS ON THE MARS.

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Introduction: Frost cracking process is widespread on the permafrost areas as well on the season-frost areas on the Earth. In the terrestrial conditions these processes are responsible to the formation of the ice wedges polygonal relief. The frost cracks appears when the soil’s thermal tensions exceed the threshold durability of the soil (1,2). Typical terrestrial polygon sizes are in the range from 10 to 30 meters. Typical polygons morphology can consist from perimeter, formed by edges over the ice or sand wedges, and rises or down center. There are different conceptions of dependences between polygons sizes and composition and structure of ground. The cracking intensity goes down in the rank: peat, loamy sand, loam, dusty sand, cracking rock. The temperature gradient have strong influence on the cracking intensity – as gradient is higher as intensity rise up (3). From the other side, the requeriments for polygons formation are following: soils pores have to be cemented and be under according freezing. This process doesn’t depend from ground types and occur in fine grain ground as well in pebbles (4). In our sight it is necessary to consider moisture of of the ground as the considerable agent of the process and freezing-thawing processes dynamic. As the processes temp have an influence on ware migration to the freezing front and posterior forming of ice layers, which have less strong as the massive rock element of ground (5). Polygonal net pattern depends from the location of polygons relatively to the unloading region of ground massive.

Observation.

Polygonal ice wedge patterns in Western Siberia.
We researched the region of Tazovsky peninsula as the typical area of demonstration of polygonal ice wedge patterns. Researched region represent the flat and plain-hill terrain with absolute marks of height from 10-15 to 70-75 meters, weathering by rivers and gullies net, swamping and laking. Climate is continental. The temperature amplitude consists 40°C, annual average temperature is -9°C. Duration of negative temperature period is 240-250 days.

Lithologic condition of the region have two section of formations:
The first one – loamy and loam-sandy depositions with sand small layers. he second type is two-layers. Upper layer consists from loamy sand with sand small layers and organic impurities. Down layer consists from dusty sand and fine-grain and small-grain sands (6-10).

Researched region is situated in the zone of permafrost with annual average temperature of rocks from -3 to -5°C. The main geological-genetic type of depositions have epigenetic type of freezing in the region of research. Their cryogeneic construction is defined by genesis of sediments and composition of ground. Polygonal ice-wedge relief is widely spread on all researched area. It is easy to interpretate them on the airphotos. The sizes of poligones are 15 meters for sand areas, 20-27 meters for peatbogs (7). Poligones have as orthogonall pattern as well non-orthogonal pattern with 3 and 4 ray crosses. Orthogonal polygons with 4 ray crosses are typical for final morphological elements – like lakeside, gully lines and the frontiers of flood-lands.

Results of our work are represent on the Fig.2 and 3. We have made the statistic data processing of polygonal size for set of researched areas and we have recived some averaged data for this region.

Polygonal ice-wedge pattern on the Mars.
The high resolution imaging of Mars by MOC during Mars Global Surveyor (MGS) mission operation (17) shows wide multiple examples of the polygonal terrains. Linking observed polygons to a thermal construction has been preliminary based on just morphological evidence. Mutch et al. (14) favored thermal construction for Viking Lander polygons, Brook (12) also favored thermal construction for Chryse Planitia polygons because of the similar scale of ice-wedge polygons on Earth. Evans and Rossbacher (11) favored a freeze/thaw cycle for polygons in Lunae Planum. Lucchita (13) examined morphology and climate condition for polygons in Deuteronilus Mensae and concluded that their thermal contraction forms and shape were compatible with terrestrial forms, that ground ice would be present, and the adequate cooling could occur. In the recent period these morphological evidences were supplemented by the new data of neutron spectrography. Feldman et al. (23) represents their interpretation of these data that there is ice-filling layer (ice content exceed 50% in high latitudes) in the under surface layer of Mars. We keep investigation of morphological evaluation of researched areas.

Results of our work are represent on the Fig.2 and 3. We have made the statistic data processing of polygonal size for set of researched areas and we have recived some averaged data for this region.

Fig.1 Researched area of Tazovsky peninsula AP #86 with polygonal pattern net.

Fig.2 Bar graph of size distribution of polygons

Bar graph of size distribution of polygons
DEMONSTRATION OF POLYGONAL ICE-WEDGES TERRAINS Abramenko O.N., Isaev V.S.

new data of neutron spectrography. Feldman et al. (23) represents their interpretation of these data that there is ice-filling layer (ice content exceed 50% in high latitudes) in the under surface layer of Mars.

Results of research of polygonal patterns on Mars and comparison of them with compatible terrestrial forms.

We have researched as small size (to some 10 meters) as well more big – size polygonal net (to some 100 meters) and their mix combination.

Fig.4 (a) Image MOC #00-00602 with net of large polygonal patterns 231.98°W 70°N.

Fig.4 (b) Image MOC #03-04614 with net of small polygonal patterns 107.61°W 64.39°S.

Fig.4 (c) Image MOC #00-00602 with mix net of large and small polygonal patterns 231.98°W 70°N.

We keep job on indication of polygonal pattern net (Fig. 4 a,b,c) on these images with following size evaluation processing.

Fig.5 (a) Graph of size distribution for image MOC #00-00602 with net of large polygonal patterns 231.98°W 70°N.

Fig.5 (b) Graph of size distribution for image MOC #03-04614 with net of small polygonal patterns 107.61°W 64.39°S.

Results of this part of job are representatives on the Fig. 5(ab) and lets us to make conclusions about the similarity of researched patterns on the Mars with terrestrial polygonal patterns.

Conclusions.

All results of this paper and analyses of results of all above authors let us to recieve basements for final confidence in thermal contraction genesis of martian polygons. That could get us ability for elaboration and application of thermal contraction models for Mars, which could based on models proposed for Earth by Lahebruch (19), Dostovalov and Kudryavcev (2) and developed by Clifford (20), Mellon (21) and Ershov et al. (22).

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VENUSIAN CORONA-NOVAE WITH ARCUATE GRABEN: EVIDENCE FOR LAVA-FLOW MODIFICATION. M.Aittola\textsuperscript{1} and V.-P. Kostama\textsuperscript{2}, \textsuperscript{1}Astronomy Division, Department of physical Sciences, University of Oulu, FIN-90014, Oulu, Finland. (\texttt{marko.aittola@oulu.fi}, \texttt{petri.kostama@oulu.fi}).

**Introduction:** Venus as a single-plate planet \cite{1} has a unique set of volcano-tectonic features. Coronae, the large circular features, have been objects of much research in the Venus studies. Along with hundreds of coronae, there are large volcanoes and smaller structures with prominent radial features. The term “nova” is used to describe this special group of Venusian volcano-tectonic structures with a radiating, stellate fracture pattern \cite{2,3,4} centered on a central summit or fracture. These two structure-types are somehow linked, because half of the novae are located in the interior part of the coronae \cite{5}. In addition, they both are proposed to represent surface expressions of diapirs or be formed by mantle upwelling \cite{e.g. 6,7,8}. We use the short term corona-novae \cite{9} in this paper for these corona structures with nova inside them.

In many cases the nova formation appears to postdate the corona annulus \cite{9,10}, indicating that the most recent phases of activity of corona-nova joint structures are in these cases the nova-related features, which are the radial structures and the lava flows produced by the nova. However, there are examples where a set of arcuate graben can be seen adjoining these features. At first glance, the graben are easy to mix with the corona annulus. However, the characteristics of graben and associating extensional structures reveal that they most clearly are not part of the annulus formation. They are located in the flanks of the corona-nova structures outside the annulus. Furthermore, in contrast to corona annulus, they seem to bend away from the nova and corona center. Thus, they probably are of different origin than the annulus. What process could cause that kind of peculiar arch-like system? To answer this question, it is reasonable to take a closer look to examples and to examine possible analogues from Earth.

**Examples:** We have found evidence of the graben in connection with several corona-nova joint structures as well as some volcanoes. In this study, we concentrate on measuring and analyzing these suites of tectonic modification of four selected example corona-novae.

The corona-nova centered at 15S/215E (Mbokomu Mons) shows a very prominent arcuate system of graben located to the southwest of the elevated nova center (Figs. 1 and 2). Actually, two separate systems can be observed. The graben are located 27 to 100 km to the west of nova and they are bent away from the nova center. The graben clearly postdate the corona-nova structures and they have deformed the lava flows associated with the latest phase of nova evolution. Thus, they represent without doubt the latest phase of activity of the corona-nova. So it is evident that the formation of the graben system is somehow connected to the mechanism of lava flow deformation. This is also supported by the locations of the graben systems on the corona-nova flanks.

**Figure 1.** The Corona-nova (15S/215E) has prominent graben system to the SW of the Nova center. The high-resolution image of the suite (white box) is shown in Fig. 2. The topographical profiles O-A and O-B are shown with the graben regions shaded in the profile.

**Figure 2.** The high resolution Magellan SAR image of the graben of Mbokomu Mons.

In the case of corona-nova located at 8S/243E (Dhorani Corona), the lava flows cover the fractures of the surrounding terrain as well as the older lava flows of the image area. It would, therefore, seem that the corona-nova structure - or at least the latest activity phases of it - are rather young. The corona-nova displays two groups of graben with
some variations in the lengths of them. The graben tend to be longer further away from the nova center and shorter in the vicinity of the nova. Nevertheless, these graben clearly postdate the emplacement of lava flows associated with the corona-nova. Thus they most probably represent the last phases of modification with this structure.

The corona-nova centered at coordinates 45S/303.5E shows two fresh-looking systems of graben around an elevated nova location. The farther set of has deformed the lava flows associated with the nova, which otherwise seem to represent the most recent activity on the region. The closer system appears to locate on a very steep-sloped flank close to the nova center. In this case, however, the graben are located on a slope that is facing towards the nova. So, these graben are not probably formed by the suggested processes, but instead present a tectonic activity associated with the nova formation rather than the deformation of the lava flows.

The last studied example, corona-nova 14S/164E shows very prominent graben system to the NE of the nova structure with similar age relations between graben systems and corona-novae as previous cases.

There can be found some differences in diameter and length of the sets, but in general the graben are 1 - 2 km in width and are situated in distances of 10 – 50 km from the nova center. The graben tend to be wider close to the nova (1,50 - 2,50 km) and more narrow (0,35 - 0,60 km) when they are situated over 50 km from the nova center. The divergences could be explained by the steepness of the flank or perhaps by the properties of the flow. This question, however, remains to be solved for further studies.

In general, the graben in all cases appear to be very young features compared to their surroundings. Additionally, the graben are mostly found in association with slopes. This would seem to promote the fact that the graben have been formed by the gravitational pull and are manifestations of post-eruption sliding/slumping processes of the lava flow.

Earth analogue: The studies of the volcano flanks of Earth have shown that horseshoe-shaped scars are formed after an eruption which indicate the occurrence of failure within the flanks of the volcano (Fig. 3a) [11]. The concentric fractures and backward tilted blocks are typical of rotational slides and slumps [12]. It is also possible to have a lateral spreading of the volcanic cone resulting in fracturing of coherent material due to plastic flow of subsequent material (Fig. 3b) [11]. These processes would be the acceptable explanations also for the observed system of graben on the flanks of the studied cases.

Conclusions: In most cases the latest active phase of corona-nova evolution process is the elevation of the nova with radial structures and lava flows associated with it. However, there are some arcuate graben associated with the young lava flows of the structure, which clearly postdate the emplacement of the flows. Moreover, those graben are in most cases bent in the other direction from the corona annulus, which - together with age relations - indicates that graben are not part of the corona annulus. The most presumable explanation for the formation of these graben sets, is the deformation mechanism of the lava flows by activity similar to landslide processes (Fig. 3), such as slope failures (slumping and/or sliding) which produce arcuate scars or depressions on the slope as shown in the studies of volcanoes on Earth such as the Izu-Oshima volcano in Japan [11].

These coronae with novae are usually very young in respect to their surrounding geology [9]. This could imply that they are representations of some kind of late-type activity on Venus. Thus, considering the deformation of the lava flows, the graben sets actually may represent the latest stage of development of the corona-novae structures of Venus and possibly Venusian tectonics in general.

METEORITE ABLATION BASED ON COSMIC RAY TRACK STUDIES.
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The ablation can be estimated from the ratio of Ne cosmogenic isotopes in a meteorite [1]. For the same purpose, it is possible to use the track data also [2]. Bhattacharya et al. [3] presented graphically the long-term averaged production rates of cosmic ray nuclear tracks (\(\rho/t\)) versus the depth \((d)\) in meteorites with preatmospheric radii of \(R = 3-1000\) cm.

On the basis of these data, we have found the generalized type of the equation describing the value of \(\rho/t\) depending on \(d\): \(\log(\rho/t) = A + Bd^C\) (1).

The values of coefficients for values of \(R\) used in [3] are given in Table. The coefficients for intermediate values of radii are calculated by the method of linear interpolation. The agreement of the data from [3] and those calculated according to (1) can be seen in Fig. 1.

We used the equation (1) for the construction of the nomogram allowing the estimation of the value of chondrite ablation (Fig. 2). The value of \(r/R\) and the ablation of \(A\), % is determined on the \(\log(m)\) and logarithm of the average value of \(\rho/t\). Here \(m\) is the mass of the found meteorite, \(r\) is its effective radius, \(A = (1-r/R) \times 100\). The average value of ablation for 83 ordinary chondrites is found equal 78.4±3.1%.

The analysis of the obtained data has shown, that the average value of the chondrite preatmospheric masses is equal to \(M \sim 90\) kg. With this, the preatmospheric masses of 95 % of the meteorites lie in the interval \(2 \sim 3500\) kg, which corresponds to the interval of radii \(R = 5-60\) cm. It is found that the meteorites with small preatmospheric mass are drawn towards higher values of ablation.

The possible dependence of the value of ablation upon the velocity of entrance of the meteoroid in the atmosphere is considered (Fig. 3). According to [4], the mass loss from a large meteorite during its hypersonic drag interaction with the Earth's atmosphere is approximately given by \(m_f = m_0 \times \exp(-\sigma(V_0^2-V_f^2)/2)\)...(2), where \(m_f\) and \(m_0\) are the final and initial meteorite mass, \(\sigma\) is the mean ablation parameter, \(V_0\) is the meteorites' out-of-atmosphere geocentric velocity and \(V_f\) is the velocity at which ablation ceases.

However, the obtained data testify that the value of ablation depends not only on the velocity of the meteoroid, but, most likely, also on its mass and shape as well as on the angle of inclination of trajectory at entering the atmosphere.

Table. The coefficients \(A\), \(B\), and \(C\) in the equation (1) for meteorites with radii \(R\)

<table>
<thead>
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<th>(R), cm</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
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<tr>
<td>5</td>
<td>12.9</td>
<td>-6.67</td>
<td>0.0372</td>
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<td>10</td>
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<td>1000</td>
<td>6.88</td>
<td>-0.715</td>
<td>0.574</td>
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References:

Fig. 1. The dependences of the track production rates \(\log(\rho/t)\), \(\text{cm}^{-2} \text{Ma}^{-1}\), versus the depth \(d\), cm, in meteorites with preatmospheric radii \(R\), cm. Dashed lines are from [3], solid lines present the calculations according to (1).
Fig. 2. A nomogram for estimation of the $r/R$ ratio and ablation ($A$) of ordinary chondrites according to the average value of $\lg(\mu/t)$ and $\lg(m)$. The points correspond to the H- and L-chondrites (filled and open symbols, respectively), which were found as one specimen. $Pe$ – Peekskill; $SD$ – Suchy Dul

Fig. 3. The relationship of $r/R$ (or ablation $A$) and initial atmospheric velocity $V$, km s$^{-1}$. 1 – regression line for all data; 2 – the same without Peekskill and Innisfree data; 3 – line according to [2]; 4 – calculation according to equation (2). Abbreviations: $Ar$ – Archie; $Br$ – Bruderheim; $Dh$ – Dhajala; $In$ – Innisfree; $Ku$ – Kunashak; $LC$ – Lost City; $Ni$ – Nikolskoe; $Pa$ – Paragould; $PR$ – Peace River; $Pe$ – Peekskill; $Pr$ – Pribram; $Ri$ – Richardton.
DENOMINATION OF PARAMETERS OF NUCLEUSES OF GALACTIC COMETS BY MEASUREMENT OF DIAMETERS OF CRATERS ON THE MARS AND THE MOON.

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1. It had been known [1] that galactic comets when they fall on the surface of planets, which have not atmosphere, create crater \( n(10–100) \text{ km} \) in diameter. With using the theoretical formulas [2] which allow to estimate diameter of a crater on the basis of parameters of space body, it was established, mass of galactic comets is \( 10^{13}–10^{18} \text{ g} \), and the size of their nucleus is several kilometers. But the decision of question as to density of comets nucleuses substance even at a qualitative level: snow \((0.1 \text{ g/} \text{sm}^3)\) or ice \((1.0 \text{ g/} \text{sm}^3)\) remained open.

2. In this message for definition of density of substance and the sizes of nucleus of galactic comets we take into consideration additional the effect of reduction of mass of these comets at passage through gas environments of planets of terrestrial group. It is known, a comet may lose mass and be slowed down in atmosphere of planets. Speed of loss by comet of its mass according to the classical theory can be described by the equation [3]:

\[
\frac{dM}{dt} = \frac{\Lambda AM^{2/3} \rho_K V^3}{2\rho Y^{2/3}}
\]

(1)

where \( V \) – speed of a comet, \( M \) – her mass, \( \rho_K \) and \( \rho \) – density of a material of a nucleus of a comet and a gas atmosphere of a planet; \( A \) and \( \Lambda \) – factors of the form and a heat transfer; \( Y \) – effective specific energy of evaporation and fusion of body.

In the assumption, that decrease of speed of galactic comets in atmosphere of planets is very small, on the basis (1) reduction of diameter of comet's nucleus to the moment of collision with a surface of a planet may be written down as:

\[
\Delta L = \frac{\Lambda AM \rho_K V_0^2}{9.67 Y \cos \vartheta}
\]

(2)

where \( H \) – height of a homogeneous atmosphere of a planet, \( \vartheta \) – a corner of fall of a comet, \( V_0 = 450 \text{ km/s} \) – speed of galactic comets.

3. Calculations with using the formula (2) have shown [1], that galactic comets can not overcome atmosphere of the Venus and the Earth. Nucleus of galactic comets in an atmosphere of these planets evaporate and do not created of a crater. Therefore a craters created by galactic comets are absent as on the Venus and also on the Earth. The Mars is other matter. Owing to low density of its gas environment, the majority of galactic comets are reaching a Martian surface and are forming craters. However the sizes of these craters appear less, than, say, on the Moon, which does not have practically an atmosphere.

4. For an illustration of the given effect on fig. 1 integral distributions of craters on diameters \( \text{N(D)} \) for "passive" hemisphere of the Mars and "continental" hemisphere of the Moon are compared.

These dependencies are constructed on the data [4] and standardized on 50% of Martian surface (71896.7 thousand \text{ km}^2) and the Moon.
It is known [1], that these hemispheres of the Mars and of the Moon are completely sated with craters with diameters \(D \geq 10\) km. Quantity of the craters formed by galactic comets in these hemispheres, approximately in 10 time more, than created by asteroids. Therefore distribution of craters \(N(D)\) on the Moon (and the Mercury) have form of exponential dependence peculiar to distribution of sizes of nucleuses of galactic comets.

5. Comparison of functions of distribution of craters of the Mars and the Moon shows, that strict performance of conditions of applicability of the formula (2) is not observed. In the field of small diameters on the Mars there is the surplus of craters. This fact speaks about dividing of nucleuses of galactic comets in a Martian atmosphere. At the same time in the field of diameters \(D \geq 100\) km the craters formed by galactic comets, in full conformity with the formula (2), on the Mars is regularly less than on the Moon on 30 km. According to the formula (2) the given effect may be caused by reduction of the size of all comet’s nucleus in an atmosphere of Mars on fixed size \(\Delta L\). At steep fall of comets \((\sin \vartheta = 0^\circ)\) this size for an atmosphere of Mars \((\rho = 1.05 \times 10^{-8} \text{ g/sm}^3; H = 12 \text{ km})\) will make \(\Delta L = 320\) m in case of an ice nucleus of a comet \((\rho = 1.0 \text{ g/sm}^3)\) and \(\Delta L = 3.2\) km for snow ones.

Substituting these values in the formula of G. Melosh [2]:

\[
D = 0.0133E^{1/3.4} + 1.5\sqrt{P_K \rho_M^{1/2}} L
\]

where \(E\) – energy of a comet, \(\rho_M = 2.7 \text{ g/sm}^3\) – density of a material of a surface of a planet, we find, that in the first case it will result in reduction of diameter of a crater on \(\Delta D = 25\) km, and in the second on 105 km. The first value has almost coincided with an observably difference of diameters craters on the Mars and the Moon, while the second leaves for all reasonable limits. From here, we have the right to draw a conclusion, the density of substance of nucleus of galactic comets, most likely, is close to density of ice.

6. Calculations with use of other models [2], similar to the formula (3), correspond to the fact sheet much worse. These models give the nonlinear dependence \(D(L)\) contradicting to distribution of comet craters on the Moon and Mercury which haven’t an atmosphere. Therefore at calculations of diameters of the craters created by galactic comets, we recommend the model of G. Melosh.

Thus, results of the this work show that the density of a nucleuses of galactic comets is close to density of ice and they size is concluded in limits \(L = 0.1–3.0\) km. Diameter of a nucleus of an average galactic comet is about 450 m.

References:
The Earth oceanic and elastic shells are deformed due to lunar-solar attraction, due to non-inertial rotational effects in pole motion and others. Different types of tides are observed on the Earth. They are caused by gravitational attraction of moving core (rigid and liquid). In classical approximation all these tides are described by linear theory of elasticity. And full effect of Earth deformations is presented as linear superposition of all pointed tides. Tensile state of the Earth is characterized by the elastic energy stored in superposition of tides.

We have obtained formulae for elastic energy of tide superposition. Full energy is not additive sum of elastic energies of separated tides and contains additional terms of mutual character.

For example mutual action of the Moon and Sun on the Earth generates additional energy with maximal value about 91.6% of elastic energy which is generated by the Moon \( E_M \). Full elastic energy of the lunar-solar tides is changed in diapason 212.6%–75.2%–137.4%. Variations of elastic energy are very important. So pointed variation in elastic energy is sufficiently more than variation of energy caused by eccentricity of the Moon orbit 67.8%\( E_M \). Full variation of the elastic energy achieves 209.4%\( E_M \). Also superposition of rotational tide with lunar-solar tides leads to additional elastic energy terms.

Part of elastic energy dissipates and goes to warm energy and to energization of different natural processes in definite rhythms. Analytical formula for energy and power of the tidal deformations was established. Spectral analysis of the elastic energy of the lunar-solar tides was fulfilled. In given paper we have shown that variations of tidal energy demonstrate clear correlations with events of earthquakes and moonquakes.

**Formula for elastic energy.** On the base of the classical solution of the problem of elasticity for model of the Earth with concentric mass distribution the evaluations of the tidal energy and power of Earth lunar-solar and rotational deformations, including their joint effect, were obtained. Let us consider the system of external celestial bodies with respect to the deformable Earth: \( P_\sigma \) (\( \sigma = 1, 2, ..., N \)). Full energy of deformations of the Earth due to attraction of the planets is determined by formula [1]:

\[
E_d = \sum_{i=1}^{N} \sum_{j=2}^{\infty} e_n \left( \frac{m_j}{r_n^{i+1}} \right)^2 + 2 \sum_{i=1}^{N} \sum_{j=2}^{\infty} \sum_{n=2}^{\infty} e_n \frac{m_j}{r_n^{i+1}} \frac{m_i}{r_n^{j+1}} P_n(S_{ij})
\]

\( S_{ij} \) is the angle between radius-vectors of the planets \( P_i \) and \( P_j \), \( r_i \) is a distance between the centres of mass of the sun and planet \( P_i \); \( m_i \) is a mass of this planet; \( e_n \) is an elastic parameters.

Taking into account only lunar-solar and rotational tides for elastic energy of Earth deformations we obtain following formula:

\[
E_d = E_S + E_M + E_R + 2\sqrt{E_M E_S} P_2(\cos S) + 2\sqrt{E_R E_M} P_2(\cos \gamma_S) + 2\sqrt{E_R E_S} P_2(\cos \gamma_M)
\]

Here \( S \) is an angle between geocentric directions to the Moon and the Sun; \( \gamma_M \) is an angle between geocentric direction to the Moon and Earth axis of rotation; \( \gamma_S \) is an angle between geocentric direction to the Sun and Earth axis of rotation; \( r_M \) is a distance between centers of mass of the Earth and the Moon; \( r_S \) is a distance between centers of mass of the Earth and the Sun; \( \Omega \) is an angular velocity of the earth rotation, \( \omega = 0.72921 \times 10^{-4} \, \text{rad/s} \).

**Evaluations of elastic energies.** Saving only main second harmonics of tidal elastic energy on the base of formulae (1) for known parameters of Earth-Moon system we obtain following evaluations: \( E_M = 5.473 \times 10^{33} \, \text{c.g.s.e.} \) is elastic energy of the Earth caused by the Moon attraction; \( E_S = 1.148 \times 10^{33} \, \text{c.g.s.e.} \) is elastic energy of the Earth caused by the Sun attraction; \( E_M = 5.013 \times 10^{33} \, \text{c.g.s.e.} \) is an elastic energy of the Earth caused by the rotation. Full variation of the tidal energy is 11.4596x10^{33} \, \text{c.g.s.e.}

**Variations of lunar-solar tidal energy.** In case circular Moon and Sun orbits maximal and minimal values of the energy of lunar and solar tides are determined by formulae:

\[
E^{\text{max}}_M = E^{(2)}_S + E^{(2)}_M + 2\sqrt{E^{(2)}_S E^{(2)}_M} = 11.6342 \, \text{c.g.s.e.}
\]

\[
E^{\text{min}}_M = E^{(2)}_S + E^{(2)}_M - \sqrt{E^{(2)}_S E^{(2)}_M} = 4.1144 \, \text{c.g.s.e.}
\]

So variation of elastic energy is

\[
\Delta E_M = 3\sqrt{E^{(2)}_S E^{(2)}_M} = 7.5198 \times 10^{33} \, \text{c.g.s.e.}
\]

Lunar eccentricity variations of the Earth tidal energy (pericenter-apocenter positions) is determined by formula
\[ \Delta E_M^{(2)} = E_M^{(2)} \left[ \frac{1}{(1-e_M^2)} - 1 \right] = 3.7084 \times 10^{23} \text{c.g.s.e.} \]

Solar eccentricity variations of the Earth tidal energy (pericenter-apocenter positions)

\[ \Delta E_S^{(2)} = E_S^{(2)} \left[ \frac{1}{(1-e_S^2)} - 1 \right] = 0.2314 \times 10^{23} \text{c.g.s.e.} \]

Full variation of the tidal energy is $1.14596 \times 10^{23}$ c.g.s.e.

**Power of tidal processes.** Resultant evaluations of powers of the tidal deformations:

\[
N_{SM} = 1.1789 \times 10^{11} \text{ Wt}, \quad N_M = 0.3142 \times 10^{11} \text{ Wt}, \\
N_S = 0.0015 \times 10^{11} \text{ Wt}, \quad N = 1.4946 \times 10^{11} \text{ Wt}.
\]

For power of mutual rotational and lunar-solar deformations of the Earth we obtain following formal evaluations

\[
N_{\text{RM}} = \frac{6\pi}{T} \sqrt{E_R E_M \sin^2 \theta_{\text{min}}} = 0.8963 \times 10^{15} \text{ Wt}, \\
N_{\text{RM}}^{\text{max}} = \frac{6\pi}{T} \sqrt{E_R E_M \sin^2 \theta_{\text{max}}} = 2.0310 \times 10^{15} \text{ Wt}
\]

and their difference will be

\[
\Delta N_{\text{RM}} = \frac{6\pi}{T} \sqrt{E_R E_M (\sin^2 \theta_{\text{max}} - \sin^2 \theta_{\text{min}})} = 1.1347 \times 10^{15} \text{ Wt}.
\]

Here $\theta_{\text{min}}$ and $\theta_{\text{max}}$ is extreme values of inclination of Earth axis of rotation with respect to normal to the plane of lunar orbit. $T$ is a period of lunar motion.

**Remark.** Evaluations of powers connected with global rotational deformation have formal character here. In reality in present epoch we can not observe this composition of deformations. In result of own evolution the elastic rotational energy was disappeared. But more fine effects of interaction and superposition of deformations caused of Earth rotation variations of course have place in reality and must be studied.

Correlations of earthquakes and moonquakes with variations of tidal energy. We have studied theoretical curves of change of tidal energy of lunar-solar tides on the Earth and terrestrial-solar tides on the Moon in period 1971-1977 years. It was shown that moments of energy variations caused by pointed mutual actions coincide (or close) to moments of big earthquakes (with magnitude 7 and 8) and moonquakes. It is important to note that mutual term of elastic energy controls and dictates seismic process. Of course earthquakes and moonquakes are observed not for all pointed tidal variations. Probably it is caused by process of accumulation of seismic energy. But in any case we can predict in definite statistical sense future big earthquakes and moonquakes. In result of analysis of theoretical curve of elastic energy of lunar-solar tides we have determine date of possible big earthquakes in 2003 years. These date are: 10-11 July, 21 July; 1 August, 4 August, 8-9 August, 19 August, 28 August; 4 September, 15-16 September, 26 September; 6-7 October, 15-16 October, 25 October; 3-4 November, 6-7 November, 12-13 November, 23 November; 2 December, 8 December, 12-13 December, 21-22 December, 31 December. In same date moonquakes can be expected on the Moon. Given approach does not let us to determine region of earthquakes but let us to analyze date of extreme perturbed states of the Earth caused by gravitational influence of external celestial bodies.

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**References.**

MONITORING MARS LOD VARIATIONS FROM A HIGH ALTITUDE CIRCULAR EQUATORIAL ORBIT. J.-P. Barriot, Observatoire Midi-Pyrenees/CNES, 14, Av. E. Belin, 31400, Toulouse Cedex, France, Tel: 33561332894, Fax: 33561253098, email: jean-pierre.barriot@cnes.fr.

Mars Lenght-Of-Day variations are unique in the Solar System, as one quarter of the CO2 atmosphere condensates during winters at the poles, and sublimes during summers. We compute the perturbations of a high altitude circular equatorial orbit of a martian probe under the influence of this variation, and show that they are measurable. For this purpose, we use a first order perturbation of the newtonian equations of motion, where the small parameter is given from an "hourglass" model of the condensation/sublimation mechanism. We demonstrate that the perturbations contain essentially three component: the first one is a sine/cosine modulation at the orbit frequency, the second one is a sine/cosine modulation at the annual frequency, the third one is composed of terms of the form $\exp(t)\sin(t)$, so the orbit is not stable in the long term (several martian years), with perturbations growing exponentially. We give the full theory and numbers.
AIRFALL CRATER DEPOSITS ON THE SURFACE OF VENUS. A. T. Basilevsky1 and J. W. Head2; 1Vernadsky Institute, RAS, Moscow, 119991, Russia, atbas@geokhi.ru; 2Dept. Geological Sciences, Brown University, Providence RI 02912, USA.

Introduction: Formation of impact craters on Venus is accompanied by emplacement of ejecta of three types: 1) knobby ballistic ejecta, 2) ejecta outflows, and 3) radar-dark airfall deposits. There is broad agreement that impact craters of Venus (with D>11 km) in the process of their formation acquire radar-dark parabolas (DP) of the airfall deposits. Some researchers suggest that direction of impact might play role in the parabola formation [11]. With time the parabolas degrade and shrink into clear dark halo (CH), then to faint halo (FH) and finally completely disappear (NH = no halo) (see e.g., [1, 4, 8, 10]). So the DP-CH-FH-NH sequence is the age sequence with DP craters being the most recent and the NH craters being the most ancient. In this work we study areal distribution of now observed and partly or completely degraded airfall deposits in the vicinities of the Venera-Vega landing sites and consider the obtained picture in the light of information on the Venus surface acquired by the lander observations.

Drawing parabolas: On the USGS Magellan-based maps for three large regions, where the Venera-Vega landers made their on-surface observations (Venera 8, 13, 14; Venera 9, 10; Vega 1, 2), around each crater >11 km in diameter we draw the model parabolas. From the data on the forty nine now observed dark parabolas [6] we found that the parabola mean length/width ratio is ~1 and that the best fit of the parabola area (A, km²) v.s. crater diameter (D, km) dependence is A = 26928D – 124000 (BF49 line). Taking in mind that the observed parabolas are at different preservation states, thus representing themselves the age sequence, we selected the twenty parabolas whose data points on the plot were above the BF49 line and calculated the best fit for them: A = 29846D + 59000 (LRG = larger parabola line). We believe that the LRG line represents better the A(D) dependence for fresh, not-degraded parabolas. Figure 1 shows an example of the model parabola around crater Stuart.

So in the regions of the Venera Vega landing sites, which in the sense of their geology are typical for Venus, the percentages of area covered by the model parabolas vary from ~40 to ~60% for the BF49 option and from ~80 to ~90% for the LRG one. Because the LRG option seems to correspond to the case of not-degraded parabolas, the latter estimates probably better represent the past+present distribution of the parabola deposits. The coverage of concrete Venera-Vega landing ellipses (circle R = 100 km) by the model parabolas is given in Table 2.

Table 1. Percentages of areas covered and not covered by the model parabolas for the Venera-Vega regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Option BF49</th>
<th>Option LRG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Covered</td>
<td>Uncovered</td>
</tr>
<tr>
<td>Venera 8-13-14</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Venera 9-10</td>
<td>61.5</td>
<td>38.5</td>
</tr>
<tr>
<td>Vega 1-2</td>
<td>59</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 2. Percentages of the area of the landing ellipses covered by the model parabolas.

<table>
<thead>
<tr>
<th>Region</th>
<th>Option BF49</th>
<th>Option LRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venera 8</td>
<td>0%</td>
<td>100%, CH, CH</td>
</tr>
<tr>
<td>Venera 9</td>
<td>90%, FH, NH</td>
<td>100%, FH, FH, NH</td>
</tr>
<tr>
<td>Venera 10</td>
<td>50%, FH, NH</td>
<td>100%, CH, FH</td>
</tr>
<tr>
<td>Venera 13</td>
<td>20%, CH, CH</td>
<td>95%, CH, CH, FH</td>
</tr>
<tr>
<td>Venera 14</td>
<td>15%, FH</td>
<td>70%, DP, CH, FH</td>
</tr>
<tr>
<td>Vega 1</td>
<td>80%, CH, FH</td>
<td>100%, CH, CH, FH</td>
</tr>
<tr>
<td>Vega 2</td>
<td>0%</td>
<td>50%, CH, CH</td>
</tr>
</tbody>
</table>

Surface at the landing sites. All TV panoramas taken at the landing sites show the presence of finely layered deposits (see e.g., Figure 3) and soil mechanics measurements indicate that these rocks are mechanically weak and porous (ρ ≈ 1.5 g/cm³) and at least a few tens of centimeters thick (see summary in [2]).
Among other hypotheses it was suggested by [2] that the layers may be composed of erosional or pyroclastic material transported from somewhere, deposited and lithified. At the time when [2] was published it was not known that pyroclastic volcanism on Venus should be rare if ever present [7] and the studies of crater associated airfall deposits on Venus were at their very early stage (see e.g., [3]). Now, taking in mind the broad coverage of the Venusian surface with the past and present dark parabolas we suggest that the layers may be the parabola airfall deposits which were then lithified and partly eroded by the subsequent eolian activities including impact generated winds (see e.g., [9]).

Terrestrial analogs. The analogs of such deposits on Earth could be some pyroclastic deposits and airfall deposits of nuclear explosion tests (Figure 4).

At the Bravo test, in the Bikini Atoll shallow lagoon, the 15 MT thermo-nuclear explosion produced a crater 1.6 km across and 60 m deep (www.bikiniatoll.com). The radioactive fallout of the Bravo test affected Japanese ship Fukuru Maru 100 miles east of Bikini. “Gritty snow-like” material (crushed coral reef) of the fallout rained down on the boat for nearly three hours. On Rongerik Atoll, ~200 miles from the explosion, the fallout thickness was 0.6 to 1.2 cm. Taking in mind the 3-order magnitude differences between energies of the Bravo explosion and the impacts produced the smallest venusian craters with associated parabolas and significantly higher capacity of Venusian atmosphere (compared to Earth’s) to carry the debris load, the meter-scale initial thickness of the parabola deposit looks reasonable. Estimates based on the Magellan measured radiophysical properties suggest that the parabola deposits are a few meters thick [5].

Deposition of the parabola-forming airfall may resemble the deposition of snow in intense snowstorms on Earth, for example, similar to the ~18 hour-long one in Providence, R.I., USA, on February 17-18, 2003, when ~50 cm thick layer of snow was deposited. By the next day, deflation/sublimation of the snow caused the initially massive looking snow deposit to show prominent cm-scale layers resembling those observed on the Venusian surface (Figure 5).

Figure 5. Layered texture of snow deposited on the Brown University campus by the February 17-18, 2003, snow storm. A pencil in the center left is 7 mm thick.

Conclusion. Analysis of areal distribution of the model crater-associated radar-dark parabolas in the regions of the Venera-Vega sites, showed that they cover 80-90% of the surface. The layered deposits seen at the Venera 9, 10, 13, 14 panoramas and consisting of porous, mechanically weak material may be the lithified and then partially eroded parabola deposits. If so, the interpretations related to the sources of the materials studied by lander geochemical instruments may need revision. In particular, vertical mixing in the process of the source crater excavation (at least down to 1 km depth) may occur and thus the possibility that deep-seated rocks (plutonic rocks, tessera basement of plains) might be part of the analyzed material should be taken into consideration.

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EJECTA OUTFLOWS OF VENUSIAN IMPACT CRATERS: CORRELATION WITH THE DARK HALO PRESERVATION DEGREE. A. T. Basilevsky¹ and I. V. Setytaeva²; ¹Vernadsky Institute, RAS, Moscow, 119991, Russia, atbas@geokhi.ru; ²Dept. of Geography, Moscow State University, Moscow, Russia.

Introduction: Many impact craters of Venus have so-called “ejecta outflows” (Figure 1). They are typically radar bright, have a flow-like morphology and emerge from the crater hummocky ejecta blanket extending outwards with tendency to follow down topographic gradient [2, 5, 7, 8, 10].

Figure 1. Craters Jeanne, D = 19 km, left, and Adams, D = 90 km, right, with prominent ejecta outflows.

There is broad agreement that ejecta outflows resulted from flow of low-viscosity fluids but the fluid nature is a subject of debate: impact melt, fluidized solid debris, a mixture of molten, solid and vaporized debris [see e.g., 2, 5, 7, 8, 10]. Estimates of percentage of craters with associated ejecta outflows vary from ~12% [2] to ~40% [8]. In this study we analyze the Magellan C1-MIDRP images of impact craters of Venus ≥5 km in diameter (smaller craters are not seen with enough details) dividing them into those with clear, unclear or none outflows (Figure 2).

Figure 2. From left to right: craters Uleken (D = 10.9 km), Erin (13.6 km) and Escoda (19.9 km) having correspondingly clear, unclear and no associated outflows.

We try to correlate the outflow presence and apparent prominence with the degree of preservation of the crater-associated radar dark deposits. The latter is a function of the crater age [e.g., 1, 3, 4, 5, 6] so our aim is to understand if the presence and prominence of ejecta outflows are dependent on the age of the craters with which the outflows associate.

The procedure. This project is a continuation of work [4] in which all 854 Venusian craters ≥5 km in diameter listed in database [9] were subdivided into subpopulation 1 (541 craters superposed on wrinkle-ridged regional plains), subpopulation 2 (212 craters superposed on the younger units) and others (101 craters). Then craters of subpopulations 1 and 2 were classified into four classes (Figure 3): those having associated radar-dark parabola (DP), clear dark halo (CH), faint dark halo (FH) and no halo (NH classes).

Figure 3. Sequence of craters with associated dark parabolas, clear halos, faint halos and no halos [4].

Some craters and their surroundings have been found to be obscured by dark deposits of other craters, regional dark mantles and sometimes by young lava. So they can not be classified into DP, CH, FH, NH classes and a fifth class - “Obscured” - was introduced [4]. In the current project we have analyzed images of all 753 craters of subpopulations 1 and 2 determining if this given crater has outflow features and if yes, whether the outflow is clear or faint. Then using the database from the previous study [4] we have found to which of the mentioned above five classes this crater belongs.

The results. We have found that among 753 craters of subpopulations 1+2, 362 craters (48%) have prominent (clear) outflows. 206 craters (27%) have barely seen, not prominent, and even probable outflows which altogether are classified as faint. Correlation of presence and prominence of ejecta outflows with crater-associated dark deposit preservation degree, i.e. with crater age is shown in Table 1 and on Figure 4 (“obscured” craters are ignored).

Table 1. Ejecta outflows types v.s. class of the associated radar dark deposits in subpopulations 1+2.

<table>
<thead>
<tr>
<th></th>
<th>DP</th>
<th>CH</th>
<th>FH</th>
<th>NH</th>
<th>Obscured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Outflows total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>84.3</td>
<td>76.2</td>
<td>79.5</td>
<td>65.0</td>
<td>74.1</td>
</tr>
<tr>
<td>Outflows clear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>66.7</td>
<td>60.1</td>
<td>45.1</td>
<td>32.1</td>
<td>41.4</td>
</tr>
<tr>
<td>Outflows faint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>17.6</td>
<td>16.1</td>
<td>34.4</td>
<td>32.9</td>
<td>32.6</td>
</tr>
</tbody>
</table>
Discussion. If to ignore the error bars, one can conclude from Figure 4 that from DP class towards NH class a slight tendency in decrease of percentages of craters having any (clear or faint) outflows exists. But when the error bars (on Figure 4 they correspond to the 66.7% confidence level) are taken into consideration, it becomes clear that along this sequence the percentages of craters having any outflows are approximately the same.

If to consider the percentages for clear and faint outflows separately the picture changes. It becomes visible that along the DP-CH-FH-NH sequence, that is a sequence from the younger to older craters [3, 4], the percentages of craters having clear outflows decreases noticeably. This decrease is obviously balanced by the corresponding increase in percentages of faint outflows.

This means that with time, in parallel with degradation of crater-associated dark parabolas into clear, then faint halo and finally to no halo, the prominence of some outflows, which were clear, decreases and they become to be faint. So for some outflows their faint appearance is certainly the aging effect. But the observation that faint halos are present in association with young (CH) and even very young (DP) craters shows that in significant number of cases the outflow faint appearance is probably primary rather than the degradational effect. Moreover, the fact that in association with 8 of 51 craters of the DP class no any outflows were observed (Table 1) means that some craters formed without outflows. This may be due to specifics of the target, impactor, or the impact geometry.

The observation that the percentages of clear + faint outflows do not change along the aging DP-CH-FH-NH sequence implies that when formed outflows, clear or faint, survived through all the time of existence of the craters they are associated with. This means in turn that ejecta outflows are more resistable to degradation by the surface processes than the crater-associated radar-dark halos.

Correlation of presence and prominence of ejecta outflows with the degree of preservation of crater-associated dark deposit in subpopulation 1 (craters superposed on wrinkle-ridged regional plains) showed the picture rather similar to the case of the combined subpopulation 1+2. Correlation of these parameters for subpopulation 2 (craters superposed on the units younger than wrinkle-ridged regional plains) showed similarity with the picture for subpopulation 1 for craters classes CH, FH and NH. For the DP craters the percentage of craters with clear outflows is unexpectedly low while the percentage of craters with faint outflows is unexpectedly high although for total (clear+faint) outflows the percentage is close to the expected one. These deviations from the expectations may be a result of the stochastic effect: in subpopulation 2 there are only 17 DP craters, of which 9 are with clear outflows and 6 are with faint ones.

Conclusions. The analysis of C1-MIDRP images of the Venusian craters superposed on wrinkle-ridged regional plains and on the younger units showed that 48% of them have clear ejecta outflows and 27% have faint outflows. Joint consideration of presence and prominence of ejecta outflows and the preservation degree of the crater-associated radar-dark deposits showed that formation of significant majority of craters (~85%) was accompanied with appearance of ejecta outflows. Most of the outflows formed clear but some were primarily faint. Surface processes changed some clear outflows into faint ones. All or almost all formed outflows survived until the present.

THE TERRA ARABIA LOW EPITHERMAL NEUTRON FLUX ANOMALY: POSSIBLE CORRELATION WITH PRESENCE OF LAYERED DEPOSITS, A. T. Basilevsky1, A. S. Kozyrev2, A. B. Sanin2, I. G. Mitrofanov2, G. Neu-kum3, S. Werner3, J. W. Head4, W. Boynton5 and R. S. Saunders6, 1Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Moscow, 119991, Russia atbas@geokhi.ru; 2Institute for Space Research, RAS, Moscow, 117997, Russia; 3Freie Universitat, Berlin, D-12045, Germany; 4Brown University, Providence, RI 02912, USA; 5University of Arizona, Tucson, AZ 85721, USA. 6Jet Propulsion Laboratory, Pasadena, CA 91109, USA.

Introduction: High Energy Neutron Spectrometer (HEND) and Neutron Spectrometer (NS), which are parts of Mars Odyssey Gamma Spectrometer, measured low neutron flux at high latitudes (both fast and epithermal neutrons) and in two low latitude areas, Terra Arabia and SW of Olympus Mons (SWOM) (epithermal neutrons only) [3, 4, 6]. The low neutron flux at high latitudes was interpreted as signature of ground water ice [3, 4, 6]. Search for correlations of neutron flux with MOLA topography, thermal inertia and bedrock geology for the ±60° latitude zone and several areas of special interest (including Viking 1 and 2 landing sites) led to conclusion that the Arabia and SWOM anomalies are due to increased abundance of chemically bound water in the upper 1-2 m of these areas which does not correlate with the area topography and bedrock geology and partially correlates with thermal inertia pattern (for Arabia only) [1, 2]. It was concluded by [2] that analysis of high resolution MOC images may be a clue to understanding the geologic nature of the suggested increase in chemically bound water.

Following this conclusion a geotraverse including analysis of 152 high resolution MOC images through the Arabia anomaly was done [7]. It was found that the Arabia low epithermal neutron flux anomaly differs noticeably from its non-anomalous neighborhood neither in abundance of fluvial channels and layered deposits considered as possible links to chemically bound water, nor in thickness and apparent texture of the surface mantle, the upper 1-2 m of which are responsible for the anomaly.

In the present study we continue the attempts to understand the geologic nature of the Terra Arabia anomaly.

The approach. This study is based on the analysis of high resolution MOC images for the most stable in time "wet" and "dry" spots within the subarea of the Terra Arabia anomaly (Figure 1).

![Figure 1. The study area on the background of Terra Arabia anomaly (HEND data) with positions of 152 MOC images (red dots) marking geotravers studied by [7].](image)

Figure 2. The map of statistical deviations (sigma) from mean value of neutron flux for subarea of Terra Arabia anomaly. Pixels are 2°x2°. The selected for geologic analysis wet areas are outlined in red and dry areas, in blue.

From the Malin Space Science Corporation website we have downloaded and studied all available by August 2003 122 narrow-angle MOC images: 47 for the wet and 75 for the dry spots. Their resolution varies from ~1.5 to ~12 m/px. At the first stage of this study, trying to reach comparable visibility of the surface morphology, we analyzed only images with resolution of ~3 m/px. There were studied 38 images, 16 for wet areas and 22 for dry ones. Some preferential association of localities showing layered deposits (seen as mesas and steps in the relief) with the wet areas was found. Then we expanded our analysis to all available narrow-angle MOC image. In particular it led us to classification of the observed deposits into two types: 1) those which surface looks on the images as medium gray and being similar in brightness to their surrounding (Figure 3) and 2) those which are obvious product of etching the looking bright mantle and surrounded by obviously darker material underlying the bright mantle (Figure 4).

The persistently wet and dry spots have been selected using the map of statistical deviations with time from the mean value of epithermal neutron flux (HEND data) for this subarea (Figure 2). The most recent version of the sigma map for Terra Arabia can be found in [5].
The results: The results of this analysis summarized in the form of the map with MOLA shaded topography as the background are shown in Figure 5. The wet spots are blue with red outlines and dry spots are yellow with blue outlines. The number of images found on the web for each of the studied spot varied from zero to 17. So neighboring to each spot are shown from none to 17 “bricks”. Presence of Type 1 layered deposits are shown as white bricks. Presence of Type 2 layered deposits are shown as pale green bricks. We did not estimate the areal abundance of the layered deposits seen in the image. To show that the layered deposit is present in the imaged area it was enough to observe the deposit at least in one locality in the image. Cases when no one locality of the layered deposits was seen in the image are shown as black bricks.

It is seen on the map that in the NE part of the studied subarea, where the wet spots dominate, in most of analyzed images the Type 1 layered deposits are observed although cases when no layered deposits have been seen are also present. In the SW part of the subarea, where dry spots dominate, the Type 1 layered deposits are rare while cases when the Type 2 layered deposits and no any layered deposits are observed are much more frequent here. More studies are needed to validate the apparent link between the Type 1 layered deposits and the HEND-found wet areas and to understand what is the geologic nature of this link.

Conclusion. The photogeological analysis of narrow-angle MOC images for the determined by HEND wet and dry spots of the Terra Arabia epithermal neutron flux anomaly showed that the increased amount of chemically bound water in the upper 1-2 m surface layer of the wet spots seem to be linked to the presence and high abundance of one of two identified types of the layered deposits

Acknowledgments: This study was supported by the Russian Foundation of Basic Research grant for AAS and IGM and by the DFG grant for ATB, SW and GN. Authors acknowledge help of Mikhail Ivanov, Mikhail Kreslavsky and Steve Pratt in this research.

THICKNESS OF CRATER-RELATED MANTLES ON VENUS  
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Introduction. The Magellan radar images of Venus’ surface have revealed a number of radar-dark diffuse features (DDF) associated with approximately one half of all impact craters on the planet. These features do not have sharp boundaries in the radar images and often exhibit parabolic shapes and rather complex patterns. The DDF were interpreted as deposits (mantles) of loose material ejected and lifted by the impact.

The presence of the mantles strongly affects the observable radiophysical properties of the surface, as well seen in the Magellan data. In the present work, we analyze Magellan microwave emissivity and SAR data to estimate the possible thickness of the deposits responsible for the DDFs.

Approach. To study the effect of the mantles on the radiophysical properties we use the model developed in [1]. According to this model, the mantled surface is considered as a half-space of one material representing the substrate covered with a homogeneous layer of another material representing the mantle. The upper atmosphere-mantle interface is supposed to be flat. The scattering at the mantle-substrate interface is calculated under the Kirchhoff approximation [e.g., 2] through the ray optics approach. For suggested electric properties of both materials, and measured emissivity and side-looking radar cross-section, the model allows estimation of the mantle thickness.

For this study, the Magellan 1st cycle results of active and passive microwave probing experiments were used. C1-MIDR mosaics were used as a source of SAR radar cross-section $\sigma$, and the emissivity maps (GEDR data set) were used as a source of emissivity values $E$. The study was limited to within $\pm 66^\circ$ of latitude, because at higher latitudes the emissivity data have too low resolution.

Mantle material loss tangent. The model prediction of the mantle thickness strongly depends on the suggestion of the loss tangent of the mantle material. The loss tangent influences the attenuation of radio waves during their passage through the mantle. The attenuation is proportional to $\sim \exp(\tan\Delta \cdot \sqrt{\varepsilon L})$, where $L$ is the path of the radiation in the mantle material with dielectric permittivity $\varepsilon$ and loss tangent $\tan\Delta$. The pass of radiation $L$ is simply related to the mantle thickness; the effect of $\varepsilon$ is weaker and its value is rather well constrained from a priori information and other radiophysical data, $\varepsilon = 3-8$. The basis for choice of the loss tangent of surface material on Venus is poor.

We tried to constrain the loss tangent through comparison with some independent estimation. Namely, we used the calculations of amount of deposited loose material from a mechanical model of material ejection and emplacement from [3] for crater Carlson (24.2$^\circ$S, 344.1$^\circ$E, 37.6 km) shown in Fig. 1. Tab. 1 shows the Magellan-data-derived mantle thickness in locations marked with “1” through “5” in Fig. 1 for different loss tangent values from 0.001 to 0.01. For comparison, these data are accompanied by the mechanics-derived thickness calculated in [3] roughly at the same locations. Both sites chosen and data referenced correspond to the deepest mantles in different parts of Carlson dark parabola. The mantle thickness predicted from cratering mechanics [3] and derived from radiophysical properties roughly coincide for 0.001$<\tan\Delta \leq$ 0.005. These values are similar to those obtained for a variety of dry powdered terrestrial rock samples [4].

![Fig. 1.](image)

<table>
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<tr>
<th>Table 1.</th>
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<tbody>
<tr>
<td>$\tan\Delta$</td>
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<tr>
<td>-----------</td>
</tr>
<tr>
<td>0.001</td>
</tr>
<tr>
<td>0.002</td>
</tr>
<tr>
<td>0.003</td>
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<tr>
<td>0.004</td>
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<td>0.009</td>
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<td>0.01</td>
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<td>From [3]</td>
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Thick mantles. A very thick mantle would cause high absorption of radiation on its pass to the substrate and back. This would lead to the situation where the substrate would be invisible through the mantle. Emissivity for such a surface would be de-
terminated by the upper interface, and the side-looking radar cross-section would fall down to zero. Very low radar cross-sections, however, are not observed on the Venus surface. Even for the darkest parts of DDF, the measured radar cross-section is usually above the thermal noise. This can be explained in several ways. First, the upper mantle surface can be not exactly flat due to some alteration processes that roughen the surface.

Second, the absorption in the mantle material could never be high enough to hide the substrate. According to the equation for the attenuation coefficient, this holds when all three of the permittivity, the loss tangent, and the mantle thickness values are not too high. From cratering mechanics, the crater-related deposits were shown in [3] to be up to several meters thick. If the mantle physical properties are not unusual, the mantles would be partly transparent.

Thickest mantles in the radar-darkest areas inside parabolic features vary from about 6 m, as for crater Faustina (22.1°N, 4.7°E, 22.4 km), down to 1.5 m, as for crater Stowe (43.2°S, 233.2°E, 80 km), if we assume tanΔ=0.003.

Thin mantles. The case of thin mantles formally comes out of the limits of ray optics validity. The lower limit of mantle thickness, above which the diffraction effects can still be averaged out, is one wavelength of radiation in the mantle material. When the mantle permittivity is ε the wavelength of radiation λ_m inside mantle is equal to λ_m = λ/√ε_m, where λ is the wavelength in the free space. In the Magellan experiments λ=12.6 cm, and, for example, for mantles with permittivity of 4.4, like for some mantles near the crater Carlson (Fig. 1), λ_m is ~ 6 cm.

The mantle depth of 6 cm becomes comparable with the vertical roughness scale, which for terrestrial analogs of Venus plains varies in the 2 cm –10 cm range [5]. In “Venera –9, -10, 13, -14” panoramas the surface shows comparable vertical topography scale [6, 7]. The loose material could fill depressions (smaller than spatial resolution of radar images) and causes partial radar darkening. It seems probable that the surface would be a combination of patches of relatively thick mantle (so the model is applicable) and unmantled surface. The emissivity of the partly mantled surface would depend on the proportion of mantled areas.

If the mantle is thin but not patchy, the emissivity would have some intermediate value between that of clean and mantled surfaces. When mantle layer is thin, the absorption of radiation does not play an important role, and the difference between pure and mantled surfaces is not seen distinctly in SAR images. However, the mantle keeps almost the same E value over the whole its extent. This would cause the presence of distinctive features in emissivity images; e.g. the crater-related emissivity parabolas [8] can be such features.

In Fig. 2 emissivity (a) and radar (b) images for crater Nadine (7.8°N, 359.1°E, 18.8 km; marked with arrow) are shown. The crater is characterized by a distinctive emissivity parabola and faint radar-dark features. Mantle depth estimates for 3 values of mantle material loss tangent in 4 sites are presented in Tab. 2. The highest radar contrast in the area is 6.8 dB it is caused by mantles of 1.5 m thick (Tab. 2, tanΔ=0.003). The largest part of the parabola is formed by thin mantles, about 20 cm thick. In site Z the mantle thickness is not recognized with the model used and points to very thin mantles.

![Fig.2](image)

**Table 2.**

<table>
<thead>
<tr>
<th>TanΔ</th>
<th>Mantle depth, m</th>
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<tr>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>0.001</td>
<td>1.3</td>
</tr>
<tr>
<td>0.003</td>
<td>0.45</td>
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<tr>
<td>0.005</td>
<td>0.25</td>
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**Conclusions.**

1. The loss tangent of mantle material appears to be in the 0.001 to 0.005 range, that is, similar to terrestrial dry powders.

2. The thickest mantle recognized for radar dark parabolic features reaches several meters.

3. Thin mantles down to 10 cm are not seen in SAR images but exhibit emissivity features like emissivity parabolas.

4. The study of radar diffuse features together with emissivity images is promising for detecting and characterizing the mantles, including those not apparently related to impact craters.

**References:**

**THE GEOLOGIC EVOLUTION OF THE URAL MOUNTAINS: A SUPPOSED EXPOSURE TO A GIANT IMPACT. G. A. Burba.** Vernadsky Institute of Geochemistry and Analytical Chemistry, Russia’s Academy of Sciences, 19 Kosygin St., Moscow 119991, Russia e-mail: burba@online.ru

**Introduction:** The Ural Mountains at the eastern boundary of the European part of Russia mark the natural topographic and geologic border between Europe and Asia. This mountain range has in general the straight linear position N to S approximately along 58–59°E. Such position changes abruptly within the middle segment of the range, between 54 and 59° N, where the mountain chains curves eastward along the semicircular outline. Such change looks to be caused by some obstacle, the lithospheric heterogeneity.

This eastward-looking arc of the Middle Ural Mountains is considered [1–3] as the eastern segment of a large ring structure, which is referred hereafter as Middle-Ural Ring Structure (MURS). The structure is located between 54 and 59°N, 52 and 62°E (Fig. 1). Its approximate outlines could be traced on the map from Perm to Yekaterinburg, then to Chelyabinsk, Ufa, Izhevsk, and further to Perm. The minimal diameter of MURS rim is 400 km and its maximal diameter is about 550 km.

**Surface topography:** The eastern half of the MURS rim is a part of the Ural Range from the area of Kachkanar Mountain in the North to Yamantau Mountain in the South. NW part of the rim is Okhanskaya Vozvyshennost (Highland) to the North of Kama river. Western part is Sarapulskaya Vozvyshennost. SW part is Bugulkinsko-Belebeevskaya Vozvyshennost (to the South of Belaya river). There are two uplands in the central part of the MURS, both are N to S elongated: Tulvinskaya Vozvyshennost and Sylvinskiy Kryazh (Range). The SE part of the MURS bottom is occupied with Ufimskoye Plateau.

The topographic level of the eastern segment of MURS rim is up to 1000-1500 m above sea level, NW segment – up to 300 m, W segment – up to 200-250 m, SW – up to 300-350 m. The uplands in the central part of the ring structure are up to 400-450 m. Minimal altitude within the MURS is 58 m (in Kama river valley, near Belaya river mouth), and maximal altitude is 1640 m (Yamantau Mountain on the south rim of MURS).

The eastern segment of the MURS rim (Middle Ural Mountains) is the lowest part within the whole Ural mountain range.

**Fig. 1.** Middle-Ural Ring Structure with maximal diameter 550 km – a possible footprint of asteroid impact more than 600 mln. years ago. The metal ore deposits are localized within the eastern rim of the structure, and the oil fields (so named “The Second Baku”) are located within depressions along the western part of the ring.

*Cities* (clockwise from the N): Perm, Yekaterinburg, Chelyabinsk, Magnitogorsk, Ufa, Izhevsk.

*Rivers* (clockwise from the N): Kama, Chusovaya, Belaya, Kama (twice).

**Legend in English:**
- iron - lead - axis of heights
- manganese - magnesium - net of faults
- chromite - gold (along rivers)
- nickel - platinum - ringed rim
- aluminium - gems - structure’s center
- copper - coal (point of the
- titanium - oil supposed impact)
River net patterning: The ring of MURS is outlined with a general pattern of the large river valleys of Chusovaya, Belaya, and Kama river (the segment between the mouths of Chusovaya and Belaya, the left tributaries of Kama). Valleys of a smaller (intermediate-sized) river valleys also outline a MURS concentric patterning. The directions of small-sized rivers (being generalized to rectilinear positions) are mainly radial to MURS. So, the concentric-radial (so named ‘broken plate’) structure takes place within the MURS.

Basement topography: There is an isometric depression in the basement under the MURS. Its depth is down to −8 km. There are two uprises of the basement with summits located at −3 km depth. These uprises are located just under the two uprises in the surface topography within the central area of the MURS. The depth to diameter ratio for the depression of the basement is 1/50.

Paleoenvironment: Paleogeographical maps show the depression of the surface within the outlines of the MURS beginning from the Precambrian time.

Mineral resources: The overwhelming majority of the mineral fields of the Ural Mountains are located within the MURS, to put it more precisely, within the eastern half of its rim [4]. There are ore fields of iron, copper, chromite, nickel, titanium, gold, platinum, and some other metallic mineral resources here. The fields of the well-known Ural gems also are within this area. One could say, that the mining industry of the Ural region is in intimately connection with the MURS. So, MURS makes the industrial power of the Ural.

The geologic depressions within the western rim of the MURS are the areas of the vast oil fields, known as “The Second Baku” (such nickname was assigned to the large region of oil fields, discovered in 1940s along Kama river and at the adjacent areas of Tatarstan, Bashkortostan, Udmurtia, and Permkskaya Oblast to compare the oil richness with the world-known Azerbaijani oil fields of Baku at the Caspian Sea).

Interpretation: The whole set of the data provides a possibility to conclude that the MURS have a structure, which looks like a giant impact crater, similar to the craters on the other planets. This crater have a sharp expression in the basement topography, and not so sharp expression in the surface topography. Such smoothed appearance in the surface topography could be connected with a thick layer of sediments, which have filled the crater. Uprises in the central part of the MURS could be considered as places of the crater’s central mountains, as they are located over the basement uprises. The mineral fields looks to be in connection with the activity within the presumable ring faults of the structure’s rim.

Conclusion: It could be suggested that the geologic evolution of the Middle Ural area took place within the net of faults, which have been originated during the impact event in Precambrian time and stay active during the further periods of geologic history. It looks like that MURS have been a stable obstacle during the formation of the Ural Mountains, so the ranges could not overpass through the MURS and changed their rectilinear propagation to circle the MURS from the east. MURS could be an ancient giant impact crater, which affected the geologic development of the Ural Mountains linear range.

ARRANGEMENT OF LAVA CHANNELS ON THE SURFACE OF VENUS: A POSSIBLE EVIDENCE OF THE INTERIOR DYNAMICS.

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Introduction: There are about 200 lengthy, weakly sinuous trenches on the surface of Venus, mainly in the plain areas. They look like the dry lava channels. Their typical length is 300 to 500 km, and width is 1.5 km.

Analysis: The spatial distribution of 71 channels 70 to 6000 km in length have been involved into consideration in this work. This set involves all the main channels (the longer ones) of the planet and so represent the major part of the total length of the channels on Venus. It was revealed, that distribution of the channels across the planet is not uniform – they are located preferably within a certain region of Venus.

“Belt” region. This region of the channels’ concentration looks like a belt with 60° of longitude in width. Axis of this belt is along the meridian 170/350°E. This axis runs across the both poles of the planet and is perpendicular to the equator. So, its position at the equator is from 140 to 200°E and from 320 to 360°E. It occupies 230x10^4 km^2, which is half of the surface of the planet. This region contains 72% of lava channels after their number and 80% of the channels’ summary length.

Circle regions. There are two regions, located outside this belt. They are circles and have diameter 120° in latitude and longitude. Their centers are on the equator at 80 and 260°E. So, the circles are located from 60°N to 60°S and from 20 to 140°E (“Eastern” circle), and from 200 to 320°E (“Western” circle). Within these two circles, which summary area is equal to the half of the planet’s area, there are just 28% of lava channels by their number and 20% by their summary length.

The two circle regions are complementary to the “belt” region to cover the whole surface of Venus.

Interpretation: Lava channels are supposed to be formed due to a specific type of thermal and chemical evolution, which produced lava of very low viscosity and high mobility. Such processes looks to be typical for the belt mentioned above, but not for the two regions, bounded with this belt.

It could be supposed that such picture is due to the specific geodynamical processes in the planet’s interior, e.g. with two-cell convection, with the ascending flow located within the belt of lava channels concentration, and the two descending flows in the two opposite regions centered on equator at 80°E and 260°E, where the channel net is scattered.

Such assumption is in agreement with preferable distribution of linear extension features (tectonic canyons) within the belt and compression features (ranges of ridges) - within the two circle areas.
SEARCH OF CORRELATION BETWEEN NUCLEAR LINES MEASURED BY GRS AND NEUTRON DATA FROM HEND ONBOARD 2001 MARS ODYSSEY. S.V. Charyshnikov, M.L. Litvak, I.G. Mitrofanov, A.S. Kozyrev, A.B. Sanin, V. Tretjakov, W.V. Boynton, D.K. Hamara, C. Shinohara, R.S. Saunders, D. Drake, Space Research Institute, RAS, Moscow, 117997, Russia, charshin@mx.iki.rssi.ru, University of Arizona, Tucson, AZ 85721, USA, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, Lansce 3, Los Alamos Nat'l Lab. Los Alamos, NM and TechSource Inc, Santa Fe, NM 87594, USA.

Introduction: Mars has a thin atmosphere and has no global magnetic field. Therefore, cosmic rays freely propagate through its atmosphere and interact with the surface. Nuclei of the subsurface planetary layer with the thickness of 1-3 m produce a large number of secondary neutrons under the bombardment by cosmic rays. Neutrons propagate out from the layer and interact on the way with subsurface matter. Two types of nuclear reactions take place between outgoing neutrons and nuclei: inelastic scattering, when they are fast, and capture, when they have epithermal or thermal energies. Observation of Mars neutron albedo by HEND onboard 2001 Mars Odyssey is used for determination amount of hydrogen [1], or water (if we suppose that all hydrogen atoms are included to compound with oxygen forming molecule of water).

The nucleus of each chemical element produces a unique set of gamma-ray lines, and the method of gamma-spectroscopy allows identifying the presence and relative quantity of chemical elements in the martian subsurface. The gamma-spectrometer (GRS) with a detector of highly purified germanium is used for measuring the spectrum of nuclear gamma lines with very high spectral resolution [2]. Nuclear lines of primary elements of planetary matter are emitted either by inelastic scattering or capture of secondary neutrons produced by cosmic rays. Therefore, the intensity of each gamma line depends on not only the corresponding nuclei, but also on the spectral density of the flux of outgoing secondary neutrons. Thus, the knowledge of neutron albedo of Mars is necessary for accurate determination of the abundance of primary chemical elements and minerals by gamma spectroscopy. It requires complicated physical analysis including joint efforts in processing both gamma and neutron data. In this study we try to make first step in this direction and find possible correlation between two types of data.

Data Analysis: In our analysis we pay attention to North and South water rich polar provinces. Each province was divided into set of 74 separate regions. For each region we used GRS results about mean concentration of selected chemical elements [3] and results of model dependent deconvolution of neutron data presenting deepness of water ice layer [4]. It give us possibility to check correlation between two types of data.

Fig 1. Dependence between concentration of H and K and water ice depth inside North polar province (>60N).

Conclusions: There were found two strong correlations between gamma and neutron data. At first case we observed direct dependence between concentration of rock composition elements K and Si and water ice depth. At second case we have seen significant correlation between hydrogen’s concentration extracted from GRS data and water ice depth.

References:
WHEN MARS WAS SIMILAR TO JUPITER.

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The origin of the Mars dichotomy still remains, probably, one of the most intriguing riddles in the planetary system. If the Earth dichotomy could be explained by the tectonic activity then the Plutonic processes on the Mars did not reach such level in order to the global tectonics of the lithospherical plates could begin. For this reason, in order to explain the origin of the Mars dichotomy the external reasons of the disastrous nature became be attracted. However, any acceptable mechanism of such catastrophe explaining the whole complex of the features of the macro relief of the planet north hemisphere until was suggested.

The reason of such position is probably concealed, first of all, in that the collision mechanism of a large asteroid with a stone body of the planet [1] is attracted. Such approach is stipulated by the empirical data on a large catastrophes happened with the Moon, Mercury and moons of the giant planets. The moon dates of such events have permitted us to estimate the time interval - 4±0.2 billion years ago - of appearance in the Solar system of a large pins population which caused the gigantic meteorite bombing of the Solar system bodies.

At the end of the last century the idea of the temporary catch of the hydrogen-helium atmospheres by the Earth group planets during the process of their formation was repeatedly suggested [2]. Besides, in the same century two space catastrophes have occurred which study results can throw light on the Mars dichotomy origin. Theses catastrophes cover the fall of the Tunguska meteorite (1908) and comet Shoemaker-Levy-9 on the Jupiter (1996).

Let us imagine that at the period of gigantic meteorite bombing the Mars was still enveloped by atmosphere (MIA) and had a commanding size that greatly increased the probability of its casual collision with the most large objects. And such a meeting once occurred. Further the events followed according to mechanical and gas dynamic models of an explosion, developed by the Soviet researchers even in 70-80 years of the last century for application to Tunguska meteorite [3-6]. Hyper-sized asteroid entered the upper layers of the atmosphere (MIA) where burst or rather was exposed to explosion-like destruction above the modern north pole location which resulted in the occurrence of a complex system of ballistic and spherical strong shock waves in the atmosphere. Upon reaching the planet solid body surface, they (like gigantic rollers having passed from polar to equatorial latitudes) practically destroyed the post-accretion topography of the northern hemisphere and induced the lowering of the topography level by ~2 km in average. It may be well founded assumed that before the catastrophe the topography of the northern hemisphere slightly differed from the southern hemisphere.

The spherical explosive shock wave was the first that reached the solid surface of the planet (in the north pole region). The angle of impingement of the shock wave edge gradually increased as the wave was propagating southward along the meridians. When its value became more than 45°, the impinging shock edge merged with reflected shock edge [7] and the main shock wave was generated which is characterized by more higher pressures. There is good reason to believe that the prime shock wave started to generate at ~70° of north latitude where the traces of ancient topography are still available. If this assumption corresponds to the reality the altitude of the explosion is easily defined – it will be ~2500 km. When propagating further the main shock wave effected the soil more strongly comparing to the falling shock wave judging from the lowest area of the depression between 70° - 50° of northen latitude.

Fig.1 shows the plan of the depression in polar coordinates. The so called “coast” line where the ancient topography starts to emerge is assumed as the border of the depression. Through the Forsida eminence the border is assumed conventional because the evolved volcanic activity imposed its influence on the terrain. In spite the fact that the plan of the depression bears little resemblance to the plan of Tunguska tree-felling “butterfly” (Fig. 2a), the nature of these formations is the same. However, for the Martian option the ratio between the power of the object explosion and the power of object brake in the atmosphere was evidently more than that of at Tunguska and this resulted in the significant increase of the “butterfly head”. It is worth noting that the power of brake is the function of the body mass and depends on mean-square value of its diameter, and the power of explosion is the function of the body mass and depends on the value of the body diameter to the third. Besides, the combined interaction between the shock waves and Elisium and Forsida eminences could make their contribution to the increase of «butterfly head».

In this and other cases the origin of the «butterflies» wings is explained by increasing the pressure on the ground along the lines of crossing the fronts of the explosive and ballistic waves. On the Mars the left «butterflies» wing is presented by Acidlia planitia and Chryse planitia, the left one by Isidis planitia and Syrtis Major planitia. If the wings
WHEN MARS WAS SIMILAR TO JUPITER. E.V.Dmitriev

of the Tunguska «butterflies» are placed symmetrically, the wings of the Mars «butterflies» are turned clockwise. If "MПА" together with the planet stone nucleus had a solid body rotation, the depression plan would be symmetrical. The turn of the «butterflies» wings to the side opposite the rotation of the planet uniquely indicates that "MПА" had a differential rotation, viz: the upper atmosphere layer rotated faster than deep one.

Fig. 2b shows the design configuration of the Tunguska tree-felling plan executed by the V.P. Korobeynikov’s group [6] for the 30° meteorite trajectory inclination angle on which the hollow between wings was clearly shown. Probably, in the first approximation and for the Mars super asteroid the same trajectory inclination angle should be assumed. Also, in the first approximation coming from the rational assumptions the size of the super asteroid at the first hundred kilometers can be estimated at \( \rho = 2 \text{g/m}^3 \) and collision on the counter courses.

The origin of the flat impact craters of the South hemisphere can be explained by falling the planetzimals after their braking and parachuting in the powerful primary atmosphere at the final phase of the Mars accretion.


Fig. 1. The Plan to martian depression

1 – Elisium uplift; 2 – Forsida uplift; 3- Chryse planitia; 4 - Acidilia planitia; 5 - Syrtis Major planitia; 6 - Isidis planitia.

Fig. 2a. The plan of Tunguska tree-felling [8]

Fig. 2b. Calculated picture tree-felling for corner of the slopping to paths 30° and height of the blast on surface 5 km.
A hypothesis about the movement of geographical poles of the Earth were discussed in [1, 2]. The global analysis of the Earth linear structure elements has allowed to define the position of geographical poles in the different geochronological periods [3, 4]. It is known that there are some regions in the equatorial band of Mars looks like the permanent polar caps. For example such layered deposits are in the region 4° south latitude and 156° west latitude. [5].

In this paper trajectories of seeming movement of geographical poles of Mars (at constant position of its geographical axis) are established. It is the curves that unite sequences of geographical poles - poles of symmetry of faults in the global stress field fixed by faults on a surface of the mantle during its rotation around of the core. Positions of poles on spirals of trajectories testify to discontinuous rotation of the mantle. For discovering these poles were made a databank of faults of Mars and were analyzed them positions. A databank of faults of Mars was done on the base of Tectonical Map of Mars [6] by Dr. J.F.Rodionova (SAI of MSU) and A.F.Ainetdinova (student of MSU); the computer program was made by Dr. A.V.Dolitsky (UIPhE RAS) and Dr. R.M.Kochetkov (MTUI), by latter was done the analysis of the data. Trajectories of movement of north and south geographical poles are consisted of four spirals having amplitudes 110°, 100°, 80° and 70°. Trajectories are symmetric to a recent geographical axis and are in ranges of latitudes +/-15-50°. Many separate poles are found in higher latitudes. To discover the age of sequences of these poles and their correlation with the recent geographical poles the computer program will be broadened. But already now it is possible to assert, that the movement of poles of Mars and magnetic field are the effect of the rotation its mantle over the core. At present time the rotation of mantle have terminated. The certificate of it is a distinction between position of spirals of movements of poles of the past and recent poles which serve for them as poles of symmetry.

J.F.Rodionova and A.F.Ainetdinova, using A.V.Dolitsky's method, have established 18 structures, that are directed to equator correlated to the time of their formation. It has allowed to define relative age of structures according to the position of geographical poles. They were found as the points of crossing of bisectors of corners of structures(U-shaped) with spirals of trajectories. All structures of detected age do not contradict a principle “Young structures bridge over ancient structures”. Orientation of structures(U-shaped) direct to equator testify that their formation is under the action of centrifugal forces of rotation of a planet. The influence of these forces is depend upon their sizes, latitude position and amplitudes of raising of the surface of planet in that region. The sizes of structures(Ushaped) and amplitudes of their raising is also depended on power of centrifugal forces. The raising begins with warming up of the planet’s crust by magma, penetrated in it through faults, but not extending on this surface of planet.

Conclusions. In the history of Mars there are three stage of its development: 1) the stage of formation of planet; 2) a stage of its warming up followed by (a) rotation the mantle over the core, (b) generation a magnetic field of planet, (c) regional structure(U-shaped)-building under action of centrifugal forces of rotation of a planet, 3) a stage of cooling of planet and
termination of rotation of the mantle over the core; at this stage the magnetic field disappears.

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<th>Geographical poles and regional structures (U-shaped) of the same time</th>
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Indexes of geographical poles and structures (U-shaped) of the same time

The first figure (1 - North Pole, 2 - South Pole), the letter, header at a designation of a pole and lower case at a designation of the structure connected to it (α - the first spiral, Bb - the second spiral, Cc - the third spiral, Dd - the fourth spiral), last figure - a serial number of a geographical pole on a spiral of a trajectory.

References:

CHARACTERISTICS OF VALLEYS ON CERAUNIUS THOLUS AND THEIR FORMATION: PART I.
Caleb I. Fassett and James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

Introduction: Gulick and Baker [1] examined the morphology and morphometry of valleys on six Martian volcanoes, including Ceraunius Tholus. They concluded that the formation of Ceraunius' valleys was due to (or initiated by) surface runoff, and that valleys were reactivated (at least partially) and enlarged by groundwater sapping. Gulick and Baker present this evolution from runoff to sapping as a general morphological path for valleys on Martian volcanoes, and argue that it is consistent with evolution of valleys on the flanks of Hawaiian volcanoes. Here, we review Gulick and Baker's work on Ceraunius Tholus using new MOC, THEMIS, and MOLA data.

This work is part of our ongoing effort which aims to place the formation of the valley networks on the Mars' volcanoes in the context of the larger hydro-geological history of the planet. The late formation of the valley networks on Mars' volcanoes (compared to the valleys in the southern highlands) makes it imperative to understand the process(es) responsible for the valley morphology we observe there because this has important implications for global climate history on Mars.

Geological Setting: Ceraunius Tholus (Fig. 1) is a member of the Uranus group of volcanoes, located at the northeast edge of Tharsis. MOLA data shows that it has an average slope of $8^\circ (\sigma = 3^\circ)$ on its flanks, which contrasts with pre-MOLA measurements of 10-12$^\circ$ [2]. It is generally believed to be a basaltic shield, although earlier interpretations suggested it was a composite cone. On its summit lies a broad, mostly flat-floored caldera that is breached at its western rim (Figs. 1). Ceraunius Tholus appears to be at least partially mantled by an easily erodible surface layer. This is most readily seen in the smooth region west of the summit caldera and was likely the result of relatively late pyroclastic eruptions (either coeval or after valley formation).

Since Ceraunius Tholus formed roughly coeval with Uranus Patera, Plescia [3] suggested that it is Late Hesperian in age. Direct crater counts of Ceraunius itself using Viking data suggests an earlier age, but are highly uncertain.

Valley Observations: The valley-like features on Ceraunius Tholus were divided into four groups by Gulick and Baker (Fig. 1): (i) relatively small, pristine valleys with steep walls, (ii) small degraded valleys with eroded walls, (iii) linear chains of connected pits and (iv) large, deeply-incised canyons. Here, we discuss the small valleys on Ceraunius Tholus ((i) and (ii)), as well as the "chain of pits" (iii). In the second part of this abstract, we focus on the large valleys found on Ceraunius Tholus' north flank (iv).

Small Valleys: Small valleys incise much of the surface of Ceraunius Tholus, except for a smooth region on the west flank. The small valleys originate below the summit rim and extend down the flanks in a roughly subparallel manner, with few tributaries and small junction angles. The width and depth of the small valleys are hard to ascertain directly because their width often includes only a few MOLA shots. Therefore, an approximate estimate of the range of typical widths is 200-600 m, although the larger channels in this class can be ~1 km wide. The width of a given channel appears to remain fairly constant. The depth of valley incision is also hard to measure directly, but appears to be somewhat more variable than width for a given valley. Depths are typically on the order of tens of meters with the largest of these valleys having depths ~100-150 m. The majority of small valleys on Ceraunius Tholus are smaller than those measured by Williams and Phillips for typical valley networks on Mars [4]. This is a function of both differences in sampling (Williams and Phillips only considered MOLA crossings of valleys in the Carr database, which includes only the largest valleys), as well as geological processes (more small valleys are seen on Ceraunius Tholus than in the highlands).

Gulick and Baker [1] suggest that some valleys on Ceraunius Tholus appear to be especially pristine, which they say implies that they were reactivated by late-stage fluvial activity which they attribute to groundwater sapping. Based on the new data, especially the available THEMIS imagery, this does not appear to be the case. Many of the valleys that look degraded in Viking frames appear to do so because they are smaller and thus harder to resolve than those mapped by Gulick and Baker as pristine. Although there is certainly a range of valley degradation across the volcano, and a few valleys are noticeably discontinuous, the distinction between pristine and degraded valleys is not striking in the new THEMIS images.

In general, however, Gulick and Baker's description of the morphology and morphometry of the small valleys on Ceraunius Tholus remains apt in light of the new data. The radial symmetry of valleys (excepting the western flank), as well as the near-summit valley heads remains strong evidence that surface runoff played a significant role in valley formation, as Gulick and Baker propose. Despite the doubt that new data casts on whether valley reactivation occurred, groundwater sapping (as well as
other processes) probably did contribute to the formation of the valley morphology that we observe on Ceraunius Tholus.

**Pitted Valleys**: Gulick and Baker drew attention to what appeared to be connected chains of pits on the southwest flank of Ceraunius Tholus, extending from near the summit caldera to the base of the volcano (Fig. 1). The chain of pits appears more continuous in THEMIS and MOC images than in the Viking frames (Fig. 2a). The new images indicate that instead of individual pits, the valley is connected and unusually sinuous near the summit. Down flank it transitions into a style quite similar to other (relatively large) valleys, and near the volcano’s base, it divides into two channels, the deeper of which truncates the shallower. Both channels have fan-shaped deposits at their base (Fig. 2b). These fans could have been formed by emplacement of lava, debris, or sediment, depending on the mechanism (or mechanisms) that cut the sinuous valley itself, which are also uncertain. Since it erodes the mantled flank west of the summit, and extends almost to the caldera rim, it is probably younger than most of the small valleys we observe on Ceraunius. Further work needs to be done to understand how this unusual late-stage valley formed.


**Figure 1**: Feature map of Ceraunius Tholus produced by Gulick and Baker [1] (their Figure 5b). The solid lines indicate valleys they consider pristine and the dashed lines indicate valleys they consider degraded. Note that they map the sinuous channel on the southwest flank (shown below in Figure 2) as a chain of pits.

**Figure 2**: (a) A section of THEMIS IR image I2063002 illustrating the unusually sinuous valley on the southwest flank of Ceraunius Tholus. Note the smooth terrain, absence of flows, and evidence of ash-deposits that may infill older valleys on the terrain around this sinuous feature, especially to its north. Also, note the breach in the western crater rim (possibly associated with this ash deposit), and the upper reaches of the large valleys that flow down the north flank of the volcano. (b) A section of THEMIS IR image I01364005 that shows the fans at the base two channels that are associated with the valley shown in (a); the bottom valley has a bigger fan and crosscuts the top valley, which must be older.
CHARACTERISTICS OF VALLEYS ON CERAUNIUS THOLUS AND THEIR FORMATION: PART II.
Caleb I. Fassett and James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

**Introduction:** Three large canyon-like valleys lie on the north flank of Ceraunius Tholus (Fig. 1). The largest of these three valleys is the westernmost valleys, which also appears to be the youngest based on crosscutting relationships evident near the volcano's summit. This valley is at its deepest and most v-shaped near the summit of Ceraunius Tholus and becomes more u-shaped near its base, below which lies a substantial fan that lies in the oblong crater Rahe (Fig. 2). The easternmost valley has a smaller delta-like deposit at its base, emplaced upon Rahe's ejecta. The third, central valley is apparently the oldest of the three. Near the base of Ceraunius Tholus, it becomes degraded and its stratigraphic relationship with Rahe's ejecta is difficult to determine. Because the westernmost valley is the largest and best exposed of these valleys, the rest of this work explores it in detail. It is likely (but not certain) that the other two valleys formed in a comparable manner.

**Mechanisms of Large Valley Formation:** There has been much speculation regarding the origin of the westernmost valley and the nature of its associated fan. The candidate models include: fluvial action [1], volcanic density flow(s) [2], lava (the valley is a lava channel) [3], and collapse [4]. Gulick and Baker [1] sensibly suggest it might require some combination of processes to explain the observed morphology. Several new observations can shed light on these possibilities.

First, the fact that this valley completely cuts Rahe's rim (and across its ejecta) is an important constraint on the valley's formation mechanism (Fig. 2). A fluvial valley created solely by channelized overland flow (strictly conforming to the topographic gradient) would not breach the crater rim, as flow would be deflected by this topographic barrier. Lava erosion also seems somewhat implausible. Although lava may erode thermally [3], it is generally not efficient at erosion in an uphill direction. Based on this constraint, pyroclastic flow and groundwater sapping are the most probable formation mechanisms for breaching Rahe's rim.

Second, using the MOLA 1/128° grid of the Ceraunius Tholus region, we measured the volume deposited at the base of this valley in Rahe crater as 1.85 x 10¹⁰ (± 0.6 x 10¹⁰) m³ and the valley itself as 2.6 x 10¹⁰ (± 0.5 x 10¹⁰) m³. The significant uncertainties result from the resolution limits of the grid, and uncertainty in defining the margin of the depositional fan. However, despite their limitations, these measurements are consistent with the fan forming entirely from sediment originating in the valley.

Third, reexamination of the Viking images of Ceraunius, combined with elevations derived by MOLA, reveals that Rahe's rim was apparently not cut in a second location which would allow water to escape the crater. Specifically, the comparatively low northeast rim remains intact, which implies that water never filled the crater and escaped across the rim onto surrounding plains. This limits the possibility that massive floods could be responsible for carving the valley. Water must have entered the crater slower than the rate at which liquid water was infiltrated back into the groundwater system, or slower than ice deposits sublimated back to the atmosphere.

Finally, the similarity of the delta-like sediment accumulation at the end of the channel just inside the wall of Rahe crater to deltas found elsewhere on Mars at the end of relatively short channels interpreted to be of sapping origin [5] strengthens the sapping interpretation.

Based on the evidence we have examined, we believe the most likely explanation for the initiation of this large valley system is groundwater sapping. The Rahe impact event created a scarp at the base of the volcano (the inner crater wall) which produced a face intersecting the groundwater table and susceptible to groundwater sapping. After headward incision had breached Rahe's rim and proceeded up the valley's north flank, runoff, collapse and/or muddy debris flows contributed to propagating the valley towards the volcano's summit.

Figure 1. Viking MDIM2 image of Ceraunius Tholus (looking southeast) draped upon MOLA topography. The large valleys on the north flank, especially the westernmost valley discussed in the text, have large fan shaped deposits at their base. Also note the relatively smooth western flank (below the breached part of the caldera rim) and the small number of valleys that evidently incise its surface.

Figure 2. Schematic drawing of Rahe crater and the base of Ceraunius Tholus (looking southwest). Note the significant breach in Rahe's rim by the largest valley, as well as the unbreached near rim (see also Fig. 1).
HIGH DENSITY PHASES AS AN ATTRIBUTE OF IMPACT STRUCTURES.
CONDITIONS OF FORMATION AND PRESERVATION IN SHOCK PROCESSES.
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High density phases are considered to be one of characteristic attributes of impact structures. Their presence or absence is usually included into a number of decisive reasons for “pro” or “contra” references of concrete structure to shock-explosive formation. However in astroblemes these minerals are formed in very small amounts, they are distributed in impactites extremely non-uniformly and arise at different times and under different conditions; they have different mechanisms of formation.

At present time high-pressure polymorphic modification of SiO$_2$ (coesite, stishovite), carbon (diamond, lonsdaleite), pyroxene (majorite) and olivine (ringwoodite) are found in impact craters [1-6]. Moreover these minerals have been discovered in meteorites and received in laboratory experiments. We may speak of the four ways of formation of the above listed minerals: 1) martensite phase transition; 2) recrystallization at solid state stages of shock metamorphism with migration of material; 3) crystallization from melt; 4) fluid-mineral interaction.

Martensite phase transition is observed in shock wave experiments with dense quartz (more than 1.55 g/cm$^3$) [7]. In this case quartz transforms into stishovite due to high shear strain with velocities of 10 orders higher than at static compression thus avoiding coesite formation. In nature such stishovite was found in impact crater Ries [8] and also in massive quartzites of crater Arizona [9]. The same mechanism is responsible for paramorphism of diamond after graphite in crater Popigai [2, 3, 6], crater Ries [10] and others.

Recrystallization on solid state stages of shock metamorphism with migration of material is described as well both in experiment and in nature. This also refers to coesite observed after low density quartz (less than 1.55 g/cm$^3$) [7]. In nature such coesite is found in porous quartzites of crater Arizona [9]. The same mechanism is responsible for formation of diamonds (tigorites) after coals of Kara crater [11, etc.]. Occurrence of ringwoodite after biotite is observed in explosion experiments with loading of slates by converging spherical shock-isentropic waves [12, 13].

Crystallization from melt is known for coesite in astroblemes El’gygytgyn [14], Popigai [6], Kamensk [15] and others. In this process the crystal coesite form (needle-like or lamellar habit) well corresponds to the data on measured water contents in melt – low in the first case [16] and high in the second one [17]. Crystallization of stishovite from impact melt is observed in Vredefort astrobleme [18] and in shock-metamorphosed chondrites [19]. The prevailing part of impact diamonds is also formed from
melts [2, 3, 6]. And, at last, skeletal crystals of ringwoodite are found in melt glasses of El Gasco (Spain) impact pumices [5, 20].

The fourth mechanism (fluid-mineral interaction) is described for formation of high-pressure phases of silica in astrobleme Terny [21].

In all listed cases high density phases usually arise in rather short time (parts of second or seconds), which is defined by diminishing rate of shock pressure and temperature. Preservation of these minerals depends on dynamics of temperature changes – they undergo annealing at slow cooling of impactites and consequently more often "survive" in suevite and fall out deposits, while they are extremely rare in melt impactites inside a crater. Extreme heterogeneity of physical and chemical conditions in astroblemes determine non-uniformity of development of high density phases in total amount of mineral structure. All these factors taken together demand very cautious approach to conclusions about presence or absence of high pressure polymorphs in individual cases.

References:
SMART-1 MISSION TO THE MOON
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SMART-1 is the first in the programme of ESA’s Small Missions for Advanced Research and Technology. Its objective is to demonstrate Solar Electric Primary Propulsion (SEP) for future Cornerstones (such as Bepi-Colombo) and to test new technologies for spacecraft and instruments. The spacecraft is to be launched in early October 2003, as an Ariane-5 auxiliary passenger. After a cruise with primary SEP, the SMART-1 mission is to orbit the Moon for a nominal period of six months, with possible extension. The spacecraft will carry out a complete programme of scientific observations during the cruise and in lunar orbit.

SMART-1’s science payload, with a total mass of some 19 kg, features many innovative instruments and advanced technologies. A miniaturised high-resolution camera (AMIE) for lunar surface imaging, a near-infrared point-spectrometer (SIR) for lunar mineralogy investigation, and a very compact X-ray spectrometer (D-CIXS) with a new type of detector and micro-collimator which will provide fluorescence spectroscopy and imagery of the Moon’s surface elemental composition. The payload also includes an experiment (KaTE) aimed at demonstrating deep-space telemetry and telecommand communications in the X and Ka-bands, a radio-science experiment (RSIS), a deep space optical link (Laser-Link Experiment), using the ESA Optical Ground station in Tenerife, and the validation of a system of autonomous navigation (OBAN) based on image processing.

SMART-1 lunar science investigations include studies of the chemical composition of the Moon, of geophysical processes (volcanism, tectonics, cratering, erosion, deposition of ices and volatiles) for comparative planetology, and high resolution studies in preparation for future steps of lunar exploration. The mission could address several topics such as the accretional processes that led to the formation of rocky planets, and the origin and evolution of the Earth-Moon system.
COMPARATIVE DEGASSING HISTORY OF EARTH AND VENUS. S. Franck and C. Bounama, Potsdam Institute for Climate Impact Research, PF 601203, 14412 Potsdam, Germany (franck@pik-potsdam.de, bounama@pik-potsdam.de).

Introduction: Parameterized convection models have provided important results for the thermal history of the Earth and of other planets [1,2,3]. Schubert et al. [4] calculated a secular cooling of about 150°C-300°C since the Archaean and showed that a substantial portion of the present terrestrial heat flux is primordial with a Urey ratio of 0.65 to 0.85. For the first time Jackson and Pollack [5] investigated the effects of volatile dependent rheology on the thermal evolution of the Earth. The first self-consistent model to calculate the loss of volatiles during the Earth’s evolution and to study the feedback between heat transport and both temperature and volatile dependent viscosity was presented by McGovern and Schubert [6]. Our calculations of whole mantle convection and a dependence of the viscosity on the temperature and the volatile content are based on a functional relationship between creep rate and water fugacity [7] (hereafter referred to as FB-model).

Model Description: Our coupled thermal and degassing model is shown in Figure 1., where we have sketched how changes in the mantle heat flow are related to changes in average mantle temperature and radiogenic heat production. It contains the mechanisms for degassing of volatiles at mid-ocean ridges and regassing via subduction, respectively.

Results for the Earth: Figure 2 shows the thermal and degassing history for the Earth with an initial average mantle temperature of 3300 K. After readjustment, the average mantle temperature, the mantle heat flow, and the Rayleigh number decrease monotonically, while the mantle viscosity increases as a result from the combined effects of the decreasing mantle temperature and the volatile loss. The degassing history of the Earth is described by a rapid outgassing event at the beginning of the planetary evolution. The timescale for the outgassing of one ocean mass is of about 100 Myr.

Results for Venus: In the case of Venus, there is the possibility that the Venusian mantle convection might have changed from oscillatory to quasi-steady circulation, i.e. Venus changed from an Earth-like planet to a Mars-like planet around 500 Myr ago as far as its tectonic style is concerned [8]. Therefore, in the evolution model of Venus 4 Gyr after the start we set the spreading rate equal to zero. This takes into account the transition from an Earth-like to a Mars-like scenario. The thermal and degassing history of Venus is shown in Figure 3. Table 1 contains only those parameters that are different from the Earth’s FB-model. We found that the volatile loss is very sensitive against variations of the average melting depth \(d_m\) from which volatiles are released from the mantle. The upper 100 km of Venus are

![Figure 1](sketch_of_the_parameterized_mantle_convection_model_with_degassing_at_mid-ocean_spreading_centers_S_spreading_rate_dm_depth_of_partial_melting_and_at_backarc_volcanoes_regassing_occurs_via_subduction_into_the_deeper_mantle.png)

![Figure 2](thermal_and_volatile_history_of_the_earth.png)

![Figure 3](thermal_and_volatile_history_of_venus.png)
dried out [9] with the result of a raised solidus. As well known the surface temperature of Venus is much higher. We conclude that $d_m$ is smaller than in the Earth’s case. The value of $d_m$ is adjusted in such a way that only 0.35 ocean masses have been outgassed from the mantle. Therefore, the recent Venustian mantle is more volatile-rich than the Earth’s mantle.

Table 1: Working values for parameters that are different for Earth and Venus. All the other quantities (material constants, rheological and tectonic parameters) are taken for both planets and can be found in [7].

<table>
<thead>
<tr>
<th>parameter</th>
<th>Earth</th>
<th>Venus</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration of gravity [m/s$^2$]</td>
<td>9.8</td>
<td>9.0</td>
</tr>
<tr>
<td>mantle outer radius [m]</td>
<td>6271·10$^3$</td>
<td>5951·10$^3$</td>
</tr>
<tr>
<td>mantle inner radius [m]</td>
<td>3471·10$^3$</td>
<td>3110·10$^3$</td>
</tr>
<tr>
<td>surface temperature [K]</td>
<td>273</td>
<td>730</td>
</tr>
<tr>
<td>mass of the mantle [kg]</td>
<td>4.06·10$^{24}$</td>
<td>3.5·10$^{24}$</td>
</tr>
<tr>
<td>average depth from which volatiles are released from the mantle [m]</td>
<td>100·10$^3$</td>
<td>53·10$^3$</td>
</tr>
<tr>
<td>recent mantle heat flow [W/m$^2$]</td>
<td>0.07</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 3: Thermal and volatile history of Venus with Earth-like plate tectonics ending 4 Gyr after the start of planetary evolution.

Conclusions: Modeling an Earth-like planet with the help of a parameterized convection model that describes the influence of the dissolved volatiles on the mantle rheology by a nonlinear functional relationship between creep rate and water fugacity we can calculate the thermal history and the volatile exchange between mantle and surface reservoirs. For both Earth and Venus the calculated time series of the average mantle temperature, the mantle viscosity, the mantle heat flow, the volatile loss, the Rayleigh number, and the Urey ratio result in values that are in the generally accepted range. In the case of Earth we find an extremely rapid outgassing event in the first 100 Myr of the earliest history. This is in correspondence with noble gas depletion ratios of $^{129}$Xe/$^{130}$Xe [10]. These ratios lead to a timescale for this degassing event of less than 170 Myr. On the other hand, under the assumption that the tectonic style of the Venustian thermal evolution changed from Earth-like to Mars-like at about 500 Myr ago and that the Venus had always the present high surface temperature and a dried out uppermost mantle, it should have less efficient outgassed. The relative small volatile loss of Venus compared to Earth, i.e. 0.35 ocean masses to 1.8 ocean masses, corresponds to the observation that there is about 5 times less $^{40}$Ar in the Venustian atmosphere than in the atmosphere of the Earth [11]. Our results are in disagreement with recent findings of Vezolainen et al. [11] that imply a relatively soft Venusian lithosphere not much stronger than the terrestrial one.

SPHERICAL ANALYSIS OF GEOMETRY OF EARTH STRUCTURES

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Methods of mathematical-statistical analysis of the order in positions of the centers of the planet and satellite formations on their surfaces are developed and applied for explanation of some known surface structures [1]. Here we suggest new method of invariant harmonic sections (method of spherical analysis of centers distribution over planet and/or satellite surface). We present a short description of this method and illustrate its application for analysis of order in hot spot positions for the Earth.

Point distribution as series of spherical harmonics. Let us assume that on the sphere we have some thin layer of material distributed with definite density, which is a function of the spherical coordinates (latitude - \( \theta \) and longitude - \( \psi \)). This density function can be presented in sufficiently general case in the form of a spherical functions series. Discrete sets of material points on the sphere is limiting case of mentioned problem, using Distribution Theory; when surface features do appear discreetly. A discrete collection of points can be described by definite development in series with respect to spherical functions. For this it is sufficient to consider series in spherical functions for one point.

It is possible to define the spherical harmonics coefficients of a point distribution, as the series of inner products of \( \delta(\psi, \theta) \) - function with the orthogonal spherical harmonics basis \( L(l,m) = Y_{lm}^1(\psi, \theta) \) built on the sphere by means of associated Legendre functions.

If we have a set of discrete points, the complex coefficients of each point are combined (by addition) into a single complex coefficient for each \( (m,n) \).

Invariant partitions of the set of spherical harmonics. From general theory [2]-[4] it follows that any suitable function \( F \), given on the sphere, can be expressed as the sum of projections \( F = \sum_i F_i \)
where \( F_i = \sum_{m,n} c(i,m)L(i,m) \).

The \( F_i \) can be computed by means of spherical harmonics, and are independent of the coordinate axes in which the development is made. Each \( F_i \) is called an invariant section of degree \( i \). The study of the shape of invariant sections is the central idea of the developed method.

Shape of low degree invariant sections. For \( i = 0,1,2 \) the shape of the invariant sections, \( F_0, F_1, F_2 \) of any suitable function \( F \) are quite simple. Here, \( F \) will be the sum of the point distributions of a discrete set of points. \( F_0 \) is always a constant function, which can be made equal to the number of points in the set, in the case that we are considering. \( F_1 \) has the shape of a zonal harmonic \( L(1,0) \) in a special system of axes, that can be geometrically described by giving the axis and the coefficient of \( L(1,0) \) in that special axis. \( F_2 \) in general has two maxima, diametrically opposed, and two minima also diametrically opposed. The shape of \( F_3 \) for any suitable function \( F \) shows usually four maxima, and four minima.

The shape of \( F_4 \) shows usually six or eight of maxima (and minima). Searching of this maxima and minima led us to study the shapes of mentioned projections. This problem is similar to the determination of the Maxwell’s poles. Maxwell’s theory is based on the recognition that any harmonic function of degree \( n \), as every invariant section is, equals a scalar multiple of the result of differentiating the potential of a single unit charge, along \( n \) successive directions. These directions are the poles of the harmonic [3]. Poles do not depend on the reference system in which the harmonic function is expressed. They are geometric invariants of the harmonic functions.

Developed method differ from the study of the poles of corresponding sections, in that we will analyze maxima (eventually minima also) of the \( F_i \) shapes, instead of the poles.

Geometry of invariant sections for the hot spot system. Results of computer analysis of the shapes of invariant section \( F_4 \) for the set of 80 hot spots are presented on Fig. 1. The six maxima are distributed along two bands almost horizontal. The angular distances of the centers of near maxima, in that particular picture, appear to be very similar. We consider this result as evidence (to be validated statistically) of the non-random (ordered) position of the hot spots.

Fig.1. \( F_4 \) Invariant Harmonic Section of hot spots
**Shape of \( F_4 \) is an Octahedron.** The greatest differences of angular distances between maxima (Fig.1) are less than 10\%. And, six points equispaced on a sphere, define a well-known shape: An Octahedron. More over, any octahedron is the dual polyhedron of a cube, whose vertices are the centers of the faces of the octahedron. As a matter of fact, the first three regular polyhedra, the first three platonic solids, are related to each other. The dodecahedron is related, in a more winded way, to these. And the icosahedron is the dual of the dodecahedron.

Thus the maxima of the \( F_4 \) section for considered system of hot spots can be located in the vertices of an octahedron or in the centers of the faces of a cube. So important regularities of the ordered positions of hot spots are illustrated by regular shapes of the invariant sections, starting by the \( F_4 \).

Figure 2 shows a skeletal octahedron superimposed to the Longitude/Latitude map of this invariant section.

**The cube in the Earth hot spots – new geometric regularity.** The duality of the faces centered versus the vertices centered polyhedra, that allowed us a choice of presentation, lead to “the cube structure in the Earth hot spots” depicted in Figure 3. The dual octahedron is shown in Figure 4.

**Measuring and rendering the Polyhedra.** Neither the cube in Figure 6a, nor the octahedron in Figure 4, is the perfect platonic body. However, the measure of disagreement can be assessed easily by comparing angles between centers of faces with the angles of the regular polyhedra.

The polyhedral shapes were discovered by looking at the distribution of maxima in flat, Longitude/Latitude, depictions of the \( F_4 \) invariant sections of sums of point distributions, which characterize the most important features of planetary geodynamical processes. But the maxima give only directions through the center of the Earth, a sphere overall shape. To mutate this spherical form into a polyhedron, using the radial directions as guide, we have several choices, and no particular reason to prefer any of them, except, as was the case, simplicity (including simplicity of implementation). The following options were contemplated: \( a \). – The convex hull of the set of point positions of the maxima of the \( F_4 \) on the sphere; \( b \). – The Voronoi tessellation of these points and its dual Delaunay triangulation; \( c \). – The convex polyhedron whose faces are planes through the points, and normal to them.

The third option is the one implemented to produce the figures shown. Just because it was the easiest to incorporate to the program code already working. As a matter of fact, for points on a sphere, this method produces the same result as the Voronoi variant of method \( b \).

Barkin’s work was accepted by Spain Sabatico grant SAB-2000-0235 and RFBR grant N 02-05-64176.

**References.**
IMPACTS OF LARGE METEORITES AS A POSSIBLE SOURCE OF ORGANIC COMPONENTS ON TITAN, M. V. Gerasimov¹ and E.N. Safonova¹. ¹Space Research Institute, RAS, Profsoyuznaya, 84/32, 117997, Moscow, Russia, mgerasim@mx.iki.rssi.ru.

Introduction: Organic molecules can be produced by various natural processes and can be found in interstellar clouds, meteorites, comets, planets, etc. There is a large number of works showing the possibility of synthesis of complex organic molecules at reduced conditions under the action of various energy sources. Processes of synthesis of organic molecules in situ on planetary bodies are of prime interest since the transfer of organic molecules from one object to another is not so easy because counteractions of space bodies usually occur at high velocities with release of large energies, which result in destructive for organics high temperatures. Hypervelocity impact itself is generally considered as destructive process for organics because of high temperatures of vaporization at impact velocities over 7 km/s. But the expansion of the hot impact-generated plume, its rapid cooling, and counteraction with the environment also acts as an energy source capable of production of organic species. Earlier we reported about rather efficient synthesis of volatile organic molecules during simulated impact-induced vaporization of silicates in atmosphere of He and H₂ [1]. The formation of nonvolatile organic components in such processes was indicated by the abundance of carbon in C-C and C-H bonding during investigation of the forming condensates by methods of X-ray-photoelectron-spectroscopy (XPS) [2]. Reduced conditions favor synthesis of organic molecules. The atmosphere of Titan is composed of methane and nitrogen and the possibility of synthesis of organic molecules is mainly considered as a result of the action of solar UV in the upper atmosphere [3]. The aim of the present work was to investigate experimentally the possibility of synthesis of complex organic molecules from atmospheric methane in case of an impact of a siliceous body on Titan’s surface.

Experimental procedure: Our experiments were performed using standard laser pulse (LP) technique [4]. Special precautions were made to decrease the background level of organic pollution and to avoid contamination during experimental processing. A sample of augite from mantle intrusions was placed into a hermetic stainless still cell with a special glass tube and plates inside, which formed internal glass compartment. The internal wall of the glass tube was covered by clean cylindrical Cu foil for collection of condensed products of simulated impact related vaporization of the sample. The cell was filled by methane at room temperature and pressure. Estimated temperature of vaporization was in the range 4000-5000 K. Organic products were extracted from the foil by their dissolution in n-hexane and were concentrated (50 times) for analysis. Chromatographic analyses were done using Perkin-Elmer S-104 gas chromatograph and LKB 9000 chromatograph-mass-spectrometer. A set of control analysis was done including check of extractions of organic substances from solvents, chemicals, minerals, and all units, which contacted samples and internal cell compartment.

Preliminary results: Chromatographic analysis shows the presence of rather complex hydrocarbons in the mixture extracted from the experiment. An example of the chromatogram is shown in Fig. 1. Hydrocarbons are mainly presented by PAHs with degree of polymerization C₁₀pC₂₀. We could measure only PAHs soluble in n-hexane but visually all the condensed material was heavily black and did not loose that color after hexane treatment. This indicates for the presence of sufficient amount of kero-gen like material or soot.

Discussion and Conclusions: Experiments show a rather efficient synthesis of complex organic molecules during an impact related vaporization of silicates in the atmosphere of methane. The output of complex organic molecules is qualitatively sufficiently higher compared to that in experiments in oxidizing environment [5]. The presence of insoluble carbonaceous material makes it difficult to estimate the conversion rate of carbon from methane into complex organics. We claim for heterogeneous catalysis on the surface of glass nano-particles which are condensing in the spreading cloud and fill-in its whole volume (see Fig. 2.). The synthesis of organics in the present experiment was performed by involvement of only carbon and hydrogen from methane. Titan’s atmosphere also has sufficient amount of nitrogen. The involvement of nitrogen together with methane into the vapor plume chemistry possibly can provide the synthesis of amino-acids since amino- and carbonyl- groups were also present in correlation with C-H bonds in the condensate in some LP experiments [6].

Performed experiments show the principle possibility of synthesis of rather complex organic compounds from the atmospheric methane on Titan during a hypervelocity impact of a meteorite, large enough for the penetration through its atmosphere. In combination with the production of a long life warm oasis in the impact crater [7] impact-produced complex organic species can contribute to the life origin on Titan.

Acknowledgment: This research was supported by RFBR grant 02-05-64419.


Fig. 2. SEM picture of the condensed material from LP experiment. The scale bar is 1 µm.
ON THE EVAPORATIVE CHEMICAL DIFFERENTIATION OF IMPACT-PRODUCED MELTS.
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Introduction: Melted spherules ejected from impact sites usually have a wide diversity of chemical compositions sometimes sufficiently different from any of target materials. The main problem of the relation of ejected melted spherules and target rocks in impact structures is the unknown degree of their differentiation during the high-temperature stage. A certain problem for the relating of melt spherules and target rocks is the mixing of target rocks and projectile material. The formed spherules can represent a continuous row of mixed compositions which is modified by volatilization of elements during high temperature processing. An investigation of trends of chemical differentiation of melted droplets during impact simulated processes can give certain evidence for correlation between melt and target rocks in impact sites. Here we present experimental data on impact-simulated vaporization of augite and obsidian that helps to reveal vaporization signatures in impact glasses formed from acidic and intermediate composition targets.

Experimental technique: Impact-simulation experiments were performed using a laser pulse (LP) technique [1]. Glass spherules with diameters ranging from around one to several tens of microns were found on the surface of the condensed film, which was precipitated on a Ni-foil at ~8 cm from the sample. Chemical analyses of spherules were performed using FESEM/EDS microprobe analyses. Chemical compositions of the augite and obsidian samples were (wt.%):

<table>
<thead>
<tr>
<th></th>
<th>Augite</th>
<th>Obsidian</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>49.29</td>
<td>57.90</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.13</td>
<td>1.32</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>9.98</td>
<td>15.02</td>
</tr>
<tr>
<td>FeO</td>
<td>8.22</td>
<td>9.31</td>
</tr>
<tr>
<td>MgO</td>
<td>13.09</td>
<td>5.11</td>
</tr>
<tr>
<td>CaO</td>
<td>15.46</td>
<td>7.37</td>
</tr>
<tr>
<td>MnO</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.75</td>
<td>2.99</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.53</td>
<td></td>
</tr>
</tbody>
</table>

We also have analyzed microareas on polished cross-sections of glass remnants on the walls of the laser-produced crater. Results of analyses were statistically treated and compared with composition of starting samples.

Results: Experiments show two distinct trends of chemical differentiation of high-temperature melts. First, there is a conservation of Ca/Al ratio. Figures 1 and 2 show that the Ca/Al ratio for melt droplets and crater melts remains stable for both obsidian and augite while the concentration of Si experience sufficient depletion due to its volatility. This effect is the result of low volatility of both Ca and Al in siliceous melts. Second effect is the distinct negative correlation trends of moderately volatile Si and refractory Al. Figures 4 and 5 show Si vs. Al concentrations in crater melt and glass spherules in comparison with that of the starting samples for obsidian and augite, respectively. The crater glasses have smaller compositional differentiation than spherules. This effect is the result of higher surface to volume ratio of droplets. Crater glasses in experiment with obsidian have higher K/Na ratio compared with that in the starting sample. This is due to different K and Na vaporization rates that is typical for acidic and intermediate composition melts [2].

Vaporization effects in natural impact glasses: We tried to identify vaporization effects in natural impact glasses from the Logoi crater (D=10 km; Belorussia) [3]. The target is a two-layer structure with sandstones overlying granite-gneisses. Impact glasses here were mainly resulted from granite-gneiss melting. Compared to a rather strict anti-correlation of Al and Si for experimental spherules (Fig. 4) Logoi glasses in general show a wider dispersion of Si vs. Al. This can be the result of inhomogeneity of the target rocks and/or mixing of gneisses and sandstones. An approach was suggested to derive a uniform population from Logoi glass compositions by an application of strict experimental trend. Fig. 3 shows the CaO/Al₂O₃ ratio and Fig. 6 shows the SiO₂ vs. Al₂O₃ anti-correlation in homogenized impact glasses and values for the average composition of the target granite-gneisses. These trends are similar to the experimental ones that confirms the validity of such approach. This approach was also supported by other elements trends also for impact glasses from other craters.

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SEARCH FOR SEASONAL VARIATIONS OF MARTIAN GAMMA-RAY FLUX BASED ON HEND/ODYSSEY DATA. V. Y. Grinkov1, I.G. Mitrofanov1, S.V. Charyshnikov1, M.L. Litvak1, A.S. Kozyrev1, A.B. Sanin1, V. Tretyakov1, W.V. Boynton2, D.K. Hamara2, C. Shinohara2, R. S. Saunders3, D. Drake4, 1Space Research Institute, RA S, Moscow, 117997, Russia, grinkov@mx.iki.rssi.ru, 2University of Arizona, Tucson, AZ 85721, USA, 3Jet Propulsion Laboratory, Pasadena, CA 91109, USA, 4Lansce 3, Los Alamos Nat'l Lab. Los Alamos, NM and TechSource Inc, Santa Fe, NM 87594, USA.

Introduction. As the result of cosmic rays and natural radioactivity, the surface of Mars emits gamma lines. CO2 ice covers each pole for a half of year, attenuating the lines. [1] Using HEND gamma data, we try to search for the variations in the flux of gamma rays registered at Mars orbit. It can be an independent evidence of seasonal changing of polar caps thickness.

HEND’s scintillation block can register gamma quants in the range from 300 keV up to 2 MeV. [2] It has an energy resolution (sixteen energy channels) insufficient to resolve separate gamma lines but enough to get the average value in several energy ranges.

Data Analysis. To search for the variations, we considered polar and equatorial data separately and split data by periods lasting as long as 15 degrees of solar longitude (Ls). The studied gamma-ray flux depends on the incident cosmic rays flux and the elemental composition of the surface. To be saved from changes of the cosmic rays we excluded all periods with solar particle events and normalized the resulting values to a selected region (Solis Planum), where we expect no seasonal variations.

The study includes data over a period of Ls = 345° - 210°, that is about 16 months. The results are presented in fig. 1. The blue and the orange lines correspond to the north and the south poles respectively. The curves for gamma (top) show no correlations in comparison with similar curves for neutrons (bottom) that distinctly reveal martian seasons. The fact that both gamma curves are depressed at Ls = 100°, as we suggest, is due to the varying cosmic background, which non-uniformly irradiates the surface of Mars.

Conclusions. There are no significant seasonal variations of the gamma-ray flux in orbit around Mars registered in wide energy ranges.

A non-uniform irradiation of the martian surface by the varying cosmic background is observed.

References:

Fig 1. Seasonal variations of the gamma radiation from martian surface are shown in normalized units. The latitude belts 75°-90° both north and south latitude are shown here by curves with different color. The orange curve corresponds to the south and the blue one corresponds to the north. (Top). Variations of neutron flux are presented at those same regions. (Bottom).
VENUS SURFACE PANORAMS: HYPOTHESES FOR THE ORIGIN OF SURFACE FEATURES. James W. Head¹, and Alexander T. Basilevsky², ¹Department of Geological Sciences, Brown University, Providence RI 02912 USA, ²V. I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Russia Academy of Sciences, Moscow, Russia. (james_head@brown.edu).

Introduction: During the sequence of Soviet exploration of Venus [1], four missions (Venera 9, 10, 13, and 14) obtained panoramas of the surface (Fig. 1), providing fundamental information on the nature of surface processes there and on their relation to geological processes observed in synoptic radar images from orbit. In this contribution we summarize the major hypotheses for the formation of the features observed in these panoramas as a step toward the framing of questions to be addressed by future missions and analyses.

Major Features in the Images: Detailed descriptions of the images are available in the literature [2-6]. The main components of the features seen in the panoramas are:

1) Platy bedrock-like surfaces with apparent layering or exfoliated surfaces (Veneras 14, 13, 10).

2) Thin unconsolidated soil cover a few cm thick and distributed discontinuously on top of the platy unit in local lows (Veneras 10, 13).

3) Blocky, sloping surface with no evidence of platy bedrock-like exposures; at least some blocks are platy (Venera 9).

Theories of Origin: Theories of origin for these components can be summarized as follows:

1) Soil surface:
   a) In situ chemical and physical weathering of bedrock to produce soil.
   b) Pyroclastic airfall from explosive volcanic eruptions.
   c) Impact airfall debris.
   d) Eolian transport of material from (a-c) above into this area.
   e) All of the above.

2) Platy, bedrock-like surface:
   a) Lithified pyroclastic airfall deposits.
   b) Lithified impact airfall debris.
   c) Lithified eolian debris.
   d) Combination of a)-c).
   e) Primary volcanic lava flow surfaces, perhaps partly weathered.
   f) Bedrock exfoliation surfaces.

3) Blocky, sloping surface:
   a) Modification of bedrock units by tectonic deformation.
   b) Modification of bedrock units by slope-related mass wasting.
   c) Combination of a) and b).

Development of Ideas in the interpretation of the features in the panoramas: Initial ideas on the interpretation of the images were influenced by the thin platy nature of the surface, the geochemical interpretations that indicated a generally basaltic composition, and the physical properties measurements that indicated lower densities, suggesting rocks more porous than solidified basalts. This led to interpretations favoring pyroclastic airfall deposits [3,4]. Others were more influenced by the Venera basaltic compositions [7], the emerging understanding of the importance of volcanism as a regional resurfacing process as revealed in Arecibo radar data, and theoretical modelling studies suggesting that the Venus environment would dramatically inhibit the formation of explosive volcanic eruptions. These studies favored some type of upper lava flow structure for the platy surface [5]. Magellan analyses provided additional data 1) suggesting that pyroclastic volcanism was not readily recognizable, 2) and that the Venera sites were indeed located in volcanic lava plains of various types. The Magellan data further illustrated 1) the importance of parabolas arrayed around impact craters and showed that much of the surface was likely to be covered to a greater or lesser extent with airfall deposits from these [6], and 2) that eolian processes and features occurred on the surface, but were very secondary to volcanism on a global scale.

Atmosphere-surface interactions, surface chemistry and climate change: The high temperatures and pressures in the atmosphere at the surface of Venus can drive chemical reactions of CO₂, SO₂, OCS, H₂S, HCl and HF and minerals in the rocks and soils on the surface [8,9]. If the T/P conditions on Venus are similar to moderately high metamorphism levels on Earth, then the atmosphere may be at least partially equilibrated with the surface materials, and thus should reflect these to some degree. Several decades of work now suggest that the abundances of CO₂, HCl and HF may be regulated (buffered) by surface mineralogy, but that the abundances of H₂O vapor, SO₂, H₂S, and CO are kinetically controlled by combinations of surface-atmosphere reactions and gas phase chemistry [8]. A key issue in this area is carbonate equilibrium, and whether carbonates are present on Venus and serving to buffer the atmosphere. Arguments can be made on both sides, but what is needed to address this fundamental issue is in situ analyses that are sensitive to calcite and other carbonates. Another question is the existence of equilibria involving HCl and HF, which have been detected in the atmosphere, and surface minerals which might be common in alkaline rocks such as those that appear to be present at several of the Venera/Vega sites. A further question is redox reactions involving Fe-bearing minerals. Oxidation of Fe²⁺-bearing minerals in surface volcanic rocks may be important for water loss and hydrogen escape to space, by way of oxidation of pyroxenes and olivines in surface rocks [10]. Altitude dependent radar emissivity relations give further evidence of atmosphere-surface interactions. Regions below about 2.4 km have radar properties typical of anhydrous rocks such as dry basalt, but higher elevations are characterized by lower radar emissivity suggesting the presence of semiconducting minerals with high dielectric constants, perhaps iron oxides, iron sulfides or even metallic frosts [11].

Finally, the sulfur cycle on Venus could be of importance in weathering. Volcanic outgassing is thought to produce SO₂ and S₈, OCS, and H₂S. The relative proportions of these gases relative to that typical of Earth eruptions is unknown, but has important implications for surface weathering. Currently, the SO₂ abundance in Venus' atmosphere is far greater than expected from equilibrium conditions and thus the chemical weathering of Ca-bearing minerals in surface rocks and soils
may be an ongoing process. Furthermore, maintenance of the current concentrations of \( \text{SO}_2 \) in the atmosphere requires continuous eruption of lava to provide atmospheric \( \text{SO}_2 \) replenishment.

Interestingly, should volcanic replenishment not continue, significant climate change could occur [8]. If the volcanic source and anhydrite sink are not balanced, fewer clouds will form and surface temperatures may decrease due to the declining influence of greenhouse gases. Furthermore, minerals such as magnesite and other carbonates currently unstable may start to form, and begin to consume atmospheric \( \text{CO}_2 \) as temperatures fall. On the other hand, if even more \( \text{SO}_2 \) is pumped into the atmosphere by increased levels of volcanic activity, additional \( \text{H}_2\text{SO}_4 \) will be produced, forming additional clouds, and causing surface temperatures to rise even further. This could cause the decomposition of minerals now stable at the 740 K surface temperature. Thus, significant climate changes may have occurred in the recent geological history of Venus [12] and could lead to a range of surface material weathering, breakdown, cementation and lithification processes.

**Conclusions:** A wide range of interpretations exist for the origin and evolution of surface features seen in the Venera panoramas. These can be tested and distinguished with surface observations and measurements in upcoming missions to Venus.

**References:**

Figure 1. Panoramas of the surface of Venus obtained by the Venera spacecraft.
THE MARTIAN HYDROLOGICAL CYCLE AND LATE NOACHIAN HYDROGEOLOGY: TERRESTRIAL BACKGROUND. James W. Head, Michael H. Carr, Patrick S. Russell and Caleb I. Fassett. 1Department of Geological Sciences, Brown University, Providence, RI 02912, 2U. S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025 (james_head@brown.edu)

Summary: A diversity of features on Mars revealed by orbital spacecraft missions (e.g., clouds, polar caps, outflow channels, fretted channels, valley networks, polygons etc.) have been interpreted to be water-related and to record the presence of water in liquid, solid and gaseous forms [1]. Differences in the characteristics and abundances of these features and their correlation with latitude and geological time have led to hypotheses that climate conditions on Mars have changed to those characteristic of the present cold polar desert, from conditions representing a variety of earlier climates, the most distinctive of which is that characteristic of a warm, wet pluvial climate in the Noachian [e.g., 2]. These changes have been proposed to occur on a variety of time scales ranging from those related to geologically relatively short-term variations in orbital parameters, to changes correlated with very long-term changes linked to the thermal evolution and outgassing history of Mars.

Generally unknown are: 1) the total abundance of water on Mars, 2) the nature and relative significance of water reservoirs at present, 3) how these reservoirs are presently connected in the hydrological system, 4) the hydrogeologic processes that are involved in transport in the hydrologic cycle, and 5) the history of the hydrologic cycle (how its nature has changed with time).

All of these unknowns and related surface features are potentially linked to the presence of groundwater in the hydrologic system and cycle. Presently, liquid water is metastable on the surface and occurs only during seasonal extremes in microenvironments [3]. At what depth does liquid water exist in the subsurface today and could it have been flowing across the surface in valley networks in the distant geological past, as many believe? Essential to understanding these questions is the nature of the hydrologic system and cycle on Mars and specifically, the role of groundwater. Although several groundbreaking studies have been carried out on the martian hydrological cycle, primarily by Steve Clifford [4,5], the details are poorly known and the concepts are often under appreciated. Indeed, this was also the case for terrestrial hydrogeology as recently as the 1960s and 1970s, until an emerging understanding of regional and basinal groundwater flow generated interest in assessing its broader implications. Even after this time, the significance of the general role of groundwater on Earth was hindered by 1) the multitude and diversity of phenomena and features generated by groundwater flow (and thus the difficulty in conceptually linking them to a common process), and 2) the lack of awareness or appreciation of interpreted regional groundwater behavior, transport and hydraulics on the part of many researchers in various subdisciplines, and thus the difficulty in making cause-and-effect links between specific features and phenomena, and basin-scale groundwater flow [6].

In order to try to provide a framework for establishing potential cause-and-effect links between the multitude of features seen on Mars, and regional groundwater behavior, transport and hydraulics, we build on the pioneering work of Clifford [4,5] to address the candidate structure of the martian hydrogeologic system, and candidate hydrogeologic processes. We then use this framework to investigate the origins of various geological features and how they might fit in modern and ancient hydrogeological systems and hydrologic cycles.

The Terrestrial Hydrological System and Cycle: The terrestrial hydrologic system consists of vertical zones including 1) an upper zone of aeration (the vadose zone) which contains both air and water, and overlies 2) the zone of saturation, in which pores in soil and rock are saturated with water (Fig. 1). The top of the zone of saturation is known as the water table, and water moving through the zone of saturation is known as groundwater.

In the terrestrial hydrological cycle (Fig. 2), water enters the system by precipitation of rain (pluvial regime) or snow (nival regime) onto the land surface and in the case of rain can immediately infiltrate the vadose zone, can be temporarily stored on the surface before infiltration (depression storage), or can drain across the land surface to a stream channel by overland flow. In the case of ice and snow, water may be temporarily stored as snowpack or ice accumulations before melting and undergoing infiltration, overland flow, or stream channelization. Water stored in the upper part of the vadose zone (soil water) can evaporate back into the atmosphere; excess vadose water undergoes gravity drainage and is pulled downward toward the water table. At the base of the vadose zone one encounters the capillary fringe, where pores approach 100% water-fill, but where the water is held in place by capillary forces. Groundwater is the term used for water stored in the zone of saturation just below the capillary fringe and the water table. It moves vertically and laterally by groundwater flow through the permeable rock and soil layers until it discharges by seepage into lakes, streams or oceans and by localized flow, as a spring. On the surface, water for stream flow can be derived from overland flow and/or from groundwater seepage. Streams that are at or below the local or regional water table are gaining water by groundwater seepage into the stream and are known as gaining, or effluent streams. Streams that are above the local or regional water table are losing water by groundwater seepage into the stream and are known as losing, or influent streams.

The vadose zone consists of a three-phase system of solid, liquid and gaseous material. The solid phase can consist of 1) soil formed from in situ weathering, 2) sediment brought from outside, 3) unweathered bedrock, and 4) organic material from decay of elements of the biosphere. The liquid phase consists of water and any dissolved solutes. The vapor phase consists of water vapor and other gases that may differ from the proportions in the atmosphere. Air pressure measured above the water table in the vadose zone is equal to atmospheric pressure, but fluid pressures measured above the water table will be negative with respect to local atmospheric pressure. At the top of the water table, capillarity will cause the rise of water.
from the zone of saturation into the vadose zone through a capillary fringe at the base of the vadose zone. Water drawn upward by capillarity can 1) return downward when gravity forces overcome surface tension forces, 2) migrate upward to the surface and undergo evaporation if the capillary fringe is close to the surface, or 3) evaporate at depth and rise through the pore spaces as water vapor.

In the zone of saturation, groundwater plays a fundamental role because of 1) its ability to interact with the environment, and 2) the systematic spatial distribution of its flow. This interaction and flow occurs at all scales of space and time, with varying rates and intensities. Interactions of groundwater with the environment include 1) chemical (and a host of related processes such as dissolution, hydration, chemical precipitation, etc.), 2) physical (pore-pressure modification, lubrication, etc.), and 3) kinetic (transport processes of heat, water, and other material).

Groundwater flows in systematized and hierarchical flow paths and thus groundwater flow systems operate as mechanisms of transport and distribution of various effects into regular spatial patterns within the basinal flow domain. For example, where groundwater flow is controlled by topography, the spatial distribution patterns of the effects of groundwater flow (e.g., springs, seepage, karst, subsidence, etc.) are functionally related to specific identifiable and characteristic segments of the flow systems.

Another major perspective on the characteristics of the interaction of the groundwater system and its environment is the tendency toward equilibrium, seeking a state of minimum free energy. This is achieved through a variety of natural processes, including mobilization, transport and deposition of water, other matter, and heat, and changes in pore pressure. A related perspective is the visualization of groundwater sources, transport zones and sinks, and the concepts of equilibrium and disequilibrium. Regional groundwater flow itself implies disequilibrium conditions, and this can be readily visualized in terms of flow in a conveyor belt, with individual systems being characterized by source regions (areas of loading and mobilization), terminal regions (areas of delivery and deposition) and the intervening regions (relatively more stable areas of mass and energy transfer) [6].
THE MARTIAN HYDROLOGICAL CYCLE AND LATE NOACHIAN HYDROGEOLOGY: TERRESTRIAL
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Introduction: In the previous abstract, we outlined initial aspects of terrestrial hydrogeology to provide a basis for comparison to Mars. Here we continue this background with a summary of groundwater flow systems.

The Terrestrial Hydrological System and Cycle (continued): Single flow system source regions (Fig. 3) are characterized by an area of origin, or recharge where the mechanical energy of the water, the hydraulic head, is relatively high, decreasing with increasing depth as the water flow moves downward and becomes divergent. In areas of termination, or discharge, energy and flow conditions are reversed, with relatively low hydraulic heads that increase downward, resulting in converging and ascending flow of groundwater. In between, in areas of throughflow, the mechanical energy of the groundwater is largely invariant with depth (hydraulic head isolines are subvertical), and flow is predominantly lateral. This regional gravity flow system produces a variety of effects, including, 1) hydraulic head conditions that vary from subhydrostatic to normal, to supraphydrostatic in the direction of flow from recharge to discharge areas; 2) relatively dry surface/soil water conditions in the recharge areas (negative water balance), to water surplus (positive water balance) in discharge areas, possibly leading to wetlands; 3) systematic changes in the groundwaters anion facies; 4) chemically leached soils and rocks in inflow areas, and increased salt contents in outflow areas; 5) regional geothermal gradients altered due to heat transport by groundwater; 6) chemical oxidation conditions predominantly in recharge areas, and reduction trends in discharge areas; 7) in areas of discharge, increased occurrences of soil and rock-mechanical failures (e.g., soil erosion, slumping, landslides, quick grounds, etc.) sometimes leading to major features such as springs, seepage zones, gullies, sapping, streams, etc. Furthermore, individual flow systems can be placed in a hierarchical structure of systems of various larger properties. (logologic, geologic, and climatologic) that determine the main characteristics of the groundwater regime [7] and include 1) water content, 2) flow system geometry, 3) specific volume discharge, 4) water chemical composition, 5) temperature, and 6) variations with time of all of these parameters. Three hydrologic environment parameters control the groundwater regime: 1) topography; 2) geology; and 3) climate. For example, climatic factors control the amount and distribution of water supplied to any region, and topographic relief and altitude can determine both the nature of the water input (rain, snow, frost), the distribution of flow-inducing energy, and the boundaries of the flow domain. The nature of the geology determines the nature of the conduit system for water movement (thick regolith, bedrock, some combination), and this in turn heavily influences the amount of water, patterns and rates of flow, and the amount and distribution of stored water.

Gravity-induced basinal-scale groundwater flow can be characterized by two important hydraulic phenomena: 1) the orientation of the vertical component of the flow, and 2) the depth (thickness) of the phreatic zone, which is relief-dependent and is reflected in the depth to the water table, which fluctuates annually. The water table is at greater depths in recharge areas than in discharge areas, and annual water-table fluctuation is also greater in recharge areas than in discharge areas (Fig. 4).

Geomorphologic features resulting from groundwater activity are numerous and include karst development and, in outflow regions, features such as seeps and springs that can grow due to groundwater-induced soil/rock mechanical weaknesses that considerably increase erodibility. This can cause significant headward erosion from springs and quick ground to form gullies and stream valleys, asymmetrically sloping consequent stream banks, and mudflows and landslides. Climate can strongly influence the nature of geomorphic features in the discharge areas, with springs and seeps being replaced in cold climate regions by ice fields and ice mounds, and frost heaving and frost mounds.

The Terrestrial Hydrological System and Cycle and Comparisons to Mars: The hydrologic system on Mars is likely to differ from that of the Earth in the following ways: 1) Lack of land vegetation cover, causing relatively more overland flow, evaporation to dominate over transpiration, organic matter in the soil to be insignificant, and groundwater recharge to be more significant on Mars. 2) Cold polar temperatures and hyperarid conditions favoring ice and frost, and favoring sublimation over evaporation. 3) Lower gravity, influencing gravity drainage through the vadose zone and groundwater flow. 4) Different soil properties, with the Mars impact-dominated, somewhat lunar-like regolith contrasting with the Earth’s often well-sorted regolith produced by processes associated with a thicker, water-rich atmosphere. 5) Dominance of fine-grained material in the impact-generated regolith on Mars and the effects on porosity and permeability, and infiltration versus overland flow. 6) Large volume of impact generated megaregolith and implications for groundwater movement and storage. 7) A different total volume of water on Mars, with implications for level of the water table. 8) The relationship of early megaregolith on Mars, and later stratified volcanic units,
and implications for aquifers and groundwater flow. 9) A geologic record on the Mars surface that spans a significant part of the planet’s history; thus, in contrast to the Earth, the geological record of hydrological systems and cycles of vastly different ages may be preserved, and may be overprinted.

Summary: A simple analog for the complexities of the groundwater system is the situation commonly encountered at an ocean beach. Here, the beach surface, commonly composed of dry loose sand, is the analog of the recharge area, while the ocean surface is the top of the water table. Rain falling on the beach surface will most often form raindrop impressions as the water immediately soaks into the porous sand. If one digs down into the sandy beach, one will pass through a dry layer (the vadose zone) and encounter a water-saturated zone below the water table. The depth to the water table increases as the elevation of the beach increases. The water table can rise and fall as a function of tides. As the ocean level recedes and drops due to tides, water drains from the ground at the edge of the beach (the discharge zone) and forms seeps and springs. As the water further recedes, discrete sapping channels form and migrate back up into the beach area, sometimes for tens of meters. Water-filled lows on the beach slowly recede and dry up as the water table drops in response to the falling tide.

Conclusions: These properties of terrestrial hydrogeologic features and hydrological systems, as well as factors in the hydrological cycle, provide a basis with which to view similar features that might have characterized the martian system early in its history, before the advent of a global cryosphere. We use the Earth groundwater system and hydrological cycle to assess how the hydrological system might operate on Mars in its early history (Late Noachian) [8]. We also discuss and compare the nature of individual features and assess how they might relate to the general hydrological and groundwater system and cycle [9-12].

LATE NOACHIAN HYDROLOGIC CYCLE: GROUNDWATER SAPPING TERRESTRIAL ANALOGS AND LABORATORY EXPERIMENTS. James W. Head¹, Michael H. Carr², Patrick S. Russell¹ and Caleb I. Fassett¹. ¹Department of Geological Sciences, Brown University, Providence, RI 02912 (james_head@brown.edu), ²U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025.

Introduction: Among the candidate origins for some martian linear erosional features are sapping processes [1-9]. Here we undertake an assessment of the nature of sapping and related groundwater processes as revealed by terrestrial field studies and laboratory experiments. We outline some of the major findings as they apply to the interpretation of fretted channels and large valley networks on Mars. In a separate abstract, we apply these to the interpretation of several classes of martian linear erosional features.

Processes of Groundwater Sapping and Valley Formation on Earth: Observations and Experiments: Groundwater outflow along slopes causes erosion, undermining, and where spring sapping is concentrated, can contribute to the formation of valleys [10]. Diffuse discharge of groundwater can cause seepage erosion, while locally concentrated groundwater discharge (springs) can cause spring sapping. Sapping caused by subsurface groundwater can produce headward channel growth and branching, in contrast to channel networks produced by overland flow, where piracy, cross-grading, and headward growth by abstraction are among the dominant factors [11]. In addition, sapping can contribute to both channel and valley development, and non-fluvial degradation can play a very major role in valley processes. Finally, the role of sapping as a geomorphic process has not been fully appreciated in earlier terrestrial studies because climate change and groundwater table lowering have decreased its present significance and obscured the more obvious cause-and-effect correlations. Other non-sapping processes have served to obscure further the role of sapping [10-12]. Thus, if sapping processes on Mars are no longer operative or are operating at much slower rates today than in the past, they may be similarly difficult to identify.

Sapping is dominated by basal undercutting processes which at the largest scale are controlled by rock type (e.g., massive resistant cap rock overlying weaker, incompetent rock), structure (e.g., regional faults and fracture systems facilitating flow and focusing sapping and valley development) and climate (e.g., promotion of sufficient recharge for the groundwater system to be active) [10]. Observations of sapping valleys in Hawaii [15] and the Colorado Plateau [13] show that they are characterized by “elongate basin shape, low network drainage density, low degree of interflute dissection, widely spaced and short tributaries to main trunk valleys, theater-like valley heads, local structural control, local examples of long and narrow interflutes between adjacent valley segments, steep-sided valley walls meeting valley floors at a sharp angle, irregular variation in valley width as a function of valley length, relatively high drainage densities in upstream portions of basins, and local examples of hanging valleys” [10].

Models of sapping valley development come from these types of observations and from laboratory experiments. Dunne’s [11] conceptual model of sapping-dominated valley development (Fig. 1) involves a water table regionally sloping toward a hydraulic sink provided by a topographically depressed region. Water then emerges along a spring line where the water table intersects the surface and a combination of chemical weathering and changes in porosity and rock strength enhance local weathering. Faults and joints further localize erosion, and enhanced undermining occurs, becoming self-enhancing as groundwater flow lines converge on the spring head. Focused and increased flow leads to headward erosion and valley formation. The evolution of flow convergence is a key to sapping valley development (Fig. 1). As the spring head retreats, greater and greater convergence in the groundwater flow field is generated, and thus the rate of headward erosion is increased. The rate of valley widening lags far behind the rate of headward sapping because the valley head is the location of greatest flow convergence. Headward growth may then intersect other zones that are particularly susceptible to sapping (such as joints or faults) and a tributary will often form. Ultimately, the process of sapping, headward retreat and branching will form a network of such valleys [10, 11]. Network development, however, works counter to the self-enhancing groundwater flow field convergence typical of the initial stages. In principle, the development of multiple spring heads further disrupts the flow field, decreasing maximal flux, slowing rates of headward retreat, and eventually allowing equilibrium with available groundwater to be reached at some optimized drainage density.

Beach-face channels formed during falling tides [14] and channels formed during controlled laboratory modelling [10, 16, 17] show many of the characteristics of the channels described above that are interpreted to have originated by sapping processes, and support the conceptual model [11] outlined above. Of particular interest is the nature of the substrate, and the role of cohesionless material in the formation and evolution of sapping valleys and associated morphology, a situation that might approximate much of the martian megagolith in the highlands. Three distinct zones are observed at a sapping face in cohesionless sediment (Fig. 1): 1) an *undermining zone* toward the headward end, where backcutting of the sapping face causes intermittent undermining of the cohesionless material. Most hydraulic erosion is concentrated in the uppermost zone of *seepage outflow*, where there are steep surface gradients and strong upward seepage. 2) a *sapping zone*, where the surface is smooth and wet, with shallow flow depths and where the predominant mode of movement is by intermittent bulk flow failures. Here, gradients are near the threshold of failure, which is determined by the balance of seepage and gravity moments, and the angle of internal friction of the sediment. Surface flow tractive stresses are unimportant here. 3) a *fluvial zone* where water depth is greater, grains move individually and channel gradients range from lower at outflow to higher at the transition to the sapping zone. Low bedforms and bars are common here, in contrast to the sapping zone. With time during experiments [10, 16, 17] the
height of the zone of undermining decreases, the length of sapping zone remains relatively constant, and the fluvial zone expands as the sapping face retreats.

Experimental data [10, 16, 17] show that the rate of backwasting of the sapping face is determined by the rate of sediment transport through the fluvial zone, which in turn is a function of sediment characteristics, the morphology of the sapping face, and the imposed hydraulic gradient through the sand. In turn, the flow pattern is dependent on the morphology of the sapping face. In summary, the temporal evolution of the sapping face is the result of a complicated interaction of 1) groundwater flow, 2) surface flow, 3) sediment transport, and 4) morphology of the sapping face.

**Sapping channel formation and growth:** Experiments [10, 16, 17] show that initially, several distinct channels from and competition is so strong that rapidly only a small number of channels remain active. This appears to be due to the fact that higher permeability channels erode more rapidly, become deeper and longer, and cause convergence of flow lines and subsurface groundwater capture, causing the stabilization of several main “trunk” channels. The factors that determine the lateral influence of a given channel on groundwater flow include: 1) the geometry of groundwater flow through the cohesionless material, 2) the depth of flow versus length of flow, 3) the channel depth, and 4) the level of critical flow necessary to initiate erosion. When the flow rate is only slightly above the sediment-entrainment threshold, short tributaries often develop along the trunk channels and in some cases both channels remain active following bifurcation, while in others activity at one channel ceases due to competitive disadvantage. In summary, three factors act together to form tributaries: 1) Headward erosion of trunk channels causes flow convergence to become stronger, tending to widen the valley head. 2) Permeability variations at the valley headwall can create two zones of lateral migration (branching). 3) Headwall slumps can locally infill, raise the channel bed, and push the zone of groundwater emergence downstream, temporarily reducing the erosion rate and allowing adjacent areas to gain competitive advantage, causing bifurcation. If flow rates are high and erosion is rapid, competition between adjacent channels is less pronounced, more trunk valleys are favored, and tributaries are rare. Introduction of cohesion (without markedly influencing permeability) [10, 16, 17] influences channel form by producing drainage patterns similar to those with low flow rates in cohesionless sand, but hydraulic gradients about 20-50% higher than for cohesionless sand are needed to initiate erosion.

**Role of a basal scarp:** The upland slope and the height of the basal scarp were varied in some experiments [10, 16, 17]. Where the upland surface is relatively flat and there is a relatively steeper lower scarp, runoff produced by emergent groundwater erodes primarily as channels cutting headward into the upper surface as a “wave of dissection” (Fig. 1a). On the other hand, where the scarp is absent or gradual and the upland slope is steeper, more abundant rills develop and subsequently deepen over a larger part of the upland surface and less erosion occurs by headward scarp retreat from the lower end of the slope (Fig. 1b). Thus, if channel development is solely occurring in association with headward scarp retreat, a small number of trunk channels emerges and survives while if groundwater is emerging from a sloping plain without a scarp, a denser network of smaller channels can form (emergent seepage).

We now use these basic guidelines as aids in the interpretation of geological features that are associated with the margins of the northern lowlands and elsewhere on Mars.


![Fig. 1. Perspective views of sapping zones with a) relatively shallow upland slope and prominent scarp, and b) relatively steeper upland slope and minimal scarp (after [10, 16, 17]). Arrows on plains surface in a) represent subsurface flow directions, which are influenced by headward retreat of sapping channels and are pirated, decreasing the flux of springs at the sapping zone. In emergent seepage, subsurface flow is more parallel and springs are more uniformly distributed and of higher flux.](image-url)

Introduction: Following their initial discovery by Mariner 9, martian linear erosional features were generally divided into three classes: 1) outflow channels (begin full-size, have few tributaries, commonly have bedforms), 2) valley networks (begin small, enlarge downstream, form branching networks), and 3) fretted channels (broad, flat-floored valleys; commonly branch upstream, widen downstream, display significant mass wasting from walls) [1-4]. Carr [4] noted that some channels could not be unambiguously classified into these basic categories, citing examples like Ma'adim Valles, that resembles a fretted channel in its lower reaches, but has network characteristics in its upper reaches, although generally at a much larger scale. Here we examine the characteristics, distribution, and candidate modes of origin of three types of linear erosional features, 1) large valley networks, 2) fretted channels, and 3) theater-headed valleys, and assess their possible role in the Late Noachian hydrologic cycle. We then interpret them in terms of processes of groundwater circulation and sapping developed in companion abstracts.

1) Large Valley Networks: In contrast to the large outflow channels, valley networks are thought to have formed by processes analogous to terrestrial stream and river valleys through erosion by running water [5-6] and/or sapping [7-8] and to have perhaps been covered by ice [9]. They are ubiquitous in the heavily cratered highlands and generally considered to be of Late Noachian age [4, 10], perhaps extending into the Hesperian [11]. Carr [4] noted the resemblance between some valley networks and fretted channels, particularly along the northern lowland-southern upland boundary. Along the boundary between 180-220 W, several broad, flat-floored valleys (e.g., Ma'adim, Al Qahira) extend deep into the uplands, appearing more like very large valley networks in their upper reaches.

2) Fretted Channels: Broad (up to 20 km), flat-floored, steep-walled valleys commonly occur along the northern lowland-southern upland boundary, extending deep into the uplands, and are particularly common in the region of fretted terrain [12] between 290-360 W. Many fretted channels show alcove-like terminations of tributaries, no dissection of interfluvies, rectangular or U-shaped tributaries, and little to no evidence of fluvial erosion on their floors [4]. With the fretted terrain, many of these channels are dominated by evidence for mass-wasting and collapse of valley walls, scarp-sap, debris aprons, and down-slope and down-valley flow of debris. Undermining and collapse have also played a role in the formation of fretted channels [4,13-14] as evidenced by aligned collapse pits and linear roof collapse in the upper reaches of some channels, suggesting the presence of underground drainage channels. This, together with examples of completely topographically enclosed fretted channels [4], provides evidence for the movement of groundwater in the region at some time in the past.

3) Theater-headed valleys: Chapman and Tanaka [17] described a series of valleys in the Mangala region of the dichotomy boundary, calling them theater-headed valleys, and mapping the units as material of theater-headed valleys (Acht). These consisted of material filling twelve deep valleys incised into plateau materials, with most valleys ending in lowland plains. The valleys have nearly constant widths and short lengths (5-60 km). They lack tributaries and a few end at the base of scarps within the plateau areas. The valley floors are at about same level as the lowland plains with which they connect. Delta-like fan deposits are observed at the mouths of some of these valleys.

The theater-headed valleys cut the intercrater plains unit and the oldest lobate plains material in the area and are partly buried by young lobate plains material [17].

Chapman and Tanaka [17] interpreted the THVs to have formed by groundwater sapping of highland aquifers along the base of scarps, particularly along the highland-lowland boundary. They interpreted the fan deposits to indicate removal of material by debris flow or glaciation. The dominant northerly trends of the strike of the THVs were interpreted to reflect structural control. This interpretation was strengthened by the fact that the three longest THVs are along the northern projections of major north-trending scarps and ridges in the ridged unit (Nplr), and the valley floors range from ~50-500 m and were interpreted to indicate that sapping horizons were at depths similar to or somewhat shallower than those of valley floors.

Discussion: It is clear that there have been relatively recent modification processes acting on fretted channels, and a major question is how to distinguish modification processes from formational ones. On the one hand, there is significant evidence for mass-wasting, scarp retreat, debris-apron and longitudinal flow, and extensive wall modification of the fretted channels. On the other hand, it is difficult to imagine that the very broad and wide channels could have formed and had their debris removed solely by mass-wasting activity. A solution to this conundrum was suggested by Carr [4], who proposed that the fretted terrain and channels formed earlier in history when near-surface liquid water was more abundant. In this scenario, convergent groundwater flow emerged at the surface along scarps as springs, causing undermining of slopes (sapping), formation of alcoves, and the headward erosion of alcoves to form the fretted valleys. Water-lubricated creep of the eroded material (rather than fluvial transport as on Earth) caused it to move down-valley by mass-wasting. According to Carr [4], subsequent planetary cooling caused the liquid-lubricated layer to become ice-lubricated, thus stabilizing and slowing the rate of modification and producing a set of landforms dominated by ice-related movement [13,15]. Thus, this scenario [4] implies that the fretted channels represent two
'fossil landscapes', an early warmer-environment landscape in which active groundwater movement played a significant role, and a later colder-environment landscape, dominated by ice and slow viscous flow, and sublimation processes.

What are some of the characteristics of this early, warmer-environment landscape? Carr [4] outlined mechanisms that would permit the eroded debris to travel the long distances required to remove the missing channel volume, citing the decreasing shear strength caused by increasing pore-fluid pressure conditions in water-saturated debris, leading to shear-strength loss, liquification and downslope flow. A fundamental implication of this scenario is the presence of near-surface groundwater during this period, most likely the Late Noachian, as part of the global migration of water toward low areas [16]. The Carr scenario [4] requires that the local to regional groundwater table intersect the surface at least as high as the base of the mobile material on the channel floor. If this scenario is correct, then the theater-headed valleys, fretted channels and large valley networks are keys to the location of the water table during Late Noachian, and to the nature of the hydrological cycle characteristic of that time. We assess the distribution of these features to document the nature of groundwater processes in the formation of theater-headed valleys, fretted channels and large valley networks, and to develop further a framework for their interpretation in the context of a Late Noachian hydrological cycle [18-21].

LATE NOACHIAN HYDROLOGICAL CYCLE: THE DICHOTOMY BOUNDARY

James W. Head and Michael H. Carr

Introduction
It has long been known that the boundary between the northern lowlands and the southern uplands (the dichotomy boundary) is characterized by both a generally distinctive topographic change, as well as characteristic geological units that appear to represent processes of weathering, topographic degradation and scarp retreat southward from the dichotomy boundary. We examine the nature and distribution of the units that characterize this boundary, and assess models for their origin. We first summarize the characteristics of this terrain and then test end-member models such as: 1) the terrain was formed by simple mass wasting processes (perhaps aided by sublimation) operating since the formation of the dichotomy boundary in the Early Noachian; 2) The terrain formed at or near the water table and represents seepage and sapping-related degradation of the dichotomy boundary.

General description and distribution
A variety of terrains characterize the dichotomy boundary (Figures 1-4). At the largest scale (1:15M; [1-3]), the southern uplands are characterized by a variety of Noachian-aged units, most prominently the Plateau and high plains assemblage [1,2] of units, of which the Plateau sequence is the most important. Members of the Plateau sequence form "rough, hilly, heavily cratered to relatively flat and smooth terrain, covering most of the highlands". The most widespread of the units there are of Noachian age and include the heavily cratered units (Npl1 and Npl2), the heavily cratered unit dissected by a higher density of valley networks (Npld), an etched terrain "similar to the cratered unit but deeply furrowed by sinuous, intersecting, curved to flat-bottomed grooves producing an etched or sculptured surface" (Nple), and smoother intercrater ridged plains of possible volcanic origin (Nplr). The surface of the northern lowlands, on the other hand, is largely covered by the younger Hesperian-aged Vastitas Borealis Formation, and older units are virtually absent at the surface [1-3].

The intervening area between the southern uplands and the northern lowlands, commonly referred to as the dichotomy boundary, is a broad region hundreds of km wide that extends along the border and has a variety of units with a range of ages. Previous mappers at the 1:15M scale have put a symbol on the map described as the "Highland-Lowland boundary scarp" which was defined as a "Diffuse zone of transition between highland and lowland physiographic provinces" [1-3] (Figs. 1-4). One of the most prominent units in association with this zone is mapped as HNu, Noachian-Hesperian, undivided [1,2]. This unit forms "closely spaced conical hills a few kilometers across whose distribution indicates that they are remnants of numerous craters." The unit also "forms rugged terrain on margins of cratered plateaus, and isolated remnants...". The unit is gradational with the Apk, the Amazonian-aged knobby plains material, where the two units adjoin, but hills in the HNu unit "are more closely spaced, larger, and occupy more that about 30 percent of the area." The HNu unit is interpreted as "eroded remnants of ancient cratered terrain produced by mass-wasting processes, possibly as result of removal of ground ice..." Etched plains material (AHpe) is composed of irregular mesas and pits, and ranges from mid-Hesperian to to mid-Amazonian in age [1-3]. Also characteristic of the boundary at this scale are outflow channels of Hesperian age and younger channels of Amazonian age, both of which strike generally normal to the slope of the dichotomy boundary and modify it.

Later regional units obscure and heavily modify large portions of the dichotomy boundary. Most prominent is the Tharsis volcanic complex which superposes and largely obscures the location of the dichotomy boundary from about 70W-140W. Just east of this, the Chryse basin and outflow channel complex obscures the boundary from ~15W to 70W. Hesperian-aged volcanic complexes, such as Syrtis Major, obscure the boundary regionally, such as along the western margin of the Isidis Basin (285W-290W), and Hesperian-aged regional ridged volcanic plains modify the surface at the boundary in Elysium Planitia (230W-265W), and in Deuteronilus Mensae (320W-355W), perhaps even underlying the Vastitas Borealis Formation throughout the northern lowlands (4). Finally, the thick mantling deposits of the Medusae Fossae Formation cover the dichotomy boundary in the Tharsis-Elysium Planitia region (125W-220W) to depths locally of several km. We now proceed to characterize the broad dichotomy boundary zone where it is not obscured by later events (Fig. 1).

Detailed Areal Distribution
One of the most prominent and aerially significant developments of this terrain occurs in the Deuteronilus Mensae region, extending ~1500 km from about 320 to 355 W, and occupying a band of terrain up to ~800 km wide along the northern lowland-southern upland dichotomy boundary. In this region, the terrain spans an elevation range from ~4 km to ~2 km. It is largely made up of fragmented and isolated islands of Hesperian ridge plains (Hr) and Noachian plains, where the fragments are large enough to map as specific outcrops, rather than components of a separate specific unit, as with HNu. Also mapped are large swaths of Apk, in the lows between the large islands, and preferentially toward the eastern edge of the region.

A second major area of development is adjacent to Deuteronilus, extending eastward along the dichotomy boundary for about 2400 km from ~275 to 320 W to the
Isidis Basin. Here the terrain is more knobby and occupies a 500-700 km wide belt that spans an elevation range from \(-3\) km to \(-0\) km. The major map unit in this area is HNu, with minor amounts of Apk.

East of the break in the dichotomy boundary formed by the Isidis Basin, the knobby terrain reappears in a swath at, and parallel to, the dichotomy boundary extending from the eastern rim of Isidis (~260 W) for about 4700 km to the vicinity of 180 W, before it becomes largely mantled by the younger Medusae Fossae Formation. In this region, the elevation range is about \(-2\) km to \(0\) km. The major unit mapped in the eastern part of this area is HNu, with minor amounts of Apk. At the crater Gale (~222 W) the proportion changes so that to the east of Gale, Apk dominates.

From this region eastward, most geological units exposed at the surface are Hesperian and Amazonian in age and comprised of Hesperian ridged plains (Hr), Tharsis volcanics, and the Medusae Fossae Formation. There is local evidence that the fretted and knobby terrain may underlie these units (for example southwest of Amazonis Planitia, where patchy outcrops of HNu occur), but neither regional development nor continuity can be established from about 180 W to 55 W, in the vicinity of the Chryse Planitia.

In the area of Chryse Planitia (~25-55W), there is little evidence for knobby terrain at the edge of the basin. Similar terrain, however, occupies a significant amount of the area south of the basin, extending from the mouth of Valles Marineris (Coprates Chasma at ~55 W) across western Margaritifer Terra, to ~15 W. This terrain is commonly associated with outflow channel formation, is mapped as Hcht (channel chaotic terrain) and is Late Hesperian in age [1,2].

Completing the global traverse along the dichotomy boundary, we find that the last segment, Western Arabia Terra, extending from ~30 W to 355 W, is almost devoid of continuous exposures of knobby terrain. Rather, numerous, but discontinuous patches of HNu are mapped all along the margin, in a swath up to 500 km in width.

Fretted and knobby terrain also characterizes some of the area surrounding the Elysium Rise, primarily to the southeast, east and north, at elevations of \(-4\) to \(-2\) km. Here it occurs predominantly as broad swaths of HNu, interspersed with patches of Apk.

Description of the dichotomy boundary using MOLA detrended topography: MOLA detrended topography (Fig. 4) where the regional slope has been removed and local slope variations are enhanced, is ideally suited to demonstrate the nature of the progressive disintegration of the southern uplands at the dichotomy boundary. Figure 4 shows a significant portion of this boundary between longitude 288W and 298W, and latitude 30 to 39N. At the base of the image, heavily cratered Noachian aged etched plains (Nple) [1,2] are exposed over the lower 200 km of the area. At the northern edge of this area, a series of complex generally east-west trending faults cut the Nple in to a series of polygonal blocks. Theater-headed valleys and channels form in and adjacent to these faults, and enlarge and often interconnect them. Northward of this, approximately in the middle of the image, is a broad, 150-200 km wide zone in which the polygonal terrain is further broken up and degraded into smaller polygons. This area is mapped as part of the Hesperian-Noachian undivided (HNu) terrain [1.2] and is clearly transitional to the larger blocks of polygons toward the southern uplands. In the upper right-hand part of the image, the terrain is mapped as Amazonian-Hesperian etched plains (AHpe) [1.2], characterized by irregular mesas and pits. This terrain is characterized by even smaller and more rounded knobs that appear to be transitional to the mesas and polygons of HNu. Thus, the case has been historically made that the units and facies that are mapped across the dichotomy boundary here represent the progressive degradation and mass wasting of the original margin of the dichotomy boundary (see summary in [3, 4]). The distance over which this terrain occurs suggests that the retreat in this area (Fig. 4) could have been 200-400 km.

Facies and terrains: In summary, in the broader context of this and related areas (Fig. 1-4) we observe a series of features and facies that characterize the dichotomy boundary across the zone. These features are not always present in the same locations, and they also overlap with each other to some degree. They are as follows:

1) Unmodified plains/uplands terrain:

2) Polygonized Craters (PCs): These have polygons developed in crater interiors and often have exit channels, which are usually fretted valleys.

3) Theater-headed valleys (THVs): These develop from PCs as well as the fracture zones and polygonal plateaus.

4) Fracture zones (FZs): Linear fractures ranging from graben to valleys, that are narrow to wide and oriented usually parallel but sometimes normal to the dichotomy boundary.

5) Polygonal plateaus (PPs): These are highly polygonized plains units that have been cut by the fractures seen in the FZ, but along which erosion and removal of material has occurred.

6) Hummocky terrain (HT): Transitional to polygonal plateaus; smaller and less distinct, more rounded, but has polygons interspersed throughout, with generally fewer toward the knobby terrain.

7) Knobby terrain (KT): Abundant small knobs, smaller and lower elevation than the hummocks in the HT, occasional hummocks.

8) Etched terrain: Appears to have undergone some combination of thermokarst and eolian reworking.

Summary and interpretation: On the basis of the successive degradation of the terrain as represented by the faulting, polygonization, polygon degradation to mesas, and their further degradation to knobs, and on the features mapped within the zone (theater headed valleys, sapping features, channels, etc.), we favor the interpretation that a significant amount of groundwater was involved in the initial degradation and subsequent retreat of the dichotomy boundary. We further hypothesize that this boundary represents the altitude region at which the water table intersected the surface in the late Noachian and into the early Hesperian. This boundary may thus be the focal point for the top of the groundwater system at this time. Above this existed the vadose zone in the southern uplands, and the water table sloped upward toward the southern uplands at an angle that was related to the level of recharge in the system at any given time [5, Fig. 4]. We further investigate the nature of the Noachian hydrologic system in [6].

Figure 4. Detrended MOLA topographic map of a portion of the dichotomy boundary between longitude 288W and 298W, and latitude 30 to 39N.
MARTIAN HYDROLOGY: THE LATE NOACHIAN HYDROLOGIC CYCLE

Summary: The global climate of Mars is thought by many to have changed to its present cold and dry state from warmer and wetter conditions earlier in its history during the Noachian. Here we summarize evidence for a major transition in near-surface hydrogeologic conditions in the Late Noachian, and a fundamental change in the martian hydrological cycle. Hydrogeologic conditions then were characterized by five main domains: 1) an accumulation zone at higher altitudes, where atmospheric water entered the system through pluvial/nival activity and was transported laterally by valley networks for tens to hundreds of kilometers before completely reentering the vadose zone, 2) an upper mid-altitude region dominated by the vadose zone where pluvial/nival activity was less important, and valley networks were much less common, 3) a lower mid-altitude region where the groundwater table occasionally reached the surface and theater-headed valleys and large fretted channels formed by groundwater sapping and headward retreat, 4) a lower altitude region, where the groundwater table normally resided and intersected the surface, and where fretted and knobby terrain formed by large-scale groundwater sapping, and 5) a very low altitude region (the northern lowlands), largely below the groundwater table, where groundwater discharge accumulated. Variations in the exact altitude distribution of these zones and the often transitional boundaries between them, strongly suggest that the groundwater system was irregularly recharged during this period and that the groundwater table oscillated vertically with time. Changing atmospheric and near-surface conditions at the end of this period resulted in the freezing of the outer layers of the crust to form a global cryosphere. At the end of this period, the hydrological cycle changed from one which was vertically interconnected from the atmosphere through the surface and subsurface to the groundwater system, to a horizontally layered one in which the groundwater reservoir is separated from the surface reservoir by a global cryosphere, a condition that still characterizes Mars today, ~3.5 billion years later.

Introduction and Background: Controversy surrounds that nature of early climatic conditions on Mars [1, 2]. In our approach, rather than trying to uniquely determine the nature of the Noachian climate from the geological record (e.g., valley networks [3]) or from global climate models [4], we have adopted the strategy of using the present environmental conditions (cold dry polar desert [5]) as a baseline, and working back in geological time until the geological evidence forces us to the conclusion that the climate must have been different. When and if such evidence emerged, this information might provide insight into the manner in which the environment changed and thus provide independent insight into Noachian climatic conditions. We outline elsewhere [6] the detailed evidence that leads us to the conclusion that cold, dry polar desert conditions and a globally continuous cryosphere [7] characterized the martian climate and near-surface conditions as far back as into the Early Hesperian. Local breaching of the cryosphere and outflow of sequestered groundwater characterized major hydrogeological activity during this 3+ billion year period, and although short-term climate variations may have occurred at these times [8], any changes appear to have been insufficient to alter the globally continuous cryosphere. Three major types of features common in the Late Noachian signal a fundamental change in these conditions: 1) Fretted and knobby terrain, which we interpret to represent the presence of a groundwater table intersecting the surface, and the consequent sapping and erosion of the globe-encircling highland-northern lowland boundary [9], 2) Theater-headed valleys/Fretted channels/Large valley networks, which we interpret to represent groundwater sapping occurring commonly near the dichotomy boundary, and focused sufficiently to cause significant erosion and headward retreat to form large sapping valleys [10], 3) Valley networks, [e.g., 3, 11] which occur primarily at higher elevations [1] are interpreted to represent overland flow and seepage of water and channelization; we interpret these to represent the result of pluvial/nival activity and to produce recharge through the vadose zone into the groundwater system [12]. Previously, we have outlined the basic hydrologic principles that govern the hydrological cycle and related processes in environments like those on Mars [13,14]. Here we outline a synthesis of these findings that describe our model of Late Noachian hydrogeology and the transition to a radically different hydrologic cycle than that in existence today [e.g., 7, 15].

The Late Noachian Hydrologic System: We believe that the Late Noachian hydrologic system shares many of the basic characteristics of the present terrestrial hydrologic cycle [13,14], modulated by some of the conditions described above. On the basis of our interpretation of the major terrain types listed above, we envision the hydrogeologic elements and hydrologic cycle at this time as follows. The most critical element for recognizing the nature of the hydrological cycle is the location of the top of the groundwater system, the water table. This most commonly occurs in the subsurface in land areas on Earth, or at the edge of large standing bodies of water, such as lakes, seas and oceans, where the margins of the water body and the water body equipotential surface itself delineate the water table. On Mars, any Late Noachian standing body of water [e.g., 15] is no longer present, and thus indirect evidence must be sought as to its location.

We interpret the fretted and knobby terrain occurring at the dichotomy boundary and encircling the majority of the boundary between the northern lowlands and the southern uplands at elevations between ~1 and ~4 km to represent the approximate location of the water table during the Late Noachian [9]. The fretted and knobby terrain is clearly derived from the collapse and degradation into knobs and mesas of adjacent upland cratered terrain. On the basis of 1) its very widespread distribution around almost the entire edge of the exposed upland terrain at the northern lowland boundary, 2) its apparent Late Noachian age (although degradation processes continued to modify it), and 3) its consistent distribution in terms of altitude range [9], we interpret this unit as marking the location of the water table and having originated in the following manner. Above this general level, the surface of Mars was a zone of infiltration, where water falling on the surface ultimately percolated vertically through the vadose zone into the saturated zone and then flowed laterally. In the vicinity of the north-south dichotomy boundary scarp, the water table intersected the surface [7]. In this region, groundwater flows through the porous rock and soil layers discharged to the surface by seepage, and by localized flow as springs. This eroded and undercut the surface topography causing...
We interpret valley networks to be water table occurs at a much deeper level below the surface. Lith in the highlands represents the vadose zone and that the layer [1,7]. Instead, we believe that the upper part of the rego-

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We interpret valley networks to be influent streams, not effluent streams. As influent streams, valley network channels form from collection of overland flow from pluvial or nival activity, leading to subsequent overland flow and stream channel formation. Valley networks are more common at higher elevations [16,17] in the southern uplands and occur on the flanks of craters at the highest elevations there. If the valley networks were to represent effluent streams drawing groundwater from the surrounding regions and were also undergoing significant related groundwater sapping, as envisioned by some [e.g., 16], then the implication is that the water table is just below the surface at elevations of ~3 km, for example in the circum-Hellas highlands. This implies that the global water inventory involves virtually all crustal pore space and thus provides a global water volume well in excess of 1 km global equivalent layer [1,7]. Instead, we believe that the upper part of the regolith in the highlands represents the vadose zone and that the water table occurs at a much deeper level below the surface. We interpret valley networks to be influent streams, not effluent streams. As influent streams, valley network channels form from collection of overland flow from pluvial or nival activity, leading to subsequent overland flow and stream channel formation. Valley networks are more common at higher elevations [16,17] in the southern uplands and occur on the flanks of craters at the highest elevations there. If the valley networks were to represent effluent streams drawing groundwater from the surrounding regions and were also undergoing significant related groundwater sapping, as envisioned by some [e.g., 16], then the implication is that the water table is just below the surface at elevations of ~3 km, for example in the circum-Hellas highlands. This implies that the global water inventory involves virtually all crustal pore space and thus provides a global water volume well in excess of 1 km global equivalent layer [1,7]. Instead, we believe that the upper part of the regolith in the highlands represents the vadose zone and that the water table occurs at a much deeper level below the surface.

Evidence supporting the presence of a vadose zone comes from the mid-altitude region of the southern uplands where valley networks are much less common. We interpret these to represent areas where pluvial/nival activity was much less important than in the highlands, and where valley networks had largely lost their transported water by influent processes and seepage and infiltration into the vadose zone. In this model, the lower abundance of valley networks at lower elevations are a natural consequence of their formation in the vadose zone and their influent behavior. Indeed, the unusual nature of many aspects of valley networks [17] can be readily explained by influent streams. If this interpretation is correct, convoluted in their characteristics is important information about soil porosity and permeability, and water flux [12].

Located in a zone between the fretted/knobby terrain and the valley networks is a series of very large valley network-like features known as fretted channels and theater-headed valleys [17]. These are broad, flat-floored, steep-walled valleys up to 20 km wide that extend from the margins of the northern lowlands deep into the uplands. The presence of headward linear closed depressions and collapsed margins strongly suggest that the channels and valleys formed by sub-surface groundwater movement and sapping [17]. They are primarily located between elevations of -3 km and +1 km, overlapping with the elevation range and area in which there are fewer valley networks. The range in the elevation distribution of the sapping channels may be due to their headward erosion, or could signal differences in the level of the water table. More discharge into the regolith would raise the water table and enhance sapping at higher levels. Alternatively, as the northern lowlands freeze and the cryosphere migrates southward, perhaps the water table rises and the groundwater builds up hydrostatic head [10].

Summary: These data and correlations, and the similarities to terrestrial hydrogeologic features and the hydrologic cycle, suggests that this model (Fig. 1) may reasonably approximate the nature of the Late Noachian hydrologic cycle. This scenario predicts that the northern lowlands were largely below the level of the water table and thus may have been flooded, although the high latitudes indicate that much of the region might have been frozen. In related contributions, we analyze each of the major geological features and assess their nature and formation mechanisms in the context of this model [6,9,10,12].

Introduction

Argyre, located in the southern highlands southeast of Tharsis, is one of the largest impact basins on Mars and formed in Early Noachian time [e.g., Hiesinger and Head, 2002]. It has been proposed that meltback of a south polar ice cap during the Noachian completely filled the basin with water, that the outflow channel in the north drained the basin, and that the water eventually entered the northern lowlands [Parker, 1994].

Two models of the hydrologic evolution

Several channels, Surius Valles, Dzigai Valles, and Palacopas Valles, breach the southern rim and empty into the Argyre basin [e.g., Parker, 1989, Parker et al., 2000; Head, 2000c, d; Head and Pratt, 2001]. Most of these channels can be traced back to the distal portions of the Dorsa Argentea Formation, which was interpreted to represent the extent of a formerly larger south polar ice cap. Numerous authors (e.g., Parker et al., 2000; Head, 2000c, d, Head and Pratt, 2001) argued that melting of the ice cap releases significant amounts of water and that this water would pond in the Argyre basin. However, there are some differences in the amount of available water and the timing of the lake in Argyre.

In Parker’s model the basin is interpreted to have been completely filled in the Noachian because he found evidence for two flood events in the outflow channel, Uzboi Valles, which is of Noachian age [Parker, 1994, 1996a, b]. Parker et al. [2000] proposed that once the basin was completely filled, water could have left the basin through Uzboi Valles, a channel in the north of the basin and flowed down the Chryse trough [e.g., Saunders, 1979; Phillips et al., 2001] towards the northern lowlands.

A second model involving water in the evolution of Argyre basin was proposed by Head [2000c]. On the basis of their investigation of the present south polar ice cap and its related geologic units, Head [2000c] and Head and Pratt [2001] concluded that a much larger polar cap existed during the early Hesperian for which they presented evidence of ice retreat in middle Mars history [Head and Pratt, 2001; Head, 2000c]. They proposed that meltwater produced by this ice retreat would pond in the Argyre basin.

Testing the models

Clifford and Parker [2001] presented a model for the evolution of the Martian hydrosphere. This model is based on the assumption that permeability and porosity of the Martian crust are high enough to allow the distribution of water to be governed by the effort to reach hydrostatic equilibrium, by flowing from regions of elevated hydraulic head to saturate the regions with the lowest geopotential. Clifford and Parker [2001] concluded that the existence of a primordial ocean that covered the northern lowlands on Mars was inevitable, given the thermal and hydrologic conditions during the early Noachian.

Parker et al. [1989, 1993] mapped several “shorelines” of such an ocean, i.e. Contact 1 and 2. Provided that the distribution of water during the Noachian is governed by the effort to reach hydrostatic equilibrium, that the ocean in the northern lowlands existed at these times, and that Argyre was filled with water at these times, then we might expect to find “shorelines” in the Argyre basin at about the same elevation as Contact 1 and 2. MOLA data indicate that at –3760 m (elevation of Contact 2) only crater Hooke would have contained water, and that at –1680 m (elevation of Contact 1) the water level in Argyre basin is well below the elevation where the entire basin would have been filled and water would have flowed through Uzboi Valles. We conclude that all of the investigated shoreline positions are below the elevation of the outflow channel of Argyre basin. If the distribution of water in the martian crust is correctly modeled by the hydrostatic model of Clifford and Parker [2001], water would flow underneath the surface toward lower regions rather than accumulating in Argyre to a level where flow through Uzboi Valles could occur. In Viking images we did not identify morphologic features which would be evidence for a shoreline at the level of drainage through Uzboi Valles. From our observations we conclude that either a complete fill of Argyre basin during the Noachian is unlikely, or alternatively, that the model of Clifford and Parker [2001] needs some revision.

The ages of the channels are not well constrained and vary in the literature from early Noachian to Hesperian. However, the age of the channels is crucial in order to address the hydrologic history of the basin. There are three possible scenarios: (1) the channels are early Noachian to Noachian in age [Parker et al., 2000]; (2) the channels are Hesperian in age but occupy valleys formed in the Noachian [Parker, 1996a, b]; (3) the channels are Hesperian in age [Scott and Tanaka, 1986; Tanaka and Scott, 1987].

If the channels, Surius, Dzigai, and Palacopas Valles, are Hesperian in age, then this is inconsistent with the model of Parker [1994] that suggests a complete fill of the Argyre basin in the Noachian by water flow through these three large southern channels. The channels can be traced down to the floor of the basin and this is consistent with the channels postdating the proposed complete fill. If the channels are early Noachian to Noachian, we face the problem of where the water came from. Parker et al. [2000] proposed meltback of a Noachian polar ice cap but Head and Pratt [2001] only found evidence for a Hesperian retreat of the ice cap. In addition, if the channels are early Noachian to Noachian in age, and the basin was completely filled at this time, then the channels should not be traceable down to the basin floor because they would have encoun-
tered a base level at a much higher elevation. If the channels are Hesperian in age but occupy Noachian valleys, this could explain the presently observed channel morphology and would leave the possibility of a complete fill of the basin during the Noachian. However, this scenario does not solve the problem of the Noachian water source.

How much water is actually necessary to initiate spill-over? Flooding models indicate that at ~3760 m, the global mean elevation of Contact 2, Argyre basin contains 3310 km$^3$ of water and at ~1680 m, the elevation of Contact 1, Argyre holds as much as 5.71 x 10$^4$ km$^3$ of water. We conclude that (1) the basin has to be filled with at least 2.1 x 10$^5$ km$^3$ of water before flow through Uzboi Valles could occur, and (2) once this hypothetical spillover through Uzboi Valles stopped, one would be left with an enclosed lake approximately half the volume of the Mediterranean. We argue that such a lake or sea should have left morphologic evidence that can be interpreted as shorelines or terraces, but such evidence has not been observed.

Parker et al. [1989, 1993] postulated a north polar ocean and argued that the formation of such an ocean should be accompanied by sedimentation, smoothing submarine terrain below the shoreline. Head et al. [1999] tested the northpolar ocean hypothesis and showed that the average surface below the shoreline is indeed smoother at all scales than the surface above. On the basis of our observations of the roughness of individual geologic units, we find that all investigated Argyre units (Hpl, Hr, Nple, and Nph) are on average systematically rougher at all baselines than units Hvm and Hvk, which are exposed in the northern lowlands [Kreslavsky and Head, 1999, 2000].

Head and Pratt [2001] found evidence for extensive melting and retreat of a Hesperian-aged southpolar cap. Assuming that the entire area of the Dorsa Argentea Formation was once covered with a maximum of 3 km of ice, Head and Pratt [2001] estimated a maximum volume of ~8.82 x 10$^6$ km$^3$. If we subtract the volume of the present day ice cap, which is of the order of 2.19 x 10$^6$ km$^3$ [Head and Pratt, 2001], the volume of the removed polar deposits would be ~6.63 x 10$^6$ km$^3$. This is a maximum estimate as it is rather unlikely that the ice cap had a constant thickness of 3 km over the entire surface area of the Dorsa Argentea Formation. If we further assume sediment/volatile ratios between one third and one half [e.g., Komar, 1980; Thomas et al., 1992; Herkenhoff, 1998], the amount of water that could be produced by melting would be of the order of 2.21-3.32 x 10$^7$ km$^3$, a volume sufficient to entirely flood the Argyre basin. However, it has to be kept in mind that this is a maximum estimate because the ice cap certainly becomes thinner towards its margins, and that only a portion of the meltwater would flow across the surface in order to pond in the Argyre basin. Significant amounts would enter the groundwater system, would remain in the pore space of the present Dorsa Argentea deposits [Head and Pratt, 2001], and large portions of the ice cap’s volatiles would go into the atmosphere. In addition, not all of the melt water would flow into the Argyre basin, but some portion would end-up in the Hellas basin [Head et al., 2001].

From numerous terrestrial and planetary examples it is well known that emplacement of thick basaltic lavas, large bodies of water or ice sheets cause subsidence of the floor of a basin or crater [e.g., Strom et al., 1975, Schultz, 1976, Solomon and Head, 1979]. We argue that flooding of the entire Argyre basin with a lake several kilometers deep would have depressed the floor, probably hundreds of meters, hence making it even harder to initiate spill over in the past compared to today.

Conclusions

In summary, we found numerous evidence for water playing an important role in the geologic history and evolution of the Argyre basin. However, this evidence does not necessarily point to a complete fill of the basin. Evidence for water in the Argyre basin are the formation of channels which can be traced to the basin floor, the morphogenies at their mouths which suggests a fluvial origin, and the availability of large amounts of water generated by the meltback of the south polar ice cap. In order to initiate flow through Uzboi Valles, the basin has to be completely filled with at least 2.1 x 10$^5$ km$^3$ of water and this is not consistent with current hydrologic models. If there was such a complete fill, probably more than 3 b.y. ago, it is not easily tested for because subsequent modification of the basin would have destroyed most of the evidence. Based on the evidence that is left, we propose that the Argyre basin was partly filled with a frozen lake during the Hesperian. In our model, Hesperian meltback of the south polar ice sheet released water, which entered the Argyre basin. The meltwater partly filled the basin floor to form a lake, which froze over. Ice thickness increased with time until the entire lake was frozen to the ground or at least until the ice became grounded in the shallower regions of the lake (i.e., close to the incoming channels). Meltwater or incoming water formed subglacial channels in which esker-like ridges were deposited. After the deposition of eskers, continued sublimation and migration of water into the substrate removed the water/ice in the basin and the eskers became visible. Eolian activity contributed to the evolution of the Argyre basin throughout its entire geologic history, mantling or exhuming morphologic features, influencing sublimation rates, and contributing to the present day morphology.

References

Abstract: Comparison of the Dark Dune Spots of the Southern and those of the Northern Polar Regions of Mars shows that northern DD spots have various shapes and they have only rarely circular shape similar to the southern one.

Introduction: There are regions on Mars which are covered by dark dune material. They are distributed across the whole planetary surface; however, there is a phenomenon which is associated with them in the Polar Regions. Because of the precipitation of the frost in the winter, the defrosting phenomenon is very well observable on these surfaces.

Dark dune fields form a wide belt around the north pole of Mars. Contrary to this, in the Southern Polar Region the dark dunes form only smaller patches; here they occur mainly inside the craters. The larger dark surface at the North Pole is more extended and the frosting-defrosting phenomenon is more complex in the North than in the South (Fig. 1).

In the Northern Polar Region we observed that during the defrosting period the shape of the dark dune spot formations is varied: they form lineaments, grids, fans-shaped, wind-blown and circular features. Instead of such diverse forms, in the Southern Polar Region the defrosting pattern of the frosted surfaces is dominated by many tumens (tumen = ten-thousands in the Eurasian Steppe Culture) of mainly circular or concentric ringed Dark Dune Spots (RDS). It was surprising to observe that on the northern dark dunes only a small number of circular or ringed dark dune spots had been found.

We studied the transformations of the circular and ringed dark dune spots. The process of their shape changes was observed to be similar in details, both in the Southern and the Northern Polar Regions (Fig. 2, 3, 4) and annual repeated appearance in a pattern of multiple DDSs on the surface [2, 4, 5, 6], and probable origin [1, 2, 4, 7, 8].
Fig. 3 Northern “test field” of ringed dark dune spots in a crater (a) at the inner end of Chasma Boreale. In spring on the frosted dark dunes (b) the dark dune spots appear and RDSs develop with time (d). The framed regions can be seen enlarged on Fig.4. In summer all barchan shaped dark dunes are defrosted and here they have dark tone (c).

Fig. 4 Springtime growth of Northern ringed dark dune spots in the Chasma Boreale (see Fig.3a). Comparing the two images we can observe that the earlier spots (a) extended in size during the five weeks (b) elapsed between the two images. The arrows point to two large RDSs.

Summary: The smaller number of circular RDS in the Northern Polar Region may be explained with meteorological differences between the Northern and Southern Polar Regions. The Southern winters and springs are warmer (cca. 30 K degrees) because Mars is in its pericentrum during Southern spring.

We suggested a possible biogenic origin model for the genesis of the Southern DDS, which we called DDS-MSO hypothesis [1, 2, 4, 7, 8]. This model uses multiple factors in interpreting the formation of the circular ringed DDS, while the rival model of Malin and Edgett [9, 10], uses geophysical-geochemical reasons in their interpretation. These two hypotheses are competitors also in explaining the phenomena in the North as discussed in the present paper.


SOME FEATURES OF THE CRATERING OF ISIDIS BASIN. J.A.Iluhina, A.V. Lagutkina, J.F.Rodionova. Sternberg State Astronomical Institute, Moscow University, jeanna@sai.msu.ru

Isidis basin is a round feature about 1500 km in diameter disposed in a transitional zone between continents and plains. It is between 0° - 25°N latitudes and 260° - 285° W longitude with the center in 13.5°N and 272.6°W. The bottom of the basin is dipper than -3.5 km [1]. The western slope pass to Syrtis Major Planum with the height about +2.0 km. The southern ridge of the basin is Libia Montes with the height +1 km and Nepenthes Fossae (parallel grabens with widths 10-15 km and length about 300 km). The north-western part is represented by Nilis Fossae (several parallel grabens with length about 900 km) [2]. The north-eastern part have no ridge: Isidis Planitia and Elysium planitiae are divided by low wall with small strait.

It is interesting that there are great positive gravitational anomaly (as for round lunar maria - mascons) in Isidis basin with the center about 12°N and 271°W and abundance mass equal 5.1x10^{20} gramm [3].

Isidis basin is a beautiful place for the investigation by space vehicles because there are a lot of interesting features there. For example the fluidized craters are on the bottom of the basin so as on the western slope and on Syrtis Major Planum althow the difference in the height level of the bottom of Isidis basin (-3.5 - -4 km) and Syrtis Major Planum (+1.5 - +2 km) is more than 5 km.

Presence of craters with fluidized deposits serves as a parameter of opening of rocks with ice. Depth of the minimal crater on the size with similar deposits in this or that area represents actually an estimation of depth a roof of frozen rocks or capacity of a superficial layer of frosty rocks [4]. Average depth of frozen rocks at the latitude of Isidis basin makes 300-350 m.

We count up density of distribution of craters in diameter of 1 km and more, located at the bottom of Isidis basin, on the western slope with difference of heights of 4.5 km and on a plateau. Craters with fluidized emissions are separately investigated.

The average density of craters of this size at the bottom of basin has made 1441 crater on the area in 1 million square kilometers. On a slope the density of craters has made 2154 while on a plateau 2141 crater Craters with fluidized deposits at the bottom of the basin have made 34 %, on a slope of 21 %, and on a plateau of 60 %. The ratio of diameter of deposits to diameter of craters is change from 1.4 to 2.5 in the bottom of basin, from 1.6 to 3.1 on the slope and from 1.9 to 3.7 on the plateau. The fluidized deposits on Syrtis Major Planum are preserved not very well and looks like buried by dust and sound.

Fig.1 represents the density distribution of craters in the bottom of Isidis basin, on the slope and on plateau. The density of craters in diameter 1-2 km is more on the slope than on the plateau. Fig.2 represents a part of Photomap used for the measurement.

References:
Iluhina J.A. et al. SOME FEATURES OF CRATERING

Fig.1 The density of craters in the plain -1, on the slope of Isidis -2, on Sirtys Major Planum-3

Fig.2 The frame of Photomap of Isidis Planitia.
Introduction: In the report we present an electrical model of polar ice caps on Mars. This problem is of interest from several points of view. Martian polar caps are the principal cold traps of the planet, which have accumulated 3-4 km of atmospheric volatiles, mostly H₂O. Lack of craters on vast areas of their surfaces indicates their young age. For this reason, the Martian polar deposits may contain a detailed record of Martian climatic and geological history.[1] The surface of northern polar cap exhibits vast perfectly smooth areas, separated from each other by a system of troughs, which spiral counterclockwise from the center of the cap to its periphery. This makes Northern polar deposits an excellent target for radar subsurface sounding, due to lack of surface clutter coming from smooth areas.

Statement of the problem: To address questions related to structure of Martian interior, a number of space missions planned during past decades carried subsurface radar sounding equipment. Several such radar experiments are now being planned. The primary objective of them is total radar mapping of ice/liquid water distribution in the upper portion of the Martian crust. We present a model of dielectrical structure of northern polar cap with implication for prospective radar sounding results.

Electrical model of the ice cap: The primary constituent of the northern polar cap is water ice. The following observations provide basis for this statement: high water vapor concentrations over the cap during summer[2], low density about 1 kg/m³[3], a thermal inertia[4] and albedo[5] corresponding to dirty water ice. The surface of the southern polar cap does not look like water ice, but there also are evidences that water ice is its major volatile constituent, too[6,7].

There are also numerous observational evidences of layered structure of Martian polar caps[1]. Thickness of individual layers in northern cap has been estimated to be 14 – 45 m[8], so we assumed its mean value about 30 m. Precipitational and sedimentational models predict that layers of dirty ice are separated from each other by a dusty cover about 1 m thick[3]. Such cover is formed from the layer material due to ice ablation, which occurs periodically according to variations of Martian orbit parameters.

We suggest a model of Martian northern cap as a stack of layers of two types, the so-called “icy” and “dusty” layers. Under common assumptions on electrical properties of ice[9] and planetary soil[10], we have shown exploiting a layered medium model[11] that only electromagnetic waves at frequencies below 1 MHz can propagate through such a layered medium without significant distortion. Above 1 MHz, there are frequency bands where the media is opaque. In the figure, the bands of opacity are shown for a range of values of permittivity of dusty layers. In the vicinity of these bands, dispersion is very strong so that the chirp pulse of the ultra wide bandwidth radar is totally destroyed. On the other hand, at frequencies below 1 MHz the northern cap is relatively transparent.

Surface clutter: The surface clutter, which is usually very significant in radar sounding, is of relative less importance for the north polar cap due to its general smoothness. Typical surficial features are the troughs which are hundred meters deep, up to ten kilometers wide and hundreds kilometers long. Bordering scarp of these troughs maybe as steep as 8 degrees. In the present work, the radar echoes of the troughs are thoroughly studied. The clutter echoes produced by these troughs can be interpreted manually because of scarcity of the troughs on the surface.

Conclusions: It has been shown that the Martian polar caps are probably very dispersive media at frequencies above 1 MHz, where most orbital and landed radars are planned to operate. On the other hand, operation at lower frequencies below 1 MHz can provide useful information about basal conditions of Martian polar caps, such as basal melting and water lakes beneath ice.

STRATIGRAPHY OF SMALL SHIELDS ON VENUS: CRITERIA FOR DETERMINING STRATIGRAPHIC RELATIONSHIPS AND ASSESSMENT OF THE RELATIVE AGE:

M. A. Ivanov1,2 and J. W. Head2, 1 - V. I. Vernadsky Institute, RAS, Moscow, Russia, 117975; 2 - Brown University, Providence, RI USA 02912

Introduction. Small volcanic edifices, shields with a diameter less than about 20 km, are common and sometimes very abundant features on the plains of Venus [1-6]. Typically, they form tight or loose clusters of structures, shield fields. Small shields are interpreted to be formed due to small-scale eruptions through numerous and distinct sources. This mode of formation is significantly different from the mechanism thought to be responsible for the emplacement of the vast regional plains of Venus. Did the eruption style of small shields occur repeatedly throughout the visible part of the geologic record of Venus? Or was this style more concentrated in a specific epoch of geologic history? Do the clusters of shields represent localized development of sources over a thermal anomaly such as a plume or do they represent exposures or kipukas of a more regional unit or units? A major step toward the solution of these questions is an understanding of small shield stratigraphy.

Criteria used to determine relative age of shield fields. Multiple criteria have been developed to assess the stratigraphic relationships of individual small shields and shield fields with the adjacent units [7-8]. In our analysis, we expanded and developed in detail the previous criteria and added detailed criteria to describe specific pattern of deformation within shield fields, cross-cutting, and embayment relationships between shield fields and surrounding units. Also, we used secondary characteristics of shield fields such as radar albedo difference, changes in shield density and size, etc. The criteria used in our study are summarized in Table 1.

Procedure. In order to assess the stratigraphic position of shield fields we used as a frame reference firstly the set of criteria outlined in Table 1, and secondly, the stratigraphic scheme developed as a result of geological mapping in many areas on Venus [9-22]. The main unit occupying the middle stratigraphic position in all schemes is represented by regional plains or plains with wrinkle ridges (hereafter, pwr). These plains represent the most widespread unit and form a background with other units being either older or younger than regional plains. In our study we use the criteria to assign the shield fields an age relative to regional plains.

In order to determine relative ages of shield fields, we applied the criteria using a three-step procedure. At the first step, three categories of shield fields were determined. A) Shield fields pre-dating regional plains (pre-pwr, fields that possess simultaneously six or more criteria from the subset 1). B) Unclear cases, C) Residual fields.

At the second step we analyzed the subpopulation C and also divided it into three categories: D) Unclear cases (similar to category B). E) Shield fields postdating regional plains (a shield field should have at least three out of four criteria from the subset 2 and none (or a few) of the criteria from the subset 1). F) Residual fields. The last category includes shield fields that apparently are synchronous with the emplacement of regional plains and fields with ambiguous relationships.

At the third step, we analyzed the last category of shield fields in attempt to separate the synchronous and ambiguous fields. The shield fields that appear to be synchronous with regional plains must have more than six criteria from the subset 1 but taken with the opposite sign. Shield fields with ambiguous relationships are those that have no more than five criteria from the subset 1 and no more that one criterion from the subset 2 (Table 1).

As the result of such a procedure, we constructed five subpopulations (categories) of shield fields. 1) Shield fields pre-dating regional plains (pre-pwr). 2) Shield fields synchronous with regional plains (syn-pwr). 3) Shield fields post-dating regional plains (post-pwr). 4) Shield fields with ambiguous relationships. 5) Shield fields with unclear relationships.

Results. In our study, we applied these criteria and analyzed in detail stratigraphic relationships of shield fields in a random sample of features (64 fields) and in the global geotraverse along 30°N (77 fields). The total number of analyzed shield fields is 141, which represent about 22% of the general population of these features catalogued by [23]. The majority of these fields, 98 fields or about 69%, pre-date emplacement of material of vast regional plains with wrinkle ridges. Fifteen fields (about 11%) appear to be synchronous with regional plains and eleven fields (about 8%) postdate the plains. Nine fields (about 6%) display ambiguous relationships with regional plains and their relative age is uncertain and eight fields (about 6%) represent unclear cases when fields are covered by crater-related materials or by young lava flows or are not in contact with regional plains.

Discussion and Conclusions. The results of our study provide the evidence for a distinct and similar change of volcanic style from the mode of formation of small shields to the mode of formation of vast regional plains in many areas on Venus. This systematic change of volcanic style appears to be inconsistent with the "non-directional" or quasi
steady-state character of the geologic record of Venus [24]. Although individual small shields were formed throughout the majority of the visible geologic history of Venus, in the syn- and post-regional plains time the small-shields-style of volcanism was significantly reduced. The shield fields that pre-date regional plains do not display a strong tendency to form a single group or a few groups and can be found virtually in all places on Venus. We interpret this observation to mean that these shield fields were globally distributed before the emplacement of regional plains. This interpretation means that the shield fields emplaced by regional plains represent exposures of a specific, globally widespread unit, shield plains (psh). In contrast, shield fields that post-date regional plains occur preferentially in the Beta - Atla - Themis region on Venus, well known for its concentration of relatively young volcanic and tectonic activity. The spatial association of relatively young fields with the large centers of young volcanism suggests a genetic link of these fields with the formation and development of the large-scale volcanic centers. The abrupt decrease of the number of shields that post-date the formation of shield plains (psh) strongly suggests a major change of the style of volcanism since the emplacement of vast regional plains.

Table 1. List of criteria for determination of relative age of shield fields.

<table>
<thead>
<tr>
<th>Criteria description</th>
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<tr>
<td><strong>Subset 1: Criteria suggesting relatively old age of shield fields (pre-pwr).</strong></td>
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<tr>
<td>1) Shield fields have a specific tectonic pattern confined in the fields.</td>
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<td>2) Shields at the edges of contiguous fields are outlined by a smooth and sharp boundary.</td>
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<tr>
<td>3) Individual shields off a shield field have a distinct break in slope and are outlined by a smooth, sharp, circular boundary.</td>
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<tr>
<td>4) Radar albedo of contiguous shield fields is different from that of surrounding regional plains.</td>
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<td>5) Individual shields nearby the contiguous shield fields have albedo different than pwr and similar to the shield fields.</td>
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<tr>
<td>6) Systematic change in the density of shields away from shield fields with abrupt drop of shield density within regional plains.</td>
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<tr>
<td>7) Systematic change in the size of the shields away from shield fields with smaller shields in regional plains.</td>
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<tr>
<td>8) Shield fields are in close spatial association with an older unit in the area (either in direct contact or in proximity).</td>
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<tr>
<td>9) Shield fields make up local highs consisting with a kipuka-like relation in contrast to construction.</td>
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<tr>
<td>10) Wrinkle ridges deform shield fields.</td>
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<td><strong>Subset 2: Criteria suggesting relatively young age of shield fields (post-pwr).</strong></td>
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<tr>
<td>11) Shields and associated flows superposed on structural elements (fractures, wrinkle ridges) in regional plains.</td>
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<tr>
<td>12) Shields and associated flows either gradually merge with or superposed on lava flows that post-date regional plains.</td>
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<tr>
<td>13) Shields are in close spatial association with distinct lava fields and/or volcanic constructs that appear to postdate regional plains.</td>
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<tr>
<td>14) Shields are at higher elevation than regional plains consistent with a construction relation in contrast to a kipuka-like.</td>
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References.
Introduction: The Mylitta Fluctus Quadrangle (V-61, 50-75°S, 300-360°E, Fig.1) covers the southern part of Lavinia Planitia (a basin-like lowland [1], 1.5-2 km deep) and the western part of the Lada Terra upland (~3 km high). Lavinia Planitia has complex patterns of deformational belts [2,3] and Lada Terra hosts several large coronae, including Quetzalpetlatl [4], connected by belts of fractures and graben [5,6]. Large lava flows complexes (fluctuses) emanate from some coronae in Lada [7]. The characteristics of Lavinia Planitia suggest the large-scale mantle downwelling there [1,8] and the specific features of Lada Terra are consistent with mantle upwelling [9].

The major questions addressed by geological mapping in the Mylitta Fluctus area are as follows. 1) What is the sequence of events in the formation and evolution of large-scale lowlands and uplands on Venus? 2) What are the characteristics and timing of formation of the transition zone from Lada Terra to the surrounding lowlands? 3) How do the units in the map area compare with each other and what information do they provide concerning models for Venus global stratigraphy and tectonic history? In our analysis we have used traditional methods of geologic unit definition and characterization for the Earth [10] and planets [11] appropriately modified for radar data [12].

Stratigraphy: Although we have mapped tectonic structure independent of material units, in a few cases tectonic features are such a pervasive part of the morphology that it becomes part of the definition of a unit. In other cases, the approach depends on scale and density of structures. Here we summarize the stratigraphic units mapped in the quadrangle. Densely lineated plains (pdl). This unit is characterized by relatively flat surfaces and swarms of dense (<1 km apart) subparallel lineaments. Ridged and grooved plains (prg). This unit has relatively high radar albedo and is commonly deformed by relatively broad (~5-10 km wide) ridges tens of kilometers long. Shield plains (psh). Abundant small shield-shaped features (from a few km to 10-20 km in diameter, many with summit pits) characterize this unit. Wrinkle ridged plains (pwr1 and pwr2). These units are morphologically smooth plains material of intermediate-dark to intermediate-bright radar albedo and is commonly deformed by networks of wrinkle ridges. The lower unit (pwr1) is relatively homogeneous and the upper unit (pwr2) has slightly higher albedo and lobate boundaries in places. Shield cluster (sc). The surface of this unit is morphologically similar to that of shield plains but, in contrast, is tectonically intact and displays distinct lava flows superimposed on the plains nearby. Smooth plains (ps). This unit is tectonically intact and has uniform and typically low albedo. Lobate plains (pl1 and pl2) have numerous flow-like internal elements and unit boundaries are typically lobate. The lower unit (pl1) is characterized by a subdued pattern of the flows and the upper unit (pl2) has very prominent pattern of the flows. Impact crater materials (c) include impact craters and related deposits.

Structures: A. Extensional structures. Long (up to 300-350 km) linear fractures and graben are seen in the NE quarter of the quadrangle at Jord Corona. They radiate to the N of Jordon and extend to SSE of it toward Quetzalpetlatl Corona. These structures cut pl1 and are embayed by pl2. In places, the extensional structures are so dense that their presence takes on a defining character to the terrain. These concentrations form linear belts (groove belts, gb) a few hundreds of km long and 50-60 km wide that are concentrated in the W and NW parts of the quadrangle. The structures of the belts are mostly embayed by psh and pwr1 and pwr2. Kalaipahoa Linea runs in the ENE direction for about 2,200 km from the center of the quadrangle to its eastern margin and rep-represents a dense set of broad (a few km wide) subparallel graben. The Kalaipahoa belt is at the summit of broad and low topographic ridge outlining the northern edge of Lada Terra. The morphology and topography of the Linea is similar to those of rift zones elsewhere on Venus. The rift zone (ri) of Kalaipahoa Linea has been formed simultaneously with pl1 but is embayed by pl2.

B. Contractional structures. Two types and scales of contractional features exist in the map area. Wrinkle ridges are so important in the broad regional plains that they in part define and characterize units pwr1 and pwr2. The young plains (pl1, pl2, ps) embay wrinkle ridges and form an upper stratigraphic limit for the ridges. The unit prg is dominated by ridges and arches. The unit form N-NE and NE trending belts that run through the map area. The northern rim of Quetzalpetlatl Corona is morphologically a ridge belt, although it is unclear whether it is a fragment of regional ridge belts or this feature is related to the evolution of the corona itself.

Relationships of units: The material units and structures commonly reveal relationships of embayment and crosscutting that suggest their relative ages. Most of the plains units embay pdl and prg implying that these units make the bottom of the stratigraphic column. Through-out the map area, psh heavily embays prg meaning that shield plains are younger. Consistent relationships of embayment occur between psh and pwr1. In many areas clusters of shields represent kipukas of a unit (psh) heavily flooded by younger regional plains. Both units of the regional plains (pwr1, and pwr2) are deformed by a network of wrinkle ridges and, thus, predates the episode(s) of formation of the ridges. The unit pwr2 is, in places, has lobate boundaries and apparently extends along local depressions on the surface of pwr1. This suggests that the unit pwr2 generally post-dates, but may be locally correlative with, pwr1. Where the units pwr1, pwr2, pl1, and pl2, are in contact, the lobate plains embay wrinkle ridges meaning that lobate plains are younger. Sometimes, there are clear relationships between pl1 and pl2 suggesting younger age of pl1.

Where groove belts and ridge belts are in contact, the structures of groove belts appear to cut the ridges implying a younger age of deformation within groove belts. The structures of ridge and groove belts are embayed by pwr1. The graben of the Kalaipahoa rift reveal both embayment and crosscutting relationships with the unit pl1 and are heavily embayed by the unit pl1 near Jord Corona.

Geologic history: The distribution of the mapped units in space and time allows outlining the geologic history within the Mylitta Fluctus quadrangle. In contrast to many other areas on Venus where tessera forms the oldest material unit [13-15], the V-61 quadrangle represents a vast tessera-free area. This suggests that either tessera never formed there or it was completely covered by subsequent lava plains. The densely lineated volcanic plains, thus, represent one of

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the oldest exposed unit in the map area. The deformation patterns in pdl are very dense, unidirectional, and were formed due to extension. Fragments of pdl occur within the upland and lowland parts of the map area suggesting a more extensive presence of the unit in the subsurface. Following (or may be simultaneously) the emplacement and deformation of pdl, a less intensely deformed plains unit was emplaced (prg). The most important features of prg are ridges. Occurrences of the unit form a large zone of broad arches within the lowlands. The arches run roughly parallel to the edge of Lada Terra. In the NE corner of the map, however, small fragments of prg are within the Lada upland. The material of prg and its deformation separate the lowlands around Lada Terra into secondary small-scale basins.

After emplacement and deformation of prg, plains with abundant small volcanoes (ps) were emplaced. The morphology of this unit indicates widespread local and shallow magma sources during its emplacement. The lack of broad ridges within ps means that regional compressional stresses had waned in intensity before emplacement of the unit. Subsequent to the formation of shield plains the style of volcanism changed [16]. Instead of abundant small volcanoes, vast plains (units pwr1 and pwr2) were emplaced from sources that are now rarely visible. The wide extent of these units and the presence on their surface of narrow sinuous channels within the quadrangle and elsewhere [17-18] suggest a high-effusion-rate mode of emplacement from a few sources. The units pwr1, pwr2, and ps were deformed by wrinkle ridges during and subsequent to their emplacement. Some wrinkle ridges are oriented consistently with the tectonic fabric typical of prg. Thus, the deformation recorded in these units appears to be consistent in trends but reflects a decrease in the intensity of deformation with time.

The V-61 quadrangle displays a rich geological record of relatively late (post wrinkle ridged plains) volcanic and tectonic activity. Abundant occurrences of smooth plains (ps) in many places tend to occur near distinct volcanic centers, which indicates that occurrences of ps at these localities are facies of late volcanism. Lobate plains (pl1 and pl2) were emplaced after formation of wrinkle ridges and are almost completely restricted within the upland of Lada Terra and related to two major sources in the northern and central parts of the upland. The latest volcanic activity has led to formation of enormous lava complexes near these centers. The absence of large or medium-sized volcanoes associated with these regions [19] suggests that the eruptions that produced the complexes were not persistent enough to form prominent volcanic constructs. Volcanism at the time of formation of ps and pl played a significant role in resurfacing and continued to operate as an important factor in formation of the extensive plains units.

There are clear trends in the evolution of tectonic regimes within the Mylitta Fluctus Quadrangle. Contractional deformation decreased in intensity from higher level associated with the formation of ridge belts to lower levels associated with deformation of regional plains (pwr1 and pwr2) by pervasive structures of wrinkle ridges. Contractional structures are absent within younger units suggesting seizing of compressional stresses by the time of units emplacement.

Extensive deformation that overprints pdl and forms groove belts (gb) and rift zones (rt) appears to have an opposite trend. Fractures in pdl are narrow, pervasive, and do not form belt-like concentrations. The subsequent extensional structures are organized into belts the individual structures of which become broader as a function of time. It is important to note that some occurrences of older groove belts continue the general trend of younger rift zone. This suggests that the rift probably inherited the structural trend of groove belts and may be a result of reactivation of a precursor deformation belt. Thus, the general orientation of tension stresses appears to be stable through a significant part of geologic history within the quadrangle, from before the emplacement of regional plains to the time of formation of lobate plains.

The results of complex search of the bulk samples and separate fractions selected from the enstatite chondrites Abee EH4 (a sample № 15832), Adhi Kot EH4 (№ 15059), Atlanta EL6 (№ 2611) and Pillistfer EL6 (№ 1864) are presented. The study of these samples was carried out with help of thermoluminescence (TL), track and neutron-activation (NAA) methods. The purposes of the given methods consist in definition of sensitivity of various methods for an estimation of the quantitative characteristics of a thermal and/or shock-thermal influence on substance of these meteorites during formation and subsequent evolution of their parent bodies.

**Thermoluminescence**

Investigations of natural and X-ray induced TL were carried out both in the bulk samples and separate fractions selected from some enstatite chondrites. The last were presented by the Abee and Pillistfer samples, differing by the grain sizes: < 45, 45-71, 71-100, 100-160, 160-260, 260-360 and > 360 μm. The natural TL intensity, saved by meteorites in cosmic space, in samples Atlanta and Pillistfer was close to background glow of apparatus. However, natural TL registered in 9 bulk samples of Abee and close to background glow of apparatus. However, cosmic space, in samples Atlanta and Pillistfer was µm. The natural TL intensity, saved by meteorites in 45-71, 71-100, 100-160, 160-260, 260-360 and > 360 Pillistfer samples, differing by the grain sizes: < 45, 6 bulk samples of Adhi Kot has shown a luminescence of various intensity in the region of ≥200 °C (see Fig. 1a, curves Ad-1, Ad-5, Ab-3 and Ab-7). So, for example, in the temperature interval of 190-250 °C the precise peak is sometimes observed. The height of the TL-peak (I TL) in different samples lies in ~200 times interval: from ~0,004 rel. un. for a sample Ab-7 up to ~0,8 rel. un. for a sample Ad-1. At that time as, for all investigated samples in the temperature region of ~250-380 °C the luminescence intensity of a TL peaks changes only within the limits of 15%. Measurements of TL in various fractions of the Abee meteorite has shown, that the fraction with the size of particles < 45 μm (curve Ab-1L in Fig. 1a) gives the greatest contribution to a TL luminescence in the region of 190-250 °C in comparison with luminescence in 250-350 °C interval. The value of the relation of the areas under TL glow-curves in interval of 190-250 °C (S1) and 250-350 °C (S2) for this sample makes S1/S2 = 1,26. In other fractions this value is much lower: ~0,4 for a sample 8L (160-260 μm) and less than 0,1 for all other size fractions. Thus, there are all grounds for supposing, that natural TL in the relatively low-temperature interval (190-250 °C) was maintained, mainly, in the fraction of size particles < 45 μm. The various parts of this fraction in the different bulk samples explain change of intensity of a natural TL in this temperature region.

The glow-curves of TL, induced by X-ray irradiation, are shown in a Fig. 1b. It is seen, that for meteorites Atlanta and Pillistfer the wide peak of a luminescence (50-350 °C) is observed with temperature of the maximal intensity near the 100 °C (curves At-3 and Pl-1). However, for Adhi Kot the high-temperature peak is observed in the region of 270 °C (curve Ad-1). The feebly marked peak at same temperature is observed also in meteorites Abee (Ab-6) and Atlanta (At-3). Accounts of the areas under glow-curves in the regions of 50-220 °C (S1) and 220-350 °C (S2) indicate, that the values of S1/S2 in the searched meteorite samples is equal to (1.31 ± 0.15) for Abee, (1.40 ± 0.03) for Atlanta and (1.61 ± 0.14) for Pillistfer, that is essentially differ from the value received for Adhi Kot: (0.40 ± 0.02).

**Research of tracks**

Track density (ρ) statistical distributions of the enstatite (En), olivine (O) and plagioclase (Pl) micro-crystals (size fraction of 100 - 200 μm), extracted from researched meteorites are given in Table 1. As it seen, the values of ρ for each meteorite vary in nearly the same interval of about (10^4 - 10^6) cm^{-2}. However, the portions of the crystals with different p-values indicate on the appreciable distinction in the region of the two specific statistical track parameters: first, for the very low irradiated (ρ ≤ 2·10^4 cm^{-2}) crystal grains, and second, for the highly irradiated (ρ ≥ 2·10^5 cm^{-2}) grains. Note, that for Abee about 30% of searched crystals contained the first statistical group. In the second highly irradiated group there are near 15% of all crystals for Abee and Atlanta meteorites, ~7% for Pillistfer and only ~3% for Adhi Kot. So, it can be constituted the some different radiation-thermal history for the searched enstatite meteorites. The Cu and Ir contents in the metal particles

The results of NAA measurements in Adhi Kot and Pillistfer are given in Table 2. Observed distinctions in the Cu and Ir contents in metal particles caused by processes existent on the pre-accretion stage of evolution of EH- and EL- group chondrite matter. Whereas the features of the variation trends in the contents of these elements respectively to the size of metal grains (see Fig. 2) reflect higher intensity of post-accretion metamorphic processes in the parent body for Adhi Kot in comparison with Pillistfer. Probably, these processes are caused both thermal and shock-thermal influences.

On the petrochemical data [5] in a meteorite Adhi Kot the signs of (up to melting of separate phases) shock-thermal processing of matter are observed. It is possible, the metal of this meteorite also could be changed and, in particular, in
it could be an additional redistribution of elements. It is obvious, that the size of secondary shock-thermal effects resulting in enrichment of metal by siderophile elements firstly depends on the size of metal particles.

**Conclusions.**

Complex analysis of the received data in comparison with results of our TL researches in olivine, quartz and calcite [1-3], results in the following basic conclusions.

Chondrites Adhi Kot and Abee have undergone the strongest shock loading that is resulted in practically complete melting and subsequent recrystallization of his matter. This assumption is coordinated well to conclusions of petrography researches [4], and as by reference of this meteorite in the group of the enstatite chondrites with features of shock-melting breccias [5].

The meteorite Atlanta also, probably, has undergone loading, which has resulted in partial melting and subsequent re-crystallization of enstatite.

The matter of a meteorite Pillistfer was under vented to the lowest (in comparison with other searched by us meteorites) shock loading.

![Fig. 1](image1.png) **Fig. 1** Glow curves of natural (a) and artificially induced by X-ray irradiation (b) TL in bulk samples from Atlanta (At-3), Abee (Ab-3, 6 and 7), Pillistfer (Pl-1) and Adhi Kot (Ad-1, and 5) enstatite chondrites, and in separated fractions with grain size from Abee (Ab-1L < 45 µm and Ab-8L – 160-260 µm).

![Fig. 2](image2.png) **Fig. 2** Grain-sized distribution of Cu and Ir in the metal of Adhi Kot EH4 ■ and Pillistfer EL6 chondrites □.

**Table 1.** Track-density distribution in the silicate crystals from enstatite chondrites Abee, Adhi Kot, Atlanta and Pillistfer.

<table>
<thead>
<tr>
<th>No</th>
<th>Chondrite</th>
<th>Crystals</th>
<th>Part of crystals with track density, cm²</th>
<th>Np≥2 10⁵/Ntot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minerals</td>
<td>P≤2 10⁴</td>
<td>P2 10⁴≤≤2 10⁵</td>
</tr>
<tr>
<td>1</td>
<td>Abee</td>
<td>Pl, Ol</td>
<td>48</td>
<td>0.29</td>
</tr>
<tr>
<td>2</td>
<td>Adhi Kot</td>
<td>En</td>
<td>64</td>
<td>-0</td>
</tr>
<tr>
<td>3</td>
<td>Atlanta</td>
<td>En</td>
<td>53</td>
<td>-0</td>
</tr>
<tr>
<td>4</td>
<td>Pillistfer</td>
<td>En</td>
<td>71</td>
<td>-0</td>
</tr>
</tbody>
</table>

**Table 2.** The contents Ir and Cu in metal particles of the different sizes from enstatite chondrites Adhi Kot EH4 and Pillistfer EL6.

<table>
<thead>
<tr>
<th>№</th>
<th>Size of metal particles, µm</th>
<th>Adhi Kot EH4</th>
<th>Relation to Cl</th>
<th>Pillistfer EL6</th>
<th>Relation to Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>260 – 160</td>
<td>Cu 1195</td>
<td>1.76</td>
<td>9.88</td>
<td>3.82</td>
</tr>
<tr>
<td>2</td>
<td>160 – 100</td>
<td>Cu 719</td>
<td>1.84</td>
<td>7.52</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>100 – 71</td>
<td>Cu 960</td>
<td>2.32</td>
<td>7.93</td>
<td>5.05</td>
</tr>
<tr>
<td>4</td>
<td>71 – 45</td>
<td>Cu 990</td>
<td>2.6</td>
<td>8.18</td>
<td>5.65</td>
</tr>
<tr>
<td>5</td>
<td>&lt; 45</td>
<td>Cu 710</td>
<td>3.5</td>
<td>5.87</td>
<td>7.6</td>
</tr>
</tbody>
</table>

**References**

THE MAGMATIC TRANSPORT OF CARBON AND HYDROGEN CONSTITUENTS FROM REDUCED PLANETARY INTERIORS. A. A. Kadik, Vernadsky Institute of Geochemistry and Analytical Chemistry, RAS, Kosygin St. 19, Moscow 119991, Russia.

Problem. Accretional models imply very reduced conditions of the carbon-bearing mantle and the depletion of the original volatiles of the Earth. The presence of a primary fluid phase in mantle is rather doubtful (Wanke et al., 1984; Arrhenius, 1987, Javoy, 1995, 1997). In this paper our major concern is to demonstrate that the carbon and hydrogen solubility in melts may have important implication for upper mantle evolution and formation of carbon and hydrogen species in terrestrial magmas during fluid-absent melting of the mantle at low oxygen fugacity (fO2).

The oxygen budget. Knowledge of the fO2’s of the mantle rocks is fundamental to any hypothesis regarding to the early history of the Earth, the composition of Earth’s primitive atmosphere and the composition of gases, exsolved by the terrestrial magmas in the upper layers of the Earth. Current models are based on the assumption that the redox state of the upper mantle has not changed, so mantle volatile species and volcanic gas composition has remained approximately constant with the time. A variety of evidence exists to support the idea that mantle was originally more reduced than today, although not as reduced as the metal arrest level, and has become progressively more oxidized.

The dissolution of hydrogen and carbon in reduced silicate melt. The transport of volatile constituents from planetary interiors to surfaces provides the primary supply of material for the upper layers of the Earth and atmospheres. The major factor controlling this transport is the solubility of volatile species in magmas and the oxide-reduction evolution of the magma relative to their mantle sources. The iron-bearing silicate melt (ferrobasalt) + iron metallic phase + graphite + hydrogen equilibrium have been considered in this study to demonstrate that the carbon and hydrogen solubility in melts may have important implication for formation of carbon and hydrogen species in terrestrial magmas under reduced conditions. The experimental conditions (3.7GPa, 1520 -1600°C) and hydrogen and oxygen fugacities (∆log fO2 (IW) = -2.32±0.06) correspond to the reduction of the part of FeO, which releases oxygen in the silicate liquid. It has been established that the liberated oxygen was consumed mainly to oxidised hydrogen into OH and H2O in much lesser extent. Only traces of CO2 and CO3− were formed. Dissolved carbon is mainly presented as atomic or amorphous carbon. It is also suggested that the network units contain Si-C bonds. The amounts of C and H dissolved in melts are particularly low. Carbon solubility remains about one order of magnitude less than that of water (about 2 wt% H2O and 0.2 wt% C).

Studies of iron-bearing silicate melt + iron metallic phase + graphite + hydrogen equilibrium demonstrate that the interaction of carbon and hydrogen with silicate melts has a number of features, which could play a key role in formation of various C-O-H volatile species at early stages of mantle evolution. We argue that magma generation in reduced environment at fO2’s in area of the Fe alloy stability and at pressures of the order of 100-150 km depth could form melts containing dissolved both oxidised, and reduced components of hydrogen and carbon species. Hydrogen is expressed mainly under the oxidised form OH and H2O. It is possible also, that some hydrogen can be present in a melt in the molecular form. Carbon is mainly dissolved in the melt as atomic C. It is possible that transitional oxidised forms of C exist. Iron-bearing silicate melt has a strong preference for dissolved H over C under reduced conditions.

Recent physical theories of planetary evolution propose that Earth and possibly other "terrestrial" bodies have experienced high-temperature conditions during their formation (Arculus, et al., 1990; Wetherill, 1990). It is suggested that about 4.5 Ga the mantle of the Earth was partially or completely molten, and molten Fe-alloy and molten silicate underwent gravitational migration. In the light of experimental data, it appears that a large scale melting of growth Earth could be associated with melts containing an oxidised form of hydrogen, although the early Earth was likely a reducing environment. In the framework of these assumptions the transport of primary magmas from the planetary interiors to the surface provides the primary supply of H2O of volcanic gases.
Acknowledgments. This study was supported by Russian Fond of Fundamental Investigations (project no. 02-05-64735) and by the Division of the Earth Sciences, RAS (priority theme 10002-251/ОНЗ-10/202-183/050603-495).

Introduction: Glass inclusions in anomalous chondrite Kaidun CR2 [1,2] were studied to investigate of both conditions of their origin, and evolution history of a meteorite as whole [3]. In this report the results of track and thermoluminescence (TL) researches of a Kaidun glass fragments are presented. On the received data the shock-thermal history of these glasses is investigated. The presence of micro-crystals in the three last types of glass fragments probably, is adjusted with essential contribution of the tracks due to 244Pu fission traces of an irradiation formed on a pre-accretion stage of formation of a meteorite matter.

With help of fission-track induced technique [7] it was shown, that in cryptocrystalline glass inclusions (24 searched samples) C_U varies in limits of ~ (0,5-7,5)×10^{-7} g/g. In 38 of transparent glass fragments it was chosen two distinct groups with average values C_U equal to (3,2 ± 0,6)×10^{-7} g/g and (7,0 ± 1,3)×10^{-7} g/g accordingly. In several samples of transparent glasses the parcels of ~10 μm by size with C_U, distinguished in 2-3 time from average C_U values of a sample as a whole, were fixed. It is supposed, that the observable disorder of C_U both for separate glass samples, and for different strips in some of them, is connected to strong heterogeneity and/or different melting degree of initial matter, as well as to comparatively small (~ mm^3) volume of formatted glass fragments.

In ~50 investigated glass fragments approximately in 10 % of samples the tracks of pre-accretion irradiation was detected. The analysis of ratio of ancient track density and C_U has shown: (a) Modal track age in ~10 % of glass samples essentially exceeds ~4.5 by, that, probably, is adjusted with essential contribution of the tracks due to 244Pu fission fragments; (b) Fossil track age in ~50 % of glass fragments lies in limits of (~4.5 - 4.0) by; (c) For residuary glass fragments ρ_OBS < ρ_B, that can be caused by the partial or complete thermal annealing of ancient tracks.

Thermoluminescence analysis. The results of measurements of sensitivity to formation of induced by X-ray TL ART for researched samples of glasses indicate a big differentiation of TL parameters in the all investigated (about 40 samples) of glasses, representing various chemical groups. Note some TL-characteristics of the searched glass samples from the Kaidun meteorite.

For glasses of the I-st and II-nd groups the formation probability of TL at T>250°C in some times below, than at lower temperatures. TL-intensity for samples of III-rd and IV-th chemical groups is approximately identical, but
that is essentially differs from TL for other glasses. The very wide temperature interval of a TL-luminosity with poorly varied intensity TL in the temperature interval of (150-350 °C) is characteristic for these glass groups. For colorless glasses is observed very wide and high-intensity TL at T> 250 °C with a set of the several precisely expressed peaks of luminosity. At the same time at lower temperatures the TL-luminosity for these glasses practically is absent. One of distinctive features of these colorless glasses is the presence of the poorly expressed polarization indicating on their partial crystallization as a result of shock-thermal influence. Note, that data of track analysis for these glasses show, that track density in them is very low in comparison with other glasses.

The sensitivity to TL formation for samples of crypto-crystal inclusions is characterized by essential excess of a TL-luminosity at T<250 °C. TL-glow curves for two glass-pyroxene chondrules are characterized by presence of two precisely expressed peaks. The comparison of parameters of a TL-luminosity for these chondrules with TL-parameters, obtained for the pyroxene crystals from a Kaidun meteorite, indicate that the TL glow-curves for chondrules are much more compound and are determined, mainly, by chemical composition and structural features of their glass phase.

As a whole, the data of TL-research of the Kaidun glasses result in the following conclusions: (a) The TL-luminosity for all investigated glass samples lies in an interval of (0.3 - 220) rel. un. (b) For the optically homogeneous glasses TL = (70±2) rel. un. (c) The glasses of crypto-crystal inclusions have TL in an interval (0.4 – 9) rel. un., and one sample with TL = 43.1 rel. un., that is, probably, connected to its secondary heating in the ablation process of a meteoric body. (d) Values of T_{PEAC} for all glass samples are in a temperature interval of (170-185) °C, that, obviously, reflects uniformity of structure of the basic TL-phosphorus, which is presented in these glasses. (e) For glasses of crypto-crystal inclusions a temperature interval of T_{PEAC} is wider: from ~170 °C up to ~220 °C. Obviously, the differing of their structural features in comparison with homogeneous and isotropic glasses causes it.

Conclusions:

It is shown that some glass fragments from chondrite Kaidun CR2 retained tracks storage in pre-accretion stage that characterized by high values of ρ_{VH} (up to ~10^7 cm^{-2}), and the total ρ_{VH} range near of two orders of magnitude

- The predominate part of glass fragments was formed in pre-accretion stage of formation of primary bodies of the early Solar system;
- Ancient tracks in some glass fragments could be formed from the two main sources: fission fragments of extinct 244Pu and VH-nuclei of solar wind VH-nuclei ions, accelerated up to energies higher of ~100 MeV/nucleon in the protoplanet nebula environments
- The processes of complete or partial melting of initial dust matter, probably, was connected to passage of shock waves and electrical discharged accompanying the outflow of solar wind plasma from the high-activity Sun at a stage of T-Tauri;
- The process of formation of glasses characterized by the large interval of a melting degree of initial matter that was caused, first of all, by the local short-thermal events of different capacity;
- Extent of the disorder of Cu values in individual fragments of a glass of meteorite, exceeding one order of value, also specifies their formation as a result of local shock-thermal events, resulting particularly, to melting of initial matte of different chemical composition;
- In the further significant share of glasses was not heated up to temperature above ~400 °C within short-time (~1 hours), that could result in them in complete disappearance of ancient tracks.

References:
Introduction: Search and identification of super-heavy elements (SHE) of \( Z \geq 110 \) in a cosmic matter were carried out by observation in olivine crystals from meteorites pallasites of the anomalous-long chemically etchable tracks - traces of braking of high-energy transuranic SH-nuclei, contained in the galactic cosmic rays (GCR) [1-3]. Calibration of track lengths formed in olivine by the accelerated \(^{238}\text{U}\) nuclei of \( \sim 30 \) and \( \sim 70 \) MeV/nucleon energy [4] indicate, that the maximum in a length distribution of specially annealed and then etched tracks for them is \( L = 230 \pm 25 \) \( \mu m \). On this base discovered in these investigations 11 very long (\( L \geq 340 \) \( \mu m \)) tracks were attributed to SH-nuclei.

Principally new approach to a SHE problem is based on registration of ternary spontaneous fission cases [5]. The experimental researches of three-prong fission fragment tracks of SH nuclei were performed firstly by V.P. Perelygin et al. [6]. At these experiments were observed the unique events of ternary spontaneous fissions of the compound SHE nuclei \(^{278}\text{C}_{110}\), formed at capture by \(^{238}\text{U}_{92}\) nuclei of accelerated \(^{40}\text{Ar}_{18}\) ions. From obtained results it was determined probability of SHE ternary fission in relation to fission on two fragments: \( \leq 3 \times 10^{-4} \). This value appears on three-four order of magnitude higher of probability of ternary fission for \(^{238}\text{U}\) nuclei [6,7].

In our report a number of issue concerning to probability of registration of three-prong fission fragment tracks in meteorite silicate crystals are considered.

Track sources in meteoritic silicate crystals. Tracks, observed in silicate crystals of meteoritic matter are formed mainly by: nuclei of VH-group (23 \( \leq Z \leq 28 \)) in GCR; fragments of spontaneous fission of \(^{238}\text{U}\) and extinct \(^{244}\text{Pu}\); and induced fission of heavy (Pb, Bi, Th, U) elements under action of primary and secondary nuclear-active cosmic-ray particles.

Spontaneous fission of \(^{238}\text{U}\) and \(^{244}\text{Pu}\) in phosphates from pallasites. The estimation of values of the contribution in expected track density of three-prong track events from spontaneous fission of \(^{238}\text{U}\) and \(^{244}\text{Pu}\) in phosphates from pallasites at concentration of uranium \( \sim (50 - 100) \times 10^{-9} \) g/g and track density of spontaneous two-prong fission equal to \( \sim 10^5 - 10^6 \) cm\(^{-2}\) gives values which is not exceed \( \sim 10^{-2} \) of three-prong events on cm\(^2\) of an analyzed surface of a crystal.

Induced by cosmic-ray nuclear-active particles of heavy elements fission. The estimation of probability of background events of three-prong fission of heavy elements (Pb, Bi, Th and U), induced by primary (p, n) and secondary (n, \( p \)) nuclear-active components of GCR, is carried out on the base of following experimental data:

The fission rate of heavy elements on two fragments, induced by cosmic radiation, is received on the data of [8]. On depth up to \( \sim 100 \) g/cm\(^2\) of the lunar soil matter the basic contribution is necessary on \(^{232}\text{Th}\). Since depth \( \sim 200 \) g/cm\(^2\), the fission rate of \(^{232}\text{Th}\) and \(^{235}\text{U}\) become comparable, mainly at the expense of highly effective fission of \(^{235}\text{U}\) under action of thermal neutrons.

The induced fission rates of others (mainly Pb, Bi) heavy elements appear on 4-5 orders of magnitude by lower.

The deep variation of total induced fission rate under action of GCR on nuclei of heavy elements in comparison with the constant on depth of spontaneous fission rates of an isotope \(^{238}\text{U}\), allows to estimate the rate of formation of three-prong cases of fission in volume of silicate crystals. These crystals simultaneously are the targets at GCR irradiation in cosmic space and the nuclear track detectors of fission fragments formed during the whole meteorite history.

In estimations also was taken into account theoretically received [7] meanings of probability of three-prong fission events are depending significantly on value of a charge of the easiest fission...
fragment (Z_L). So at increase of Z_L from 6 up to 25 effective cross-section of three-prong fission in nuclear reaction (N + Au) decreases from 5 up to 0.08 mb, and for reaction (N + Th) from 15 up to 0.8 mb under nitrogen ions energy of E_N = 1.5-2.5 MeV/amu. The relation of fission probability on three and two fragments for the mentioned above nuclear reactions equal to 10^{-3}-10^{-4}.

Some methodological remarks. It is need to indicate several methodological sources of errors: (1) thermally un annealed VVH (Z ≥ 30) cosmic-ray nuclei; (2) possible etching of track-like figures; (3) uncorrected annealing temperature of fission fragments; (4) tracks from the neutron-induced fission of U and Th isotopes; (5) formation of V-shap tracks due to nuclei fragments from cosmic-ray spallation reactions.

Three types of cosmic-ray induced fission possibilities must be considered; (a) 235U by neutrons (E ≤ 1 Mev); (b, c) 238U and 232Th by neutrons (E = 1 – 100 MeV) and (E ≥ 100 MeV). Experimentally determined proton-induced fission of U and Th as a function of a simulated lunar material depth [8] give possibility to derive corrections accounted with the depths, exposure ages, and heavy target elements (U, Th, Bi and Pb) contents in the searched samples. Table gives the uranium concentrations and measured track densities in the two main silicate minerals from pallasite meteorites.

The results of estimated corrections show that proton-induced fission is negligible and it makes a minor contribution even at a maximum flux of ~5 protons/cm²·sec. Conclusions: On the basis of the carried out estimation of the values of contribution from various sources of heavy element nuclei fission at an irradiation of meteorites in cosmic space, and also, starting from the received experimental meanings of track density three-prong (ρ_3) and double-prong (ρ_2) of fission of compound-nuclei of SHE (Z = 110) [1], the value of the relation probability of three-prong track events was determined: in comparison with the probability of three-prong fission of SHE nuclei contribution of all possible background sources not higher ~ 10^{-3}.

The carried out quantitative estimation of expected volume track density of three-prong cases of SHE nuclei fission has shown, that in view of the probable contribution of all considered sources of a background at viewing not less ~0.1 cm² of total volume of phosphate crystals from meteorites, in them it can be revealed several cases of three-prong fission of SHE nuclei.

Thus, detection of three-prong fission cases in phosphate crystals of meteorites, the formation age of which makes ~ (4.45 - 4.55) by, will testify to registration of traces of SHE nuclei fission in the early Solar system matter.

The present work has been performed under the support of Russian Foundation of Fundamental Investigations, Grant No.01-02-16410.


Table 1. Track densities, measured in pallasite silicate minerals.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>U Content, ppb</th>
<th>238U (4.6·by)</th>
<th>Cosmic-ray §</th>
<th>Cosmic-ray induced fission $^\vee$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olivine Phosphate</td>
<td>0.1 - 1, 50 - 100</td>
<td>10^{-4} - 10^{-3}</td>
<td>(1-10)×10^{5}</td>
<td>(1-2)×10^{-1}</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.5-1)×10^{6}</td>
<td>(2-20)×10^{5}</td>
<td>~10^{3}</td>
</tr>
</tbody>
</table>

* - For a cosmic-ray exposure age of 100 Myr. § - Track production rate in depth of ~200 g/cm² [8]. $^\vee$ - Accounted for the heavy target elements U, Th, Bi, Pb.
MAPS OF MATURITY-CORRELATED PARAMETERS OF THE LUNAR REGOLITH. V. Kaydash¹, Yu. Shkuratov¹, C. Pieters², V. Omelchenko¹, and D. Stankevich¹. ¹Astronomical Institute of Kharkov University. 35 Sumskaya St., Kharkov. 61022. Ukraine. ²Geoscience Brown University, Providence, RI 0291. USA. vkaydash@astron.kharkon.kharkov.ua

Introduction: There are several parameters that characterize maturity degree of the lunar regolith [1,2]. Most reliable of them are the maturity degree L/FeO and the agglutinate content. It was found also that a characteristic size of particle correlates with the lunar regolith maturity [1]. In present paper we map the parameter L/FeO, the abundance of agglutinates in the lunar regolith, and the characteristic size of regolith particles, using measurements of lunar samples made by Lunar Soil Characterization Consortium (LSCC) [3] and multispectral lunar data of high spatial resolution available after the Clementine mission to the Moon. Then we study correlation between these parameters.

Maturation effects: Several processes accompany to maturation of the lunar regolith. Among them are [1]: (1) formation of nanophase reduced iron grains in regolith particles, (2) formation of agglutinates, and (3) changing the average size of particles. All these processes are due to micrometeorite bombardment. The first and second processes change the spectral properties of the regolith resulting in its darkening. In contrast, decreasing the particle size by micrometeorite impacts can cause small brightening of lunar soils. The latter is mainly due to decreasing the mean pathlength of light in regolith particles, as the particle size decreases.

Source data and technique: The coordinated chemical, mineral, and spectral investigations recently provided by LSCC [3] gave the unique opportunity to study correlation between maturation effects and the spectral properties using the lunar samples database. We used lunar samples returned with Apollo 11, 12, 14, 15, 16, and 17 missions. All samples are presented with three size fractions (<10 µm, 10-20 µm, and 20-45 µm) and with bulks. Note that particles smaller than 45 µm are optically dominating on the lunar surface [4], therefore, we have excluded bulks from our analysis. Totally we analyzed 52 samples of different size fractions. This set is significantly wider than in our previous studies [5]. To map the maturity degree, agglutinate abundance, and characteristic size of particles (D), we used spectral UVVIS Clementine mosaics provided by USGS. The value D should not be confused with the average particle size usually used in the literature [1,7], as D is limited with the available size particle separates. On the other hand, D is expected to be strongly correlated with the average particle size [5].

The UVVIS Clementine mosaics correspond to the following five spectral bands 0.42, 0.75, 0.90, 0.95, and 1.00 µm. Using all these bands leads to very noisy results with the prominent residual latitude trend that is often revealed in analyses, e.g., [7]. Our studies have shown that the best results can be obtained with using the three bands 0.75, 0.95, and 1.00 µm. Note that to map the mineral content using the same samples data, the best set of the bands is 0.42, 0.75, 0.90, and 1.00 µm [8].

The main point we used in our approach is to find the closest correlation between a studied parameter P and linear combination of spectral albedos A of the lunar samples log P = k_1·A_0.75+k_2·A_0.95+k_3·A_1.00+k_4, varying the weight coefficients k_i (i=1..4) of the linear combination [5]. Actually we minimized the RMS deviation of predicted values from the measured ones. The values k_i and correlation coefficients r are given in Table for the maturation parameters.

<table>
<thead>
<tr>
<th></th>
<th>k_1</th>
<th>k_2</th>
<th>k_3</th>
<th>k_4</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/FeO</td>
<td>-20.00</td>
<td>15.92</td>
<td>1.91</td>
<td>1.96</td>
<td>0.92</td>
</tr>
<tr>
<td>Agg.</td>
<td>-5.66</td>
<td>-6.37</td>
<td>10.76</td>
<td>1.80</td>
<td>0.80</td>
</tr>
<tr>
<td>D</td>
<td>12.55</td>
<td>-10.74</td>
<td>-2.73</td>
<td>1.46</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Results of the mapping. Having determined the weight coefficients, we produced maps of the parameters. The map of the parameter D of regolith particles is shown in Fig.1a. Dark color corresponds here to low values of the parameter. We note coarser particles in craters and their rims. The maria have greater values of D in comparison with the highlands. The maps of L/FeO and the agglutinates content we present in Figs. 1b,c. The majority of craters and ray systems reveal low maturity as can be anticipated. There are almost no mare/highland differences in L/FeO and agglutinate distributions proving that it is insensible to compositional variations. The agglutinate content map looks very similar to the L/FeO map. This similarity can also be expected from laboratory studies of lunar samples, e.g., [1]. Note that in captures to Figs. 1a-c we give also the average content and the RMS variation.

Our technique can be applied to the high-resolution 100 m/pix Clementine USGS mosaics. We studied the Reiner-γ region. The formation is the best example of lunar swirls. The characteristic size distribution for this area (Fig. 2a) shows relatively small differences of swirl and surrounding mare soils as compared to mare craters. It consists with our previous analysis [5]. The map of L/FeO (Fig. 2b) indicates the swirl as fairly immature feature.

Correlation of maturation parameters: We studied two correlations, "L/FeO-D" and "L/FeO-agglutinate". The proper diagrams are shown in Figs. 3 and 4. The first diagram reveals a complicated relationship between L/FeO and D, at least three oblong clusters can be seen here, each shows anti-
correlation between the parameters. Less particle size in highland soils as compared to mare regolith can be explained in terms of fragility: highland rocks consist largely of plagioclases which are crushed more effectively in micrometeorite impacts than mare basalt. The direct correlation between \( \text{I}/\text{FeO} \) and agglutinates distributions (Fig. 4) reflects the process of increasing the total amount of nano-phase iron in the volume of regolith particles during agglutination. The detailed analysis of the diagram shows several parallel trends (clusters) in the common direct correlation. The two main clusters correspond to the maria and highlands. Craters and their ray systems form tails of the clusters.

Conclusion and future work: Developing our technique [5,6] allows us to map three maturity-correlated parameters: the maturity degree \( \text{I}/\text{FeO} \), the agglutinate content, and the characteristic size of regolith particles. We found a close correlation between \( \text{I}/\text{FeO} \) and agglutinate content. It consists with the laboratory data [1]. We plan to make a cluster analysis of the correlation diagrams shown in Figs. 3 and 4 in order to map different structure types of the lunar surface.

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ARKHYZ-DESTURBED METEORITE CRATER IN NORTH CAUCASUS.

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Arhyz meteorite craters half-oval depression on Great Zelenchuk river left coast. Center coordinates are 43°36’ N and 46°19’ E D = about 2 km. Great N part is good preserved only.

Arkhys crater meteorite genesis is proofs by lie sinkcyn on the rim basis, water-gaps presence on Great Zelenchuk and Kizguch rivers around crater lake (1), numerous planar features in quartz aus allogenous breccias, of systems m, ω, π, and others, by Ni presence in impact glass (cover around allogenous breccias debrises). Ni content in impact glass is 0,007 and 0,003 % (spectral analises in IGEM and GEOCHEM Ac. Of Sci., Russia) (2). Gravimeteric profile across crater has typical for such structures character and has anomalies values – 3 mGal in center and +2 mGal over the rim (3).

These facts permit to consider Arkhyz proofs meteorite crater.

Crater N part has good expressed rim with lie syncline in the rim bases and crossed by creeks.

Crater crosses by two faults. Sublatitude fault is along Great Zelenchuk river. Crater South part had displacement to East on 0,5 km, and behined them crater morphological features are poorly expressed. From Zelenchuk to North places longitudinal fault along steep gabbro intrusion contact crossing crater East part. Behind this fault had not displacement, but behind them crater morphological features also are obliterated.

Facts showed above permit to do conclusion, that impact wave effects from faults and behind faults loses significant part of its power. Therefore behind fault morphologic features of meteorite structures have been badly expressed. It is obvious, this circumstance is need to bear in mind by deshi-frition on the Earth and other planets.

TECTONICALLY AND CHEMICALLY DICHOTOMIC MARS IS THE LEAST OUTGASSED OF TERRESTRIAL PLANETS. G. G. Kochemasov, 35 Staromonetny, 119017 Moscow, Russia, kochem@igem.ru

The comparative wave planetology [1, 2] successfully overcomes the most principal martian test [3, 4, 5, 6]. The new wave paradigm declares that “celestial bodies are dichotomic” (Theorem 1 [7]), “celestial bodies are sectoral” (Theorem 2), “celestial bodies are granular” (Theorem 3), “angular momenta of different level blocks tend to be equal” (Theorem 4). Mars is, from one hand, a typical terrestrial planet, from the other hand, a planet with many peculiarities that result from its position in the Solar system. Out of 4 terrestrial planets it is the farthest from Sun and thus with smallest tide effects. But nevertheless it has the highest relief range and seems to be most distorted and broken by deep fissures. The wave theory explains this by a warping action of standing waves and broken by deep fissures. The wave theory is produced by a wave long 2π R/2 = π R/6, Mercury π R/16, Mars π R/2. It is the martian “fate” that its tectonic granularity produces inevitable tectonic dichotomy (the fundamental wave 1, long 2π R, sectoring (wave 2, π R, and other overtones), granulation. A granula size depends on an orbital frequency: the higher frequency the smaller granula. The Earth’s granula, as a scale, is π R/4, Venus has π R/6, Mercury π R/16, Mars π R/2. It is the martian “fate” that its tectonic granularity is produced by a wave long π R (π R/2 x 2 = π R) which is in resonance with the first overtone (wave 2) of the fundamental wave 1. This resonance reinforces a warping action of the characteristic for Mars π R/2-granula producing waves and this largely contributes to its distortion. So, wave 2 is very pronounced in the martian shape and adds very important peculiarities to its sharp N-S dichotomy.

With increasing solar distance in the four planets increase, along with tectonic granulation, the relief range (Mercury ~5 km, Venus 14, Earth 20, Mars ~30 km) and compositional (density) difference between lowland and highland lithologies [1]. The lowland compositions become Fe-richer and denser: enstatitite (Mercury), Mg-basalt (Venus), tholeiite (Earth), Fe-basalt (Mars). The highland compositions get less dense, lighter: anorthosite, alkaline basalt, andesite, conditional “albitite”. A density contrast between average lowland and highland rocks is proportional to the relief range (Theorem 4 [7]) and granula size: 0.03 – 0.1 – 0.25 – 0.45 g/cm3 [1]. This fits well to an overall appearance of two extreme terrestrial planets: Mercury is dull with a very weak albedo contrast, Mars, on the contrary, is bright with pronounced albedo contrast between dark lowlands and light highlands.

The martian highland compositions were assigned to albitite because of a high albedo and spotting “white” rock [3]. Later on to albitite we added syenite and granite – also acid not dense and light in color rocks [4]. Discovered by “Pathfinder” enriched in Si, Al, K contact rocks (andesites ?) in a transitional zone near to the dichotomy boundary proved predicted chemical fractionation of the martian crust. Thus, lighter, less dense than andesites lithologies can be found further inside highlands. Recently published in Internet (March 13, 2003) data show distribution of Fe, Si, Th in a belt between +45° and -45° latitude. Further polarwards gamma-measurements are obviously hindered by volatiles and dust deposits but even at the near-equatorial belt eolian processes obscure primary geochemistry. Nevertheless, Si and Fe confirm the distinct chemical dichotomy correlated with the planetary tectonic dichotomy and required by the regular wave planetology (Theorem 4). It is interesting also that high-Si areas propagate onto basaltic lowlands showing intensive wasting Si-rich material from highlands. The bottom of Hellas resembles basalts as it should be for a very deep depression (Theorem 4). Thorium is not characteristic for highlands; this could indicate that potassium is not very abundant there as Th geochemically is close to K. On the contrary, Na could prevail there (albitites – oligoclasites). In this respect uranium data are very important as U is close to Na; U/Th ratio could be very revealing. High Th in the northern part of Acidalia Planitia could indicate that some basalts are of the KREEP type (?)

Basalts are very widespread on surfaces of terrestrial planets but their compositions are variable and this is secured by a wide isomorphism of constituent minerals: Na-Ca feldspars and Fe-Mg dark minerals. Ratios between light and dark minerals as well as Fe/Mg in dark minerals play an important role in regulation of basaltic densities. Compositions of crustal basalts are very sensitive to hypsometric (tectonic) position of planetary blocks. At Earth oceanic depressions are filled with Fe-rich tholeiites (the deepest Pacific depression is filled with the richest in Fe tholeiites), on continents prevail comparatively Mg-rich less dense continental basalts. Mare lunar basalts are often Fe, Ti-rich; at higher crustal levels appear less dense feldspar-rich KREEP basalts. This tendency (an action of Theorem 4) for martian basalts became clear after TES experiment on MGS [8]. The TES data on mineralogy of low-albedo regions show that type 1 spectra belong to less dense basic rocks (feldspar 50%, pyroxene 25%) than type 2 spectra (feldspar 35%, pyroxene + glass 35%). It means that the highland basaltoids are less dense than the lowland ones. A discovery of the a layer of olivine-
rich rock exposed in the walls of Ganges Chasm (a part of Valles Marineris – a huge rift on the body of Mars) [Ph. Christensen, Internet, March 2003] tempts us to compare it with the basic-UB layered Bushveld complex in South Africa. This complex intrudes Precambrian continental crust in an area of the southern extension of the largest East-African rift zone of Earth.

The comparative wave planetology helps to understand the surprising discovery of vast amounts of hydrogen in the form of water ice in soils at two polar and near-polar regions. Mars looks less outgassed than it was previously thought. “Orbits make structures” – this concerns solid planetary spheres as well as gaseous ones. Tectonic granulation (Theorem 3) of lithospheres of Venus, Earth and Mars is repeated in structures of their atmospheres [9]. Moreover, their atmospheric masses correlate with their orbital properties: the higher orbital frequencies the larger atmospheric masses, this means more complete sweeping volatiles. Venus is covered with a thick dense atmosphere, Mars possesses very weak transparent one, Earth is in the middle (Mercury is practically bare).

Compare “sweeping” volatiles out of the planets. In a sphere of radius R there are 55.7 grains of radius πR/12 (Venus), 16.5 grains of radius πR/8 (Earth), 2.06 grains of radius πR/4 (Mars), 1057 grains of radius πR/32 (Mercury). Venus is 3.38 times finer-grained than Earth and 27.04 times than Mars, but 19 times coarser-grained than Mercury. Venusian wavelength 6000 km (πR/3) gives oscillation frequency 0.07 kHz, terrestrial wavelength 10000 km (πR/2) 0.03 kHz, martian 10660 km (πR/1) 0.025 kHz, mercurian 960 km (πR/8) 0.3 kHz. Venusian oscillations 2.33 times more frequent than terrestrial ones and 2.8 times than martian ones, but 4.3 times less frequent than mercurian ones. If planets outgassing is proportional to the square (outgassing goes through surface) of the production of granulation and oscillation frequency, then Venus is 62 times more outgassed than Earth [(3.38 x 2.33)² =62.1] and 5732 times more outgassed than Mars [(27.04 x 2.8)² =5732.3]. The smaller martian mass (7.5 times less than Venus’mass) makes this outgassing difference 5732 x 7.5 = 42990 times. Actually venusian atmosphere is 90 times more massive than terrestrial one and ~18000 times than martian one. A rather high discrepancy between Venus and Mars (actually 18000, calculated 42990) is probably due to higher ellipticity of the martian orbit promoting volatile sweeping.

Following the established regularity one may say that Mercury is 477 times more degassed than Venus [(19 x 4.3)² =6675; 6675 : 14 (mass difference of the two planets) =477]. The most outgassed of the terrestrial planets Mercury is the only planet bearing distinct traces of earlier planetary contraction: escarp or lobate ledges. A direct evidence of earlier intensive degassing is in numerous so-called secondary craters. These small and deep holes are controlled by planetary lineaments, weakness zones. Two the most degassed planets – Venus and Mercury – rotate very slowly. This is due to angular momenta redistribution between solid and gaseous envelopes. Solid bodies slow down, atmospheres rotate faster. However, if Venus keeps its atmosphere, Mercury has lost it by solar wind sweeping (remain traces of noble gases, Na, K). Mars, on the contrary, is very mildly outgassed and keeps a lot of CO₂ and H₂O. Two small terrestrial planets – Mars and Mercury – are “antipodean” bodies. Mercury is dull, heavy, Fe-rich, low-relief range, contracted, slowly rotating, without atmosphere (“candle-end”). Mars is bright, less dense, with high relief range, extended (at least partially), rapidly rotating, with an atmosphere. And this is due to different solar distances explaining not only different primary accretional compositions but also different orbiting frequencies so crucial for evolution of celestial bodies.

References:
A notion of similarity and correlation of wave structurization of planets, satellites, asteroids, comets and the Sun (a star) is rather crazy as it dares to compare two separately standing fields of astronomy and touches basis of natural sciences. Nevertheless, this idea is not entirely new as, not satisfied with convections, astronomers have been developing theories of global Sun’s oscillations to explain the sunspot cycle [1]. The comparative wave planetology includes stars as representatives of celestial bodies introducing general theories of celestial bodies shaping and structurization [2, 3]. The gathered latest SOHO and TRACE results show astronomers that waves play an important role in structurization of solar spheres. Impressed by these results they had a special meeting at Palma de Mellorka (Sept. – Oct. 2003) for discussion of the wave processes at the Sun [4]. Remembering solar supergranules, known for almost 70 years, scientists are curious why they have this size – 30000 or so km in diameter. No theory answers this fundamental question. But the comparative wave planetology at the very beginning firmly stated that “structures are made by orbits” [5, 6] and there is the concerted wave supergranulation of the solar system bodies including the solar photosphere [5].

The higher orbiting frequency the smaller supergranule made by an interference of standing waves warping any body in 4 orthogonal and diagonal directions. The supergranule size for Earth, as a scale, is πR/4 (a half of the wavelength πR/2) matching the orbital frequency 1/1 y. Correspondingly, asteroids, the terrestrial planets and the solar photosphere have the following row of supergranule sizes now, due to many images supplied by astronomical observations, well documented: asteroids πR/1, Mars πR/2, Earth πR/4, Venus πR/6, Mercury πR/16, Sun πR/60 (R - a body radius) [6 and others]. All these bodies orbit the center of the Solar system and are warped by inertia-gravity waves arising in their spheres due to periodically changing accelerations. Thus, the Sun is no exclusion as its photosphere has the certain radius (heliocentric distance 0.005 a. u.), the corresponding orbiting frequency (1/0.07 y., about 1 month period) – both in line with the other bodies of its system. By this way a bridging is made between planets and stars in that concerns their wave structurization. Consequences of this joining one may hardly overestimate as we now know that the body granulation is the 3-d process, not only affecting surficial spheres. Thus, the solar depths are concerned as the supergranule vertical size could be estimated. Then, the discussed wave warping involves a certain geometrization of celestial bodies spheres. Earth with its 4 waves in the great circle tends to transform the circle into a square (in volume it makes a cube), the Venus’ great circle acquires symmetry of hexagon, the mercurian one – of 16-gon, the solar one – of 60-gon. 60 waves fit in the solar equator are well known [7]. The geometrization of stars’ spheres, their approximation by polyhedrons could have an effect on stars’ twinkling. Here could be revived the not accepted Kepler’s idea about twinkling stars as rotating polyhedrons. Many other aspects of the stellar astronomy could be touched in connection with this new planets – star wave relations. The conclusion about the size of the solar photosphere supergranulation is so important that it should be checked by some other independent way. “Orbits make structures”. Can be found a body in the Solar system with similar to the photosphere orbiting frequency? Fortunately, there is such a body – the Moon. Equal monthly periods must produce equal wave structures. And this was verified when appeared the whole Moon gravity map. Reduced to the same size both the solar disk with supergranulation and the Moon’s disk with the gravity map show similar structural patterns [8].

The supergranules 30-40 thousand km across live 1 day or longer. They inhale (include) smaller features: long ago known granules 1-2 km across (life ~10 min) and recently known mesogranules 3-10 km across (several hours life) [9]. As it is prescribed by the wave interference invariant periodic table [10] modeling a real picture of the wave interference produced structures, shapes of granules are polygonal with the rectilinear outlines (Fig. 1-3). The size dispersion of real granules and theoretical polygonal granules of the table is similar. The likeness of the model and reality is strengthened by the comparison of the size ratios of supergranules (s), mesogranules (m) and granules (g) known in reality and taken from the table. S : m : g = 1 : (0.1-0.3) : (0.03-0.06) in reality and 1 : (0.2-0.3) : (0.02-0.06) from the table. The stable supergranules oscillate in vertical direction (standing wave) but +, - phase change occurs in neighboring supergranules with a certain time shift so that the overall picture reminds a traveling wave made by spectators at stadium [11]. A certain wave order one observes taking successive images of short living granulation. Instead of chaos a recurrence or an order is revealed. “Many granules seemed to be jointly bobbing up and down in a regular fashion, with a period of about 5 minutes in addition to their individual relatively random motions” [7]. The bound behavior of neighboring blocks and opposite signs (+ or –) of their vertical movements are inherent to the model wave interference (Fig. 1). Advection of granules and mesogranules after their formation to supergranule boundaries [9] is apparently characteristic of mobile gas medium organized in supergranules by the wave process. If the supergranules pattern relatively long lived (a day or longer) is easier to study and it is established that it is closely connected with the Sun rotation, magnetic field and oscillations (its “superrotation” now is understood and canceled [12]), the short lived granulation is harder to explain. The highly turbulent plasma of the convective zone makes it difficult, if possible, to create a realistic model of convection (advection) leading to the granulated surface with the size scale of 1000-2000 km. The size of supergranules 30-40 thousand km across (πR/60) follows directly from monthly rotation of photosphere and orbiting frequencies of planets (the photosphere also orbits the center of the Solar system) because they are regularly connected in one sequence. But what means the granule size? Following the established regularity (the higher frequency the smaller granule) one may conclude that small granules reflect the higher frequency, that is the faster solar rotation, in the past. Otherwise, the Sun

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STRUCTURES OF THE WAVE PLANETOLOGY AND THEIR PROJECTION ONTO THE SOLAR PHOTOSPHERE: WHY SOLAR SUPERGRANULES ARE 30000 KM ACROSS. G. G. Kochemasov, 35 Staromonety, Moscow 119017, Russia, kochem@igem.ru

PHOTOSPHERE: WHY SOLAR SUPERGRANULES ARE 30000 KM ACROSS. G. G. Kochemasov, 35 Staromonety, Moscow 119017, Russia, kochem@igem.ru
has a memory. Its past faster rotation is kept ("written") in its fundamental granular structure.

This conclusion is justified because we know that losing angular momentum by a celestial body degassing leads to its slower rotation (Venus, Mercury). Degassing depends on a body granulation (the smaller wave granulation the stronger degassing [13]). In the sequence planets – Sun the last body with the highest orbiting (rotation) frequency is the most outgassed. Its puzzling slow rotation and small angular momentum comparative to the rest of the solar system well correlate with its large outgassing (some think that its mass was 10% larger in the past [14]; indeed, some young stars seem to have shed some of their material). Lost angular momentum to cosmos (planets, solar wind, outer heliospheres) caused an important slowing of rotation. But the finer wave structures produced by standing waves due to more rapid rotation (orbiting) in the past are rather tenacious and show themselves as granules. On the granular pattern are superimposed the supergranular pattern reflecting much slower rotation at present and the mesogranular pattern corresponding to some intermediate state of rotation reflecting a gradual loss of angular momentum. Looking at the whole solar system one may make the following subdivisions of its bodies marking their increasing outgassing from outer to inner parts of the system: rapidly rotating gas giants, moderately rotating Mars and Earth, slowly rotating Venus, Mercury, Sun.

Thus the both puzzling features of the Sun: its slow rotation and the size of its supergranulation (as well as granulation) are in relation and ascent to the wave planetology. The predictive power of this science is demonstrated over and over again.

MODIFIED ALPHA PARTICLE X-RAY SPECTROMETER FOR USE IN PLANETARY RESEARCH.

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Introduction: Instruments, that use the excitation of soil by alpha-particles from radioactive sources and measure the back scattered alpha-particles and X-ray characteristic spectra of elements by semiconductor detectors, were used in space research since studies of chemical composition of lunar soil by Alpha-Proton Spectrometers on the “Surveyor” spacecrafts. The application of such a method have demonstrated its efficiency and was resulted in the building of constantly improved Alpha Particle X-ray Spectrometer (APXS) instruments. It was successfully used during “Mars Pathfinder” mission and are included in the payload of American recently started Mars Exploration Rovers 2003 missions and in the postponed European mission to comet (Rosetta). APXS instruments have a good perspective to be used in future American, Russian, European, or joint space missions (e.g. Bepi Colombo project). Nevertheless, the simplicity of the method does not exclude the necessity of detailed methodological investigations of the workability of the method in different planetary like environments.

Description of the APXS: The Athena Alpha Particle X-ray Spectrometer works by exposing martian materials to energetic alpha particles and x-rays from a radioactive 244Cm source, and then measuring the energy spectra of backscattered alphas and emitted x-rays. The instrument is conceptually similar to the APXS instrument that flew on the Mars Pathfinder mission. However, there are several differences that improve the instrument’s reliability and performance. Unlike the Pathfinder APXS, the Athena APXS does not have a proton mode. The proton mode has been dropped because recent increases in the spectral resolution and sensitivity of the x-ray mode have made it unnecessary. Significant modifications have also been made to the instrument to reduce the CO2-induced background (see Fig. 1) that was observed on Pathfinder, to improve x-ray spectral resolution, and to decrease susceptibility to electromagnetic interference. In addition, the Athena APXS will have two onboard reference targets for postlanding calibration on Mars.

The APXS instrument consists of a sensor head mounted on the rover’s Instrument Deployment Device, and electronics mounted in the rover’s Warm Electronics Box.

The sensor head contains six 244Cm alpha radioactive sources with a total source strength of about 30 mCi. The sources are each covered with 3-µm aluminum foils that reduce the energy of emitted alpha particles from the initial value of 5.8 MeV to about 5.2 MeV. At this energy, the alpha particle scattering cross section of carbon is significantly reduced. The reduction is accompanied by a slight degradation of the alpha spectral resolution caused by broadening of the excitation spectrum, but the net result is a significant suppression of atmospheric background in the alpha spectra. Collimators in front of the sources define the instrument’s field of view, which is about 38 mm in diameter at the nominal working distance of 29 mm.

Surrounding the sources are six thin alpha detectors. The FWHM for the alpha mode of a 244Cm peak at 5.8 MeV is less than 100 keV. Interior to the ring of sources is a single high-resolution silicon drift x-ray detector with a 5-µm beryllium entrance window. The FWHM of this detector at 6.4 keV is about 160 eV (see Fig. 2), compared to 260 eV for the Pathfinder APXS. The noise level in the x-ray mode will be less than 600 eV at temperatures below −30°C, and the efficiency at the 1.24 keV line of Mg is at least 20%.

Preamplifiers for both detector channels and a circuit to generate detector bias voltages are also mounted on the sensor head, significantly reducing the instrument’s susceptibility to electromagnetic interference.

The entrance to the detector head is normally protected from martian dust and other potential contaminants by a pair of doors. These doors swing inward and lock open when the sensor head is pressed against a target or other hard surface. They can be closed again by actuation of a release mechanism. The inner surfaces of the doors provide a calibration reference surface for the instrument.

Signals from both detector channels are processed by electronics mounted in the rover WEB. Alpha signals from charge-sensitive preamplifiers — and similarly-x ray signals from a customized voltage-sensitive preamplifiers in the sensor head — are further amplified and filtered (semi-Gaussian pulse shapes) and then routed to peak detectors, a multiplexer, and into a 16-bit A/D converter for digitization. Signals from comparators that trigger if signals exceed a preset level initiate a sequence of logic signals necessary for peak detection (sample gate and signal hold) and the conversion process (program interrupt, alpha/x-ray flags). A microcontroller selects the appropriate input to the multiplexer and controls analog-to-digital conversion. The analyzed...
events are stored in the microprocessor buffer memory, building up alpha- and x-ray spectra.

The rover can place the APXS sensor head in contact with rock surfaces or soil surfaces at inclinations within the range of 0 to 90°. Under normal conditions, it should be possible to position the instrument centerline within 0.4 cm of a target location.

Proper preflight calibration is essential to analysis of APXS data, so the Athena APXS is undergoing an extensive calibration program. All calibration measurements are made in a chamber filled with a mixture of gases that closely matches the composition of the martian atmosphere, at the appropriate atmospheric density. Calibration measurements include:

- spectral “library” measurements of pure elements and oxides;
- geochemical standards that span the full range of plausible martian surface compositions;
- standard targets under a range of atmospheric densities and measurement geometries;
- standard targets in both natural and powdered form, to investigate texture effects;
- the APXS flight calibration target;
- several blind certified geochemical reference standards, for independent assessment of the accuracy with which compositions can be measured.

All of these measurements are made using the flight radiation sources.

The accumulation time for the APXS will typically be at least 10 hours per sample analysis, although significantly shorter durations are possible when only the x-ray mode is used. However, it is desirable to break the total accumulation time into several shorter accumulation periods. The APXS can store up to 12 sets of accumulated spectra and can transmit the data to the rover either after each accumulation period, or all sets of spectra at the end of the final accumulation period.

The x-ray mode is sensitive to major elements, such as Mg, Al, Si, K, Ca, and Fe, and to minor elements, including Na, P, S, Cl, Ti, Cr, and Mn. The alpha mode is sensitive to lighter elements, particularly C and O. The depth of analysis varies with atomic number, ranging from approximately 10 to 20 micrometers for sodium, to approximately 50 to 100 micrometers for iron. The detection limit is typically 0.5 to 1 weight percent, depending on the element. The APXS is mainly insensitive to small variations of the geometry of the sample surface but that need further methodological investigation.

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**Fig. 1.** X-ray spectrum of albite measured by APXS in 10 mbar atmosphere of CO₂.

**Fig. 2.** Alpha particle spectra of albite measured by APXS in vacuum (dashed black line) and in 10 mbar atmosphere of CO₂ (solid black line). Gray line gives the difference between the two spectrum lines and shows the input of atmospheric carbon and oxygen.
POST-IMPACT DEPRESSIONS ON MARTIAN CRATER FLOORS: PRELIMINARY RESULTS AND A CASE STUDY OF THE GREATER HELLAS REGION. J. Korteniemi\textsuperscript{1}, V.-P. Kostama\textsuperscript{1} and J. Raitala\textsuperscript{1}, \textsuperscript{1}Astronomy, Department of Physical Sciences, University of Oulu, P.O.Box 3000, FIN-90014 Oulu, Finland <jarmo.korteniemi@oulu.fi>.

Introduction: The surface of Mars, especially the southern highlands, is saturated with impact craters. These structures display a variety of types, such as rampart and polygonal craters. The formation of these different types depends partly on the material at the impact site and partly on the local zones of weakness [1], as well as the evolution of the crater after the impact event.

Craters with distinctive depressions on their floors are found around the planet. Continuing our study [2], we show their distribution and classify them into types. We also look closer at the characteristics of examples found in the Greater Hellas region and aim to test and suggest possible causes for the particular phenomenon and features involved.

Definition: In this study we concentrate on the depressions created after the crater formation onto the crater floor. We deliberately excluded the depressions generally known as “central pits” [3] from this study, as they have been studied quite extensively [3, 4, 5]. We aim to study the mechanisms for causing the more irregularly shaped and situated depressions on the crater floors.

A: Dichotomy boundary: Characteristically, the crater floor depression morphology starts far off in the highlands as solitary streaks on the crater floor, or in some cases irregular collapse pits similar to type C. Closer to the dichotomy boundary the streaks or cracks start to multiply and cover the entire crater floor in a more symmetric way (Fig. 2). Near the dichotomy boundary the streaks widen and become more complex, eventually making the crater chaotic (see also [7]). Being the origins of several fluvial channels and bearing features associated with fluvial erosion, the dichotomy boundary type of depressions can safely be associated with water release.

B: Outflow channels: The collapses located in the Xanthe Terra and Valles Marineris region are in fact a subtype of the type A, with the exception that these are even more closely linkable with fluvial activity.

C: Greater Hellas region: The depressions associated with this type are quite uniform. They are small, solitary, irregular and generally not very concentric (Fig. 3). The depressions resemble the more irregular depressions found in type A and B.

Global distribution: Locally, the craters with depressions are most often found in rather closely packed clusters of different sizes. Their regional distribution is also concentrated in specific regions. Thus they may indicate and define areas with distinctive local geology. The pits, collapses and depressions in such craters have clearly formed after the initial formation of the “parent” crater, and they seem to be unrelated to the crater age. Generally the collapses seem to be one of the youngest features created onto the crater floor.

Going through all the Viking MDIM2 [6] and MGS MOC wide-angle maps, we have found 397 craters with collapsed features (Fig. 1). They can further be classified into several categories by location:

Figure 1: Global distribution of craters with depressions. The categories are described below, and the locations of the examples shown are indicated by black circles.

Figure 2: Examples of type A depressions. Left (15.2\degree S, 41.5\degree E) is a sample from the highlands; the right one (5.9\degree S, 108.0\degree E) is located closer to the dichotomy boundary. Craters are 50 km in diameter.

Figure 3: Examples of type C depressions (crater coordinates: left 44.9\degree S, 28.3\degree E; right 31.6\degree S, 40.9\degree E). Note that some depression walls are straight, indicating possible zones of weakness. Craters are 90 km in diameter.
D: Claritas Fossae; E: Memnonia Fossae; F: Tempe Terra: These are areas with definitely tectonically created crater floor depressions. Graben and faults traverse across the terrain, in places intersecting a crater and deforming its floor (Fig. 4).

In addition to these types, there are a few sporadic craters with depressions around the globe.

Greater Hellas Region: There are 78 craters with depressions in this area. Most of them, 70%, lie on the western side of Hellas basin, while the rest are distributed mainly to the north and very sporadically to the east and south. The distribution of depressed craters mostly coincides with results from earlier and broader crater morphology studies of the area [8], adding just a few individual craters to the list (Fig. 5).

Zones of Weakness: We measured the directions of straight depression walls in the craters of Hellas area, in order to compare the result with directions of the polygonal crater walls in the region [1]. The results are a bit ambiguous, since the amount of craters with depressions is rather small.

However, one can observe a definite trend of walls radial to Hellas (Fig. 6), thus displaying that the regional zones of weakness caused by Hellas are still active in the region, or at least were during the depression formation. However, several collapses display walls, which are either radial (directed towards the crater center) or concentric (follows the shape of the crater; Fig. 7). This indicates that in those cases the fracture zones from the crater formation dominate over the regional zones of weakness.

The reason for the formation of the Hellas depressions is most probably volatile release. At the same latitude range, but on the eastern rim of Hellas, there are several large outflow channels which indicate that there was water in that area, most probably permafrost, at some point in the planet’s history [e.g. 8, 9, 10]. On the western rim [11] there are no heat-releasing volcanoes, and the possible permafrost might have been trapped there for a long time. Whatever their cause, the concentration of crater floor depressions make the Noachis area west of Hellas unique.

Conclusions: Especially the Greater Hellas area depressions inside crater floors clearly tell us about the local geology, and possibly more importantly about the volatile content in the local material. They also seem to tell about the local zones of weakness, although the crater formation has most probably destroyed the pre-existing tensions locally. This suggests that the crustal tensions have continued to work after the crater formation at least until the collapse or depression was formed.

Introduction: Detection of the enhanced hydrogen in some areas of polar regions of the Moon, has confirmed an opportunity of detection in these areas of deposits of water ice [1,2]. In the previous work we investigated distribution of constantly shaded areas in polar craters of the Moon and connection of these areas with areas of the raised increased maintenance contents of hydrogen [3]. In the present work we investigated distribution of temperatures inside such craters.

We researched the regions with latitude higher than 60° for both hemispheres of the Moon. 950 craters and 1127 craters with diameters larger than 10 km were considered for North and South Polar regions, respectively. The areas, permanently shaded during the all period of regression of the line of nodes of the Moon’s orbit Sp, exist in 88 craters in the North Pole region, and in 103 craters in the South Pole region. The areas of these terrains are 0.0089% and 0.0131% of total lunar surface, respectively.

We investigated the influence of regression of the line of nodes of the Moon’s orbit on change of the sizes of permanently shaded areas inside polar craters of the Moon for the period of 18.6 years or 230 solar days on the Moon. For each day temperatures inside the craters containing areas of a constant shadow and conterminous to areas of the enhanced hydrogen have been designed. For an estimation of temperature of a surface in a crater we took into account geothermal heat flow, the lateral conduction from the area covered by direct solar beams, thermal emission from the covered wall, secondary heat flow from the walls and crater's floor [4].

We took into account change flow from the Sun depending on position the line of nodes of the Moon's orbit.

In the previous work the craters connected with enhanced hydrogen and being tanks water ice deposits have been revealed. In area of North Pole of the Moon of such craters it was revealed about 40 (diameter > 10 kms), and in area of the South Pole of the Moon - about 35 (diameter > 10 km). Temperatures at the bottom of the some craters located within the limits of 3° from pole do not exceed 110 K during the all period of regression of the line of nodes of the Moon's orbit. Therefore, water ice can be kept in such craters without a covering by a layer of regolith independently of orientation of an axis of rotation Moon concerning a pole of ecliptic [5, 6]. Temperatures at the bottom of the large craters located from poles are farther (such as Cabo, Faustini, Hermite and Pari in which area it was revealed enhanced hydrogen), exceed this limit, therefore water ice in such craters can be kept under a layer of regolith.

As an example the data for a crater in diameter 22 km, located about the South Pole the Moon (85, 1 N, 188,2 E) are resulted. In this area the spacecraft “Lunar Prospector ” has registered the raised contents of hydrogen [2]. On the fig. 1 shown of change of the area of the permanently shaded area during day inside 22 kilometer craters near the North Pole of the Moon and midday height of the Sun are resulted depending on position of a pole of rotation of the Moon concerning a pole of ecliptic. The minimal value permanently shaded areas for this crater within day makes 57, 8 %, maximal - 77, 2 %.

On the fig.2 shown the distribution of maximal and average temperatures inside a crater. The designed temperatures at the bottom of a crater and in a southern part of its walls do not exceed a limit 110 K. It means, that in such crater can exist unburied under a layer of regolith water ice deposits.

COLD TRAP ON THE MOON: E.A. Kozlova

Figure 1. The dependence of change of the area of the permanently shaded area $Sp$ during day inside 22 kilometer craters near the North Pole of the Moon and change the midday height $h_0$ of the Sun above the horizon are resulted depending on position of a pole of rotation of the Moon concerning a pole of ecliptic.

Figure 2. The distribution the temperatures inside the crater (85, 1 N, 188,2 E). In figure the maximal and average temperatures for the period of regression of the line of nodes of the Moon’s orbit are shown. Dark blue color shows border permanently shaded area. Red color - border of a shadow at the maximal height of the Sun above horizon, lilac - border of a shadow at the minimal height of the Sun above horizon. The bottom of a crater constantly remains shaded.
SUBSURFACE WATER DISTRIBUTION IN MARTIAN EQUATORIAL REGIONS FROM HEND/ODYSSEY DATA. A.S. Kozyrev¹, I.G. Mitrofanov¹, M.L. Litvak¹, A.B. Sanin¹, V. Tretyakov¹, W.V. Boynton², D.K. Hamara², C. Shinohara², R. S. Saunders³, D. Drake⁴, ¹Space Research Institute, RAS, Moscow, 117997, Russia, kozyrev@mx.iki.rssi.ru, ²University of Arizona, Tucson, AZ 85721, USA, ³NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, ⁴Lansce 3, Los Alamos Nat'l Lab. Los Alamos, NM and Tech-Source Inc, Santa Fe, NM 87594, USA.

Introduction: The analysis of water abundance in Martian subsurface is presented for equatorial regions of Mars. In our study we used observational data of neutron albedo gathered by HEND instrument onboard 2001 Mars Odyssey ([1,2]). The previous results based on neutron spectroscopy of Martian surface shows presence of significant amount of water at equatorial latitudes of Mars near Arabia Terra and Elysium Fossa [1]. The preliminary calculations shows that average content of at these regions may be as high as 10% by weight [3]. This value is close to natural limit, which may be explained by presence of chemically bound water. From other side one may say that water is not homogenously distributed trough the surface and there are some wet spots where content of water may be significantly higher then ~10%.

Data Analysis. The main goal of this study was to search for most wet spots inside Arabia Terra and Elysium Fossa. We also try to investigate temporal stability of data accumulated at these wet spots. The whole set of data accumulated at equatorial regions was distributed into several groups corresponding to different season intervals. For each season interval we create map of statistical deviations from mean value of neutron flux to locate geographical spots with significantly low neutron fluxes. It was found that most stable behavior with time is demonstrated by small region around 30E, 10N. Practically for all season intervals we observe here minimal values of neutron flux, which correspond to presence of maximal quantity of water. To estimate content of water in this wet spot we used model depended deconvolution of neutron data gathered at this region for whole time period (Ls=330-190 degree, see fig 1). Calculations shows that content of water may be close to 16%. The similar analysis applied to Elysium Fossa revealed that maximal presence of water in this region might be as high as 12%.

Fig 1. The distribution of statistical deviations from mean value of neutron flux is presented for large region near Arabia Terra

References:
**Introduction.** Calderas are defined as large, more or less circular, volcanic collapse depressions with diameters considerably larger than any included vent [1,2] resulting from collapse into partially drained near-surface magma chamber [2]. They have been defined as having diameters >1 km [3], with smaller depressions being called craters. Usage of term caldera, includes features described as “cauldrons”, which represent a variably deeper erosional level of the same fundamental structures [4, 5]. Our goal here is to overview types of calderas on Earth, mechanisms and models of their formation for following comparison with venusian calderas [6].

**Methods.** We summarized aspects of calderas formation using models of caldera formation [5,7], maps and description of typical calderas [8-10], and overviews of calderas formation and classification [2,5,7].

**Caldera geometry, structural elements.** Structural and morphologic elements of a simplified caldera model include [5,7] (Fig. 1-3): topographic rim, inner topographic wall, bounding faults (if present), structural caldera floor, intracaldera fill (ash-flow tuff, lava flows, and landslide debris from caldera walls), and the underlying magma chamber or solidified pluton.

**Classification of calderas.** There are few classifications of calderas (genetical, chemical, tectonic). We took one of them by [2] with some modification and simplification according to Vic Camp volcanology website [11]. Three morphological classes are important on the Earth: basaltic shield volcano calderas, Crater-lake type of calderas, and ash flow calderas.

**Basaltic shield volcano calderas.** The summit regions of many active shield volcanoes are marked by calderas (Fig. 1). It is generally believed that shield caldera formation is due principally to drainage of magma rather than explosive removal of it from a magma chamber. Instead, they subside in increments to produce a nested structure of pits and terraces. Basaltic calderas like these are gradually enlarged by episodic collapse, due to the extraction of lava from shallow-level magma chambers underlying the summit areas. Shield calderas form in basaltic volcanoes, with tholeiites being typical rock types for both large and small shields, sometimes in aluminous basalts and basaltic andesites [2,12].

**Crater-lake type of calderas** (Fig. 2) is generated after the main phase of a Plinian eruption, during collapse of a stratovolcano (Mt. Mazama in Crater-lake caldera) into the void of the underlying, depleted magma chamber. Although the waning phase of a Plinian eruption is often associated with the generation of pyroclastic flows, piston-like collapse of the volcanic edifice can generate the additional eruption of voluminous (0.1-100 km³), pumice-dominated sheet flows along ring fractures surrounding the collapsing mass. These sheet flows form thick deposits of ignimbrite, the hallmark of both Crater-lake type and ash flow calderas. Caldera formation has occurred two or more times in many stratovolcanoes; many stratovolcanoes have a caldera as their final evolutionary stage. Stratocone calderas usually form in volcanoes made of basaltic andesite or andesite, with occasional basaltic, trachytic, and phonolitic structures [13]. Ejecta associated with stratocone caldera formation is typically dacitic to rhyolitic.

**Ash flow calderas** result from collapse following the eruption of extremely large (100-1000 km³) volumes of dactitic to rhyolitic ash flows (Fig. 3). These calderas are the largest, and most were not formed on existing massive volcanoes. Ash flow calderas also dominantly erupt dacitic to rhyolitic ignimbrite or alcalic rocks. Many calderas larger than about 20 km diameter have resurgent centers, apparently updomed during or by the refilling of the underlying magma chamber [2,14] (Fig. 3). With diameters ranging from 15 to 100 km, resurgent calderas dwarf those of the Crater-Lake type. They are similar to Crater-Lake type calderas in that they are also generated by crustal collapse above shallow magma chambers. Resurgent calderas, however, are too
large to have been associated with a Crater-Lake type central volcano. Apart from their large size, the definitive feature of resurgent calderas is a broad topographic depression with a central elevated mass resulting from post-collapse upheaval of the caldera floor. The caldera floor is typically filled with rhyolitic lavas, obsidian flows, and domes; the uplifted centers often contain elongate rifts (graben) along their crests (Fig. 3).

Caldera diameters

[2,13,15]. Shield calderas comprise about 65% of calderas with diameters D<2 km, but frequency declines fairly rapidly to 0% at D=20 km. Stratovolcano calderas are the dominant class of terrestrial caldera in the range D=20 km. Ash flow calderas first occur at D=5 km, rise to dominance at D=13 km, and account for all tabulated terrestrial calderas with D>20 km.

Caldera subsidence processes. Many calderas have such varied transitional geometries and structures that subclassification into discrete types seems less useful than relating subsidence geometry and resulting structures to a few geometrically simplified end-members [5,7] (Fig. 4). Small calderas (<3-5 km diameter) commonly have funnel geometry (e) because of dominant enlargement by slumping into an areally restricted vent. Many larger calderas dominantly involve plate (piston) collapse (a) of a coherent floor, bounded by steeply dipping ring faults; they are inferred to reflect voluminous eruptions from large shallow magma chambers. Trap-door subsidence (c), bounded by an incomplete ring fault and by a hinged segment, reflect early downsagging and incipient plate collapse related to smaller eruptions, an asymmetrical magma chamber, or regional tectonic influences. Deep magma chambers or small eruptive volumes may favor downsag subsidence (d) without large bounding faults, although the appearance of downsag can be generated by younger volcanic units draped over a pre-existing caldera or structural basin. Pervasively brecciated chaotic disruption (b) of subsiding caldera floor is uncommon, at least at calderas more than a few kilometers across. Interpreting caldera structures in terms of a continuum of subsidence styles, rather than as end-member types, can clarify relations between eruptive and structural processes in comparison with size of the eruption and geometry of the cogenetic magma chamber. The size of magma chambers and volume of ash-flow eruptions strongly influence both caldera-subsidence processes and the lithologies of exposed intracaldera volcanic fill.

Evolution. Five principal stages can be recognized [4]: 1) precursor; 2) caldera collapse; 3) early post-collapse volcanism; 4) major ring-fracture volcanism; and 5) hydrothermal activity. Development can be terminated at any stage; stages can also be repeated. Resurgent doming can occur during stage 3 or later; doming can also be enhanced by reactivation of cauldron structures by postvolcanic basin and range faulting.

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Introduction. Calderas on Venus are described as “circular to elongate depressions not associated with a well-defined edifice and are characterized mainly by concentric patterns of enveloping fractures” [1]. They are most common 40-80 km in diameter [1-3]. The "Catalog of Volcanic structures of Venus" [2] includes 97 calderas. We have studied topography and geology of all calderas and their surroundings by way of detailed geological mapping [3]. Our goals are to compare venusian and terrestrial caldera geology, topography and mechanism of formation. Methods. We used previous work for analysis of venusian calderas [1-3] and our review in this issue for analysis of terrestrial calderas [4].

Observations. Diameter. Venus: Average diameter of calderas from "Catalog" [2] is 67.8 km, standard deviation 36 km. Earth: Quaternary calderas vary widely in size (1.6-over 50 km), 94 % of examples being less than 20 km [5].

Topography. Venus: 53% of calderas are represented by simple depressions, 11% have an irregular flat shape, 6% are depressions with a very low rim (Fig. 1,4), 1% is dome-like, and 29% have topo data not sufficient for analysis. Depth of caldera depressions is usually first hundreds of meters, up to 1 km (Fig. 4). Earth: Not eroded calderas usually have a prominent topographic rim and inner topographic wall (Fig. 2).

Tectonic structures. Venus: 4 sets of tectonic features are observed [3]: 1) Concentric extensional structures are observed in 63% of calderas; 2) Concentric extensional fracturing and radial compressional structures inside and/or outside of the concentric fracturing are observed in 29%. In some cases, concentric ridges inside depressions are observed; 3) 7% of calderas have concentric and radial extensional fracturing; 4) 1% has radial fracturing only. Most characteristic concentric extensional fracturing of calderas is dense, fracture to fracture spacing is usually 200-300 m and less, and is located in broad belt (30-50 km wide) on the slope of depression. In some cases influence of regional stress on distribution of fracturing were identified (Fig. 4). Earth: Bounding caldera faults are mostly gravitational in nature forming by reservoir subsidence. Ring faults can accommodate uplift as well as subsidence [6], ring dike formation have connection with faults formation. Ring faults may be vertical, inward and/or outward [6,7]. At many calderas regional tectonic trends have influenced the geometry of collapse to varying degree [6,7].

Associated volcanism. Venus: Calderas have no evidences of collapse of one volcano. Secondary shield volcanoes are associated with 47% of calderas, extensive lava flows with 24%, both are associated with 17% (Fig. 4); 12% show no volcanic activity. Calderas also have related pit craters, pit chains and canali (Fig. 4). Most volcanic activity has a connection with dense concentric fracturing. Earth: see summary in this issue [4].

Subsidence depth. Venus: In most cases the caldera depression is not totally covered by lava plains [3], and depth of subsidence is no more than 1 km, in few cases 1.5 km (Fig. 4e). Earth: Almost in all cases calderas are filled by lavas and ash deposits (Fig. 2,3), the best solution for total subsidence depths at large calderas (exclude ash deposits) are typically at least 3-4 km, sometimes more [6,7].

Resurgence. Venus: There is no structural evidence for resurgence [3], only volcanism is observed after caldera subsidence (Fig. 4). Earth: Many terrestrial calderas have traces of resurgence; e.g. Yellowstone caldera has two resurgent domes at SW and NE parts of caldera interior (Fig. 3, Fig. 3 in [4]) [9].

Geodynamic position. Venus: Calderas are clustered in Atla-Beta-Themis triangle [1,2,3]. At Venus (one-plate planet) we can correlate caldera location with location of rift systems only [3]. Eighty three percents of calderas are located outside of rifts and/or fracture belts, and only 17% are located inside rifts and/or fracture belts. Earth: Shield calderas are most common at ocean hot spots such as Hawaii, Galapagos, etc. [10]. Smaller shields also occur at subduction zones (Oregon, California) and spreading centers. Most of Crater-lake type calderas occur at subduction zones, and also at extensional zones rifts, and at both oceanic and continental hot spots [10]. Ash flow calderas are concentrated mostly at subduction zones and rifts [10].
Interpretation and discussion. 1) Average diameter of venusian calderas is more than twice larger than terrestrial, therefore their formation should have connection with evolution of larger magmatic reservoirs than on Earth or be due to other causes. Only a few terrestrial calderas connected with uplift of large magmatic diapirs (as Yellowstone caldera) may be compared in size with venusian. 2) Smaller depth of subsidence in venusian calderas is evidence for rather small volume of melt in formation of these calderas (and/or deep position of reservoir) relative to terrestrial structures, whose formation is connected with collapse of rather small magmatic reservoir inside the crust. 3) Both venusian and terrestrial calderas have similar sets of tectonic structures, but concentric fracturing of venusian calderas is much more dense and prominent in more wider area at caldera periphery. Also in venusian calderas tectonic features are observed which are not usual for terrestrial – radial compressional structures and sometimes radial extensional fracturing. Formation of these tectonic features on Venus is usually described as traces of influence of evolving magmatic diapirs [11-13]. 4) Most of volcanic activity of venusian calderas is connected with dense concentric fracturing, which is evidence for transport of melt to the surface through this fracturing, or for possible formation of this fracturing by ring dikes. 5) All venusian calderas, opposite to majority of terrestrial, have no connection with collapse of volcanic construct. 6) We do not see traces of resurgence in venusian calderas. 7) Most of venusian calderas have no association with rifts. Their spatial distribution with concentration in Atla-Beta-Themis region [1-3] is not distinguished from distribution of coronae and arachnoids, which believed as produced by diapirc uplift [11-13]. 8) Topographical shape and tectonic structures of venusian calderas is evidence for downsag subsidence model of these calderas formation (Fig. 4 in [4]). Some calderas have asymmetric topographical profile, which evidence for possible trap-door subsidence [6]. Both of these models are favor by deep magma chambers and/or small eruptive volumes [6].

Summary. Summarizing all observation and interpretation we see evidence that formation of venusian calderas occurs in different conditions than majority of terrestrial. Formation of venusian calderas appears to be related to evolution of large magmatic diapirs and small volume of pressure released melting in diapir head perhaps due to thicker lithosphere than on Earth, similar to arachnoid and coronae on Venus [11-13]. Morphology of sets of tectonic structures, topography, and also volume and style of volcanism may be evidence for formation of concentric fracturing due to downsag or trap-door subsidence and ring dike emplacement from rather small and deep magmatic reservoir on the diapir head. In this case formation of venusian calderas may be mechanically similar with formation of large cauldrons [14] and large ash flow calderas (as Yellowstone) on Earth above large magmatic diapirs [15] without previous formation of large strato- or shield volcano. The difference in style of volcanic eruption may be also influenced by low likelihood of explosive eruption on Venus [16], that lead to possible replacement of ash deposits in terrestrial calderas (Fig. 2, Fig. 2, Fig. 2 in [4]) by lava flows in venusian volcanic structures (Fig. 1,4).

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POSSIBLE ROLE OF MAGNETIC MATERIALS IN RADIOPHYSICS OF VENUS SURFACE.
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Introduction: The dominant amount of all the data on the Venus surface available now and potentially available in a reasonable future are the results of the remote sensing of the surface (from the Earth and from the orbiters) in the microwave part of the electromagnetic spectrum. The measurable and mappable quantities are controlled by the surface structure and the electromagnetic properties of the surface material. At the frequencies probing methods commonly used, the electromagnetic properties of the material can be described with two quantities, the effective bulk dielectric permittivity $\varepsilon$ and the effective bulk magnetic permeability $\mu$, both quantities being complex numbers. In the data analysis $\mu = 1$ is often assumed, that the magnetic properties of the surface material are neglected [e.g. 1]. Such assumption, however, is not necessarily true.

We would like to draw attention of the community to possible effects of magnetic properties of the surface materials on the radiophysical properties. Here we analyze the principal possibility to explain radiophysical observations with magnetic effects. We also would like to point to bistatic radar studies as a promising tool for future study of Venus.

Magnetic materials on Venus. As thermodynamic calculations have shown [e.g., 2, 3], at Venus conditions magnetite Fe$_3$O$_4$ is an expected weathering product of basaltic minerals. Magnetite is a ferrimagnetic with the Curie point 853 K; below this temperature, magnetite has non-negligible $\mu$. Magnetite is an endmember of several series of substitutional solid solutions with spinel crystal structure and ferrimagnetic behavior, e.g. titanomagnetics $x$Fe$_2$TiO$_4$\(1-x\)Fe$_3$O$_4$, magnomagnetics Mg$_x$Fe$_{2(1-x)}$O$_4$, magnetite-spinel series Mg$_x$Fe$_{1(1-x)}$Al$_{2(1-x)}$Fe$_{2(1-x)}$O$_{4-x}$, etc. The Curie point decreases in these series from the magnetite endmember and reaches the temperature range of the surface for some compositions. Hematite Fe$_2$O$_3$ is also an endmember of series of minerals with peculiar magnetic behavior.

At the microwave frequencies, $|\mu|$ is substantially lower than in the static case, however it is still prominent and can influence the observed radiophysical properties. At some frequencies in the microwave range, the ferromagnetic resonances occur. Near the resonance, Re$\mu$ has a local peak and a local dip, often below 1 and even below 0, and Im$\mu$ has a local peak. The resonance frequencies depend on the mineral type and on the temperature. Unfortunately, there are no laboratory measurements of magnetic properties of materials at the microwave frequencies at high temperatures. The exact resonant frequencies and the resonance widths for high temperatures of the Venus surface are not known.

It is important that $\mu$ is not solely defined by the mineral type; it strongly depends on the amount of defects in the crystal structure. The minerals formed on Venus very slowly at stable temperature and not experienced mechanical disturbance are expected to have perfect crystal structure, and hence, much higher $\mu$ than any terrestrial sample of the same mineralogy in laboratory.

Radiophysical properties of the highlands? The peculiar properties of the highlands are overviewed, e.g., in [1]. The main peculiarity is the anomalously high reflectivity $R$ at certain elevation interval between the critical levels. A number of mechanisms of this phenomenon were proposed. Metallic films or semiconducting layers [1, 2, 4] are consistent with the Magellan bistatic radar experiment, which indicated Im$\mu$ > 0 (meaning high conductivity) for Maxwell mountains. However, these theories do not explain the drop of $R$ at the higher critical level in the equatorial highlands. Ferroelectrics [5, 6] perfectly explain the gradual increase and then sharp decrease of $R$ with elevation for the equatorial highlands with the phase transition. Both hypothesis share one strong shortcoming: they demand large amounts of very rare elements at the surface.

We have proposed that the magnetic properties of magnetite and similar minerals could be responsible for the phenomena in the highlands [7]. It would be very attractive to explain the elevational spike of $R$ in the equatorial highlands with the temperature passage through ferrimagnetic Curie point of a specific magnetite solid solution, when $R \sim 1$ due to $|\mu| >> |\varepsilon|$. However, we found [7] that in this case we would expect the sharp increase and then gradual decrease of $R$ with elevation, the opposite to that is observed.

We have proposed that the natural ferromagnetic resonance can be responsible for this. Having no measurements at high temperatures and proper frequencies, we made some estimations "from the first principles" for magnetite [7]. We showed that a very reasonable set of parameters of our solid-state-physics model perfectly describes the elevational dependence of $R$ at 12.6 cm wavelength.

However, the resonance inevitably means the frequency dependence of $R$. This means that the critical levels should change with the wavelength. We compared the location of the critical level in Magellan (12.6 cm wavelength) and Pioneer-Venus (17 cm) data. The festoon flow in Ovda Regio [6], where the upper critical level crosses gently sloping
MAGNETIC MATERIALS ON VENUS: M. A. Kreslavsky and L. V. Starukhina

surface, gives an excellent opportunity for the test. We found no difference between the two data sets with the accuracy allowed by Pioneer Venus resolution. This means that the upper critical level is the same with ~100 m accuracy, which contradicts to the resonance model.

For Maxwell Mountains, the bistatic Magellan radar experiment [4] gave clear indication of strong electromagnetic losses. Electric losses (Imε > 0) and magnetic loss (Imμ > 0) would give the opposite senses of the received circularly-polarized component. In the literature, there is a great mess in definitions of right and left circular polarization, and [4] does not allow to track the signs. P. G. Ford and G. H. Pettengill kindly agreed to do a huge work and reanalyze the results. They unambiguously showed that the observed polarization sense corresponds to Im ε > 0, hence the cause for high R on Maxwell is conductive rather than magnetic losses.

Unfortunately, there are no bistatic radar data for the equatorial highlands, however, there are Magellan dual linear polarization emissivity data for a section of Ovda Regio. In [6] it was shown that these data agree with high values of Reε and the ferroelectric model. We reanalyzed these data and applied scattering models including magnetic properties. Unlike [6], we work with emissivity ratios between points within the same orbits [8], which excluded systematic errors in the emissivity data [9]. We found that for the transition through the lower critical level from low to high R, the data are consistent with the increase of |ε|, regardless of the balance between Reε and Imε, and are not consistent with increase of |μ|. Thus, high R of highlands is not related to the surface magnetism. For the transition from high to low R through the upper critical level, the dual polarization emissivity data are consistent with either drop of |ε| back (as predicted by the ferroelectric model) or sharp increase of |μ|, which could occur due phase transition in a magnetite solid solution. In the latter case the observed drop of R demands rather high values of μ, up to |μ| ~ 10, with Imμ ~ Reμ. Pure magnetite at microwave frequencies in laboratory has |μ| ~ 2-3; its solid solutions have |μ| even lower. Due to the perfect crystal structure, μ values on Venus are probably higher than in the laboratory, but it is not clear, if they can be high enough. Note that |μ| ~ 10 refers to effective μ of the uppermost centimeters of the surface rather than to its magnetic component.

Radiophysical properties of plains? If thermodynamics predictions [2, 3] are correct and magnetite is present at the surface, it should influence the radiophysical properties because of its very unusual electromagnetic characteristics. At Venus temperatures magnetite is a semiconductor with conductivity on the order of 0.03 Ω⁻¹ cm⁻¹ (this is too little to be responsible for high R in highlands), which gives Imε on the order of 25. At microwave frequencies it is a ferrimagnetic with strong dispersion of μ and hence with relatively high Imμ; for laboratory conditions it is on the order of 1. For small concentrations of magnetite in the soil, its effect on the reflectivity R is not strong. About 5% of magnetite by volume gives measureable increase in the reflectivity and decrease in emissivity. However, the variations of reflectivity and emissivity due to magnetite presence cannot be distinguished from variations due to other factors.

Influence of small amounts of magnetite on the bistatic radar experiment results is small due to unlucky combination of conductivity and magnetic loss values. Calculations with the use of Maxwell Garnet mixing formula showed that if we suggest laboratory value of μ for magnetite, the observed [4] absence of received circular polarization (with accuracy 0.02) outside the anomalous highlands restricts the magnetite content below 20% by volume in the uppermost few cm of the surface.

Prospective data. Future bistatic radar experiments similar to that carried with Magellan [4] can give excellent information on the electromagnetic properties on Venus. Such experiments do not need any special equipment onboard spacecrafts and can be carried out with S-band data transmission system.

Bistatic probing of highlands above the upper critical level can distinguish between the drop of |ε| and the increase of |μ|. For the lowlands, the circular polarization is sensitive to the presence of small (~3-10%) amounts of semiconductors and ferrimagnetics (except the unlucky case of magnetite). In particular, this allows to test the hypothesis of pyrite as a cause of high reflectivity of some young lava flows [10].

Conclusions.

1. Magnetic minerals can influence the observable radiophysical properties of Venus surface.

2. Anomalous high reflectivity of highlands is due to conductivity rather than magnetic minerals.

3. The upper critical level in equatorial highlands can be due to ferrimagnetic phase transition.

4. Magellan bistatic radar experiment is not sensitive to small concentration of magnetite in lowlands.

5. Bistatic radar experiments can give very useful information about the surface composition.

CRATERS AND OTHER CIRCULAR FEATURES IN NORTHERN CIRCUMPOLAR AREA, MARS.
M. A. Kreslavsky$^{1,2}$, V.-P. Kostama$^3$ and J. W. Head$^{1,2}$

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Introduction: The complex of polar deposits (the polar cap, its icy outliers and dune fields) at the North pole of Mars is surrounded by the Vastitas Borealis Formation (VBF) [1], vast generally flat geologically homogeneous plains. The VBF marks the boundary between the Hesperian and Amazonian eras in the geological history of Mars [2, 3]. At high latitudes ($\sim$55$^\circ$), the VBF is covered with a thin geologically young mantle with specific decameter-scale surface texture [4, 5] containing much water ice [6, 7]. High-resolution MGS MOC images [4] showed many circular features interpreted to be mantled craters [4] (see Fig. 118, 119 there).

Our objective is to assess geological processes that occurred in the region during the Amazonian, and the relative and absolute time scales of these processes, including those related to the origin of the shallow subsurface ice. To approach this goal, we studied the size-frequency distributions of circular features of different morphology, as well as peculiarities of the surface texture. We are carrying out a systematic survey of the high-resolution MOC images in the region. Preliminary results related to the textures and the fresh small impact craters have been reported [8, 9]. Here we report on our observations regarding the other circular features.

Survey: We systematically overview the mantle texture, study morphology and measure diameters of the circular features of 50 m to 1 km in diameter (see examples in Fig. 1, 2) in the northern plains northward from 55$^\circ$N. We use the narrow-angle MOC images of 4.8 m/pix resolution. Features smaller than 50 m in diameter are identifiable, but the size estimate for them is too inaccurate, and the morphology of them is not distinguishable. Although we try to do the survey as homogeneously as possible, the ability to identify the features and textures differ from image to image due to the differences in atmospheric scattering, illumination geometry, presence of contrasting albedo features on the scene, electronic settings of the camera etc.

Fresh craters and pits: Several images at latitudes below 70$^\circ$N contain a set of small sharp circular depressions, apparently randomly scattered over the image; a few of them sometimes are larger than 50 m, other are smaller (see examples in Fig. 1B, 2B). This situation is very similar to that should be expected for an accumulating population of impact craters. The crater density calculated [8, 9] over several images with such probable impact crater population gave an age estimate on the order of 1 Myr, using the Neukum production function [10] recalculated for Mars [11]. This estimate is highly uncertain (within an order of magnitude. There are many images in the lower latitudes where there are definitely no impact features. This observation suggests, that the crater retention age of the mantle in different locations differs at least by one order of magnitude.

In the 55$^\circ$N -70$^\circ$N zone, there is a number of circular or quasi-circular pits (Fig. 1a). Some of them clearly have collapse origin. There are several large clusters of pits. The size-frequency distribution of the pits in the clusters (Fig. 3a) is steeper than the impact crater production function. This means that the pits can hardly be the result of the impact crater degradation. For small features it is impossible to distinguish between a fresh collapse pit and a fresh impact crater. This makes it difficult to obtain more reliable age estimates using small impact crater population.

Some of the pits in the clusters are fresh, but the majority of them are covered with the typically textured mantle (Fig. 1). There are examples where a pit covered with the basketball texture has a fresh depression in the center. This may be a sign of reactivation. These facts say that the formation of the pits and of the mantle texture is interleaved.

Mantled circular features: These features have a wide range of morphologies from well-expressed impact craters covered with the textured mantle (Fig. 1B), shallow subsurface ice. To approach this goal, we studied the size-frequency distributions of circular features of different morphology, as well as peculiarities of the surface texture. We are carrying out a systematic survey of the high-resolution MOC images in the region. Preliminary results related to the textures and the fresh small impact craters have been reported [8, 9]. Here we report on our observations regarding the other circular features.

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to hardly distinguishable circular chains of lineaments and/or arcuate albedo markings (Fig. 2B). The ability to distinguish weak features strongly depends on the observational conditions and the presence and nature of the albedo markings on the surface. In addition, for such features it is not clear what should be considered as the feature diameter. When circular lineament chains were observed, we used the outermost circle for diameter measurements. If only albedo markings were seen, we used the inner arcuate albedo contrast, because in many cases where both lineaments and markings are present, the markings were outside the lineaments. Impact origin of features of this type is not completely clear. We found a series of transitional morphologies between clearly expressed impact craters (Fig. 3A) and the subtle features, which can be considered as evidence for impact origin of many of them.

The size-frequency distribution of the largest (1-2 km) mantled crater-like features (Fig. 3b) is close to the production population of the Early Amazonian age. The deflection from the Amazonian / Hesperian boundary is below a factor of two in the crater density. Taking into account the possible bias in our diameter measurements, possible failure to identify some heavily modified and mantled features, and possible deflection of the actual production function from the adopted one, we cannot state that this subpopulation of features differs from the production population of the VBF. For smaller diameters the difference is obvious. The crater retention age for smaller features is much younger. We interpret this as a result of repeating deposition and removal of meters to tens meters thick ice-rich deposits similar to the present-day mantle and the polar cap outliers.

Some mantled circular features, especially smaller ones, are not of impact origin. Their rims (when seen) sometimes irregularly deflect from perfect circles. They tend to cluster obviously much stronger than randomly. In the most populated images the circular feature density correspond to crater accumulation population older than the VBF (though this inference is of low statistical significance; Fig. 3b). The slope break in the size-frequency distribution (arrow in Fig. 3b) may be related to characteristic size of this subpopulation of circular features. Cratered cones similar to observed in the VBF in Isidis Planitia [12] out of the mantle extent might be candidates for some of mantled circular features.

**References:**

We have constructed models of the constitution of Callisto based on Galileo gravity measurements and geochemical constraints on the composition of silicate fractions of ordinary chondrites. The total thickness of an outer water-ice shell of Callisto is estimated in the range of 270-315 km. The permissible thicknesses of an icy crust and internal ocean are estimated to be 135-150 km and 120-180 km respectively. The surface temperature is found to be 100-112 K.

Results from the Galileo mission have increased the scientific interest in knowledge of the internal structure of large icy satellites. An important question is the possible existence of a subsurface water ocean. There are indirect geological and geophysical evidence that Callisto may possess subsurface salty liquid-water ocean. The existence of a water ocean was recently supported by magnetic measurements and surface morphology features obtained with Galileo. The discovery of the induced magnetic field of Callisto has been interpreted as evidence for a subsurface ocean [Zimmer et al., 2000].

The purpose of this paper is to reproduce characteristic features of the internal structure of Callisto's water-ice shell on the basis of its mass and moment-of-inertia factor [Anderson et al., 2001]. Models of the internal structure of the ice-liquid outer shell are based on geophysical (the mass and moment of inertia from recent Galileo gravity measurements), geochemical (chemical composition of meteorites), and thermodynamic (modeling of phase relations and physical properties in the Na₂O-TiO₂-CaO-FeO-MgO-Al₂O₃-SiO₂-Fe-FeS-H₂O system) constraints [Kronrod and Kuskov, 2003]. The equations of state of water and high-pressure ices are taken into account. The equilibrium phase assemblages were calculated using the technique of free energy minimization and thermodynamic data for minerals. The density variations in the mantle shells and core radii are found by the Monte-Carlo method.

There are two possible models for the radial structure of large icy satellites. If the heat transfer in the outer layer is efficient enough to transport all of the heat to the surface, the initial ocean has completely crystallized. In the other models the outer shell is not able to release all of the heat outward. A residual ocean is still present below the outer shell, Fig. 1. The evolution of the structure of large icy satellites is usually based on models of heat transfer through the outer ice I layer. Reynolds and Cassen (1979) have shown that thermal convection is very likely to occur in this layer. Moreover, they pointed out that heat transfer is efficient enough to complete the crystallisation of the initial ocean in a short time (≈ 5x10⁸ years); the viscosity of water ice was taken as newtonian. The real behaviour of water ice, as observed in laboratory experiments, is in fact non-newtonian. In the present study we proposed that rheological behaviour was non-newtonian. In this case the outer ice shell becomes stable against convection (Ruiz, 2001).

The mass and moment-of-inertia factors are used to model the internal structure of Callisto and the thickness of an outer water-ice shell. Ordinary L and LL chondrites are taken as representatives of the nebular matter. Our calculations were confined to a five-layer model of icy differentiated satellite, which consists of an outer water-ice shell, a three-layer rock-ice mantle and an iron-rock core. The phase diagram of H₂O and equations of state of the high-pressure polymorphs of ice are taken into account. The density variations in the mantle are found by the Monte-Carlo method [Kronrod and Kuskov, 2003]; the entire range of the geophysically allowed mantle densities is examined for balancing.
Kronrod, Kuskov, **CALLISTO**

the mass and moment within the experimental error.

Before the onset of convection, heat is transmitted into Callisto’s outer shell only by conduction. Under these conditions, the variation of temperature in the outer ice I with depth can be described through Fourier’s law. Water ice I thermal conductivity is a function of the temperature, \( k = k_0 T^{-1} \), where \( k_0 \) is a constant. The temperature at the base of the shell obviously corresponds to the melting point of ice, which is a function of pressure. Distribution of pressure can be described by the equations of hydrostatic equilibrium.

The results of calculations are illustrated in Fig. 2 and Table I. The thickness of a conductive ice shell of Callisto in terms of heat flow (F) through the shell is shown in Fig. 2. The modelling results indicate that we can estimate the thickness of Callisto’s outer ice shell with confidence. The total thickness of an outer water-ice shell of Callisto is estimated in the range of 270-315 km. The permissible thicknesses of an icy crust and internal ocean are estimated to be 135-150 km and 120-180 km respectively. The surface temperature is found to be 100-112 K. The results of modeling support the hypothesis that Callisto may have an internal liquid-water ocean.

**Acknowledgements.** We thank the RFBR (Grant 03-05-64413) for financial support.

**References.**


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<th>( \rho_{Fe-Si} ), g/cm(^3)</th>
<th>( H_{ice-I} ), km</th>
<th>( H_{water} ), km</th>
<th>( H_{tot} = H_{ice-I} + H_{water} ), km</th>
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<td>3.15</td>
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<td>120-180</td>
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<td>3.62</td>
<td>135-150</td>
<td>120-165</td>
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</table>

* \( H_{ice} \) – thickness of a conductive ice shell of Callisto, \( H_{water} \) – thickness of a water ocean, \( H_{tot} \) - total thickness of a water-ice shell of Callisto, \( \rho_{Fe-Si} \) – density of a rock-iron core.

**Table I. Total thickness of Callisto's water-ice shell**

![Fig. 1. Internal structure of Callisto.](image1)

![Fig. 2. Heat flux F as a function of the thickness of a conductive ice shell of Callisto (H_{ice}) and two possible values of the surface temperature T_0.](image2)
More than 10 years ago, the specialized database (DB) on planetary researches - Planetary Data System (PDS) has been created in America. It comprises the data by results of all space programs conducted by this country. Besides the information from other countries participating in space researches was presented in this system. To the information stored in PDS, access through Internet global network is organized.

In this system the huge amount of the data on space researches is collected. All world uses them, and as the analysis has shown, analogues of such DB do not exist yet.

But, on our opinion, in spite of all positive sides, PDS has very essential lack: because there are no data on results of the Russian space programs a lot of which has been carried out since the beginning of the space age.

Now the Institute for Space Researchs by Russian Academy of Science) (IKI RAN) and the Moscow State University for Geodesy and Cartography (MIIGAiK) is started by joint efforts in scientific work on creation of Russian information system with results of Russian space programs.

As the first stage of such DB creation it was decided to place it on IKI base with results of Solar system bodies surveying which were carried out within the framework of the Russian space programs. (See the table below).

The images of the lunar surface received from board of AMS «Zond –7, -8» appeared the most available ones. Originals of these images were stored in MIIGAiK.

At present 70 high resolution photos of the lunar surface are scanned. The provisional volume of electronic images has about 3 Gb. Now they are stored on CD ROM and on IKI server.

The following stage in preparation of the information for entering into a database is the ordering and the analysis of the surveying parameters transferred on telemetry, and their comparison to pictures. For the further reprocessing space images, values of the following parameters are important: date of surveying, number of a session, image number, time of photographing, a corner the Sun – Object – the Moon, a corner the Sun - Object –the Earth, a corner the Moon - Object – the Earth, a corner the Moon – the Earth - Object, length of a Moon - object vector, length of a Earth - object vector, height
above the Moon surface, and also coordinates of the Moon surface (latitude, longitude). Camera characteristics play also an important role. It is necessary to have the following parameters: a designation of the camera model, type of the objective, the focal length, the corner of a field of vision, a relative aperture, distortion, resolution, type of shutter, a range of exposures, a format of the picture area, the interval of photographing maintained by the command device.

The data of telemetry received from space vehicles "Zond" during a lunar surface surveying as well as images, were kept in MIIGAiK. Access to them is received and now their processing is carried out.

After all data on images on the "Zond" program will be picked up, this part of the information becomes accessible on the server of the Institute for Space Researches through a Web-site.

The main result of this work is to have the opportunity of repeated data processing with use of modern computer systems and software products.

<table>
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<th>Space vehicle</th>
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THE CRATER LAKES AND OTHER IMPLICATIONS FOR STANDING BODIES OF WATER IN HELLAS REGION, MARS. H. Lahtela1, V.-P. Kostama1, M. Aittola1, T. Öhman2 and J. Raitala1. 1Planetology Group, Department of Physical Sciences, P.O. Box 3000, FIN-90014, University of Oulu, Finland, <hlahtel@paju.oulu.fi>, 2Institute of Geosciences, Department of Geology, P.O. Box 3000, FIN-90014, University of Oulu, Finland.

Introduction: The highlands of the Martian southern hemisphere are dominated by at least two large impact basins, Argyre and Hellas. Hellas basin has a depth of ~9 km and a diameter of ~2000 km [1], which makes it one of the largest impact basins in the solar system [2].

Basin’s influence on the evolution of Mars since its formation in the Early Noachian [e.g. 1] has been enormous. An obvious outcome of the impact are the concentric and radial fractures and graben, which have in turn affected e.g. drainage patterns [3,4] and the morphology of younger craters [5]. It has also been suggested that the formation of volcanic paterae and associated plains on the NE and S rims of Hellas basin [3,4,6,7] and even the enigmatic volcanic region around Alba Patera antipodal to Hellas [8,9] might have been controlled by the Hellas impact. Hellas influences also the modern-day Mars, since numerous regional and global dust storms originate from the Hellas region [10]. Hellas region is also rich in details of quite recent fluvial formations. In addition to the dominating outflow channels of the eastern rim we also have a very high number of smaller channels on both sides of Hellas. In many cases these channels are associated with craters as well as troughs and depressions of the region creating a good case for suggesting the existence of reservoirs in some point of regional geological history. In this still ongoing study we examine these probable, but now dry reservoirs in the greater Hellas region and present photogeological evidence for their existence.

Morphology: Although a wide variety of different channels can be observed on both sides of Hellas, particularly the low eastern plains region bears softened features adjacent to large channel formations. Actually, the eastern rim of Hellas has been practically eroded away probably by this fluvial activity. Origin for these channels could be the late-stage effusive volcanism of the Tyrrhena Patera [11], which triggered collapse and outflow erosion, producing the obvious Dao, Niger, Harmakhis and Reull Vallis and possibly even larger scale flooding of the region. Cutting the surface down-slope towards Hellas, the large channels change radically in their morphology at the suggested “shoreline” scarp of Hellas [12], which is also a distinct change in regional topography (Fig. 1). They transform from sharp and exposed features into diminished and partly buried. In this they closely resemble the terrestrial marine channels, which continue beyond the mouths of large rivers.

Figure 1. The Hellas impact basin topography (MGS MOLA) and the “reservoirs” located within the region. Notice the continuous shoreline in pale green and the sharp depression around the Alpheus Colles plateau within the basin itself.

Figure 2. Examples of Hellas region crater lakes. A. Closed and B. open system. (Viking MDIM)

Within the region there are also several craters and depressions which show interaction by post-impact fluvial activity (e.g. Teviot Vallis and craters in Figs. 2 and 3). The crater lakes of Hellas region are one of the most prominent features of lacustrine processes. They are identified by in- and sometimes out flowing rim channels. The crater lakes are either closed systems with only a distinct inlet channel (Fig. 2a) or open systems with the additional outlet channel (Fig. 2b) [13]. If there are at least two craters connected by same channel, a lake chain is formed (Fig. 3a). Of course, craters are not the only possible candidates for reservoirs; there are also layered deposits and smooth floors within other depressions such as the Teviot Vallis (Fig. 3b). Distribution of these reservoirs is shown in Fig. 1.

Lacustric sediments: Past lacustrine environments can be recognized easily from the sediments deposited in a standing body of water. In still water they steadily sink to the bottom causing vast lateral sheets, which smooth features. Also deltas can form sub-aquatically at the mouth of inlet channels. In the study area there are few of such features, which have probably formed under water. They are located in an
area whose morphology supports the existence of a body of liquid water. However, in a case that the delta-like structures could not be linked to water, it is impossible to set them apart from alluvial fans sedimented to dry land.

Figure 3. A. Possible crater lake chain adjacent to the Reull Vallis (THEMIS I01982002). B. Teviot Vallis reservoir (Viking MDIM).

After the water is removed from the basin, lacustrine sediments are exposed to other kinds of modifications. Because they are usually very water-rich they are easily modified by frozen-thaw cycle. One prominent sign of this are polygon structures. They are linear fractures forming a network cutting the terrain to polygonal areas.

Hellas Basin as a lake: The Hellas basin area displays a great variety of features and formations classified as lacustric. The observations can be interpreted as strong evidence of lakes existing in the area. Analysis of different surface structures indicates extensive lake sedimentation in the area, as well as natural erosion created by lakes.

The floor of Hellas Basin, Hellas Planitia, is extensively smoothed, indicating widespread sedimentation in the area. In the N-W part of the Hellas Planitia large polygonal fractures several hundred meters in diameter are also found. These two facts suggest that the sedimentation took place in a body of water. The lower Hellas Planitia creates a distinct contrast, which can be regarded as a shoreline, to the sharper features at the basin edge and the modified texture of Alpheus Colles plateau in the center of it. In these places also large topographical changes can be found.

At the eastern rim a clear level, where the elevation of the surface drops sharply as approaching the basin floor is observed. The great outflow channels are situated here too. Their clear-cut shapes imply that they were not underwater after their initial formation. But at an elevation of -6000 m with an error margin of 100 m their shapes soften quickly almost beyond recognition. Because this boundary is at the same altitude for all the outflow channels in the Hellas area, their ending up in a body of water is a natural possibility for the formation of such features. To create such a sharp edge in the occurrence of features, the water level should have had to stay at a constant elevation for a considerable amount of time.

Alpheus Colles gives also one boundary for the water level at some time. According to MOLA data this altitude is on average at -6600 m, but the variation along the plateau is high because of its surface structures, for example impact craters. Alpheus Colles is formed of a vast sediment layer, probably composed in water [14]. However, its surface is noticeably higher than the surrounding areas and the transition zone from the Hellas basin floor to it is very steep. Such a rise thus shouldn’t form just due to sedimentary stratification onto the floor of a basin. In other words, the area of Alpheus Colles must have risen or the surroundings be subjected to considerable erosion. Hellas Basin, being the lowest areas of its region and on the whole planet, is a natural ending point for sediments created or transported to there. If water has ever flown to Hellas creating a lake basin, sediments must have been transported with the water and been deposited there.

Conclusions: Fluvial as well as lacustrine processes are important factors in post-impact modification processes on Mars [14]. Hellas region is rich in formations of both fluvial and lacustrine origin. As seen from the distribution of the possible reservoirs, they are extinct within the volcanic regions of Malea and Hesperia Planum. Concentration seems to be to the eastern outflow channels and to the north of Hellas basin itself, which could have functioned as a lake also at some point. Several erosion levels, shorelines, and possible lacustrine sediments can be found in the basin. The fact that they are situated in different parts of the basin implies that a very extensive body of water might have created them. In addition, abundant evidence of smaller lakes exists in several locations in Hellas. Especially possible crater lakes are found in quantity in Hellas area, as several craters have their rims breached by a channel. Many of them are also associated with delta-like features.

There is still a lot of unclarity in the water history and surface geology of the Hellas area. Much research needs to be done from many points of view before we can obtain a clear overview of the processes involved in the evolution of the area. Especially the formation and modification of the central plateau within the basin, the Alpheus Colles, is a very interesting point in the history of Hellas.

Introduction. The aubrites, or enstatite achondrites, are relatively rare group of stony meteorites. As indicated by their name, the silicate phases contain almost no oxidized iron; the metal phase frequently contains elemental silicon; titanium and calcium, which are strongly lithophile elements, are present as sulfides; and unique, nitrogen-containing minerals occur. This unusual mineralogical composition indicates that these meteorites must have originated under highly reducing conditions.

The origin of the aubrites has been debated, with some authors [1, 2] proposing their formation as nebular condensates, while other [3, 4] favor igneous processing on an aubrite parent body.

Rare earth element (REE) patterns (in particular Eu anomalies) have been interpreted as suggestive of an igneous origin [4, 5] as has a correlation of no-volatile with volatile lithophiles and siderophiles [4].

Most aubrites have negative Eu anomalies. Whole-rock REE patterns with negative Eu anomalies have been used as one of the major arguments in favor of an igneous origin for aubrites [3, 4].

Samples and method. In the present paper the results of elemental abundances in separated grain-sized fractions, “matrix”, unaltered and altered enstatite from Pesyanoe and Norton County aubrites are reported. The fractions were selected by handpicking under microscope and by particle-size analysis. Their elemental composition was determined by INNA. The table shows the average element enrichment factors relative to C1 chondrites [6].

Results and discussion. Of 12 grain-sized fractions of Pesyanoe and Norton County aubrites analyzed for REE, 11 are depleted in light REE (0.07 – 0.9xC1) and 10 show negative Eu anomalies. The fine-grained fraction and “matrix” of Pesyanoe aubrite show the positive Eu anomalies.

All 5 fine-grained fractions (1< d < 45 µm) analyzed for REE are enriched in light REE (1 - 5.3xC1) and heavy REE (1.8 – 6.1xC1).

Negative Eu anomalies in whole-rock REE pattern are commonly attributed to plagioclase. However, the study Bishopville and Bustee aubrites [7] show that positive and negative Eu anomalies are not necessarily associated with plagioclase, because REE patterns for oldhamite, the major REE carrier, display both positive and negative anomalies. The low abundance of volatile Cs in oldhamite [10] is compatible with a relict origin for CaS.

Of 4 fractions enstatite analyzed for REE, 2 (Norton County) are depleted (0.3 – 0.7xC1) and 1 (Adhi Kot) is enriched (1.2xC1) in light REE, display both positive and negative Eu anomalies.

The Pesyanoe and Norton County aubrites show a typically igneous siderophile element pattern with Ir (0.006 – 0.02xC1) more depleted than Au (0.007 – 0.2xC1) and Ni (0.008 – 0.4xC1).

Conclusions. From observed differences of compositions of enstatites and grain-sized fractions it follows that our trace element data accord with idea that aubrites reflect melting processes within or on the surface on the parent body rather than nebular processes.

Table. The average element enrichment factors of mineral fractions of enstatite meteorites.

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<tr>
<td>Ir</td>
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<td>&lt;0.002</td>
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1 – Adhi Kot EH4; 2 – Pillistfer EL6; 3 – Norton County (aubrite); 4 – Pesyanoe 217 (aubrite); 5 – Pesyanoe 217a; 3a – unaltered and 3b – altered enstatites from Norton County.
SOME PROBLEMS OF THE EVOLUTION OF ASTEROID – RUBBLE PILE  G. A. Leikin and A. N. Sanovich, Sternberg State Astronomical Institute, Moscow State University, 119992, Moscow, Universitetskij Prosp. 13, Russia, E-mail: san@sai.msu.ru

ABSTRACT. We consider the collisional evolution of inner structure of a asteroid – rubble pile as a qualitative problem and analyse the results of this evolution in interaction with interplanetary medium. The analysis shows, that asteroid – rubble pile loses its fast fragments in no time but the retaining fragments forms a compact structure immersed in dust – gas atmosphere, created by interaction of interplanetary medium with dispersed product of collisional evolution of asteroid. By interaction of an asteroid – rubble pile with interplanetary medium structures asteroid can increase its brightness on account of blowed up dust simulating phenomenon of distant comet’s brightening.

We consider the evolution of an asteroid – rubble pile as an isolated object. Evidently, we can distinguish two processes: distant interactions, where there is no direct contact between separate fragments, and close contact interactions, where the fragments collide with one another. The process of distant interaction is essentially similar to that of the evolution of scattered star clusters and, in itself, leads to the ejection from the pile of individual fragments with maximum energy and angular momentum, the distribution of which may roughly be described by a Maxwell distribution. At the stage of distant interaction, there is practically no inelastic loss of energy.

In contrast, the process of contact interaction is accompanied by a loss of kinetic energy of the fragments, spent in disrupting the rock in collision and contact events, which brings the fragments closer and eventually leads to a quasi-spherical form (or for those retaining an angular moment – quasi-elliptical form) for the rubble pile in the absence of external perturbations.

For estimating a distant interaction time interval we introduce the concept of core of asteroid - rubble pile – a volume in that the fragments mean free path length is comparable to volume dimension .It is clear that the time interval of distant interaction is comparable to $\sim T \sqrt{N}$ ($T$ – the time of crossing the core by fragment having parabolic for asteroid velocity. We assume radius of asteroid’s core $R \approx 50$ km, $N \approx 100$, bulk density $\rho \approx 2.5$ g/cm$^3$, parabolic velocity $\sim 10$ m/s, this gives the distant interaction time interval of order of some hours. It means that in some hours after the breaking of parent body in core of asteroid – rubble pile the spread of fragment velocities should not exceed 10 m/s.

There is also another mechanism of high velocity fragment losing from the asteroid core: asteroid moves on heliocentric orbit and the spread of fragment velocities must result in spread of orbital elements. Making a crude estimate of semi-major axes spread we get $\Delta \alpha = (1/\pi) T_0 \Delta \nu$ ($\Delta \alpha$ - spread of semi-major axes, $T_0$ – geliocentric period of the asteroid, $\Delta \nu$- fragment velocities spread). If $\Delta \alpha \approx R$, after the time $T_0$ in the core should remain no fragments having velocities higher $\approx \Delta \nu (\pi R)/T_0$, i.e. having velocities higher $\sim$ cm/s.

It is clear that the evolution of a closely bound pile leads to the formation of a plentiful fine-fraction on the surface of the fragments. Such an asteroid structure should have an observable density considerably lower than solid rock.

Unprotected from cosmic rays and solar radiation, areas of the surface on the fragments should become charged. This charge should be sufficient to balance the
fluxes of positively and negatively charged particles.

Balance of electrical charges at the fragment surfaces is maintained by low-temperature component of interplanetary plasma ($\approx 10^5$ K). It can be shown, that in this instance particles $\approx 1\mu m$ will form an dust-plasma atmosphere of asteroid. The scale height of the atmosphere is low ($\sim$ cm).

Such a rubble pile with a dust atmosphere differs from a cometary nucleus only in the absence of a volatile gas component, which is usually considered the cause of the appearance of cometary dust.

In the case of an asteroid rubble fragments of the pile; however, its interaction with the solar corpuscular fluxes does not differ from that of cometary dust and should therefore show the same effects.

In particular, the observation of ‘cometary’ activity at great heliocentric distances doesn’t necessarily indicate the cometary nature of the active bodies – it could be a result of an asteroid – rubble pile entering the solar corpuscular flux. The turbulisation of the magnetized flux on interaction with the asteroid – rubble pile may lead to short-period bursts of activity (especially on interacting with a rotating asteroid), and in some cases, on turbulent disruption of the dust atmosphere of the asteroid, to the formation of an ‘asteroid phantom’ – a magnetized cloud of dusty plasma.

It should be mentioned, that dust atmosphere blowing up must probably be associated with interplanetary structure crossing (sector border and flare shocks).

In conclusion we should notice, that for a two-fold increasing of asteroid’s visual brightness the mass of blowing up dust must amount $\approx 10^{10}$ mass of asteroid.
THE CONCEPT ON FORMATION OF THE TERRITORIAL-SPATIAL DATA BASE DEVELOPMENT AS A TOOL TO REPRESENT THE CARTOGRAPHIC INFORMATION OF SOLAR SYSTEM BODIES. Leonenko S.M. The Moscow state university for geodesy and cartography (MIIGAiK), 105064 Moscow, Gorohovskij per.,4; e-mail: - leonfam@rambler.ru

Planetary Cartography Laboratory of Moscow State University for Geodesy and Cartography is busy with developing of the Geoinformation System for Planetary Cartography (GIS). The Databases on the separate parameters describing this field are the basic parts of the system. That’s why the important stage is the development of such database structure.

The preliminary concept of the territorial-spatial data base formation is represented by the schema (fig.1) given below. It shows the main phases for solution of considered tasks. The schema includes the following blocks:

- The block "the Original Data and "Addresses" of Solar System Objects " contains the information of the research goals (the technical project, statement of a task), and also the data, which help to users to identify an object of research among set of the same objects (it can be the name of object, its coordinates, the address or a site of object among other objects). Important sub-unit of this block is "Original cartographic materials ", which contains set of maps, plans, schemas (including photoschemas), etc. with various thematic content and various scales. The choice of main cartographic data for development of design proposals is a problem as available cartographical materials essentially depend on results of space programs. In some cases it is necessary to provide mechanisms of constant continuous modification for the available cartographical material, connected with new results received during space missions.

- The block " Preliminary researches " contains the complex characteristics of object received by results of the previous space programs. This block includes the data of date and time of research, and also results of control of the processes which are taking place in investigated area, etc.

- The block " Project proposals " contains the information on the developed project. " Approbation and updating " is sub-unit of this block in which the information of all changes brought in design proposals is fixed, this block must be in interactive connection with the block "Project proposals ".

- Block " Data «new» space programs " contains the information about the projects after full cycle of coordination, and also technical and economic parameters of the project. After finishing of this block tasks, the project is ready to realize. Block " Mapping of Solar System Bodies " is upgraded taking into account new information which was received during space missions. The upgrading results placed

in block “Original Cartographic Materials” for the further design activity.

This concept of the territorial - spatial data base formation is only preliminary and in the near future its updating and expansion is planned, with the goal of creation of the universal concept which could approach to any of Solar system bodies.

The electronic version of « Atlas of Terrestrial Planets and their Moons» is used as basic model by development of this GIS. The received experience testifies to expediency of development and introduction of Geoinformation systems. The territorial - spatial data bases can really used as a tool for storage and an effective utilization of the information, and also management of the project.

Introduction such data bases promotes economy of time expenses, decrease in financial losses at carrying out of development. The database created on the concept submitted above, raises efficiency of research work under condition of maintenance of a continuity of entering new data in blocks. Such Database will provide carrying out of the comparative analysis of new information, and also will enable planning of the further research and programs.

Fig.1
OBSERVATIONS OF MARS SEASONAL CAPS FROM HEND/ODYSSY DATA. M.L. Litvak1, I.G. Mitrofanov1, A.S. Kozyrev1, A.B. Sanin1, V. Tretyakov1, W.V. Boynton2, D.K. Hamara2, C. Shinohara2, R. S. Saunders3, D. Drake4, 1Space Research Institute, RAS, Moscow, 117997, Russia, max@cgrsmx.iki.rssi.ru, 2University of Arizona, Tucson, AZ 85721, USA, 3NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, 4Lansce 3, Los Alamos Nat'l Lab. Los Alamos, NM and TechSource Inc, Santa Fe, NM 87594, USA.

Introduction: The observations of Mars neutron albedo by HEND onboard 2001 Mars Odyssey [1,2] may be used to follow up seasonal redistribution of atmospheric CO2 between martian poles. The thickness of CO2 snow depth is large enough (10 cm – 1 m, [3]) to cause significant variations of neutron flux from summer to winter seasons. It occurs because CO2 frost hides upper water ice rich surface layers from the orbit observations. The variations of neutron flux between winter and summer may achieve up to several times [4,5]. This dependence was used to estimate thickness of CO2 deposit at different latitudes[5]. In this study we used model-depended technique to extract CO2 snow depth from neutron data and observe behavior of total mass of seasonal caps with time.

Data Analysis. To realize this approach we split our study in two steps. On first one the only summer data were processed when surface was free from seasonal CO2 frost. It helps us to create regolith model and find best fit parameters describing regolith structure in given region [6,7]. Here we split surface covered by North seasonal cap by 74 and surface covered by South seasonal cap by 98 separate regions with equal squares. In case of south hemisphere we select 24 additional regions because south seasonal cap extends to lower latitudes then north one.

On second step of this investigation we insert additional layer in our numerical model. This layer emulates CO2 frost and its thickness may be used as free parameter of the model. Changing this parameter one may find best fit correspondence between neutron data and model predictions. This analysis was applied to the neutron data accumulated for each selected region at different winter seasons. It allowed us to create 4 dimensional models of seasonal deposit on North and South describing how its column density (g/cm2) varies from place to place with time. The mass of seasonal deposit accumulated in given region may be obtained as product of average CO2 frost column density and region’s square. It give us possibility to follow up time history of mass of seasonal deposit at different latitude belts (see fig 1).

Conclusions: Analysis of HEND data obtained for 1.5 years of 2001 Mars Odyssey mission shows that total masses of North and South seasonal caps may be estimated as 3.6x1015 kg and 6.7x1015 kg correspondingly. It was found that CO2 condensation and evaporation process has different behavior for different latitude belts. The peak corresponding to the accumulation of total mass for polar latitudes shifted in time in comparison with peak for middle latitudes (see fig 1).

Fig 1. Time dependences of seasonal deposit masses are shown for different north latitudes. The north latitude belts 60°-70°, 65°-75°, 70°-80°, 75°-85°, 80°-90° are shown here by curves with different thickness. The thickest curve corresponds to 60°-70° and thinnest one corresponds to 80°-90° (Top). Time history of total mass of North seasonal cap is also presented (Bottom).

References:
POSSIBLE REASONS OF LOW Fe\textsuperscript{3+}/Fe\textsuperscript{2+} RATIOS IN TEKTITES IN COMPARISON WITH THAT OF INITIAL TARGET MATTER INVOLVED IN THE IMPACT PROCESS. O.A Lukanin and A.A. Kadik, Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS, Kosygin st. 19, Moscow, 119991 GSP-1 Russia. e-mail: lukanin@geokhi.ru

Introduction: The composition of tektitic glasses formed as the result of impact events is characterized by significantly low Fe\textsuperscript{3+}/Fe\textsuperscript{2+} in comparison with that of target rocks that are the initial material for tektites. Possible reasons of iron valency change during impact process are the object of discussion: (1) oxygen removal from the system together vapor phase in the process of melting and vaporization; (2) degassing of tektitic melts, (3) the presence of such inherent (intrinsic) reducers in initial target matter as carbon, sulfur and their compounds, (4) fractionation of iron ions at the vapor phase condensation during of tektitic melts formation etc. [1-3]. Authors of this communication suppose that the reducing reactions with the assistance of ions of iron and other elements may be the result of appropriate change of oxygen regime in the process of adiabatic decompression of matter at very high temperatures after its impact compression.

Oxygen regime and Fe\textsuperscript{3+}/Fe\textsuperscript{2+} in impact melts: The suggested model of impact process oxygen regime assumes that with temperature and pressure increase the pO\textsubscript{2} value of impact melt with given Fe\textsuperscript{3+}/Fe\textsuperscript{2+} ratio increases just in the same manner as pO\textsubscript{2} of solid phase buffers such as magnetite-wustite (MW). This assumption is based on two observations. 1) Electrochemical measurements of intrinsic \(\text{O}_2\) of tektitic glasses within range of 800-1050\(^\circ\)C show that temperature dependence of tektite pO\textsubscript{2} is similar to that for MW buffer [3]. 2) The data on the redox state of iron ions in basic silicate melts evidence that pressure increase (T and Fe\textsuperscript{3+}/Fe\textsuperscript{2+} in the melt are constant) leads to increase of pO\textsubscript{2} value in the melt approximately to the same magnitude as the one for QFM and MW buffer [4,5].

The main condition for reducing reactions to proceed is full melting of matter, involved in the impact process, and the attainment of very high temperatures (>1700-2000\(^\circ\)C) that are characteristic for tektite formation at the unloading stage. In this case oxygen partial pressure (pO\textsubscript{2}) during the adiabatic decompression of the melt approaches the value of total pressure in the system (P\textsubscript{tot}). Starting from some value of total pressure its subsequent decrease causes inescapable decrease of pO\textsubscript{2} that accordingly leads to partial reduction of Fe\textsuperscript{3+} in the melt. It should be noted, that in this case reducing reactions run in closed system and they don’t require oxygen to move away from the system.

Fig. 1 explains the decomposition mechanism of Fe\textsuperscript{3+} reduction in impact melt. This figure shows the change of impact melt pO\textsubscript{2} depending on P\textsubscript{tot}, T and Fe\textsuperscript{3+}/Fe\textsuperscript{2+} ratio in the melt. Let the temperature of impact melt at the unloading stage under ≥ 30-40 kbar is ≈2250\(^\circ\)C and the matter is completely melted. The Fe\textsuperscript{3+}/Fe\textsuperscript{2+} ratio in the melt is equal to R(MW) and corresponds to pO\textsubscript{2} value of MW buffer. Adiabatic gradient of silicate melt is ~ 1\(^\circ\)C/kbar because the melt adiabatic decompression can be considered to the first approximation as isothermal process. Consequently as P\textsubscript{tot} decreases, pO\textsubscript{2} value of the melt with Fe\textsuperscript{3+}/Fe\textsuperscript{2+} = R(MW) changes accordingly to the trajectory that is similar to the one on the fig.1A (thick line). The calculated value of pO\textsubscript{2} becomes close to P\textsubscript{tot}, when P\textsubscript{tot} is ~ 50 bar. However the condition pO\textsubscript{2}=P\textsubscript{tot} is not realized in fact, because of the presence of other components besides oxygen in forming vapor phase. Total (summarizing) vapor pressure \(P_v = \Sigma P_i\), where \(P_i\) is partial pressure of every component of vapor phase including oxygen. There are no experimental and thermodynamic data on estimations of these values under given PT conditions. Therefore it is not possible to calculate exactly the \(P_v=P_{tot}\) equality conditions during the melt decompression, although it can be proposed that this equality is achieved under pressures somewhat higher than 50 bar. Subsequent P\textsubscript{tot} decrease should be accompanied with pO\textsubscript{2} decrease and consequent reducing of Fe\textsuperscript{3+} in the melt resulting in Fe\textsuperscript{3+}/Fe\textsuperscript{2+} change from R(MW) to R(mw-2). The higher the temperature is the higher is P\textsubscript{tot} when the P\textsubscript{tot} = P\textsubscript{v} = pO\textsubscript{2} condition is realized, and the degree of melt reduction can be more significant at final stages of adiabatic decompression. But the iron oxidation degree of impact melt with given Fe\textsuperscript{3+}/Fe\textsuperscript{2+} = R(mw) is not change during decompression if its temperature is ≤ 1750 \(^\circ\)C (fig 1B).

If residual temperature at the certain stage of decompression reaches the values of full vaporization of impact melt (>2500-3000\(^\circ\)C), the melt, that is formed in the process of condensation during subsequent decompression and cooling of the system (under P\textsubscript{tot} < 10\(^{-2}\)-10\(^{-3}\) bar), should be more reduced than initial impact melt was before its vaporization. It is possible that during the processes of full vaporization and subsequent condensation of impact melt the proposed reducing mechanism is realized the most effectively, because the reactions in vapor phase proceed essentially faster and redox state of the condensed liquid is closer to equilibrium conditions.

Conclusion: Thus essential reducing of high-temperature impact melts can be expected under adiabatic decompression without resorting to the
assumption that oxygen is removed from the system together with vapor phase or selectively dissipates from the vapor. During the final stage of impact process, that is characterized by catastrophic increase of the volume of explosion cloud, scattering and cooling of the substance, the system is not closed. Quenching glasses formed under these nonequilibrium conditions keep reduced state of tektite melts that were formed mainly at previous stages of decompression. The vaporization process of impact melts at this stage is able to perform an additional contribution to reducing of Fe³⁺ as a result of oxygen escape together with vapor phase in upper rarefied layers of the atmosphere under very low pressures.

Fig.1. Scheme of "decompressional" reduction of impact melt.
A - The change of pO₂ depending on total pressure (P_{tot}) for melts with various Fe³⁺/Fe²⁺ ratios under isothermal conditions (T=2250°C) is shown. R(mw), R(mw ± n) - Fe³⁺/Fe²⁺ ratios in the melt correspond to (or n orders more/less as that of) pO₂ of MW - buffer. (R(mw+2)>R(mw+1)>R(mw)>R(mw-1)). Thick lines with arrows are trajectories of pO₂ in the process of decompression for melt with initial Fe³⁺/Fe²⁺ = R(mw).
B - The change of pO₂ depending on temperature of melt with Fe³⁺/Fe²⁺ = R(mw). Numbers at curves are temperature in °C. Additional explanations see in the text.

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The formation of hydrated silicates in Edgeworth-Kuiper Belt objects. A. B. Makalkin, Institute of Earth Physics, RAS, Moscow, RF (e-mail: makalkin@uipe-ras.segis.ru); Dorofeeva, V. A. Vernadsky Institute of Geochemistry, (RAS), Moscow, RF (e-mail: dorofeeva@geokhi.ru); V. V. Busarev, Sternberg State Astronomical Institute, Moscow University, RF (e-mail: busarev@sai.msu.ru).

Introduction: Visible-range absorption bands at 600-750 nm are recently detected on two Edgeworth-Kuiper Belt (EKB) objects [1]. Most probably the spectral features may be attributed to hydrated silicates. In this paper we indicate possible conditions of the phyllosilicate formation in the EKB bodies.

The model and results: The EKB objects orbit the Sun outwards of the Neptune orbit, 30 AU to 50 AU, and are possibly the most primitive large solid bodies in the solar system. According to [2,3], the EKB objects formed in situ though some part of their material could come with projectiles from the formation zones of giant planets, mainly of Neptune and Uranus. Contemporary models of the solar nebula [4,5] yield very low temperatures and pressures of $T = 15-30$ K and $P = 10^{-2}$-10$^{-3}$ bar at the radial distance ($r$) of 30-50 AU and the nebula age of about $10^6-10^7$ yr, when the EKB bodies of sub-planetary size were formed. At these $T$-$P$ conditions all volatiles excluding H$_2$, He and Ne were in the solid state (mostly ices and some organics), and the abundance of rocky (silicate) dust component was lower than that of ices in accordance with the solar ratios of elements [6].

Phyllosilicates may form in EKB bodies during aqueous alteration [7]. A liquid state of water requires a considerable elevation of temperature in the bodies’ interior. Plausible mechanisms of heating were decay of radionuclides (short-lived $^{26}$Al and long-lived $^{40}$K, $^{235}$U, $^{238}$U and $^{232}$Th) in the bodies and mutual collisions between the bodies. In this paper we consider the former mechanism only. As shown in model calculations [8], the long-lived radioisotopes were insufficient for total melting of ice fraction in the icy satellites of giant planets of radii up to 800 km, although partial melting was possible.

Was the concentration of captured $^{26}$Al (half-life 7.2 x $10^7$ yr) sufficient for melting of water ice in the EKB objects? If the time of EKB bodies’ formation was substantially larger than the half-life of $^{26}$Al, then independently of the isotope concentration it couldn’t heat the EKB bodies with rather high efficiency.

The formation time of hundreds-km-sized EKB bodies was from about one million year [9] to several tens of million years [10]. Taking into account the model of cometary body formation by [9], accretion of bodies up to 100 km in radius at the EKB distances 35-50 AU within $\approx (1-1.5) \times 10^6$ yr seems to be possible, though this time is near the lower limit of accretion timescales. In this consideration we suppose that formation of planetesimals at $r$ of the EKB could begin several $10^6$ yr after the collapse of the protosolar cloud.

If the accretion of bodies of radius $R = 100$ km had completed no later than a few $^{26}$Al half-life times, the decay of this isotope provides enough heat to melt the water ice in the interiors of these bodies. To check this conclusion we adopt the mass fraction of silicates (silicates (ices + dust)) in EKB parent bodies of 0.30 [11]. The rock component with chondritic (solar) abundances of refractory elements contains 1.3 wt. % of aluminum. We also adopt the $^{26}$Al/$^{27}$Al ratio of $1 \times 10^{-5}$ which is obtained from the “canonical” initial $^{26}$Al/$^{27}$Al ratio of $5 \times 10^{-7}$ and accretion time of a EKB body 1.6 Myr (after CAIs). This time possibly but not necessarily coincides with the age of the solar nebula (from the collapse stage).

The above figures, giving the $^{26}$Al abundance, should be added with the decay energy of $^{26}$Al = 3 MeV per atom and its decay constant $\lambda = 9.63 \times 10^{-10}$ year$^{-1}$ to yield the heat production rate $Q = 0.4$ J kg$^{-1}$ yr$^{-1}$. The time $t_n$ required to heat a large EKB body to the water-ice melting point and to melt the ice in its interiors can be estimated from the equation

$$\int_0^\tau Q \exp(-\lambda t) dt = \int_{t_n}^\tau c_p dT + L_f m_w,$$

where $T_0 = 30$ K is the adopted value for the initial temperature of the body, $T_m = 273$ K is the melting temperature of water ice (a good approximation to at $P < 25$ MPa, characteristic for interiors of a EKB body of radius $R < 300$ km), $L_f = 3.34 \times 10^7$ J kg$^{-1}$ is the latent heat of fusion for H$_2$O, $m_w = 0.38$ is adopted for the H$_2$O mass fraction, $c_p$ is the thermal capacity at constant pressure per unit mass for the body’s material. With some overestimation of $c_p$, at temperatures from 30 to 150 K we can take the temperature dependence of specific heat for all main components similar to that for water ice: $c_p_{\text{H}_2\text{O}} = 7.67 T$ J kg$^{-1}$ K$^{-1}$ [12]. In this approximation the values of thermal capacities (all in J kg$^{-1}$ K$^{-1}$) is: $c_p_{\text{rocks}} = 3.1 T$ for rocks (mainly silicates), $c_p_{\text{CHON}} = 5.7 T$ for refractory organics, and $c_p_{\text{vol}} = 10 T$ for volatile organics and gases (the approximation for gases is most crude, but this has little effect due to their low content). We use also mass fraction of CHON $m_{\text{CHON}} = 0.22$ and combined mass fraction of volatile organics and gases $m_{\text{vol}} = 0.10$. With these values we obtain the thermal capacity for the mixture $c_p \approx c_p_{\text{rocks}}$, where $c_p_{\text{rocks}} = 6.1$ J kg$^{-1}$ K$^{-1}$. After substitution of this value in Equation (1) and integration we have the majoring estimation for the time $t_n$:

$$\tau_n = -\lambda^{-1} \ln\{1 - \lambda c_p(T_0^2 - T_0^2)/2 + L_f m_w / Q\} \approx 1.9 \times 10^6\text{yr}.$$  

Thus the water ice in the bodies can be melted in less than 2 million years after the body formation and, hence, at the age of the solar nebula of 3.5 Myr. During this time only a surface layer of thickness $\Delta R \sim 10$ km could be frozen, as follows from the simple estimation:

$$\Delta R \sim \sqrt{\kappa \tau},$$

where $\kappa$ is the thermal diffusivity related to the thermal conductivity $k$ as $\kappa = k / (\rho c_p)$. The temperature
dependence of $\kappa$ for water ice I is $\kappa = \kappa_0 T^{-2}$, where $\kappa_0 \approx 9.1 \times 10^{-2} \text{m}^2\text{K}^{-2}\text{s}^{-1}$ [13]. However, the porosity of ices $\rho \approx 0.5$ decreases the thermal conductivity 5 to 50 times [14]. The porosity is the maximal at the surface and reduces to the low values at the bottom of the layer. Thus the reasonable estimate for the thermal diffusivity of the layer is $\kappa \approx 10^{-6} \text{m}^2\text{s}^{-1}$.

The consequences of water ice heating are much more important. First, huge amount of water ice evaporated at low pressures in the porous medium should condense in the upper layers of the bodies, substantially reducing their porosity. As a result of insulation of the interiors from the outer space, the pressure below the upper layer of thickness $\Delta R$ would become higher than 1 bar and melting of water ice should occur when heated to $T > T_w \approx 270$ K. Probable admixture of volatile organics might slightly decrease this temperature. Thus, as follows from Equations (1) and (2), internal water ocean in the young EKB bodies forms at their age $\approx 1.9 \text{Myr}$, that is after $\approx 3.5 \text{Myr}$ after CAs and solar nebula formation.

Consider the evolution of the internal water ocean in a young EKB body of $r = 100 \text{–} 300 \text{km}$. The thermal convection in the ocean should be vigorous, if the Rayleigh number $Ra$ is much higher than its critical value $Ra_c \approx 10^6$. We can estimate the value $Ra = a g d^3(\Delta T)/(g \nu)$, where $a \approx 10^{-4} \text{K}^{-1}$ is the volumetric thermal expansion coefficient of the mixture, dominated by liquid water, $g$ is the gravitational acceleration ($g \approx 4\rho GR^2$), $d \approx 0.8 \text{–} 0.9 \text{R}$ is the convective layer thickness, $\Delta T$ is the temperature difference across the layer, $\kappa \approx 10^{-7} \text{m}^2\text{s}^{-1}$ and $\nu \approx 10^{-5} \text{m}^2\text{s}^{-1}$ are the thermal diffusivity and kinematic viscosity of the water–solids mixture. At $d = 70 \text{km}$ and the very low value of $\Delta T = 1 \text{K}$ we nevertheless obtain a very high value $Ra \approx 10^{21}$. The Nusselt number (Nu), which is the ratio of the total heat flow (including convective one) to the conductive flow is related to Ra by [15]

$$Nu \approx 0.2 Ra^{1/3}.$$ With these data we can estimate the time of heat transport through the convective water ocean $\tau$, by relation (3) where $\Delta R$ and is substituted for $d \approx 0.8 \text{R}$ and the molecular thermal diffusivity $\kappa$ is substituted for the effective thermal diffusivity $\kappa_e$ which accounts for convection, with $\kappa_e = \kappa \cdot \nu$. At the above parameters we obtain $\tau \approx 10^3 \text{years}$. The time is very short relative to the thermal evolution time scale of the bodies $t_w \approx 10^6 \text{years}$. The latter is also the time scale for heat transport through the outer body’s shell (thermal boundary layer) of thickness $\Delta R$. Owing to the rapid radial heat transport through the water ocean its $T$ is stabilized near the temperature of maximum water density $\approx 277 \text{K}$ (the adiabatic compression for hundreds-km-sized bodies is negligible) and probably never exceeds $280 \text{K}$. After a lapse of time a continuing decrease of radiogenic heat production yields the freezing of the internal ocean beginning (as in a usual terrestrial ocean) from the upper layer.

The lifetime of the ocean (till the beginning of its freezing) in the early EKB body of radius $R$ can be estimated by comparing the heat flow $F_1$ underneath the solid shell (thermal boundary layer) of thickness $\Delta R$ and the heat flow $F_2$ in the shell. The flow $F_1$ is generated in the interiors being heated by the $^{26}\text{Al}$ decay and quickly transferred to the lithosphere. Thus we can write $F_1 \approx \frac{1}{2} \rho (R - \Delta R) \Delta T \approx \rho (R - \Delta R) \Delta T$ on the assumption of $^{26}\text{Al}$ homogeneous distribution, where $\rho = 1.4 \times 10^3 \text{kg} \text{m}^{-3}$ is the mean density of the body (calculated at the above fractions of components). Flow $F_2$ can be written as $F_2 = k \Delta T / \Delta R$, where $k$ is the thermal conductivity of shell, $\Delta T = 273 \text{–} 320 \approx 240 \text{K}$. We assume $k = 2 \text{W} \text{m}^{-1}\text{K}^{-1}$, taking into account the empirical relation for crystalline ice $k(T) = 567 / T \text{W} \text{m}^{-1}\text{K}^{-1}$ and compensating effect of increasing porosity from the base to the surface of the shell [16]. The freezing of the water ocean begins when the incoming flow from interiors $F_1$ becomes lower than the flow $F_2$ coming from the shell. By equating two flows from (4) and (5) we obtain the estimate of the lifetime of the ocean of liquid water as $\tau_f \approx 0.6 \text{–} 1.8 \text{Myr}$ for the bodies of radius $R = 100 \text{–} 300 \text{km}$ respectively.

This lifetime is quite sufficient for silicates to form phyllosilicates by reaction with water.

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LUNAR CRATERS HAVE ENDOGENIC NATURE.
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Introduction: Matched craters of two lunar Sides reveal their endogenic nature.
To prove the endogenic nature of lunar craters, it is sufficient to reveal nonrandom disposition. There is a simple method to implement this. The author has applied that method to reveal the structural symmetry of the Earth’s shell (F.1) and the shell of planet Mars (F.2). By superimposing the maps of two hemispheres one to another, it is easy to see, that large-sized basins and crack systems on two sides of planets are mutually matched. The basis of this method, accessible for anyone, is made up by the author’s revealing (1993) of the axial structural earthen symmetry. First it is necessary to abandon the agreed-upon inconsistent theory of continent drifting and to accept the conception of the earth’s ocean formation by subsiding underneath the cover basalts of many km thick -author’s books 1978, 1983a, 1983b, 1986, 1993, 1997,[1] and my web-site www.gpi.ru/~mknr/lpsr Otherwise the earthen structures must change their position all the times.

Tectonic position of basalt lava fields in the time, in other structures and in the ranges of the geological formations is: the rear sides of mountain fold arcs of planetary scale and of different ages. Lava’s position in geocycle is the post-orogenic and pra-taphrogenic. Ocean ridges - are closed by their fronts geosyncline/fold systems. They are overlapped from two rear sides of their own systems by final lavas and later dislocated by taphrogenic grabens. The symmetrical structuralism of earthen shell is empirical evident fact.

![F.1](image1)

On the Earth we can see (geology and geophysical methods) we can see all the structures, all fold zones with their green-rock belts. On the Mars we can see modern structural and volcanic forms only [2]. Many forms of two hemispheres are coincide. Grand volcano Olimpus and crater system on another planet side create the “flower” pattern on such map of matching. This flower is imaginary, its elements are the forms of different hemispheres. In one case the evolution of volcano-forms took place from the center to its boundaries, in another – to its center (Olimpus)

Now we can see lunar maps [3] of different hemispheres (F.3, upper – near, down – back side) and the scheme of general structures (F.3, center). On the scheme the structures of near side (points) and back side (lines) are: Imbrium – Moscovensis (SW), Viner (W), Campell (NW), Dalamber (N), center the place of crater Slivko, Trumpler; Serenitatis – Bredihin (SW), Krylov (NW), Everinder (N), Nicols (E) Center – Miner etc. in other lunar imaginary “flowers”. Many of structural rings of different hemispheres are coinside absolutely - Fecundidatis and Herschprungs, Al-Horesmy and Geibl with its small crater envelop system. On the Earth in this position there are on the Earth Indonezian fold arcs.

![F.2](image2)
Earthen and Lunar oceans are formed in one way (see F.4, 1-lunar, earthen lines, 2,3 – old and more young lavas of both planets, 4- earthen ocean ridges, other structures.

**Conclusion:** Lunar craters are endogenic.

ESTIMATED VOLUMES OF DAO, NIGER, HARMAKHIS AND REULL VALLIS AND THE DEPOSITS INSIDE HELLAS BASIN. I. Manso Rogeiro, J. Raitala, M. Aittola and V.-P. Kostama, Planetology Group, Department of Physical Sciences, P.O. Box 3000, FIN-90014 University of Oulu, Finland. manso@paju.oulu.fi, jouko.raitala@oulu.fi, marko.aittola@oulu.fi, petri.kostama@oulu.fi

Introduction: The present Martian project will continue the previous planetological approaches made by the Planetary Group of Oulu. The actual research efforts include detailed studies on Martian paleo-environment, erosional features and water-related formations. The project adopts quantitative methods in studying Martian erosional structures. It includes photogeological analysis of existing data sets over eroded Martian structures in order to interpret their formation.

Dao, Niger, Harmakhis and Reull Vallis are large outflow channels located northeast of the Hellas basin in the southern cratered highlands of Mars (Fig. 1). The complex morphology of the region suggests a series of fluvial, permafrost or glacial events and open water periods which all indicate that the surface has not been as dry and inactive as it seems to be now.

Outflow Channels and Hellas morphology: The Hellas impact basin, the floor of which is 4 to 9 km below the surrounding terrain is one of the most prominent topographic features in the southern hemisphere of Mars. The main basin rim is approximately 2300 km in diameter [1] and the interior floor materials are interpreted to be depositional in nature. This study concentrates on the outflow channels of the eastern rim of the Hellas basin; Dao, Niger, Harmakhis and Reull Vallis (Fig. 1b).

The main canyons of Dao, Niger and Harmakhis Vallis are parallel and morphologically similar canyons trending ~S45°W. They extend from the eastern Hellas rim into the smooth interior of the Hellas basin. Dao and Harmakhis Vallis are separated by about 200 km. The large steep-walled canyons of Niger Vallis and the upper part of Dao Vallis contain numerous knobs and hills on their floors. The lower parts of Dao and Harmakhis Vallis are narrow and slightly winding channels.

Reull Vallis is a more complex system consisting of three morphologically distinct segments [2]. Reull Vallis appears to originate from the highlands of Promethei Terra, where it trends S50°W. The lower end of Reull Vallis may have been connected to the source of Harmakhis Vallis, but by now a debris apron formation appears to cover their junction [3].

The global Mars Orbital Laser Altimeter (MOLA) topographic data has allowed the first accurate assessment of the area drained by the Hellas basin. In the central part of Hellas basin lays the elevated Alphes Colles Plateau. Along the eastern part of the basin interior lays the discontinuous semiannual band of plains marked by smooth, locally undulating deposits that partly bury the wrinkle ridges and other older formations. The steep ravines of Dao and Harmakhis Vallis change to smoother channels when approaching the floor deposit units [4]. The older northwestern to southwestern Hellas interior plains form a second discontinuous annular band which is locally gradational with plateau and rim units and cut by a few minor channels. Rims of larger and older craters are subduged [4].

Fluvial activity: The outflow channels, delta formations and shorelines indicate ancient water and/or ice activity. The MOLA data reveal that the recognizable Hellas paleo-shoreline lies almost entirely at ~6000 m elevation level (Fig. 1a) [5, 6]. The outflow channels of Dao, Niger, Harmakhis and Reull Vallis, locating on the NE rim of Hellas, might have been sources of some of the deposits found inside the Hellas basin. These major Hellas channels suggest basin rim alterations due to erosional processes and they have thus provided localized source regions for at least some of the interior deposits. We have examined these channels in detail and estimated their volume, in order to evaluate their morphology and formation.

Methods: This work is based on analyses of Martian image and topography data sets. Parameters related to properties of geological materials help to estimate the surface variables associated with the erosional effects identified, measured and analyzed. Our objective is to determine the lower volume limit for the eastern Hellas deposits (Fig. 1b) and to compare it with the volume with the upper erosional volume limit obtained by measuring the cross-sections and areas of the four major outflow channels.

The MOLA data set was used to study the channel and basin topography, to measure topographic profiles, and to estimate the volume of the basin deposits. The Viking MDIM2 data was used to measure the area of the eastern Hellas deposits.

The volume of the eastern semi-annular basin floor deposit was estimated using its relative mean height compared to that of the older western unit. The measured relative mean height of ~650 m and the total area of 223 320 km² gave us the estimation of the lower limit for the deposit volume which was found to be ~145 000 km³.

The total volume of the interiors of the four major channels was estimated based on their topographic profiles and photogeodetic outlines. Profiles made across the Dao, Niger, Harmakhis and Reull Vallis were graphically studied and measured. Their mean depth and width values were measured and cross-sections calculated together with their projected length measurements in order to estimate the upper...
limit of their erosional channel volume values. According to the numbers obtained, the upper limit values for the total volume of the materials eroded from the interiors of Dao, Niger, Harmakhis and Reull outflow channels is ~38 200 km³ (Table 1).

Because of the uncertainties in the actual measurement process (the neglectance of the small islets inside the channels etc.), the method adopted provides preliminary order-of-magnitude estimations in stead of the very exact volume values. However, we are confident that our calculations give us the lowest possible volume for the eastern Hellas deposits and the highest erosional volume value for the analyzed outflow channels. These lower and upper volume values, respectively, prove that the actual volume of materials eroded from the outflow channels of Dao, Niger, Harmakhis and Reull (~38200 km³) is inferior when compared to the volume of the easter Hellas deposits (~145000 km³) obtained.

Table 1. Estimated volumes of material eroded from Hellas eastern outflow channels.

<table>
<thead>
<tr>
<th>Vallis</th>
<th>Length, km</th>
<th>Volume contributed, km³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dao</td>
<td>~740</td>
<td>~9600</td>
</tr>
<tr>
<td>Niger</td>
<td>~450</td>
<td>~10200</td>
</tr>
<tr>
<td>Harmakhis</td>
<td>~600</td>
<td>~4400</td>
</tr>
<tr>
<td>Reull</td>
<td>~1170</td>
<td>~14000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>38200</td>
</tr>
</tbody>
</table>

The volume of the deposits of the Hellas interior as well as the possible eroded material from the four major valleys of the Hellas rim have been estimated earlier by using the Viking data [7]. This previous estimation gave the volume of the material eroded from Hellas rim valles the value of 50000 km³. The calculation was based on the assumptions that the average depth of the erosion on the valles would be 1 km and that the average interior deposition depth would be 1 km in general.

**Conclusions:** The estimated volumes of materials eroded from the four major outflow channels are inferior when compared to the estimated volumes of floor deposits that are infilling the eastern Hellas basin floor. This conclusion becomes still more evident if we take into the account that we estimated the lower limit value for the volume of the eastern Hellas floor materials and compared it with upper limit value of the materials eroded from the outflow channels. This allows to conclude further that there have been additional sources of the deposited materials during the early phases of Martian history. The studies of Martian ancient erosion, transportation and sedimentation events have to be continued in order to define the processes and locations involved. The project to study Martian erosion and deposition features will use the existing and still-cumulating data sets. The results will be implemented, combined and improved with the future Mars Express HRSC-SRC high-resolution data.

VOLCANIC FESTOON DEPOSITS ON VENUS: FRACTAL ANALYSES AND IMPLICATIONS FOR EMPLACEMENT. S.M. McColley1 and J.W. Head III1, 1Department of Geological Sciences, Brown University, Providence, Rhode Island 02912, USA.

Introduction: A fractal is an object that is “self-similar” at all scales [1]. Various naturally occurring objects have been identified as fractal (e.g., rocky coastlines, snowflakes, river networks, fern leaves, etc). Each object’s fractal nature is described by its fractal dimension. Bruno et al. [2] determined that lava flow margins are fractal and used fractal dimensions to distinguish between Hawaiian pahoehoe and a’a lava flows. A’a flows typically have fractal dimensions in the 1.05-1.09 range, while pahoehoe flows tend to fall in the 1.14-1.23 range (assuming relatively smooth preexisting topography). These observations indicate that flow morphologies correlate with fractal dimension.

However, Lipkaman and Gregg [3] state that fractal dimensions do not reflect surface morphology in as much as they indicate emplacement style. They found that lava flows with a’a morphologies (typically emplaced as single lobes) that had been emplaced via lobe networks produce fractal dimensions within the pahoehoe range and that pahoehoe flows (typically emplaced as lobe networks) that were emplaced as continuous or channeled units fall within the a’a range.

Terrestrially, episodic emplacement is typical of dacitic or rhyolitic compositions. Higher viscosity magmas tend to stall or block the conduit which feeds the flow allowing a solid carapace to form on the surface of previously erupted lava. As magmatic pressure increases, hot magma is injected beneath the carapace manifesting itself as endogenous growth by deforming the overlying solid carapace in a ductile manner. The resulting flows are thicker and appear to have been emplaced as one continuous unit with predictable surface structure depending on the distance form the vent [4]. Endogenous growth is favored by, but not limited to more evolved compositions. Inflation (e.g. flow thickening) occurs in basaltic flows as well, but predominantly lower viscosity flows grow in an exogenous fashion (e.g. breakouts of coalescing lobes and toes). Continuous eruptions are favored in a basaltic environment [5].

In a planetary context, specifically on the surface of Venus, many of the observed flows appear to have been emplaced via lobe networks (e.g. long, thin, lobe flows). However, there are three anomalous appearing flows (festoons) relative to the basaltic nature of the remainder of the planet. We have been analyzing these flows to characterize and assess their emplacement [6]. The festoon deposits are located in the Aino Planitia, Ovda Regio, and Atalanta Planitia regions, with each flow displaying steeper and thicker flow margins than those observed on other Venusian flows. In an attempt to further characterize these enigmatic deposits, fractal dimensions were calculated for the festoons in the Aino Planitia (Artemis-Imdr festoon) and the Ovda Regio (Ovda festoon) regions.

Method: The “structured-walk” method (as seen in Bruno et al. [2]) was employed digitally to determine the fractal dimensions for the Artemis-Imdr and Ovda festoons. The method involves ‘placing’ rods of equal length (r) (see Table 1 for actual lengths) end-to-end along the outer margin of each deposit in both a clockwise and counterclockwise fashion (accomplished using Canvas 5.0 software). The initial rod is ‘placed’ alongside the flow margin at an arbitrarily chosen starting position. The margin is then circumnavigated while laying consecutive rods of equal length end-to-end. As the initial position is approached, the number of whole rod lengths is summed with the partial (typically the final rod is not full length) length of the final rod. The process is then repeated in the opposite direction for each individual rod length. To ensure accuracy, the average of the two values (clockwise and counterclockwise) is used as the total number (N) of rod lengths to determine the apparent length (L= Nr) of the margin [2]. The apparent margin length, L_0, for each rod length, is then plotted as a function of r on a Richardson (log-log) plot (Figs. 1 and 2) to determine the fractal dimension (D) which is given by (1), where C is the y-intercept of the resulting curve. Fractal dimension is also given by (2) where m is the slope of the resulting curve on the Richardson plot.

\[
\log L = C + (1-D) \log r \tag{1}
\]

\[
D = 1 - m \tag{2}
\]

Figure 1. Richardson plot showing that the fractal dimension for the Ovda festoon falls well within the pahoehoe range [2].
Table 1. Line lengths and fractal dimensions for the Ovda and Artemis-Imdr festoons

<table>
<thead>
<tr>
<th>Festoon</th>
<th>Line Length (r)</th>
<th>Dimension (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ovda</td>
<td>75</td>
<td>1.251585</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>Artemis-Imdr</td>
<td>225</td>
<td>1.122958</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
<td></td>
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<tr>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.** Richardson plot showing that the fractal dimension for the Artemis-Imdr festoon falls in the pahoehoe range [2].

**Discussion:** Fractal dimensions may not necessarily reflect surface morphologies [3], but they may still be useful in discussions regarding emplacement style [3]. The Ovda festoon shows no discernable evidence (at 75 m / pixel) for a complex network of interconnected lobes within the flow’s interior, while the outer margin appears sinuous and lobate. The margin appears to be conforming to and embaying the preexisting tesserae on which it was emplaced. These observations suggest that the preexisting terrain played a dominant role in shaping the outer margin. The flow appears to have been emplaced as a single continuous unit, with pervasive ductile deformation of the overlying carapace, while the preexisting terrain acted to enhance the sinuosity of the margin. This observation is highlighted by the elevated fractal dimension (Fig 1) that falls well within the pahoehoe range, irrespective of the lack of internal lobe networks. Preexisting positive or negative topography may act to increase or decrease fractal dimension respectively [2].

Observations of the Artemis-Imdr festoon indicate that emplacement was clearly pulsed, with what appears to be a minimum of two distinct eruptive phases. The fractal dimension (Fig. 2) for the Artemis-Imdr festoon is in agreement with episodic emplacement as well. It falls in the transitional area from a’a to pahoehoe [2] suggesting that either the flow was emplaced as one continuous unit or a complex lobe network. The markedly lower fractal dimension of the Artemis-Imdr festoon may also be an indication of the relatively smooth preexisting topography on which it was emplaced.

**Conclusions:** The Ovda Regio festoon shows a lack of internal lobe networks and pervasive ductile deformation of the overlying thermal boundary layer. Although the observed morphology is consistent with emplacement of a continuous unit, the fractal dimension (Table and Fig. 1) indicates that the flow was emplaced via a lobe network. Thus, the underlying topography (tessera) had a profound impact on the geometry of the flow margin, culminating in an elevated fractal dimension.

The Artemis-Imdr festoon was emplaced on lowland plains and shows clear evidence for a pulsed emplacement with at least two distinct eruptive phases. The margin of the flow is complex showing embayment of previously emplaced lobes by later stages of the eruption. The fractal dimension (Table 1 and Fig. 2) is consistent with a flow that was either emplaced as a continuous unit or via a lobe network [3]. The final geometry of the margin appears to have been the product of flow dynamics and not the underlying topography (plains).

An algorithm for autonomous identification of crater centres from topography data has been improved in accuracy since [1,2] by taking account of the slope direction on the interior of the crater rim. A crater is identified by maximizing a function which integrates the inwardly directed component of the slope around a ring of given radius for all points over the surface under investigation.

The algorithm has been applied to remeasure the coordinates of 19,000 craters from the Viking-based SAI Mars crater catalogue [3] within the MGS MOLA topography data [4].

This being done, a series of radial profiles are extracted for each crater (Fig. 1) and used to attempt to produce a generalized profile for the crater (an average, excluding extreme values). A number of parameters can be derived from the generalized profiles describing the crater depth, rim, floor, and ejecta blanket, and the variation of these parameters examined over the population.

The Beagle-2 lander of the Mars Express mission will come to rest on the surface of Isidis Planitia in late December 2003 to carry out a series of geochemistry and exobiology experiments. We are compiling an atlas of the presently available data products pertinent to the landing site at 11.6N 90.75E, which is intended for distribution both as a printed and an electronic resource. The atlas will include Viking, MOC-WA, and THEMIS IR image mosaics, and a catalogue of high-resolution images from MOC and THEMIS with location maps. There will be several MOLA topography-based products: colour-scaled, contoured, and shaded maps, slope, and detrended relief. MOLA-derived simulated camera panoramas from various positions about the nominal landing site may assist in determining the spacecraft’s position. Other maps, both raw, and in composites with image mosaics, will cover TES thermal inertia and spectroscopy, and Odyssey gamma and neutron spectroscopy. Maps at the scale of the Isidis context will additionally cover geology, temperature cycles, and atmospheric circulation.

The poster will show selected maps and images from the atlas, describe the simulated panoramas, and discuss the probability of observing local MOLA-scale topographic features from the landing site.
VERTICAL DISTRIBUTION OF SHALLOW WATER IN MARS SUBSURFACE FROM HEND/ODYSSEY DATA. I.G. Mitrofanov\textsuperscript{1}, M.L. Litvak\textsuperscript{1}, A.S. Kozyrev\textsuperscript{1}, A.B. Sanin\textsuperscript{1}, V. Tretyakov\textsuperscript{1}, W.V. Boynton\textsuperscript{2}, D.K. Hamara\textsuperscript{2}, C. Shinohara\textsuperscript{3}, R. S. Saunders\textsuperscript{3}, D. Drake\textsuperscript{4}, 1Space Research Institute, RAS, Moscow, 117997, Russia, imitrofa@space..ru, , 2University of Arizona, Tucson, AZ 85721, USA, 3NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA, 4Lansce 3, Los Alamos Nat'l Lab. Los Alamos, NM and TechSource Inc, Santa Fe, NM 87594, USA.

Introduction: The two years of neutron mapping measurements onboard Mars Odyssey spacecraft are presented based on High Energy Neutron Detector (HEND) observations. HEND instrument is a part of GRS suite responsible for registration of epithermal and fast neutrons originating in Mars subsurface layer \[1,2\]. The cosmic gamma rays easily go through thin atmosphere and generate fast neutrons in martian subsurface layer. Propagation of these neutrons is strongly dependent on presence of hydrogen atoms or water. Even several percents of subsurface water cause decreasing of epithermal and fast neutron flux by tens of percents \[3,4\]. It means that observations of martian neutron albedo may be used as most effective way for search water in Mars subsurface.

There is direct correspondence between energy of registered neutron and depth where it was produced. The production rate of fast neutrons has maximum at depths less than tens of centimeters while the epithermal neutrons originate in layer placed 1-3 m below the surface. Combining measurements in epithermal energy range with measurements above 1 MeV one may reconstruct the water abundance distribution at different depths starting from thin subsurface layer and going down to several meters depths. It allows to check simple model describing layered structure of regolith.

Data Analysis. To extract regolith structure from neutron data we used model depended approach based on numerical modeling of martian atmosphere and surface. We implement two types of regolith models. One of them uses homogeneous distribution of water with depth. Another takes into account that martian regolith may be presented as two layers structure with relative dry (\textasciitilde2\% of water) upper soil layer covering the bottom water ice rich layer. For first model there is only one free parameter – content of water in martian regolith. For second model it is necessary to implement two free parameters: thickness of upper layer and content of water in bottom layer. For both models we used the same approximation of martian atmosphere taken from CGM model developed in Ames. The orbital measurements are gathered from large surface area. The sizes of the footprint area may be as large as 600 km x 600 km. To minimize calculation time and avoid non-evident model dependent deconvolution of neutron data for small pixels we restrict calculations by selection of large regions on martian surface. These regions have sizes comparable with footprint area and covered north and south provinces of Mars. Some wet equatorial regions inside Arabia Terra were also investigated to find most wet places at equatorial latitudes.

Results and Conclusions. The analysis of HEND data revealed that homogeneous model of martian regolith can not adequately describe observational data. Only two-layers model can provide appropriate agreement between model predictions and observational data accumulated for north and south water ice

Fig 1. The distribution of water ice is shown for North region. Top graph presents data showing how deep water rich layers may be placed beneath surface at different latitudes. On bottom graph one may see the content of water in water rich layers at different latitudes. Black color corresponds to 80\(^\circ\)N-90\(^\circ\)N latitude belt. The red, yellow, green and blue colors correspond to 75\(^\circ\)N-85\(^\circ\)N, 70\(^\circ\)N-80\(^\circ\)N, 65\(^\circ\)N-75\(^\circ\)N, 60\(^\circ\)N-70\(^\circ\)N latitude belts.
rich provinces. Parameters of this model are presented on Fig 1 and Fig 2.

It is easily seen that ice depth on South and North hemispheres are quite different. On South water bearing layers are placed significantly deeper then on North.

Studying of equatorial water rich regions also argues for two layered structure of regolith. Calculations for Arabia Terra wet regions shows that water rich layer lies 30-40 cm beneath the surface and consists of 9-10% of water. It was found that the most wet spot at equatorial latitudes (30°E, 10°N), has about 16% of water placed at a depth of 30 cm.

Fig 2. The distribution of water ice is shown for North region. Top graph presents data showing how deep water rich layers may be placed beneath surface at different latitudes. On bottom graph one may see the content of water in water rich layers for different latitudes. Black color corresponds to 80°S-90°S latitude belt. The red, yellow, green and blue colors correspond to 75°S-85°S, 70°S-80°S, 65°S-75°S, 60°S-70°S latitude belts.

References:
MAPS OF LUNAR PYROXENES. V. Omelchenko¹, Yu. Shkuratov¹, C. Pieters², D. Stankevich¹, V. Kaydash¹.
¹Astronomical Institute of Kharkov National University, 35 Sumskaya St., Kharkov, Ukraine, ²Geological Science, Brown University, Providence, Rhode Island, 0291, USA. omelchenko@astron.kharkov.ua

Introduction: Mapping of the chemical and mineral surface composition is one of the most important tasks in studies of the Moon. Several techniques for estimation of the lunar surface composition have been offered, however, all the techniques have severe restrictions. Data from the Lunar Prospector mission allow a quantitative analysis of the abundances of the main rock-forming elements in the lunar surface, e.g., [1]. Unfortunately, these data do not contain important information about the mineral composition.

For the last years we develop a new technique [2-4] to estimate the mineral composition of the lunar surface, which is based on statistical analysis of spectral and composition data presented by the Lunar Soil Characterization Consortium (LSCC) [5] for regolith samples. For prognosis mapping Clementine UVVIS multispectral data are used. We have presented preliminary data concerning the surface distribution of plagioclase, olivine, ilmenite, and pyroxene content [4]. The latter constituent has previously considered as a general unit, whereas there are different types of lunar pyroxenes determined at the LSCC analysis. These types have different influence on the lunar surface spectral properties and we can anticipate that our technique might be extended to map pyroxenes of different types. Thus the results of the present study are preliminary maps of the content of orthopyroxene, pigeonite, and Fe- and Mg-pyroxenes.

Data and their analysis: We use the data for LSCC-characterized mare soils of the Apollo-11, -12, -15, and -17 missions (mare regoliths) and data for Apollo 14 and Apollo 16 soils (highland regoliths) (one Apollo 17 sample representing the orange glass has been eliminated from our consideration). Coordinated compositional and spectral measurements were carried out for each sample presented as three subsamples with controlled particle size: <10 µm, 10-20 µm, and 20-45 µm. Bidirectional reflectance spectra were obtained with the RELAB spectrometer in the spectral range 300–2600 nm at the phase angle of 30°.

We use the method suggested earlier [3-5]. The main idea of this method is to find the closest correlation between a studied parameter $P$ (pyroxene content) and a combination of spectral albedos $A$ of the lunar samples varying parameters (and even type) of the combination. In this paper we use the following simple linear combination of Clementine UVVIS spectral albedos $A(415 \text{ nm}), A(750 \text{ nm}), A(900 \text{ nm}), A(1000 \text{ nm})$ taken in %,

$$P = aA_{415} + bA_{750} + cA_{900} + dA_{1000} + e,$$  \hspace{1cm} (1)

varying weight coefficients $a, b, c, d,$ and $e$ of the linear combination. We do not use here albedo at 950 nm because of it gives a strong latitude trend that is related to shortcomings of the photometric correction of Clementine data. Note that in case of mapping maturity degree and agglutinates the bands 0.90 and 0.42 µm should be eliminated [6] to escape this problem.

If studied parameter is close to zero, then $\log P$ instead of $P$ in the equation (1) should be used to avoid negative values of the predicted parameter. We found that the linear expression with $P$ gives high correlation coefficients and small residual errors for pigeonite, and Fe- and Mg-pyroxenes. The case with $\log P$ is more acceptable for orthopyroxene. The weight coefficients $a, b, c, d,$ and $e$ are given in Table 1. In the last column the correlation coefficient $k$ for measured and predicted pyroxene compositions is given. As can be seen in Table 1 the most reliable predictions correspond to pigeonite and Mg-pyroxene.

Table 1. Weight coefficients for equation (1).

<table>
<thead>
<tr>
<th></th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
<th>$d$</th>
<th>$e$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthopyroxene</td>
<td>-0.04</td>
<td>0.32</td>
<td>-0.78</td>
<td>0.47</td>
<td>0.27</td>
<td>0.65</td>
</tr>
<tr>
<td>Fe-pyroxene</td>
<td>0.09</td>
<td>0.28</td>
<td>0.26</td>
<td>-0.58</td>
<td>1.57</td>
<td>0.63</td>
</tr>
<tr>
<td>Mg-pyroxene</td>
<td>-1.46</td>
<td>1.58</td>
<td>6.07</td>
<td>-6.55</td>
<td>6.61</td>
<td>0.85</td>
</tr>
<tr>
<td>Pigeonite</td>
<td>-2.27</td>
<td>3.57</td>
<td>3.22</td>
<td>-5.12</td>
<td>5.45</td>
<td>0.83</td>
</tr>
<tr>
<td>Total pyroxene</td>
<td>-0.07</td>
<td>0.22</td>
<td>-0.03</td>
<td>-0.16</td>
<td>1.33</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Note that we had a good opportunity to test our results as we can estimate the total pyroxene abundance using directly the LSCC data and calculate it to sum the components (orthopyroxene, Fe- and Mg-pyroxenes, and pigeonite). We have obtained excellent coincidence of the compared total pyroxene maps.

Results and discussion: The maps of the contents of pyroxenes are presented in Figs. 1-5. In figure captures we give also the average content and RMS variation of each pyroxene. Table 2 gives a notion about quantitative estimates for four lunar areas, central parts of the craters Tycho (75×75 km), Grimaldi (105×75 km), Darwin (270×270 km), and Reiner-γ formation (45×30 km). All estimates in Table 2 seem to be reasonable corresponding in general to the proper values of the lunar samples.

Table 2. Pyroxene contents for different areas, %.

<table>
<thead>
<tr>
<th></th>
<th>Tycho</th>
<th>Reiner-γ</th>
<th>Grimaldi</th>
<th>Darwin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortho</td>
<td>0.39</td>
<td>1.29</td>
<td>1.62</td>
<td>1.22</td>
</tr>
<tr>
<td>Fe-Py</td>
<td>2.99</td>
<td>1.77</td>
<td>1.23</td>
<td>0.68</td>
</tr>
<tr>
<td>Mg-Py</td>
<td>10.4</td>
<td>9.51</td>
<td>5.74</td>
<td>3.64</td>
</tr>
<tr>
<td>Pigeo</td>
<td>11.45</td>
<td>9.33</td>
<td>5.39</td>
<td>3.98</td>
</tr>
<tr>
<td>Total</td>
<td>23.8</td>
<td>21.6</td>
<td>14.0</td>
<td>9.84</td>
</tr>
</tbody>
</table>

As can be seen in Figs. 1-4 almost all young craters demonstrate high abundance of pyroxenes of the clinopyroxenes group (pigeonite, Fe- and Mg-pyroxenes), as can be expected for immature soils. The abundance of clinopyroxene is higher in mare regions; that is quite reasonable. Clinopyroxenes have higher abundance in the South Pole – Aitken region.
Fig. 1. Map of total pyroxene abundance (mean = 11.4 %, s = 3.38 %).

Fig. 2. Map of Mg-pyroxene abundance (mean = 4.05 %, s = 1.66 %).

Fig. 3. Map of pigeonite abundance (mean = 4.67 %, s = 1.52 %).

Fig. 4. Map Fe-pyroxene abundance (mean = 0.86 %, s = 0.31 %).

Fig. 5. Map of orthopyroxene abundance (mean = 1.76 %, s = 0.59 %).

The orthopyroxene map demonstrates the parasitic latitude trend in highland regions. We were not able to eliminate it trying to exchange the bands 0.90 and 0.95 μm as in the case of maturity degree and agglutinate maps [6]. The orthopyroxene abundance does not correlate with the lunar albedo pattern; on average almost equal amounts of orthopyroxene can be found in the lunar maia and highlands. We note lower content of orthopyroxene in the crater Tycho, Copernicus, and Aristarchus.

A petrologically important parameter is the ratio Mg/Fe. In relation to this we mapped the ratio Mg-pyroxene/Fe-pyroxene presented in Fig. 6. As one can see the ratio map correlates with the red/blue color-index distribution in mare regions. For instance, clear difference between Mare Serenitatis and Mare Tranquillitatis and portions of Mare Imbrium can be observed in the map. We also calculated the ratio clinopyroxene/orthopyroxene for the central part of the lunar nearside (see Fig. 7). We found prominent variations of the ratio over mare and highland regions. The greatest values of the ratio are found for the crater Tycho.

Fig. 6. Map of the ratio Mg-pyroxene/Fe-pyroxene.

Fig. 7. Map of the ratio clinopyroxene/orthopyroxene for the central part of the lunar nearside.

Conclusion: Thus we found strong difference between clinopyroxene and orthopyroxene distributions over the lunar surface. Correlations between abundance of the pyroxenes of clinopyroxene group are fairly close.

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**A4 format**

**MICROSTRUCTURE PROPERTIES OF THE REINER GAMMA FORMATION AS DEDUCED FROM EARTH-BASED PHOTOMETRY AND POLARIMETRY.** N. Opanasenko and Yu. Shkuratov, Astronomical Institute of Kharkov National University. 35 Sumskaya St. Kharkov, 61022, Ukraine. opanasenko@astro.kharkov.ua

**Introduction:** Swirls are structures, occurring on the Moon and Mercury, that are considered to be results of cometary or meteoroid swarm encounters [1-3]. The Reiner Gamma Formation (RGF) is the best swirl example on the Moon located in the western portion of the nearside. The RGF is the most studied swirl. Infrared data obtained during lunar eclipses show the formation to have somewhat lower thermal inertia [4], indicating presence of fine-grain regolith. Radar measurements reveal no significant enhancements for the RGF area [5]. Hence, the RGF exhibits a near-surface population of stones and blocks resembling the average mare regolith layer.

Photometric observations of the RGF at different phase angles are fairly poor. The formation is generally considered to have strong forward scatter as it shows up at large phase angles near terminator, whereas craters with bright halos disappear [6]. This is consistent with the telescope and Clementine phase ratio images obtained for this region [7,8]: the RGF material is characterized by slightly lower slope of the phase function as compared to surrounding mare regions. The RGF shows a polarimetric anomaly at large phase angles [9], which indicates either presence of coarse-grained regolith or that the regolith is comparatively dense. The photometric quality and spatial resolution of our former telescope observations [7,9] was not high, because of in the beginning 90th we used photographic imaging of the Moon.

The purpose of this paper is photometric and polarimetric studies of the RGF using modern CCD telescope data.

**Source Data:** Photometric and polarimetric observations of the Moon were carried out with the telescope Zeis-600 of Simeiz Observatory (Crimea). A CCD LineScan Camera SONY ILX707 was used. The western portion of the lunar disk was scanned with the 2048 pixels line at the wide spectral band with $\lambda = 0.65 \mu m$. Several scans of the Moon were done at the phase angles near 17° and 87°. The latter is fairly close to the angle of maximal lunar polarization. In this case we used a polarization filter orienting it along and perpendicularly to the equator of intensity. The spatial resolution of our data was near 1 km in the center of the lunar disk.

All images were transformed to the direct orthographic projection. Using these data we mapped three characteristics: albedo, phase-ratio, and polarization. The image of albedo variations was obtained from initial data at small phase angle with compensation of the brightness trends from the limb to terminator and the poles to equator [10]. The degree of polarization was imaged from albedo components corresponding to the parallel and perpendicular orientations of the polarizer. Then, using technique suggested in [9], we obtained an image of polarimetric anomalies, which is approximately the image of the second Stokes parameter [9]. This image reflects the distribution of a characteristic particle size, regolith density, and the complexity of lunar micro-topography. For control, we made the described procedure using several source images.

**Results and Interpretation:** Thus, in Figs. 1 – 3 we present our preliminary data, respectively, for distributions of albedo at the small phase angle 17°, phase-ratio (87°/17°), and parameter of polarimetric anomalies obtained for the area that includes the RGF. As one can see the RGF shows up in the phase ratio image (see Fig. 2). This means that the slope of the phase angle curve of the RGF is less than in case of surrounding regions. It is clearly shows the RGF to be characterized with relatively prominent backscatter effect that consists with results obtained with Clementine data [8]. However, as can be seen, this backscatter effect is not more than in the case of highlands. In contrast young craters, their bottoms and rims, demonstrate high slope of phase curves.
indicating relatively rougher surface than their vicinity. It should be noted that this roughness effect does not compensated with albedo influence. In Fig. 2 one can see also young craters with bright halos. This was found in [8] and interpreted as an example of very young lunar surface for which the saturation of the regolith microstructure has not yet been achieved.

The phase ratio anomaly of the RGF can be attributed to its high albedo, like in the case of lunar highland regions. However, an additional reason of this anomaly can be the regolith microstructure. This is in agreement with our polarimetric data (see Fig. 3) that also indicate here an anomaly.

We note that the bright halo craters in Fig. 2 are bright also in the polarimetric image. The latter can be interpreted as availability of coarse grains in the regolith. This is consistent with young age of the formations. The possibility of grain size anomaly in the area is generally confirmed in [11,12], where preliminary maps of the characteristic particle size is presented. The parameter was mapped with lunar sample data and Clementine mosaics.

**Conclusion:** Our new telescope observations showed that the RGF is a small microstructure anomaly that can be caused with smoothed microtopography. This is consistent with our preliminary studies [3,11,12] where we conclude that the RGF regolith can contain two modes of particle sizes. One of them correspond to coarse particles (immature soils [11,12]) and another one is presented with dust that could be formed at origin of the RGF [3]. Another result is a confirmation of the fact found in [8] that there are two populations of lunar young craters with bright halo. One of them has also halos in phase ratio images indicating smoothed microstructure topography at the site, and the other does not reveal such a peculiarity.

**Acknowledgments:** This work was partially supported by INTAS grant # 2000-0792.

**References:**
Introduction: A large concentration of seemingly collapsed features and associated outflow channels are found between western Lunae Planum and western Arabia Terra in the cratered highlands (units Npl1 and Npl2 [11]) and the volcanic plains (unit Hr [1]). Comparisons with terrestrial flood channels, such as those of Channelled Scablands in eastern Washington, suggest that the Martian channels were eroded by catastrophic floods [2,3,4]. Most of the Martian channels originate from chaotic terrains interpreted to represent areas where the ground collapsed as water, confined under the permafrost, was released under high hydrostatic pressures within artesian basins [5,6].

Sources related to the excavation of the Shalbatana Valley System main section: Understanding the geologic history of the Shalbatana Valley System (SVS) can improve our knowledge of groundwater recharging and extraction mechanisms, and the derivation of the history of valley formation in the highlands. Shalbatana Vallis was interpreted as an outflow channel excavated by water flow from an ice-covered paleolake in Ganges Chasma [7] and from catastrophically released from confined aquifers as the permafrost seal [8] was disrupted at three locations, forming chaotic regions [9]. Rodriguez and others [10] proposed that, at least, the excavation of the SVS main section (Figure 1, VS-I, B-A and VS-II) involved water released from extensive underground cavernous systems and proposed an alternative hypothesis for the origin of the Shalbatana upstream chaotic region; they suggest that a highly degraded late Hesperian impact crater (SE part) collapsed over the putative cavernous system. The chaotic terrain in B-A (Figure 1) was used as evidence that this basin resulted from collapse over an aquifer [9]. Rodriguez and others [11] proposed that flow from VS-I intercepted a series of collapsed craters in this region and possibly formed a crater-lake system, which might have temporarily ponded the flow of the part of the VS-I, B-A and the VS-II [12]. They also suggest that the geological materials composing the western margin of this lake system were apparently volatile rich and that the chaotic material within B-A was shed from the VSIII upland. The karst-like features (seen on the top edges of B-A [12]), are consistent with collapse processes for this part of the valley. It follows that water released from confined aquifers did not play a significant role in the excavation of the main SVS.

In this work we will discuss the early stages of the excavation of the SVS and we will discuss the origin and significance of the chaotic region forming the upstream region of the western VS-IV (Figure 1).

The meso-outflow channel stage: Rodriguez and others [10] proposed that the CCC, the SVHS (SER) and the WR (Figure 1) formed part of an extensive NE trending cavernous system and that this cavernous system was multilevel. The presence of a 200-meter deep collapsed region (Figure 2, CR) on the Noachian plateau adjacent to the WR is consistent with this interpretation.

In the NE part of the WR, there is an abandoned terrace (Figure 2, AT), which shows surface flow features such as tear-shaped islands and grooves. An incised channel (Figure 2, IC) suggests that the flow rate waned and was long-lived. The setting of this region at the terminal end of the WR, and the fact that AT is connected to the north with the CR though a shallow channel (Figure 2, Ch) suggest that the flow, which excavated AT, was fed by the Shalbatana Cavernous System [10]. This hypothesis is also consistent with the fact that AT is about 1 km above the main channel floor and about 1.5 km deeper than the adjacent highlands, what is also the depth of the collapsed sinkholes [10] between the Shalbatana SVHS and the Aromatum Chaos.

We have called this period of outflow activity, the meso-outflow channel stage, and suggest that it was during this stage that the greatest part of the present SVS channels’ bulk volume was excavated, prior to the large scale collapsed features we observe in the CCC [10].

Sources related to the excavation of the Valley System IV: Cabrol et al. (1997) proposed that the chaotic region (Cht) formed by the imposition of a thick lava sheet onto the ice-rich flood plain of Xanthe Terra province of Chryse Planitia. They also propose that this chaotic terrain can be considered as the headwater of the 10 km wide flat-floored channel reworked by small grooves.

Using 128 pixel/degree MOLA based DEM’s we have recognized 6 main regions within the Cht region (Figure 1, Figure3). The Valley System IV Headwater Source region (Figure 3, VS-IV HS) is a chaotic terrain, which is upstream and topologically lower than the adjacent VS-IV to the North. The Subsided Plateau Margin region (Figure 3,SPM) consists of fractured highland, whose blocks have undergone displacement, apparently in response to subsidence. The modified crater floor region (Figure 3, MCF) forms part of the region CA (Figure 3), a region where, knobs and ridges partially bound a lower lying flat and fractured region. We have interpreted CA as a highly degraded crater, and the MCF as the result of partial collapse and subsidence of the NW region of this crater. The paleochannel region (PchR) lies lower than the VS-IV HS and has a smooth surface texture, showing no signs of collapse. To the west, it is bounded by a steep cliff [slope 14.5 degrees, depth 914 m, width 5.9 km], which is similar to the cliffs forming the terminal end of VS-III canyon [22.6 degrees, depth 960 m, width 7 km]. We propose that these regions formed once a continuous canyon; the VS-IV paleovalley (VS-IV PV). The Rough Knobby Channel floor region (Figure 3, RKchf) forms the northern section of the VS-III main canyon. The transition from the VS-III to the RKchf region is characterized by widening of the canyon and an increase in roughness to that characteristic of “chaotic terrains” and an elevation drop of about 100 meters. Within the RKchf, there is the local smooth depression region (Figure 3, LSD), which is elliptical and in plain view and about 1400 meters deep and 9 km wide. We propose that early in its history, the main valley from the VS-III was continuous with VS-IV paleovalley, which extended extended along the present course of the VS-IV.Thermal and/or mechanical erosion produced by flows along the VS-IV PV resulted in the breaching of the permafrost seal of a confined aquifer, what led to surface collapse and catastrophic water release, producing the floods, which excavated the present VS-IV. The material resultant from surface collapse produced the VS-IV HS region (Figure 3). Drainage of the confined aquifer might have led to local lowering of the water
Sources of water related to the excavation of the Shalbatana Valley system
J.A.P. Rodriguez et al.

Table, and subsequent subsidence and collapse of the margins bounding the channel and chaos system. This resulted in the formation of the SPM and MFC regions (Figure 3), which collapsed over a section of VS-IV PV. The formation of the SPM and MFC regions might have block any later floods from the VS-III. Temporal ponding of this region could have resulted in the water enrichment of the substrate, which led to later surface collapse, possibly thermokarstic degradation and lateral expansion of the canyon by mass waste, resulting in the formation of the RKChf region. Local collapse and subsequent filling might have produced the LSD region. We propose that the water involved in the excavation of the VS-IV was derived mainly from drainage of the temporally ponded [12] VS-I, B-A and VS-II regions (Figure 1), by the VS-III channel d2 [9,11]. Rodriguez and others [11] proposed that subsidence related to longlasted subsurface degradation, possibly by water flowing through underground conduits [10], took place in the VS-III region. We suggest that ground water might have also acted as a source for the excavation of the VS-IV. According to our observations, the chaotic material in the region Cht (Figure 1) derived from surface collapse over a confined aquifer (Figure 1, VS-IV HS), is much smaller than previously estimated [9]. We propose that the water released from this confined aquifer flowed along the preexisting VS-IV PV, but did not significantly contribute to the excavation of the VS-IV bulk volume.

THE CASTALIA MACULA REGION: A PLATE RECONSTRUCTION MODELLING TEST CASE.  G. W. Patterson and J. W. Head, Department of Geological Sciences, Brown University, Providence, RI, 02912 (Gerald_Patterson@brown.edu).

Introduction: Images of the surface of Europa, gathered by both the Voyager and Galileo spacecraft, have indicated the ubiquitous nature of strike-slip and extensional features [1] but identification of compressional features has been more elusive. Several hypotheses have been put forward [2,3,4,5,6] but, to date, no single hypothesis has been satisfactory in accounting for the amount of extension observed on the surface. Furthermore, it is more difficult to find a unique reconstruction for regions that are suspected to have undergone compression using the qualitative ‘cut and paste’ method of reconstructing plate motion for divergent and transform boundaries that has been more commonly used to date.

Here we report on the development of an inverse model capable of quantitatively determining the Euler pole of rotation between two (or more) plates and therefore providing a more unique and constrained reconstruction of the plate history in a given region. We use this model on the Castalia Macula region of Europa, a region that appears to have undergone compression [5,6]. The subsequent reconstruction of these plates serves to test the hypothesis of ridges as sites of extensional features [1] but identification of compression [2,5].

The Model. The inverse model we have developed uses an iterative grid-search method to find an Euler pole of rotation for the region to be reconstructed such that ridges cut and offset will be re-aligned. The result is a minimized best-fit pole with confidence regions. This is a brute force method that is mathematically simpler than other methods but computationally more cumbersome. The computational requirements of this modelling technique limit the resolution of the grid that can be used to determine the Euler pole but it is sufficient to fully resolve the pole for the resolution of the image used.

The model uses two points (A and B) on a fixed plate to form a plane through the body. The normal to that plane is determined using equation 1 and the distance from that plane to a point on the plate to be reconstructed that corresponds to the offset feature of the fixed plate is determined using equation 2.

\[
\begin{align*}
N_x &= (A_y \times B_z - A_z \times B_y) / \sin \delta \\
N_y &= (A_z \times B_x - A_x \times B_z) / \sin \delta \\
N_z &= (A_x \times B_y - A_y \times B_x) / \sin \delta \\
\delta &= \cos^{-1}\left(\frac{A_x \times B_x + A_y \times B_y + A_z \times B_z}{|A_x \times B_x + A_y \times B_y + A_z \times B_z|}\right)
\end{align*}
\]

A best-fit reconstruction of the points described involves rotating point C on the plate to be reconstructed about an Euler pole such that it falls in the plane of points A and B on the fixed plate. To accomplish this we can rotate point C using a rotation matrix (equation 3), where \(R_q\) is the rotation matrix and it is defined by an Euler pole \(E = (E_x, E_y, E_z)\) and an angle of rotation \(\Omega\) [7].

\[
\begin{bmatrix}
C_x' \\
C_y' \\
C_z'
\end{bmatrix} =
\begin{bmatrix}
R_{11} & R_{12} & R_{13} \\
R_{21} & R_{22} & R_{23} \\
R_{31} & R_{32} & R_{33}
\end{bmatrix}
\begin{bmatrix}
C_x \\
C_y \\
C_z
\end{bmatrix}
\]

The confidence regions (95% and 99%) for the determined pole is calculated using the following equation [8]:

\[
R = R_{\text{min}} \left(1 + \left(\frac{N / M - N}{N, M - N, 1 - \alpha}\right)^{1/2}\right)
\]

Study Area: The region reconstructed is located in the Castalia Macula region of Europa (Fig. 1). The region in the image is centered about the equator and spans ~800 km. We rotated one plate in this region that is marked by numerous offset features (Fig. 1), 27 of which were used in this analysis (the main criterion for choosing these features was clarity of the precise location of each feature across the plate boundary).

The model determined the Euler pole that minimized the distance between the offset features after iterating through every possible combination of pole location and rotation. The resolution of the grid used was increased steadily until we reached the resolution limit of the image. Figure 2 indicates the location of the best-fit pole for this region. The final grid employed was a 1° x 1° latitude/longitude grid with possible rotations tested ranging from -1° to 1° in .01° increments. The pole location is 11° lat. and 253° lon. with ~0.43° rotation and the post reconstruction misfit of previously offset features for this reconstruction is within the resolution of the image. This, along with the tightly constrained confidence regions, indicates that a best-fit Euler pole for the region in question has been determined.
Fig. 1. Castalia Macula region (centered at ~0° lat and 227° lon) as seen in Galileo E17REGMAP01 mosaic (220m/pix; transmercator projection).

Fig. 2. Graph indicating position of best-fit Euler pole for Castalia Macula region. Dashed lines represent 95% and 99% confidence regions.

Conclusions: The reconstruction of this region (Fig. 3) indicates that compression has taken place in the history of this region and that it is primarily found the eastern ridge indicated in Fig. 1. This method represents a quantitative fit to the data and indicates with a high degree of confidence (Fig. 2) that the reconstruction shown in Fig. 3 is the unique solution. The applicability of this model goes beyond resolving one reconstruction though. Given increased spatial coverage provided by future missions, this model will be useful in developing a more complete picture of the global distribution of tectonic styles on the surface of Europa. Furthermore, it would also be applicable to any body with evidence of plate motion.

Fig. 3. Reconstruction of Castalia Macula region. Red lines indicate pre-reconstructed position of plate and yellow lines indicate post-reconstructed position.

Acknowledgements: We would like to thank Donald Forsyth for his assistance in developing the inverse model.

EARLY EARTH AND XE-MISSING PROBLEM SOLUTION. G. V. Pechernikova, A. V. Vityazev and A. G. Bashkirov, Institute for Dynamics of Geospheres RAS, 38 Leninsky pros p. (bldg. 1), 119334 Moscow, Russia (avit@idg.chph.ras.ru)

Introduction. The “Missing Xenon Problem” is an outstanding cosmo- and geochemical puzzle that relates to observed concentrations of noble gases in the Earth’s atmosphere. Many chondrites show similar noble gas abundance patterns, referred to as the planetary noble gas pattern (see Fig. 1). Compared to the solar pattern, the planetary pattern is enriched in the heavier noble gases. After considering addition of radiogenic Ar and loss of He, elemental rations of noble gases in the Earth’s atmosphere are similar to those in the solar system (as determined from meteorites) with the notable exception of a 10- to 20-fold deficiency in Xe [1-4]. We suggest that Xe was stored in carbon dioxide clathrate hydrates at the early Earth and was missing during the late stage bombardment.

Backgrounds for estimations.

(1) According to analytical calculations [5, 6] and computer simulation [7] the Earth accreted 95-99% of its present mass in a 50-100 Ma period. With a planetesimal mass spectrum \( n(m) \propto m^{-q} \) we can estimate as a rough approximation that during the ensuing 100–200 Ma the Earth has been impacted by \( \sim 10^{10} \) bodies of sizes 1 km, \( \sim 10^7 \) bodies of sizes 10 km, and \( \sim 10^5 \) bodies of sizes 100 km. About 5-10% (in projectile mass) of near surface substance was ejected from the Earth [5, 6].

(2) Smaller then modern Solar luminosity and lower annual temperatures of the early Earth favoured the occurrence of gas hydrates in permafrost or in early seas. Radiogenic \( ^{129}\text{Xe} \) and fission \( ^{136}\text{Xe} \) data tell that missing Xe stage must be during this period [8].

(3) In order to estimate the amounts of Xe and other gases stored in gas hydrates in permafrost or in early seas during hydrate formation we can take into account the data enrichment factors for noble gases in current oceanic gas hydrates [9].

Results. Assuming that it is essential to lost \( 10^{16} \) g of Xe. Taking into account its content in clathrates 2-10\(^7\) [9], it needs incidentally to draw off \( 10^{22} \) g of C and \( 1.5\times10^{23} \) g of H\(_2\)O. The last value is appropriate for the case of permafrost but it would be 2-3 time more in the case of sea-clathrates. For the clathrates layers at a depth of 500–1000 m the conservative estimation gives the value closely to the water mass of modern oceans \( 1.4\times10^{24} \) g. Takin into account fractionation of the noble gases during gas hydrate formation [9] we estimated the losses of Ar, Kr and Xe along with early gas hydrates during the late stage bombardment (dashed line 7 in Fig. 1).

Conclusion. According to our explanation of missing xenon problem the surface of the early Earth was not so hot (here and there, from time to time), despite the violent differentiation processes in deep interiors and late bombardment effects.

![Figure 1. Relative abundances of noble gases in solar system matter (from data of Table II in [2]). The losses of gases relative solar abundances are shown (in the Log-scales) by curves: 2 – for meteorites C1 chondrites, 3 – for meteorites E chondrites, 4 – for Venus atmosphere, 5 – for Earth’s atmosphere, 6 – for Mars atmosphere. Solar abundances are shown by curve 1. Estimated losses of Ar, Kr and Xe along with early gas hydrates during the late stage bombardment are shown as dashed line 7.](image-url)

ON A PROBLEM FOR SEARCHING OF EXO-PLANET SATELLITES. N.I.Perov¹ and A.A.Nahodneva², ¹State Pedagogical University, Astronomical Observatory, Respublikanskaya, 108. 150000, Yaroslavl, Russia, e-mail: perov@yspu.yar.ru, ²State Pedagogical University, Department of Theoretical and Experimental Physics, Respublikanskaya, 108. 150000, Yaroslavl, Russia.

Introduction: Dynamical evolution of the Solar planetary system [2], [6], [3], [4], and since 1995 evolution of theexo-planets [9], is one of the main problems of celestial mechanics. Discovery, based on the observations, of extrasolar planetary systems (at November 2002 there had been found 100 planets like Jupiter) was one of the important results of the astronomy of the end of XX century and stimulated development of astronomy. The general direction of theoretical works, devoted to extrasolar planets, is improving of the cosmogonical models. The modern cosmogonists consider the discoveries of planets Earth-type and minor bodies, formed new planetary systems, will be in observing astronomy in the first and the second decades of the XXI century [7], [8].

We determine of regular, irregular, coorbital satellites of planets as natural celestial bodies, diameters of which are no less 1 km, and which are revolving around the planets (distance between the planet and the satellite is smaller by a factor of several orders in comparison with the distance between the planet and the Sun). In this case the «planet centric» force predominates over forces, are due the influence of the Sun, others planets and secondary satellites, oblateness of the planet, though the letters may set up significant perturbations of satellites orbits. It should be noted for the solar planets satellites the perturbations from the others planets are small, in comparison with perturbations of the Sun, and so others planets perturbations do not determine the motion of the satellites [2], [6].

In 1999-2003 many new small satellites of Jupiter (44), Saturn (13), Uranus (6) and Neptun (3) has been detected [4], [10]. Opening this unusual collection of the satellites, discovered for the short interval of time, is an outcome of application of special methods for searching these objects and using of modern equipments, including 8.3 m telescope “SUBARU”, permitting to scan across the great regions of sky near the giant planets [10].

In accordance with aforesaid it is very important and interesting to estimate by theoretical way numbers of unknown satellites of Saturn, Uranus, Neptun (the number of known satellites of Neptun remains almost constant for the decade and a half, after the flight of “Voyager-2” near this planet [5]) and satellites of the exo-solar planets basing on the known parameters of these planets.

Oblateness of the solar planets and number of theirs satellites: In the table 1, made up with due account of observed data [4], [10], connection between number (N) of the secondary satellites and geometric oblateness (α) of the Solar system planet is set up. N₀ is known number of the observed planetary satellites and Nᵣ(α) is a number of satellites, calculated by a formula (1)

\[ N(\alpha) = -0.0264 + 312.4280 \cdot \alpha + 10836.6567 \cdot \alpha^2 \]  

(1)

Table 1. Oblateness (α) of the Solar system planets and number (N) of the planetary satellites (1.09.03).

<table>
<thead>
<tr>
<th>Planet</th>
<th>Oblateness, α</th>
<th>Number of observed satellites</th>
<th>Theoretical number of satellites, Nᵣ(α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Venus</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Earth</td>
<td>0.0034</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mars</td>
<td>0.0052</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Jupiter</td>
<td>0.062</td>
<td>61+rings</td>
<td>61</td>
</tr>
<tr>
<td>Saturn</td>
<td>0.103</td>
<td>31+rings</td>
<td>147</td>
</tr>
<tr>
<td>Uranus</td>
<td>0.06</td>
<td>21+rings</td>
<td>58</td>
</tr>
<tr>
<td>Neptun</td>
<td>0.02</td>
<td>11+rings</td>
<td>11</td>
</tr>
<tr>
<td>Pluto</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

The equation (1) is derived with help of the least square method (the planets and the satellites up Jupiter including are considered). The great number of the significant digits underscores the negligible influence of computers errors (32 significant figures with help of system REDUCE are kept up). Criterion of Fisher - Snedecor [1] for the (1) equations gives \( F=74184.820>> F_{0,01;2;2}=999.0 \) (\( F_{0,01;2;1}=4999.5 \)), that is evidence of significance of regression equation (1). Moreover, coefficient of determination is \( R^2\alpha=0.999986 \) and variance is \( S^2=0.0196 \). It is clear, \( N(\alpha) = 0 \) for \( a_0=0.028915 \) and \( a_1=0.00008414 \). The minimum of the function of \( N(\alpha) = N(\alpha) = -0.014415 \) < 0, but usually only positive values of oblateness (α>0) are dealt with.

Pay attention two facts. A) In the frame of the restricted three body problems it is proved the great value of oblateness of the planet interfere with falling dawn of the nonecliptical satellites on surface of the central body [2, 6]; B) Poincare’s and Crudely’s theorems impose restrictions on angular velocity of rotation and geometric oblateness of gravitating liquid in a state of relative equilibrium.

Table (1) illustrates good agreement \( N_0 \) and \( N(\alpha) \) for the planets nearest to the Earth (and space of near which is better investigated). Since for Neptune \( N_0=N(\alpha) = 0 \), we should wait the satellite sys-
tem of Neptun are not so developed as the satellite systems of Jupiter, Saturn and Uranus.

Basing on the table 1 we suggest the hypothesis: with help of cosmic mission “Cassini” 116 satellites of Saturn will be discovered since July 1, 2004 (if these unknown satellites will not be discovered earlier from the ground and cosmic observations) and state the number of unknown satellites of Uranus equals 37 (at September, 2003) and the geometrical oblatenesses of Mercury and Venus are about of 0.00008 and oblateness of Pluto equals approximately 0.003.

**Size distribution of the solar planet satellites:**

Based on the [11] we may set up a statistical formulae for distributions of the radii of the satellites of the Solar system planets depended on the semimajor axes of the satellites orbits. From majorities of such formulae we draw the next one

\[ R = A r^B \exp(C r^D) + E F, \]  

(2)

where \( R \) is radius of the satellite and \( r \) is the orbital semimajor axes of this satellite and \( A, B, C, D, E, F \) are constants to be determined. For the case \( D=-1.0 \) and \( E=-1.0 \) it is easy to find the numerical values of \( A, B, C, D \) for the satellite systems of the giant planets. (Table 2).

<table>
<thead>
<tr>
<th>Planet</th>
<th>( \ln(A) )</th>
<th>B</th>
<th>C</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>7.1573</td>
<td>-5.0038</td>
<td>0.7179</td>
<td>-2.7109</td>
</tr>
<tr>
<td>Saturn</td>
<td>5.9636</td>
<td>-2.3553</td>
<td>1.0184</td>
<td>-0.9880</td>
</tr>
<tr>
<td>Uranus</td>
<td>3.5883</td>
<td>-2.8164</td>
<td>0.28045</td>
<td>-1.7321</td>
</tr>
<tr>
<td>Neptun</td>
<td>4.7893</td>
<td>-2.1114</td>
<td>0.3253</td>
<td>-1.1656</td>
</tr>
</tbody>
</table>

For Jupiter: \( F_{t;0.56}=72.7, R_{\mathrm{ma}}^2=0.7956, S_e^2=0.8239 \). For Saturn: \( F_{t;1.27}=10.9, R_{\mathrm{ma}}^2=0.5483, S_e^2=1.9840 \). For Uranus: \( F_{t;1.17}=22.9, R_{\mathrm{ma}}^2=0.8019, S_e^2=0.4655 \). For Neptun: \( F_{t;1.7} =14.8, R_{\mathrm{ma}}^2=0.8641, S_e^2=0.32 \).

Here, \( F_{t;1.2} \) is criterion of Fisher [1], \( R_{\mathrm{ma}}^2 \) is coefficient of determination and \( S_e^2 \) is dispersion. (The least squares method has been used). Formally for the Solar system planets all the equations of regressions (2) are significant (\( F_{0.05;3}=4.35 < F_{t;1.2} \)).

**Conclusion:** The exact quantitative relationships between numbers of natural satellites of the planets of the Solar system and parameters of these planets, and between radii of the satellites and theirs orbital semimajor axis would make it possible to discover and investigate satellite systems of exo-solar planets, because the Solar system is not unique in the Galaxy [9].

PHOTOMETRY OF REGOLITH-LIKE SURFACES: ALBEDO AND SURFACE ROUGHNESS EFFECTS. D. V. Petrov, Yu. G. Shkuratov. Astronomical Institute of Kharkov National University. 35 Sumskaya St. Kharkov. 61022. Ukraine. petrov@astron.kharkov.ua

Introduction: Spectroscopic, photometric, and polarimetric observations of planetary regoliths demand fundamental interpreting basis that at present time includes theoretical modeling, computer and laboratory simulations of light scattering by particulate media. The most effective approach to study light scattering objects of complicated structure (like planetary surfaces) is computer experiments. The basic idea of the experiments is very simple. In the computer memory a scattering object is generated. This can be a regolith-like medium or a random surface with complicated topography. Then the object is illuminated by a great number of rays that are multiple scattered between different elements of the system (between particles or topography elements). The experiments result in the scattering indicatrix of the object. Unlike real measurements, the computer modeling allows control of parameters described a given light scattering problem. Besides, there are problems that, because of their complexity, can be resolved only with computer simulations. One of such problems is multiple scattering on hierarchically arranged topography. This problem is very topical for interpretation of planetary photometric data.

At scales much more than particle size, the planetary regolith surfaces are complicated with a random topography that influence phase curves primarily at large phase angles (see Fig. 1a,b).

First approximation models accounting for the influence of the large-scale topography were presented by Smith [1] and Hapke [2,3] and used in many applications. Improvements of the models are very difficult, as the rigorous description of shadowing even for single-valued random surfaces demands continual integrations (e.g., [4] and references therein). We consider here results of our computer modeling, which allow us to estimate the roles of the hierarchy in multiple scattering for planetary surfaces.

If a planetary surface is weakly absorbing (e.g., the surface of an icy satellite), incoherent multiple scattering can contribute considerably to photometric properties in the whole range of phase angles. The standard photometrical model does not take into account it [3]. Meanwhile, the multiple scattering on a surface topography results in decrease of effective surface roughness, as this decreases the effect of shadowing [3,5-7]. Hence the phase curve of a rough surface with high albedo should have fewer slopes than that of a dark surface with the same roughness. We can expect that the albedo increasing may at least approximately be compensated with the proper roughness decreasing [6]. Thus one can say about the effective or photometric roughness depending on the surface albedo (e.g., [5-7]). We study this possibility for continuous random surfaces with Gaussian statistics including the case of hierarchical topography.

Computer Model Description: We use here a ray-tracing model that is applied to study single and multiple light scattering by continuous random surfaces characterized with the angle of RMS slope $\theta$. An initial ray is traced from a random point of the surface in the direction of a light source. This ray can either leave the surface without interruption (and hence the point is illuminated) or intersects the surface (and hence the point is shaded). After that, a new ray is traced from the point in the direction of an observer. If this ray does not intersect the surface, the corresponding point is visible. If the point is both visible and illuminated, it gives a contribution to the intensity of scattered light in the first order of scattering. To calculate the second scattering order, we trace a ray from a visible point (point 1) in a random direction. If the ray intersects the surface in an illuminated point (point 2), this provides the contribution of double scattered light.

To calculate higher scattering orders, we repeat these steps allowing for that if a ray does not intersect the surface or intersect it in a non-illuminated point, its contribution equals zero. The procedure is repeated many times from the very beginning for different surface points to reach desired accuracy of the ray-tracing process at calculation of all needed scattering orders. Surface elements are considered to have the Lambertian indicatrix. Computing multiple scattering we use single scattering albedo $\omega$ of the surface element.

Results and Discussion. Our model allows calculations at arbitrary illumination/observation geometry, but we focused here on one of them. We use the so-called mirror geometry, when $i = \varepsilon = \alpha/2$, $\varphi = \pi$, where $i$ and $\varepsilon$ are the angles of incidence and emergence, respectively, $\varphi$ is the azimuthal angle between the planes of incidence and emergence, and $\alpha$ is the phase angle.

Fig. 1. Types of topographies: (a) a simple random Gaussian topography, (b) a hierarchically arranged random Gaussian topography.
As has been pointed out multiple scattering of light between different parts of a rough surface decreases and we can expect that the albedo increasing may approximately be compensated with the proper roughness decreasing that leads to introducing of effective roughness $\theta_{\text{eff}}$ depending on the surface albedo. Fig. 2 shows dependences of $\theta_{\text{eff}}$ on $\theta$ for a simple random Gaussian topography.

Fig. 2. Dependences of $\theta_{\text{eff}}$ on $\theta$ for random Gaussian surfaces with different albedo $\omega$ at the mirror geometry.

An analogous consideration can be carried out for a hierarchical topography. We study here a topography with two hierarchical levels (each is a random Gaussian topography with a given $\theta_0$), when the large-scale topography is regarded as a reference surface for the small-scale topography (see Fig. 1b). Fig. 3 shows $\theta_{\text{eff}}$ as a function of $\theta$ for hierarchical surfaces of 2-levels, each being a random Gaussian surface with $\omega = 20^\circ$. As before the calculations were made for the mirror geometry. The effective characteristic angle is larger than $\theta$, as we use a 1-level surface to simulate the 2-levels one.

Thus we may summarize that influence of multiple scattering on large-scale topographies with the characteristic angle and albedo more than $30^\circ$ and 20%, respectively, is important. As the standard model [3] does not take into consideration the multiple scattering effect, all numerous determinations of the roughness parameter with this model appear to be slightly underestimated. The same was obtained for other illumination/observation geometries [5].

Fig. 3. Dependences of $\theta_{\text{eff}}$ on $\theta$ for a hierarchical surface formed with 2-levels that are random Gaussian surfaces with different albedo $\omega$ at the mirror geometry.

**Conclusion.** Multiple scattering between topography elements is important factor that should be taken into account in improvements of interpreting photometry of planetary surfaces with high enough albedo. Numerous determinations of the roughness parameter of planetary surfaces with the standard model [3] appear to be slightly underestimated. This is also important to analyze laboratory photometric measurements.

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We present a revised model of soil evolution constrained by the recent LSCC data for lunar soils. In addition to an observed universal increase in feldspathic components in the finer fractions of soils [Taylor et al., 2001, 2003a, 2003b], both differential melting and lateral mixing processes appear to be required during the evolution of lunar soils. We propose mare-highland mixing of a significant glass component along with a preferential melting sequence for agglutinitic glass formation of: glass > plagioclase > pyroxene.

In Press:
VENUS: GLOBAL MAPPING OF RIDGE BELT PATTERNS. E.V. Pivchenkova¹, V.P. Kryuchkov²,
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Summary: Using Magellan SAR images we have mapped globally one of the most widespread
compressional structures of Venus – Ridge Belts (RB). This is the first Global Ridge Belts’ map in
the history of investigation of Venus. We plan to use this map to model then the formation of the
Ridge Belts network of Venus using technique of the analog tectono-physical modeling (see, e.g.1).
This is aimed to understand the mechanisms of tectonic deformations in the upper part of Venesian
lithosphere including its crust. But even by now we can represent some information we’ve obtained
from the results of our mapping.

Introduction: Ridge Belts are linear elongated structures which extend up to several thousand km
in length, 70 to 300 km in width and have as much as up to 1.0 - 1.5 km of relief [2]. They are
composed of ridges arranged in subparallel clusters with few kilometers mean spacing of the ridges.
According to stratigraphical scheme proposed by [3], the material, of which RB is composed, and the
ridges themselves formed in the Lavinian period of the geological history of Venus and thus are
considered to be rather old.

Procedure of mapping. Using the Magellan SAR images (C1 format) we performed
photogeologic computer mapping. We mapped outlines of the Ridged Belts on individual C1-
MIDRs and then compiled all the fragments into one global digital map (fig.1).

Discussion.

1. Distribution and the strike: Ridge belts are distributed irregularly on the surface of the planet.
They tend to cluster at the areas near the geographic poles of the planet while in equatorial zone RB occur mostly as isolated islands embeded
by younger units’ material (see the map). In total the belts and their fragments tend to have NW-
NNW strike. Subordinate orientation of the RB strikes are NE and NW. Other orientations are relatively rare (fig.2).

2. Relationships with other units: The Ridge belt (Pfr) material in all observed by us localities is
embayed by the Pwr/Psh regional plains thus confirming stratigraphic relations described by [3].

The relationships between Tessera Terrain and RB material still remains uncertain. In the areas
where we can observe the RB and Tessera contacts, the former either adjoin Tessera or cuts into it
slowly vanishing. In some of these cases, for example, in Ovda Regio, within the Tessera
material are observed ridges looking as a continuation of the deformation of the neighboring Ridge belts.
The thickness of competent layer: We also measured the spacing of ridges in belts which made
4.3 km in average. Then using the coefficients proposed by [4] we estimated the thickness of
competent layer on the moment of deformation as 0.5< h< 2.5 km.

Impact craters and RB: As it was shown in
previous works [5] ∆T/T should be equal Npred / Npost, where Npred - amount of craters superposed
on the older unit formed before the end of younger unit emplacement; Npost - number of craters
superposed on the older unit after the emplacement of a younger one. In this case ∆T is the time
interval between the formation of RB tectonic structures and the emplacement of regional plains material, T- the average age of the surface of Venus
[5]. Using our previous results [6] we calculated
∆T=14%T. This means that the time period responsible for the transition from RB material
deformations to the regional plains emplacement (including their deformation by wrinkle ridges) was
sufficiently short. Our estimates should be interpreted cautiously due to the assumptions we
made, but they can be used to illustrate the suggested by [3] model of the geological evolution
of Venus: at the early stages of the morphologically recorded part of its geological history, Venus was
much more active that in the subsequent (post-regional-plains) time.

Tectonic origin: Broad ridges in Ridge Belts are most likely to be formed by compressional
deformation [7],[8],[9], while the fractures observed in some localities of RB unit are due to
extensional strain. Thus both compression and extension participated in the formation of these
structures.

Conclusions: RB are no doubt the evidence of a certain tectonic regime in the history of Venus.
They formed in general in the compressional condition. Their well ordered global pattern
demands explanation which we hope to get in the future investigations.

Acknowledgments: We wish to thank A.T. Basilevsky for the suggestion to do this work and
further support.

Fig. 1 The Map of Ridge Belts and Tessera Global Distribution on the Surface of Venus.

Fig. 2. The Ridge Belts Strikes Histogram. (N-the number of belts or their fragments with certain orientation of the ridges)

Abstract
We compared analogous sites on Earth to those Martian areas where a peculiar spotting phenomenon on the dark dunes occur. We found possibly candidates to these appearing and disappearing living organisms: those cyanobacteria which form the crypto-biotic-crust in hard terrestrial conditions.

Terrestrial spots with transient living conditions
According to Australian analogies (in the "Red Heart" of Australia, between Alice Springs and the Ayer's Rock) the Crypto-Biotic-Crust (CBC) regularly occurs and forms continuous, some hundred meter - kilometer sized spots with dark violet color on the wet plains between the hills or dunes, where the waters are collecting. After one-two months of active life period the dried CBC waits for the next wet season. The violet-black color is given to the surface by the scytonemin pigment of the cyanobacteria which play important role in this crust. This violet-black color pigment accumulates in the gelatinous cover of the cyanobacteria and it is protecting the living cell and its pigments for assimilation from the intensive UV radiation, and such way this layer makes possible the survival of the cells. Because the cyanobacteria are capable to survive in extreme cold or heat, and moreover dry conditions, it is probable that they also can survive the hard Martian conditions. Even those cyanobacteria were capable to awake to live which were in frozen state for millions of years in the Siberian permafrost. On the basis of these analogies we may suspect and assume that in the given Martian conditions the dark dune spots are resulted in from CBC consisting of cyanobacteria or other similar living organisms.

Martian spots with transient living conditions
These spots are named Dark Dune Spots (DDSs) and various hypotheses have been put forward for their origin and formation process, which fall into two main groups: geophysical and biological [1, 2, 3, 4, 5, 6 and 10].

Based on a detailed study of more than 400 MGS NA MOC images of Southern Polar Region of Mars we suggested a kind of biogenic origin of DDSs [2, 6], which is similar in many aspects to those life cycle, then that of the CBC organisms.

Characteristics of the Dark Dune Spots
Here we summarize the main characteristics of the DDS phenomenon in order to show the basic similarities to a CBC-type behavior.

The main morphological characteristics of DDSs are [6]: Ø diameter varies between a few dozen and a few hundred meters, Ø on the flat areas the majority of the early DDSs are circular (Fig. 1a, 1b, 1d, Fig. 2), Ø circular shapes of DDSs are super imposed on the local small-scale topography, Ø on slopes elongated DDSs develop (Fig. 1e), Ø elongation depends on the slope angle (from some spots extensions point downwards), Ø seasonal changes (Fig. 1a,b,c and Fig. 1d, 1e, 1f) and Ø annual reappearance (Fig. 3a, 3b).

Fig. 1.-The seasonal changes of the DDSs in the same places (a, b, c) of the Inca City (295°E, 82°S) and the different places (d, e, f) of the Pityusa patera (37°E, 66°S) areas from winter to summer. Arrows indicate lighter gray patches.

We observed [2, 5, 6], that the DDSs slowly changes in shape, extent, and number and reappears in the next year. We found the following time sequence of the morphological changes of DDSs: initially little gray fuzzy spots (or fields of spots) appear (Fig. 1a); the boundary of the gray fuzzy spots gradually becomes sharper and grayier (Fig. 1b, 1d, Fig. 2a, 2b).

Finally, the boundary extends, when all frost have sublimated (summer), lighter gray patches (LGP rings with darker central portion) remain at the site of the DDSs (Fig. 1c, 1f) and in next year about 70% of DDSs reappear in the same places [9].
ON THE BASIS OF TERRESTRIAL ANALOGUE SITE STUDIES ARE THE DARK DUNE SPOTS REMNANTS OF THE CRYPTO-BIOTIC-CRUST OF MARS?

The dark dune spots (DDSs) on Mars appear in early spring and grow larger until the end of spring, but summer no traces of DDSs can be seen on the defrosted dark dunes.

**Discussion: Current CBC on Mars?**

The fact that extensions originate from some spots indicates some downward seepage or flow, i.e. transport of a fluid phase, which occurs below the frost cover (Fig. 1c).

We interpreted the DDS sequence of changes in the following way.

The bulk radial symmetry, (some outflow – seepage – patterns) and the defrosting beginning from bottom of the frosted layer means that a process begins at the frost-soil surface boundary.

DDSs gradually become holes in this process. In the DDS process – gray period – the frosted layer gradually becomes thinner and finally disappears. This may imply that the melting/evaporation process “eats up” the frosted layer. The DDS holes allow the light and atmosphere to make contact with the dark surface at the bottom where the DDS centers develop.

**Fig. 3 The annual reappearance of the DDSs in the Inca City (a, b, [6]) from 1998 to 1999.**

**Summary**

We suggested a CBC type terrestrial analogue process as a biological interpretation of the DDS phenomena [2, 6]. In this model we combined the sublimation processes with some kind of process are cyanobacteria type organisms which constitute the crypto-biotic-crust cover on terrestrial extreme surfaces [11]. If such CBC type crust of extremophile bacteria exist on Mars (earlier we called them Martian Surface Organisms - MSOs), they could live only below the surface ice, and they could survive the cold and dry (summer, autumn) periods, without the frost cover, in a dried state. When the frost layer is heated up by its absorption of sunlight, MSOs produce water from the frost, grow and reproduce through photosynthesis. This way CBC-MSOs can generate their own living conditions (liquid water and water vapor can also contribute to sustain this form of life). Activity of the MSO communities governs the defrosting/melting process on the top of the dark dune surface where the DDSs can be observed.

**Acknowledgments**

Authors thank for the use of MGS MOC images of NASA and Malin Space Science Systems [12].

**References**

In the previous papers we considered correlation the Lunar Prospector thorium contents with structure of the lunar surface [1]. The surface roughness was estimated by means comparison of the local phase function and the average integrated lunar indicatrix. The average integrated lunar indicatrix was used as a background photometric model [2]. The great difference between the modelled and observed phase functions for phase angle in range about 18° demonstrates a high degree of the surface roughness. The value of this difference of intensities was used as a photometric parameter of the surface roughness. A good correlation between the local size-frequency distribution of the fragments and photometric parameter of roughness was observed. Comparison of the local cumulative number of the particles (N per 10⁴ m²) and photometric roughness parameter (∆I) shows in Figure 1.

Figure 1. Comparison of the local cumulative number of particles N per 10⁴ m² and photometric roughness parameter ∆I.

In this report we research data of the IR thermal radiation, the rough structure of the lunar regolith and mineralogy characteristics upper layer of the surface. The analytic model of the lunar thermal field was realized as an angular function of the thermal infrared radiation in the IR spectral region (10-12 micron). The basic material for investigations is the scanned cosmic spectrozonal images of the lunar surface transmitted by the first Russian geostationary artificial meteorological satellite of the Earth “GOMS” [3]. The model the surface described the surface-temperature by the radiation temperature vector in the range of positive values of the angular parameters: the incidence angle (i), the reflection angle (ε), and the azimuth angle between the plane of the incident and reflected rays (A). Figure 2 shows diagram of the vector of the thermal radiation for angle incidence of the solar-light i = 60°, the reflection angle ε = 0° - 90°, and the azimuth angle A = 0° - 180°.

Figure 2. The spatial graphical function of the lunar-surface thermal radiation.

A comparison of the analytic model of the lunar thermal field and radiation temperatures measured shows a systematic departure of the measured values from the average values. The statistical analysis of the photometry database given lunar sites has allowed allocating 4 groups of thermal anomalies. The sites of the surface having a different thermal conduction of the ground, sites located on the edge of the Moon’s limb, "hot spots" - sites, which area are less than the sanction of the detector, anomalies stipulated by the relief concern to thermal anomalies. Thermal anomalies connected to relief may be related to non-stationary thermal phenomena. The thermal anomalies are dated for such large craters as Copernicus, Tycho, Stevinus and other craters. That is called by irregularities of the relief of the crater floor. On detail study of large-scale photographs some anomalies are identified with small-sized craters, others with separate clusters of stones. Images of the crater Copernicus and crater Tycho are shown on the figures 3, 4. The difference of the surface temperature these thermal anomalies exceed 20 K, the value of the cumulative number of particles composes 4 and 32 respectively.

Figure 3. Image of the crater Copernicus (94 km, 10°N, 20°W, Clementine picture).
The values of thorium contents and iron contents for separate sites of the lunar surface have been determined under catalogue Lawrence [4].

We have compared the data of thorium and iron contents and the value IR radiation temperature of the surface for landing sites. It's observed a good correlation between temperature TK and the local Th-content, between temperature TK and FeO-content. The lines of the polynomial trend of the dependence of radiation temperature, thorium content and iron content, quantity of particles, difference of the measure and calculation temperature were shown on diagram (figure 5). The separate points on diagram represent areas of landing sites: Surveyor I (43°W, 2°S), Surveyor III (23°W, 3°S), Surveyor V (23°E, 1°N), Surveyor VI (1°W, 0°N), Surveyor VII (11°W, 41°S), Apollo 11 (22°E, 1°N), Apollo 12 (23°W, 3°S), Lunokhod 1 (35°W, 38°N), Lunokhod 2 (30°E, 26°N), Lunar Orbiter II.

Table gives the parameters of the regression coefficients of the equation \( Y = a \cdot T + b \) for temperature-thorium (T-Th) and temperature-photometric index (T-\( \Delta I \)).

<table>
<thead>
<tr>
<th>Statistics Data</th>
<th>Y = a \cdot T + b</th>
<th>m</th>
<th>( \sigma )</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TK</td>
<td>384,9</td>
<td>10,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Th.</td>
<td>0,12 *T-41,7</td>
<td>4,3</td>
<td>1,4</td>
<td>0,89</td>
</tr>
<tr>
<td>( \Delta I )</td>
<td>-0,02 *T+9,82</td>
<td>1,2</td>
<td>0,3</td>
<td>-0,75</td>
</tr>
</tbody>
</table>

We may propose that possible KREEP-rich materials and the anomalies of the radiation temperature associated with photometry roughness of the crater floor. Probably, Th and FeO enter into composition of ejecta lunar materials; these are located on the surface or small depth. KREEP-rich materials are concentrated to mare basalt with a high content FeO. The local assimilation KREEP-rich materials ascribed to volcanic extrusions released or localized by impact and essentially influence on thermal balance of the Moon.

References:
Introduction: Each of the three Tharsis Montes volcanoes on Mars has unusual fan-shaped deposits located exclusively to the west-northwest of each shield. The fan-shaped deposits of the Tharsis Montes generally share three major facies: 1) a ridged facies, 2) a knobby facies, and 3) a smooth facies. Any explanation for the origin of the fan-shaped deposits must take into account both the similarities and differences in their morphologies, their approximately similar Amazonian age, and the fact that all three occur on the west-northwestern sides of the volcanoes [1]. Based on Viking Orbiter data, several models have been proposed for their formation, including massive landslides [2], glacial processes [3,4,5,6] and pyroclastic flows [6]. We support a glacial origin for the fan-shaped deposits and refine the previous models using new data. We have examined the Pavonis fan-shaped deposits using new Mars Global Surveyor and Mars Odyssey data. The Pavonis fan-shaped deposit (Figure 1) extends approximately 250 km northwest of the shield base along a N35°W trend [5]. This deposit ranges from 2.8-9.2 km above the Mars datum and covers an area of about 75,000 km², approximately half of the area covered by the Arsia deposit.

Ridged Facies: The ridged facies is present around the distal margins and the in central regions of the Pavonis deposit. A larger 50-100 m outer ridge defines the margins of the deposit, while nearly 100 smaller 5-30 m inner ridges lie within and concentric to this outer ridge.

We interpret these ridges as drop moraines formed at the margins of a retreating cold-based glacier [7]. The fact that these ridges can be seen in the proximal regions of the Pavonis fan-shaped deposit suggests that at least one major phase of retreat and deposition occurred. The ridges are superposed on underlying topography, including a lobate lava flow to the west, and are not deflected by obstacles. The fact that the ridged facies is observed up to elevations of 9.2 km above Mars datum on the northern flanks of Pavonis suggests that a large glacier would have covered a significant portion of the flanks of the shield.

Knobby Facies: The knobby facies at Pavonis is characterized by circular to elongate, km to sub-km scale hills and hummocks. The knobby facies is superposed on the ridged facies in several regions of the Pavonis fan-shaped deposit. There are two main concentations of the Pavonis knobby facies in the northern and western regions of the deposit. Using basic morphology and superposition relationships, we interpret the knobby facies at Pavonis as a sublimation till, passively deposited during in-situ down-wasting of stagnant glacial ice [7].

Smooth Facies: The smooth facies consists of broad, convex outward plains with gentle slopes and vast dune fields covering the surface. The smooth facies is interpreted to be the youngest unit within the fan-shaped deposits based on superposition relationships. There are four major isolated regions of the smooth facies within the Pavonis deposit. They cover an area of approximately 12,000 km², dominated by one continuous deposit north of the shield extending into the central regions of the fan-shaped deposits.

MOLA topography data reveal that the central regions of the smooth facies are over 500 m above the surrounding terrain, arguing against a pyroclastic origin. A series of secondary ridges, concentric to the current margins of the smooth facies, is also observed in the northern regions of the deposit. Based on new data, we interpret the smooth terrain to be debris-covered residual ice from the last major ice sheet present at Pavonis. Lineations within the main smooth facies deposit suggest that rock-glacier-like flow of the buried ice may be occurring.

Flow-like Features: Several unique flow-like features exist in the western regions of the fan-shaped deposits (Figure 1), which have been termed “lobate flow features” [5]. These features are morphologically distinct when compared to subaerial lava flows at higher elevations on the flanks of Pavonis or the Tharsis Plains flows beyond the fan-shaped deposits to the west. They consist of elevated plateaus with leveed edges and steep walls, some with a relief of over 500 m. High-resolution MOC images across these flow-like features reveal that they are superposed in places by the knobby facies, which continues uninterrupted onto the surrounding terrain. Based on Viking Orbiter data, Scott et al. [6] identify these features as elongate, sinuous ridges and suggest that they may be eskers formed by deposition of sedimentary material beneath or within a wasting ice sheet. They suggest an alternative explanation that these features may be unique lava flows originating from troughs on the lower western flank of Pavonis [5, 6]. An alternative explanation for these features involves subglacial eruptions [8]. This hypothesis is consistent with the unusual morphology, steep scarps, aspect ratios and superposition relationships of these flows. Terrestrial subglacial flows of this volume would be expected to produce a significant amount of heat and meltwater. We have observed some candidate fluvial features off the northeastern...
margin of the Pavonis fan-shaped deposit, which may represent meltwater outflow.

**Radial Ridges:** Several approximately linear ridges are present in the central regions of the fan-shaped deposits. These ridges are radial to the base of the shield and have dimensions of approximately 100-200 m high, 1 km wide, and 30-60 km long. One of these ridges continues beneath the smooth terrain and another is superposed by the western flow-like features. They have previously been interpreted as levees at margins of a broad flow channel [9] and eskers [6]. Analysis of high-resolution MOC images reveals that these features often display a forked morphology with steep peaks. Using these data, we believe that these features are radial dikes that erupted in a subglacial environment [8].

**Cold-Based Glacial Model:** Temperatures on Mars are such that glacial activity is more likely to be cold-based (i.e. polar glaciers) as opposed to wet-based glaciers typical of more temperate latitudes [7]. The fan-shaped deposit at Pavonis Mons appears to be the result of piedmont-style cold-based glaciation which occurred off the northwestern flanks in recent martian history. The well-preserved morphologies of each of the three main facies are all analogous to features associated with cold-based glaciers in the Antarctic Dry Valleys [7].

Additional evidence in support of a glacial hypothesis comes from three arcuate scarps concentric to the margins of the deposit. These scarps are typically 80-120 km long with an average relief of around 250 m. It appears that these scarps were formed when lava flows comprising the Tharsis plains were deflected from flowing toward areas of lower topographic elevation by the margins of an ice sheet.

**Origin of Proposed Glacier:** Recent modeling efforts reveal that the obliquity of Mars typically varies from 13°-42° with extremes between 0° and 60° [10]. The proposed ice sheet could have formed during periods of high obliquity where equatorial regions receive less solar insolation than the poles and can become cold traps [11]. Under these conditions, significant evaporative loss of any volatiles at the poles would occur [11]. These evaporative losses would increase the atmospheric volatile content, eventually resulting in precipitation at cold traps. Thus, “at high obliquities (>35°), significant amounts of water could be transported equatorward to be deposited as ice at low latitudes” [12]. It is possible that during periods of high obliquity, “a localized icecap could have been enhanced by orographic effects on wind circulation” [12]. We would expect that mountain-wave clouds would form over the summit of each of the Tharsis Montes and if the water-content of these clouds was sufficient, precipitation would occur. The fact that all three of the Tharsis Montes fan-shaped deposits are observed on the west-northwestern side of each shield would indicate that regional winds out of the east-southeast existed at the time of deposition.

If these ice caps forming during times of active volcanism, their composition would be influenced by erupted volatiles and ash [4]. The proposed ice sheets undoubtedly contained a significant amount of englacial and supraglacial dust or ash. This debris would be deposited as the ice sublimated and retreated, forming the features of the fan-shaped deposits.


Figure 1: a) MOLA topography of Pavonis Mons and associated fan-shaped deposits; b) Sketch map of area with ridged facies (R), smooth facies (ST), hummocky/knobby facies (H), flow-like features (FF), flank eruptions (FE).
EVALUATING THE STRUCTURE OF THE SURFACE LAYER OF MERCURY.

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Introduction. Like all atmosphereless bodies, Mercury is likely to be covered by a regolith layer that was formed in the process of space weathering. In addition, typical processes of space weathering (meteorite and micrometeorite bombardment, solar insolation, temperature changes, and others) must have their specific consequence in the case of Mercury. The ultimate result of these processes - the regolith structure - may indicate to what extent the individual features of Mercury's environment affect the formation of the surface layer. The ESA BepiColombo project plans to launch a spacecraft that will carry a lander to examine the surface of the planet, thus providing a direct study of the structure of its surface layer [1]. This is an appropriate time to make a preliminary assessment, using remote sensing data and taking into account the known similarity of the surface structures of Mercury and the Moon.

Photometric Analysis of the Lunar Surface Analogue. Based on the postulate of the identity, to a first approximation, of the photometric properties of the Moon and Mercury, one can represent the model of the surface layer of the regolith of Mercury using real images of the surface layer of the lunar regolith. The fragments of panoramas of the surrounding landscape transmitted to the Earth by the unmanned Luna 13 station [2] were selected for analysis. The advantage of these materials for photometric processing is their uniformity. Identical fragments of three panoramas obtained at different angles of incidence of solar rays were used. The operating range of reflection angles was $65^\circ$ - $80^\circ$, while the range of azimuth angles was confined within the range $70^\circ$ - $85^\circ$. This allowed the values of the measured phase function to be obtained in the range of phase angles from about $70^\circ$ to $75^\circ$. The images of exactly the same site obtained at three different angles of incidence of solar rays (the values of the angles are indicated in the figure caption) are given in Figure 1. These images demonstrate how the shadowed area changes together with the total brightness of this area. The smallness of the total area where measurements were made suggests that the upper regolith layer exhibits no albedo variations, except for some stony fragments.

The value of the measured integral brightness of each area was inferred from the average value of the image density (using a histogram). The resulting values were then reduced by the least squares method to the system of relative brightness specified by the phase function of the Moon or Mercury.

Fig. 1. Images of the same region of the lunar surface taken at different angles of incidence of solar rays: (a) $i = 58.4^\circ$; (b) $i = 62.7^\circ$; (c) $i = 68.2^\circ$. The reflection angle is $76.5^\circ$ for all images. The approximate size of the each site is 10 cm by 10 cm.

Fig. 2. The phase function obtained directly on some segments of the lunar surface: 1- phase function of the Moon, 2 - phase function of Mercury, 3 - phase function of segments, converted to the lunar phase function system (correlation 0.8), 4 - phase function of segments, converted to the Mercurian phase function (correlation 0.9).

The results of the observations and model comparison are shown in Figure 2: the fragments of the phase functions of the Moon and Mercury are given for phase angles from $60^\circ$ to $90^\circ$, and some phase brightness values (triangles) match the determinations from the panoramas obtained directly on the lunar surface and reflect the photometric properties of the surface layer of the
lunar regolith. It should be noted that the sample of areas for measurements, which is obtained in a random way, unexpectedly closely correlates in terms of the variation of phase brightness with the Mercurian phase function and less closely with the phase function of the Moon.

The Luna 13 landing site (63.05°W, 18.87°N) is located in the region of intense bright rays corresponding to the ejecta from the young Glushko crater. It is likely that this circumstance explains the anomalous character of the photometric properties of the lunar surface in the region of interest, with the properties of the mantling substance approaching the reflectance properties of Mercury's surface.

**Model of the Mercurian Surface Layer.**
Since an increase in brightness (see Figure 2) is accompanied by the general smoothing of the surface due to the destruction of larger irregularities and to the growth of the relative content of the thin regolith fraction [3], the above estimates of the roughness of the Mercurian regolith agree with the inference made above on the basis of the photometric analysis: the surface of the Mercurian regolith is smoother than the surface of the lunar regolith.

Figure 3 represents the result of modeling the surface structure of the Mercurian regolith layer on the basis of the lunar unit using the photometric properties shown in Figure 2. The lunar regolith upper layer is more rough than the modeled surface layer of the Mercury regolith (b). The picture (b) represents a possible view of the Mercurian surface under the same illumination. This modeling was performed by means of the decreasing shadow area algorithm. The phase function of segments such as (b) coincides with the disk – integrated phase function (see Figure 2). Therefore, the surface whose image is presented in Figure 3b may tentatively serve as an analogue of the structure of the upper layer of the Mercurian regolith.

**Conclusions.** The method described and the results of some remote ground-based investigations of Mercury show that the similarity of the surface structure of this planet to the Moon's surface can be used to obtain preliminary estimates of the structure and characteristics of the Mercurian regolith. Although in general similar to the Moon, the surface of the Mercurian regolith is nevertheless smoother, probably contains a greater amount of the fine particle size fraction, and has, on average, greater maturity. The results presented and their further modification are also of applied significance in planning and implementing the aforementioned space projects.

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**References:**
**Introduction.** Differential photometry of the surface of Mercury can be carried out with result of Mariner 10 imaging the planet. The spacecraft data contain valuable information on regional variations of upper layer photometric properties. Because of trajectory and pointing angle constraints the planet could be observed from Mariner 10 only over a small range of phase angles between about 75° and 110°. Therefore the photometric investigations are restricted to measuring the distribution of brightness on the Mercurian disk. Nevertheless it’s possible to obtain surface distribution of the photometric relief or roughness characteristics along visible disk of the planet.

**Initial data.** The relative brightness of areas on the visible disk were measured on two far-encounter low-resolution pictures. Raw versions of real-time processing pictures FDS 0000984 and FDS 0000986 were used (images 196 and 202). The pictures were obtained from distance of 422619 km and 423500 km from center of Mercury accordingly from outgoing part of Mariner 10 trajectory. Position of spacecraft relatively planet was the same for both images: latitude 21.26° and longitude 175.80° in the planet coordinate system. Solar coordinates were latitude 0.0° and longitude 101.10°, and phase angle was 75.76°. Both images were taken through the blue filter (effective wavelength about 486 nm). Originals of FDS frames contain a photometric scale (table) which was used in process of measurements for calibration of the film copies. For example original negative image 196 is shown in Figure 1.

![Fig. 1. Raw version of real-time processing image 196 (Mariner 10 outgoing trajectory).](image1)

Photomosaic showing the area of photometric measurements is presented in Figure 2. The mosaic negative image is constructed from the frames 196 (South part) and 202 (North part). This photomosaic is similar to visible disk of Mercury as photographed by the departing spacecraft. In Figure 2 the line MM is projection of central meridian (longitude 175.80°) on the visible disk. Line LL shows position of the luminous equator. The calibration curves are shown in Figure 3. These two curves let us to convert a measured film density into relative brightness. Since there is no evidence indicating that Mercurian photometric function is not similar to that of the Moon, analysis of the brightness distribution can be fulfilled using the mean spatial indicatrix of backscatter for all lunar
surface (photometric function) of Shevchenko [1]. Each measurement of brightness corresponds to set of angle parameters: \(i\) – angle of direction of the incident beam (angle of incidence), \(\varepsilon\) – angle of scattered beam (angle of emission), and \(A\) – angle between plans of incident beam and of scattered beam (azimuth). Values of the photometric function (relative intensity) can be obtained for each set of angles of incidence, emission, and azimuth, using the mean spatial indicatrix of backscatter. The photometric angles were determined by using the control net established by Davies [2] to locate the frame on the surface of Mercury and by using trajectory data to locate the spacecraft in relation to the planet [3]

**Results of the Photometric Measurements.** Generalization of the obtained results compared with earlier determinations by Hapke et al. [4] represents in Figure 4. The plot shows relationship between average lunar photometric function (similar to Mercurian one as it was demonstrated above) and relative brightness of the number of the geologic units obtained from Mariner 10 data. The shown values of brightness correspond to the negative image. Measurements of Hapke et al. [4] were converted into photometric system of the given investigation. The marks in Figure 10 are following: 1 – brightness of intercraters plains and smooth plains according to Hapke’s measurements, 2 – brightness of plains of different types (given investigation), 3 – brightness of bright craters (given investigation), 4 – brightness of bright rays (given investigation), 5 – brightness of bright rays (Hapke’s data), 6 – brightness of secondary crater fields (given investigation). From the data obtained it might be concluded there appear to be at least three main type of the photometric relief. The character one of them (exponential regression 2) demonstrates that Mercurian plains are covered by soil with more high level of porosity. In spite of the variations of the local albedo are not considered a good correlation (-0.924) is observed between the values of photometric function and the relative brightness of the investigated formations. Surface of the bright crater areas has a more smooth character of structure in cm-scale of roughness. Linear regression 3 corresponds to this type of the photometric relief. Coefficient of correlation in the case is equal -0.974, that demonstrates a good conformity between surface structure and the type of photometric relief. According to the earlier determinations by Hapke et al. [4] the bright crater surface possesses a combination of relatively bluish color and high albedo that may arise because the crust of Mercury is low in Ti, and metallic Fe. Surface of the secondary crater fields has a similar photometric relief and it is characterized by linear regression 3 too with a good correlation between brightness variations and photometric function (-0.954). Finally, the bright rays surface has an intermediate level of porosity that is characterized by linear regression 5.

**Conclusions.** It should be noted that given estimations don’t consider parameters of the fragment fields because the shape of photometric function in the range of phase angles about 60° - 100° (and more) depends on the surface cm-scale and smaller roughness in the main. The method described and the results of some remote investigations of Mercury show that the similarity of the surface structure of this planet to the Moon’s surface can be used to obtain preliminary estimates of the structure and characteristics of the Mercurian regolith. The results presented in this work and their further modification are also of applied significance in planning and implementing the aforementioned space projects planned by NASA and ESA.

**Acknowledgement.** This work was supported by INTAS-ESA grant # 99-403.

REMOTE METHOD OF IDENTIFICATION OF THE EJECTA LUNAR TERRAINS AND THEIR COMPOSITION FITURES. V.V. Shevchenko1,2, P. Pinet2, S. Chevrel2, S.G. Pugacheva1, Y. Daydou2. 1 Sternberg State Astronomical Institute, Moscow University, 13 Universitetsky pr., 119992 Moscow, Russia; 2 UMR 5562/CNES/Observatory Midi-Pyrenees, Toulouse University, 14 avenue E. Belin, 31400 Toulouse, France. shev@sai.msu.ru

Introduction. We proposed that information retrieved from the local surface photometric behavior of the Moon could be used for guiding the remote sensing analyses of specific geological targets. It was shown that difference between the modeled and observed phase function for phase angle in the range of 18° is sensitive to the degree of surface roughness at the meter scale [1].

Photometric Data and the Debris Size-frequency Distribution. The average integrated lunar indicatrix [2] was used as a background photometric model. The Saari and Shorthill catalogue [3] data were used as observed local phase functions. The value of the difference of intensities mentioned above may be used as a photometric parameter $\Delta I$ of the local surface roughness. The size-frequency distribution of the resolvable fragments on the lunar surface at the spacecraft landing sites was used to estimate the influence of the number of particles per unit area on the meaning of the photometric information. The greatest number of large fragments was observed at the Surveyor VII site. This area is pla -

Figure 1. The area is located to the North from crater wall of Tycho. Surveyor VII landing site is placed in the center of the image (Clementine series).

Figure 2. Mosaic of narrow-angle Surveyor VII pictures (fragment) [5].

number of particles $N$ per $10^4$ m$^2$ is about 22 of blocks < 4 m (Fig. 2). Comparison of the observed phase function of the Surveyor VII landing site and the average integrated lunar indicatrix shows a high value of the difference of intensities which is using as a photometric parameter $\Delta I$ (Fig. 3).

Figure 3. Phase function of the Surveyor VII landing site.

Photometric parameter dependence on the fragmental debris size-frequency was examined in terms of statistical data for a number of landing sites (Surveyor I, III, V, VI, VII, Lunokhod 1 and 2, Apollo 11, 12 and 15), and an area in Sinus Media (Lunar Orbiter II high resolution pictures) [4 – 10]. The data were extrapolated to block size estimates in the range of 4 m. A good correlation (0.815) between the local size-frequency distribution of fragments and the photometric parameter of roughness is observed (Fig. 4).
The Local Composition Features. In a preliminary investigation, we have compared the Lunar Prospector thorium contents for some regions of the lunar near side [11] with surface roughness estimated by means of the local photometric function. In the areas under study, the surface roughness photometric parameter (which can vary between 0 and 1) varies from 0.05 (smooth mare surface) to 0.25 (crater Tycho and its ejecta). Interestingly, a good anticorrelation (-0.985) is observed between the local thorium content and the photometric roughness parameter, indicating a possible association of Th-rich materials with the structure of the regolith disturbed by the emplacement of ejecta materials, which could indicate the surface distribution of KREEP materials. Figure 5 represents the diagram of relationship between photometric roughness parameter and local thorium content in different lunar regions. The line shows a mean polynomial trend. The dots represent areas of a number of landing sites (Surveyor I, III, V, VI, VII, Lunokhod 1 and 2, Apollo 11, 12 and 15), and an area in Sinus Medii (Lunar Orbiter II high resolution pictures). If the correlation between the local thorium content and the photometric roughness parameter reveals a possible association of Th-rich materials with the structure of the regolith, one may retrieve from the examination of ejecta an indirect information bearing on the thorium local distribution.

Conclusions and Future Work. According to these results, there may be a possibility to investigate, within specific anomalous Th-rich regions identified by Lunar Prospector, the local distribution of KREEP material and to explore whether there are some systematics in its mode of emplacement, either originating from the lower crust by impact basin cratering or resulting from volcanic processes [12]. Dedicated targets such as the Apollo 14 site where a significant in situ variability in the thorium content is known to occur could be surveyed by AMIE / SMART-1 to train and validate the procedure. Then, on this basis, the spatial variability of the thorium abundance could be derived for different geologic contexts such as within the South-Pole Aitken basin, the Apennine bench formation, the Procellarum Kreep Terrane and at the Apollo 15 location.

Acknowledgments: The authors wish to express their thanks to W.C. Feldman and S. Maurice for useful discussions. This work was supported by INTAS-ESA grant No. 00-0792.

Introduction. The main spectral/optical effects of space weathering are a reduction of reflectance, attenuation of the 1-μm ferrous absorption band, and a red-sloped continuum creation [1]. Lucey et al. [2-4] proposed to estimate the maturity of lunar soils from Clementine UVVIS data using a method which decorrelates the effects of variations in \( \text{Fe}^{2+} \) concentration from the effects of soil maturity. The method calculates optical maturity defined as parameter OMAT [5].

Spectropolarimetric Maturity Index. Shevchenko et al. [6, 7], and Pinet et al. [8] developed the method to determine the maturity of lunar soil by using spectropolarimetric ratio \( P_{\text{max}}(B)/P_{\text{max}}(R) \) for blue (B) and red (R) spectral regions. On the basis of known laboratory results and telescopic data, it was found that ratio \( P_{\text{max}}(419\text{nm})/P_{\text{max}}(641\text{nm}) \) could be used as a remote sensing parameter of lunar soil maturity. This parameter does not correlate with the soil chemical composition (for example, with FeO content) but a good anticorrelation (\( r = -0.951 \)) was found with \( \text{I/FeO} \) values for Apollo and Luna landing sites [7, 9, 10]. So, it is possible to consider the ratio mentioned above as an independent remote sensing index of the lunar soil maturity level.

Conformity between maturity parameters. A detailed remote sensing survey of ten lunar regions of mare and highland types has been carried out by means of Clementine spectro-imaging data with the purpose of establishing the regional distribution of the maturity state and weight percent of iron content in the lunar soils. The spectral dataset has been instrumentally calibrated and a radiometric calibration using previous telescopic spectra has been made, resulting in the production of absolute reflectance spectra organized in regional image cubes [11-13]. The data are used to obtain a scale of conformity between spectral index of maturity OMAT and spectropolarization index established by Shevchenko et al. [10]. A special optimization technique has been developed on the basis of maximal likelihood, to locate very precisely the spectropolarimetric telescopic observations available [14] in the Clementine regional mosaics. For example, in Figure 1, is shown the Clementine image of crater Proclus which is a very young lunar crater, with an extensive ray system. The boxes inside the crater exhibit for the process for the search of the real site position operates from the reference catalog [10]. Size of the each box is 5.6x5.6 km that is resolution of the telescopic observations for these sites. Center of bright rays system – crater Proclus is probably very young lunar object. Given the likely recent origin of these features, one may consider the age of their formation as nearly equal as to the exposure age of their soils. On the other hand, soils of old formations such as highland craters have been exposed for an extended period of time. It means that most of the petrographic and chemical parameters of maturity should have reached steady-state values with exposure time. In that case, any local variation seen in the soil maturity should be explained as the result of space weathering process. As mentioned above, ten lunar surface zones are chosen for the purpose of this study. The list includes the highland crater Alpetragius, mare units in Mare Humorum and in Oceanus Procellarum near by Aristarchus, post-mare craters Aristarchus, Herodotus, and Reiner, which have different ages of emplacement. On the bases of these data, a scale of conformity between the two types of maturity parameters is obtained. The diagram, depicted in Figure 2, plots the ratio \( P_{\text{max}}(419\text{nm})/P_{\text{max}}(641\text{nm}) \) versus the spectral index of maturity OMAT (Lucey’s parameter).
The interval of maturity index covers the geological formation time span from recent impact to old highland craters. These quantities display a good correlation (exponential regression) with a correlation coefficient \( r = 0.980 \) for the interval of spectral index of maturity, ranging from 0.22 to 0.38. Shevchenko et al. [10] shows that the spectropolarization index represented, as ratio \( P_{\text{max}}(419\text{nm})/P_{\text{max}}(641\text{nm}) \), correlates directly with maturity index \( I_{\text{s}}/\text{FeO} \) established by Morris [15-16]. The correlation coefficient between the average values of Morris’ parameter for Apollo and Luna landing sites and the \( P_{\text{max}}(419\text{nm})/P_{\text{max}}(641\text{nm}) \) values for the same places derived from telescopic observations is \( r = -0.951 \). Making use of the dependence mentioned above it is then possible to build a graph of maturity index \( I_{\text{s}}/\text{FeO} \) versus the spectral index of maturity.

Fig. 3 shows the type of relationship between \( I_{\text{s}}/\text{FeO} \) and OMAT. The Apollo and Luna landing sites data, combined with the ten selected lunar features data, are used to establish the graph in the interval of OMAT from about 0.23 to 0.38. The data concerning the most mature surface soils arise from the individual sample stations at the Apollo-17 landing site and are used to establish the graph in the range from 0.12 to 0.23. The estimates of parameter OMAT are derived from Clementine UV-VIS reflectance values for Apollo 17 landing-site sample stations published by Jolliff [5]. Average values of \( I_{\text{s}}/\text{FeO} \) for the sample stations are compiled by Jolliff from Morris’ data. Part of the plot from 0 to 0.12 is extrapolated from the linear trend observed data of Apollo 17 stations. It is needed to point out that value OMAT = 0 (Lucey’s “optimized origin”) asymptotic behavior only. As it follows from the plot in Fig. 3, a significant inflection of the curve is seen for values of \( I_{\text{s}}/\text{FeO} \sim 70 – 75 \). As revealed by Fisher and Pieters [1], when a soil reaches maturity, exposure.

**Conclusions.** The trend shown in Fig. 3, isoptical properties no longer change with further consistent with this effect which is accounted here by the curve flattening of the spectral index of maturity values at \( I_{\text{s}}/\text{FeO} > 70 – 75 \). Shevchenko [7] and Pinet et al. [8] from correlation between maturity index and exposure age of a collection of lunar samples found that exposure age of 100 Myr corresponds to maturity index value of \( I_{\text{s}}/\text{FeO} \sim 75 \). The present results suggest, that the slope in flexion detected for \( I_{\text{s}}/\text{FeO} \) values around 75 is indicative of the beginning of the asymptotic behavior expected for a lunar regolithic soil when it reaches maturity steady-state. The implication is that one should be careful when interpreting OMAT relative estimates less than 0.22 ±0.02 in terms of local variations of maturity in the lunar regolith, at the 100 – 200 m resolution available with Clementine.

SIMULATION OF SOME SPACE WEATHERING EFFECTS IN PHOBOS REGOLITH BY LASER IRRADIATION OF CARBONACEOUS CHONDRITE MIGHEI. T.V. Shingareva¹, A.T. Basilevsky¹, A.V. Fisenko¹, L.F. Semjonova¹, Chistyakova N.I.², Nechelyustov G.N.²; ¹Vernadsky Institute, RAS, Moscow, 119991, Russia, shingareva@geokhi.ru; ²Fedorovsky All-Russian Mineral Institute of Raw Materials, Moscow.

Introduction: The current study is a continuation of the laser irradiation experiments [1-3], which in turn continued the work [4]. Our project is devoted to simulation of effects of space weathering due to melting the regolith material by the micrometeorite bombardment on the surface of Phobos, which is considered by some researchers as compositionally close to carbonaceous chondrites [5]. At the first stage of our project we irradiated by laser the artificial mixture whose chemical and partly mineralogical composition was close to that of CM carbonaceous chondrites [1-3]. Now we used two analogs of the Phobos material: 1) the natural CM chondrite Mighei and 2) the newly treated artificial mixture used in our previous study. This paper describes shortly the mineralogical and chemical changes recorded in melting products of both Mighei and the artificial mixture thus modeling the appropriate changes in the Phobos regolith. We plan then to measure the UV-VIS-IR spectra of the initial analog materials and the experiment products, as it was done by [1-4], that is important for understanding the results of remote sensing of Phobos.

The initial materials. The first analog material is CM-chondrite Mighei consisting largely of fine-grained black matrix, which is a chlorite-serpentine intergrowth, and of olivine chondrules, it contains also troilite and up to 2.5 % of amorphous carbonaceous material [6]. The second analog is the artificial Mixture used in [1-3]: 46 mass % of non-magnetic fraction of L5 chondrite Tsarev [7], 47% of serpentine, 5% of natural carbonaceous material kerite and 2% of calcite [1-3]. In the previous study, the mixture was not enough homogeneous in the grain size that led to some bias in the melting process. That’s why in the current work the mixture was ground again and sieved to <40 µm. Mighei was ground and sieved to <40 µm too. Chemical compositions of the analog materials are presented in the Table (see below).

Experimental procedure. The micrometeorite impact melting and subsequent crystallization were simulated by impulse laser irradiation of the powdered analogs under (2–4) x 10⁻⁴ mm Hg vacuum. In the process of irradiation of Mighei, the pressure in the experiment chamber increased by an order of magnitude apparently due to the volatiles release from the melting material. During irradiation of the Mixture, the pressure increase was less significant. The solid-state Q-switch Nd:YAG cw pumped laser (λ = 1.064 µm, impulse frequency 30–40 KHz, laser power 1.2 KW) was used. Pulse duration was 0.5–1 µs and the laser beam was 100 µm wide. Comparing with irradiation of the Mixture, irradiation of Mighei was accompanied by sufficient sputtering of the melted matter probably because of its more volatile-rich composition. Apparently due to electrostatic forces, the powdered analog materials formed agglomerate clots up to 1-2 mm in diameter. In some of these clots, the laser beam made series of holes of ~100 µm in diameter (fig.1). In the process of laser irradiation the powdered analog materials melted forming spherical glassy droplets from ~30 µm to ~300 µm in diameter and their aggregates which were then sieved into several size fractions. The coarser fractions were used for SEM and microprobe studies.

Mineralogy and petrology of altered samples. Chemistry analysis and BSE imaging of altered samples were made at the Fedorovsky All-Russian Mineral Institute of Raw Materials by the roentgen-microprobe facility JXA-8100 and Energy-Dispersion Spectrometer INCA.

Fig.1. BSE image of the crossection of melted hole in agglomerate of Mighei. 1 - initial material; 2 – melt; 3 - metal/sulfide; 4 – unmelted Ol clasts.

Fig.2. BSE image of altered Mighei: Ol – olivine, ms – mesostasis.

Mighei. It is seen that sometimes the laser heating of Mighei did not lead to complete melting. In such cases the altered aggregates contain unmelted angular clasts of two compositional types of forsterite (Fo₉₀ and Fo₇₂) incorporated in the melt. The clasts are 6-35 µm in length and surrounded by thin (~1-2 µm) envelopes with more ferrous composition (Fo₆₅). The melt consists of interstitial mixture of compositionally zoned (with Fe-rich ~1-2µm rims) skeletal to filamentous olivine (Fo₉₀) crystals (8 to 150 µm long and 2 to 13 µm wide) and ferrous mesostasis (fig.2). The melt contains gas bubbles from ~0.1 to 70 µm in diameter and metal/sulfide aggregates up to 60 µm in diameters which include the large bubbles, too. The metal/sulfide inclusions are mostly concentrated in the external parts of the
melt droplets, not as splashes on the droplet surface but being disseminated in the droplet groundmass. Comparing to the initial materials the bulk melt composition is depleted in FeO and S (probably due to FeNi/troilite segregations and to vaporization) and proportionally enriched in all other components (Table).

**The Mixture.** The melted material is partly crystallized forming interstitial texture. In contrast to Mighei melting products, it practically does not contain the unmelted clasts of the initial mixture components in the droplet interiors. The exceptions are rare small (<20 µm) clasts of forsterite (Fo76). Glassy droplets contain gas bubbles ranging from ~0.1 µm (the image resolution limit) to 50-90 µm in diameter with some of them occupying a significant part of the droplet interior. The bubble abundance in the Mixture melt is in general lower than in the case of the Mighei melt. The crystallization of the Mixture melt resulted in formation of skeletal, dendrite and needle-like Mg-rich (Fo93) olivine crystals with very thin (<1 µm) Fe-rich outer zones. The crystal length varies from 5-10 to 60 µm and the width, from 1 to 9 µm. The crystals are cemented by glassy mesostasis, which occupies small areas between the Ol-crystals. The mean bulk chemistry of the melt (olivine + mesostasis) is similar to the “dark” melt obtained in our earlier experiments [1-3] and if compared with the initial material shows significant enrichment in SiO2 and MgO, minor enrichment in CaO and Al2O3 and striking depletion in FeO (Table). It is well known that in high temperature processes FeO may vaporize and escape in FeO (Table). This phenomenon was observed in our experiments, but now the aggregates are µm in diameter). This phenomenon was observed in the current study is due to higher homogeneity of the initial mixture.

**Discussion and conclusions.** The above description shows that the laser pulse irradiation of the CM chondrite Mighei and the CM chondrite stimulant led to local melting, formation of the melt droplets and their subsequent partial crystallization. This resulted in formation of glass and compositionally zoned (Fe-enriched rims) skeletal to filamentous Mg-olivine crystals. Metal/sulfide phases segregated concentrating mostly in the outer parts of the melt droplets. Although not specially studied, the volatile components (H2O of serpentine and chlorite and CO2 of calcite) have undoubtedly escaped from the melting products. FeO depletion is probably due to vaporization of FeO and sputtering of the Fe-enriched products during the laser treatment. So FeO left the melt and partly deposited on the neighboring to the beam portions of the initial material, part of which then composed the unmelted fractions. The experiments showed that comparing to Mighei, the CM simulant seems to be more susceptible to laser pulse melting as it contains Mg-serpentine instead of Fe-Mg clorite. In this process the volatiles such as H2O and CO2 escape, seemingly playing no role in the melting, which effectiveness is controlled probably by the composition and grain sizes of nonvolatile components.

**Acknowledgment:** The work was supported by RFBR grant 02-05-65156.

**References:**

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**Composition of the analog materials and the experiment products as determined by JXA-8100 and INCA facility**

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Initial sample</th>
<th>Bulk melt</th>
<th>Olivine</th>
<th>Mesostasis</th>
<th>Initial sample</th>
<th>“dark” melt</th>
<th>Bulk melt</th>
<th>Olivine</th>
<th>Mesostasis</th>
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<tr>
<td>SiO2</td>
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<td>38.16</td>
<td>39.87</td>
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<td>39.24</td>
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<td>0.14</td>
<td>0.06</td>
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<td>1.43</td>
<td>2.18</td>
<td>1.95</td>
<td>3.41</td>
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<td>28.01</td>
<td>25.91</td>
<td>22.15</td>
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<td>13.54</td>
<td>7.64</td>
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<td>MnO</td>
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<td>0.33</td>
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<td>0.33</td>
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<td>K2O</td>
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<td>b.d.</td>
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<td>b.d.</td>
<td>b.d.</td>
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<td>88.61</td>
<td>99.81</td>
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<td>100.68</td>
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</table>

*Zolensky et al, 1993, GCA, 57, 3123-3148.*
Some results by using of nonlinear algorithm for calculation of transformation parameters between planet coordinate systems. A.M. Shirenin. Moscow State University for Geodesy and Cartography, 103064, Moscow, Russia.

This investigation is considered as the next step by [1] developing.

There are same new calculation results, in the table, on the base of data received in Russia and USA in different periods.

It is restful to remember. The main in content of the previous paper [1].

The task of the estimation of parameters of transformation between two coordinate systems, with using the vectors of positions of common points given in each of systems, was considered by many authors. As a rule, it is solved on a method of least squares in linear statement. Thus it is supposed, that the angles of mutual orientation of coordinate axises are small, and the vectors of positions of common points are given with unknown errors and are not adjusted.

In [1] work nonlinear algorithm is offered. In contrast to of the designed algorithms, this algorithm is not required the suppositions about smallness of angles of mutual orientation of each of systems and, besides during the parameters estimation the vectors of positions of common points are considered as vectors-samples of measurements with given covariance matrixes of errors [2]. It enables simultaneously with evaluations of parameters of transformation to correct values of vectors of positions by single-error corrections in limits of restrictions, given by covariance matrixes of errors of vectors of positions. Also restrictions are taken into account which arise from conditions of equality with a given exactitude of vectors of positions at their recalculation from one system in other. A problem is offered here, is equivalent to task of an equalizing of a web of vectorial triangles which are located on common leg, with side legs, given in different from each other coordinate systems, with unknown beforehand of parameters of transformation.

The algorithm is based on solution of the task of minimization of the following goal function: [3,4]:

\[
(q,R,l) = \arg \min \left\{ 0.5 \left[ \tilde{q} - q \right]^T K_{\tilde{w}} (\tilde{q} - q) + \left( \tilde{R} - R \right)^T K_w (\tilde{R} - R) + l^T U \right\}
\]

\(\tilde{R}\) – \(6m\), 1 a vector-sample, containing vectors of positions of \(m\) common points, given in both systems; \(K_{\tilde{w}}, K_w\) – accordingly covariance matrixes of errors of vectors \(q\) and \(R\);

\(l\) – \(3m\), 1 vector of multipliers of the Lagrange;

\(U\) – \(3m\), 1 vector, containing for each i-th point 3,1 subvectors of restrictions \(U_i = \mu M_{ii}R_{ii} + R_{ii} - R_{ii}\).

\(\tilde{q} = [\tilde{\omega}_x, \tilde{\omega}_y, \tilde{\omega}_z, \tilde{R}_{x}, \tilde{R}_{y}, \tilde{R}_{z}]^T\).

For calculation of a zero approximation to \(q\), special algorithm was created. It has allowed to execute on the computer a series of numerical experiments. Expediency of using of the given algorithm for the estimation of parameters of transformation and adjusting of vectors of common points was be shown for cases, when both systems have an equal exactitude, or when one of systems is considered as a basic and high precision, and other is given with a smaller precision and must be inserted into the first.

References:


Table

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>X₀</th>
<th>Y₀</th>
<th>Z₀</th>
<th>Wₓ</th>
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<td>Km</td>
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<td>-0,226</td>
<td>-12'54'',1</td>
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<td>0,15</td>
<td>-0,35</td>
<td>-0,31</td>
<td>-13'36''</td>
<td>2'17''</td>
<td>4'26''</td>
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<td>3. Venera-15,16 - Venus-86</td>
<td>-3,2</td>
<td>4,5</td>
<td>5,1</td>
<td>36'30''</td>
<td>22'15''</td>
<td>15'40''</td>
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<td>-2,25</td>
<td>40'36''</td>
<td>-51'16''</td>
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<td>15'20''</td>
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</table>
Previously we revealed six harmonic oscillations of mercury vapor flow from the Earth-crust to the Earth atmosphere [1]. Their frequencies correspond to frequencies of the earth-crust tides, resulted from the interactions with the Moon and the Sun with a precision better than 1 %. In this study we found that the sensitivity of mercury vapor flow to earth-crust tides increases by a factor of 75 with decreasing their frequency (from T = 8.28 h to T = 662 h). This phenomenon is attributed to "inertness" of mercury vapor flow.

Results of Fourier analysis of hourly measurements of mercury vapor flow performed during 2.5 year in Dushanbe suburb were reported previously [1]. Six periods were revealed with frequencies of 328, 25.82, 24, 12.42, 12.00, 8.28 hours (Mf, O1, 24, S 2, M 2, and M 3 respectively). These periods (or "waves" in mercury vapor flow) correspond to frequencies of the earth-crust tides, resulted from the interactions with the Moon and the Sun with a precision better than 1 %.

However, relative amplitudes of harmonic oscillations of mercury vapor flow differ significantly from the corresponding relative amplitudes of earth tides. This study is focused on analysis of this finding and its explanation.

Previous Fourier analysis was performed by breaking the realization of mercury flow values (n=20 000) into 89 segments of 3 200 points each. Fig. 1 summarizes mean values of mercury flow (F) and amplitudes of its variation on six frequencies (Mf, O1, 24, S 2, M 2, and M 3) for each segment.

We calculated correlation coefficients of amplitudes Mf, O1, 24, S 2, M 2, and M 3 waves with mean value of mercury vapor flow F: 0.600; 0.837; -0.057; 0.428; 0.557; 0.659. Correlation coefficients for Mf, O1, M2, and M3 are significant and imply a synchronism between amplitudes of these waves and mean value of mercury vapor flow.

Wave 24 is a superposition of waves P1 and K1 (frequencies 1.0055 and 0.9999 day\(^{-1}\) respectively) with similar amplitudes but opposite sign of deformation. Besides, this wave is superimposed with variations of mercury vapor flow caused by variations of atmospheric pressure and "pump-effect". Impact "pump-effect" is estimated as 20 pg \(\times\) m\(^{-2}\) \(\times\) h\(^{-1}\)/mbar and seems to be dominating.

Wave S 2 is superimposed with 1st harmonic (12 h) of variations of atmospheric pressure. This lowers correlation coefficient r (S 2, F) = 0.428.

It is noteworthy that mercury vapor flow rate in a soil is low ~ 8 cm/h and changes significantly with changes in soil gas-permeability. These changes are caused by wetting of a soil with rain, dew, or freezing in wintertime. As a result, mean value of mercury flow and amplitudes of waves caused by earth tides are unsteady.

It is possible to calculate a sensitivity of mercury vapor flow toward earth-tides for different waves (frequencies). Frequencies and amplitudes of earth-tides are well known [2] and the frequencies and amplitudes of mercury vapor flow were determined in our experiments. Results of the calculation of sensitivities for different waves are given in the Table and Fig. 1. For estimation of the sensitivity we used a ratio \(\log\Delta F(\omega)/\log\Delta\varepsilon/\varepsilon\) (column 6). Absolute sensitivities of mercury flow toward relative deformation are given in column 7 for each frequency.

Evidently, the sensitivity of mercury vapor flow toward deformations of the earth crust increases significantly with
decreasing frequency. Thus, for monthly period sensitivity is two times higher than for half-month periods.

It is possible to conclude that a new phenomenon is found: “Modulation of mercury vapor flow from earth-crust to earth atmosphere by gravitation interaction of the Earth with the Moon and the Sun”.

References.


Table. Parameters of the earth-tide waves and the waves of mercury vapor flow.

<table>
<thead>
<tr>
<th>Wave symbol</th>
<th>Period, h</th>
<th>Frequency ω, day⁻¹</th>
<th>Hg vapor flow, pg m⁻² h⁻¹</th>
<th>Relative deform., 10⁻⁸ Δε/ε</th>
<th>Relative sensitivity of Hg flow to deform.</th>
<th>Absolute sensitivity of Hg flow to deform.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mₘ</td>
<td>662</td>
<td>0.0362</td>
<td>127</td>
<td>0.83</td>
<td>0.260</td>
<td>150</td>
</tr>
<tr>
<td>Mₙ</td>
<td>328</td>
<td>0.0730</td>
<td>137</td>
<td>1.6</td>
<td>0.275</td>
<td>85</td>
</tr>
<tr>
<td>O₁</td>
<td>25.82</td>
<td>0.9270</td>
<td>39</td>
<td>3.8</td>
<td>0.214</td>
<td>10</td>
</tr>
<tr>
<td>M₂</td>
<td>12.42</td>
<td>1.9271</td>
<td>34</td>
<td>9.2</td>
<td>0.217</td>
<td>4</td>
</tr>
<tr>
<td>S₂</td>
<td>12.00</td>
<td>1.9945</td>
<td>52</td>
<td>4.3</td>
<td>0.233</td>
<td>12</td>
</tr>
<tr>
<td>M₃</td>
<td>8.28</td>
<td>2.8906</td>
<td>23</td>
<td>0.12</td>
<td>0.152</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 1. Dependence of the sensitivity of mercury vapor flow toward earth-tide deformations on their frequencies, rₓᵧ = -0.873.

Fig. 1. Means of mercury flow, F, for 89 segments (1-3200; 180-3380; 360-3560; etc) and amplitudes of the 6 spectral lines of mercury flow for these segments.
NUMERICAL SIMULATION OF VERTICAL DISTRIBUTION OF NEUTRONS BORNE BY COSMIC RAYS IN A MODEL MARTIAN SOILS FOR PROCESSING OF HEND/ODYSSYEY DATA.

To interpret the observations of Mars neutron albedo made by HEND onboard 2001 Mars Odyssey [1,2] it is need know a composition of soil which will be used for data processing. HEND scientific team did comparisons of real HEND counts and model fluxes early [3] for two soil model – homogeneous model and two layer one. It was find criteria for acceptance one of the models for different regions of Mars.

Numerical modeling. Next step of HEND data processing – find a distribution of particles in soil which need both in searching for water enriched regions on Mars and for studies of soil composition on base data of Gamma Ray Spectrometer GRS on board 2001 Mars Odyssey. Code MCNPX (a special Monte-Carlo code for numerical modeling of nuclear particles interaction and transport in a materials) used for numerical modeling of neutron fluxes from Mars. Initial source of cosmic ray particles was taken as flux of protons with spectrum well known from literature [4]. Geometry of task was oversimplified down to concentric spheres to speed up calculations. Knowledge the soil composition obtained from NASA “Pathfinder” [5] and atmosphere composition from AMES model [6] is used in calculations. As it was described in [7] the model spectrum were convoluted on HEND response function of different detectors to fit the best correspondence between data set and model predictions. First approximation was the soil with homogeneous water content and this model is appropriate for some region only. The second step was a two layer model and it was found that according to $\chi^2$-criteria it is much more suitable for many regions of planet in comparison with homogeneous model [8]. It is seems that two-layer model is more close to reality. Main result of MCNPX modeling on base of these models is that neutron fluxes distributions are strongly differ for two models (see fig 1). The simulated on MCNPX gamma ray spectra (see fig 2) are new evidence of it and this fact must be taken in account in data interpretation for both HEND and GRS data sets.

Conclusions: Application of numerical modeling on base MCNPX code is powerful instrument for data interpretation and comparison between the real counts of HEND detectors and modeling fluxes of Martian neutron albedo to search hydrogen-enriched areas on Mars. Other soil model will be use for HEND observations interpretation [9] and calculated neutron distributions in soil will be use in future to build of vertical structure of Mars soil.

References:
THE MORPHOMETRIC ANALYSIS OF THE FEATURES OF MARTIAN CRATERS. I.A. Ushkin\(^1\), G. G. Michael\(^2\), E.A. Kozlova\(^3\). \(^1\) Moscow State University, Vorobjovy Gory, 119899, Moscow, Russia, gray_pigeon@mail.ru. \(^2\) ESA, Noordwijk, the Netherlands. greg.michael@rssd.esa.int \(^3\) Sternberg State Astronomical Institute, 119899, Moscow, Russia.

**Introduction:** In the present work the morphometric parameters for 87 large martian craters [1](with diameters from 411 up to 110 kms) have been determined: depth of a crater-\(\Delta H\), the relation of depth of a crater to diameter (\(\Delta H/D\)), height of a rim – \(h\), with the help of profiles constructed on the basis of supervision of space vehicle MGS [2]. The comparison with similar morphometric parameters of large lunar craters also is fulfilled. Also attempt of an estimation of thickness of layer of regolith of the planet as result of distribution of approach from the work of Melosh [3] on large craters is lead.

The following extreme parameters of sizes interesting us are received: the maximal values of them are those: \(<\Delta H> = 2965 \text{ m}, \langle h\rangle = 975 \text{ m}, \langle\Delta H\rangle / D = 0.024\). Their minimal values the following: \(<\Delta H> = 184 \text{ m}, \langle h\rangle = 0 \text{ m}, \langle\Delta H\rangle / D = 0.001\). It is interesting, that the central hill of some craters on the profiles where distinctly visible, strongly towers above rim of a crater (Fig. 1). Comparison of the received results with morphometry of lunar craters [4] has been lead.

As result of generalization of calculations we obtained the following dependence (Fig.2):

A degree of degradation - depth.

\[
\Delta H(RD) = -393^*RD + 2921 \text{ for the Mars}, \\
\Delta H(RD) = -800^*RD + 5733 \text{ for the Moon}.
\]

The height of lunar crater rim [4] for the same degree of degradation is more than for the height of martian crater rim.

Graphic generalization of results in the following conclusion: for the same degree of degradation such morphometric characteristics of lunar craters as depth and height of a rim are expressed more strongly, than at martian craters. It is a result of stronger gravitation on Mars (as speech here goes about large craters for which its role is especially important), and also active atmospheric processes.

**Estimation of thickness of layer of regolith.** Geological targets are not homogeneous and isotropic and have no ideally flat surface. In real situations we deal or with layered targets, or with the targets consisting from casual of rocks with various mechanical properties, but influence of these roughnesses of a relief on process of formation of a crater till now is badly investigated.

The most investigated case - a layered target: the soft layer lays on strong material (it is investigated at the end of 60-th [3]). It has been found, that the morphology of a resulting crater strongly depends on the relation of diameter of a crater on a crest of a rim (D) and thickness of a layer. Process of an estimation of thickness a layer of regolith of a planet on this method (more detailed description of it can be found in [3]) is reduced first of all to correlation of a crater with one of four characteristic morphological attributes - presence of the central hill, a flat bottom, a concentric crater and normal morphology.

For reception of the most authentic estimations we have accepted as follows: have allocated most close laying craters (their coordinates to us are known from [1]). It is natural to expect, that thickness a layer of regolith, appreciated on the basis of morphology of these craters, should coincide approximately. For the greater reliability it is natural to compare the estimations received on craters of various morphology.

Figure 1. The half-profile of a crater, at which height of the central raising is more than height of a rim approximately on 750 m.

Figure 2. Dependence the crater depth - degree of degradation for craters on Moon and Mars. The upper schedule is for the Moon, the lower – for Mars.
Thus for explanation it is applied linear or nonlinear expressions on estimated parameters. enough a low degree; can be used and various \( \phi \) assumes in the beginning approximation \( f(t) \), \( \epsilon(t) \) (a random variable, a mistake). term, cyclic) function; \( \xi \) number(line) of supervision stochastic function \( \Omega \), \( F \), \( P \) - probability space on which circuits MLS can be applied and, corresponding adaptation, use of the simplified program and realized and applied at processing TS and so forth.

We shall note the basic stages of processing of TS on which circuits MLS can be applied and, hence, the stated remarks are fair.

Let \( (\Omega, F, P) \) - probability space on which stationary process \( Y(t) \) is set, observable during the equidistant moments of time \( t_1, t_2, \ldots, t_N \):

\[
Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t); \quad Y(t) = f(t) + \phi(t) + \epsilon(t);
\]

where \( Y(t_1), Y(t_2), \ldots, Y(t_N) \) - a number(line) of supervision of stochastic function \( \xi(t) \), named a time number(line); \( f(t) \) - not casual (long-term) function of a trend; \( \phi(t) \) - not casual (seasonal) periodic function; \( \phi(t) \) - not casual (long-term, cyclic) function; \( \epsilon(t) \) - irregular a component (a random variable, a mistake).

Allocation of a regular component of lines assumes in the beginning approximation \( f(t) \), \( \phi(t) \), \( \psi(t) \) with algebraic and trigonometrical polynomials enough a low degree; can be used and various nonlinear expressions on estimated parameters. Thus for explanation it is applied linear or nonlinear MLS.

After the first regular representation rests \( Y_1(t) \) are burdened with autocorrelation more often. Therefore at the following stage we are trying to allocate periodic seasonal and if appears probable, long-term cyclic fluctuations \( \phi(t) \), \( \phi(t) \). If for rests \( Y_1(t) \) the hypothesis about an opportunity of representation is postulated by periodic function \( \phi(t) \):

\[
Y_1(t) = \phi(t) + \epsilon(t),
\]

determined by decision MLS of linear systems of the equations. At this stage there are problems of the importance of the decomposition containing more of 50 % noise harmonics more often.

The ambassador of elimination of the second regular function \( \phi(t) \) and in part \( \phi(t) \). The purpose of TS-analysis – modelling of casual rests \( Y_2(t) = \epsilon(t) \) AR-models of various orders, ARSS-models, etc., including use of models of martingale approximations. To definition of various weight factors in decomposition it is here too applied MLS. The basic problem thus is the choice of criteria of quality of model and elimination of autocorrelations.

So, at all stages of approximation of additive functions in the right part of a forecasting model (1) factors represents MLS – estimations. For maintenance of properties of a solvency, stationary and efficiency MLS – estimations application of methodology regression modelling [1] is necessary.

**Algorithms of DRM:** The set of the algorithms providing the decision of a problem of development of a forecasting model (1), should include basically algorithms of approximations, estimation and structural identification; except for that it should include procedures of formation as criteria of quality of approximations, and criteria (analytical and graphic) performance of conditions of application of computing procedures of modelling of TS and RA-MLS (criteria of the consent), and also to provide tools of adaptation to infringements of conditions.

We shall briefly note some procedures, programmed and realized and applied at processing of TS.

To algorithms of the preliminary analysis and processing TS concern: - procedures of calculation of autocorrelation function, in particular, Darbin-Watson's criterion (DW); - procedures of check stationary lines (a constancy of average value by nonparametric criterion of shift; constancies of a dispersion by Kokhren’s criteria, dispersion, inversions, etc.).

The class of approximating functions already was examined by us (linear and transcendental models, algebraic and trigonometrical polynomials as Fourier series, AR-model, sliding average, martingale approximations).

The general circuit of research of dynamics is those: at the first stage the trend, in the elementary kind is allocated

\[
Y = A + Bt
\]

or a derivative from given, received by linear transformation. For more exact representation of a trend models sliding average are used.

The second stage assumes research of the rests of a trend on stationary and revealing periodic a
component. Existence periodic a component in the analysis of time series is standardly determined by means of autocorrelation function, the Fourier-analysis and other methods. However recently the increasing popularity is got with methods of the wavelet-analysis or wavelet-transformation (WT).

For carrying out Fourier of the analysis the standard estimation of spectral density is used

$$\hat{S}(f_k) = \frac{1}{N\Delta t}|X(f_k)|^2$$

with Fourier factors:

$$X(f_k) = \Delta t \sum_{i=0}^{N-1} x(i) \exp\left(-\frac{ji2\pi k}{N}\right)$$

As is known, Fourier transformation is not located in time, but extremely located in frequency area. As opposed to this in WT nucleus of transformations which sizes are coordinated with scale of investigated characteristics of process are used. Basic idea of WT answers specificity of series of dynamics with unstable basic characteristics, such as average value, a dispersion, the periods of basic harmonics, their amplitudes and a phase.

For construction WT allowing not only to trace presence periodic a component, but also to estimate stationary of fluctuations, it was used Morle wavelet – the flat wave modelled by haussian,

$$\psi(t) = e^{-\frac{t^2}{\Delta t^2}} \cdot e^{j\cdot 2\pi \cdot t}$$

(4)

giving the results most coordinated with terms of the Fourier-analysis.

For allocation of harmonious components of lines it is involved regression model of a kind

$$Y(t) = \sum_{i=1}^{k} a_i \sin\left(\frac{2t\pi}{T_i} + \phi_i\right)$$

To reveal harmonious components in the analyzed rests research of their spectral density of capacity S(f_k) on a half-cycle of researched lines allows: k=0,1,..N/2.

In a spectrum it is expedient to search for maxima on frequencies $$\frac{2\pi}{b}$$; b=0,1,2,... N/2. Set of peaks of spectrum T=(T_1, T_2, ... T_m) defines a set of harmonious components in decomposition.

For observance of a conditions of regression analysis about excess of number of the equations of amount of unknown persons at least in 5 times, the number of harmonics the maximal amplitude k gets out about N/10; the system of the equations is formed and solved by MLS. For search optimum in sense of a set of basic harmonics of regress the step-by-step method «inclusions with exception» is used. Adaptation to other conditions of application RA-MLS depends on a degree of their infringement.

Residual fluctuations smooth out or autoregression model of the suitable order, or methods of martingale approximations (or consecutive application of these two approaches). The choice about AP-model is based on Akaik’s information criterion.

From methods of martingale approximation for the purposes of the analysis of time series of the most suitable can count function of the following kind:

$$Y = ax (1 - b | x | c),$$

where a, b, c – some factors.

Software of DRM: The developed package of processing of the statistical data allows to enter the data directly from the keyboard, and also from various text files and spreadsheets. The module of display of the graphic information allows to build various kinds of schedules as dependences (on time or on a variable), distributions, histograms, etc.

In the program such frequently used transformations, as are realized: removal of a trend, smoothing sliding average, etc. Thus there is an opportunity of search of the best sets of parameters in sense of square root mistakes. All results of transformations and the rests are accessible to the further analysis and a conclusion to the schedule.

Except for standard statistical tests, such as the test on normality samples, construction of autocorrelation function, the spectral analysis of lines on time and frequency areas, in the program is included some of stationary test. Conclusions about stationary of TS are based on check of stationary of dispersions (criterion of dispersion, Kokhren criterion), stationary of average value of lines (nonparametric criterion of shift, criterion of inversions) and the test on stationary (Pirson’s criterion of consent). At construction of harmonious model of TS the question of stationary of base harmonics is important. The methods of the wavelet-analysis included in a package, allow to draw statistical conclusions about stationary of such characteristics, as the period and amplitude of base harmonics.

Construction of forecasts of time series are possible by trend models, AR – models with an automatic estimation of orders of models, harmonious model with an automatic choice of base harmonics a method of step-by-step regress. The standard set of results of construction of model contains estimations of parameters, standard mistakes and correlations. Such variety of various methods allows to process BP a various origin.

This scientific work is carried out within the framework of grant MO the Russian Federation on basic researches in the field of natural and the exact sciences (EO2-7.0-30).

MODELLING OF MOVEMENT OF THE EARTH POLES ON THE BASIS OF THE DRM-APPROACH
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Introduction: On long-term measurements of geographical breadths in several points of the Earth it has been noticed, that breadths of these points doesn’t not remain constants, and periodically vary, deviating their average value up to 0.3. Such fluctuations of geographical breadths shows that the body of the Earth is displaced concerning an axis of rotation and as this displacement does not influence an axis of rotation of the Earth which direction remains fixed in space at various times various points of a surface of the Earth coincide with poles of rotation. In result the Earth poles "floats" on its surface.

Movement of Earth poles, as well as fluctuation of geographical breadths, has periodic character. The basic periods are Chandler's 14-month's period and the 12-month's or annual period. Last period is obviously connected to seasonal changes in distribution of air weights, with carry of weights of water as a snow from one hemisphere of the Earth on another, etc. Chandler's Period — the natural period of fluctuations of the Earth.

At present time works of definition of position of a Earth pole and construction of models of its movement are conducted in the following directions:
- specification of design procedures of position of a pole of the Earth;
- modeling of movement of the Earth pole, in particular, by means of the mathematical technique of the dynamic and kinematics equations of Euler (the modal approach);
- search of statistical connections between position of the Earth pole and seismic activity;
- search of statistical connections between solar activity and seismic activity.

Within the framework of application of the DRM-APPROACH [1] construction of models of movement of the Earth on coordinates X and Y as trend component, the further allocation harmonious or autoregression components and the subsequent smoothing of noise by methods of martingale approximations [2] is supposed.

Construction of models and their analysis: For construction of models of movement of a pole a time series of coordinates of North Pole, calculated by IERS with step-type behavior 0.05 (eopc01) was used. The number of supervision N is equal 1000.

Fig. 1. For elimination of a trend component by coordinate X optimum from possible 16 pair dependences appeared linear model of kind: \( Y = A + B \cdot t \) with factors \( A = -3.6713869 \), \( B = 0.0018634 \); the factor of correlation \( R \) is equal 0.184; settlement value of F-criterion of Fisher equally 34.627; mean squared error (MSE) of model appeared equal 0.144 (a Fig. 1).

Fig. 2. On Y-coordinate the trend as \( Y = A + B \cdot t \) with factors \( A = -8.988 \), \( B = 0.00467 \) is allocated; settlement value of F-criterion of Fisher equally 200.31; the factor of correlation \( R \) is equal 0.43; MSE it is equal 0.142 (a Fig. 2).

Autocorrelation function (Fig. 3), Darbin-Watson's factor, spectral and wavelet-analyses of the rests of both coordinates specify presence of autocorrelation that assumes allocation harmonious or autoregression components.

Fig. 3. The further analysis of the rests from allocation трендовых components assume
allocation harmonious a component as the sum harmonious a component [2]:

\[ Y(t) = \sum_{i=1}^{k} A_i \sin\left(\frac{2\pi T_i}{T_i} + \phi_i\right). \] (1)

**X-component.** Harmonic №1 with period \( T = 23,809 \), amplitude \( A = -0.0915 \), a phase \( \phi = -0.0043 \); harmonic №2 with period \( T = 20 \), amplitude \( A = 0.0090 \), a phase \( \phi = 0.0423 \). MSE of the model is equal 0.12461 (a Fig. 4).

**Y-component.** Harmonic №1 with period \( T = 23,809 \), amplitude \( A = -0.0875 \), a phase \( \phi = 0.0041 \); a harmonic №2 with period \( T = 20 \), amplitude \( A = 0.0371 \), a phase \( \phi = -0.037 \). MSE of the model is equal 0.18537 (a Fig. 5).

Thus, fluctuations of Chandler’s and annual frequencies come to light on both coordinates. Period \( T = 23,809 \) corresponds to Chandler’s period of fluctuations (step-type behavior of supervision \( N = 20 \) in one year; \( 23,809/20 = 1.19 \) years); period \( T = 20 \) - to annual fluctuations.

**The conclusion:** Spectral and wavelet-analyses of movement of a pole specifies periodic displacement of Chandler’s frequencies that is caused by elastic deformations of the Earth.

Harmonious models of movement of a pole on coordinates X and Y short series of supervision (about 40-50 years), not taking into account century fluctuations, specify that Chandler’s and annual fluctuation on X-coordinate are in an antiphase. At studying longer time intervals the given effect is not shown. The amplitude of fluctuations on Chandler’s to frequency practically twice exceeds amplitude of annual fluctuations.

The analysis of the rests after allocation harmonious specifies components existence of autocorrelation that is caused by a series of the reasons: - non-stationary of the period of fluctuations it does not allow to be arranged precisely under dynamics of model, - non-stationary of palpation on the given period does not allow to allocate amplitude of fluctuations completely. As a whole the model can be counted suitable for the forecast for those time intervals on which it is kept stationary of the period of Chandler’s fluctuations.

In the further researches construction of models of movement of poles is planned at the greater step-type behaviour of the data (quarter - half-year - year) for allocation and the description of fluctuations of the big periods and smaller step-type behaviour for specification of character of fluctuations Chandler’s components.

This scientific work is carried out within the framework of grant MO the Russian Federation on basic researches in the field of natural and the exact sciences (EO2-7.0-30).
Introduction: Results of studying of solar activity, and also a technique of data processing have the most direct relation to a series of geophysical and geodetic problems, such as the forecast of earthquakes, polar motion of the Earth, etc.

The substance on the Sun everywhere represents the magnetized plasma, a mix of electrons and nucleus of hydrogen and helium. Sometimes in separate areas intensity of a magnetic field quickly and strongly grows. This process is accompanied by occurrence of the whole complex of the phenomena of solar activity in various layers of a solar atmosphere. One of forms of display of activity of the Sun is a stain in photosphere. As is known, solar stains appear in pairs in those places where lines of the deformed magnetic field leave a surface and enter into it. Thus a pair of spots forms a pair of poles of a field - southern and northern. Within the increased solar activity the magnetic field is deformed more strongly and spots on the Sun more. Within the "quiet" Sun of spots can not be at all.

At the decision of problems of construction of dynamic models of solar activity, seismic activity and movement of poles of the Earth the basic problems are allocated some:

- discrepancy in registration of the initial data, in addition caused and the subjective factor;
- big volume of noise information in the processable data;
- nonstationary cycles of solar activity.

Application of classical circuits of regression analysis (RA) – a method of the least squares (MLS) does not allow to describe precisely enough behaviour of some Volf counts because of strong non stationary supervision, and non stationary is shown as well as in amplitudes of fluctuations (non stationary of the mean and on a dispersion), and in infringements of cyclicity of processes.

In particular, at attempts to allocate trend a component as a polynom the researcher collides with such infringements of circuits of RA as: a high degree of autocorrelation dependence between the subsequent and previous members of time lines as the rests; infringement of the assumption about normality of distributions of the rests, caused by presence of regular displacement and a changeable dispersion of process.

Within the framework of application of a technique of the DRM-APPROACH [1] construction of models of number of solar spots as a trend component, the further allocation harmonious or autoregression components and smoothing of noise by a method of martingale approximations [2] are supposed.

The primary goals of research are: - smoothing of a trend components of SA, - allocation of a harmonious components.

Construction of models and their analysis: For construction of models of movement of a pole a time series of the data of solar activity World Data Center for the Sunspot Index was used, http://sidc.oma.be/, The USA; NASA, http://sohowww.nascom.nasa.gov, The USA.

The number of observations N is equal 296.

For elimination of a trend component on coordinate X optimum from possible 16 pair dependences appeared linear model of kind Y=A+B*t with factors A =-153.987; B=0.1102147; the factor of correlation R is equal 0.233; settlement value of F-criterion of Fisher equally 16,80; mean square error (MSE) of model appeared equal 39.238 (Fig. 1).

Autocorrelation function (Fig. 2), Darbin-Watson's factor, spectral (3) and wavelet-analyses of the rests from allocation of trend component is specify fig. to a component presence of autocorrelation that assumes allocation harmonious or autoregression components.
analysis testifies about non stationary harmonious a component both on amplitude, and on the periods.

The further analysis of the rests from allocation of trend components assume allocation harmo-

nious a component as the sum harmonious a com-

ponent [2]:

\[
Y(t) = \sum_{i=1}^{k} A_i \sin\left(\frac{2\pi t}{T_i} + \phi_i \right).
\]  

(1)

Harmonic №1 with period \( T_1 = 10.96 \) year., amplitude \( A_1 = 1.233 \), a phase \( \phi_1 = 1.14 \); harmonic №2 with period \( T_2 = 9.866 \) year., amplitude \( A_2 = 1.928 \), a phase \( \phi_2 = 3.088 \); harmonic №3 with period \( T_3 = 98.66 \) year., amplitude \( A_3 = 5.566 \), a phase \( \phi_3 = 1.842 \) are selected. MSE to model it is equal 40.584 (a Fig. 4).

The conclusion: The standard models of solar activity received with MLS, contains noise and non-significant harmonics in decomposition. Solar activity is not stationary, that results in infringements of substantive provisions of existing circuits of MLS. In particular, attempts of modelling of SA on the big interval of supervision as the sum of harmonics with the constant periods (1) result in construction of inadequate models because of absence of normality in the data.

The analysis of the rests after allocation harmonious specifies components existence of auto-

correlation that is caused by a series of the reasons: - non stationary of the period of fluctuations it does not allow to be arranged precisely under dynamics of model, - non stationary palpation on the given period does not allow to allocate amplitude of fluctuations completely. As a whole the model can be counted suitable for the forecast for those time intervals on which it is saved stationary the period of fluctuations.

The lead of wavelet-analysis is to confirm stationary of the basic harmonious components of the process. Harmonious models are applied to the description of process on the limited sites of the data that allows allocating harmonious components (2-3, 11 years harmonics) without taking into account of long-period fluctuations. Intervals get out in view of the following preconditions: after removal of the trend components confirmation of stationary is necessary for dispersion, the general stationary of the data by Pirson’s criterion of consent and stationary harmonious a component, confirmed with the wavelet-analysis.

For carrying out of the further researches in this area performance of variations of solar activity by ARMA-MODELS or as a neural network for the primary description of the data, reduction of supervision a normal kind and the further allocation of harmonious components is planned.

This scientific work is carried out within the framework of grant MO the Russian Federation on basic researches in the field of natural and the exact sciences (EO2-7.0-30).

In 1972-79 seven geological structures of Ukrainian shield were determined to be astroblemes. By the crater statistics and geological data the new astroblemes discovering were predicted but by the lack of exploration efforts this is not confirmed till now. Nevertheless some new principle data were obtained last time by investigations of known astroblemes.

Among them the new data of the age of Boltysh crater (D~24 km) which once more attracts attention due to new results of fission track dating of its glassy impactites: 65,04±1.1 Ma [1], and stimulated by this work new Ar-Ar determination which confirmed this age: 65.17±0.64 Ma [2] for the finely crystallized Boltysh impactite matrix. Such age of the crater was also confirmed by the new biostratigraphic data [3,4]. In the cement of sedimentary dikes in the base of ejecta cover around the Boltish crater the microfragments of sedimentary rocks with late Maastrihtian fauna were found. In accordance with modern data of fauna age intervals the lower limit of the age of these sediments is 66,8 Ma. The ejecta deposits are overlapped by the sandy Lusanovka suite with a NP1 Nankplankton foraminifera zone equivalent to 65,0 Ma age. So, this is an probable evidence of the complex structure of crater-forming bodies flux on the Earth near KT boundary.

The ammonites and foraminifera of lower part of middle Aptian (112 Ma) were distinguished in the crater sediments of Rotmistruvka crater (D~2,2 km) [3].

Both late Maastrihtian and Middle Aptian sediments were not distinguished in this part of Ukrainian shield before. So, the new significance of crater sediments study for regional Geology was proved.

Two craters of the Ukrainian shield (Zeleny Gay and Obolon) have a distinct elongated form. New data of Zeleny Gay double crater structure (D1≥0.9 and D2≥0.7 km) were obtained. The smaller South-East crater were at first straightly confirmed by the petrological study of core which was obtained by the drilling under N.N Kirianov leadership last year.

In the lithic impact breccia of this core the rare impact glass particles and numerous mineral grains with distinct shock-methamorphic features are distinguished such as PDF in quarts grains and so on. Among them the rare ones: impact diamond grains (Fig.1) and kink band in perthitic feldspar (Fig.2).

The distance between the crater centers is near 600 m. Both of them seem to be slightly elongated along SE-NW direction. The to-day data are not sufficient for choosing the true model of craters formation: two individual falling or ricochet. The model of the one deep eroded crater is less probable but could be also examined.

It is proved that Obolon crater (D~20 km) formed in shallow sea near Bathonian-Bajocian boundary. This crater probably have the unique for the Earth astroblemes structure with the central and some additional holes. The explanation of this fact is done.

The new intermediate level for the structure of impact diamond grains from Belilovka (Zapadnaja) astrobleme (D=4 km) was determined [5]: the blocks apx. 0.1 mcnm with different phase contents. The complex history of robust carbon phases formation under the shock wave action was interpreted.

So, Ukrainian astroblemes continue to be the source of fundamental data of impact cratering on the Earth.

SOUTH-POLAR POLYGONAL PATTERNS – PHENOTYPES AND LOCAL GEOMORPHOLOGIC CONTEXT.  S. van Gasselt¹, D. Reiss¹, G. Neukum², ¹German Aerospace Center, Institute of Planetary Research, Rutherfordstrasse 2, D-12489 Berlin, Germany, ²Freie Universitaet Berlin, Germany (Stephan.vanGasselt@dlr.de).

Introduction: The general shape and distribution of small scaled polygonal patterns on Mars have been attributed to ice-wedge polygons similar to their terrestrial analogs of high latitude periglacial environments, sand-wedges, desiccation cracks of dried water- or mudlakes, or to contraction cracks of cooled lava. Whatever the exact process is based on, the composition of the (sub-)surface medium, its mechanical properties, as well as the dynamics of the fracturing process still remain unknown to us. The global distribution of polygonal patterns (e.g., [1]) is in general accordance with the distribution of water and ice in the shallow sub surface of Mars, according to modelled data provided by Mars Odyssey’s HEND experiment [2] and theoretical modelling of earlier years [3], still there is a lack of evidence for polygonal patterns caused by thermal contraction cracking and the existence of ice wedges. As an approach for further understanding of the phenomena we have investigated the south polar region of Mars as a primary target for ice-wedge formation and catalogued the small-scale properties of polygonal networks and their geologic and geomorphologic context.

Geologic Settings: The south-polar region between 80°S and 90°S consists primarily of the Amazonian aged polar layered deposits (Apl) [4] and a patchy distribution of old highland terrain adjacent to the Apl materials. Towards the pole center the residual ice cap (Api) is present and shifted towards longitudes between 0°W and 90°W. At longitudes between 265°W and 90°W parts of the upper and lower Hesperian-aged Dorsa Argentea Formation are exposed (Hdu, Hdl). The areal extent of this unit corresponds with the topography in terms of elevation values of 1200 m (fig. 1). At 10°W and between 70°W to 95°W remnants of the undivided Hesperian and Noachian material (HNu) occur and show degradation by possible removal of ground ice, mass wasting and eolian processes occur [4].

Observations: From a number of ~6000 MOC-NA images between 80°S-90°S we have found over 700 images showing features of small-scale polygonal patterns. The resolution of the catalogued images ranges from 1.37 m/pixel to 14.45 m/pixel with 40% of all images ranging from 2 m/pixel to 3 m/pixel. Image acquisition ranges from Ls=7-356. The cluster effect of the distribution (fig. 1) is not bound to local settings mostly, but is constrained by the coverage density of image data of the Mars Orbiter Camera. This results in large clusters at Inca City, the Chasma Australe system and the distribution at the 87°S cirum polar circle. The geographic distribution of polygonal terrain is described in [5]. On the basis of these observations it is possible (with some restrictions concerning transitional morphologies) to distinguish at least five dominant types of polygonal patterns. About 75% of the mapped polygon types fit into this scheme, but still, in order to understand the mechanical and climatic conditions, this classification needs to be enhanced.

The polar trough type polygons (fig. 2a) are restricted to the polar layered deposits, troughs and re-entrants (Apl) of the south polar region. About 10% of the catalogued imagery show polygonal patterns on a single layer or across multiple layers. The polygons are characterized by orthogonal as well as hexagonal trough intersections with a polygon diameter of 80 m to 150 m but diameters of 20 m to more than 300 m are occasionally observed. The polygon troughs have a constant width of several meters across each investigation area, they appear fresh to moderately degraded. Only few polar layer type polygons present higher degree polygonal patterns with diameters of 5 m to 6 m within the main polygons. Lateral limitations in their extension are due to topographical steps or changes in surface material which cause changes in material strengths. The complex type polygons (fig. 2b) are a set of primary polygonal troughs and high order polygons, which vary in trough widths and
intersecting angles. The major troughs are radial to an initial crack center, the troughs are interconnected by higher order troughs orthogonal to the main troughs. Higher order troughs form intersections with lower angles. Their troughs are filled with bright frost as observations have been made within a limited seasonal period of Ls=250-290, when frost material has not been removed completely from the troughs. The polygonal features can be observed on top of the dark deposits of the Nplh, Hd(u,l), and Hnu units at 80°W and 340°W, only. The smooth plains type polygons (fig. 2c) are the commonest types of polygons and are distributed on smooth plains of average albedo values across the polar layered deposits (Apl) and on the residual ice cap area (Api). The surface topography on which they appear is flat or undulated. Commonly, they appear on small low albedo patches near the lee-ward sides of knobs or dunes. The polygonal troughs are filled with dark material and their polygons range from 20 to 60 m in average, but observations with diameters of up to 100 m can also be observed. Their trough intersections are orthogonal. The polygonal network consists either of a mixture of short straight trough segments and highly arcuate troughs or rectangular short trough polygons. The surroundings of patches with polygonal patterns are covered by deposits of eolian material and frost or they terminate at topographical steps. The regularity in terms of polygonal shape implies a homogeneous surface material in which they form [6]. Their occurrences are restricted to imagery of spring to late summer seasons. The fretted trough type polygons (fig. 2d) are characterized by small straight trough segments filled with either high or very low albedo material. The polygons extend across large areas in the Apl unit independent of the topographical situation and are situated along the 87°S circum-polar region. Their seasonal context is late southern spring to late southern summer, when the disappearing frost uncovers the surface polygons. The short troughs show a dendritic pattern, in which short secondary (high order) troughs originate at the main trough and propagate in orthogonal direction. The size of the polygons reach up to 100 m, the side arms have lengths of a few meters only. The polygonal pattern is very distorted and interrupted, but it seems, that they originate in one point growing into a radial direction. The small side troughs are already formed in this early stage of development as it can be observed in several images. The dissected dune related type polygons (fig. 2e) are a set of small and short orthogonal troughs which have a highly uncomplete appearance. The polygons have diameters of a few tens of metres. The low albedo polygonal troughs occur between small dark patches of dune fields on a bright frost covered surface. Their appearance is bound to the 87°S-Apl units and the northernmost Nplh units. They appear throughout the seasons but the well developed polygons are restricted to about Ls=200 (early winter). At this time we can expect that the circum-polar areas are covered by large amounts of frost and that in contrast to other polygonal patterns described above, the troughs appear relatively fresh.

Conclusions: The observability of polygonal patterns and trough fill on Mars are directly tied to Martian seasons [e.g., 7]. The Amazonian polar layers and adjacent units present a variety of polygonal patterns which occur after removal of frost cover or at winter time. The characteristics in terms of shape and sizes can be attributed to the appearance of the surface material, to variations in topography and to geologic units, according to [8], but for a specification of surface material properties and crack processes data from mid-latitude areas need to be added and compared with the results for the south-polar area.

ON ABILITY OF STUDY OF NATURE OF CELESTIAL BODIES UNDER POLARIZATION
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The degree of linear polarization ($P$) is formed, mainly, during a single light scattering in atmospheric high layers and in dust of atmosphericless celestial bodies. The degree of circular polarization ($V$) is predominantly formed at a multiple scattering on the spherical or chaotically oriented aspheric particles. Therefore independent analysis of the observation data about $P$ and $V$ allows to determine the physical characteristics of dust and aerosol.

The polarimetric investigations are powerful method for remote sensing study of physical properties of solar system bodies. The polarimetric observations have allowed to determine spectral values of a refractive complex index of particles in planetary atmospheres, to determine parameters of a distribution function of these particles on the sizes, to solve the problem on difference of height of an upper edge of clouds in Jupiter’s zones and bands, to determine of methane quantity and value of atmospheric pressure in planetary abovecloudy layer and etc. At the same time for atmosphericless celestial bodies and for comets there is much less opportunities to determine its physical characteristics from the polarimetric data. First of all, it is explained by absence of the theory of formation of Stokes parameters of the light, which one is diffusely reflected by rough surfaces and multicomponent particles. Nevertheless, series of the relevant effects in polarization properties of light, which one reflected by a solar system bodies now is revealed. However, in some articles Umov’s effect will use for obtaining of a qualitative conclusions about a microstructure of surface layer and for calculation of an atmosphericless celestial bodies reflectivity. We pay attention to some ideas dealing with using Umov’s effect.

Some problems and achievements in polarimetric investigations of very extended and very rarefied cometary atmospheres are considered. At the beginning of 80 years Morozhenko attempted to agree all available polarimetric and spectrophotometric results of cometary observations with calculations for spherical particles. But this attempt was unsuccessful. It was supposed that the cometary aerosol is very large, oriented and rough (or aggregate) particles. Their sizes should be so large, that their spectropolarimetric properties would have similar to the atmosphericless celestial bodies. Later, Dollfus has made the same conclusion.

In the present report we give the most essential effects in observed polarization properties of diffusely reflected light by celestial bodies, and we shall supplement these effects by the data of laboratory investigations of particles from ground materials. We shall mention only those results where one this or that observed effect was discovered for the first time.
GEOLOGY AND STRATIGRAPHY OF IMPACT CRATERS ON CALLISTO – RESULTS FROM HIGH-RESOLUTION IMAGES OF THE GALILEO SSI CAMERA

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Introduction: The surfaces of the two largest icy Galilean satellites Ganymede and Callisto exhibit a wide range of impact crater morphologies not known from the surfaces of the terrestrial planets in the inner solar system. Impact craters on these two satellites include flat, bright plains (palimpsests), craters featuring central domes, and craters with a “regular” morphology reminiscent of e.g. lunar craters [1]. During the entire Galileo Jupiter orbit tour from 1996 to 2002, spanning a total of 34 orbits, the Galileo SSI camera was targeted to selected features on each one of these two satellites. In this paper, we will address (1) geology, (2) stratigraphy and (3) ages of craters observed by the SSI camera on the outermost Galilean satellite Callisto.

Data base and procedure: Geologic units identified in selected impact features were (1) mapped as members of each respective crater formation, based on albedo and morphology, and (2) the frequencies of superimposed craters were measured in order to derive a relative age sequence. Each crater formation was referred to a time-stratigraphic system defined by giant impacts which, from oldest to youngest, created the basins Asgard, Valhalla, and Lofn [2]. Absolute ages for each formation or member were obtained from two cratering chronology models for the Jovian system [3, 4, 5]. In one model [3], impacts are believed to stem mainly from asteroids, with a Late Heavy Bombardment period as on the terrestrial planets, since the shapes of crater size distributions on e.g. the Moon and on the Galilean satellites are very similar. In another model [4] (and its update [5]), craters are assumed to have been created mainly by impacts of comets with a more or less constant impact rate. The large basin Valhalla on Callisto has been assigned a nominal age of about 2 Gyr in both versions of the comet impact model [4][5].

Target areas: We focused our investigation on the following impact features: (1) Dome crater Har and regular crater Tindr, observed in Callisto flybys C9 and C10 (143 m/pxl and 390 m/pxl respectively); (2) dome crater Doh (C10; 90 m/pxl); (3) bright ray crater Bran (C20 and C30, 610 and 640 m/pxl).

Geologic units: The dome crater Har (45 km diameter) and the regular crater Tindr (73 km diameter) are close neighbors. Secondary crater clusters and chains from Tindr overlap the older crater Har. Continuous ejecta, secondary craters, crater floor material, and two units associated with a central pit were mapped in crater Tindr. Dome crater Har features a continuous ejecta blanket, floor material, and the central dome material. Dome crater Doh is characterized by smooth or knobby materials on the floor, dissected material surrounding the dome, and the central dome material itself. The actual diameter of Doh is larger than 55 km. The actual crater rim is degraded more or less, and the dissected unit represents the rim of a central pit with the dome in its center. Bran is a large (ca. 150 km) bright ray crater with a morphology reminiscent of palimpsests in places, i.e. a bright, smooth unit. Its rim, and an inner ring surrounding are degraded. The strongly asymmetric configuration of its ejecta suggest an impact at a low angle.

Results: Stratigraphically, Har can be placed between the Asgard and Valhalla impact events, while Tindr formed after Valhalla, at a time comparable to the formation of the youngest basin Lofn. Cumulative frequency diagrams of these two craters, and their relative ages in comparison to the ages of two major basins on Callisto, are shown in figure 1. The cratering model of Har age is 4.1 Gyr [3], or 3.32 Gyr [4] respectively, while the model age for Tindr is 3.87 Gyr [3], versus 1.35 Gyr [4]. Bran and the multi-ring basin Valhalla are comparable in their model ages (about 4.0 Gyr [3], or about 2 Gyr [4, 5]). Different crater morphologies in two closely spaced craters (older dome crater, younger regular crater) suggest either a change in rheology with time, or water ice or slush being concentrated in pockets in the subsurface [6]. The cratering model age of dome crater Doh, however – 3.86 Gyr [3], versus 1.25 Gyr [4] – is lower than that of Har, inferring that dome craters could still form at later time. In terms of the updated cometary impact model [5] there is not much change in model ages between the older version [4] since Callisto’s surface is generally assumed to be “old” (>> 3.5 Gyr). It must be kept in mind, however, that cometary impacts produce a strong apex-antapex asymmetry in crater frequency [5]. In this view, the two basins Valhalla and Lofn are assumed to be of the same age since Valhalla is more densely cratered but located closer to the apex point of orbital motion than Lofn, as discussed by [5]. Hence, Tindr with a similar distance to the apex as Lofn is also about the same age as this basin and as Valhalla. On the other hand, the dome crater Doh with a crater frequency comparable to Tindr must be older then due to its greater distance from the apex...
point. In the context of the asteroid impact model, the cratering rate is the same on all longitudes, and crater frequencies are directly comparable independent of geographic position [3, and references therein].


Figure 1: Cumulative frequencies of dome crater Har and regular crater Tindr. Curve shown is the crater production function for Callisto [3], fitted to the measured crater size distributions. The diagram shows the age sequence from the older Asgard basin (only curve shown) to Har, Valhalla basin (only curve) to the younger crater Tindr.
STRATIGRAPHY AND AGES OF LUNAR VOLCANIC DOMES: HANSTEEN AND HELMET REGIONS. R. Wagner¹, J. W. Head III², U. Wolf³, and G. Neukum⁴. ¹Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstraße 2, D-12489 Berlin, Germany; ²Dept. of Geol. Sciences, Brown Univ., Providence, RI, USA; ³Institut für Geowissenschaften, Freie Universität Berlin, Malteserstraße 74, D-12249 Berlin, Germany.

**Introduction:** The areally dominating volcanic process on the Earth’s moon was the widespread emplacement of basaltic low-viscosity lava materials by which the mare regions on the nearside were formed. A second, spatially less abundant volcanic process is associated with domical features which were formed by lava materials of higher silica content and much higher viscosity. These volcanic domes are morphologically and spectrally distinct from their surrounding mare or highland materials. The domes are termed red spots and are spectrally characterized by a high albedo, strong absorption in the ultraviolet, and also by a wide range of morphologies [1][2][3]. From photogeologic mapping and measuring crater frequencies on these domes and associated units, we expect to put constraints on the crustal evolution throughout the Imbrian and Eratosthenian periods of lunar geologic history.

**Previous work:** The Gruithuisen domes, located in northern Oceanus Procellarum at about 36° northern latitude and 40° western longitude, in relatively close proximity to the large crater Iridium, have been examined recently [3][4][5]. Out of a total number of three domes in this area, on two of them the superimposed crater frequency could be measured on medium and high-resolution Lunar Orbiter frames. Following the large impact event which created the Imbrium basin 3.91 Gyr ago [6], Iridium crater was formed, and its ejecta were emplaced on top of Imbrium ejecta. Then, on a geologically short time scale after this impact event, the three Gruithuisen domes were created by extrusion of viscous lava, similar in composition to terrestrial rhyolites or andesites [4][5]. The domes remained active in the Late Imbrian epoch, between 3.85 and 3.7 Gyr ago [4], confirming an Imbian age as has been suggested earlier [7]. This kind of high-viscosity volcanism was followed by the emplacement of large volumes of basaltic mare lavas, with model ages peaking at 3.55 Gyr, 3.2 – 3.3 Gyr and about 2.4 Gyr [4][8][9].

**Hansteen-Helmet region in southern Oceanus Procellarum:** Two areas displaying similar spectral red spots and volcanic domes were selected for ongoing studies. Both areas are located in the southern Oceanus Procellarum, close to the Humorum basin.

**Hansteen region.** Hansteen is a bright, polygonally shaped, domical feature located at about 11.5° southern latitude and 50° western longitude. The nearest major impact features are craters Hansteen α, a crater whose floor is partly flooded by mare lavas, and Billy whose floor is completely flooded by lava materials.

**Helmet region.** This region covering at least one minor domical feature at about 16° southern latitude and 30° western longitude is located at the northwestern edge of the Humorum basin which is mostly covered by mare materials. The domes are associated with mare units and ejecta of Humorum basin.

**Data base and procedure:** Photogeologic mapping and measurements of crater frequencies in the Hansteen-Helmet region were carried out on Lunar Orbiter high-resolution frames LO IV 149, 156 (both Hansteen), and LO IV 132 and LO IV 137 (Helmet). Geologic units were distinguished by albedo and morphology, previously published maps were used as references (e.g. [10][11]). Crater size-frequency distributions were fitted by an 11th-degree polynomial representing the time-invariant lunar crater production function in order to extract relative ages (normally the cumulative frequency equal to, or greater than, a diameter of 1 km). Then, the lunar cratering chronology model calibrated by the radiometric ages of lunar rocks returned during the Apollo missions [6] was applied to derive absolute ages for each unit.

**Results:** Preliminary results from the Hansteen region are discussed in this abstract. Crater frequencies clearly reflect stratigraphic relationships between the units. In the case of some units, however, their chronostratigraphic positions had to be corrected by means of crater counts. On two areas on Hansteen dome, model ages cover a range from 3.74 to 3.6 Gyr, ages which are comparable to those measured on the Gruithuisen domes. The Hansteen dome was assumed to be Eratosthenian or even Copernican by [11] but could now be verified as Late Imbrian by crater counts. Surrounding mare materials also could be verified as Late Imbrian, instead of Eratosthenian [11], while Early Imbrian ages were confirmed for craters Hansteen α or Billy, with model ages of about 3.8-3.9 Gyr. On these latter craters, smaller superimposed craters were removed along slopes of the rims and ejecta materials of these two larger craters causing a flattening of the crater size distribution towards smaller craters. Spectral analyses carried out recently also confirm that the Hansteen dome was emplaced on top of the ejecta materials of craters Hansteen α or Billy [12]. Figure 1 is a cumulative diagram showing the stratigraphic relations between the oldest units (such as crater Billy), the Hansteen dome, and the younger mare.
Stratigraphy and ages of lunar volcanic domes: Hansteen and Helmet regions – Wagner et al.

Materials. Crater counts on domes in the Helmet region and surrounding mare and highland materials (as previously mapped by e.g. [13]) are currently underway.


Figure 1: Cumulative frequencies of three units in the Hansteen region on the Moon. The diagram shows the stratigraphic sequence from older (Early Imbrian) units, such as crater Billy, to younger units such as the Hansteen dome (Late Imbrian) and mare materials which were emplaced after the formation of the dome (Late Imbrian). Caused by erosional removal of smaller superimposed craters on the ejecta blanket on crater Billy, the distribution at smaller crater sizes becomes flatter, and consequently the frequency at sizes smaller than about 1 km is lower than e.g. the frequency in the mare, hence lower than the stratigraphic position would imply.
GIANT POLYGONS IN MARTIAN LOWLAND PLAINS AND THE EXISTENCE OF AN OCEAN.
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**Introduction:** Utopia and Acidalia Planitiae are occupied by extensive areas of polygonal terrain, so-called giant polygons. They consist of 200 to 800 meter wide steep-walled and flat-floored troughs some tens of meters deep and 5 km to 30 km in diameter. A number of hypotheses for the origin were mentioned such as thermal cooling and contraction in permafrost, desiccation of water-saturated sediments, cooling of lava, and tectonic deformation. Pechmann [1] has shown that none of these terrestrial analogs would lead to a satisfactory description of the mechanisms and scales involved. McGill and Hills [2] besides others were able to explain the observed large size of the polygons and could account for the stresses responsible for the polygonal troughs by plate-bending and finite-element models which indicate the shrinkage of desiccating sediments or cooling volcanics accompanied by differential compaction over buried topography. The giant polygonal pattern is accompanied by ring- or double-ring-like structures which are assumed to be buried craters (ghost craters) and have been used to estimate the thickness of the overburden.

**Geologic Settings:** Following the geological interpretation by [3,4] the polygonal terrain material was deposited in the late Hesperian. The age relation of troughs to superimposed craters indicate that the polygon formation occurred immediately after the deposition [5]. Lucchitta et al. [6] advocate the material being of sedimentary origin deposited in a standing body of water and emphasize the areal correspondence between topographic low regions in the northern plains, polygonal terrain and outflow channels. Carr [7] describes the capability of the outflow channels to supply immense volumes of wet sediments to the lowland region. Crater counts indicate a coincidence between outflow events and origination of the polygonal terrain [8]. Age determination [9] indicated that the channels which might have fed the lowland region were cut into a surface that is younger than the polygonal terrain.

**Crater Counts on Giant Polygon Terrain:** We performed new measurements in selected areas of the Utopia region which cover polygonal terrain and surrounding units (Fig.1). All crater size frequency distributions (SFD) of the selected units converge in the smaller crater diameter size range and give an age of 3.4 Ga. The diversity or deviation from the expected crater production function [10,11] for the larger crater diameter size range (larger than 3 km) most likely depends on different target properties or the geologic evolution of that area. A few of these units show an "excess" in the crater SFD of larger craters (Fig. 1, Unit G) as has been already observed by [9]. Crater counts on these units yield an age of 3.8 Ga. The measured distributions converging in the small-size range lead to an age of 3.4 Ga and indicate a resurfacing event at 3.4 Ga ago detectable in all units.

**Results:** Investigating the region of polygonal terrain in the Utopia and Acidalia Planitiae we obtain SFDs which appear to have an unusual deficiency of large craters compared to the proposed production function. This unusual lack of larger craters is interpreted to be due to target property effects in the cratering process leading to different crater morphologies and sizes. For the polygonal terrain in Utopia Planitia first we measured the crater size-frequency distribution of the clearly visible craters and obtained an age of 3.4 Ga. The same distribution has been combined with the population of so-called ghost craters, the buried craters which causes the ring-like grabens. The sum of visible and ghost crater populations yield an age of 3.8 Ga as it has been observed in regions with strong excess of craters in the larger diameter range (Fig. 2).

**Interpretation:** Whatever causes the diversity or obscures the expected production function of the crater SFD in the larger size range occurred between 3.4 and 3.8 Ga. These distributions can be explained by extensive resurfacing effects within a time span of roughly half a billion years. This is consistent with the existence of a proposed ocean in the northern lowlands and with the interpretation that the polygons formed through desiccation and differential compaction of sediment over buried topography.

**References:**
GIANT POLYGONS ON MARS: S. C. Werner et al.

Fig. 1 (left): The crater size-frequency distributions of selected areas in Utopia Planitia show a diversity in the large-crater diameter size range and a convergence in the small-crater diameter size range (roughly smaller than 2 km).

Fig. 2 (top): The crater size-frequency distribution in the polygonal terrain is shown with and without the contribution of the ghost crater population.
THE ROLE OF SINGLE SCATTERING IN SHAPING OF NEGATIVE POLARIZATION BRANCHES OF DARK REGOLITH-LIKE SURFACES. E. Zubko, A. Ovcharenko, Yu. Shkuratov, and G. Videen, 1Astronomical Institute of Kharkov National University, 35 Sumskaya St. Kharkov. 61022. Ukraine, 2Army Research Laboratory AMSRL-CI-EM, 2800 Powder Mill Road, Adelphi Maryland 20783, USA. zubko@astron.kharkov.ua

Introduction: Regolith-like surfaces consisting of small particles demonstrate negative polarization branches (NPB) at small phase angles. These NPB have different shapes, e.g., [1]. Study of physical factors that influence the shapes is important to develop remote sensing researches of atmosphereless celestial bodies. The NPB of a regolith-like surface can be formed by the multiple coherent backscattering as well as single particle scattering [1,2]. Here we link the NPB of individual particles and particulate medium composed by these particles. For calculations of scattering by single particles we use the Discrete-Dipole Approximation (DDA) method [3,4]; for calculations of light scattering in particulate media we use the Monte Carlo ray-tracing technique developed in [1].

Particles, media, and ray tracing technique: The DDA method is described in many works, e.g., [3,4]. Thus we present here only the model of the irregular particles studied. To simulate them, a set of 137376 cells is used to form an approximately spherical volume. Then a number of randomly chosen cells of the volume are marked as seeds of particle material and empty space. Each cell that differs from the seeds is marked as the nearest seed cell. Examples of irregular particles are shown in Fig. 1.

To generate a random medium, we use a cubic box consisting of scatterers with a finite size. The upper side of the box corresponds to the boundary (plane on average) of the medium. The other sides of the box are cyclically conjugated (e.g., if a ray goes out the box through the bottom, it returns into the box through the upper side). We use the ray tracing in media constructed from particles with finite size taking automatically into account the shadowing effect. This is valid if the geometric optics approximation is justified. When the particles are comparable to the wavelength, the ray tracing can be considered only as a technique to estimate light attenuation in the medium. We calculated six orders of scattering that is enough for dark media [1,5].

Results and discussion In Fig. 2 we show results of computer simulation and laboratory measurements [1] of a red water-color powder. This sample was prepared by drying of alcohol suspension of the water-color. That gives a dense layer consisting of small particles. To have low albedo we measured this sample in blue light obtaining $A = 4\%$. As one can see we have in this case almost symmetric NPB (points). To model this NPB we use irregular particles that have not own NPB (curve 1). The size parameter of the equivalent sphere for the particles is $x_{eq} = 2 \frac{2\pi r}{\lambda}$, where $\lambda$ is the wavelength and $r$ is the sphere radius). The refractive index is $m = 1.5 + 0.1i$, and single scattering albedo is $\omega = 0.66$. The medium volume density is $\rho = 0.3$. The box modeling the semi-infinitive medium contains 2000 particles and they are illuminated by 1000 rays. The scattering properties result from averaging of 300000 realizations of the medium. Thus we have very good statistical averaging. Our calculation of the polarimetric coherent backscatter effect shows excellent coincidence of experimental and model data (curve 2).

Fig. 3 shows our measurement of smoked carbon soot with albedo of about 2\%. This is a very fluffy dark surface with very low $\rho$. An asymmetric NPB is observed in this case. The position of the NPB minimum shifts to the zero phase angle. To model this measurements we use almost the same particles
and parameters of ray-tracing at $\rho = 0.07$. Comparing Figs. 2 and 3, one can conclude that the symmetric shape of NPB corresponds to denser surface, and the asymmetric curve is characteristic of fluffy medium. This is consistent with our experimental data [1].

Our earlier laboratory studies showed that a very dark dense carbon water-color generates asymmetry such that the position of the NPB minimum shifts toward the inversion angle [6]. Now we confirm this result using computer modeling. In Fig. 4 we show our calculations of NPB for a dark medium composed by particles having an asymmetric NPB at $x = 5, m = 1.5 + 0.5i, \omega = 0.47$, and $\rho = 0.3$. Curves 3 and 4 present individual particles and medium, respectively. The initial cubic box contains 5000 particles, number of rays is 1000. As one can see the asymmetry generated by single particle scattering is clearly revealed in the case of the model medium. For comparison we present in Fig.4 curves 1 and 2 that show NPB of individual particles and medium, respectively, for the case when the single particles have no own NPB at all ($x = 1, m = 1.5 + 0.05i$, and $\omega = 0.6$). The volume density of the medium is $\rho = 0.3$, the initial cubic box contains 5000 particles and it is illuminated by 1000 rays. In this case, 8 orders of scattering are taken. Scattering properties are averaged on 10000 realizations of the medium. Comparing the pairs 1,2 and 3,4 shows that multiple scattering generates NPB when single particles have not NPB, but decreases NPB, if the single particles do have NPB.

These results are developed with the data shown in Fig. 5, right. In this case we use for our calculations scattering characteristics of particles that were found experimentally; we use measurements of irregular particles of Locon volcanic ash presented in [7]. The mean size parameter of the particles is near 90 [7]. In our simulation the volume density of the medium was $\rho = 0.1$. The cubic box contains 3000 particles. The box is illuminated with 1000 rays. We take here 6 orders of scattering using averaging of 260000 realizations of the medium. Curve 1 presents smoothed data for the single particle of Locon volcanic ash [7]. Curve 2 corresponds to our simulation of scattering by the medium composed with such particles. Open circles present results of our measurements of the Locon volcanic ash powder. Albedo of the powder is fairly low, near 6%. As one can see the calculated curve exhibits the double-minimum (bi-modal) form. The minimum at large phase angles is caused by NPB of individual particles. The second minimum, at small phase angles, is due to the coherent backscattering enhancement mechanism. Comparison of the theoretical and experimental curves for the powder does not show good coincidence: measurements do not reveal the narrow NPB spike that is predicted with our model. Although some hint for the narrow spike exists in the experimental data, it is of course too small to be seriously discussed. This points out imperfections of our model: we, perhaps,

![Fig. 4. Curves 1,3 and 2,4 present individual particles and medium, respectively.](image)

underestimate contributions of large particles providing in the medium large interference lengths which shift the NPB spike to phase angles less than 0.2°, that is beyond the limit of our experimental equipment.

**Conclusion:** Our computer simulation of NPB has shown: Multiple scattering can generate NPB when single particles have no own NPB, but decreases NPB, if the single particles do have own NPB. The model predicts bi-modal NPB for dark regolith-like surfaces, though in laboratory measurements we find only slight hint for such bimodality.

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**References:**
LUNAR SOUTH POLE-AITKEN IMPACT BASIN: CLEMENTINE TOPOGRAPHY AND IMPLICATIONS FOR THE INTERPRETATION OF BASIN STRUCTURE AND STRATIGRAPHY

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Introduction: Lunar impact basins show a variety of internal and external structure [e.g., Wilhelms, 1987; Head et al., 1993, Spudis, 1993] and states of degradation and preservation. Orientale, one of the youngest and best-preserved large basins, shows a configuration of internal topography, ring structure, and deposit morphology (Orientale-type; Figure 1) that is generally similar to other relatively undegraded lunar basins. Other, more heavily degraded basins on the Moon (Tranquilitatis-type) have apparently undergone significant viscous relaxation subsequent to their formation, reducing basin topography [Solomon et al., 1982]. These older basins have also been subject to significant impact degradation. Both of these morphologies are in contrast to some impact basins on icy satellites characterized by many more rings and little topographic expression (Valhalla-type) [e.g., Passey and Shoemaker, 1982; Greeley et al., 2000], a morphology thought to have been formed as part of the very early modification stage of the impact event, due primarily to sublithospheric flow into the cavity area and attendant formation of many multiple rings [McKinnon and Melosh, 1980]. We discuss three basic scenarios for the formation of basin topography and facies:

1) The Valhalla-type, formed by near instantaneous collapse of the cavity, sublithospheric flow due to the presence of a ductile layer at shallow depths, and sublithospheric lateral shear leading to the formation of many multiple rings and little basin topography.
2) The Orientale-type, formed by impact into a target that has sufficient target rigidity to form a small number of multiple rings and to preserve them over geologic time.
3) The Tranquillitatis-type, formed in a manner likely similar to the Orientale type but in a target thermal structure that subsequently allowed for long-term crustal flow and viscous relaxation of the major topographic elements to produce a very shallow basin.

The lunar South Pole-Aitken (SPA) impact basin is one of the largest and oldest impact basins and has thus been heavily degraded by post-basin-formation primary impacts and their ejecta. Here we use Clementine altimetry data [e.g., Zuber et al., 1994] to delineate evidence for superposed craters and basins, and for remaining evidence for topographic internal structure. We summarize the evidence for basin ring location and character, and use these data to assess which basin type the South Pole-Aitken Basin most closely resembles. Finally, we assess the implications for basin origin, evolution and stratigraphy and suggest scenarios for future exploration.

Orientale Basin structure and cross-section interpretation: The youngest large basin structure on the Moon, the Orientale basin, exhibits several clearly defined ring structures, the Cordillera ring, the Outer Rook ring, and the Inner Rook ring. Head et al. [1993] proposed that the transient crater penetrated to lower crustal depth and later collapsed along an outer rim fault (Cordillera ring) and rim material rotated inwards and upwards in order to form the Outer Rook ring and the Inner Rook peak ring (Figure 2). On the basis of morphologic and topographic comparisons, Head [1974, 1977] and Bratt et al. [1985] suggested that the Orientale Cordillera ring was equivalent to a scarp marking the outer part of a collapsed megaterrace, the Outer Rook ring was the closest approximation to the transient crater rim, and the Inner Rook Mountains were equivalent to a peak ring. The innermost depression was related to thermal contraction of the cooling central basin uplifted geotherms.

Fig.1 Lunar Orbiter IV image of the Orientale Basin

South Pole-Aitken basin topography and structure: Clementine altimetry data indicate a complex structure of the SPA basin and support earlier findings based on Zond microsymposium.
Wilhelms et al. [1979, 1980, Shpekin, 1983; Leikin and Sanovich, 1985] and Apollo laser altimetry data [e.g., Wollenhaupt and Sjogren, 1972; Kaula et al., 1973]. For example, Clementine data show that the SPA basin is more than 8 km deep, hence having a morphology very different from the Valhalla-type multiringed impact basins. Making use of Clementine topographic data, we identified three, possibly four rings for the SPA basin. The three outer rings are best defined in the eastern and northeastern sections of the SPA basin, but are indistinguishable from the highland terrain in the western parts of the basin, probably due to pre-SPA topography and post-SPA modifications by younger basins. Our outermost ring (#1 in Figure 3) is defined by a sharp drop in elevation of ~3-4 km and can be traced for several hundreds of kilometers. Ring 2 is characterized by another drop in elevation of ~2-3 km and can be traced for similar distances. Parts of this ring are modified by the younger Apollo basin (Figure 3). Ring 3 encloses the deepest parts of the basin, which are ~2-3 km below the terrain between ring 2 and 3. These three ring structures form a step-like topography across the northeastern quadrangle of the SPA basin (Figure 4).

**Discussion: Pre-SPA Events:** The general area around the SPA basin is characterized by numerous pre-Nectarian basin structures, for example the Australe, Hertzprung, Mendel-Rydberg and Korolev basins. Similar sized old impact basins in the South Pole-Aitken area would have created and modified the pre-SPA impact topography at large scales, thus influencing the final morphology and topography of the SPA basin. This might be reflected in significant differences in the present day topography of terrain surrounding the South Pole-Aitken basin. In the north of the SPA basin the terrain is at elevations of ~3000-4000 m (peaks up to 7500 m) whereas areas to the west and east appear to be significantly lower in elevation (~0 to ~1000 m) and this has also been attributed to the deposition of SPA ejecta. We also identified a possible fragment of an ancient basin ring (“A” in Figure 3) that coincides with low topography within this inferred basin structure. Both factors, pre-SPA basins and inherent topographic differences, contribute to the difficulties in ring placement and detailed characterization of the SPA structure in the western parts of the SPA basin.

**Post-SPA Events:** Since the South Pole-Aitken impact, the region has been extensively modified by subsequent impact cratering at various scales. Multiple craters are superposed on the SPA basin and have further modified its structure. These impact craters include the large internal basins such as the Apollo, Poincaré, Schrödinger and Planck, as well as external basins, e.g., the Orientale basin, which deposited its ejecta across the South Pole-Aitken basin (Figure 3) [e.g., Haskin, 2002].

Besides impact cratering, the South Pole-Aitken basin has been modified by volcanism as evidenced by mare deposits and light plains. According to the geologic map of Wilhelms et al. [1979] and recent spectral studies [Yingst and Head, 1997, 1999; Pieters et al., 2001], these mare deposits occur preferentially in post-SPA craters and basins (e.g., Mare Ingenii, Von Karman, Leibnitz, Apollo, and Poincaré) and are of upper Imbrian and Eratosthenian age.

**Basin Structure:** Previous attempts to define ring structures of the South Pole-Aitken basin suffered from the fact that the basin was located at high southern farside latitudes and thus had limited image coverage as well as from the lack of topographic data that covered the entire basin. Consequently there are large differences in the location of ring structures defined in previous studies, e.g., Stuart-Alexander [1978], Wilhelms et al. [1979], and Leikin and Sanovich [1985]. As described earlier, we used Clementine altimetry data to define at least three ring structures of the SPA basin. On the basis of our investigation, we think that our ring 1 might be related to the initial collapse of the SPA transient crater, inward slumping of the rim along an outer rim fault, and the formation of a megaterrace. Ring 2 and 3 might have formed by inward and upward movement of crustal blocks in response to the transient crater collapse. In this scenario, ring 2 would be the closest approximation of the transient crater. If our interpretation is correct, this makes ring 1 similar to the Orientale Cordilleran ring, ring 2 might be the analog to the Outer Rook ring, and ring 3 the analog of the Inner Montes Rook ring of the Orientale basin. Thus we interpret the original dimension and structure of the basin as follows: ring 1 is approximately 2400 km in diameter, ring 2 is ~2100 km in diameter, and ring 3 is ~1500 km in diameter. On the basis of our ring structures, we find the basin center at roughly 174°W and 55°S.

This is different from previous interpretations in the following manner. Stuart-Alexander [1978] proposed that the basin is 2000 km in diameter, centered at 180°W and 50°S. Wilhelms et al. [1979] mapped a basin 2500 km in diameter and centered at 180°W and 56°S and a possible inner ring 1800-2000 km in diameter. Wood and Gifford [1980] estimated a diameter of ~2600 km with a center at 180°W and 60°S, whereas Leikin and Sanovich [1985] find the diameter of the SPA basin to be on the order of 2200 km and its center at 183.5°E and 41.5°S.

**Conclusions:** On the basis of our investigation we conclude that the South Pole-Aitken basin is not the Valhalla-type, and that it is also not the Tranquillitatis type in that there has not been significant viscous relaxation. Thus, the implication is that the impact was originally into a target that was not sufficiently ductile at depth to produce initial Valhalla-type basin structure, and also not to produce longer-term viscous relaxation.

One goal for future sample return missions is to establish the age of the SPA basin. Impact melt, which dates the SPA event most reliably, is likely to be found in high concentrations within the inner ring (#3). In addition the innermost and deepest parts of the SPA basin likely tapped lower crustal or upper mantle material, making the basin center a good candidate for returning such samples to Earth.
References

Fig. 3 Clementine Topography of the South Pole-Aitken Basin and interpretative sketch map of its ring structures

Fig. 4 Profile across the SPA basin (along the black line in Figure 3) showing the approximate position of three possible ring structures and a stairstep-like topography