

# *EUG XI*



Symposium EVO4

Interaction of Endogenic, Exogenic and  
Biological Terrestrial Systems and Possible  
Extraterrestrial Impacts during the  
Early Palaeoproterozoic

Convenors

Victor Melezhik  
Evgenii V. Sharkov

## EVO4

### Interaction of Endogenic, Exogenic and Biological Terrestrial Systems

#### Wednesday AM Session

##### EVO4 : WEam02 : F5

##### Tectonic Control of Chemical and Isotopic Composition of Ancient Oceans

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A numerical model (Godderis and Veizer, 2000) that couples carbon-sulfur-strontium and atmospheric oxygen cycles is used here to explore the impact of continental growth on the long term (in excess of 10<sup>9</sup> yrs) evolution of the isotopic composition of seawater. Three growth scenarios are tested: "big bang" generation of continents shortly after the accretion of the Earth and two more gradual scenarios, with a major growth episode around the Archean-Proterozoic boundary. The corresponding <sup>87</sup>Sr/<sup>86</sup>Sr,  $\delta^{34}\text{S}$ , and  $\delta^{13}\text{C}$  of seawater and the sizes of the respective crustal sedimentary reservoirs are calculated for each scenario and compared to the available data. The gradual continental growth scenarios yield a better fit to the existing <sup>87</sup>Sr/<sup>86</sup>Sr and  $\delta^{34}\text{S}$  isotope data for ancient seawater than does the "big bang" model and can be in agreement also with the measured seawater  $\delta^{13}\text{C}$ , providing Corg participates in carbon subduction flux over the Earth history. These scenarios also generate a progressive oxygenation of the ocean/atmosphere system, with a large pO<sub>2</sub> rise coincident with (and due to) the major continental growth event around the Archean-Proterozoic transition, in accord with the geologic record that indicates a major oxidation event in the early Proterozoic. The advancing oxygenation of the planetary exogenic system may therefore be a consequence of tectonic evolution rather than of biological innovations such as the photosystem 2. A similar tectonic control is indicated also for the Phanerozoic (Veizer et al., 1999) where all these isotopic systems are strongly interrelated, indicating that we are dealing with a unified exogenic system driven by tectonics via its control of (bio)geochemical cycles.

Godderis Y & Veizer J, *Am. J. Science*, **300**, 434-461, (2000).  
Veizer J, Ala D, Azmy K, Bruckschen P, Buhl D, Bruhn F, Carden Gaf, Diener a, Ebneth S, Godderis Y, Jasper T, Korte C, Pawellek F, Podlaha OG & Strauss H, *Chem. Geol.*, **161**, 59-88, (1999).

##### EVO4 : WEam03 : F5

##### Isotopic Composition of Paleoproterozoic Carbonate Successions on the Kaapvaal Craton: Implications for the Secular Carbon Isotope Curve

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Several carbonate units with unusually heavy carbon isotopic composition were recently identified in the Paleoproterozoic Pretoria Group, Transvaal Basin, and the Olifantshoek Group, Griqualand West Basin, and have been used to propose multiple carbon isotope excursions for the Paleoproterozoic (Buick et al., 1998). This contrasts with the view of only one single global carbon isotopic excursion at ca. 2.1 Ga that heralded the rise of oxygen in the Earth's atmosphere (Karhu and Holland, 1996). Results of detailed stratigraphic, sedimentological and geochemical studies of the Pretoria and Olifantshoek Groups have now provided the necessary evidence to resolve this discussion and to propose the presence of two distinct carbon isotopic excursions recorded by Paleoproterozoic carbonates on the Kaapvaal Craton. The first excursion is restricted to the 2.45-2.3 Ga Duitschland Formation in the Transvaal Basin. The base of the Duitschland Formation is marked by a glacial diamictite overlain by shale and a cap carbonates with characteristically negative carbon isotopic composition. However, unconformably overlying this glacial succession of the Lower Duitschland Formation, are

carbonates in the upper Duitschland Formation with carbon isotopic values up to +10‰. These isotopically heavy carbonates must represent an excursion older than the well established 2.1 Ga global excursion. Evidence for a second, younger carbon isotope excursion is preserved in the Silverton Formation of the Pretoria Group as well as the Lucknow Formation of the Olifantshoek Group. Both contain thin carbonate units with carbon isotopic compositions close to or exceeding +10‰. Detailed stratigraphic studies have recently indicated that the lower part of the Olifantshoek Group, including the Lucknow Formation, is correlative with the upper part of the Pretoria Group in the Transvaal Basin. In this revised stratigraphic correlation, the Lucknow and Silverton carbonates are time equivalent with an age range of 2.25 Ga to 2.06 Ga. This second carbon isotopic excursion is similar in age to the global carbon isotopic excursion defined by Karhu and Holland (1996). Our data thus supports the presence of two distinct heavy carbon isotopic excursions in the Paleoproterozoic.

Buick IS, Uken R, Gibson RL & Wallmach T, *Geology*, **26**, 875-878, (1998).

Karhu JA & Holland HD, *Geology*, **24**, 867-870, (1996).

##### EVO4 : WEam04 : F5

##### The Great Early Paleoproterozoic (Huronian) Glaciation: Convergence of Astrophysical, Plate Tectonic and Biological Phenomena?

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There is a considerable body of field evidence supporting the existence of early Paleoproterozoic glaciation (~2.3 Ga) on several continents (North America, northern Europe, South Africa and Western Australia). In some successions (Huronian Supergroup of the north shore of lake Huron, Ontario; Snowy Pass Supergroup, S.E. Wyoming) there is evidence of three distinct glacial periods. Sparked largely by studies of much younger (Neoproterozoic) glacial deposits, there has been a resurgence of the idea, first promoted by Harland (1964), that the widespread Proterozoic glacial deposits were essentially contemporaneous and that the entire Earth was subjected to unusually low surface temperatures. This idea was articulated as the "snowball Earth" hypothesis by Kirschvink (1992) and was elaborated on by Hoffman et al. (1998) who, following Knoll et al. (1986), added stable isotopic data (particularly carbon isotope data) to the equation. Some have attempted to apply the same interpretation to Paleoproterozoic glacial deposits. There is much in common between these two major glacial episodes that mark the beginning and end of the Proterozoic Eon. Both appear to have formed at a particular phase in the Wilson plate tectonic cycle. Deposition of the Huronian is thought to have occurred during the breakup of a late Archean supercontinent (Kenorland), whereas the Neoproterozoic glacial deposits were formed during the rifting of the much younger (and larger?) Grenville supercontinent, Rodinia. The significance of this is unknown but it is possible that tectonic events (mountain building, crustal thickening) involved in the formation of the supercontinents brought about increased chemical weathering and drawdown of atmospheric CO<sub>2</sub>. The arid interiors of end-Archean supercontinent(s) may also have led to enhanced atmospheric dust production which could also have brought about cooling by blocking radiation from the sun (Broecker, 2000). Such dust could also have introduced Fe to the upper part of the hydrosphere, thereby stimulating phytoplanktonic blooms that would have enhanced weathering-related CO<sub>2</sub> drawdown and led to concentration of <sup>13</sup>C in oceanic waters. It is likely that the Paleoproterozoic glaciations occurred under an atmosphere that was highly enriched in CO<sub>2</sub> and at a time when the sun's radiative output was weak - the so-called "faint young sun". This interpretation is supported by the juxtaposition of glacial (unweathered) sediments and supermature rocks like the orthoquartzites of the Lorrain Formation. Interpretation of the ancient glacial deposits has been complicated by the discovery that many of them formed at sea level in low palaeolatitudes. Some have inferred from this that glacial conditions encircled the globe (snowball Earth) but the presence of indicators of strong seasonality (varved deposits, ice-wedge structures) appear to support the theory of anomalously high (>54 degrees) obliquity of the Earth's ecliptic (Williams, 1993).

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Kirschvink J, *The Proterozoic Biosphere: a multidisciplinary study*, Cambridge University Press, 51-52, (1992).

Knoll AH, Hayes JM, Kaufman AJ, Swett K & Lambert IB, *Nature*, **321**, 832-838, (1986).

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##### EVO4 : WEam05 : F5

##### Paleoproterozoic <sup>13</sup>C-Rich Carbonates: More Evidence for Restricted Depositional Environments

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Since the Paleoproterozoic positive isotopic shift (PPIS) of carbonate carbon was suggested to be associated with perturbation of the global carbon reservoir (Baker and Fallick, 1998a) three major questions remain unanswered: (1) does the PPIS represent a single excursion or a series of excursions (Baker and Fallick, 1998b), (2) to what extent isotopic values were driven by global factors, and (3) what was the contribution of local depositional factors (Melezhik et al., 1999). At present, the first problem cannot be reliably resolved in view of poor age constraints (Karhu and Holland, 1996; Buick et al., 1998; Melezhik et al., 1999), whereas the two others can be tackled by comprehensive sedimentological studies (e.g., Melezhik et al., 2000). Only when these three questions are resolved will the mechanism behind the PPIS be better constrained.

When <sup>13</sup>C -rich Paleoproterozoic carbonate formations retain primary sedimentary features they exhibit predominantly stromatolitic structures, evaporitic affinities and are associated with terrestrial, highly oxidised 'red beds' and evaporites. These features suggest restricted or partly restricted depositional environments. Thus, comprehensive sedimentological studies are absolutely necessary before isotopic signatures obtained from Paleoproterozoic carbonates are used for the reconstruction of seawater composition.

This contribution presents detailed sedimentological and isotopic data obtained from the Kuetsjärvi Sedimentary Formation (KSF) in the Pechenga Greenstone Belt, NW Russia, where a high resolution study was based on drill-core material. The KSF, one of the key successions in the investigation of PPSI, is 150 m thick and represents lacustrine sediments accumulated with an intracratonic rift setting. Carbonate rocks, predominantly stromatolitic dolostones, contain abundant hot-water spring, sulphate bearing travertine crusts and mounds as well as stacks of caliche profiles. The sequence stratigraphy suggests that the dolomite-depositing system was frequently decoupled from the bordering lake, and subjected to several extended episodes of emergence followed by vadose alteration. The dolostones, accumulated in restricted environments, have  $\delta^{13}\text{C}$  ranging from +4 to +9‰ vs V-PDB. This isotopic range was overprinted by hot-water springs, depositing dolomite with an initial  $\delta^{13}\text{C}$  value of -4‰. Further, the carbon isotope system was subjected to alteration in a vadose zone and formation of caliches in semi-arid climate. Caliche carbonates have been found to be enriched in <sup>13</sup>C up to 1.5‰ with respect to substrate dolomite.

Isotopic values measured from the KSF carbonates have been previously used for the reconstruction of the Paleoproterozoic  $\delta^{13}\text{C}$  reference curve. The results obtained by this study suggest that the KSF should be avoided for such exercises unless it is proven to represent carbonates deposited in equilibrium with coeval atmospheric CO<sub>2</sub>.

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**EVO4 : WEam06 : F5**  
**Palaeoenvironmental Factors in World-Wide Formation of  $^{13}\text{C}$ -Rich Carbonate Sediments at 2.2-2.0 Ga: Geochemical and Sr Isotope Evidence**

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The world-wide Palaeoproterozoic positive excursion of  $\delta^{13}\text{C}_{\text{carb}}$  is one of the most remarkable geochemical phenomena in the Earth's history. It has been earlier suggested that some highly positive  $\delta^{13}\text{C}_{\text{carb}}$  values were caused by interplay between global and local depositional factors. This study demonstrates a contribution of local palaeoenvironmental factors as based on geochemical and Sr isotope investigation of marginal marine, sabkha and lacustrine evaporite carbonates from the Canadian and Fennoscandian Shields.

The Canadian Shield is represented by the Dunphy and Uve dolomitic formations, and the quartzite-dolomitic Alder Formation of the lower part of the Knob Lake Group (2.17-2.14 Ga).  $^{13}\text{C}$ -rich carbonates of the Fennoscandian Shield include the Tulomozero Formation (2.09±0.07 Ga) occurring in the Omega Lake area. The formation is composed of stromatolitic dolostones interbedded with minor magnetites and abundant red sandstones and siltstones.

Dolomites deposited in distal and proximal facies of a marginal shallow marine palaeobasin contain only 50-125 ppm of Sr. The dolomites from distal facies have Fe/Mn ratios of 2.3-7.7, whereas those from proximal facies exhibit lower ratios fluctuating between 0.4 and 1.7. The marine dolostones yielded low  $^{87}\text{Sr}/^{86}\text{Sr}$  values ranging from 0.70343 to 0.70420. These values are considered to represent a composition of the coeval Palaeoproterozoic seawater.

The sabkha dolomites contain more Sr, Mn and Fe (up to 250, 1600 and 800 ppm, respectively) and have a lower Fe/Mn (0.05-0.45) ratio and higher  $\delta^{18}\text{O}$  values (by 1.5‰ on average) as compared with marine dolomites.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios obtained from the sabkha dolomites (0.70499-0.70534) suggest that depositional environments had sustained continental inflow and were occasionally connected to an open sea.

The calcites and dolomites formed in lacustrine evaporite palaeoenvironments have very high Sr content (up to 2080 and 530 ppm, respectively) and a low Fe/Mn ratio (<0.40) suggesting the presence of sulphates in original sediments. All  $^{87}\text{Sr}/^{86}\text{Sr}$  values measured from the limestones (0.70827-0.70871) and the dolostones (0.70643-0.70668) are inherited features of isolated evaporate lakes or ponds.

The restricted shallow-water carbonates with most radiogenic strontium isotopes are also marked by the highest  $\delta^{13}\text{C}$  values (+10.8 to +15.4‰ V-PDB) as compared to those deposited in relatively open marine depositional systems (+5.3 to +10.2‰ V-PDB). The strontium isotope study has confirmed the earlier statement that restricted palaeodepositional environments were important factors in the formation of carbonates with highly elevated  $\delta^{13}\text{C}$  at 2.2-2.0 Ga.

This work was supported by the INTAS Grant 99-4024 and the RFBR Grant 00-05-64915.

**EVO4 : WEam09 : F5**  
**Black Shales, Organic Matter, Ore Genesis and Hydrocarbon Generation in the Paleoproterozoic Franceville Series, Gabon**

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Abstract The 2.1 Ga old FB Formation of the Franceville Series, southeastern Gabon, contains one of the greatest accumulations of organic carbon of its age. The weakly metamorphosed, dominantly pelitic FB Formation, ranges in thickness from 600 m to 1000 m, covers over 35,000 km<sup>2</sup>, and consists of about 80% marine shale with 0.5 to 15% total organic carbon. Results of geochemical analysis shows that, compared with black shale standard SDO-met, the average FB Formation black shale is enriched only in Au, Ag, Ba and Cr. Pauticities in U and Mn represent negative anomalies in this area of world class U and Mn deposits. The manganese deposits are a consequence of extreme lateritization. Genesis of the uranium ores is closely linked to the burial history and the maturation of organic matter in black shales near the base of the Franceville Series. The presence in these rocks of diverse fossil remains, including a Gunflint-type association of stromatolites and microfossils, various planktonic species of Gunflintian age, and abundant carbonized microbial-like forms, provide the link to genesis of liquid bitumens in the Franceville Series. Prolific amounts of liquid hydrocarbon, the remnants of which have since solidified, were generated through the "oil window", opened during burial of the FB Formation ca. 2.0 Ga ago. The coincidence of uranium-bearing aqueous solutions with the main interval of hydrocarbon migration led to the localization of uranium ores in petroleum-type structural traps. Some of the richer uranium deposits served as loci for the development of the Oklo natural nuclear fission reactors. Hydrothermal solutions circulating about the reactors during their operation ca. 1.968 Ga ago, resulted in a second interval of local migration of liquid hydrocarbons. Geochemical analysis by LAM-ICP-MS of mineral matter-free portions of solid bitumens sourced from the black shales confirms the presence of various metals (possibly as organometallic complexes) and serves to elucidate evolutionary pathways of bitumen and particular metal associations.

**EVO4 : WEam10 : F5**  
 **$\delta^{13}\text{C}$  Anomalies in the Archaean and Proterozoic: Organic Anomaly or Mile Stone of a Global Tectonic Reorganization**

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Since the Archaean, the bulk of  $\delta^{13}\text{C}$  of organic carbon ranges between -10‰ (rel. to PDB) and -40‰ (mean between -20‰ and -30‰). Twice, in the Archaean (Fortescue Group: approx.  $2.7 \times 10^9$  yr.) and in the Proterozoic (Francevillian Series: approx.  $2.1 \times 10^9$  yr.) anomalous low values reaching -50‰ and -45‰, respectively, are reported (Schidlowski, 1988). A number of investigations has shown that such low values are widespread in the Archaean (Strauss et al., 1993). Extremely low values are also reported from living communities around active brine seeps on the continental slopes at several locations (Paull et al., 1985). Carbon-rich sediments (0.1 to 3.5 wt.% TOC) from the Archaean Sukumaland Greenstone Belt have been investigated in detail (Rammlmair et al., 1995). By means of microscopy, SEM, grain size fractionation, Raman spectroscopy, C-H-N contents and pyrolysis first time two distinct carbon sources could be identified. The first carbon source is of a primary kerogen ( $\delta^{13}\text{C}$  = -25‰; 0.1 to 0.3 wt.% TOC; grain size >0.1 to 200  $\mu\text{m}$ ) which suffered local metamorphic overprint. Carbon from the second source ( $\delta^{13}\text{C}$  = -60‰; 0.1 to 3.5 wt.% TOC; grain size <0.1  $\mu\text{m}$ ) was introduced post peak metamorphism in varying amounts, via active shear zones to the primary kerogen. The second carbon most probably derived from a thermogenic, highly fractionated methane. In the two-source-model, the past interpretation of anomalous low  $\delta^{13}\text{C}$  bulk values is questionable. Were Archaean methane consuming organisms responsible for these low values or did methane-derived carbon move into sheared, more or less metamorphosed black shales and precipitate as minute particles? Both, the organic and the inorganic trapping of

methane requires an at least locally higher methane flux in these time periods. Could this higher flux be provided by deeply rooted mega-shear zones which could even point towards major changes in the global tectonic style?

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**EVO4 : WEam12 : F5**  
**The Palaeoproterozoic as the Main Turning Point of Endogenic Evolution of the Earth: Evidence for the Baltic Shield**

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The main change in tectonic-magmatic evolution of the Earth occurred during the Palaeoproterozoic (Bogatikov et al., 2000). During the Archaean on all Precambrian shields granite-greenstone and granulite-gneiss terranes simultaneously evolved. The such type of tectonics, however under conditions of more rigid crust, was continued in the early Palaeoproterozoic (2.5-2.2 Ga ago), but the mantle-derived komatiite-basaltic series were substituted by magmas of the siliceous high-Mg series (SHMS). We discuss the situation on example of the Baltic Shield. Three types of structural provinces were active on it at that time: (1) vast areas of uplift and extension with the mantle-derived magmatism (Karelian and Kola cratons with SHMS magmatism); (2) zone of submergence and compression between them (medium pressure Lapland-Umba granulite belt with crustal-derived enderbite-charnockite magmatism), and (3) transitional zones of tectonic flowage occurred between these low- and high-grade terranes. These structural provinces formed a symmetric regional structural-metamorphic zonation, which was characterized by gradually increasing of deformations and metamorphism from the cratons toward the granulite belt. This type of tectonics was rather differed from plate-tectonics and could be described in terms of plume-tectonics.

Geological evidence for plate-tectonic activity (ophiolite complexes, suture zones, back-arc basins, etc.) in the region are fixed only from 2.2-2.0 Ga ago, practically simultaneously with the first appearance of new types of magmas - geochemically enriched Fe-Ti picrites and basalts, similar to the Phanerozoic within-plate magmas, and MORB. From this time the further evolution of the shield could be characterized in terms of plate-tectonic. We suggest that such type of tectonic-magmatic activity was linked with uprising of new type of mantle plumes, generated on the mantle-core boundary. Such a situation occurred on all Precambrian shields. Thus, about 2.2-2.0 Ga ago the Earth entered into a new stage of its development.

It is important that our planet is not the only example of such evolution. On the Moon about 3.9 Ga ago ancient magnesian-suite magmatism the lunar highlands, which intruded the primordial anorthositic crust, was changed by maria magmatism (low- and high-Ti basalts), which filled in new-formed mare depressions. Origin of this type of tectonic-magmatic activity was probably linked with uprising of the mantle plumes of the second generation initiated on the boundary of the lunar mantle and then existed lunar liquid core (Sharkov, Bogatikov, 2001). So, existence of such sharp change of development is characteristic for the Moon also, and likely for the Mars and the Venus.

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## EVO4

### Interaction of Endogenic, Exogenic and Biological Terrestrial Systems

#### EVO4 : WEam13 : F5

##### Palaeoproterozoic Crustal Evolution of the Western Ukrainian Shelf: Sm-Nd and U-Pb Zircon Ion-Microprobe Isotopic Data

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Unlike the Baltic (Fennoscandian) Shield, where the 2.2-2.0 Ga history was manifested by the breakup and dispersal of Archaean crust, and attendant rifting and intense mafic magmatism, the western part of the Ukrainian Shield at the same time featured abundant subduction-related igneous activity and sedimentation.

The western Ukrainian Shield is subdivided into four major tectonic units. From north to south these are: the Northwestern Domain which includes the Osnitsk-Mikashevichi Igneous Belt and the Terev volcanic-sedimentary belt, the Berdichev zone of granulite-facies granitoids, the Palaeoarchaean Dniestr-Bug Domain and the Ros-Tikich Domain of both Archaean and Proterozoic rocks.

Our whole-rock Sm-Nd isotopic data demonstrates that the crust in North-Western Domain, the Berdichev zone and the northern part of the Ros-Tikich Domain is Palaeoproterozoic in age (T Nd (DM) = 2.2-2.4). In the North-Western Domain the Palaeoproterozoic ages have also been yielded by U-Pb zircon ionmicroprobe analysis (NORDSIM) in Stockholm. Even detrital zircons from Terev metasediments are dominated by the Palaeoproterozoic 2.3-2.2 Ga crystals.

From these results, it follows that the northwestern part of the Ukrainian Shield was formed 2.2-2.0 Ga ago from dominantly juvenile mantle-derived material. Thus it represents a southward continuation of the accretionary-collisional belt which occurs along the northwestern margin of Sarmatia and beneath the sedimentary cover of the East European Platform all the way to the Baltic Shield (Claesson et al., 2001).

Effects of this accretionary crustal growth can be traced also in simultaneous tectonothermal events much further south even at distances of ca. 350 km. Isotopic data for magmatic and metamorphic rocks, including our zircon ionprobe data suggest that even the early Archaean Dniestr-Bug enderbitics have experienced repeated high-grade metamorphism at about 2.0 Ga.

#### EVO4 : WEam14 : F5

##### Palaeomagnetic Evidence for the Evolution of the Earth during Early Palaeoproterozoic

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Palaeoproterozoic continental rifting was a world-wide event that affected all Precambrian shields at 2.5-2.4 Ga ago. As a consequence of the rifting, the different cratons show many similarities, like the emplacement of layered intrusions and associated mafic dyke swarms. Palaeomagnetic studies are aimed to study whether the cratons formed a single supercontinent at that time. In the Fennoscandian Shield, palaeomagnetic studies have been carried out on layered intrusions and dykes both in the Karelian and Kola cratons, thus allowing also studies on intracontinental tectonic movements related to the ca. 2.4 Ga events. Moreover, because the ancient palaeolatitudes of the continents are defined by palaeomagnetic investigations, the palaeomagnetic results can be used in palaeoenvironmental studies as well.

Palaeomagnetic results from 2.45 Ga gabbro-norite dykes, associated with the Olanga layered intrusions in Russian Karelia, show that at 2.45 Ga the Fennoscandian Shield was located at the Equator. At that time the Fennoscandian Shield formed a unity comprising both the Kola and Karelia cratons. Coeval reliable ca. 2.45 Ga palaeomagnetic data is also available from the Matachewan dyke swarm in the

Superior Province of Laurentia (Bates and Halls, 1990) and from the Widgiemooltha (Evans, 1968) and Ravensthorpe (Giddings, 1976) dykes in the Yilgarn craton of Australia. The data show that at 2.45 Ga Laurentia and the Fennoscandian Shield were joined, both locating at the Equator, so that the dykes on both cratons probably formed a single dyke swarm. On the contrary, the Yilgarn craton was not connected with Fennoscandia-Laurentia, but was located at a high palaeolatitude of ca. 70° which implies that at 2.45 Ga no global supercontinent existed.

It is suggested that soon after the first stages of rifting of the Fennoscandian Shield, between 2.45-2.40 Ga, the Karelia and Kola cratons started to drift apart, evidenced by slightly different 2.4 Ga pole positions of the cratons. Based on average pole positions, the Karelia craton occupied a latitude of ca. 30° and the Kola craton a latitude of ca. 15°, implying the existence of an ocean between the Kola and Karelia cratons at ca. 2.40 Ga ago.

New palaeomagnetic studies from a dated 2.3 Ga (Hölttä et al., 2000) Tulisaari dyke in central Fennoscandia give a similar pole as at 2.40 Ga for the Fennoscandian shield. Based on the new results, it is suggested that during 2.4-2.3 Ga, which is the time of glaciation in the Fennoscandian Shield, the shield experienced no latitudinal movement, but was located at the latitude of ca. 30° which is in agreement with observations from other shield areas showing low or near-equatorial palaeolatitudes for Palaeoproterozoic glaciations (e.g. Evans et al., 1997).

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## Wednesday PO Session

#### EVO4 : WEpo01 : PO

##### Evolution of the Lower Crust Throughout Earth History

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Our study of deep-seated xenoliths of the Baltic and Arabian shields, and tectonic blocks in Eastern Siberia (southern Prisan'y'e) and the Alpides show that composition of the lower crust has changed during the Earth's evolution both in chemistry and mineralogy. In most cases samples of the lower crust are represented by basaltic rocks and were formed as a result of underplating. On the Baltic Shield xenoliths of garnet granulites from the Kola-Karelian domain represent the high-grade metamorphic equivalents of basalts, emplaced into the lower crust in the late Archaean-early Proterozoic times (~2.4-2.6 Ga). Similarities in major and trace element systematics suggest that they formed in response to the same plume-driven magmatic events that created the widespread Palaeoproterozoic igneous siliceous high-Mg (boninite-like) province at 2.4-2.5 Ga ago. Another type of the early Palaeoproterozoic lower crustal garnet granulites with interlayers of garnet-kyanite schists was found in tectonic block in Eastern Siberia (Arbansky massif); their origin was probably related to zones of "drawing" beneath granulite belts. Fragments of the Neoproterozoic lower crust were found as xenoliths of titanomagnetite garnet granulites in the Mesozoic diatremes in Syria. In their chemistry they are close to the Phanerozoic intraplate basalts. The Phanerozoic lower-crustal rocks which found as xenoliths and tectonic blocks in Alpides are represented mainly by pyroxene granulites are close to the MORB in composition. Thus, the early Precambrian lower-crustal rocks, formed mainly as a result of underplating, are rather different in composition and conditions of formation from the late Precambrian and Phanerozoic ones. The early Precambrian rocks derived mainly from depleted mantle sources and were formed under high-pressure conditions (12-18 kbar). We have no information yet about the late Palaeoproterozoic-Mesoproterozoic lower crust aside from that it could be unusual thick (Central Finnish Massif, Baltic Shield). In the Neoproterozoic were firstly found geochemically enriched garnet granulites with Ti-Mag, and in the Phanerozoic - mainly analogs of MORB, formed under moderate pressure conditions (8-10 kbar). From this, probably, follows that the thickness of the Earth's crust decreased with time and its composition changed according to the evolution of the main types of the mantle-derived melts.

#### EVO4 : WEpo02 : PO

##### Thermal Structure and Suggested Heightened Heat Flow through Lithosphere of the Palaeoproterozoic Supercontinent: Probable Consequences

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Although Rodinia has dominated for recent years, palaeomagnetic data (Piper, 1983, 2000) and tectonic analysis (Khain & Bozhko, 1988; Condie, 1989, 1994) suggest existence of the Proterozoic Supercontinent that was episodically rifted, in some cases with an origin of narrow intracontinental oceans, but never disrupted in full. Tectonic analysis and geochronological data witness some short periods of intensive subduction along the Supercontinent margins from 2.5 to 0.6 Ga and limited development of spreading and subduction processes in its interior (Condie, 1994; Mints, 1998). May this evidence rapid recycling of juvenile oceanic crust without related subduction magmatism (Condie, 1994)? Or alternatively, this specifics of the Proterozoic evolution allow suggestion on lowering of spreading rate and lower heat loss through mid-oceanic ridges? As heat production in Planet's depth couldn't have been significantly reduced during Proterozoic and rapid variations in thermal evolution are strongly inhibited, the second case could be real only if lowering of heat loss in oceanic areas was compensated by heightened heat flow within Supercontinent. Mints & Konilov (1997) had shown that thermal gradient within lower crust during granulite metamorphism ("internal"

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thermal gradient) have been very low, around 5–10°C/km or less. Integration of P-T parameters of the 1.95 Ga granulite metamorphism in the northeastern Baltic shield obtained from Lapland belt and deep crustal xenoliths evidence that Lapland granulite assemblage and “xenolithic” crustal layer were portions of initially single section of the Palaeoproterozoic lower crust. Thermal gradient within that crust from 70 to 20 km depth during granulite metamorphism was ~1.4°C/km! Corresponding thermal gradient in the covering upper crust must have been very high, around 70°C/km. Significant input of mantle heat must be inferred to explain this thermal structure (Mints et al., 1999). This to suggest that heat flow through the surface of the Supercontinent during high-grade metamorphic events must have been similar to heat flow in modern oceanic ridges and modern riftogenic zones within continents, i.e. around 100 mW/m<sup>2</sup>. Seismic investigations of continental crust and data from deep crustal xenoliths show evidence for worldwide distribution of the granulitic rocks in the lower and mid crust of continents. According to Rudnick & Fountain (1995), 43–56% of the existed lower crust have been formed during Proterozoic in agreement with predominance of the Proterozoic age of outcropped granulite assemblages which are understood as upthrust fragments of the lower crustal “layer”. On a basis of above consideration we suggest unexpectedly high heat flow through continental lithosphere during Proterozoic that could be especially significant for the pulses of hot mantle upwelling resulted in rifting, high-grade metamorphism, magmatic underplating and climatic changes.

#### EVO4 : WEpo03 : PO U-Pb Systematics and the Age of Early Palaeoproterozoic <sup>13</sup>C-Rich Carbonate Rocks of Kola Peninsula and Karelia, Northwestern Russia

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Palaeoproterozoic dolostones from the Pechenga area, Kola Peninsula (Kuetsjärvi Sedimentary Formation, KSF) and southeastern Karelia (Tulomozero Formation, TF) represent occurrences of <sup>13</sup>C-rich carbonates (Yudovich et al., 1991; Karhu, 1993; Melezhih and Fallick, 1996) which occur world-wide at around 2.4–2.0 Ga. They underwent greenschist-facies metamorphism. U-Pb systematics were studied on samples from drillcores in order to constrain depositional ages of <sup>13</sup>C-rich carbonates.

KSF dolostones in 6 samples have small-scale variations in U (0.07–0.29 ppm) and Pb (0.78–1.1 ppm) contents as well as in <sup>238</sup>U/<sup>204</sup>Pb ratios (5.0–15.8). A <sup>208</sup>Pb/<sup>204</sup>Pb–<sup>206</sup>Pb/<sup>204</sup>Pb cross-plot shows a linear trend with the well defined slope. Such a trend implies resetting of the U-Th-Pb systems. A <sup>207</sup>Pb/<sup>204</sup>Pb–<sup>206</sup>Pb/<sup>204</sup>Pb diagram shows a straight line with an age of 1880±80 Ma (MSWD=0.7) that coincides with the Svecofennian metamorphism.

The TF dolostones have been separated into three groups. Group 1 (11 samples) plots on a <sup>207</sup>Pb/<sup>204</sup>Pb–<sup>206</sup>Pb/<sup>204</sup>Pb diagram along a straight line with the age of 2090±70 Ma (MSWD=5.4). These samples are marked by rather wide ranges of the U (0.02–0.29 ppm) and Pb (0.02–9.3 ppm) contents and <sup>238</sup>U/<sup>204</sup>Pb ratios (0.17–17.8). In a <sup>208</sup>Pb/<sup>204</sup>Pb–<sup>206</sup>Pb/<sup>204</sup>Pb plot the samples plot parallel to the <sup>206</sup>Pb/<sup>204</sup>Pb axis, implying that the U-Th-Pb systems did not undergo post-depositional alteration. Consequently, 2090±70 Ma is considered to represent a depositional age.

Group 2 (7 samples) spreads above the isochron on a <sup>207</sup>Pb/<sup>204</sup>Pb–<sup>206</sup>Pb/<sup>204</sup>Pb diagram. These dolomites are comparatively poor in U (<0.12 ppm), rich in Pb (>3 ppm) and have a rather low <sup>238</sup>U/<sup>204</sup>Pb ratio (<2.0). <sup>208</sup>Pb/<sup>204</sup>Pb values range from 35.1 to 36.4. <sup>206</sup>Pb/<sup>204</sup>Pb ratios correlate with the Pb content and do not depend on the U concentration, suggesting a resetting of the U-Pb systems during the Svecofennian metamorphism at ca. 1.9 Ma.

Group 3 (6 samples), whose data points lie below the 2090 Ma isochron, are rather rich in U (>0.12 ppm), poor in Pb (<1 ppm) and have high <sup>238</sup>U/<sup>204</sup>Pb (>13) and <sup>208</sup>Pb/<sup>204</sup>Pb (35.8–39.4) ratios. <sup>206</sup>Pb/<sup>204</sup>Pb values correlate with the U content and do not depend on the Pb content. The U-Pb systems were reset during an epigenetic mobili-

zation of uranium. A three-dimensional discordia method yields two ages, ca. 2130 Ma and ca. 300 Ma, close to the Pb-Pb isochron age of the Group 1 carbonates (2090 Ma) and to the age of the pitchblende-carbonate deposit in the north-eastern Onega area (ca. 210 Ma).

This study allows for the first time to constrain a depositional age of the <sup>13</sup>C-rich TF carbonates (2090±70 Ma), whereas the age of KSF still remains unknown.

This work was supported by grants of the RFBR (99-05-65181) and the INTAS (95-0928).

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#### EVO4 : WEpo04 : PO Some Aspects of Studying Early Palaeoproterozoic Rocks

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For understanding of specificity of a biosphere and lithosphere in Early Palaeoproterozoic (EPP) one of the most elements is the studying an organic world of that time. The development at this time is stromatolites, acritarchs (probably, phytoplankton), and organisms of a uncertain status, presumptively of one of most ancient single-celled eucaryotes, is doubtless. However, to found in different time and by different authors rests, interpreted as the lowest fungi, is of greatest interest. Their constant presence at rocks of this age, probably, essentially distinguishes ecosystems EPP and reflects specificity of sedimentation of basins. Of specify interest is the studying of schungites of representative rocks of this age permitting, on the one hand, even more to point out specificity EPP, and with other – to approach to a problem of abiogenic and biogenic globulization of carbonaceous matter. The similar data were obtained also on ancient phosphorites.

#### EVO4 : WEpo05 : PO Regarding Occasional Sun Fly within Star-Cloud 2600 Million Years Ago and its Feasible Repercussions for the Earth

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A new astrophysical phenomenon has been recently discovered. It is associated with substance stream flow from nucleus of spiral galaxies. It has been established that during Sun movement around Galaxy centre, all planets in Solar system are being bombarded by galaxy comets with time period of 20–40 million years and Sun is forced to change its own orbit parameterises approximately every 1000 million years because of its interaction with massive stars clouds.

In the latter case asteroids loose stability of their trajectory in asteroid zone. Consequently, a lot of asteroids enter interplanetary space and later on fall down on planet surfaces in 107–108 years. We are inclined to think that similar event took place nearly 2600 million years ago.

The paper discusses certain estimations of asteroid substance accumulation precipitated on the Earth at that time and some consequences for hydrosphere and atmosphere of the planet. We pay special attention to four processes initiated by massive fall down of asteroid bodies, namely: 1) dehydration of surface rocks with water liberation into free phase; 2) appearance of large oxygen volumes entering the atmosphere as a result of impact evaporation of earth's rock; 3) severe activation of chemical erosion leading to formation of ferriferrous quartz; 4) creation of favourable conditions for life evolution.

#### EVO4 : WEpo06 : PO Evolution of the Karelian Palaeo-Proterozoic (2.25–1.95 Ga) Volcanic Associations (Eastern Part of the Fennoscandian Shield): Geodynamic Significance

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The Jatulian-Ludian volcanic association considered in the present paper was formed between the early stage of the Fennoscandian palaeoproterozoic tectonic evolution (2.5–2.35 Ga) and the Svecofennian orogeny (1.95–1.80 Ga). Jatulian flood-basalts occupied huge areas of Fennoscandian shield and their major occurrences are placed in Karelian Province. Jatulian volcanics are very similar to Phanerozoic continental tholeiitic basalts. Early Jatulian basalts are characterized by high LREE contents and strongly fractionated REE patterns (average (Ce/Yb)<sub>n</sub> and (La/Sm)<sub>n</sub> ratios are 4.6 and 2.1 respectively). Middle Jatulian basalts REE patterns have less fractionated character with average (Ce/Yb)<sub>n</sub> and (La/Sm)<sub>n</sub> 1.85 and 1.53. Late Jatulian volcanics and gabbro-dolerites REE patterns are close to Middle Jatulian basalts but contain more REE than all the samples mentioned above. Sm-Nd isotopic data for the whole rocks and mineral fractions from Late Jatulian intrusions show isochronous age 2186±68 Ma with eNd(T) = -2.01±0.53. Jatulian Group is overlain by intracratonic Ludian carboniferous black shales and sandstones, pillow lavas and pyroclastic sediments which indicate marine transgression. Early Ludian basalts are slightly HFSE-depleted in comparison with the Jatulian lavas. That is probably caused by more primitive character of source magma. These rocks are mainly characterized by almost non-fractionated REE-patterns with average (Ce/Yb)<sub>n</sub> = 1.57 and (La/Sm)<sub>n</sub> = 1.35. Late Ludian lavas form a single picrite-tholeiitic magmatic suite where plagioclase-porphiric basalts and basaltic andesites are considered to be the most fractionated members of this sequence. All Late Ludian volcanic rocks including picrites are enriched with incompatible elements. Average (Ce/Yb)<sub>n</sub> and (La/Sm)<sub>n</sub> ratios in picrites and olivine-clinopyroxene basalts are 3.85 and 1.41. Sm-Nd isochrone shows the age 2013±52 Ma with eNd(T) = -0.5±0.18. This age conforms to the data obtained by the same method for Late Ludian intrusion - 1975±24 Ma (Pukhtel et al., 1995). Geochemical features of Jatulian volcanics together with geological observations and palaeogeographical reconstructions (Melezhih et al., 1996) show that the earth crust extension didn't take place at Jatulian time. The magmatic events of this stage were controlled by huge mantle plume uprising. Later this plume was parted to the number of small plumes. Interaction of the mini plumes initiated intracratonic rifting mechanism. Some of these mini plumes were able to live locally being accompanied by quiet week earth crust extension that is supported by the geochemical data on Ludian magmatism of the Central Karelia. However, the greatest events of Fennoscandian shield Palaeoproterozoic tectonic evolution were connected with continental crust destruction and palaeoceanic formation. Fragments of the ancient oceanic crust with the age about 1.96 Ga are well known in Eastern Finland (Kontinen, 1987). Metabasalts with the geochemical characteristics of the oceanic tholeiites ((Ce/Yb)<sub>n</sub> = 0.96, (La/Sm)<sub>n</sub> = 0.90, eNd(T) = +5.5–6.0) were discovered also in Southern Karelia (Ivanikov, Philippov, 1998).

#### EVO4 : WEpo07 : PO Stromatolites in the Palaeo-Proterozoic <sup>13</sup>C-Enriched Carbonate Successions of the Fennoscandian Shield.

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Stromatolites had their maximum distribution on the Fennoscandian Shield during Jatulian time (Palaeoproterozoic). Here they were abundant both quantitatively and taxonomically (Melezhih et al., 1997). In Russian Karelia (eastern part of the shield) stromatolites are occurring in terrigenous-carbonate sequence of the Upper Jatulian Onegian Formation which has an Pb-Pb age 2130 million years (whole rock determination, Vasilyeva et al., 2000). The 800 m thick succession of Onegian Formation mainly consists of reddish <sup>13</sup>C-enriched dolostones with mud-cracked siltstone and ripple-marked quartzite interbeds. The sediments show numerous lithological features of an evaporitic environment (Melezhih et al., 1999). In the sequence of the Onegian Formation stromatolites form 5 successive assemblages following each

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other. Some of these assemblages are traced laterally across a long distance - a few hundred kilometres on Karelian territory. It has been a basis for establishing biostratigraphic units in regional Early Proterozoic succession - beds with phytoliths (Makarikhin, 1992). With help of these units both subdividing and correlation of separate parts of the carbonate sequence are possible at least within Karelian region of the Fennoscandian Shield. There are stromatolite localities to the north of Karelia - in the Kola Peninsula and in the Western Fennoscandian Shield - Finland and Sweden (Melezhik et al., 1997), which mark the same Late Jatulian time level. Besides, some Palaeoproterozoic stromatolites from approximately the same time interval of the Canadian Shield are similar to those from the Fennoscandian Shield (Hofmann, Davidson, 1998). These coeval stromatolite-bearing Palaeoproterozoic successions in time interval 2.2-2.0 Ga are also characterized by carbonates with unusual high positive values for  $\delta^{13}\text{C}_{\text{carb}} = 8.0 - 9.0 \text{ ‰}$  on average (Karhu, Holland, 1996) also. Thus after detailed investigations including description and comparison of the stromatolites, subdivision and correlation of these terrigenous-carbonate sequences will be possible not only in the Fennoscandian Shield but between Fennoscandian and Canadian Shields too - both regional and intercontinental correlations will be possible.

The research was supported by Russian Fund for Basic Research grant 00-05-64445.

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