



**Russian Ridge Workshop
dedicated to memory of
Leonid Dmitriev
– Founder of R-Ridge and one
of pioneers in Study of Mid-
Oceanic Ridge World System**



**Russian Ridge Workshop'07 dedicated to
memory of Leonid Dmitriev
– Founder of R-Ridge and one of
pioneers in Study of Mid-Oceanic Ridge
World System
5-7 June, 2007, Moscow**

**Geochemical, petrological and geophysical
segmentation of the Mid-Oceanic Ridges and
its relationships with geodynamic parameters
of the oceanic lithosphere accretion**

Russian-Ridge'07 Workshop program

June 5, Tuesday

9.00 - 9.45 – Registration)

9.45 - Opening statement of N. Bortnikov

10.00 – 10.15 – Information of Russian national correspondent in InterRidge – S.Silantyev

10.15 – 10. 55 - S. Scott (University of Toronto, Canada). Sulfide-polymetallic ore deposits in oceanic basins and their resources.

10.55 – 11.35 - H. Bougault (IFREMER, Brest, France). Hydrothermalism on Oceanic Basins: yesterday and tomorrow. Perspectives for future research involving: metallogenesis, potential environments for the origin of life, hydrocarbon synthesis and/or cracking/hydrocracking.

11.35 – 11.55 – **Coffee Break**

11.55 – 12.35 - S. Petersen (IFM-GEOMAR, Kiel). Hydrothermal systems of the modern ocean floor as a perspective mineral resource of the XXI Century.

12.35 - 13.15 – D. Desbruyeres ((IFREMER, Brest, France). Diversity and biogeography of deep hydrothermal vent communities in the World Ocean.

13.15 – 14.30 – **Dinner**

14.30 – 14.50 – E. Bonatti, D. Brunelli, A. Kipriani, M. Ligi. (Istituto Scienze Marine, CNR; Lamont Doherty Earth Observatory, Columbia University; Dept. Of Earth Sciences, University of Modena). Accretion at a Mid-Atlantic Ridge segment at 10°N: a 25 million years long story.

14.50 – 15.10 - N. Bortnikov (IGEM RAS). Evolution of the fluid chemistry, isotope composition and temperature in modern seafloor hydrothermal systems

15.10 – 15.30 – A. Sagalevich (Shirshov Institute, RAS). Investigation of the hydrothermal fields of mid-ocean ridges with submersibles.

15.30 – 15.50 – **Coffee Break**

15.50 – 16.10 - S. Silantyev, E. Krasnova, N. Bortnikov, S. Karpenko, N. Kononkova, P. Plechov (Vernadsky Institute, IGEM RAS, MSU). Oceanic Core Complex as a key to reconstruction of the magmatic and tectonic evolution of the Slow-Spreading Ridge Lithosphere: An example of Atlantis Massif, MAR, 30°N.

16.10 – 16.30 – G. Cherkashev (VNIIOkeangeologia). Some results of isotope studies of massive sulfides from Ashadze, Logatchev and Krasnov hydrothermal fields, Mid-Atlantic Ridge

16.30 - 16.50 – S. Sokolov, N. Sokolov (GIN RAS, MSU). Transoceanic East-West zones with “forearc” properties cross MAR and abyssal plains of Atlantic Ocean.

16.50– 17. 30 – Discussion.

June 6, Wednesday

10.00 – 10.20 - E. Dubinin, Yu. Galushkin, A. Sveshnikov (MSU). Hierarchy of magmatic systems and morpho-structural segmentation of Spreading Ridges.

10.20 – 10.40 - B. Bazylev (Vernadsky Institute). Spectrum of metamorphic processes in mantle peridotites of oceanic lithosphere: Atlantis FZ, 30°N.

10.40 – 11.00 – E. Dubinina, I. Chernyshev, N. Bortnikov, A. Lein (IGEM RAS, Shirshov Institute RAS). An isotopic ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, $^{87}\text{Sr}/^{86}\text{Sr}$) and geochemical features of carbonate-brucite deposits of Lost City in hydrothermal field (30°N, MAR).

11.00 – 11.20 – Coffee Break

11.20 – 11.40 - S. Silantyev, M. Mironenko, A. Novoselov (Vernadsky Institute). Thermodynamic simulation of peridotite - sea water interaction in serpentinite hosted hydrothermal system in the Slow-Spreading Ridges

11.40 – 12.00 – E. Sharkov, S. Abramov, V. Simonov, D. Krinov, S. Skolotnev, V. Beltenev, N. Bortnikov (IGEM RAS, IGGM SB RAS, GIN RAS, PMGRE). Hydrothermal-Magmatic system of the Mid-Atlantic Ridge, 6°N (Markov Depression).

12.00 – 12.20 – K. Shatagin, E. Sharkov, I. Chernyshev, N. Bortnikov, I. Krassivskaya (IGEM RAS). Small-scale $^{87}\text{Sr}/^{86}\text{Sr}$ heterogeneity of basalts at Sierra-Leone trough, Mid-Atlantic Ridge, 5-7° N

12.20 – 12.40 – Coffee Break

12.40 – 13.00 – B. Bazylev (Vernadsky Institute). Geochemical peculiarities of clinopyroxenes in mantle peridotites from spreading- and anomalous segments of MAR .

13.00 – 13.20 – S. Merkouriev, N. Gurevich (SPbF IZMIRAN, GIN RAS). Evolution of the Reykjanes Ridge: the influence of the hot spot and of the plate tectonic kinematics

13.20 – 13.40 – R. Almeev, F. Holtz, J. Koepke, A. Ariskin (Institute of Mineralogy, Leibniz University of Hannover, Germany). The effect of minor H₂O content on crystallization in

MORB: experiments, model, applications.

13.40 – 14.40 – Dinner

14.40 – 15.00 - N. Sushevskaya, B. Belyatsky (Vernadsky Institute, VNIIOkeangeologia).

Geochemical source for tholeiite magmas enrichment at the Knipovich Ridge.

15.00 – 15.20 – A. Peyve, N. Chamov, A. Zayonchek, N. Sushevskaya, S. Sokolov, , E. Rodionova, V. Lavrushin, K. Dobrolyubova, A. Eskin, (GIN RAS, Vernadsky Institute).

Peculiarities of the geological structure of Northern part of Knipovich Ridge.

15.20 – 15.40 – A. Novoselov (Vernadsky Institute). Experience on thermodynamic modeling of descending path of hydrothermal cell in Slow-Spreading Ridge with the use of solid solution data.

15.40 – 16.00 – Coffee Break

16.00 – 16.20 – G. Zakariadze, S. Karamata, T. Bayanova, S. Karpenko, S. Korikovskiy, F. Mitrofanov, S. Sergeev (Vernadsky Institute; Serbian Academy of Sciences and Arts; GIN KB

RAS; IGEM RAS; VSEGEI). Composition and problems of origin of Paleozoic oceanic lithosphere framing European platform from south, exemplified by Eastern Mediterranean area.

16.20 – 17.00 – Discussion and Workshop closing.

18.00 – 21.00 – Social dinner

The effect of minor H₂O content on crystallization in MORB: experiments, model, applications

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The role of H₂O on mineral cotectics and petrochemical trends in MORB systems has been thoroughly discussed in the literature (e.g. [Danyushevsky, L. V., 2001]). However, quantification of the effects of small amounts of H₂O on the liquidus of olivine (Ol), plagioclase (Plag) and clinopyroxene (Cpx) is still limited by the lack of experimental data with well-constrained values of water activity. This, probably, results in a considerable inconsistency between the models [Danyushevsky, L.V., 2001, Ghiorso, M.S. & Sack R.O., 1995. *Contrib. Mineral. Petrol.* 119, 197-212, Ariskin A.A., 1999. *JVGR.* 90, 115-162] designed to predict the mineral liquidus depression as a function of the water content in the melt.

To address the problem we have conducted a set of crystallization experiments at 200 and 500 MPa. All experiments were performed in an internally heated pressure vessel at intrinsic oxygen conditions using pure argon as a pressure medium. Three starting basaltic compositions have been chosen so that Ol, Plag or Cpx were crystallized together as a cotectic assemblage. The H₂O concentrations in the glasses were obtained by infrared spectroscopy and Karl-Fischer-Titration. As a result of the study we parameterized our experimental data in the form of simple equations describing the liquidus of the Ol, Plag and Cpx cotectics as a function of H₂O dissolved in the melt. Finally, these equations have been incorporated into the basic algorithm of the COMAGMAT program [Ariskin A.A., 1999. *JVGR.* 90, 115-162].

Application of the updated version of COMAGMAT is presented here for a suite of basaltic lavas from the Mid-Atlantic Ridge (MAR) east of Ascension Island (7-11°S). To estimate crystallization conditions of the MORB basalts two series of equilibrium and fractional crystallization calculations have been carried out. The results indicate that MORB-magmas beneath different segments of the MAR have crystallized over a wide range of pressures from 100 to 900 MPa. Nearly isobaric crystallization conditions of 100-300 MPa were obtained for the geochemically enriched MORBs, whereas the N-MORB magmas are characterized by higher pressures ranging from 200 to 900 MPa. Our results demonstrate almost anhydrous crystallization conditions of N-MORBs, whereas geochemically enriched MORBs were successfully modeled in the presence of 0.4 to 1 wt % H₂O in parental magmas. These results are in good agreement (± 200 MPa) with previous estimates of MORB crystallization conditions.

However, the effect of H₂O on the pressure estimates is within the uncertainty of the calculations.

Peculiarities of geochemistry of clinopyroxenes from mantle peridotites of normal and anomalous MOR segments

B.A. Bazylev
Vernadsky Institute

Normal segments of slow-spreading MOR

Compositions of clinopyroxenes from ten samples of spinel peridotites of the Mid-Atlantic, Arabian-Indian and Southwest Indian Ridges were examined. The studied samples are representative and cover all intervals of partial melting degrees that are typical of spinel peridotites of geochemically normal segments of slow-spreading MOR ($Cr\#$ of primary spinels varies from 0.16 to 0.36).

Clinopyroxenes show spoon-like spectra of REE, the regular lowering of contents from Yb to Sm (typical of critical melting) is exhibited in all compositions. Two of ten samples show elevated concentrations of Nd, seven from ten samples have elevated contents of Ce, and the elevated contents of La are typical of all studied samples. The elevated contents of Sr relative to Nd are pointed in four samples. The ratios of $(Sm/Yb)_n$ regularly decrease with increasing of co-existing spinel $Cr\#$ from 0.66 to 0.009. The values of $(La/Sm)_n$ vary in the interval of 0.02-2.3 and do not correlate with spinel $Cr\#$. These features are typical of clinopyroxenes from normal segments of slow-spreading MOR [Hellebrand et al., 2001; Brunelli et al., 2006].

In most of the analyzed clinopyroxenes from N-MOR contents of Ba, K, La and Ce are well correlated with each other although concentrations of these elements vary by as much as two orders (for La 0.005-0.3 relative to PM). These features of the spinel peridotites can be attributed only to melting in system open for enriched melt introduction. Melting of DMM source even at very low degrees (0.05 %) is not consistent with elevated Ba contents in clinopyroxenes. It is most probably that introduced melt was originated at low degree melting of PM or more enriched source.

In some samples REE, alkali and calc-alkaline elements show different behavior expressed in lowed concentrations of K, Ba and Li (judging from low values of K/La, Ba/La and Li/Y). This indicates that K, Ba and Li were bleached from clinopyroxenes. At the same time sodium and

strontium contents are not lowered. The later indicates that serpentinization is not responsible for this effect.

Geochemically anomalous 13-16°N segment of MAR

Compositions of clinopyroxenes from nine spinel harzburgites and two cumulus spinel peridotites (olivine clinopyroxenites [Bazylev et al., 1999] and clinopyroxene dunite) were examined. In addition grains of clinopyroxenes crystallized from penetrating melts were measured in two samples of harzburgites.

Clinopyroxenes of the harzburgites (primary spinel Cr# vary in the interval of 0.38-0.65) show spoon-like and U-shaped REE spectra (PM normalized contents of REE vary in the interval of 0.2-1.4). The concentrations of titanium and heavy REE in clinopyroxenes are well correlated with each other but they do not correlate with spinel Cr# [Bazylev, 2005]. The established positive correlation between sodium contents in clinopyroxenes and spinel Cr# is also found for Nd, Sm, Eu and Gd. As the spinel Cr# increase concentrations of these elements increase. This indicates that high melting degrees resulted from introduction of enriched melt into the system. Contents of REE are well correlated only with each other. Concentrations of Ba, Nb and Ba and Sr, Zr and Ti to the lesser extend are correlated with each other as well. Unlike peridotites of normal segments of MOR clinopyroxenes exhibit intensive positive Na and Nb anomalies and Li anomalies in some samples. Judging from (La, Ce) – (Ba, Nb, K) ratios in clinopyroxenes an influence of at least three different enriched components can be assumed.

Clinopyroxenes of cumulus peridotites have hunch-like REE spectra (PM normalized heavy REE are about 1-3) with negative Li, Ti, Zr and Sr anomalies. Clinopyroxenes show similar abundances in REE but clinopyroxenes entrapped in orthopyroxene have high medium and light REE as well as Zr and Nb and big negative Ba, K, Sr and Na anomalies.

One of the late magmatic clinopyroxenes from harzburgite is compositionally similar to clinopyroxenes from cumulus spinel peridotites and differs from them only by absence of negative Li anomaly. Late magmatic clinopyroxene from another harzburgite is extremely enriched. The total contents of incompatible elements are about 30-80 for Ba, Nb, La and about 10 for PM normalized heavy REE. This clinopyroxene has negative Li, Ti, Sr, Zr, Eu, Sr and Ba negative and Ce positive anomalies.

Thus compositions of clinopyroxenes from peridotites of geochemically anomalous segment of MAR reflect process of partial melting of mantle source accompanied by both introduction of compositionally different enriched melts and interaction of restite peridotite minerals with late magmatic melts and possibly juvenile fluids.

Metamorphic processes in mantle peridotites of the oceanic lithosphere: the Atlantis fracture zone, 30°N MAR

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The Atlantis fracture zone is one of the places from where mantle spinel peridotites of the MORs were firstly dredged and studied (Miyashiro et al., 1969). Even at that time the presence of hornblendes in spinel peridotites of the Atlantis fracture zone was already pointed out. Samples used in this study were collected during 16-th cruise of the “Akademik Boris Petrov” research ship. They were dredged at the lower part of the northern flank of the Atlantis fracture close to the location where spinel peridotites described by Miyashiro with co-authors (1969) were taken.

All of the dredged samples are metamorphosed spinel peridotites that are free of igneous (gabbroic) veins and show neither mineralogical nor petrographic marks of metasomatic processes [Bazylev et al., 1999]. On the contrary these rocks exhibit features indicative of multiple stage regressive metamorphism resulted from extremely deep penetration of circulating MOR hydrothermal fluid to oceanic lithosphere (Bazylev et al., 1992). Combination of widest interval of P-T conditions of metamorphism with satisfactory preservation of both primary and metamorphic minerals of different generations and no signs of metasomatism and contact metamorphism makes this object to be the reference oceanic metamorphism of spinel peridotites.

Peridotites compose massive boudins confined by foliated serpentine-chlorite-amphibole beds. Primary minerals are preserved as relics. Among them the yellowish brown chromian spinel (36-45 wt. of Al₂O₃, Cr# 0.25-0.36), orthopyroxene grains (3.7-4.4 wt. % of Al₂O₃) with lamellae of clinopyroxene (4.3-5.5 wt. % of Al₂O₃, 0.10-0.20 wt. % of Na₂O), clinopyroxene grains with lamellae of orthopyroxene (up to 5.2 wt. % of Al₂O₃) and olivine (0.06 wt. % of CaO and more, Mg# 90.3-90.4).

The studied peridotites exhibits peculiar features that are typical of oceanic metamorphism. Among these features are regressive multiple stage metamorphism, not completeness of metamorphic reactions and mosaic recrystallization. Mineral assemblages of all metamorphic stages including relic minerals can be distinguished in a single thin-section. Minerals of the earliest metamorphic stage commonly compose relics in later lower temperature metamorphic minerals. At this stage assemblage of high alumina amphibole (hornblende with 8.5-12 wt. % of Al₂O₃) and recrystallized medium alumina (2.6-3.5 wt. % of Al₂O₃) pyroxenes (grains and rims)

is formed. Contents of alumina in co-existing metamorphic spinels are 23-26 wt. % of Al_2O_3 while concentrations of titanium in these spinels remain as low as those in primary spinels and manganese contents do not exceed 0.3 wt. %.

With a temperature lowering chlorite becomes stable and equilibrium mineral assemblage is Cpx-Opx-Ol-Hbl-Chl-Spl. Concentration of Al_2O_3 in pyroxenes of this assembles is even low (0.8-1.5 wt. %), calcium content decreases up to 0.18 wt. % CaO. Content of Al_2O_3 is 6-8 wt. % in hornblende and about 19 wt. % in metamorphic spinel. Chlorite in this assemblage is low in alumina (9-11 wt. % of Al_2O_3). Probable temperature of this assemblage crystallization estimated based on compositions of equilibrium minerals is $775\pm 10^\circ\text{C}$; equilibrium pressure is 8,7 kbars, and partial water pressure is 6.5 kbars.

As a temperature drops more pyroxene becomes unstable, and talk appears in assemblage with olivine, amphibole, chlorite and metamorphic spinel. Compositions of amphiboles allow distinguishing statistically several successive but discrete stages of rock recrystallization (8.5-12; 5-8.2 (the main stage), 3-5 and 0-2 wt. % of Al_2O_3). At the latest stage secondary diopside (no less than 0.15 wt. % of Al_2O_3 , Mg# 94-96) starts crystallizing along with tremolite and marks the lower limit of amphibole stability (about 450°C) in peridotites.

For approximate estimations of metamorphic temperatures of mantle peridotites based on compositions of metamorphic amphiboles or chromian spinel (for mineral assemblage Am+Ol+Spl+/-Chl+/-Ta+/-Opx+/-Cpx, contents of alumina in weight per cents) the following thermometric equations [for details see Bazylev et al., 2003] can be used:

$$T_A(^{\circ}\text{C}) = 10000 / (14.88 - 2.418 * \ln(x\text{Al}_2\text{O}_3\text{Am})) - 273 \quad (\text{for } x\text{Al}_2\text{O}_3\text{Am} > 2.5\%);$$

$$T_A(^{\circ}\text{C}) = 10000 / (13.569 - 1.0026 * \ln(x\text{Al}_2\text{O}_3\text{Am})) - 273 \quad (\text{for } x\text{Al}_2\text{O}_3\text{Am} < 2.5\%);$$

$$T_S(^{\circ}\text{C}) = 10000 / (13.076 - 1.0206 * \ln(x\text{Al}_2\text{O}_3\text{Spl})) \quad (\text{for } \text{Cr}/(\text{Cr}+\text{Al}+\text{Fe})\text{Spl} > 0.5);$$

$$T_S(^{\circ}\text{C}) = 10000 / (12.695 - 0.8994 * \ln(x\text{Al}_2\text{O}_3\text{Spl})) \quad (\text{for } \text{Cr}/(\text{Cr}+\text{Al}+\text{Fe})\text{Spl} < 0.5).$$

Relative stability of peridotite minerals at medium and high temperature metamorphism differs from that at serpentinization (Spl >> Cpx > Opx > Ol). At high temperature metamorphism of spinel peridotites the most unstable mineral is clinopyroxene (relics of this mineral is very rare). Orthopyroxene and primary chromian spinel are more stable, and olivine is the most stable mineral. At regressive transformations of metamorphic minerals spinel and olivine are most stable, clinopyroxenes and chlorite are less stable, and orthopyroxene and talk are the least stable minerals. During the medium and high temperature metamorphism olivine composition changes which expresses in lowering of calcium contents (lower than 0.06 wt. % of CaO) and differing of Mg# (89.8-90.7) from primary ones.

Thermomagnetic method allows estimations of temperatures of two petrographically distinguished stages of serpentinization in peridotites of the Atlantis, e.g. temperatures of

transformations of metamorphic silicates resulted in crystallization of alumina serpentine (Ol+Chl+Ta – Al-Serp+Mt, 310°C) and replacement of olivine by fibrous serpentine and magnetite (225°C) [Popov et al., 2006].

Non-isochemical character of metamorphism is fixed from the earliest stage (increasing of sodium contents up to 0.3 wt. % in metamorphic pyroxenes along with crystallization of sodium rich hornblende). Comparison of trace and rare earth elements (ICP-MS, LA-MS) in relic clinopyroxenes and hornblendes indicates inert behavior of elements that are more compatible than titanium. In comparison with clinopyroxenes amphiboles are abundant in Eu and Zr by as much as half an order, Sm and Sr by as much as an order, LREE, Rb, Ba, K, Pb, U, Nb, Ta, Th by as much as more than order. It should be stressed that not only fluid-mobile elements but also elements (such as Th, Nb, Ta and Zr) that are traditionally considered as inert ones were introduced to peridotites during metamorphism.

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Accretion at a Mid Atlantic Ridge Segment at 10°N: a 25 Million Years Long Story

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Lithospheric accretion at a segment of the Mid Atlantic Ridge at 10° N can be reconstructed from ~ 25 million years ago to the present, thanks to the exposure on the ocean floor of an uplifted, ~ 300 km long section of oceanic lithosphere (Vema Lithospheric Section). Temporal variations in the processes of lithosphere generation can be reconstructed from the geochemistry and petrology of mantle and crustal rocks exposed along the lithosphere section, as well as from gravity data obtained in profiles normal to the ridge segment. Two different trends were observed. From roughly ~ 26 to ~ 19 million yrs. ago the extent of melting of the mantle upwelling below the ridge decreased slightly, while from 18 to 2 million yrs. ago it increased steadily. The older interval suggests decreasing mantle temperature and/or fertility, while the 18 to 2 m yrs. interval may be related to increasing mantle temperature and/or fertility. The two trends are separated by a relatively short (2 to 4 m. yrs) interval when ultramafic mylonites

prevail in the mantle section; this interval marks probably a thermal minimum, when lithospheric emplacement was mostly tectonic rather than magmatic.

Superimposed on both trends we observed short-wavelength (2-4 m. yrs.) oscillations in mantle degree of melting and crustal thickness. The two trends reflect probably long-wavelength changes in the thermal properties and/or composition of the mantle that upwells below the ridge. These changes may be due to the influence of mantle derived from N. Atlantic plumes, or from lateral migration of the Mid Atlantic Ridge above mantle domains with different thermal properties and composition.

Hydrothermalism in Oceanic Basins: yesterday and to-morrow.

Perspectives for future research involving: metallogenesis, potential environments for the origin of life, hydrocarbon synthesis and / or cracking / hydrocracking.

Henri Bougault

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The earliest discoveries of hydrothermal sites were made in 1977 - 1979 on the Galapagos Spreading Centre and on the East Pacific Rise. Several cruises were welcome to find new hydrothermal sites in this area (medium to fast spreading rate) and describe the various aspects involving many scientific fields such as geology and geophysics of the Ridge axis, fluid properties, metallogenesis, biology and microbiology. Nevertheless an overview on hydrothermal exchanges over the Mid-Oceanic Ridge system required discovering and studying hydrothermal processes in the different geodynamic contexts of spreading centers.

- Fast to slow spreading rates, axial rise to deep rift valley
- Depth
- Volcanoes formed at or close to the ridge axis
- Back arc systems
- Hot spots and influence of hot spots along the ridge system
- Fracture zones, intersection between the ridge axis and fracture zones, off sets of different types

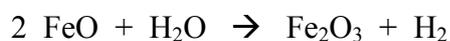
There were at least two principal reasons to study hydrothermal exchanges in those various contexts: the different compositions of rocks forming the oceanic substratum (influence on the

chemistry of hydrothermal products) and the life time of active hydrothermal cells (influence on the size of hydrothermal deposits and development of life). It is important to note that many scientific fields are involved to study the potential diversity due to these two factors, from geophysics to microbiology.

Nevertheless, we had to wait for some years to see programs developing in other contexts than the EPR, for instance on slow spreading ridges or in back-arc contexts. We had to wait for 1986 to discover the first active hydrothermal site in the deep rift valley of the slow mid-Atlantic ridge at 26°N, in the TAG area where indication of hydrothermal deposition were known well before the earliest discovery on the Galapagos Centre.

Most of the geodynamic contexts listed above have been the object of investigation: each of them, as expected, displays different hydrothermal properties. For the purpose of this paper I will concentrate my interest on slow spreading ridges. Just before the discovery of the first active hydrothermal site over the TAG area, a French – Russian cooperative program was planned to study both mantle heterogeneities through sampling basalts at “zero age” and hydrothermal activity through sampling the water column within the rift valley and detecting hydrothermal anomalies (Mn, CH₄, ³He). The second cruise of the R.V. Akademik Boris Petrov (1985, Leonid Dmitriev Chief Scientist) was dedicated to these two objectives on the MAR. A major result of the cruise for its hydrothermal component was to detect the first CH₄ anomalies within the rift valley and to dredge at about the same location basalts, gabbros and ultramafics. The occurrence of ultramafics along the MAR had been previously documented by dredging as soon as in the sixties at 45°N, and at several locations by the Deep Sea Drilling Project (Leg 37 in 1974 at 36°N; Leg 45 in 1976 at 22°N; Leg 82 in 1979 between 34 and 37°N). The important contribution of the second cruise of the R.V. Boris Petrov was to locate those ultramafics on the walls of the rift valley. Several years later, the Logatchev hydrothermal site was discovered at about one mile from the location where CH₄ anomalies were detected and ultramafics recovered. After 1985, occurrences of ultramafics along the walls of the rift valley were documented in many places along the MAR. Russian programs played a key role in this study. Along the ridge segment at 15°N on the MAR, ultramafics were documented symmetrically on each wall of the valley at the same latitude. Such results are essential to understand the construction of slow spreading ridges and associated Hydrothermalism. A French cruise (Serpentine, in the area of 15°N on the MAR) part of the French Russian cooperative program to study hydrothermal processes that involve the outcropping mantle just ended in April 2007. The direct interaction between seawater and ultramafics along slow spreading ridges is an important result as far as the diversity of hydrothermal exchanges is concerned but it is also a key point for the chemical reaction between seawater and the oceanic substratum.

Petrologists are used to study the diversity of solids, rocks and minerals, involved in the serpentinisation reaction. The other product of this reaction is hydrogen. Except few examples, much less interest was dedicated to hydrogen: this gas can only be detected and sampled close to the active sites since hydrogen disappears very quickly in seawater. One can write the production of hydrogen through serpentinisation in a very simple way:



Chemically, the serpentinisation reaction can be considered to be the reduction of H₂O by the ferrous iron contained in rocks. From this point of view, it is an analog of the production of the “**Water Gas**”, the first industrial production of gas which developed by the end of the 19th century.



The analogy is not restricted to the reduction of water to produce hydrogen. Carbon is present as a minor compound (CO₂) in ultramafics. Referring to the “Water Gas” reaction and the subsequent Fisher Tropsch polymerisation reactions used in the industry, hydrothermal cells should be as well the location where the same chemical reactions develop. CH₄, a typical hydrothermal tracer to locate hydrothermal sites, is the first abiogenic molecule resulting from those reactions. Linear hydrocarbons, aromatics and cyclic compounds are now identified in hydrothermal fluids. The occurrence of nitrogen in these molecules is more than likely. To continue with the analogy of the “Water Gas”, it has to be reminded that the industrial production of synthetic gasoline was effective in the 1920th, and that the industrial production of hydrogen through the “Water Gas” reaction allowed the industrial synthesis of NH₃ and of several organic molecules involving nitrogen. In some ways, all these scientific and industrial developments that started by the end of the 19th century with the “Water Gas” are as many supports or guides for a scientific reflection on natural hydrothermal reactions (including the possible formation of amino acids) and for developing future programs of research. One can imagine three directions.

The origin of life: what likely ecological context? Marcelin Berthelot (1827 – 1907) broke the “life strength” theory: according to this theory, organic molecules (e.g. ethylic alcohol, urea) could only be generated by life, which means by God. Through spark discharges in the so call “Berthelot’s egg”, Berthelot synthesised acetylene, ethylene and from ethylene, ethylic alcohol. The “life strength” theory was broken. Interestingly, we now are looking for abiotic organic molecules as a necessary preliminary step to develop life. Using spark discharges as well, in different gases, Stanley Miller demonstrated that complex organic molecules (involving nitrogen atoms) can be synthesised. From his experiments, Stanley Miller concluded that life developed in a primitive atmosphere of the Earth and felt very unlikely that life originates from high temperature hydrothermal vents.

Nevertheless, the convection circuit of hydrothermal fluids with its associated abiotic organic chemistry is definitely a candidate for the origin of life. It does not mean that the ecological conditions are restricted to high temperature vents at the axis of mid-oceanic ridges. Although quite a large range of pressure and, more important, of temperature does exist within a single hydrothermal cell and between different hydrothermal cells along spreading centres, the early opening of an ocean offers an even wider spectrum of conditions. It could be a situation similar to the situation of the Gulf of California or of the Red Sea where spreading centres are covered by sediment layers. For the origin of life, these sediments should be free of any biotic organic products. In a context of a sedimented ridge axis, hydrothermal fluids circulate through the crust, then through the sediments and can find a much wider spectrum of conditions to develop abiotic organic molecules. Because of this wide spectrum, one can expect to find a combination of conditions that could be a potential ecological context for developing life.

Investigating in this direction is not easy. Even if we can have access to deep sediment involved with hydrothermal circulation, it is not possible today to sample deep sediments that were free of potential pre-existing life. Despite this major difficulty it would be anyway of great interest to demonstrate how bacteria's are associated with hydrothermal circulation in this sedimented context compared to sediments free of hydrothermal influence. It can be observed that this hypothesis could be an additional component for the development of a deep buried biomass.

Generating abiotic gas or oil? Abiotic hydrocarbons are present in hydrothermal fluids. One may think that large quantities of abiotic hydrocarbons could be produced by hydrothermal systems through the Fisher Tropsch reaction. Nevertheless any recovery of those abiotic hydrothermal hydrocarbons requires some storing reservoir. A crustal reservoir is more than unlikely. A sedimented spreading centre, as mentioned above, would be able to provide the appropriate conditions to store "abiotic gas or oil" according to the present knowledge of petroleum reservoirs. This hypothesis for abiotic gas and oil is supported by the existence of a hydrogen reservoir in Kansas associated to ultramafics, hydrogen and gas seeps of deep origin that potentially involve serpentinisation and by $\delta^{13}\text{C}$ characteristics of some crude oils.

Cracking and / or hydrocracking? The early opening of an ocean and the formation of continental margins are the typical context where the biogenic organic matter in sediments is transformed and petroleum stored in reservoirs. Both the Ocean / Continent transition zone and the time when the oceanic crust took place are critical points. Hydrothermal processes were necessarily part of the process during this phase. Hydrothermal fluid convection is important in this context for two main reasons:

- Heat transfer: cold margins and hot margins refer to heat flow along margins. Models that describe the transformation of organic matter are developed accordingly. Nevertheless, heat is not homogeneously transported by conduction: it is transported by fluids by convection and namely in this context by hydrothermal fluids. Introducing convection in models is difficult and needs to introduce random and discontinuous parameters in the system. It explains why models based only on conductive heat flow are not really reliable.
- Hydrothermal fluids transport heat, but also hydrothermal hydrogen and, may be, abiotic hydrothermal hydrocarbons. Heat is responsible for cracking the organic matter whereas hydrogen and heat can perform hydrocracking. In this later case, final products are more valuable than those resulting from simple cracking.

Along margins, in the specific context of early oceanic opening, more specifically in the ocean / continent transition zone, hydrothermal systems had the following effects:

- Heat is transported by convection; modelling the transformation (cracking) of the biogenic organic matter in overlying sediments is more complex than only accounting for a simple conductive heat flow.
- Hydrothermal fluids transport hydrothermal hydrogen: hydrocracking of biogenic organic matter in overlying sediments should be considered.
- Hydrothermal hydrocarbons are potentially produced according to Fisher Tropsch reactions. They can contribute to some reservoirs in overlying sediments.
- As far as the origin of life relies on the availability of prebiotic inorganic molecules, the context of the Ocean / Continent transition zone provides a wide range of ecological conditions to develop life thanks to the sediments overlying hydrothermal systems. It can contribute to the deep buried biomass.
- Metallogenesis is also concerned in this context. As already shown on sedimented ridges (e.g. Juan de Fuca or Gorda Ridge), metallic deposits are formed within the overlying sediments. Along a margin, sediment can contain pre-existing metallic deposits such as placers. Hydrothermal fluids percolating through those pre-existing deposits can remobilize some elements and at the end make more complex deposits than those known so far along mid-oceanic ridges.

Programs are still to be developed along mid-oceanic ridges to better describe and understand the properties and processes involved in hydrothermal systems. Nevertheless, thinking in terms of hydrothermal systems in Oceanic Basins, it may be interesting to look at off axis hydrothermal systems. In complement to studies already conducted at “zero age”, the Ocean / Continent transition zone along the margins can be the location for new scientific objectives

involving metallogenesis, cracking and hydrocracking of biogenic organic matter in sediments, synthesis of abiogenic hydrothermal hydrocarbons and the origin of life.

Acknowledgements. This meeting is dedicated to Leonid Dmitriev. I met Leonid for the first time in Brest in 1969. It was a port of call of the R.V. Akademik Kurchatov after a French Russian cooperative program in the Bay of Biscay conducted by Xavier Le Pichon and Gleb Udintsev. Since that time, Leonid and I developed cooperative studies, participated in cruises on board French and Russian Research Vessels, on board the Drilling Vessel Glomar Challenger (DSDP International Program), and established a formal cooperation between France and Russia involving several laboratories on both sides. The French cruise Serpentine (MAR, 15°N) that just ended in April 2007 is an example of this fruitful cooperation.

Leonid pushed us to think about hydrothermal processes that take place off axis in the Oceanic Basins. In particular, he pushed us to model the off-axis production of hydrothermal hydrogen. I am sure that he would have supported the reflection on hydrothermal processes that took place in the Ocean / Continent transitional zone mentioned above. He would have supported the multidisciplinary approach, involving Marine Geology and Geophysics, Metallogeny, Prebiotic Chemistry, Microbiology and Petroleum Geology.

Many of us are in debt for this cooperation that took place over 35 years. Not only cooperation: a friendship.

Diversity and biogeography of deep hydrothermal vent communities in the world ocean

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Discovered in April 1977 on the Galápagos Spreading Centre, the hydrothermal vent communities were initially regarded as isolated and rare biological phenomena but a rapid pace of exploration has found that similar communities are associated with nearly all spreading centres and active volcanic arcs. The discovery of these extraordinary communities has been the most exciting biological advance in the deep sea in the past 50 years.

It had been a longstanding assumption that, in the deep sea environment, all biological life relies on organic import from surface layers and continental shelves (POM, plant remains, carcasses ...). Generally speaking the biomasses of the soft-sediment abyssal plain communities are low

(<2g . m⁻¹ w.w.) but these assemblages are very diverse, composed of a myriad of tiny “infaunal” forms, mostly bivalves and gastropods, polychaete worms and diverse crustaceans.

One can hardly imagine a greater contrast to the abyssal soft bottom communities than the lush assemblages of fauna that live around sites of active and reach vent densities of animals with standing biomasses as high as that of the most productive marine ecosystem. The biological diversity of the rich deep hydrothermal habitat is low when speaking of metazoan, as compared to usual deep-sea fauna. When a typical deep-sea specific diversity exceeds 200 species / m², the known world vent fauna from Pacific, Atlantic and Indian Oceans, hardly reaches 600 species adapted to the life in these harsh habitats. The most common taxa found at vents are molluscs (mussels, clams, snails and limpets), crustaceans (shrimps and crabs) and different annelids (giant tube worms, scale-worms, pompeii worms). One major characteristics of vent biological communities is the “endemism” or specialization for the vent habitat (more than 85% of the vent taxa have been observed only from this environment) many taxa showing important adaptations to the vent environment (i.e. detoxication processes, symbiotic relationship between bacterial primary producers and invertebrates, opportunistic life-history traits). The vent species form a homogeneous faunal entity; two vent communities even distant from each other, share more taxa than a vent and one adjacent deep-sea community. The vent taxa have been thus assumed to belong to the same set of species with strong affinities with other fauna living in deep-sea oxygen-depleted habitats (plant remain accumulations, carcasses of large mammals and reptiles, wood-falls, cold-seeps on continental margins, OMZ).

At a global scale, biogeographic factors (physical barriers and corridor) as well as the tectonic dynamics creating isolation of the vent fauna on different ridge segments or complexes might yield a different, separately evolved set of species filling the same niches. The most basic pattern of distribution to emerge is an inverse relationship between faunal similarity and distance separating vent fields. For historical and logistical reasons, our knowledge of the vent communities is relatively limited to accessible part of the ridge system and we presently still ignore the vent communities living in a large part of Indian, the Southern Atlantic Oceans and the Polar Ridges. Nevertheless, considering the present knowledge on vent fauna, we identified five biogeographical domains (1) the EPR and GPS from 21°N to the Easter Microplate (2) the North East Pacific communities of the Juan de Fuca, Explorer and Gorda Ridges (3) the Western and South-western Pacific Back Arc Basins with latitudinal variations (4) the Mid Atlantic Ridge communities structured by depth zonation (5) the Indian Ridges vent communities. An analysis of faunal proximity at the generic level brings together Eastern Pacific Vent Communities as opposed to a cluster of (a) CIR and BAB vent fauna and (b) MAR vent assemblages. Vicariance events (e.g. the split of Fallaron Pacific Ridge by subduction under the North American Plate 28

Ma ago or the closure of the Isthmus of Panama 5 Ma ago) are the main explanation of the divergent evolution of the vent fauna and the isolation of biogeographical domains. At regional scales, edaphic factors (soft vs. hard substrate) and depth/pressure related fluid properties (phase separation) have important consequences on the composition of communities (e.g. Guaymas Basin vs. EPR – Gorda Ridge vs. Juan de Fuca Ridge).

A number of biological and successional factors affect the distribution of species at the biological scale (within the life span of vent species). Dispersal processes are related to the life-history traits of the species (e.g. planctotrophic or demersal, teleplanic larvae) and to the local instability of venting (at a first order related to spreading rate). Marine invertebrates ensure gene flow, dispersal between active areas and colonisation through their larval stages which are passively transported inside the axial valley by the bottom currents. A number of topographic (fracture zones, continental plates, hot spot interacting with ridges) and/or hydrological (fronts, transverse currents) features can act as barriers and impede selectively the dispersal of vent species. If we have now a clear understanding of the successional patterns at vents on fast spreading ridges (e.g. EPR 9°50'N and 13°N), very few is known from slow spreading ridges as MAR. Nevertheless, recent observations during Serpentine cruise demonstrated that the venting fluctuations and instability of the substratum have major impacts on the composition of vent fauna.

Hierarchy of magmatic systems and morpho-structural segmentation of spreading ridges

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A non-steady thermal model of spreading with periodic axial intrusions allows an explanation of some specific features in formation of magma chambers of various scales in dependence on spreading geodynamics. The model takes into account the following parameters of spreading and mantle processes: periodic character of tectonic-magma cycles (spreading episodes), hydrothermal cooling of the crust, mantle temperature and heating, chemical composition of oceanic crust, depth and width of intrusions and others. According to the modeling, five interconnected magma systems of different scale there are in the spreading axial zones.

- a. The system in the upper mantle (asthenosphere), where start of generation, adiabatically rise and focusing of basaltic melt take place near the spreading axis.

- b. The undercrust system with 10-20% melt content. It is formed within the focused mantle upwelling by melt accumulation in the asthenosphere roof just under the Moho boundary.
- c. The system in the lower crust with 3-5% of basaltic melt. It is presented by lower part of crust magma chamber in fast spreading ridges, where melt fraction is small.
- d. The system in the middle crust with high melt fraction (40-90%). In fast spreading ridges, it is presented by melt lens located near to roof of crust magma chamber, whereas in slow ridges it is constrained by single sills within the third layer of the oceanic crust.
- e. The system in the upper crust presented by withdrawal dikes systems.

In addition the off axial system is feeding from the undercrust magma source and explains formation of volcanic seamounts located off the ridge axis can be chosen.

The mantle temperature and spreading rate are the most important parameters in the magma system development.

The above magma systems of different depth and scale have an influence on morphological segmentation of spreading ridges (scale, dimensions and life time) and their axial relief.

A difference in structure of magma systems in the fast spreading ridges from the ones in the slow ridges are most considerable within the crust magma systems (3-5 levels).

Difference in location depth, shape and sizes of magma chambers in the fast and slow spreading ridges result in considerable differences in rheologic behavior and accretion mechanisms of the crust and therefore in relief and deep structure of the crust. The steady-state crust magma chambers in the fast spreading ridges secure a differentiation of basaltic melt and determine a stratified structure of the crust. On the contrary, in the slow spreading ridges, the crust is characterized by nonregular, chaotic structure. The regions of anomaly heated mantle (mantle plums) or migration of asthenosphere flows along ridge axis can be an exception.

Thus, a difference of magma systems and morphostructural segmentation of ridges is a fundamental and global attribute of the MOR geodynamics, reflecting the difference in three dimensional accretion processes in divergence plate boundaries. As a rule, magmatic, morphologic and tectonic structure of small scale segments depend on the processes in the segments of more great scale. But every segment of given scale is determined by own processes controlling its existence, structure and evolution.

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An isotopic ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, $^{87}\text{Sr}/^{86}\text{Sr}$) and geochemical features of carbonate-brucite deposits of Lost City hydrothermal field (30 °north, MAR)

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The isotope ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$, $^{87}\text{Sr}/^{86}\text{Sr}$) and geochemical features of low-temperature hydrothermal carbonate deposits of Lost City Field (LCF) were studied. The LCF is spatially connected with ultramafic serpentinized rocks of massif Atlantis. The mineralogy of the deposits was studied by x-ray and electron-microscope methods. Only three main phases were found – calcite, aragonite and brucite, but under electronic microscope the thin aggregates of chryzotile was found out (Fig. 1).

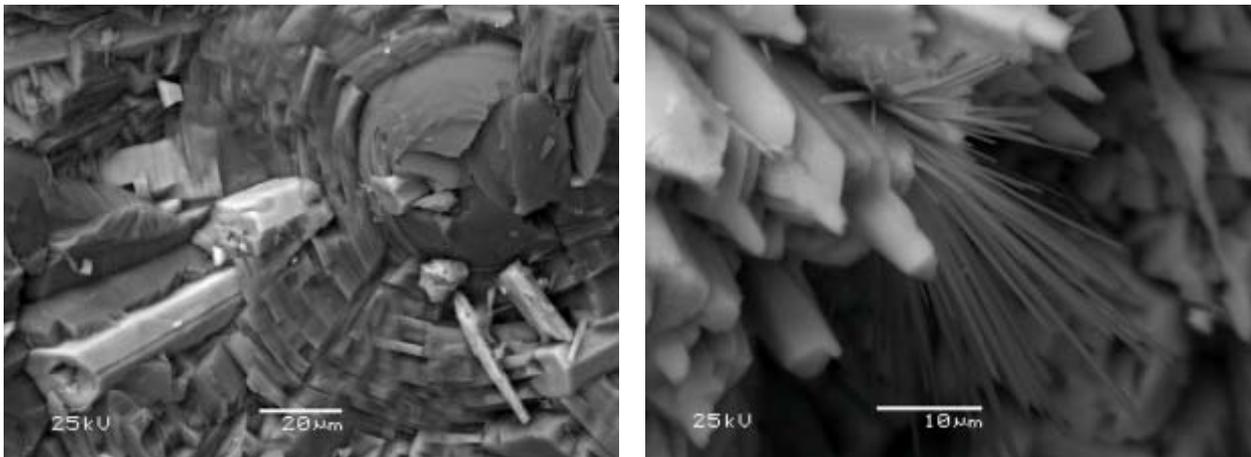


Fig.1. The images of the sample 67-M1-1/3 under electronic microscope: the aragonite crystals growth through the layered brucite aggregate (left), the “needle”-type aggregate of chryzotile (right).

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio at 8 samples of carbonate material decrease from “oceanic water” values to 0.7069 as the brucite proportion relatively carbonates increase.

It’s clear that the isotope composition of carbon, oxygen and strontium of carbonate material are controlled by mixing of warm hydrothermal fluid with cold near-bottom oceanic waters. This process can be illustrated by the dependence of calculated from oxygen isotope data temperatures on the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio. At this context, the strontium isotopic ratio reflects the proportion of oceanic water during the mixing with hydrothermal LC fluid. However, the calculated temperatures from isotopic equilibrium between calcite(and aragonite) and water are systematically lower than the observed ones. On the contrary with carbonates, the temperatures obtained from the brucite-water equilibrium are in accordance with the observed values. This fact can be explained, firstly, the early deposition of brucite, when the cold oceanic water proportion is lower at the mixture with warm LC fluid. From another hand, the oxygen isotope

disequilibrium can take place because the pH of the LC fluid is too high (up to 9-10) [Kim S.-T., O'Neil J.R., 1997]. Due to the isotope disequilibrium the calculated temperatures will be lower than the observed, if the source of carbonate(bicarbonate)-ion is not only oceanic water. The last assumption is in accordance with the strong correlation between $\delta^{13}\text{C}$ and strontium isotopic ratio at the carbonate material of LC deposits. Such, but less strong correlation was found for $\delta^{18}\text{O}$ too. If the source of dissolved carbonate was the oceanic water only, the carbon isotope composition will be near constant during the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio at the mixture solution will change due to oceanic water proportion growth. However, our data and data from [Früh-Green G.L. et al., 2003] show that the samples with strontium isotopic composition close to oceanic water has more high values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ and fall down with the $^{87}\text{Sr}/^{86}\text{Sr}$ decreasing. So, the assumption about the additional source of dissolved carbonate at the LC fluid is preferable. The extrapolation to the "primitive" Sr isotope composition, the $\delta^{13}\text{C}$ value about $-2 \div -2.5$ ‰ relatively PDB was obtained. The near same values was measured at the calcites from veins located at the upper parts of massif Atlantis serpentinites and gabbro: $-2 \div -2.8$ ‰ [Früh-Green G.L. et al., 2003]. This type of material can be an additional source of dissolved carbonate at the Lost City hydrothermal fluid during filtration from the serpentitization front through the cooled altered zones to underwater vent.

The quantitative description of the C, O, Sr - isotopes behavior during the mixing of LC vent fluid with the ocean water and carbonate deposition is quite complex because the each isotope system has a specific features in this processes. When the minerals are studied, the real proportions of mixing oceanic water and vent fluid will be recorded by only Sr isotope system, because it is insensitive to temperature and pH. The oxygen isotope system of carbonates is under influence the temperature, pH, and source of dissolved carbonate(bicarbonate)-ion at high pH conditions. At the contrast, the carbon isotope system is not under influence the temperature at the high pH, because at these conditions almost all dissolved carbonate quickly precipitate from solutions.

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Composition and problems of origin of Paleozoic oceanic lithosphere framing European platform from south, exemplified by Eastern Mediterranean area

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Paleozoic oceanic complexes of the transition area from European Platform to Eastern Mediterranean Hercynides exemplified by the Balkan-Carpathian ophiolite belt and paleoceanic zones of the crystalline basement of the Great Caucasus are described.

1. The Balkan-Carpathian ophiolite (BCO) belt, framing from south the Moesian Platform, extends over 250 km from NW to SE. The ophiolite sequences of the belt were considered as fault-block remnants of a single Late Precambrian-Earliest Cambrian (563±5Ma) ophiolite thrust sheet formed in a mid-ocean ridge setting and possibly representing a crustal fragment of large oceanic basin. It is assumed, that BCO is a part of extended South European paleoceanic suture continued on southeast in Pontides and further in the Arabian-Nubian Shield and representing a trace of proto-Tethys closed in early Paleozoic in relation with Cadomian orogeny [Haydoutov, Yanev, 1997; Savov et al. 2001]. A complex petrological, geochemical and geochronological investigation of representative samples of gabbros and associated diabase dike body, sampled in eastern part of Deli Jovan massive (BCO, Eastern Serbia) has been carried out. All studied gabbros represent high-alumina (19-24.5 % Al₂O₃) gabbro-troctolites and correspond to Ol₈₂₋₈₉+Cpx₇₉₋₈₇+Pl₇₇₋₉₁ cumulates originated from shallow level (≤ 1kb) crystallization of low-K (< 0.3 % K₂O) tholeiitic basaltic melt (T= 1050-1160°C). Dike body corresponds to fine-grained, Cpx-Pl microphyric, high-magnesian tholeiitic gabbro-diabase. Multielement pattern and characteristic trace-element ratios of the series [(La/Sm)_n=0.18-1.31; (La/Yb)_n= 0.22-1.35; Th/La= 0.073-0.19; Zr/Y=1.60-2.39; etc.] fit well a MORB type setting. All geochronological data carried out for fresh Deli Jovan gabbros showed narrow Late Silurian-Early Devonian interval: a) Sm-Nd mineral isochron age of 406±24 Ma, MSWD=0.71, ¹⁴³Nd/¹⁴⁴Nd_{init}=0.512547±0.000044; WR εNd_T=8.32±0.39; ⁸⁷Sr/⁸⁶Sr_{init}= 0.702592±0.000160; b) U-Pb isotope dilution zircon age 399.7±5.2 Ma, MSWD= 1.8; and c) U-Pb SHRIMP zircon age 405.0±2.6 Ma, MSWD= 0.36. Nd and Sr isotopic ratios evidently indicate that the studied basic series are related to strongly depleted mantle source. Two of five samples of studied gabbros have shown clear overprint of the prograde regional metamorphism of upper part of greenschist facies at T ~ 400-450°C (as. actinolite+hornblend+chlorite+epodote+plagioclase). The age of

the prograde metamorphic event was estimated by lower intercept of discordant zircons 261 ± 19 Ma, MSWD= 0.095 for metamorphosed gabbro sample. Accordingly, the BCO reveals a complex geological history, along with Late Proterozoic complexes Paleozoic (Late Silurian-Early Devonian) fragments of paleoceanic lithosphere are also obviously presented here.

2. The Crystalline Core and Front Range zones of the Great Caucasus Hercynides framing south the Scythian platform (southernmost part of the European Platform), include paleoceanic thrust sheets of Paleozoic age [490-470 Ma; Adamia et al. 1990, 2004, Somin et al. 2006]. Two types of series were identified. The first low-silica ($\text{SiO}_2=43,94-48,10\%$), high-titanium ($\text{TiO}_2=2,-3,03\%$, high phosphorus $\text{P}_2\text{O}_5 = 0.22-0.88\%$) tholeiitic basalts of T-MORB type [(La/Sm) $n=2,98 \pm 0,57$; (La/Yb) $n=5,72 \pm 2,05$; (Tb/Yb) $n=1,42 \pm 0,62$; (Yb) $n=13,15 \pm 4,73$ and (Yb)MORB= $0,97 \pm 0,35$]. And the second of supra-subduction type corresponding to comparatively high-silica ($\text{SiO}_2=47.54-53.94\%$), low-titanium ($\text{TiO}_2=0,46-1,09\%$), low-potassium tholeiitic, basalts and associated basaltic andesites and andesites. Basalts of the latter series show an exclusively low total (51 ± 31 ppm) and clearly fractionated REE pattern (La/Sm) $n=0.77-2.40$; (La/Yb) $n=0.72-3.38$. HREE is somewhat lower compared to the average N-type MORB [(Tb/Yb) $n=1,04 \pm 0,34$, (Yb) $n=9,97 \pm 3,44$, (Yb) $n=0,62 \pm 0,28$].

3. Despite of the revealed essential heterogeneity of composition of the studied oceanic complexes, we suggest that the Paleozoic oceanic suture of the Balkan-South Carpathian ophiolite segment probably extends eastwards to the Paleozoic ophiolite zones of the Great Caucasus. To the south from this extended Paleozoic suture zone an extensive peri-Gondwanan Thracian-Transcaucasian terrane is located pre-Hercynian crystalline basement of which show clear record of Cadomian orogenic events [Zakariadze et al. 1998; 2007; Carrigan et al. 2005; Kounov et al. 2006].

Evolution of the Reykjanes Ridge: the influence of the hot spot and of the plate tectonic kinematics

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Nearness of the Reykjanes Ridge (RR) to the Iceland hot spot (HS) resulted in its considerable difference from others slow spreading MOR. The goal of this investigation is to determine the temporal and spatial changes of the HS influence on the RR. Magnetic data, with attracting of all published information about the RR, allow observe changing of the geodynamic regime at the RR' axis.

Spreading type magnetic anomalies have been well developed and defined in the large area of the Northern Atlantic to the south of the Iceland because of its high linearity. Magnetic anomaly axes from 1 to 6 in the north part of the RR' axis and from 19 to 24a in the deep parts of the Iceland and Irminger Basins are straight, oriented approximately parallel to the RR and obliquely to the spreading direction.

Typical slow spreading oceanic crust occurs between these two areas: Spreading Center (SC) was orthogonal to the spreading direction; the oceanic crust and magnetic lineations, observed at the slope of the Ridge and dated by chron 18 – 7 (Oligocene), was segmented by numerous faults (“disturbed magnetic zone”).

Evolution of the Reykjanes Ridge can be divided into three main stages according these characteristics of magnetic anomalies:

- **the first stage:** the beginning of relatively fast (half spreading rate 2.0 cm/yr) oblique spreading during the Eocene (54 – 40 Ma ago);
- **the second stage:** ultraslow orthogonal spreading during the Late Eocene – Oligocene (40 – 24 Ma ago);
- **the third stage:** oblique slow spreading during the Neogene (24 – 0 Ma ago).

The absence of the crustal segmentation and oblique spreading revealed on the basis of magnetic anomalies are evidences for high temperature of the upper mantle because of the hot spot influence on the oceanic crust accretion at the axis of the RR during **the first stage** of its evolution. Increased crustal thickness and a progressive concentration of magmatism toward the Iceland hotspot track recognized by Deep Sea Drilling and seismic reflection and refraction [Holbrook et al., 2001] confirm this conclusion.

All succession of magnetic anomalies in the “disturbed magnetic zone” has been identified in terms of detailed bathymetric and magnetic researches fulfilled by Russian ships during some last dozens years [Karasik et al., 1990]. Reorganization of the RR' axis during the Oligocene was the result of changing in plate tectonics of areas surrounding RR. At anomaly 19, the RR consisted of a single axial segment oriented north-east, oblique to the opening direction. The spreading rate on RR decreased to 0.8 cm/yr and its axis divided to segments 30 – 80 km length soon after the magnetic anomaly 19, after spreading slowing on the Run Ridge in the Labrador Sea. The spreading segments strike (~N10°E) became approximately orthogonal to the new sub-latitudinal spreading direction.

The last reorganization of the RR began at anomaly 13 time (~ 35 Ma ago), consisting in south-western CS propagation (Mercuriev et al., 1994), at the same time, when spreading in the Labrador Sea and in the Baffin Bay ceased. At anomaly 6 time (~ 26 Ma ago) the Agir Ridge

became extinct, spreading arose at the Kolbeinsey Ridge and spreading rate increased to 1.1 cm/yr at the RR.

Analysis of rare earth elements in basalts from the hole 407 DSDP, that lies on the crust 37 Ma age, has shown reduction of melt thickness (thickness of the igneous crust) to 7 km [White et al., 1995].

All mentioned above suggest that kinematics of the ocean floor movement from the system of the SC influenced on the crustal accretion in the RR axis during **the second stage** of its evolution. There is no direct evidence for southward asthenosphere flow during this stage. May be the presence of faults put obstacle to the asthenosphere flow from HS and thus its influence on the crustal accretion in the RR' axis.

The axis part of the RR that was formed during **the third stage** of the evolution from 24 Ma ago to the present is characterized by the absence of segmentation and by oblique spreading from its axis. This is an indicator of the Iceland hotspot influence.

Previous studies of geophysical and geochemical characteristics of the RR and theoretical analysis ascertained: asthenosphere flow below the axis of the Ridge from hotspot; more hot upper mantle and low crust; unusually shallow depth; an axial high instead an axial rift valley in the north RR; increased crustal thickness and its gradual decrease with the distance from hotspot; the presence of the V-shaped ridges, crossing the oceanic floor isochrones [Vogt, 1971; Vogt, Johnson, 1973; Taylor et al., 1977; Searle et al., 1988 and so on]. All these data confirm essential influence of the Iceland hotspot on the Reykjanes Ridge during **the third stage** of its evolution.

The changing of the geometry and segmentation of the SC depend upon the kinematic parameters (spreading rate and direction) has been investigated.

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Experience on thermodynamic modeling of descending path of hydrothermal cell in Slow-Spreading Ridge with the use of solid solution data

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The main goal of this investigation is determination of differences in thermodynamic modeling of descending path of hydrothermal cell with the use of “simple” mineral and solid

solution data. Calculations were implemented on a basis of complex GEOCHEQ including program of equilibrium calculation and thermodynamic data base [Mironenko et al, 2001].

Two series of calculations with one algorithm were realized. I used “simple” mineral data in the first case (control calculation). There are 7 solid solutions in the second case: aragonite-strontianite, Ca-Mg-Na saponite, Mg-Fe chlorite, chrysotile-greenalite, Mg-Fe olivine, Mg-Fe talc, Mg-Fe tremolite. The modeling is carried out on base of thermodynamic calculations of the interaction between percolated sea water and peridotite substratum. Calculation follows by flowing reactor method. This reactor is consists of 22 consecutive blocks at $T = 19^{\circ} - 482^{\circ}\text{C}$, $P = 0.48 - 3.92$ kbar and $W/R = 1438 - 2$.

Received data for the system with solid solutions were normalized to the control calculation's result. To estimate this value has been carried next inferences:

Chemistry of fluid -

Take place the difference in the trend of carbon compounds after the derivation of aragonite. Carbon compounds have an increase of 65% in the case with solid solutions. Sulphates have an increase of 15% during high temperature (last 3 blocks). Iron anomaly is down 70% (last 3 blocks). It's related with a character of mineralogy. Sr concentrates more intensive in the rock.

Bulk chemistry of rock -

Some differences take place only in first two blocks. There are Na (-20%), Sr (+80%) and Ca (-10%). It's related with the derivation of solid solutions of saponites and aragonite-strontianite.

Mineral phases -

Most important differences are related with the formation of saponites and aragonite-strontianite during low temperature and olivine during high temperature. The carbonatization of rock is more intensive in the case with solid solutions. The carbon phase has an increase of Sr (+75%). Saponites are characterized by another composition: $\text{Ca}_{0,02}\text{Mg}_{0,22}\text{Na}_{1,53}\text{Mg}_{18}\text{Al}_2\text{Si}_{22}\text{O}_{60}(\text{OH})_{12}$. Olivine has more magnesium (the control case - $\text{Fo}_{0,89}$, the case with solid solutions – $\text{Fo}_{0,98}$).

This investigation has shown that using of solid solutions data don't change result of calculations greatly. However, some minerals and compounds depend from this method. There are aragonite-strontianite, saponites and olivine.

The study has been supported by the Russian Foundation for Basic Research (Grant N 06-05-64003) and by Program of the Presidium of Russian Academy of Sciences “ Basic Problems of Oceanology: Physics, Geology, Biology, Ecology” (Theme: “Interaction of magmatic and hydrothermal systems in the oceanic lithosphere and ore deposits”).

Northern part of Knipovich ridge geological structure

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Studying of Knipovich ridge structures, including its northwest and western flank, up to Borrey basin, by complex of geologic-geophysical methods during 24 -th expedition of R/V "Academik Nikolaj Strahov" has shown, that basalts composing heights to the west of Knipovich rift valley can characterize initial stage of extension between Greenland and Spitsbergen with formation of diffuse spreading structures. Local basalt volcanism took place in formed multiple-aged rift structures. In the beginning of Miocene basic stretching zone has been localized within a modern rift valley of Knipovich ridge. Thus absence of magmatic material to the north of 77°54' N probably testify about amagmatic stage of the most northern ridge segment. Here thinning of continental crust is not enough for generation and outflow of oceanic basalts. To the south, despite occurrence of volcanic activity signs in the form of volcanic constructions and flows, slopes of a rift valley are substantially composed of Oligocene - Miocene lithified sedimentary rocks.

Studying of deformations in deposits and taking into account morphological relief features testifies that in Knipovich ridge area extensional deformations (normal faults) prevail, compression results in the form of upthrusts and gentle folds in deposits are seen less often. Both from our point of view are the result of global right-lateral shift movements in an area between Spitsbergen and Greenland, localized in various structures and existing for long time (Low Paleocene rocks are touched by these movements).

Molloy basin located to the north can be considered also as a result of initial stage of extension of crushed Spitsbergen island western continental margin which have not reached stage of generation and outpouring of basaltic melts.

Hydrothermal systems of the modern ocean floor as a perspective mineral resource of the XXI Century

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Rising metal prices have recently sparked growing interest in the economic potential of seafloor massive sulfides. There are currently a few companies that are claiming areas for exploration licenses in the territorial waters of Papua New Guinea (PNG), Tonga, Fiji, New Zealand and other countries. This contribution deals with the variability of presently known seafloor hydrothermal systems and their likelihood to become an economic target or even a major metal resource in the future.

More than 300 sites of hydrothermal activity and sea-floor mineralization are known, and examples have now been found in all of the ocean basins. About 160 of these are sites of high-temperature venting and polymetallic sulfide deposits. They occur at mid-ocean ridges (62%), in back-arc basins (25%), and on submarine volcanic arcs (13%), however, these numbers may only reflect the current exploration status of the various regions of the world. Theoretical calculations based on heat flow studies show that ~500-1.000 large hydrothermal systems can be expected on the modern seafloor, indicating that we have already found a substantial part of these sulfide-bearing systems. Investigations of seafloor hydrothermal systems over the past decade revealed important variations in their geological setting not previously recognized on the modern seafloor. Deposits have now not only been found to be associated with basaltic (N-MORB) volcanism typical for mid-ocean ridges, but also with enriched E-MORB lavas, at least partially influenced by hot-spot volcanism, with gabbros and serpentinites in areas of crustal uplift at slow- to ultra-slow spreading ridges, and with more evolved volcanic suites in both oceanic island arc and continental crust. Differences in volcanic substrate, as well as temperature-dependent solubility controls, account for the main geochemical associations found in the deposits.

Hydrothermal systems along mid-ocean ridges vary dramatically, from small scale sulfide pinnacles, conventional mound-like, Cyprus-type massive sulfides, large steep-sided sulfide/sulfate chimneys directly forming on basaltic substrate, to massive talc-anhydrite deposits, and huge carbonate-rich towers occurring in water depths ranging from 4100 m to as shallow as 100 m. However, even greater variability is found along submarine portions of volcanic arcs and back-arc basins. This setting is of importance since felsic-dominated volcanic arc complexes, which account for 80% of the world's VMS deposits on land, have yet to be

extensively explored on today's seafloor. Tectonic complexity arising from subduction zone processes leads to considerable variability in styles of mineralization, and exploration in the active marginal basins has led to the discovery of several new deposit types not recognized on the mid-ocean ridges (e.g., submarine epithermal gold and high sulfidation-type VMS). Recent cruises discovered hydrothermal systems within arc volcanoes that are strongly influenced by magmatic degassing with some systems dominated by CO₂-discharge while others show lakes of native sulfur related to the disproportionation of magmatic SO₂. The possibility of those volcanoes to harbor massive sulfides with unusual metal characteristics is still poorly investigated.

Economic feasibility of seafloor massive sulfides can only be shown by drilling. Several attempts were made in the past, however, often showed disappointing results from an economic point of view. ODP drilling at the TAG mound in 1994 provided the first opportunity to sample and model the interior of a VMS deposit formed on a modern, sediment-starved mid-ocean ridge. It became clear, that base and precious metal enrichments observed at the seafloor, could not be met in the subseafloor. Therefore, despite a moderate tonnage and grade (4Mt @ 2.1% Cu and 0.6% Zn), it seems unlikely, that TAG will become the focus of a marine mining operation. Drilling the sediment-hosted Middle Valley site during ODP Legs 139 and 169 has shown that the mineralization is the result of a structurally focused, long-lived hydrothermal system that produced stratigraphically stacked massive sulfide lenses over a depth interval of 210m. Although penetrating over 100 m of massive sulfide, the drilling also proved this deposit to be uneconomic, since largely Fe-sulfides were drilled. Other disappointing examples include the ODP-drilling programs at Escanaba Trough (ODP Leg 169) and PACMANUS (ODP Leg 193) as well as drilling campaigns at Suiyo Seamount and at Brothers Seamount in the Kermadec arc. On the other hand shallow drilling at PACMANUS (PNG) in 2002 using a mobile drill showed encouraging results at depth as did ship-based commercial drilling of the SuSu knolls sites (also PNG) in 2006. The aforementioned results indicate the importance of seafloor drilling to validate grades and tonnages of seafloor massive sulfides often only characterized by surface sampling using submersibles, ROV or grabs.

The majority of known black smoker vents occur on fast-spreading mid-ocean ridges, but the largest massive sulfide deposits are located at intermediate- and slow-spreading centers, at ridge-axis volcanoes, in deep back-arc basins, and in sedimented rifts adjacent to continental margins. The largest black smoker deposits contain 3-5 million tonnes (e.g., TAG Hydrothermal Field, Galapagos Rift, Southern Explorer Ridge, and 13°N on the EPR), and two sediment-hosted deposits, Middle Valley and the Atlantis II Deep, are known to be much larger (10-20 million tonnes and 90 million tonnes, respectively). Despite moderate tonnages in several seafloor

deposits, recovered samples from about 50 deposits worldwide represent no more than a few hundred tonnes of material. Based on existing data and lacking information on the third dimension it seems premature to comment on the economic significance of seafloor massive sulfides. Published geochemical analyses of sulfide samples indicate that some deposits may contain important concentrations of base and precious metals. Out of the more than 160 sites of hydrothermal sulfide mineralization currently known at the modern seafloor, only about 10 deposits may have sufficient size and grade to be considered for future mining, however, other factors such as water depth, distance to land, and jurisdiction may also impact the economic potential. Marine mining appears to be feasible under specific conditions ideally including (1) high gold and base metal grades, (2) site location close to land, i.e., commonly within the territorial waters (200 nm Exclusive Economic Zone or even 12 nm zone) of a coastal state, (3) shallow water depth.

Under these circumstances, massive sulfide mining can be economically attractive considering that the mining system is likely portable and can be moved from one site to another. Given the limited sulfide tonnage presently known on the modern seafloor when compared to the geological record, some mining of black smoker deposits on the seafloor might occur in the not so distant future, but it seems unlikely, that seafloor massive sulfides will be a substantial metal resource for humankind as often suggested.

Oceanic Core Complex as a key to reconstruction of the magmatic and tectonic evolution of the Slow-Spreading Ridge Lithosphere: An example of Atlantis Massif, MAR, 30°N

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Widespread distributed ultramafic rock outcrops along Mid-Atlantic Ridge (MAR) axis strike are characteristic markers of oceanic core complex (OCC). As a rule OCC localized at inner corner high's in a many places of crest zone of MAR: 15°04'N, 30° N Atlantis Massif, RTI at Hayes FZ, etc.). Main object of this study was sample collection selected by submersible "MIR" Dives at upper part of South slope of Atlantis Massif (AM) in 50-th cruise of R/V "Akademik Mstislav Keldysh" (2005) and peridotites sampled from lower part same slope of AM during 16-th cruise of R/V "Akademik Boris Petrov" (1990). The data presented in Initial Report on

Drilling in AM Central Dome in ODP Expedition 304/305 Scientists, 2005 [Blackman et al., 2006] has been used in this work also.

Peridotites from South Slope of AM characterized by variation in bulk rock chemistry into range corresponding to MAR Peridotites compositional field. However Harzburgites sampled in upper part of AM (1254-761m) display more wide variation scale (including very depleted units) as compared with Mantle Peridotites sampled in more deeper part of AM (3500m). Variation of Mg# vs Cr# in Spinel from Sample examined testifies that Harzburgites from upper part of AM (1254-761m) were exposed to interaction with magmatic melts. Same conclusion is evident from data on composition of Spinel, Olivine and Pyroxene from Peridotites studied. Relationships between sampling depth of ultramafic Rocks from South Slope of AM and composition of Spinel and Olivine from them testifies that Peridotites sampled in upper part of AM (1254-761m) characterized as a whole by higher melting degree as compared with Peridotites from lower part of massif (3500m). Phlogopite has been detected in Harzburgite sample #4805-9. This sample characterized by highest depletion degree among Harzburgites sampled in upper part of South Slope of AM (1254-761m) and corresponding to Phlogopite compositional field from most depleted MAR Peridotites. Remarkable compositional peculiarity of Gabbroic Rocks sampled in upper part of Atlantis Massif is their primitive geochemical nature (MgO# = 0.74-0.78). Data presented in this work are in agreement with results obtained by drilling in Hole U1309D in “Central dome” of AM locates just to North of area examined: “Gabbroic rocks including gabbro, olivine gabbro, troctolite and gabbro-norite have compositions that are most primitive sampled anywhere along the MAR...” [Blackman et al., 2006]. Nd isotope composition in Atlantis Massif Gabbro fits the isotope signature of DMM reservoir and conforms to most depleted Atlantic MORB. Nd Isotope Composition in Peridotites sampled in upper part of South Slope of AM conforms to isotope characteristics in MORB of North Hemisphere MAR. Unexpected result of this Study is clear evidence for isotope heterogeneity in sample set examined. Harzburgite collection from Atlantis Massif includes samples with DMM isotope signature as well as Samples with HIMU one. Mantle Peridotites from AM with low Nd isotope ratio by their Nd isotope composition corresponding to depleted Harzburgites from geochemically enormous MAR regions such as Anomaly 14o48’ and Northern Oceanographer. Hence it is possible to suppose that two different kinds of mantle substratum take a part in construction of the South Slope of AM: 1) Close to DMM Reservoir (including associated Gabbro); 2) Close to HIMU Reservoir (only in upper part of sequence). Variation of Sr and Nd isotope composition in peridotites from South slope of Atlantis massif allow to conclude that serpentinization of these rocks took a place at wide range of W/R ratio: $1 - n \cdot 100$. Moreover, W/R higher than 100 have been established for serpentinites from upper part of Atlantis massif

where carbonation is extensively distributed. As it has been shown earlier most depleted peridotites from South Slope of Massif Atlantis locate in its upper part. These rocks also characterized by HIMU isotope signature and mineralogical evidences for their interaction with magmatic melt. *Key question is: That is nature of this melt?*

Most probable candidate for role of this melt is trondhjemites from “late magmatic leucocratic dikes” drilled in Hole U1309D and widespread into upper igneous sequence (1415mbsf- meters below sea floor)) of AM. Trondhjemitic veins and dikelets are common member of sequence of MAR OCC. Trondhjemites have clear reaction contact with host gabbroic and ultramafic rocks and are responsible for their secondary enrichment in incompatible elements as well as for Phl formation. Trondhjemites from AM have geochemical peculiarities same as trondhjemites from other MAR OCC where clear evidences for their reaction influence on host rocks composition were established. The Phl presence in most depleted Harzburgites from upper part of AM can be related also with such magmatic interaction.

All samples from submersible “MIR” dives studied in this work were collected in upper part of AM into range of sequence depth corresponding to upper 600m. Thus, compositional heterogeneity established in harzburgites from AM can be explained by tectonic emplacement at least two big ultramafic pockets relative to each other. One of this pocket (1254-760m) has been composed ultramafic rocks intruded by gabbro, diabases and throndhjemites; second (3500m) is only ultramafic in composition.

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Thermodynamic simulation of peridotite - sea water interaction in serpentinite hosted hydrothermal system in the Slow-Spreading Ridges

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Serpentine hosted hydrothermal systems are common for Slow- and Ultra Slow – Spreading Ridges: MAR, Gakkel, SWIR. Ultramafic outcrops are widespread along MAR axis and

sometimes occupies a floor space of hundreds square kilometers: e.g. at 15°04'N MAR – Bougault and Dmitriev Mountains (ODP, Leg 209, Initial Report, 2003). Main goal of this work is thermodynamic simulation of processes related with hydrothermal alteration of ultramafic rocks during hydration of Slow-Spreading Ridge lithosphere. The modeling is aimed at solving a following tasks: 1) Estimation of time of effective serpentinization of the Slow-Spreading Ridge ultramafic substratum at various P-T conditions; 2) Reconstruction of formation succession of secondary phases in Oceanic Peridotites during their interaction with Sea Water derived Fluid according to conditions of Hydrothermal System; 3) Reconstruction of compositional evolution of Sea Water derived Fluid and Host Peridotites with space (setting in sequence) and time.

We used a developed version of GEOCHEQ complex [Mironenko et al., 2000]. A thermodynamic database on gas and aqueous species and one-component solids up to 650 c and 5 kbar is based on SUPCRT92 database [Johnson et al., 1992; Shock et al., 1997] mainly. Additional information on non ideal gas and solid solutions, as well as kinetic data for calculating rates of mineral dissolution at various conditions were added. The calculating code was further developed for thermodynamic-kinetic modeling of irreversible chemical water-rock interactions. It takes to note that estimations of time of chemical transformations are relative because of uncertainty of several input parameters like degree of exposition of mineral grain surface to water, etc.

The CHEMEQ code was enhanced to consider non-ideality of gases, formation of solid solutions, and reaction progress with use of kinetic data.

As evident from modeling data serpentinization degree ($SD = \text{Serpentine/Rock}\%$) in peridotites by their exposition on sea floor surface is left extremely low (0.11) even during first 10000yr interaction with Sea Water at low temperature. Serpentinization becomes effective beginning at temperatures are of 130° - 150°C and reaches SD more than 70 approximately after 4800 yr for hydrothermal interaction. Data obtained by Modeling allow to suppose that the most part of serpentinites of Slow-Spreading Ridge (typically $SD \geq 60$) were formed at temperature no less that 130°C and on the sequence depth is of 3.5-4.5km. Succession of secondary phases formation in peridotites related with serpentinite hosted hydrothermal systems is strongly depend on values of W/R, pH and temperature. Changes in secondary phase assemblages of peridotite corresponding three main types fluid regime established earlier for serpentinite hosted hydrothermal systems: sharp oxidizing (near-surface), moderate oxidizing (fluid-dominating), and reducing (rock-dominating) [Silantyev et al., 2003]. As it has been shown by modeling generation of CH₄ becomes effective beginning at temperatures are of 130° and Sequence Depth is of 3 km and continues until 460° C and Depth about 11 km. Same behaviour is characteristic of H₂ and H₂S. The change in bulk chemistry of Host Peridotite (Ca-Input and Mg-Loss) is most

pronounced in near bottom surface conditions and corresponding to low temperature. Modeling Data can be applied to reconstruction of geodynamic conditions favourable for serpentinite hosted Hydrothermal system formation.

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Transoceanic East-West zones with “forearc” properties cross MAR and abyssal plains of Atlantic Ocean

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Observed along Mid Atlantic Ridge (MAR) geological-geophysical data shows the presence of two systems of facts describing the structural aspects, tectonics, geodynamics and petrology of the rocks comprising MAR: the system of ocean crust accretion along MAR axis and the transoceanic superimposed system, crossing MAR and abyssal plains.

The fact system of ocean crust accretion along MAR, which was the object of investigation by L.V.Dmitriev, is presented by following sequence:

- the types of basaltic magmatism, P-T-conditions of mantle substance emerging and magma generation and its relation to geodynamic conditions;
- high degree of correlation between petrological properties of basalts along MAR and geophysical and seismological parameters;
- constituting of a logically undiscrepant reason-consequence system by petrological and geophysical data, joining into united fact chain of petrology and geodynamics of MAR [Dmitriev et al, 1999; Dmitriev et al, 2003; Dmitriev et al, 2006]

This fact system presents integrated and renewed description of the classical processes known at divergent oceanic border.

In 2003 L.V.Dmitriev had initiated the study of MAR geodynamical condition typization by cluster analysis of geological and geophysical data. This analysis was done for all territory of Atlantic Ocean, including abyssal plains and continental slopes (except Scotia and Caribbean seas). The analysis had lead to the substantial detection of seria of east-west transoceanic zones with “**forearc**” properties crossing Atlantic from east to west. “Forearc” character of these zones was defined from combination

of extremal values of absolute maximums of Bouguer anomalies and minimums of Isostatic anomalies, and also was approved by the existence of thrust structures on the north-south seismic sections. It is defined at least 7 zones of this kind between Bouvet and Iceland islands, and two of them are spatially correlated with forearc and subduction zones of Scotia sea and Puerto Riko trench.

In the areas of intersection of these zones with MAR it could be observed the phenomena of convergence of transform faults passive parts, the presence of discontinuity zones in the structure of MAR rifts and formation of short transforms with almost zero offsets and oblique orientation to the MAR axis. By the mentioned observations the second fact system - transoceanic superimposed system, which apparently is not genetically related to the first system. Its existence could be explained only by the modification of current geodynamical model of oceanic evolution and (or) by the considering of an **alternative source of horizontal tectonic forces**.

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Geochemical source for tholeiite magmas enrichment at the Knipovich ridge

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The Knipovich Ridge is the northern extremity of the whole spreading system of the Atlantic Ocean and has been forming at minimal velocities. Abnormal structure of the Norway-Greenland basin's bottom expressed in asymmetry of the ridges' margins, mixed character of magnetic anomalies, mosaic structure of transform zones [Crane et al., 2001] has been caused by general evolution of Norway-Greenland basin. Its development took form of pulses with shifting of spreading axes, the main pulsing event was in Neogene, when the present position of the Knipovich ridge close to the western margin of Spitsbergen island had been fixed. Shifting of the spreading axis of the Knipovich ridge and the successive opening coincides in time (about 20 Ma ago) with magmatic activity at Svalbard archipelago developed, as a rule, in the form of cover basalts.

In Quaternary time, about 1 million years ago, this process caused formation of three volcanoes which are alkaline by magma composition. The spreading activity of the Norway-Greenland basin could stimulate magmatic activity within continental margin of Svalbard archipelago [Crane et al., 2001]. Primary melts of alkaline magmas were formed from enriched,

fluid saturated subcontinental mantle and by their composition were close to strongly enriched melts found in the form of veins in mantle nodules of Quaternary volcanoes of Spitsbergen island [Ionov et al., 2002]. The enriched melts migrated not only within continental mantle, but to the apical parts of the old oceanic depleted (asthenospheric) mantle as well. Miocene jumping of spreading axis from Norway sea to the area along the continental margin of Spitsbergen was the reason of involving of suboceanic enriched mantle into the melting process and formation of melts with isotope characteristics close to the Spitsbergen melts. The obtained data of distribution of incoherent elements and isotope ratios of Sr, Nd and Pb evidence to the similarity of the enriched component developed in alkaline lavas of Spitsbergen and poorly enriched tholeiites of the Knipovich ridge.

Geochemical characteristics of the basalts from the Knipovich ridge could be caused by the addition of 1% of substance from the enriched source similar in composition to vein material in xenoliths from Quaternary lavas of Spitsbergen [Ionov et al., 2002] to the substance of depleted mantle. Higher values of $^{208}\text{Pb}/^{204}\text{Pb}$ (38.8) for basalt glasses from the Knipovich ridge are marked for the southern segment – the region 76°N which points out to some difference in composition of the mantle source of two segments – 77° and 76°N.

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Hydrothermal-magmatic system of the Mid-Atlantic ridge, 6° N (Markov depression)

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A new type of sulfide deposits of the Mid-Atlantic Ridge (MAR) has been studied in the metasomatically altered brecciated gabbroids. It was found in the Markov Depression of the Sierra Leone Segment, the axial part of the ridge, during Cruise 10 of the R/V “Akademik Ioffe” in 2001-2002 and confirmed during Cruise 22 of the R/V “Professor Logachev” in 2003.

The dredged magmatic rocks are subdivided into two associations: (1) MORB basalts and their intrusive analogs, and (2) rocks of siliceous Fe-Ti-oxide series, including volcanic and subvolcanic varieties (hornblende basalts and dolerites) and intrusive rocks (ultramafic

cumulates, troctolites, ferrogabbroites and ferrodiorites). Practically all the magmatic rocks are enriched in Pb, Cu, U, Rb, Ta, Nb, as well as Cs and Rb, and depleted in Th and Hf. The Fe-Ti-oxide series rocks differ in the elevated contents of Zn, Sn and Mo and low contents of Ni and Cr.

Major ore-bearing zone is contained in cataclased hornblende gabbro and gabbroites of Fe-Ti-oxide series, which are situated in the lower part of the eastern slope of the depression. Mineralization in the metasomatically-altered rocks includes quartz-sulfide and prehnite-sulfide veins, as well as disseminated and stringer-disseminated copper sulfides. Pyrite, chalcopyrite, sphalerite, pyrrhotite, bornite, chalcocite and digenite are major ore phases in the zone. Grains of native metals (Cu, Pb, Zn and Sn) and intermetallides (isoferroplatinum and tetraferroplatinum) are found among unconsolidated sediments immediately beneath the ore-bearing zone in the eastern slope of the depression.

The study of mineral assemblages of ore-bearing metasomatites and fluid inclusions in minerals showed that metasomatic processes occurred at temperatures from $\sim 400^{\circ}\text{C}$ to 160°C and low oxygen potential. The stringer-disseminated ores were formed at $170\text{-}280^{\circ}\text{C}$. $\delta^{34}\text{S}$ values in sulfides varies from +3.0 to +15.3‰, which are intermediate between those of isotopically light magmatic rocks and heavy sea water.

These data indicate that hydrothermal fluids were initially of magmatic origin and separated from water-bearing melts of Fe-Ti-oxide series in a shallow magma chamber. During development of the hydrothermal system, they were gradually diluted by sea water circulating in fractured oceanic lithosphere. Ore components could be obtained both from the ore-bearing magmatic fluids and cataclased wall-rock Fe-Ti-oxide series gabbroids through extraction by metasomatic processes.

Thus, a new perspective type of sulfide ore deposits was found in the axial part of the MAR. It is probably a fragment of ancient “black smoker” feeder system, which was recently exposed on the eastern slope of the Markov Depression owing to modern tectonic movements.

Small-scale $^{87}\text{Sr}/^{86}\text{Sr}$ heterogeneity of basalts at Sierra-Leone trough, Mid-Atlantic Ridge, 5-7° N

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IGEM RAS

The study of Mid-Atlantic ridge (MAR) in the vicinity of Sierra-Leone trough (between 7°10' and 5°00' N) were undertaken during 10th cruise of "Academik Ioffe" in 2001-2002. The ridge there is highly uneven, the rift valley consists of an echelon of deep basins. Dredging of the basins over 300 km distance discovered that slopes the basins are composed from abyssal rocks including peridotites and gabbros. Fresh basalts with glassy crusts were dredged from the basins floor as well as from neovolcanic rises at the ridge escarpment. First results of Nd-Sr isotopic study of pillow-lavas with glassy crusts, gabbros and metasomatic rocks revealed pronounced heterogeneity for the whole sample set and, in particular, irregular difference in $^{87}\text{Sr}/^{86}\text{Sr}$ between crusts and basalts of some of the sample [Shatagin et al., 2006].

Here we present new data on $^{87}\text{Sr}/^{86}\text{Sr}$ distribution in pillow-lavas obtained by studying of randomly chosen parts of a given sample fragment. The obtained data allow to distinguish several samples that are heterogeneous (taking into account analytical errors) in scale of a given rock fragment.

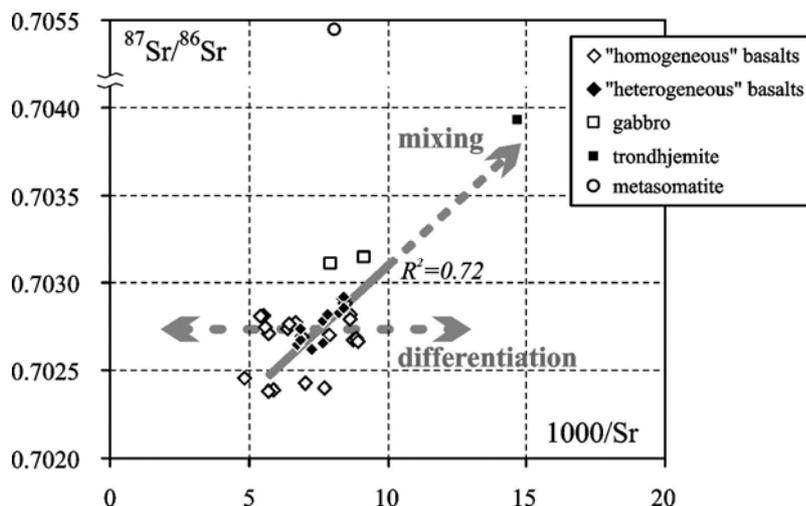


Fig. 1. Mixing diagram for 7°-5°N MAR samples. The line with dotted continuation towards the trondhjemite point was calculated for "heterogeneous" basalts; R² – correlation coefficient of the plot.

On a mixing diagram (fig. 1) "heterogeneous" basalts form an array of points against a background of poorly correlated nearly horizontal cluster of "homogeneous" basalts. The array projections are directed to the point of trondhjemite ($^{87}\text{Sr}/^{86}\text{Sr}=0.7040$, [Sr]=68 ppm) and to the most isotopically primitive "homogeneous" basalts ($^{87}\text{Sr}/^{86}\text{Sr}=0.7024$, [Sr]=170-200 ppm) – the

two possible end-members that might constitute the "heterogeneous" basalts. Trondhjemites form relatively scarce veins in gabbros of the 3rd oceanic crust layer at the area and couldn't be a major source of basaltic magma contamination. However, it is highly possible that gabbros of the similar geochemical affinity are presented at the area. Recent petrographic data [Sharkov et al., in prep.] allows to state that the basalts contain partially melted xenocrystic plagioclase similar in composition to that of gabbro. This fact undoubtedly confirms that the basaltic magma and the gabbros interacted.

As we believe, mixing between the basaltic magma and the crystalline rocks of the 3rd oceanic crust layer took place shortly before an eruption of the former to the ocean floor, most probably in a feeder or intermediate chamber. The rapid eruption of unevenly contaminated magma could prevent its homogenization with respect to its Sr isotope composition. This mechanism could explain the absence of regularities in the distribution of Sr isotopes between glassy crusts and their pillows as well as between different parts of a single specimen, because any part of the lava flow could be chilled during the eruption.

The suggested interpretation for the $^{87}\text{Sr}/^{86}\text{Sr}$ variations in "heterogeneous" basalts doesn't account for the whole range of isotope diversity in the basaltic rocks of the area. The variations in "homogeneous" basalts are even wider (and obviously "older") than any differentiation of the basaltic magma. Most probably these $^{87}\text{Sr}/^{86}\text{Sr}$ (and respective $^{143}\text{Nd}/^{144}\text{Nd}$) variations reflect isotope heterogeneity of a mantle source.

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Some results of isotope studies of massive sulfides from Ashadze, Logatchev and Krasnov hydrothermal fields, Mid-Atlantic Ridge

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Two different types of massive sulfides isotope studies ($^{230}\text{Th}/\text{U}$ dating and Cu isotope composition) were applied for the samples from three MAR hydrothermal fields: Ashadze (13^o N), Logatchev (14^o 45' N) and Krasnov (16^o 38' N).

1. $^{230}\text{Th}/\text{U}$ measurements were done in prepared (extracted) samples with alpha-spectrometric determination of the specific ^{238}U , ^{234}U , ^{232}Th , and ^{230}Th activity using a semiconductor surface-barrier silicon detector and a pulse analyzer AI-1024.

The time parameters obtained by the $^{230}\text{Th}/\text{U}$ method for massive sulfides were estimated in the range from 2.1 ± 0.3 to 65.1 ± 3.7 kyr BP. The oldest samples were recovered from the Krasnov field ($16^{\circ}38'\text{N}$). A correlation of the age values obtained for the different fields within the MAR allows to conclude that at least four stages of hydrothermal activity can be detected for all of them: modern period (0-7) and three older ones (16-23), (33-40) and (58-65) kyr BP. It was concluded that comprehensive radiochronological, geochemical and mineralogical investigations of massive sulfides and metalliferous sediments are the necessary conditions for the detailed study of evolution of hydrothermal processes.

2. Cu isotopic measurements were collected on a Neptune MC-ICP-MS using sample-standard bracketing and mass bias correction using a nickel internal standard.

The obtained data demonstrate considerable variation of Cu isotope composition within the Ashadze field and clear difference in average isotope composition of massive sulfides from the other fields. These variations are higher than those already published for the MAR hydrothermal fields [Zhu et al., 2000; Larson et al., 2004; Rouxel et al., 2004]. But variations of isotope composition of the primary sulfides within each studied chimney are quite restricted ($\pm 0.5\text{‰}$ $\delta^{65}\text{Cu}$). At the same time, $\delta^{65}\text{Cu}$ variation within separate chimney is exceeded 2.0‰ from central to outer part for the same minerals (chalcopyrite, bornite). The absence of obvious correlation between the isotope composition of the studied sulfides and the total Cu content, type of mineralization (massive, spotted, chimneys) and hydrothermal activity (jet-like/diffused/inactive) allows to suggest that isotope composition of primary sulfides reflects, first of all, the characteristics of the metal sources. The primary sulfides of the Ashadze field with the age of the first event of high-temperature activity about 25 kyr BP characterize the most depleted isotope composition: up to -4.2‰ $\delta^{65}\text{Cu}$. The main variation of Cu isotope composition within the each hydrothermal field is determined by the fractionation processes caused by evolution of fluid and redox-reactions where Cu complexes take part, leaching of Cu isotopes from primary sulfides and redeposition in the secondary ones, by the low-temperature processes of sulfide minerals transformation under the influence of water and bacterial leaching and coincides well with the earlier obtained data [Rouxel et al., 2004; Graham et al., 2004]. Maximum shifts towards heavier isotope composition up to 3‰ relatively the coexisting primary chalcopyrites have been observed for the minerals of atacamite group that is in a good agreement with experimental data [Ehrlich et al., 2004; Maher, Larson, 2005; Mason et al., 2005].

Thus sulfides from ultramafic hosted Ashadze field are characterized by more depleted Cu isotope composition and its greater variations in comparison with the sulfides associated with basalts from another hydrothermal fields.

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Evolution of the fluid chemistry, isotope composition and temperature in modern seafloor hydrothermal systems

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A comparative study of chemistry, fluid chemistry, He, and S isotopes in minerals from sulphide edifices in hydrothermal fields at East Pacific Rise, Mid-Atlantic Ridge and back-arc spreading zones of South Pacific have been carried out. A fluid inclusion study found that homogenization temperatures ranged from 102 to 398°C and fluid salinity varied from 2 to 26 wt % NaCl-equiv are wider the range of mineral formation temperatures and fluid salinity obtained by direct measurements for fluids venting onto the seafloor. Variations of fluid salinity were assumed to be caused by fluid separation at a temperature near or above the critical temperature of seawater, which leads to brine formation in modern hydrothermal systems. Light hydrocarbons: (CH₄, C₂H₆, C₃H₆, C₃H₈, i-C₄H₁₀, α-C₄H₈, and n-C₄H₁₀) are the important constituents of the mineral-forming fluids. The R/Ra ratios = (³He/⁴He)/(³He/⁴He)_{air} measured in fluids trapped by sulfides are of 7,69 to 8,44 (EPR 9°N), 5,85 to 7,13 (EPR 21°N), 5.2 to 7.2 (Rainbow), 5.6 to 8.3 (Logatchev-1), 4.6 to 7.1 (Broken Spur), 4.6 to 7.3 (“Mir” zone, TAG), edifices is of to 3.05 to 4.3 (“Vienna Wood”, Manus basin, were formed from fluids with the higher R/Ra ratios of 6.7, 5.1 and 7.7 (“White Tower” and “Died Wood”), 3.1 to 5.3 (Lau Basin). The R/Ra ratio indicates a mixture of upper mantle components and seawater in these hydrothermal systems. Sulfur isotope composition in minerals varied from +0.5 to +6.3‰ (EPR 9°N), from +0.8 to +3.0‰ (EPR 21°N). The R/Ra ratios = (³He/⁴He)/(³He/⁴He)_{air} measured in fluids trapped by sulfides are of 7,69 to 8,44 (EPR 9°N) and from 5,85 to 7,13 (EPR 21°N). At the Mid-Atlantic Ridge, the δ³⁴S value ranges found for sulfides associated with basalt rocks are of -4.4 to +8.2 ‰, while those obtained for sulfide related to serpentinites are enriched in the heavier ³⁴S isotope: +0.7 to +13.8‰. Considerable variations of the δ³⁴S values were found in sulfides deposited in back arc environments. They vary from -7.7 to +10.9‰ (Herzig et al., 1998, this study). The sulfur isotope composition was found to vary in the different hydrothermal field.



**Geochemical, petrological and geophysical segmentation of
the Mid-Oceanic Ridges and its relationships with
geodynamic parameters of oceanic lithosphere accretion.**

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