HYDRATION OF THE LITHOSPHERE AND OCEANIC MAGNETIC FIELD

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Abstract. A joint analysis of the results of geomagnetic surveys and the data of petromagnetic study of samples from different geotectonic zones of the World Ocean indicates that, along with the basaltic layer, deep sources, which are associated with serpentinite formations, make an important contribution to the anomalous magnetic field of the ocean. These formations are formed as a result of hydration by the oceanic water of hyperbasites of the upper mantle. The depth of penetration of oceanic water into the mantle is determined by the depth of the surface of the elastic-plastic transition, where the microcracks in the substance are melted, and its deformation begins to occur due to plastic flow. Numerous petromagnetic studies of oceanic serpentinites show that the main carrier of magnetism in them is magnetite, amounting to 5% or more. The magnetic parameters of magnetite in serpentinites are determined not only by its quantity, but also by the shape of its grains and by the nature of their distribution.

According to different conditions of formation of serpentinite massifs in the main morphostructures of the ocean floor, four main morphogenetic types of such formations are distinguished: serpentinites of rift zones of mid-oceanic ridges, serpentinites of zones of transform faults, serpentinites of zones of intra-plate aseismic uplifts, and serpentinites of subduction zones.

Based on the solution of the inverse magnetic problem, computer models of the sources of magnetic anomalies are constructed for the typical structures from all these zones. A complex petrophysical analysis of the available samples was also carried out. On the basis of a joint interpretation of these data with the results of other geophysical methods, convincing evidence for the existence of serpentinite formations in various geotectonic zones of the World Ocean has been obtained.

Keywords: serpentinization, natural residual magnetization, magnetic anomalies, hydration, intraplate aseismic uplifts, magnetic layer model, effective magnetization, inverse problem, sources of anomalies

Introduction

A joint analysis of the results of geomagnetic surveys and the data of petromagnetic study of oceanic lithosphere samples from different geotectonic zones of the World Ocean indicates that, along with the basaltic layer, deep sources associated with serpentinite massifs, make a significant contribution to the anomalous magnetic field of the ocean. These formations are formed as a result of hydration of the upper mantle ultramafic rocks with the oceanic water.

Serpentinization is a widespread process of postmagmatic alteration of essentially olivine ultrabasic rocks, consisting in substitution of initially anhydrous ferruginous-magnesian silicates, olivine, rhombic pyroxene by hydrous magnesium silicate, serpentinite. This process has hydrothermal nature and occurs in the temperature range of 290–400 °C (Hess characteristic isotherm). Serpentinization of peridotites in the upper mantle begins when the water reaches this temperature range. As a result, a serpentinite layer is built up below the base of the gabbroic layer. Water penetrates into the mantle through the system of cracks from above, as indicated by isotopic water analysis in ophiolites [Lobkovsky, 1988]. In this case, iron, partially not encapsulated in the newly formed serpentine is released in the form of secondary magnetite [Bazylev, Popov, Shcherbakov, 2002].
The depth of penetration of oceanic water into the mantle is determined by the depth of the surface of the elastic-plastic transition, where the microcracks in the rock are melted. Besides, the newly formed plastic material becomes impermeable to water and steam.

Numerous petromagnetic studies of oceanic serpentinite show that its major magnetic component is magnetite, amounting to 5% or more. [Bazylev, Popov, Shcherbakov, 2002]. The magnetic properties of magnetite in serpentinites are determined not only by its amount, but also by the shape of its grains and their distribution.

According to different conditions of formation of serpentinite massifs in the main morphostructures of the ocean floor, four main morphogenetic types of such formations can be distinguished.

Mid-oceanic ridges. Rift zones

Numerous data obtained from geological studies of mid-oceanic ridges indicate the wide distribution of serpentinized hyperbasites in various regions of the World Ocean, for example, such as the axial part of the Mid-Indian ridge and rift zone of the Mid-Atlantic ridge. Serpentine protrusions were discovered when diving the deep submergence vehicles “Mir” in the area of the Kane fault. The thickness of basaltic layer at this point does not exceed 600 m, and the intense anomaly of magnetic field recorded above the rift zone is apparently associated with the discovered serpentinite protrusion. Residual magnetization of the samples selected from the outcrop of serpentinites varies from 4 to 12 A/m.

According to the gravimetric surveys, the rift mountains are isostatically compensated in the ridge zone of the Mid-Atlantic ridge [Astafurova et al., 1996]. In this regard, serpentinization can be considered as the most likely process leading to their uplift, since it causes the decrease in density of ultrabasic rocks of the upper mantle from 3.3 to 2.7–2.8 g/cm³. Uplift of large blocks of the oceanic crust suggests that serpentinization process involves large areas under the crust on both sides of the ridge. It leads to the formation of the lower magnetic layer of the crust of considerable thickness (Fig. 1) [Gorodnitsky, Shishkina, 1996].

One of the features of serpentinization in the slow-spreading Mid-Atlantic ridge, where the correlation between anomalies in effective magnetization, integral crust density and spreading rate [Astafurova et al., 1996] has been revealed, is its relation to the discrete spreading mode in the slow growth mode, when magmatic eruptive phase can be followed by dry tectonic phase. When the spreading is slowed down and the transition from the eruptive phase to a tectonic one occurs, hydration of the upper mantle hyperbasites with seawater takes place through the crack system in the axial part of the ridge. Besides, rocks undergo the serpentinization not only in the rift zone of the mid-oceanic ridges, but also in the zones of its intersection with transform faults.

The above mentioned mechanism leads to the formation of narrow protrusions, and in some cases to the formation of an extended fault-line ridge. Such processes can cover a vast area, causing the uplift of large blocks of the crust that are hundreds of kilometers wide. Thus, the oceanic crust of slow-spreading ridges should have a block structure and, depending on the spreading rate variations, should include areas with and without serpentinite layer.
Fig. 1. Model of magnetoactive layer in divergence zone: a is a section of magnetoactive layer; b is a generalized petromagnetic section, right panel shows the plot of magnetization versus depth distribution. Modified from [Gorodnitsky, Shishkina, 1996]

1–3 blocks: (1) directly magnetized, (2) reverse magnetized, (3) weak-magnetic and non-magnetic; 4–10 are rocks: (4) basalts, (5) transition zone, (6) dike complex, (7) isotropic gabbro, (8) cumulative gabbro and layered complex, (9) serpentinized peridotites, (10) mantle peridotites; white dashed line in a is the Curie isotherm 350 °C

The data allow us to assume that the serpentinization process, controlled in the slow spreading ridges by the decrease in spreading rate, is the main source of lateral anomalies of the topography, gravity and magnetic fields. Probably, the presence of the serpentinite layer in the oceanic crust influences the lateral variations of the topography that were earlier associated with the phase transitions in the lithosphere [Gorodnitsky, 1985].

Zones of transform faults

Numerous dredgings performed in transform fault zones of the North Atlantic (Atlantis, Hayes, Oceanograph and the fault at 15°20’), and also within the Arabian-Indian ridge (the Vityaz and Vima faults), gave an extensive material that allowed obtaining the data on magnetic properties of hyperbasites [Astafurova et al., 1996]. The dredged samples are represented by hydrothermally altered dunites, harzburgites and lherzolites with different degree of serpentinization and temperature metamorphic grade. The most intense magnetization is associated with serpentinized peridotites of the Hayes fault ($I_n$=8 A/m) and the Vityaz fault ($I_n$=6.8 A/m). The lowest magnetization was observed in the samples from the Atlantis, Owen and Vima faults ($I_n$=0.6 A/m) [Popov, Bazylev, Shcherbakov, 2006]. Variations of magnetic properties of the peridotites are determined both by the serpentinization peculiarities of rocks (stage and degree) and by the degree of the preceding temperature metamorphism of peridotites, when the magnetite crystallization occurred before the serpentinization of peridotites at the temperature of 450–600°C.

In the zone of Romansh transform fault, in the axial part of the Mid-Atlantic ridge when dredging were selected samples of ultrabasic rocks and dunites; away from the ridge the ultrabasic rocks are completely serpentinized. The same zoning can be traced even more clearly along the Vima transform fault where the serpentinized ultrabasic rocks form the southern side of the trough, and the serpentinization degree increases with depth [Gorodnitsky, Shishkina, 1996].

More detailed information about the mechanism and degree of serpentinization in zones of slow mid-oceanic ridges and transform faults can be derived from the model calculations
performed at four profiles located in the area of intersection of the Mid-Atlantic ridge (MAR) and the fault 15°20' (data were taken from the geophysical database GEODAS) [https://www.ngdc.noaa.gov/mgg/geodas/]. The analysis of areal magnetic anomalies at the test site in the intersection zone of these structures was also carried out (data were collected during the survey with RV “Akademik Nikolay Strakhov”).

Location of the test site, profiles and geomagnetic sections of the fault constructed from the modeling results, are shown in Fig. 2.

The Linverse2D software [Ivanenko et al., 2012] was utilized for the inverse problem solution in a 2-D formulation; this software involves almost all modern technologies for solving such problems. First, the geometry of distribution zone of anomalous magnetization was found using the algorithms for determining the singular points, the Euler deconvolution and analysis of analytic signal together with a priori data on sea bottom topography and seismic data. Then the region is divided into elementary blocks, the forward problem for initial geometry is solved, and an iterative process of solving the linear inverse problem with control of given properties of the solution is started. In this case, objective function included complex quality criterion for the solutions – the weighted sum of their compactness [Last, Kubik, 1983] and the sharpness of boundaries [Portniaguine, Zhdanov, 1999].

The analysis of areal anomalies was performed using the following algorithms: algorithms of isolating horizontal boundaries of the sources and estimation of their depth by spectral method, as well as by the Euler deconvolution method and using the analysis of analytical signal morphology.

Sublatitudinal profiles 1 (~400 km), 2 and 3 (~600 km each) intersect the MAR in the region of the fault 15°20'. In this case, profile 1 passes almost 100 km to the north of the fault, the profile 2 – near it (in its eastern part almost along the fault), the profile 3 – in 60 km to the south of the fault. Submeridional profile 4 (>300 km) intersects the fault at right angle and profiles 1–3 approximately at 46° W. Stable solutions of the inverse problem were obtained for all profiles. Their main property is the presence of two layers associated with the sources of observed magnetic anomalies.

The first layer is a “classical” magnitoactive layer of oceanic lithosphere with a thickness of 1.5–3 km and it is characterized by inverse (sign-changing) magnetization structure. The bottom of this layer is marked by subhorizontal black thickened line in Fig. 2.

Profiles 1 and 3 indicate a distinct symmetry of magnetization pattern relative to the ridge axis that allowed reliable identification of linear anomalies from 1 to 5 on the geochronological scale. In profile 2 the reliable identification of anomalies from 1 to 4 is possible only in its western part at the intersection with the northern part of the ridge. In the eastern part of the profile, where it intersects the southern part of the ridge, the identification is rather ambiguous.

A more complicated pattern of horizontal distribution of the sources of magnetic anomalies is observed directly in the area of interaction of the ridge with the transform fault. Most likely, this is due to the instability in time of the spreading axis position in the studied area.

The second layer that is associated with the identified sources of magnetic anomalies is located below the first one in the depth interval of 3-13 km under the sea bottom and contains horizontally extended (up to 100 km) objects 5-10 km thick in vertical direction, magnetized with the same polarity. We interpret these deep objects as magnetic bodies formed as a result of medium temperature metamorphism and / or serpentinization of peridotites that are accompanied by crystallization of magnetites and, consequently, occurrence of secondary
residual magnetization. Areal magnetic anomalies studied at the test site (Fig. 3, a) allow to supplement the interpretation with estimates obtained in 3D approach.

Fig. 2. Geomagnetic sections constructed according to the results of modeling along the profiles 1–4 in the area of intersection of the Mid-Atlantic ridge (MAR) and the transform fault 15°20’. Arrows in the profile 1 is the intersection of the profile with the MAR, in the profiles 2, 3 are the projections on the profile of the northern and southern parts of the MAR. The plots of anomalous magnetic field are given above the sections.

The test site located in the intersection of the southern part of the Mid-Atlantic ridge and the transform fault 15°20’, covers an area of 30×50 km. The test site topography is a linear extended structure complicated by local uplifts with depths from 3500 to 5600 m. The southern part of the ridge has a submeridional strike and is bounded by two elongated uplifts intersected by deep hollows of irregular shape. In the north-eastern part of the test site, there is an extensive minimum reaching 200 nT, in the south-eastern part there are fragments of intense positive anomaly exceeding 100 nT; in south-western part there are local isometric anomalies with the value of 50 nT. These anomalies are well correlated with the topography: the negative ones are located at the intersection of the transform fault and the ridge, the positive ones are confined to the elongated uplifts along the ridge. This may indicate that morphological features of the ridge make a significant contribution to the observed anomalies.

An efficient way to study the morphology of magnetic anomalies is to analyze the anomalous field gradient: the norm of the horizontal and full gradients (the so-called “analytical signal”) that are easily calculated from original anomaly data using gridding techniques. Analytical signal serves as an indicator of the position of sources of magnetic anomalies, reflecting their geometry. This approach allows one to obtain data on the intensity and spatial localization of the source of magnetic anomalies without any additional constraints. 3D-analytical signal has a number of useful properties: in the map view, its maxima correspond to the centers of magnetic masses of isometric sources or lateral
boundaries of extended anomalous bodies. The applied procedure makes it possible to automatically select the local maxima of the analytical signal and / or the sequence of such maxima, plotting them on the map.

The map of analytical signal magnitude and its local maxima interpreted as lateral boundaries of sources of anomalies shows two geometrical types of such boundaries (see Fig. 3, b).

1. Concentric (quasi-circular) boundaries of the sources with the diameter from 7 to 12 km, located at the uplifts both on the main ridge axis and on its lateral branch. Such sources can be interpreted as possible localizations of the main centers of volcanic activity.

2. Linear extended (length from 15 to 25 km) boundaries striking north and north-east. Sources of this type mainly correspond to the uplifts of the ridge or orthogonal to them that is clearly seen when overlaid onto the topography. Such sources can be interpreted as markers of the main subhorizontal magmatic channels.

The average depth to the upper edge of the sources of anomalies at the test site is estimated by spectral method at 3.77 km, which is in good agreement with the average depth to the bottom at the test site. The average thickness of the magetoactive layer is estimated as 4.5 km, that is significantly greater than values accepted in “classical models” [Magnitnoe ..., 1993; Petromagnitnaya, ..., 1994]. Obtained estimates, in our opinion, can also be interpreted as an evidence for the presence of deep sources of magnetic anomalies in the intersection zone of the Mid-Atlantic ridge and the fault 15°20', including those associated with serpentinization.

**Fig 3.** Maps of (a) isodynamic lines of anomalous magnetic field and (b) magnitude of analytical signal constructed for the test site located near the intersection of the southern part of the Mid-Atlantic ridge and the transform fault 15°20' (see Fig. 2). Yellow and pink lines in b are boundaries of the sources of magnetic anomalies isolated by the interpretation results of analytical signal.
Zones of intra-plate non-seismic uplifts

The direct connection between the anomalies of the magnetic field and serpentinite layer of the oceanic crust was found in the zones of non-seismic uplifts and intra-plate deformations where the cover overthrust structures were formed under the compression settings according to the mechanism of two-layer tectonics. A typical example of such formations is the underwater Gorringe ridge in the North Atlantic that is a part of the Horse Shoe seamount system located in the eastern part of the Azores Gibraltar fault zone, traced from the point of triple junction of the North-American, Eurasian and African plates in the area of the Azores islands in the west to the Strait of Gibraltar in the east. This tectonic structure is one of the largest in the North Atlantic and defines the boundary between the Eurasian and African plates.

Geological structure and tectonic evolution of the Gorringe ridge appear to be complicated. In this region, rocks of ophiolite complex were identified containing serpentinized peridotites, gabbroids, dolerites, and tholeitic basalts, as well as alkaline volcanites. Underwater research using the manned underwater vehicles and deep-water drilling [Auzende, Charvet, Le Lann, 1979] has shown that the western peak of the ridge (the Gettysburg mountain) is formed of serpentinized harzburgites and gabbro-dolerites and the eastern peak (the Ormond mountain) of gabbroids and alkaline basalts. The underwater drilling carried out by the vessel “Bavenit” in 1991 at the Gettysburg mountain provided 50 m of core entirely composed of aphorharzburgite serpentinites [Matveenkov et al., 1995].

Anomalous magnetic field above the Gorringe ridge is sharply dissected; the magnitude of local anomalies is more than 700nT at period of 1–1.5 km. A negative magnetic anomaly with the intensity of 400 nT was observed above the Gettysburg peak. Two predominant directions of anomalies are noted within the ridge: the north-eastern striking of 20–30° and perpendicular to it of 110–130° [Gorodnitsky, Brusilovsky, 1996].

The main magnetic feature within the Gorringe ridge in the area of the Gettysburg peak is the massive outcrops of serpentinized ultramafic rocks represented by aphorharzburgite serpentinites [Brusilovsky, Gorodnitsky, Ivanenko, 1993; Gorodnitsky, Brusilovsky, 1996; Matveenkov et al., 1995]. Thus, the average natural magnetization of serpentinites from the well drilled in the first run of the drilling vessel “Bavenit” (1991) was obtained from 200 measurements and amounted to 15 A/m. The main mode on the histogram of magnetization distribution covers more than 50 % of all measured samples and lies in the range from 1 to 3 A/m [Popov, 1996]. Besides, the value of the Koenigsberger factor in all cases is more than 1. It should be noted that as a result of magnetic cleaning in the serpentinite cores, two predominant directions of magnetic inclination vector were singled out: one covering about 34% of the studied samples is 0–5°, the second one (about 20 %) is 17°. The obtained data indicate that serpentinitization of the Gorringe massif occurred in two stages.

Serpentinites are the main magnetic object within the Gorringe ridge. Its physiographic map is given in Fig. 4. a. Geomagnetic section in Fig. 4, b is constructed from the results of inverse problem solution for profiles 1–5 intersecting the ridge.

In the lower layer of oceanic crust in the area of intraplate deformations of the Central basin of the Indian Ocean, a layer 2–5 km thick was revealed with P-wave velocities of 7.2–7.6 km/s indicating an area of reduced rock density associated with serpentinites [Neprochnov, Levchenko, Kuzmin, 1990]. Fig.5 illustrates a model of schematic submeridional section showing the propagation mechanism of serpentinized peridotites through the crustal faults. Density modelling of the area suggests the presence of decompacted root with a negative density anomaly of 0.05 g/cm³, whose additional thickness can reach 5 km. Between the transform faults Indira and Indrani an uplift was revealed with
unusual geophysical parameters. It is possible to propose at least two equivalent hypotheses about the nature of its formation.

**Fig. 4.** (a) Position of the profiles 1–5 on the physiographic map of the Gorridnge ridge and (b) the constructed geomagnetic sections. On the right is the scale of effective magnetization $I_{ef}$. The first hypothesis assumes the formation of the considered uplift as a result of the formation of cover-overthrust structures under the meridional compression along the transform faults, that is indirectly expressed by the linear shape of anomalous magnetic field along the fault 80°30' [Gorodnitsky, Valyachko, Palshin, 1990]. This uplift also manifests itself on the structural map of acoustic basement surface [Levchenko, Merklin, Sviridov, 1990].

According to the second hypothesis, the uplift of the serpentinite protrusion to the surface can be the cause of the uplift formation in accordance with the decompaction mechanism. In fact, this is a serpentinite layer with velocities of 7.2–7.6 km/s, causing an increase in magnetic field anomaly. Neprochnov, Levchenko and Kuzmin [1990] treat this layer as a decompacted upper mantle. The same layer was revealed by seismic data at the profile between the deep-water oceanic drilling wells 215 and 218 in the area of 2–2.5° N. [Curray et al., 1982].

**Fig. 5.** Schematic section of the area of tectonic deformations of the Central basin of the Indian Ocean according to [Verzhbitskii, Lobkovskii, 1993]

1 ocean water; 2 sediments and basement blocks; 3 serpentinites; 4 imantle; 5 direction of the compression
The main reason of intraplate deformations occurrence in the Central basin is a collision of the Indo-Australia plate with the Eurasian plate [Lobkovsky, 1988; Gorodnitsky, Valyachko, Palshin, 1990], that began in Oligocene-Miocene. At the same time, the thin lower layer of the oceanic crust formed by serpentinites, with a thickness of about 3 km, plays a role of a plastic layer, over which the overlying blocks of the crust move, forming uplifts by the mechanism of two-layer tectonics. Areas of abnormal thickening of the crust, as well as the outcrops of the bottom of serpentinite formations, are characterized by the increase in magnetic field anomalies, decrease in the gravity field and abnormally high density of heat flow. Epicenters of some intraplate earthquakes are associated with these areas. Joint interpretation of geophysical data allows to assume a thickening of the crust in the blocks of intraplate deformations up to 20 km.

It should be emphasized that formation of this morphostructures as well as anomalous geophysical fields confined to them is associated with the lower crust layer that is represented by decompacted serpentinitized ultrabasic rocks and plays the role of “asthenosphere” in the lower part of the oceanic crust. The presence of such layer makes it possible to form the cover-overthrust structure of crustal blocks under compression. The resulting thickening of the crust and the formation of serpentinite protrusions as a result of its increased permeability lead to the increase in thickness of magnetoactive layer and a corresponding increase in magnetic anomalies, as well as to a decrease in gravity anomalies due to decompaction during serpentinization. In addition, the infiltration of serpentinite protrusions and dissipative heating of the contacting crustal blocks cause the formation of zones with uncommonly high densities of the heat flow.

Subduction zones

According to the analysis of the world map of lithospheric magnetic anomalies [Purucker, Clark, 2010], linear, parallel to the trench anomalous zones were detected in the Aleutian arc, southern Alaska, the Kuriles and in South America. They are usually located above the submerged plate and the continental crust (Hokkaido, South America). We studied the process of serpentinization in subduction zones by the example of the Kuril island arc, where large volume of geological and geophysical studies including the magnetic surveys [Brusilovsky et al., 2012] were conducted in cooperation with the Pacific Oceanological Institute FEB RAS. In morphostructural plane, the studied area is located between the Uturup and Urup islands, and the Kurile-Kamchatka deep-water trench. It includes the island side of the trench, the Vityaz under-water ridge that was considered as an external non-volcanic arc in the general arc-trench system, and the inter-arc trough separating the ridge from the Kuriles. Maps of the anomalous magnetic field for the studied area were constructed according to the data of geomagnetic surveys (Fig.6).

The largest identified magnetic field anomaly is an area of intense sign-changing anomalies of supposedly serpentinite nature, stretched between the front of the island arc and the deep-water trench. The presence of local positive anomalies of predominantly isometric form can be associated either with diapir serpentinite mountains or with overlaid volcanism at a later stage of active magmatism. Further this zone can be traced in the area of Hokkaido in the form of the so-called “magnetic belt” [Okubo, Matsunaga, 1994], formed by the intense positive magnetic anomalies.

Sources of magnetic anomalies within the “magnetic belt” [Okubo, Matsunaga, 1994; Maekawa et al., 2001; Purucker, Clark, 2010] are located in the depth range of ~30–40 km. Thus, we can see the similarity in nature and mechanism of formation of these objects with
nature and mechanism of serpentinite magnetic zones in the Aleutian arc and in other island arc systems of the Pacific Ocean.

For a number of anomalies, the position of upper and lower edges of their sources was estimated. According to the calculation, a highly-magnetized body of supposedly serpentinite composition is localized in the depth range of 20-25 km [Brusilocsky et al., 2012]. The obtained data correlate with the seismic section for the same profile [Piip, Rodnikov, 2004].

Analysis indicates the presence of specific area of magnetic anomalies in the subduction zones, which is usually subparallel to the frontal line of the underthrust and is apparently associated with serpentinite bodies formed as a result of hydration of peridotites of the upper mantle with the oceanic water penetrating through the system of cracks in the subducting plate at its fracture at the critical depth in the underthrust process [Gorodnitsky et al., 2015]. Modern researches [Blakely, Brocher, Wells, 2005; Puruker, Clark, 2010] show that the serpentinized part of the upper mantle becomes magnetic. The subducted plate at the depth of 40-50 km can be broken by cracks through which the oceanic water penetrates, and when reaching the Hess temperature, the serpentinization and formation of magnetite occurs.

Along with hydration of the subducted plate with the oceanic water downward the system of cracks, the hydration of mantle rocks of the “obducting” plate also occurs as a result of dehydration of the subducted plate. As a consequence, a magnetic serpentinite wedge is formed in the lower part of the “continental” plate, that is marked by the decrease in the gravity field values due to its decompaction (Fig.7).

Thus, the intense magnetic anomalies detected in the subduction zones serve as an important signature of zones of active mantle hydration with water released from the subducted plate in the area of disjunctive dislocation. Similar anomalies can be found in other subduction zones along the Pacific Ring of Fire [Maekawa et al., 2001].

One of the examples of serpentinization in subduction zone (see Fig.7) can be the Pekul'ney Complex in the central Chukotka Peninsula. In terms of tectonic zoning, the
Pekul'ney complex within the ridge of the same name, is recognized as an independent part of the West Koryak fold system [Bazylev, Ledneva, Ishiwatari, 2013].

Fig. 7. (below) Scheme of two types of serpentinization in subduction zones: 1 is hydration of the upper mantle with the oceanic water penetrating through the cracks in the subducted plate; 2 is hydration of the upper mantle in the obducting plate by the water squeezed out from the subducted plate. Above the scheme are plots of (a) anomalous magnetic field $\Delta T$, and (b) gravitational anomaly in the Bourguer reduction $\Delta g$.

In the submeridional mélange zone, in the axial part of the Pekul'ney ridge, there are tectonic blocks of one kilometer in size, composed of orthometamorphic crystalline schists and amphibolites with fragments of banded bedded bodies of cumulative ultramafites, which formation occurred presumably at the base of island or continental arc. Certain interlayers in the bodies of ultramafites with the thickness from tens to first hundreds of meters are composed of dunites. Rocks containing the bodies of cumulative ultramafites are regionally metamorphozed in the epidote-amphibolite facies and have features of regressive metamorphism.

Data obtained from petromagnetic analysis of the samples indicate that magnetic characteristics of serpentinites are sufficient for intense magnetic anomalies in the zones of their formation [Popov et al., 2015].

Moreover, the subducted lithospheric plate, when losing water, becomes brittle and fragile, and this is exactly where the epicenters of the strongest earthquakes, such as the tsunamigenic earthquake in Sumatra in 2010, can be located.

Diapir serpentinite mountains are often formed along the axes of the Izu-Bonin and Marian trenches [Stokking et al., 1992]. Their formation mechanism is similar to the mechanism described for the Central basin of the Indian Ocean.

It can be assumed, that local isometric magnetic anomalies detected within the “serpentinite” belt during the runs of RV “Akademik Lavrentyev” [Brusilovsky, Baranov, Babayants, 2014] can also be associated with serpentinite diapirs, rather than with the volcanic structures.

In more detail, the structure of ultramafite bodies is studied in the work [Bazylev, Ledneva, Ishiwatari, 2013].
Conclusions

Results of the studies indicate the necessity of detailed research of the identified areas in the subduction zones with the aim of creating geological, geophysical, and geochemical models of serpentinization belts formation and subducted plate destruction that might be associated with strong, as well as tsunamiogenic earthquakes [Gorodnitsky et al., 2015].

The obtained results allow to estimate the temperature and time interval, in which the peridotites of the mid-oceanic ridges acquire the secondary magnetization through serpentinization [Bazylev, Popov, Shcherbakov, 2002; Popov, Bazylev, Shcherbakov, 2006]. Since the lower temperature limit of serpentinization of oceanic peridotites (and, correspondingly, the accompanying magnetite crystallization in them) is 100–150 °C [Bonatti et al., 1984], then crystallization of the magnetic phase in oceanic peridotites can occur in a wide temperature range (about 500 °C). For peridotites that underwent uplifting in the axial zone of the Mid-Atlantic ridge and are outcropped, for example, at the edges of the rift valley, this process takes about 100–200 thousand years [Bazylev, Silant’ev, 2000]. This time is incomparable with estimates of the duration of magnetite crystallization during the serpentinization of ophiolitic peridotites amounting to more than 2 millions of years [Nguyen, Pechersky, 1989]. On the one hand, this is another evidence for the fact that serpentinization of peridotites of the mid-ocean ridges and serpentinization of ophiolitic peridotites are completely different processes associated with different geodynamic conditions and differing in their mineralogy, petrology and geochemistry [Bazylev, 2000]. On the other hand, the shortness of the time interval for magnetite crystallization in peridotites of the axial zone almost excludes the possibility of geomagnetic field reversal during this stage and, correspondingly, the presence of ferrimagnetic grains with magnetization with different polarities in one sample is extremely unlikely. However, it should be noted that cooling of peridotites lying at the top of lithosphere mantle on the sides of the mid-ocean ridges and at the seafloor should occur significantly slower, and in this connection these rocks might need substantially longer time for acquiring the secondary magnetization.

The above indicates that hydration of the upper mantle is an important factor forming serpentinite massifs that make a significant contribution into anomalous magnetic field in all oceanic areas.

At the same time, the widespread distribution of serpentinites in general has not yet been proven. The nature of their distribution also remains unclear; whether it is a continuous layer or blocks, protrusions, etc. The issue is complicated by the practical inaccessibility of the lower layer of the oceanic crust for geological study. The evidence for the presence of serpentinites can only be obtained at transform fault zones, axial parts of slow spreading ridges and non-seismic uplifts, as well as by indirect geophysical signatures suggesting their presence in the lower crust [Puruker, Clark, 2010].

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