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Sulfide geochronology along the Northern Equatorial Mid-Atlantic Ridge

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ABSTRACT

Hydrothermal processes and seafloor massive sulfide (SMS) deposits have different characteristics at fast and slow spreading mid-ocean ridges. One such parameter is the age of a SMS deposit, which differs by 1–2 orders of magnitude between the fast spreading East Pacific Rise (EPR) and the slow spreading Mid-Atlantic Ridge (MAR). The large collection of SMS samples dated from the 18 hydrothermal fields of the northern equatorial part of the Mid-Atlantic Ridge (194 samples) demonstrates a relatively old average age of hydrothermal fields here (~66 ka) with the oldest one estimated as ca. 223 ka (Peterburgskoye field). Based on geochronological data it was confirmed that hydrothermal discharge has an episodic character: active and inactive periods of the SMS formation alternate. The distribution of events at all hydrothermal fields demonstrates that maximum activity occurred at 38–35, 30–20, and 8–2 ka and increased with time. Based on statistical analyses, dating variations can be explained as a superposition of several periods of activity with the duration of ~15, 10 and 5 ka. Relationship between the age and distance from the axial rift zone as well as between the age and aerial distribution is different for SMS deposits hosted by basalts and by gabbro-peridotites depending on their geological setting on the particular MAR segment. This difference can be explained by a variety of hydrothermal processes determined by “tectonic” or “magmatic” segment evolution and symmetrical or asymmetrical mode of accretion (Escartin et al., 2008).

1. Introduction

Seafloor massive sulfides (SMS) are considered modern analogues of land-based volcanogenic massive sulfide (VMS) deposits which formed over the entire history of our planet from the Archean to the present (Hannington et al., 2005; Franklin et al., 2005).

The age (onset time of sulfide deposit formation) and the longevity (lifespan) of the mineral accumulation process should be distinguished because they represent two different important parameters required to understand the evolution of the hydrothermal system. The isotope geochronological methods used for VMS dating (primarily Re/Os) enable the assessment only of the onset time of mineral formation. The longevity of VMS formation remains unknown because the duration of the mineral-forming process and the age of the deposits are not comparable. It is true that in VMS, the duration can at least have maximum bounds established based on dating footwall and hanging wall rocks. However, the precision of K/Ar, Re/Os and other dating methods of the ancient rocks has a rather rough character.

The discovery and study of modern SMS deposits made it possible to considerably fill the gaps in the knowledge of ore-forming process evolution. First, direct observations and monitoring of black smokers activity became accessible. The last growth of a sulfide chimney measured in days-weeks-months and years was recorded in hydrothermal fields for example on the Juan de Fuca Ridge: one sulfide chimney grew up to 1.2 m during one day (Delaney et al., 1990); another 10 m high edifice formed over a year (Kelley et al., 2012). Second, apart from direct observation, isotope analysis of modern oceanic mineral deposits allows us to reconstruct the hydrothermal activity process over a time interval of 10 to 10^5 years. This method is the same as that used for ancient ores and rocks. However, unlike the ancient VMS, short-lived (from years to several hundred thousand years) U-series ^{230}Th, ^{226}Ra and ^{210}Pb isotopes are used for dating modern sulfides based on ^{230}Th/U, ^{226}Ra/Ba and ^{210}Pb/Pb ratios, which make the geochronological study considerably more precise. Seafloor massive sulfides are usually dated by the ^{230}Th/U method reaching in age back to ~350 ka; the younger ages are determined also by the ^{210}Pb/Pb and ^{226}Ra/Ba methods (from 0 to 110 and 200 to 20,000 years, respectively).

The dating of modern seafloor massive sulfides followed their discovery in the end of the 1970s. The first age data were determined in the 1980s for samples from the Pacific (East Pacific Rise) (Lalou and

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Brichet, 1982) and later from the Atlantic (Mid-Atlantic Ridge) (Lalou et al., 1990, 1993) and Indian Ocean (Southwest Indian Ridge) (Munch et al., 2001; Wang et al., 2012; Lalou et al., 1998a,b). Even later, sulfide dating was carried out on samples from intraoceanic arcs (de Ronde et al., 2011; Ditchburn et al., 2012) and then from the Juan de Fuca Ridge (Jamieson et al., 2013).

The dating of modern oceanic sulfides has both fundamental (understanding evolution of the Earth) and applied/exploration importance for SMS study. It enables the determination of the time of onset and termination of mineralization which is defined by tectono-magmatic processes. Tectono-magmatic processes could provide a heat source and permeability of host rocks for fluid circulation and massive sulfides deposition during the active stage. Conversely, the heat deficit and/or lowering of permeability of host rocks result in termination of the hydrothermal mineral-forming process. Thus, the dating of sulfide deposits enables the reconstruction of tectono-magmatic processes as a whole and hydrothermal venting and SMS accumulation in particular. The last aspect has exploration importance (e.g. the age data can be used for resource estimation of SMS deposits).

Further discussion of fundamental and exploration issues is considering below based on dating of SMS deposits from the northern equatorial (NEq) part of the MAR.

The hydrothermal mineralization of the NEq MAR within the segment between 10° and 20°N has been studied by Russian geologists during numerous cruises of RV Professor Logatchev executed by Polar Marine Geosurvey Expedition and VNIIOkeangeologia (St. Petersburg, Russia) (Cherkashev et al., 2013). As a result, 18 hydrothermal fields with SMS deposits have been discovered. Some groups of closely located fields have been united as SMS clusters and now, 11 sites (fields and clusters) with SMS deposits are known within the area (Fig. 1).

The first age data for SMS samples recovered at the NEq MAR in 1994 at 14° 45′N (Logatchev field) were obtained (Lalou et al., 1996). The systematic determination of SMS age from other hydrothermal fields started in early 2000s at the St. Petersburg State University and is ongoing. During this time period, a large collection of massive sulfides from all known SMS deposits at the NEq MAR have been dated. Some data for separate hydrothermal fields have been published in Russian (Kuznetsov et al., 2007, 2013 – see Table 1) and just for three of them (Logatchev, Semenov and Peterburgskoye) in English (Kuznetsov et al., 2006, 2011, 2015).

We present here new dates for the Surprise, Pobeda, Semenov-5 and partly for the Peterburgskoye hydrothermal fields and review for all known deposits at the NEq MAR and adjacent area.

2. Geological setting and characteristic of deposits

NEq part of the MAR between 10° and 20° N is a typical slow spreading ridge segment which is characterized by a deep, fault-bounded axial valley with rift floor from 1.5 to 13 km wide and valley walls from 0.8 to 2.5 km high. Full spreading rate is estimated as 2.4 to 2.5 cm/year (DeMetz et al., 1990; Fujiwara et al., 2003). Three transform faults (Kane, Fifteen-Twenty and Marathon) divide the MAR into second order segments. The next (third) level is expressed by the occurrence of 24 segments with lengths from 13 to 72 km divided by non-transform discontinuities (Fig. 1).

Based on the mode of accretion and type of hosted rocks, two geological settings of SMS deposits at slow-spreading ridges are identified: symmetrical mode of accretion with basalts and asymmetrical accretion with gabbro-peridotites (Escartın et al., 2008). The same division of the MAR as a typical slow-spreading ridge is describing by other terms as “magmatic” (with domination of volcanic processes) and “tectonic” segments where magmatism is reduced and tectonics prevails. Half of the SMS deposits at the studied NEq of the MAR are associated with basalts (magmatic segments) and the other half with tectonic segments, with uplifted lower crust and mantle rocks (oceanic core complex – OCC) (Table 1). OCC is tectonically uplifted along detachment faults, which

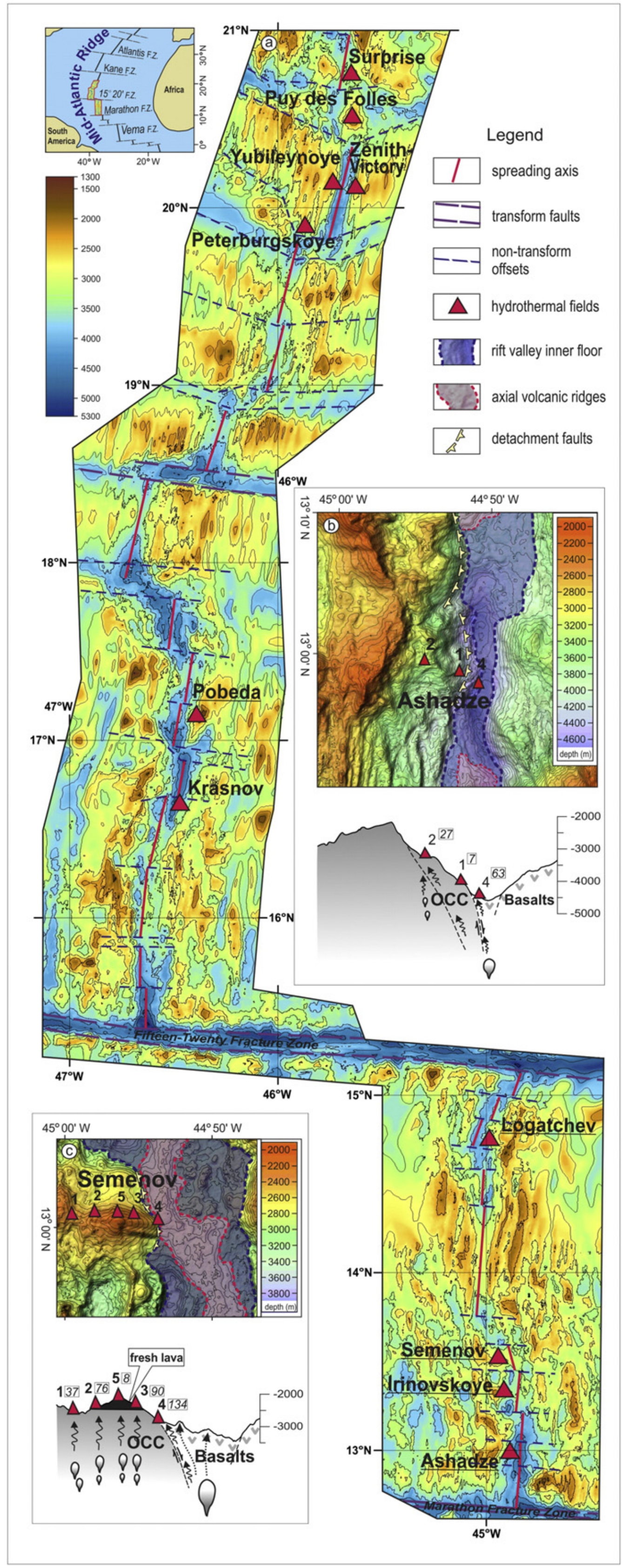

Fig. 1. Location of SMS deposits at the Northern Equatorial part of the Mid-Atlantic Ridge (a). Underlined – ultramafic-hosted deposits. (b) and (c) – detailed maps and cross-section for Ashadze and Semenov hydrothermal fields. Numbers in squares – age (ka).