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Residual Sediments of the Vema Fracture Zone, Central Atlantic

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Abstract—The Vema Fracture Zone orthogonally intersecting the Mid-Atlantic Ridge along 11° N is a complex tectono-sedimentary system, through which bottom water is transferred from the western to the eastern Atlantic. The southern surrounding of the fault valley is an extended (about 320 km) transverse ridge. At the early stages of the Vema System evolution, the ridge was located at shallow depths in the photosynthesis zone, which led to the formation of extensive biogenic carbonate buildups on its surface. Spreading, general sinking of the system, and associated movements along faults caused disintegration of ultramafic basement and bioherms with subsequent fractionation of colluvial–pelagic sediments and their eastward transport by bottom currents. The formation of coarse-grained residual sands completely devoid of pelitic material is associated with the high flow rates of Antarctic bottom waters. The presence of rounded pebbles of organogenic limestones and ultramafic rocks with traces of bioproductivity indicates that clastic material was transferred over a few hundred kilometers.

Keywords: Mid-Atlantic ridge, biogenic carbonates, currents, colluvium

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VEMA FRACTURE ZONE

The characteristic structural feature of the Central Atlantic is the presence of fracture zones (Shepard, 1948; Heezen et al., 1959; Klenova and Lavrov, 1975; Emery and Uchupi, 1984), which form both single transverse structures and near-fault systems. The latters are sometimes termed megatransforms (Pushcharovsky et al., 1988) and referred to as faults or systems, the active part of which displaces the Mid-Atlantic Ridge (MAR) for a distance over 100 km. Among the megatransforms are 15°20′ N (Pushcharovsky et al., 1988; Kelemen et al., 2004), Romanche (Gorini and Bryan, 1976; Pushcharovsky et al., 1994; Bonatti et al., 1994; Ligi et al., 2002), St. Paul (Hekinian et al., 2000), and Doldrums (Skolotnev et al., 2020) zones, as well as the Vema Fracture Zone (Van Andel et al., 1971; Bonatti et al., 1994), which orthogonally intersects the Mid-Atlantic ridge along 11° N (Fig. 1).

The structural and hydrological peculiarities of the Vema Fracture Zone have attracted the attention of many researchers (Bonatti et al., 1983, 1994; 2005; Kastens et al., 1998; Lagabrielle et al., 1992; Ligi et al., 2002; Peyve et al., 2000; Skolotnev, et al., 2003; Morozov et al., 2010).

At a width of 20 km, the Vema transform valley is extended over 500 km and reaches a depth of more than 5400 m. In the south, it is bordered by an extended (nearly 320 km) transverse ridge reaching a depth of 1033 m at present. The ridge recovers rocks of the third layer of oceanic lithosphere (Peyve et al., 2000), which is typical of large systems cutting across the Mid-Atlantic Ridge.

The ridge is eroded along the crest and its flat surface is crowned by a thick (about 500 m) carbonate buildup consisting of shallow lagoonal and/or reef limestones. As guyots, the ridge experienced vertical high-amplitude movements, which caused several stages of its emergence above sea level, subsequent submergences, and erosion (Bonatti et al., 1983). The initial emergence of the ridge above sea level (10–5 Ma ago) was replaced by submergence, which led to the formation of flat erosion surface and initiation of carbonate buildup on it (about 4 Ma ago). Then, the biogenic carbonates emerged from the sea twice (3 and 2.5 Ma ago), with rapid sinking at 2.5–2.0 Ma ago (Bonatti et al., 1994).

Due to its structure and spatial position, the Vema Fracture Zone serves as a pathway for the transport of bottom waters from the western to the northeastern Atlantic Ocean (Mantyla and Reid, 1983; McCartney et al., 1991; Morozov et al., 2010). This transfer is accompanied by the precipitation of Quaternary sediments up to 485 m thick in the fracture trough (DSDP Holes 26 and 353). The above value is very high for the average sedimentation rate of 5–7 mm/ka in pelagic zones.

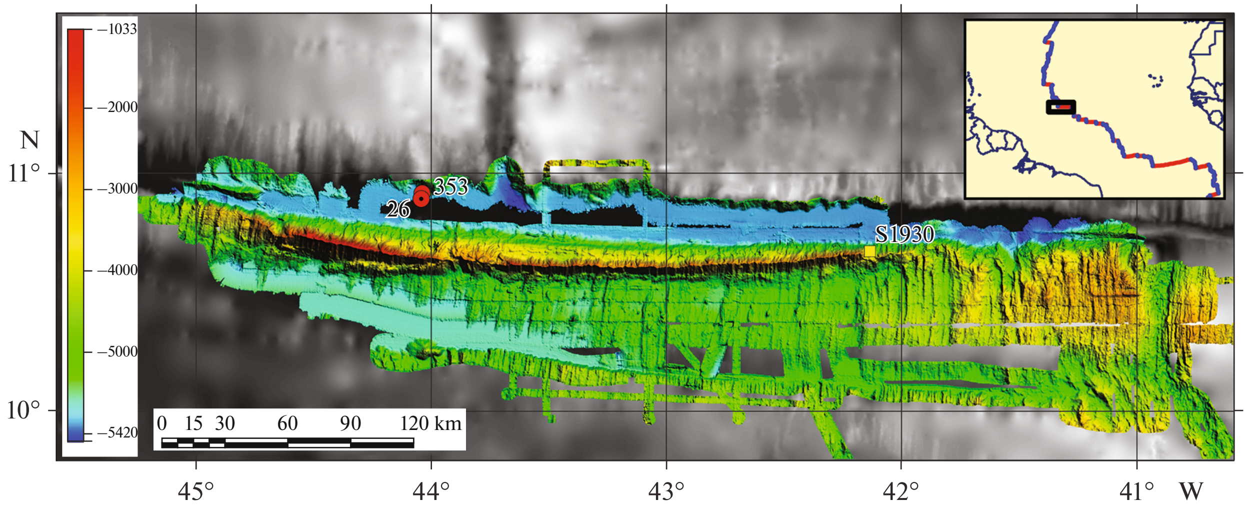

Fig. 1. Vema Fracture Zone and transverse ridge. Based on data of the Lamont Doherty Earth Observatory (https://www.gmrt.org/, cruise EW9305, Kastens K.) and Geological Institute of the Russian Academy of Sciences during cruises 19 (1998) and 22 (2000) of the R/V *Alademik Nikolai Strakhov*. Circles show DSDP holes, square indicates the dredging station. Inset shows the position of the map within the Central Atlantic.

This paper reports new data on rocks collected during Cruise 19 of the R/V *Akademik Nikolai Strakhov.*

RESULTS

During Cruise 19 of the R/V *Akademik Nikolai Strakhov* (Fig. 1), the slope of the transverse ridge was dredged at station S1930 from a depth of 3950 m (10°40.3′ N, 42°08.1′ W) to 3480 m (10°39.3′ N, 42°08.2′ W). About 150 kg of rock samples from the third layer of oceanic crust and >10 kg of foraminiferal sand were uplifted on board (Fabretti et al., 1998).

Rock fragments (about 10 cm across) are angular, devoid of any signs of rounding, and covered by 2- to 3–cm-thick Fe–Mn crusts. They are represented by serpentinized ultramafic rocks (98%), gabbro (1%), basalt (1 sample), breccias and limestones (1%).

Ultramafic rocks are lherzolites, harzburgites, apodunite serpentinites, and serpentinized peridotites. The lherzolites are massive coarse-grained rocks with vague mineral flattening and lineation, and, possibly porphyroclastic texture (sample S1930/11). The harzburgites (with scarce diopside grains) are massive coarse-grained rocks with weak mineral flattening and slickensides (sample S1930/7-10). The apodunite serpentinites are massive rocks with indistinct chromite bands (3–5 mm). Chrome-spinels form aggregates of intricate shape (sample S1930/30-35). The serpentinized peridotites are intersected by veins of greenish and bluish green serpophyte and chrysotile asbestos, sometimes with zoning (sample S1930/72-76).

The leucocratic and mesocratic gabbro is coarse-grained rock and experienced low-temperature alteration, with the formation of saussurite and the replacement of amphibole by chlorite and pink Mn-bearing (?) zoisite (sample S1930/2-6).

The basalt is fine-grained, massive, aphyric, and weakly altered (sample S1930/1).

The breccias are made up of angular fragments of serpentinized ultramafic rocks (?) in a carbonate cement (sample S1930/80).

The limestones are fine-grained biomicritic rocks with fragments of mafic minerals and partially crystallized biomicritic material (sample S1930/85-91).

The **formaminiferal sands** are light gray, coarse- and medium-grained (>100 μm) rocks devoid of the pelitic material (Fig. 2a). Planktonic foraminifers compose the most part of the assemblage (>90%), but benthic species also occur. Some shells are covered by Fe–Mn coats (Figs. 2b–2e).

The sands contain numerous rock fragments from a few millimeters to 1–2 cm (Fig. 2f). Pebbles comprise all varieties of ultramafic rocks and carbonates, which were dredged from slopes of the transverse ridge during Cruise 19 of the R/V *Akademik Nikolai Strakhov*. The fragments are usually moderately rounded, but well-rounded flat pebbles are also observed.

The main types of planktonic foraminifers are shown in Fig. 3. Based on the finds of foraminifers *Globorotalia truncatulinoides,* sediments dredged from station S1930 have a Quaternary age. The assemblage in sediments contain typical Pleistocene subtropical-tropical species, such as *Globigerinoides ruber* pink, *Globorotalia hirsuta*, *G. truncatulinoides*, *G. scitula*, *G. tumida*, *G. menardii*, *Neogloboquadrina dutertrei*, *Pulleniatina obliquiloculata*, and *Orbulina universa*. The presence of species *Globigerinoides ruber* pink also

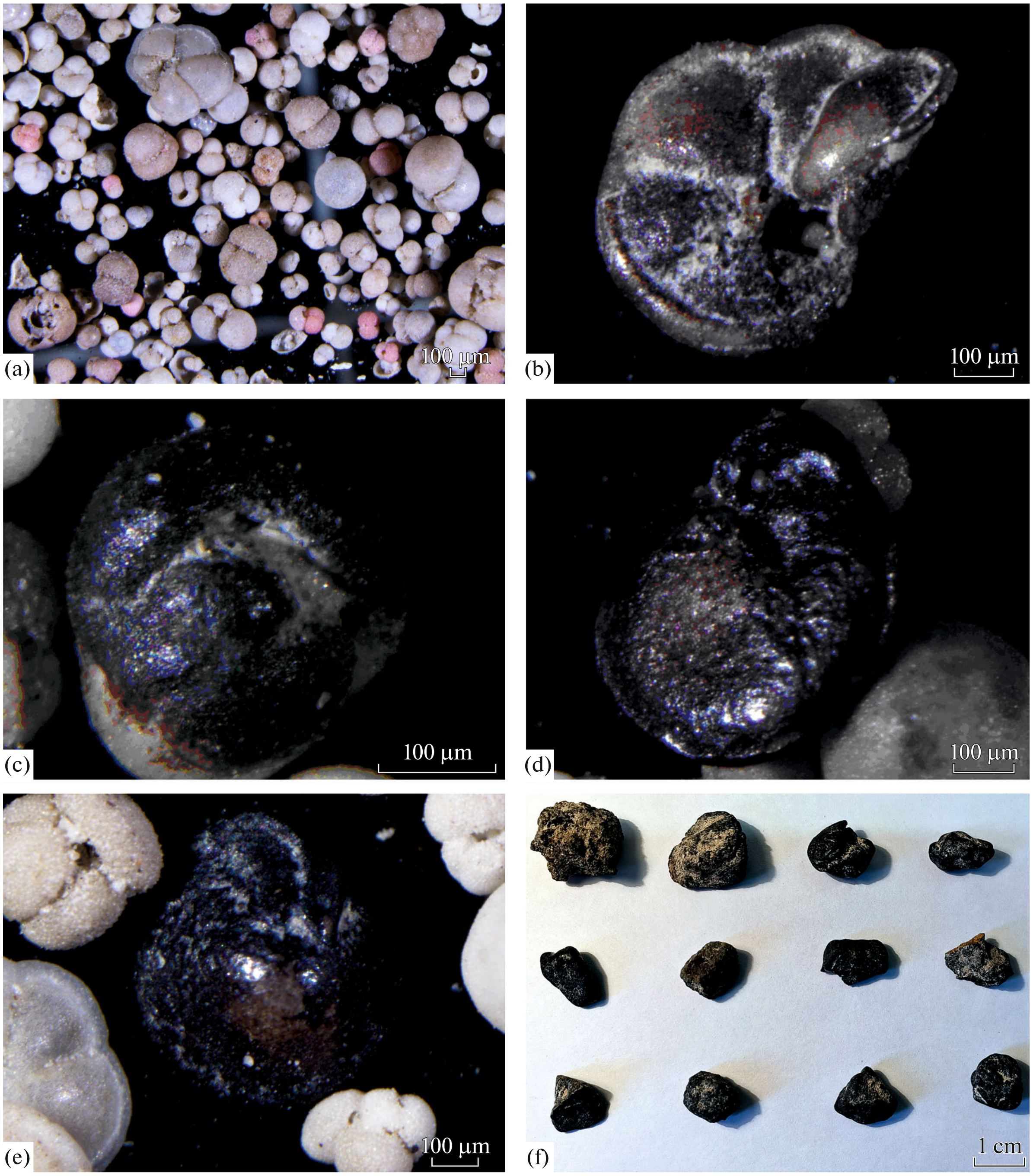

Fig. 2. Foraminiferal sands and pebbles dredged at station S1930. (a) Foraminiferal sands; (b–e) foraminiferal shells covered by Fe–Mn coats: (b) *Globorotalia tumida*, (c) *Pulleniatina obliquiloculata*, (d) *Cibicidoides wuellerstorfi,* (e) *Cibicidoides kullenbergi;* (f) pebbles from foraminiferal sands.

indicates that the sediments are not older than 0.28 Ma (Barash et al., 1986).

The benthic species are dominated by secretory-calcareous *Cibicidoides wuellerstorfi*, *C. kullenbergi*, *Oridorsalis umbonatus*, *Globocassidulina subglobosa,* with less common *Nuttallides umbonifera, Fursenkoina complanata*, *Pyrgo* spp., *Uvigerina peregrina*, and agglutinated *Hyperammina elongata*.

The petrographic study of pebbles in thin sections showed that they contain rocks of the third layer of oceanic lithosphere. Of most interest is the discovery of traces of bioherm buildup growth on the ultramafic rocks, as well as the penetration of marine biota into rocks (Fig. 4).

Black (in transmitted and polarized light) rims are usually developed at the contact of magmatic rocks

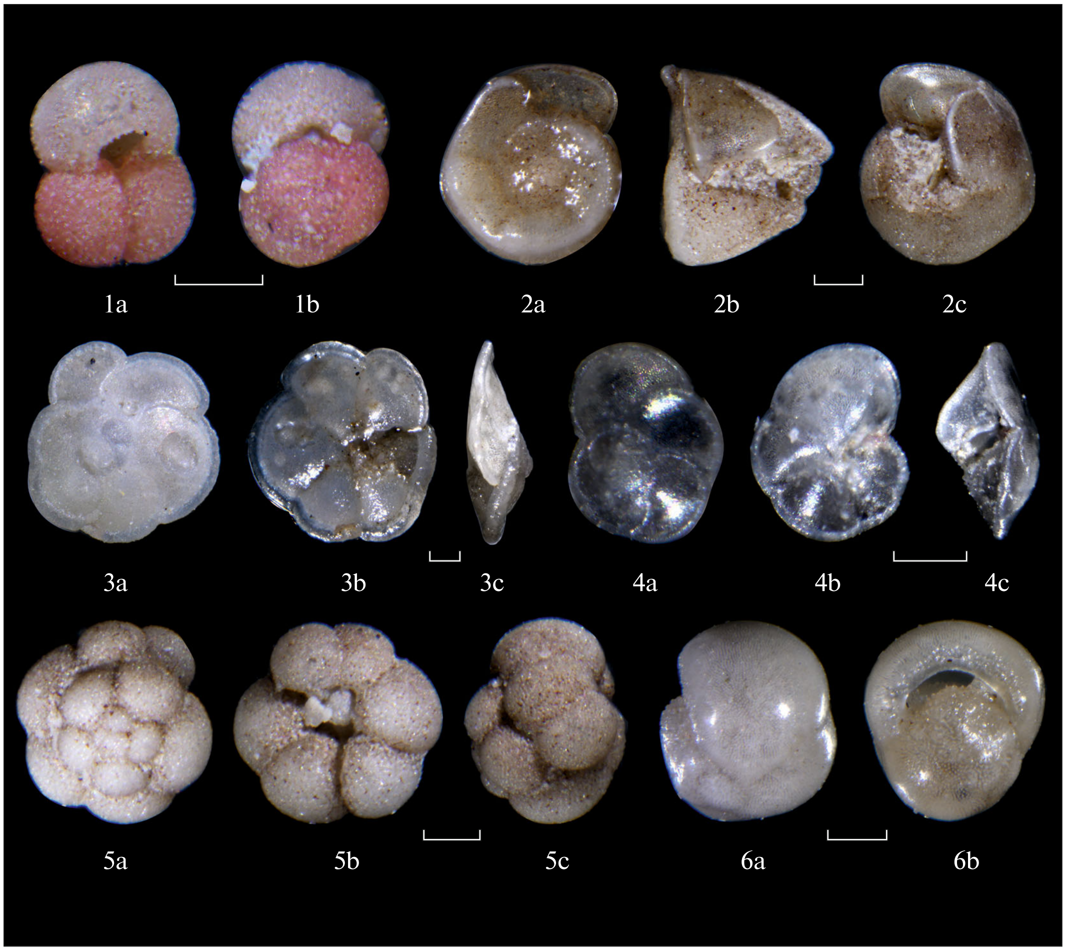

Fig. 3. Main species of planktonic foraminifers (station S1930). (1) *Globigerinoides ruber pink*, (2) *Globorotalia truncatulinoides*, (3) *G. menardii*, (4) *G. scitula*, (5) *Neogloboquadrina dutertrei*, (6) *Pulleniatina obliquiloculata*. Length of scale bars is 100 μm.

and organogenic ooze (Figs. 4a–4d). Thin lamination is frequently observed in oozes filling the fractures and cavities (Fig. 4b). Some thin sections show a clear zoning: magmatic protolith—bioherm—organogenic ooze (Fig. 4e). Sometimes, the fragments of well-developed bioherm buildups are observed (Fig. 4f). The growth of bioherm limestones on ultramafic rocks indicates the involvement of protolith in the photosynthesis zone.

DISCUSSION

The source of detrital material transported to the Vema Fracture Zone has been controversial problem since the drilling of first DSDP holes. On the one hand, sediments in the mid-ocean ridge, the least subsided area, have a significant thickness. On the other hand, detrital material shows evidence for the continental origin (Heezen et al., 1964; van Andel et al., 1967 and others).

The late Pleistocene (lowermost of the known) portion of the section was recovered by DSDP Holes 26 and 353 on the slope of the northern flank of the valley (Fig. 1). The core shows an alternation of grain-size sorted sands with carbonate oozes (Thiede, 1977). DSDP Hole 26 contains abundant plant remains, without any traces of detritus from flanks of the fracture zone (Bader, 1970).

Sediments dredged at station S1930 are ascribed to the uppermost (modern) part of the sedimentary cover of the Vema Fracture Zone. Initially, they were formed as a mixture of colluvial and pelagic sediments at the base of the transverse ridge. The resultant (presently observed) grain-size composition of these sediments was formed by the reworking of primary sediments under conditions of highly dynamic hydrological regime.

The absence of pelite fraction in the foraminiferal sands can be explained based on the concept of residual sediments, when fractions were separated by the mechanical weathering. Under subaerial conditions, such a mechanism provides the formation of gravel sediments of desert valleys, where the fine sediment particles are removed by wind. Under submarine con-

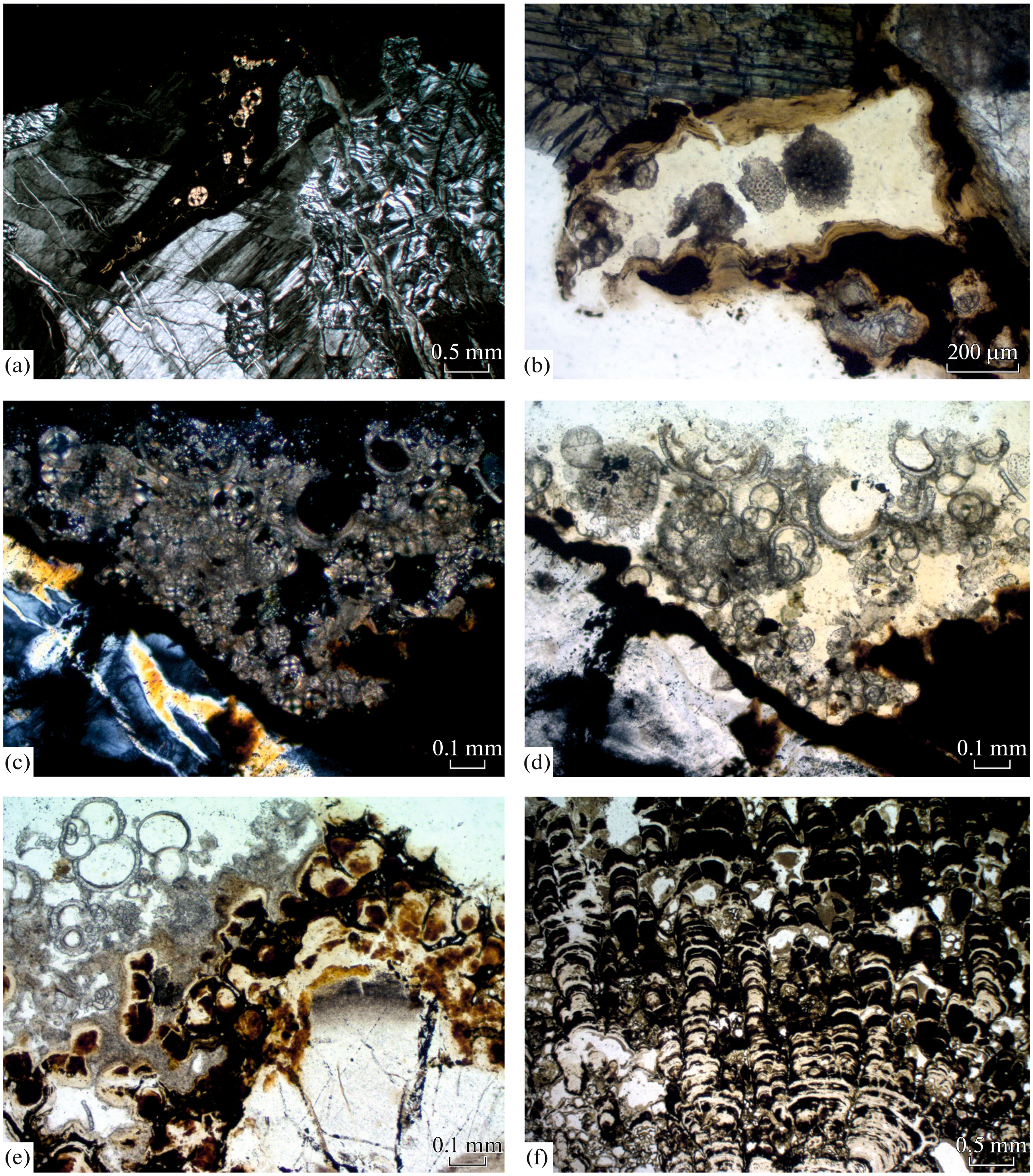

Fig. 4. Images of thin sections of pebbles from foraminiferal sands of station S1930. (a) Microfossils in fracture cutting across the serpentinized peridotites (crossed nicols); (b) zoned infill of cavity (parallel nicols); (c, d) enveloping of the rock by biogenic ooze: (c) crossed nicols, (d) parallel nicols; (e) enveloping of peridotite by the organogenic carbonate with transition to the biogenic ooze (parallel nicols); (f) bioherms (parallel nicols).

dition, the separation of particles is driven by bottom currents.

The existence of intense bottom currents in the Vema Fracture Zone is related to their confinement to the interaction zone of cold Antarctic and warmer Atlantic waters. Hydrophysical studies along the fracture revealed a rapid eastward flow of bottom waters with a velocity up to 30 cm/s (Demidov et al., 2007). These data are consistent with the presence of benthic foraminiferal species *Cibicidoides wuellerstorfi* (Fig. 2d), which is typical of regions with intense bottom currents.

According to hydrophysical measurements (Demidov et al., 2007), bottom flow in the eastern direction is displaced to the southern slope of the main channel, i.e., station S1930 is located directly in the zone of its influence and, likely, discharge. Decreasing influence of the bottom Antarctic waters at station S1930 follows from the composition of benthic foraminiferal assemblage, which is typical of the North Atlantic deep waters. The amount of species *Nuttallides umbonifera* associated with the Antarctic bottom water is subordinate.

The presence of Fe–Mn coats on the shells of some foraminifers indicates a multiple redeposition and transfer of the detrital material, which could be related to both climatic variations and migration of the axial line of bottom water flow. Ferruginous films on some fragments and foraminiferal shells could be related to the redeposition of boundary layer, which separates the terrigenous hemipelagic lutites and turbidites from the overlying pelagic foraminiferal oozes and lutites (McGeary and Damth, 1973).

The highly dynamic regime of bottom currents explains the inequigranular composition of sediments, in particular, the presence of numerous polymictic pebbles in the foraminiferal sands.

The presence of pebbles of diverse ultramafic rocks, which compose the transverse ridge, reflects a long-distance mobilization and transport of the detrital material. Inferred vertical zoning in the distribution of ultramafic rocks in the ridge (Bonatti et al., 1983 and others) and evidence for the initial occurrence of some of them in the photosynthesis zone indicate a vertical range of detrital influx from 0 to a few kilometers.

It is reasonable to suggest that the main part of bioherm fragments was supplied from a carbonate buildup, the least subsided part of which is located at about 260 km from station S1930 (Fig. 1). Even assuming the supply of pebbles from the periphery of carbonate massif, they were transported over at least 100 km.

The established foraminiferal species have a young (no older than Pleistocene) age. Following the concept presented in (Bonatti et al., 1994) that the final subsidence of the carbonate buildup occurred about 2 Ma ago, microfossils found in the thin sections of pebbles should be older than foraminifers from sand. Unfortunately, it was impossible to separate the volume species at this stage.

CONCLUSIONS

Quaternary coarse- and medium-grained foraminiferal sands dredged from station S1930 comprise rounded fragments of bioherms and ultramafic rocks bearing traces of bioproductivity, which reflect some tendencies in the formation of the structure and modern sedimentary cover of the Vema Fracture Zone.

The absence of pelite fraction in the foraminiferal sands is likely related to their mechanical weathering (redeposition) by intense bottom currents in the interaction zone of the cold Antarctic and warmer Atlantic waters. These data are consistent with the presence of benthic foraminifers *Cibicidoides wuellerstorfi* typical of areas with intense bottom currents.

The presence of Fe–Mn coats on shells of some foraminifers indicates a multiple redeposition and transfer of detrital material, which could be related to both climatic variations and migration of the axial line of bottom currents.

The existence of highly dynamic bottom currents explains the presence of numerous polymictic pebbles in the foraminiferal sands. The presence of diverse ultramafic rocks from the transverse ridge in pebbles reflects an extended region of the mobilization and transport of detrital flux.

The main part of bioherm fragments was delivered from a carbonate buildup, the least subsided part of which is located at about 300 km from station S1930. Assuming the derivation of pebbles from the periphery of the carbonate buildup, they were transported over 100–300 km.

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