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GEODYNAMICS

Geodynamic Setting of the Passive Part of the Charlie Gibbs Twin Transform Fault (North Atlantic)

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Abstract—The study of the neotectonic deformation features of the sedimentary cover and seismicity of the Charlie Gibbs twin transform fault has shown that its southern trough is developed in a transtensional mode and its northern thrust, in a transpressional mode. Signs of activity in the structure of the upper part of the sedimentary section were noted in the eastern passive parts of the fault at a distance of at least 150 km from the active rift zone of the Mid-Atlantic Ridge. Dislocations of normal fault kinematics and signs of an increased sedimentation rate and occurrence of landslide clastic deposits near the trough slopes are manifested in the sedimentary section of the southern trough. The median ridge with folded structures, overlain by sediments with angular unconformity, is established in the axial part of the northern trough. Faults located south of the ridge are interpreted as reverse faults. At the present stage, the Northern trough is accompanied by the formation of piercements of the median ridge during extrusion of deep matter and accompanying deformations of the sedimentary cover.

Keywords: Charlie Gibbs transform fault, sedimentary cover deformations, seismicity, geodynamic setting, seismoacoustic section

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INTRODUCTION

The Charlie Gibbs twin transform fault (Fig. 1) is located in the North Atlantic. It displaces the axial part of the Mid-Atlantic Ridge (MAR) by ~340 km at ~52°25′ N. This structure includes a small (up to 40 km) spreading segment between the northern and southern troughs of the Charlie Gibbs Fault at ~31°50′ W (Fig. 1). There are not many transform faults, which divide the axial part of the MAR into segments along its ~16000 km length with the displacement of 300 km or more along the active part of the fault. Transform faults are generally concentrated in the Equatorial and Central Atlantic segments and have been called "faults–terminators" [4]. Later, these extended structures, usually consisting of several transform troughs [5], were called "megatransforms" [6]. For the North Atlantic, the Charlie Gibbs Fault is the only structure of this type. These faults are significant, because they separate the MAR segments with different ages of a spreading start [7] and the duration of thermal evolution of the mantle, from the continental rifting to the present time. According to the data of indexed magnetic anomalies [8], the MAR segment to the south of the Charlie Gibbs Fault began to open from 130 to 108 Ma ago, and the segment to the north of the Charlie Gibbs Fault began opening about 59 Ma ago.

This means that, for a long time, the passive parts of the Charlie Gibbs Fault have been an ocean–continent boundary of the transform type. In the Atlantic Ocean, this type of boundary, arising due to differences in the spreading start, occurs frequently. It was reflected in the known atlases of paleoreconstructions [9].

The impact of the Icelandic plume [10] caused the opening of the Atlantic north of the Charlie Gibbs Fault. However, it is not the main driving force of rifting and further drift of the lithospheric plates [11]. In the MAR axial zone north of the Charlie Gibbs Fault, the plume rests in a structural barrier with a large displacement of the MAR southern segment to the west. The structural barrier prevents the long-axis flow of the heated and partially melted mantle matter southward. This is confirmed by the seismic tomography data [12] and by the deep section plotted along the MAR on the basis of these data [13]. The mentioned differences in the mantle properties to the north and

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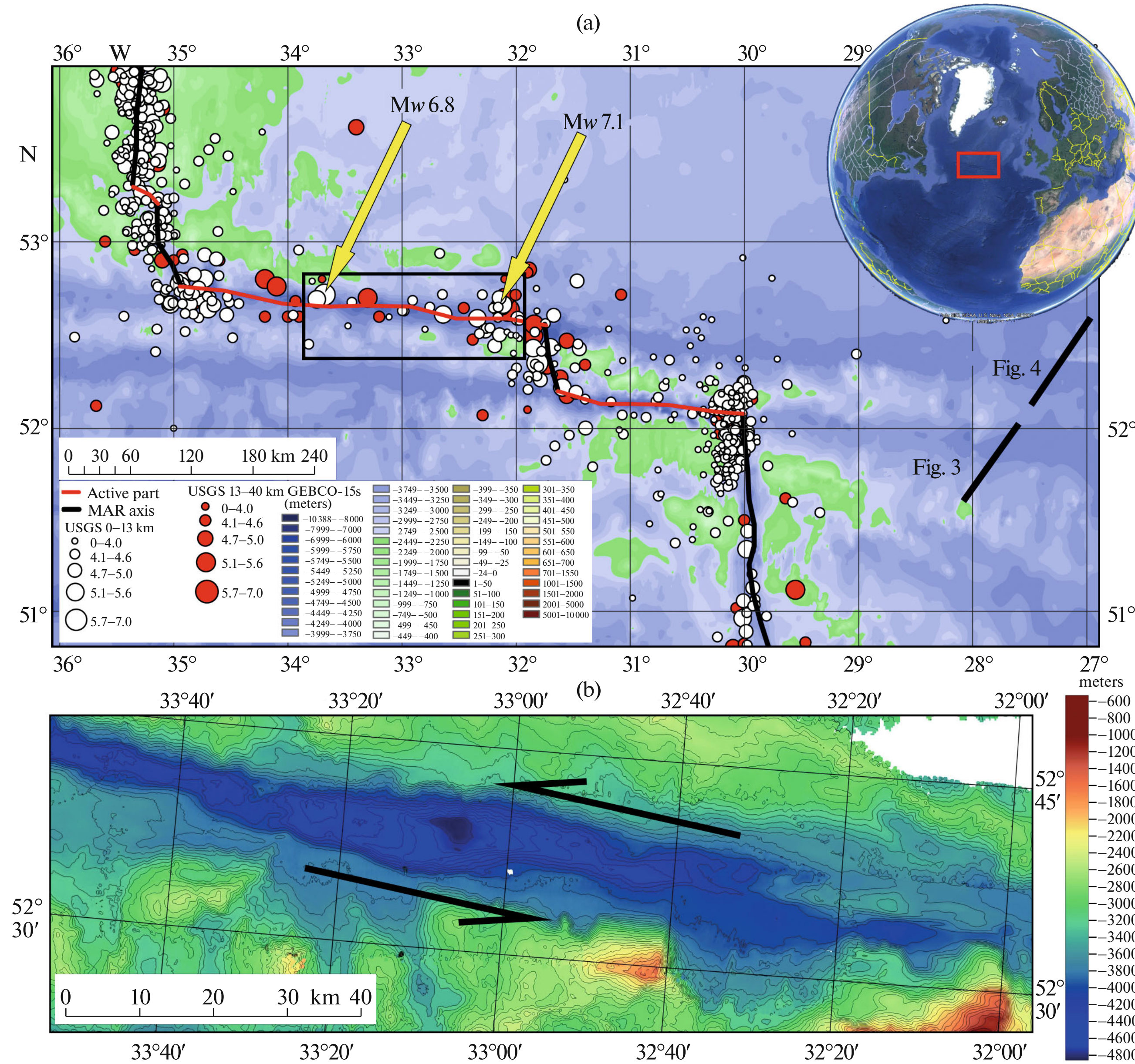

Fig. 1. The area of the Charlie Gibbs twin transform fault. (a) Seismicity according to [1, 2], seafloor relief according to [3], and positions of the sections of Figs. 3 and 4. The inset illustrates the general position of the study area in the North Atlantic; the rectangle shows the position of the plot (Fig. 1b) with detailed relief. (b) Sinistral strike–slip depression pull-apart according to multibeam bathymetry data of the 50th cruise of the R/V *Akademik Nikolai Strakhov* (Geological Institute, Russian Academy of Sciences, 2020) on the axis of the northern transform trough.

south of the Charlie Gibbs Fault are expressed in the different character of basaltic magmatism and, as a consequence, in the different morphology of the ridge relief of the seafloor in the area of the Charlie Gibbs Fault and adjacent segments of the MAR [14], as well as in the morphology of superimposed small volcanic edifices of the central type. According to [14], gabbro, dunite, and peridotite occur in the structure of the intra-fault space inside the Charlie Gibbs Fault. This is the general origin and morphology of the basement, on which the sedimentary cover is formed from material brought to the troughs from the east to west by contour currents from the Arctic [15].

In the active, in terms of geodynamics, regions, the heterogeneous structure of the crust and upper mantle leads to differentiated mobility of the lithospheric blocks. The mobility can be determined reliably by tectonic deformations of the poorly consolidated sedimentary cover [7, 17]. The zones of their development were mapped during the 50th and 53rd cruises of R/V *Akademik Nikolai Strakhov* of the Geological

Institute, Russian Academy of Sciences [14, 16]. A specific feature of these zones is deformations outside the active part of the Charlie Gibbs Fault. The deformations are established in the eastern passive parts of the transform fault at distances up to 150 km from the junction of the active part with the MAR axis. The facts of tectonic activity in the structures defined in theory as passive should be investigated to refine the model of tectogenesis in the ocean. The purpose of this work is to illustrate different geodynamic settings in the troughs of the passive part of the Charlie Gibbs Fault and to interpret their origin.

TECTONICS OF THE AREA

Seismicity is one of the main signs of geodynamic activity of the MAR structure distinctly contouring the currently active segments. It is clustered along the transform fault and adjacent MAR segments (Fig. 1). The strongest deep-focus events occur along the active parts of the fault system, while frequent shallow-focus events are manifested along the rift segments. Along the fault, events with a strike–slip mechanism are manifested and rift segments are active mainly due to normal fault events in the oceanic structure of tension [14]. According to [1], the specific seismicity distribution is evident in dense isolated clusters, in the almost complete absence of shallow-focus events in some segments, and in the predominance of deep-focus events, which are especially manifested in the transform zone (Fig. 1).

The shallow-focus seismicity is grouped into compact clusters with an average interval of 70–80 km along the MAR. This apparently corresponds to the average interval of focused upwelling of heated matter in hierarchically organized spreading cells (Fig. 1). Deep-focus seismicity is generally concentrated along the nontransform displacements on the MAR flanks and in the center of the active part of the Charlie Gibbs Fault, where, according to [2], events with magnitudes up to 7.1 Mw have been recorded (Fig. 1). The origin of these events is not related to magma generation, but exclusively to strike–slip tectonic displacements of the plates adjacent to the MAR. They make the main contribution to the energy release along geodynamically active zones of the ocean with passive type margins. The released energy in the rift segments has a background level. The main release of the tectonic energy is concentrated not in the zones of magmatic accretion of the crust, where the conventional driving forces of plate drift (ridge push) act, but in the area of plate friction at the transform intra-plate boundary of the Charlie Gibbs Fault.

The dense shallow-focus cluster is superimposed on the Charlie Gibbs Fault southern trough (Fig. 1), which indicates the propagation of magma generation through the trough into the intra-fault ridge. In addition, the axis of this cluster does not coincide with the MAR axis. It is displaced by ~10 km to the west and rotated clockwise by ~10° so that the direction of tension does not coincide with the orientation of the passive part of the southern trough, which is orthogonal to the MAR. The northern trough of the Charlie Gibbs Fault is represented by spatially scarce events with larger magnitude and strike–slip mechanisms, indicating a more viscous lithosphere. Therefore, the seismicity shows the possibility of differences in the geodynamic settings in the troughs of the twin transform system.

The twofold asymmetry of the spreading half-rates (Fig. 2a) suggests that the North American plate block together with the MAR structure may drift westward, accompanied by a westward jump of the axes of its segments. Signs of this process can be indicated from the seismicity distribution (Fig. 1a) and the seafloor relief [14]. In spite of the dextral strike–slip kinematics of the displacement of the plates adjacent to the northern trough of the Charlie Gibbs Fault, this asymmetry can create local conditions for the sinistral strike–slip along it and for the formation of a pull-apart depression (Fig. 1b). Figure 2b demonstrates the spreading half-rates (mm/yr) along the 4 Ma isochrone, shown by a pair for the western and eastern flanks of the MAR and plotted from [8]. From these data, it is evident that there is a general asymmetry of half-rates in the North Atlantic, with values exceeding those on the eastern flank of the MAR [13]. There are some segments in which the asymmetry practically disappears (Fig. 2b). They are associated in [13] with superplume branches under the MAR axis. However, the regions of greatest interest are those in which there is an inversion of the half-rate asymmetry (Fig. 2b), and the values on the western flank exceed those on the eastern flank. One such segment is the region immediately north of the MAR, and, to all appearances, this creates conditions for the formation of local sinistral strike–slip kinematics along the northern trough of the Charlie Gibbs Fault.

DEFORMATIONS OF THE SEDIMENTARY COVER

Figure 3 demonstrates the seismoacoustic section of the eastern passive part of the southern trough of the Charlie Gibbs Fault. In the middle part of the trough, its effective depth extends to 85 m. The section shows dislocations typical of both strike–slip paragenesis, with a symmetrical normal fault pattern of displacements, echeloning the main transform displacement in the depression axis, and normal faults near the trough sides. According to [17], if there is a difference in the spreading rates in the lithosphere blocks on opposite wings of the transform fault, there may be strike–slip displacements in its passive part that compensate for this difference. We note the presence of layers with acoustic turbidity on the southern side, typical of clastic sediments that arise from the chaotic accumulation of poorly consolidated sediments with a

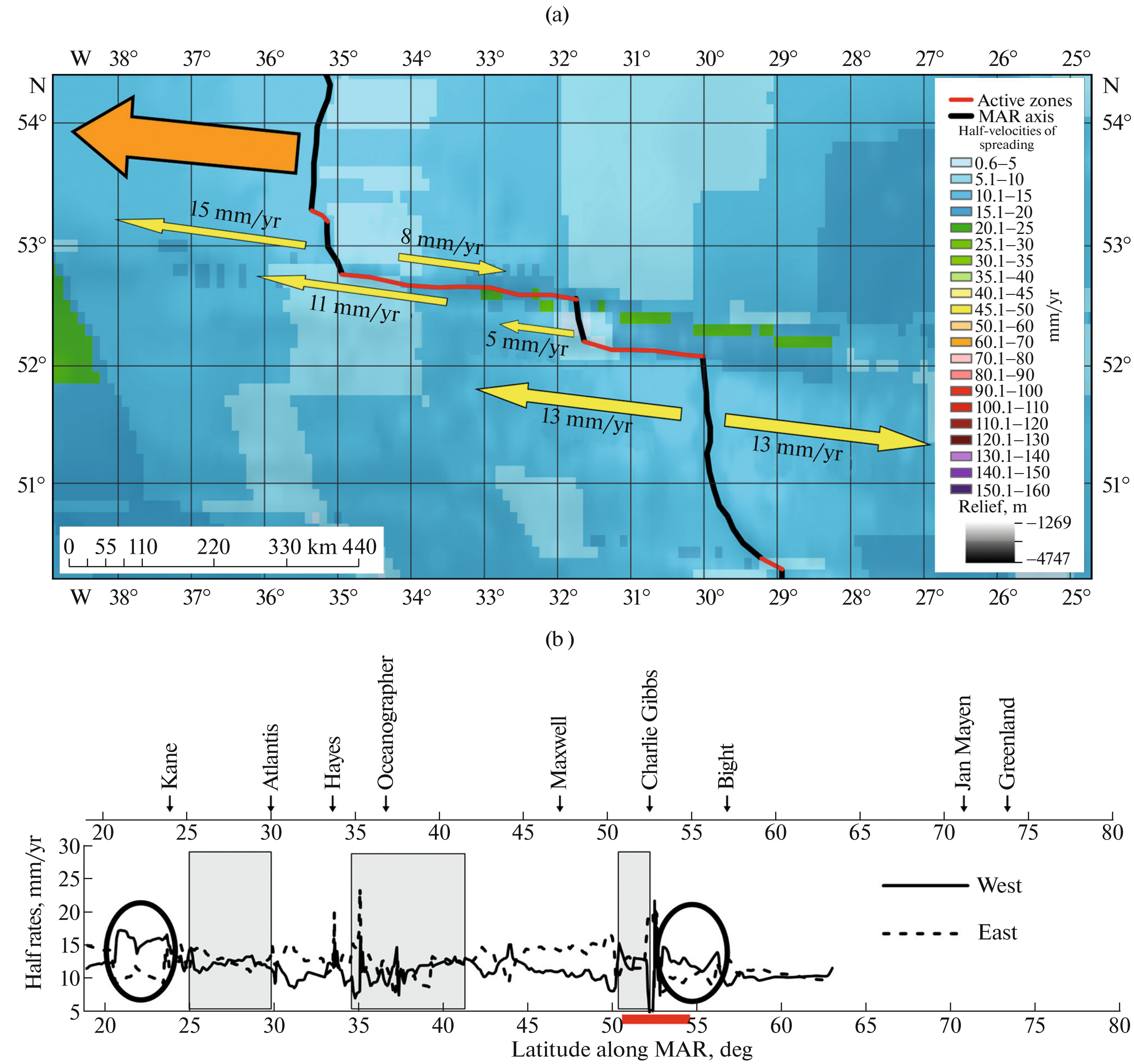

Fig. 2. Asymmetry of spreading half-rates in the Charlie Gibbs Fault region. (a) Spreading half-rates according to [8], yellow arrows show characteristic values; the orange arrow shows possible displacement of the North American Plate together with the MAR axis. (b) Areas of inversion of asymmetry of spreading half-rates according to [8] along the 4 Ma isochrone along the MAR flanks in the North Atlantic (ovals) and areas of almost symmetric values (gray rectangles). The red line indicates the position of the fragment of Fig. 2a on the MAR axis; the position of intersections of the main transform faults with the MAR axis and their names are given.

composition of different particle sizes. They accumulate on the sides of the trough as a result of transport of terrigenous material by contour currents [15] and have an unstable profile. Under the conditions of tectonic activity of the structure and its proximity to seismicity centers, the appearance of such anomalies in the acoustically stratified sequence is typical. The sediment section of the depression (Fig. 3) also differs in an increase in thickness of two near-surface layers with distinct acoustic transparency. Such a record is fixed under the conditions of modern warping in the trough structure at increased rates of accumulation of the poorly consolidated sedimentary sequence with a homogeneous particle size composition. The record is acoustically transparent in the wave field of the section.

The observed configuration of reflectors indicates the existence of a modern transtension in the passive part of the southern transform trough of the Charlie

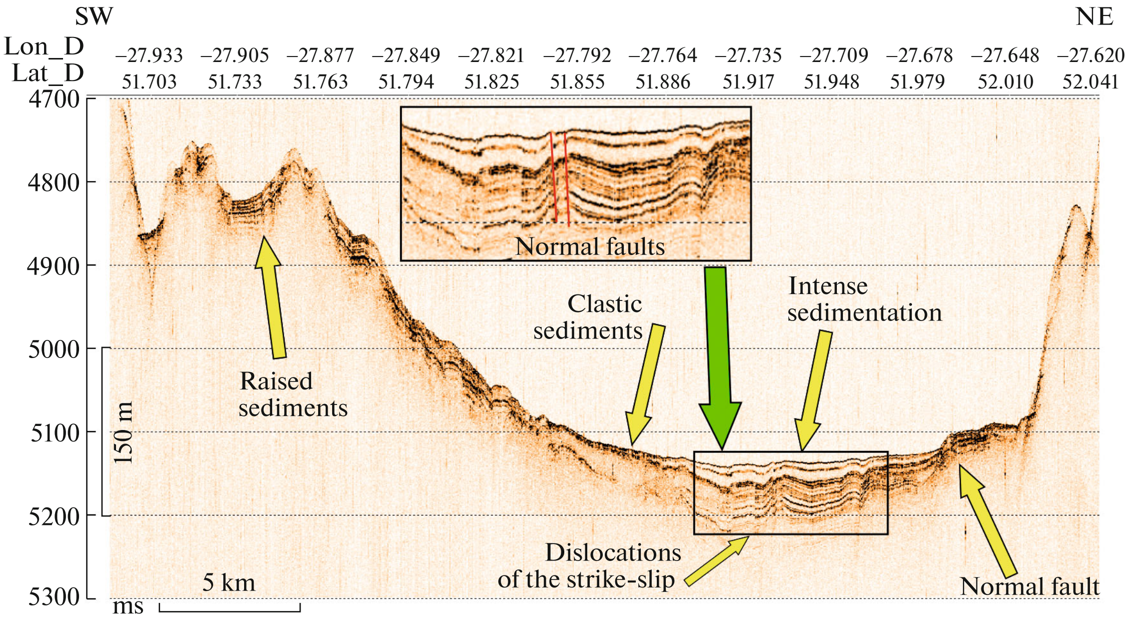

Fig. 3. Fragment of the ANS53-50 seismoacoustic section at the intersection of the southern trough of the Charlie Gibbs Fault obtained by EdgeTech 3300 profiler with CHIRP-type signal in the frequency range from 2 to 5 kHz. The position of the fragment is shown in Fig. 1. The elements indicated by arrows are explained in the text.

Gibbs Fault at distances of ~150 km from the active rift segment (Fig. 3). The data obtained so far do not allow us to estimate the distance from the active structural elements of the MAR, where strike–slip displacements attenuate completely in the passive parts of the transform fault. Above the strike–slip axis, maximum warping of the trough is observed. The northern flank of the trough is modified by normal fault dislocations, which are quite common in the passive parts of the faults [17]. The southern side contains rises with preserved undisturbed stratified sedimentary bodies on the tops. At the base of the slope, sedimentary bodies with acoustic turbidity are observed. This is usually characteristic of clastic sediments resulting, in particular, from landslides.

The abovementioned gives an additional argument in favor of local uplift on the southern side of the trough, which may arise due to isostatic compensation in tension. Under the conditions when the MAR segment and the southern trough of the Charlie Gibbs Fault are almost orthogonal (Fig. 1), but the axis of shallow-focus seismicity cluster, showing the current orientation of tension, is rotated clockwise by ~10° relative to the MAR, the tension in the trough may be submeridional in addition to strike–slip displacements.

Figure 4 illustrates the section through the northern transform trough of the Charlie Gibbs Fault. In its axial part, a median ridge is distinguished, framed by folds in the sediments. The folds indicate modern penetration of the sedimentary sequence by the ridge. A fold on the north side of the median ridge has an angular unconformity in a fold lock with a reflector lying at a depth of about 6 ms over the erosion-damaged fold lock. The sedimentary layer for which this reflector is the basement is also deformed above the fold, indicating continued vertical movement of the ridge and the adjacent sedimentary sequence. In this regard, the faults south of the ridge are interpreted as reverse faults. This concept is supported by the presence of sediments with acoustic turbidity south of the raised segment with stratified sediments. Therefore, we can conclude that the northern trough of the Charlie Gibbs Fault is, at the present stage, under the conditions of transpression, which is accompanied by the formation of the median ridge with extrusion of deep matter and by the formation of specific deformations of the sedimentary cover.

The extrusion structure observed in the section across the strike of the northern trough is a link in a chain of similar structures located in the eastern passive part of the Charlie Gibbs Fault with a spacing of 70–90 km (Fig. 5). We believe that their extrusion under the conditions of compression and uncompensated difference in spreading rates in the passive part of the fault may form similar median structures at distances of the first hundreds of kilometers from the active part. Studies of analogs from other transform faults are needed.

The acoustic stratification of the upper part of the sedimentary section in the eastern passive parts of the Charlie Gibbs Fault is traced clearly within the trough. However, local increases in thicknesses [14] are observed; they occur in the antiform locks. Near the

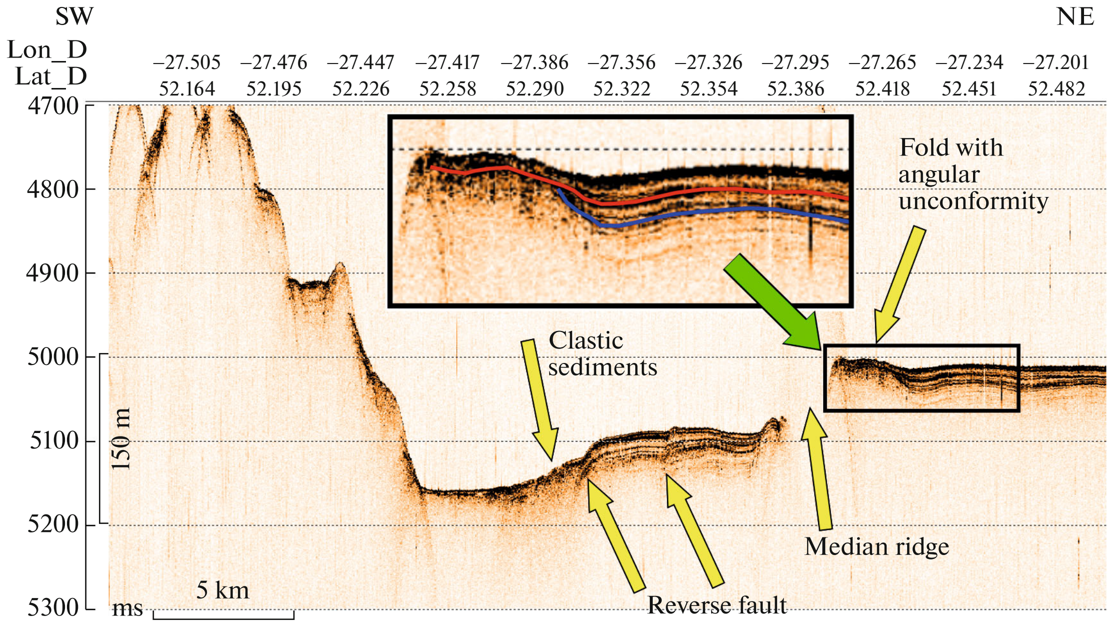

Fig. 4. Fragment of the ANS53-50 seismoacoustic section at the intersection of the northern trough of the Charlie Gibbs Fault obtained by the EdgeTech 3300 profiler with a CHIRP-type signal in the frequency range from 2 to 5 kHz. The position of the fragment is shown in Fig. 1. The elements indicated by arrows are explained in the text.

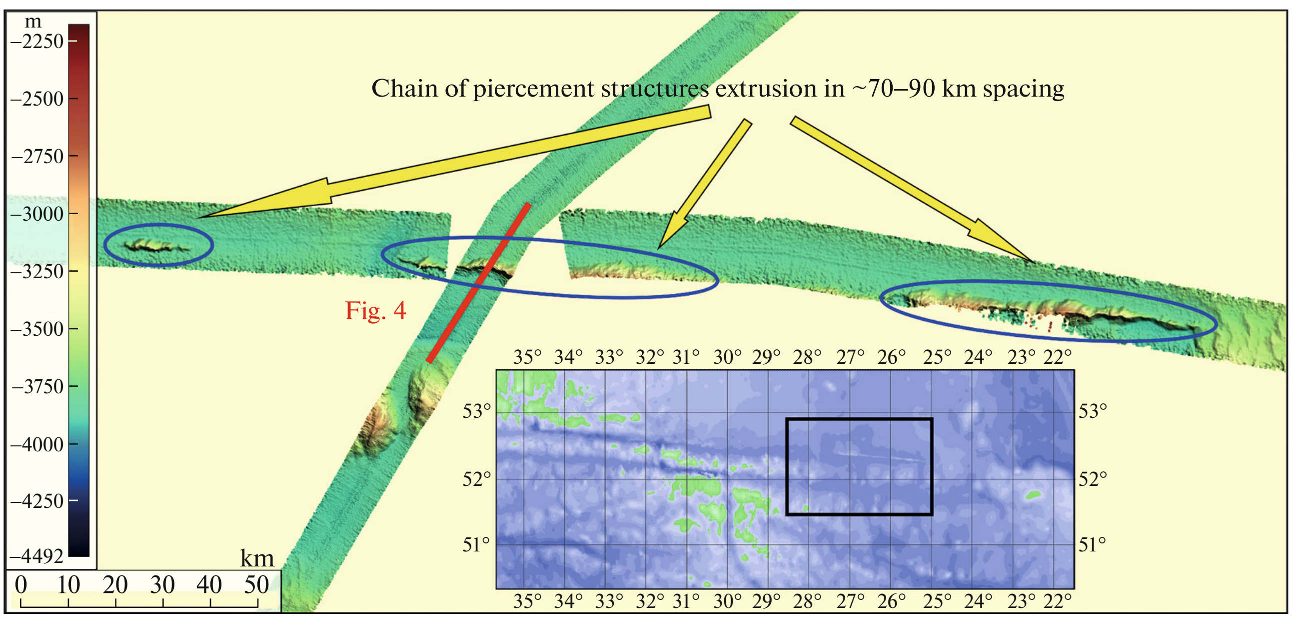

Fig. 5. Swath bands of the seafloor relief from multibeam echosounder data of the 50th and 53rd cruises of the R/V *Akademik Nikolai Strakhov* (Geological Institute, Russian Academy of Sciences, 2020, 2022) in the northern trough of the Charlie Gibbs Fault. The inset shows the position of the main plot in the area of the eastern passive parts of the transform fault. The position of the transect of Fig. 4 is shown. Extrusion structures are explained in the text.

basement scarp, the record acquires an acoustically turbid character. This indicates a more intensive process of material deposition during the formation of channel drifts and the input of material from adjacent slopes, resulting in a chaotic structure of the sedimentary body due to the migration of the seafloor current of the Northeast Deep Water (NEDW) [15] and because of slope landslide processes. The factors forming the wave field anomalies in the acoustically stratified sequence are complex, depending on both the hydrological setting and the modern tectonic processes.

CONCLUSIONS

(1) The results of study of the modern neotectonic deformations of the sedimentary cover and seismicity show that the southern trough of the Charlie Gibbs Fault develops in the transtensional mode, while the northern trough develops in the transpression mode. Signs of activity in the structure of the upper part of the sediment section are noted in the eastern passive parts of the twin transform faults of the Charlie Gibbs Fault at a distance of at least 150 km from the MAR active zone.

(2) The sedimentary section of the southern trough of the Charlie Gibbs Fault shows dislocations of transtensional paragenesis, signs of an increased sedimentation rate, and accumulation of landslide clastic sediments near the slopes of the trough. Normal faults are manifested on the northern side, and undisturbed stratified sedimentary bodies on the basement scarps are manifested on the southern side.

(3) The median ridge with the folded structures, overlain by sediments with angular unconformity, is established in the axial part of the northern trough of the Charlie Gibbs Fault. Faults south of the ridge are interpreted as reverse faults. The northern trough of the Charlie Gibbs Fault is under the current transpression, which is accompanied by the formation of the median ridge during extrusion of deep material and deformation of the sedimentary cover.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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