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Romanche fracture zone: Structure, evolution, and geodynamics

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Abstract. This work is based on survey data from the 13th and 16th cruises of the R/V *Akademik Nikolai Strakhov*. The tectonic structure of the Romanche fracture zone in the Equatorial Atlantic is considered. Based on its dynamics, kinematics and historical evolution, the zone does not seem to be a uniform structure. Its segments are of different age and evolved according to different dynamic and kinematic laws. The fracture zone is not continuous in space: deformations complicating it migrate both along and a cross its strike, creating new fracture zones with somewhat different orientation. Three geodynamic systems are recognized within the fracture zone, namely Rom 1, Rom 2 and Rom 3. In the eastern junction of the rift and the Romanche fracture zone, the rift valley jumps northward with simultaneous prograding. A "dry" spreading mode is pronounced in the region.

Introduction

The Romanche fracture zone is the largest in the central Atlantic. It extends approximately along the equator from Africa to the South America and is named after the French research vessel *Romanche*. During the expedition of the *Romanche* in 1883, the Vema depression, the deepest one in the Atlantic, was discovered in this region. *Heezen et al.* [1964] was the first to describe the principal morphologic features of the fracture zone. Later, data on the fracture zone were published in the works by Bonatti, Gorini, Chermak, Belderson, etc. [*Belderson et al.*, 1984; *Bonatti et al.*, 1977, 1979; *Bonte et al.*, 1988; *Chermak*, 1979; *Gorini*, 1977; *Honnorez et al.*, 1991; *Prinz et al.*, 1976; *Pushcharovskiy et al.*, 1993; *Searle et al.*, 1993; *Sushchevskaya et al.*, 1994]. The bathymetric survey discussed in the present paper covered practically all the Romanche fracture zone.

The present work is based on data gained in two joint Russian-Italian expeditions in 1992–1993 by the R/V *Akademik Nikolai Strakhov* as part of the "Deep Geospheres" and "PRIMAR" (Russian-Italian Project on the Mid-Atlantic Ridge) projects. A tectonic map of the fracture zone, covering its central area about 1000 km long, is used as the basis for this structural analysis.

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Approach to Compilation of the Tectonic Map

The tectonic map in Figure 1 is based mainly on bathymetric data. Data from single-channel continuous seismic profiling (CSP) and partly processed profiles of multichannel seismic reflection (CDP technique) were used for detailed areas. Dredging and magnetic data as well as information on earthquake epicenter locations were considered wherever possible. All available reference sources on the Romanche fracture zone were utilized.

In the central parts of the ocean, tectonic and volcanic activity play the main role in the formation of topography. Other parameters are subordinate. During compilation of the tectonic map, topographic features generated from volcanic activity and sedimentation were excluded wherever possible. For greater objectivity in drawing structural lines, boundaries were drawn at the upper or lower change in slope. Corresponding marks show how steep the topographic slope is and its relative altitude. The contour interval is not equal over the area: isobaths are drawn mainly at 200 m intervals, but in the western third of the region, the bathymetric basis is less reliable, and in some places, isobaths are given at 50 m intervals. Bathymetric profiles were also used as the map, which is a generalization itself, cannot reflect small but significant details at this scale.

In the course of analysis, it was assumed that the dip and steepness of the slope did not always reflect the corresponding structures (fracture, flexure). Rock-

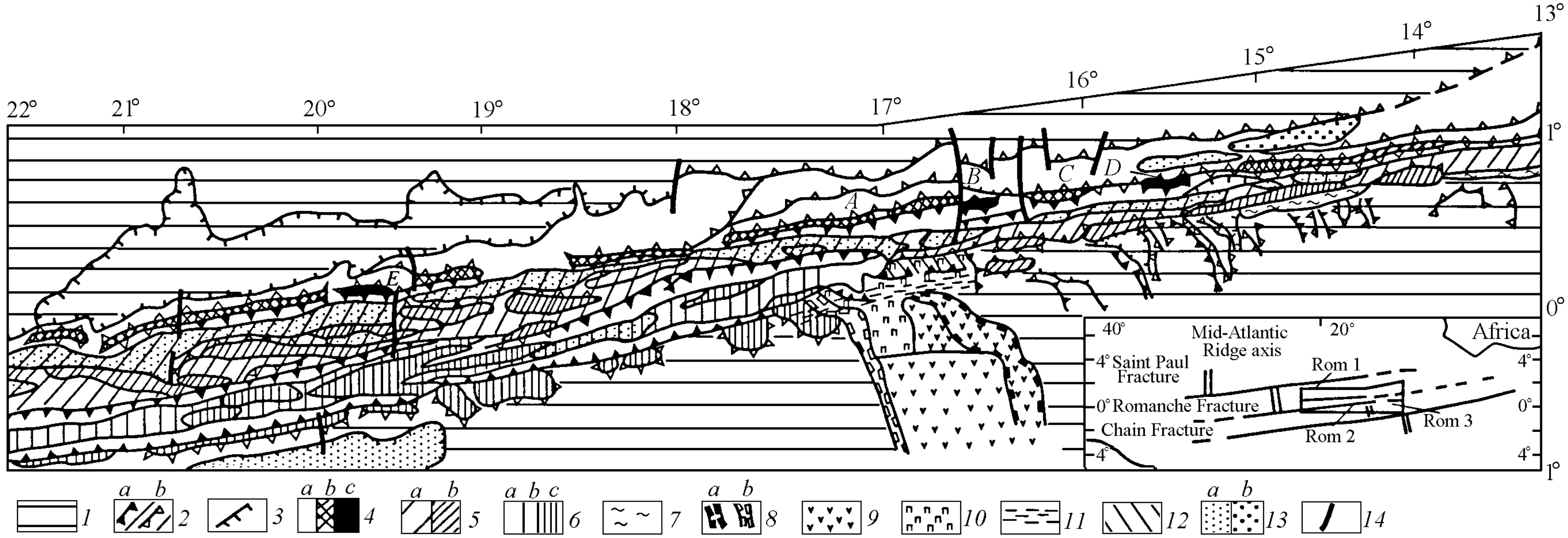

Figure 1. Tectonic map of the Romanche fracture system; 1, oceanic plates; 2, tectonic escarpments: a, steep; b, gentle (lines correspond to the upper slope bend); 3, boundaries of horizontal or dipping structural terrace (lower slope bend); 4 and 5, Rom 1 fracture zone, its walls: 4, hanging (a and b, elongated and c, isometric uplifts within it), 5, foot (a and b, uplifts within it); 6, Rom 2 fracture zone: a, slopes and b, bottom of the trough, c, uplifts within it; 7, Rom 3 fracture zone; 8–12, junction zone of rift valley with the Romanche fracture system: 8, rift valleys: a, Recent and b, ancient ("aborted" rift); 9 and 10, areas of occurrence: 9, basalt, 10, peridotite; 11, generating transform; 12, area of dispersed spreading; 13, depressions with sedimentary cover: a, horizontal bedding, b, deformed in the lower section and horizontal bedding in its upper part; 14, small faults. Letters from A to E are explained in the text. Inset: position of the region presented in the scheme.

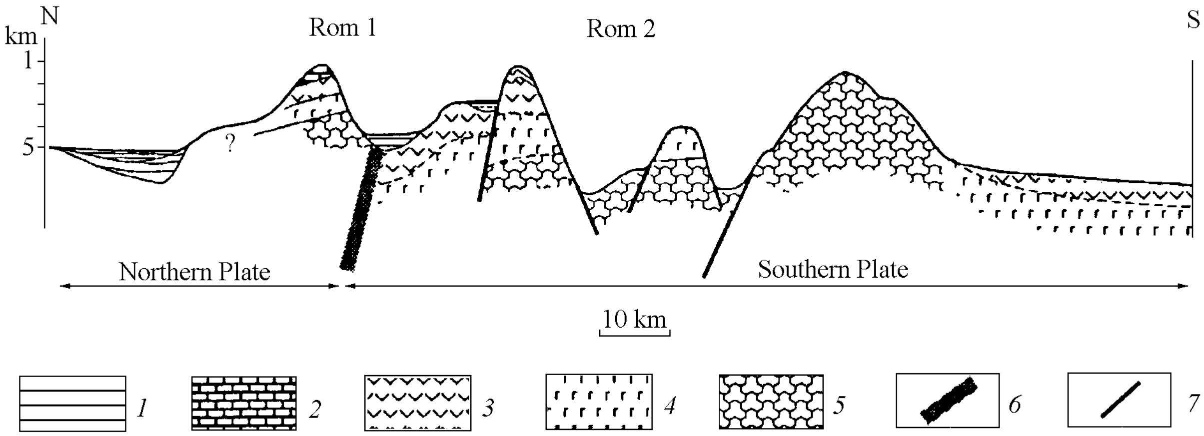

Figure 2. Cross-section of the Romanche fracture zone. 1, sediments; 2, limestones; 3, basalt; 4, gabbroids; 5, ultrabasites; 6 and 7, principal faults: 6, at the stage of Rom 1 and 7, at the stage of Rom 2.

fall breccia and landslide sediment may camouflage the tectonics. In the study region, gravity structures play an important role [*Monti and Mercier,* 1991], so the dip and steepness of the topographic slope do not provide any direct information on the actual fault type (normal fault, upthrust, thrust). It is natural to suppose that, in most cases, normal faults would correspond to the upper edge of the slope change, whereas upthrusts and thrusts would correspond to its lower one.

Within the studied segment of the Romanche fracture zone, we can distinguish several principal structural elements, namely (from north to south) the northern plate (we have practically no data on its structure), Romanche 1 fracture zone (Rom 1), Romanche 2 fracture zone (Rom 2), the southern oceanic plates separated by the rift into the western and eastern ones, the rift itself, and structures of its western boundary. The Romanche 3 (Rom 3) fracture zone can be recognized in the easternmost part of the study area.

Description of Structures

Romanche 1 Fracture Zone (Rom 1)

The Rom 1 fracture zone is bounded the north by the northern plate (Figure 1). A sediment-compensated deep can be traced along its boundary with the plate. It is pronounced only in the western part of the region going eastward beyond the edges of the tectonic map. Three structural elements are recognized in the fracture cross-section, namely (from north to south) the northern hanging wall of the fault, escarpment of the fault, and the southern footwall of the fault.

The northern hanging wall of the fault has a simple structure. It dips gently northward, and only its central segment is complicated by a supplementary structural terrace and corresponding flexure bending. Two types of local dislocations are recognized in the hanging wall of the transverse fault. The first type is linear flat-top structures with an almost horizontal crest. They are characterized by a gentle northern limb and steep southern limb, changing at the escarpment of the Rom 1 fracture zone. Uplifts A and C belong to that type (Figure 1). From seismic data [*Bonatti et al.,* 1993] and dredging results, the tops of the uplifts are made up of horizontally bedded limestones. The latter overlie basalt, gabbroid and ultramafics (Figure 2).

The second type of local dislocation are isometric structures extending along the fault (uplifts D and E in Figure 1). These uplifts do not conjugate directly to the fault escarpment but are separated from it by a relatively gentle slope dipping southward. In the western part of uplift D, limestones and terrigenous rocks were dredged earlier. They contain Paleocene–Eocene and Early Miocene microfauna (*Bonatti*, oral communication). These rocks are anomalously old for the axial segment of the Mid-Atlantic Ridge and cannot be explained by simple spreading of oceanic crust.

Multichannel seismic profiling across this uplift reveals a thick (about 4 km) sequence with complex dislocations (Figure 3) [*Bonatti et al.,* 1993]. Bonatti believes that the sequence in question is a thick formation of deformed volcanic-sedimentary rocks probably not of oceanic origin.

Uplift E in the western part of Rom 1 seems to belong to the same morphologic type (Figure 1). From dredging data, this uplift is composed of oceanic crust rocks that form a normal sequence from serpentinized peridotites at the bottom through gabbroids in the middle to basalt at the top of the section. No sedimentary rocks

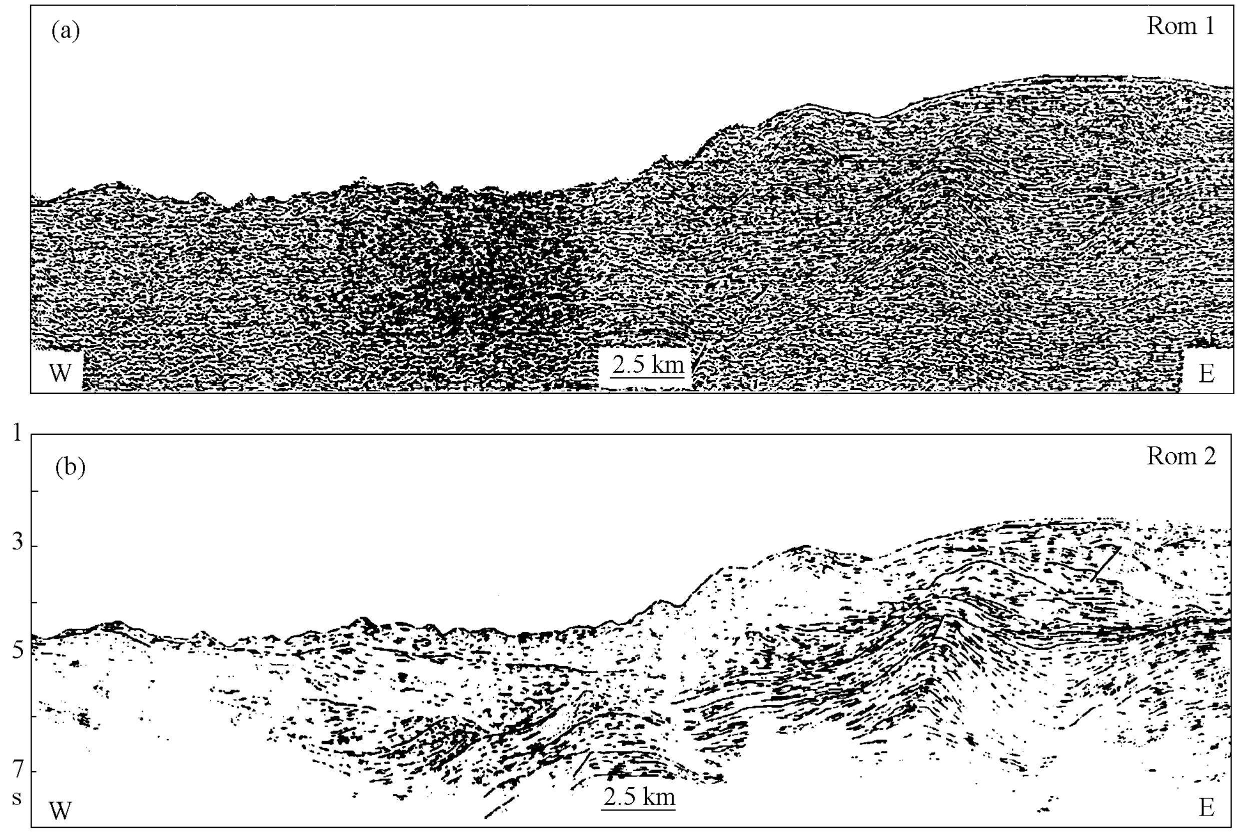

Figure 3. Fragment of seismic reflection profile along Rom 2 across uplift D [*Bonatti et al.,* 1993]: a, migrated temporal section and b, interpretation of temporal section.

have been detected either by dredging or by geophysical surveys.

The Rom 1 fracture escarpment is almost continuous along strike across the study area. At its western and eastern flanks, the escarpment is somewhat uplifted and is not steep. These parameters increase significantly in the zone of the eastern junction of the rift with a transform fault. The fault escarpment was dredged in several places. Serpentinized tectonites with deformed clusters of various gabbroids and pyroxenites were collected at the base of the slope of the D uplift (Figure 1). Their appearance resembles that of serpentinite melange in ophiolite associations. Tectonized rocks of oceanic crust were also dredged by Bonatti from the lower part of the escarpments of uplifts C and A (Figure 1) [*Prinz et al.,* 1976]. On the whole, tectonized rocks of oceanic crust and upper mantle predominate in the lower section of the Rom 1 fracture escarpment.

The footwall of the Rom 1 fracture is most pronounced in the western part of the zone. Two principal structural types can be recognized there, namely flat-top uplifts and separating deeps, variously compensated by sediments. Flat-top uplifts usually have flattened crests which change sharply to comparatively steep symmetrical limbs. In most cases, one pericline is steep and has a flat-top geometry, the other is more gentle and extended. Several small uplifts commonly form a single, gentle archlike structure. Deeps have pronounced linear geometry with a flat-top pericline in plan. According to seismic studies, sediment thickness in the deeps vary from one deep to another and locally from the periphery to the center of the same deep. Thus, sediments filled the primary isolated topographic depressions but are not part of the common cover.

Stratification of sediments filling the deeps show no distinct signs of synsedimentary deformation, only passive deposition in low spots. Gentle dips of sedimentary beds at the margins of the deep seem to follow primary bedding of sediments. The sediments probably covered earlier-formed topography, and their subsequent dislocations were very small. Only in close proximity to the Rom 2 fracture zone do we see signs of tectonic influence: southward bedding toward the Rom 2 fracture zone. In plan, the location of uplifts and deeps corresponds to the distinct pattern of echelonlike structures associated with dextral displacement. It is most pronounced in the western part of the fault zone, though it is also sufficiently distinct in its eastern part.

It is far more difficult to determine the dynamics and kinematics of the structure in the Rom 1 fracture zone. In cross-section, the structure is similar to a one-sided graben with an upthrown northern limb. The occurrence of echelonlike structures which complicate the lower limb suggests dextral displacement along the fault. We believe that the fault has a vertical thrust component and thus dips steeply to the north, based on the cross-sectional geometry of the structure, which shows a northern dip for the hanging and footwalls. The character of complicating structures on both limbs seems to result mainly from strike-slip faults with a vertical component. The juxtaposition of tectonites at the foot of the escarpment against relatively undisturbed rocks in the escarpment and its upper boundary agrees well with the suggested morphology of the fault.

The thrust component easily accounts for the anomalous high altitude of local dislocations along the hanging wall of the fault, which Bonatti frequently mentioned in his works. According to his data, not only recent altitudes are higher than the estimated ones, but these structures also were uplifted above sea level at the end of the Miocene–beginning of the Pliocene. The amplitude of uplift is several kilometers.

Romanche 2 Fracture Zone (Rom 2)

By its morphology, the Rom 2 fracture zone (Figure 1) differs sharply from Rom 1. In cross-section, it is a typical trough bounded by escarpments on the north and south. It is elongated in an east-northeast direction and is well defined from the western edge of the map almost to its transection with the southern branch of the rift (approximately to 17°30′W). In cross section (from north to south) the northern escarpment, subsided bottom of the trough, the southern escarpment, and local dislocations near the fault with discontinuities along strike can be distinguished.

The northern escarpment is made up of two independent echelonlike segments with sinistral displacement. Echelons are oriented to the north more than in the trough. The western segment varies considerably in the relative altitude of the upper boundary of the escarpment and in slope steepness. On the eastern flank, both parameters decrease gradually, and the escarpment dies out. The eastern segment of the escarpment (east-northeast) can be divided into two parts. This division may be due to the erosion-accumulative processes as well as tectonic factors. In any case, this discontinuity in escarpment structure corresponds to the northeastern margin of the only sedimentary basin (the Vema depression) at the trough bottom. The relative altitude and steepness of the slope of the eastern escarpment segment increases very gradually eastward along strike off the western end. Both these parameters decrease sharply only in the vicinity of its transect with the rift. There, the escarpment disappears, becoming the lower limb of the Rom 1 fracture zone.

Rom 2 structures are extremely young: the trough bottom has practically no sediment and these sediments are concentrated only in small local deeps. The Vema depression corresponds to the deepest part of Rom 2. There, a thin sedimentary cover is present. Isolated, relatively low linear uplifts can be traced along the trough bottom. This pattern changes in the zone between 19°and 20°W. Because this discontinuity is traced across the entire Rom 2 and Rom 1 zones, we shall consider this phenomenon separately.

The southern escarpment is also divided into two segments, western and eastern ones. In the southern and northern escarpments, change of the corresponding segments (one segment for another) occurs at the same transect. We observe a characteristic reflection of structures: if the eastern segment of the northern escarpment is shifted southward with respect to the western one, the analog segment of the southern escarpment is shifted northward.

The western segment has the steepest and highest amplitude escarpment in the central part. West and east of it, these characteristics decrease. Similar variations along strike occur along the escarpment of the eastern segment. However, the eastern side of the escarpment terminates very abruptly in contrast to the western one. The southern escarpment cannot be traced east of 17°30′W.

The southern transverse uplifts do not form a uniform transverse ridge but are fragmentarily spaced. In the western part of the map, a single linear and narrow transverse ridge is present, though the bathymetric basis for this area is not of high quality. The apparent pronounced difference may be explained by the poor accuracy of the bathymetric maps used as a basis for our analysis. West of the eastern intersection, the transverse structures are associated with the eastern segment of Rom 2. Here only local structures occur instead of the uniform transverse ridge. They are either isometric uplifted blocks which dip gradually southward and are cut abruptly in the north by the southern escarpment of Rom 2 fracture, or linear structures which follow the southern escarpment. Small supplementary linear uplifts with symmetrical slopes can be seen locally at the crests of both. The transverse uplifts are dissected by submeridional, steep grabenlike structures which cross the fracture strike. They seem to be related to the structures of the southern oceanic plate.

Some structural features of the Rom 2 fracture zone cannot be described by a simple graben model. First are transverse uplifts along the southern escarpment. Some upthrow of the structure also occurs along the outer side of the northern escarpment, though it does not result in the formation of independent transverse uplifts. The transverse uplifts of the southern escarpment bear little resemblance to the antithetic transverse structures which are commonly present along the hanging wall of normal faults. All the above suggest an alternative mechanism to simple extension. The models which suggest diapiric (magmatic?) uplift rather than tension and graben formation seem to be more correct. Linear uplifts inside the graben can be hardly explained by a simple extension.

East of the rift, sublatitudinal flat-topped asymmetric linear uplifts are present in the marginal part of the southern oceanic plate. In morphology, these structures are similar to uplifts in the footwall of Rom 1 in which the northern wall is steeper. These structures suggest direct extension of the footwall of the Rom 1 fracture. Structures of Rom 2, from west to east along the fracture, cut gradually and almost completely the stripe of sublatitudinal structures of the Rom 1 footwall. Rom 2 fades out in its typical expression at a distance from the modern rift. The northern escarpment can be traced farther eastward than the southern one. Below, we will attempt to show that the southern escarpment of Rom 2 continues to the east as a prograding transform fault.

Rom 1 and Rom 2 have different structures in the transverse meridional zone, between approximately 19°30′ and 20°W. In the same transverse zone, a cluster of epicenters of earthquakes with $M > 3$ are present. This phenomenon can be explained by general changes in the strike of the entire Romanche fracture zone (from sublatitudinal in the west to ENE in the east) [*Bonatti et al.,* 1993]. The transverse zone is expressed differently in the Rom 1 and Rom 2 fractures. In the Rom 1 fracture zone, it corresponds to meridional transverse faults which, from bathymetry, can be related to normal faults with an eastern hanging wall. It is characteristic that the boundary of the Rom 1 fracture in the hanging wall of the fault is shifted northward with respect to the same boundary but in the western footwall. Such a displacement verifies once again the northward dip of the fault toward the upthrown limb.

In the Rom 2 fracture zone, the northern and southern escarpments are dissected and displaced in the same cross-section. The Rom 2 trough bottom is complicated there by three longitudinal linear uplifts (median ridges) with steep symmetric slopes.

Eastern Extension of the Romanche Fracture Zone

There are not many data on the structures of the Romanche fracture zone east of its transect with the eastern rift segment. We can rely only upon bathymetry and a scarce network of seismic profiles. East of the Romanche transect with the rift, there are only Rom 1 structures which remain unchanged up to 14°W. The only difference is that, in the place of the structural terrace at the rear of the Rom 1 strike-slip fault with a vertical component, north of it, there is a rear deep compensated by sediment and traced over the top of the acoustic basement. To the east, new structures appear and old ones are modified. There, the rear deep is pronounced in topography and is filled with sediments. Sedimentary thickness and relative depth of the trough increase gradually eastward. Two distinct structural layers separated by an unconformity are clearly seen in the structure of the sedimentary cover. The lower deformed complex forms an asymmetric synsedimentary clinoform, the sedimentary thickness of which increases southward. The upper stratified complex unconformably seals this structure. The general pattern resembles the one which would originate when listric fault structures are formed.

Eastward, the structure of Rom 1 itself is transformed considerably. The amplitude of the main strike-slip fault with a vertical component increases rapidly. It is not connected with sedimentation because the width of the sedimentary depression and sedimentary thickness decrease sharply in this direction. On the whole, the Rom 2 structure diminishes eastward until it dies out almost completely.

South of the Rom 1 structures, there appears a new trough parallel to it. This trough can be traced from 14°30′W (Figure 1). Eastward, the trough gets more pronounced and shows more topographic contrast. In the western cross-sections, it is filled with horizontally stratified sediment, the thickness of which decreases eastward until it completely disappears at the easternmost end (13°10′). In other words, this structure gets younger eastward. We have insufficient data to determine whether it is an independent structure equal to Rom 1 or Rom 2. However, we believe that the eastward fading out of Rom 1 structures is accompanied by the appearance of a new subparallel structure which gets younger in the same direction. This structural complex is recognized as the Rom 3 structure.

The Southern Plates

There is essentially no data on the structure of the southern oceanic plates. In the area adjacent to Rom 2, the most western of the plates is complicated by submeridional troughs and uplifts which separate transverse structures. More data are available on the marginal part of the eastern plate adjacent to the Rom 1 fracture and located east of the Recent rift. In the range from 16°30′W to 15°W (Figure 1), the submeridional structures of the oceanic plate change their strike rather sharply as they approach the Rom 1 fracture zone, first,

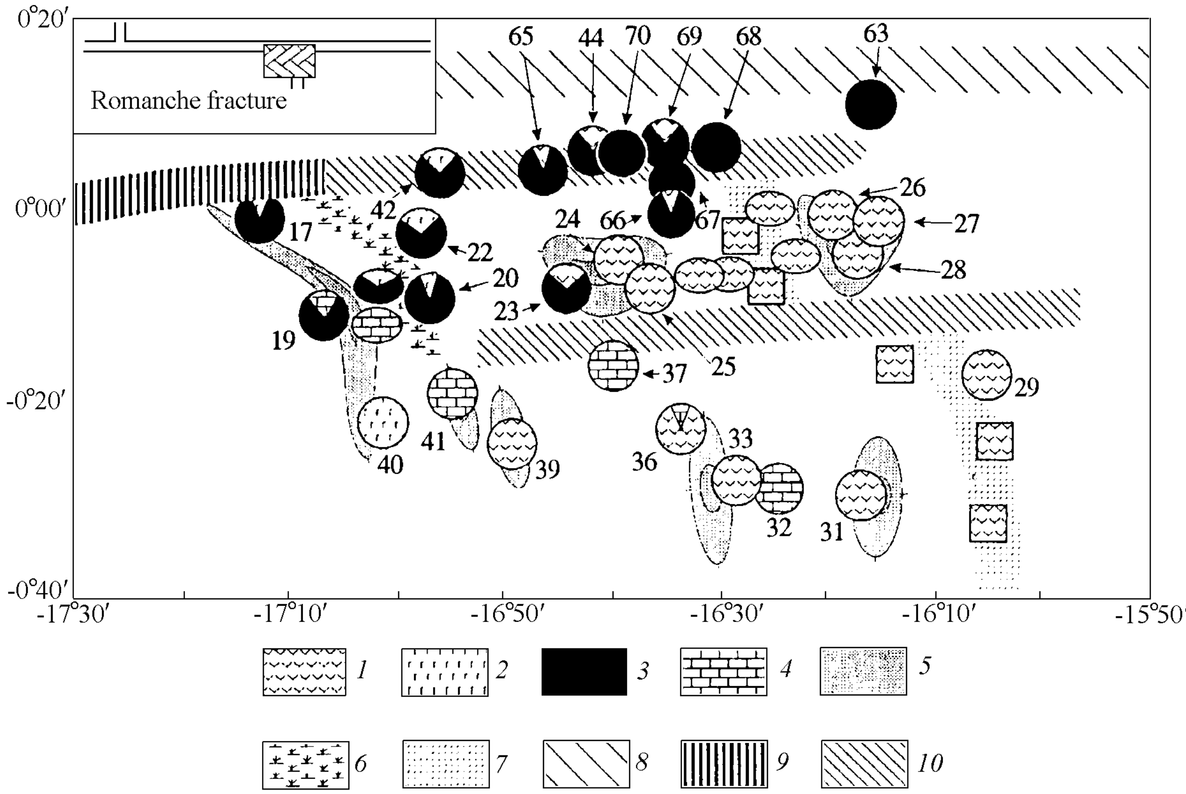

Figure 4. Location map of dredging sites at the eastern intersection of the Romanche fracture. 1–4, rock types: 1, basalt, 2, gabbroids, 3, ultrabasites, 4, limestones; 5–10, morphostructures: 5, uplifts, 6, "aborted" rift, 7, Recent rift; 8, Rom 1, 9, Rom 2, 10, small-amplitude transform faults. Circles stand for dredging data in the 16th cruise of the R/V *Akademik Nikolai Strakhov*, ellipses indicate those of the 13th cruise, squares show data by Shilling and Bonatti. Inset shows location of the area described in Figure 4.

for the NW one, and then, for the sublatitudinal one. Both troughs and uplifts are present.

The uplifts, when they have sublatitudinal orientation, have features of the uplifts of echelonlike structures in the footwall of Rom 1 fracture, and, most probably, are related to this zone. This zone seems to preserve the structural change from the longitudinal structures of the plate to the sublatitudinal local dislocations at the footwall of the shear fault. This supposition is verified by the structure of the stratified sedimentary rocks compensating the depressions. Based on seismic profiles across the depressions, horizontally bedded sediments seal these curving depressions in the same way as they do in the case of the footwall in the western segment of the same structure near 15°W.

East of 14°W, NNW linear troughs and uplifts can be seen in the marginal part of the plate. They have a right-angle junction with sublatitudinal structures of Rom 3. Seismic profiles across longitudinal troughs of this system demonstrate that sedimentary rocks have local character and small thickness if any. Most probably they are related to another dynamic system (Rom 3) which is characterized by this mode of sediment distribution.

The Rift and Its Western Edges

Two principal longitudinal tectonic elements can be distinguished within the eastern intersection, namely the Recent rift to the east and an extinct rift to the west. In addition, two transverse structural elements can be distinguished: small-amplitude transform fault in the south and a newly generated transform zone in the north in place of the rift junction with the Romanche structures (Figure 4).

The Recent rift is dissected into three segments, a southern segment which extends with no displacement to the transform fault, the middle one, which goes to the zone of the new transform, and the northern one which is related to the Romanche structures. The southern segment is morphologically pronounced. The rift valley is slightly asymmetric: its western wall is more steep as compared to the eastern one. The bottom is flattened and gentle. Uplifts are distinct on both sides. In the southern segment, fresh basalt (N-MORB) was dredged at three sites. The middle segment has similar structure. However, the rift bottom is complicated by additional longitudinal uplifts and faults. Uplifts at the rift sides are not so distinct. N-MORB, E-MORB and alkaline basalts were sampled there [*Sushchevskaya et al.,* 1994]. The northern segment cannot be called a rift. There, no morphologically uniform rift zone occurs. Adjacent to the Romanche zone is a complex mosaic of orthogonally oriented small blocks of troughs and uplifts which locally have extremely steep slopes. Numerous dredgings in this zone have yield mainly serpentinized hyperbasites. In some dredged samples, fresh basalt may occur in minor quantity; it does not exceed several percent of the total dredged material.

Magnetic anomalies compiled from the data of the 13th cruise of the R/V *Akademik Nikolai Strakhov* do not reflect the structure of the Recent rift; there is no apparent coincidence of the boundaries of magnetic anomalies with the structures. Most of the rift corresponds to a negative magnetic lineation, which is not typical of Recent mid-oceanic rift systems, in which an axial positive magnetic lineation is most pronounced.

We believe that the above features can be explained by simultaneous gradual northward prograding and evolution of the rift system. The southern segment shows the most advanced evolution; the middle segment corresponds to a less mature stage of the rift development, when the deeper mantle was drained.

The "aborted" rift named and described by Bonatti is situated to the west. It is a negative linear structure extending submeridionally as the rift does. Two segments separated by a small-amplitude fault can be recognized in its longitudinal section. The southern segment of this structure is expressed by isometric depression. From the data gathered on the 13th cruise of the R/V *Akademik Nikolai Strakhov*, the depression is filled with stratified sedimentary rocks with horizontal bedding which seal this structure. Linear uplifts can be traced over depression flanks which stress its resemblance to the rift. Basalts, gabbroids and ultrabasites were dredged from the slopes of the boundary uplifts, whereas limestones were dredged from the top of one of the linear uplifts.

The northern segment of the "aborted" rift is well expressed morphologically. It consists of a narrow graben-like trough with steep walls the relative elevation of which increases northward. The given trough is probably a graben, the bottom of which is covered by sediment. Local uplifts with moderate elevation are situated on the fault flanks. The outer slopes of these uplifts dip off the graben. In the southern part, the graben has a longitudinal strike. To the north, as it approaches the Rom 2 trough, the structure bends sharply westward and then, directly at its junction with the trough, northward. The "aborted" rift graben is separated from the trough bottom by a small sublatitudinal uplift.

From dredging data, the arch of the uplift at the western flank of the rift is covered by limestones. Dredging of the slopes and bottom of the northern part of the "aborted" rift showed a complete absence of basalt which is typical of rift valleys. The dredged cores contain predominantly hyperbasites, and to a lesser extent, gabbro and limestones.

The appearance of the "aborted" rift suggests jumping of the spreading axis. This is supported by basalt hardened glass, which is a good criterion to determine the relative duration of effusive exposure at the bottom surface. Absent erosion, the metamorphic grade of glass is proportional to the relative age of the dredged lava. Dredging was performed along the latitudinal profile from the Recent rift to the interrift area to the "aborted" rift. This dredging did not show a regular progressive increase in the metamorphic grade of glass away from the spreading axis slightly metamorphic glass appears in the vicinity of the "aborted" rift.

Lower Miocene foraminifera and nanoplankton were detected in limestones overlying the western flank of the "aborted" rift (Site 19, Figure 4). Limestones dredged to the east between the "aborted" and Recent rifts (Site 36, Figure 4) contain Upper Miocene foraminifera and nanoplankton (identified by Krasheninnikov and Muzylev). Paleontological data thus verify the jumping of the spreading axis and corresponding rifts.

Comparison of the "aborted" rift with the Recent one shows that the former is more mature. It is expressed morphologically as a rift along its entire extent. There is no area of dispersed spreading typical of the primary stage. Similar to the Recent rift, the northern part is characterized by a "dry" spreading mode, although the boundary of such spreading is displaced southward.

A small-amplitude transform zone is well developed in the strike variations of the Recent rift walls. A sharp kneelike bending of the rift is attributed to this zone. However, its axial part is not broken. In the "aborted" rift, the transform fault shows eastward displacement of its eastern wall in the southern segment. The transform fault does not cross the "aborted" rift and does not shift the structures of the western wall. The fracture zone is well pronounced in the magnetic anomaly map, where it corresponds to the kneelike bending of the isoanomals and local latitudinal anomalies.

The transverse zone seems to be more complex; it is a new transform fault zone. It consists of a comparatively wide stripe within which structures experience sharp kneelike bending with sinistral displacement of limbs of horizontal flexures. There, sublatitudinal faults which dissect longitudinal structures are practically absent. Boundaries of local magnetic anomalies follow the same curves. Trifonov described similar structure along the strike of the transform fault but inside the Recent neovolcanic zone of Iceland. That was verified in later works. In this case, bending structures showed extremely deep tension fractures or chains of small centers of fracture lava eruption. They were considered to be newly established transform faults.

Results and Conclusions

The Romanche fracture zone cannot be considered as a structure with a uniform dynamics, kinematics and evolution. Its different segments evolved at different time and according to different dynamic and kinematic modes. Moreover, the fracture zone is not continuous in space.

Deformations complicating it move not only along the strike of the structures but also across strike, thus forming new fracture zones with different spatial orientation. This conclusion is drawn in some works [*Bonatti et al.,* 1993; *Searle et al.,* 1993], though opinions may differ.

The relatively more ancient dynamic system of Rom 1 has a constant east-northeast orientation, which according to plate tectonics, corresponds to structures with extremely great pole distance. Dynamics and kinematics of that structure have dextral displacement against relative compression which leads to the formation of upthrust-normal faults with northward dipping of hanging and footwalls. From the bathymetric data (locally not very detailed), this structure can be traced far to the west of the Romanche segment and is levelled (dies out?) at a distance approximately 150–200 km short the transect with the western segment of the rift, not at the level of the southern end of the rift but considerably to the north. This structure is apparently wedging out eastward in the cross-section where a new sublatitudinal structure, situated to the south, originates (Rom 3).

The younger structure of Rom 2, as compared to Rom 1, also continues westward beyond the study area. In the west, the Rom 2 system approaches the western rift at a right angle. The junction zone (intersection) of the transform fault with the rift is regular. There, we can see a nodal depression and inside corner high, and fresh basalts are spread over the intersection.

The eastern intersection has considerably different structure. A nodal depression and corner high are absent there. There is no pronounced rift valley at the intersection either, and basaltic volcanism is practically absent ("dry" spreading mode of diffusive type). The well expressed fault boundary of the southern trough boundary terminates abruptly west of the intersection.

We suggest an interrelation between these phenomena. The general intersection structure in its classic version seems to be determined by superposition of two independent factors: dynamics determine the kinematics of structure formation, whereas magmatism and the hot melt inflow producing it yield diapirism which is manifested in such structures as a transverse ridge or corner high. A lateral magmatic discharge may be partly responsible for the formation of nodal depressions. Diapirism naturally enhances the development of vertical motions due to dynamics. In its turn, tectonic motions extend the magmatic flow direction. In the eastern intersection we proposed the case of a prograding rift where tectonic prograding is a bit ahead of the magmatic one. Such lagging is particularly distinct in the case of the "aborted" rift, where "dry" spreading is far ahead of the magmatic one. Not all characteristic features of a classic intersection are present there, as the southern fault is cut west of this place. Further evolution of the zone of the developing transform fault, which separates areas of "dry" diffusive and normal volcanic spreading, would build up the transform zone of Rom 2 farther to the east. It seems expedient to discuss a possibly more complex model of rift and transform fault formation which could explain the numerous anomalous structural and evolutionary features of this complex geodynamic system.

Another feature of the eastern intersection is related to eastward jumping of the rift. It is hardly possible that jumping occurs in the "aborted" and Recent rifts exclusively. Most probably, there were several jumpings like this one. A detailed study of dike complexes in ophiolites provides evidence for the common occurrence of such phenomenon in ancient oceanic crust. Jumping as a phenomenon was first studied in Iceland and subsequently was recorded in some places on the Mid-Atlantic ridge. From the available data, jumping in a given structure would occur in only one direction. Therefore, it is natural to expect a system of "aborted" rifts west of the Recent intersection. The apparent arc geometry of Rom 2 in plan and also the comparatively sharp bend of this structure in the vicinity of 19°30′W, where an unusual transverse structural zone is described, seem best explained by a combination of subsequent northward prograding of the rifts and eastward jumping.

Figure 5 is an attempt to generally explain the possible evolution and subsequent stages of tectonic events along the entire Romanche extension from the western intersection to the eastern part of the study area. The western rift is assumed to be to be a stable reference mark with respect to all lateral displacements.

At the stage when Rom 1 was set and evolved, the western intersection was situated slightly to the north of the Recent rift termination. A passive segment of Rom 1 probably did exist. In any case, a sublatitudinal tectonic escarpment can be traced on the bathymetric map of Recent structure 150 km west of the rift and symmetric

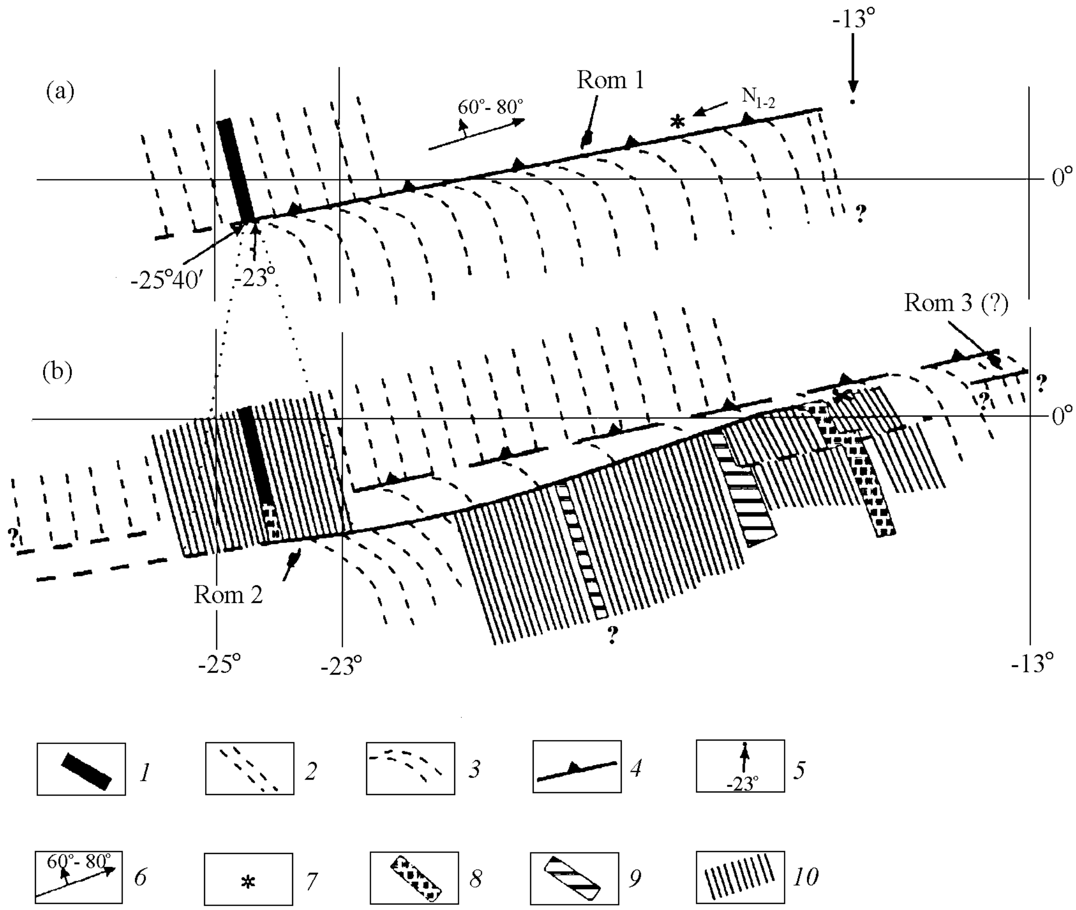

Figure 5. Evolution of the Romanche fracture zone for the life time of Rom 1 (a) and Rom 2 (b) systems. For (a): 1, western intersection rift and 2, supposed rift of eastern intersection; 3, newly formed crust; 4, Rom 1 fracture; 5, present reference marks in the reference network of Rom 1 fracture during its active stage; 6, strike-slip component orientation and supposed fault dip; 7, sampling site of the Late Miocene–Early Pliocene fauna. For (b): 8, newly set rifts and rift segments; 9, "aborted" rifts; 10, newly formed crust.

to the western termination of Rom 1. It is more difficult to determine the eastern side of the fault. If we assume that the kinematic system of a strike-slip fault with a vertical component is preserved for the entire length of the active segment, the eastern intersection should be in the place where the structures of the footwall approaching the fault in the east change to orthogonal ones. This change occurs near 13°W. By reconstructing the structures at the final stage of active motion, we may gain the desired result. Assuming the spreading rate was about 2 cm/yr, this reconstruction does not contradict the presence of Late Miocene–Early Pliocene fauna in the hanging wall of the fault. In this reconstruction, relative plate motions correspond to the observed structural pattern of a dextral shear fault. Synsedimentary processes which occurred at the rear of the hanging wall of Rom 1 fracture apparently correspond to this active period.

The appearance of the new Rom 2 dynamic system resulted in the fading out and sealing of the old one. The western rift prograded southward with no latitudinal displacement up to its present position. We can only guess whether it was a one-time prograding or not. According to the bathymetric map, it occurred in several stages. The eastern segment of the rift was set considerably to the west of the previous one, which resulted in a complete reorganization of the entire system and creation of a new transform fault. A new eastern rift subsequently shifted eastward repeatedly, most probably jumping northward and then prograding to its present position. This scheme does not allow formation of a passive transform segment, as the latter is compensated by eastward jumping of the rift. The data seem to agree with the proposed scheme. The basic model based on plate tectonics and tectonic lamination of the lithosphere. However, the data make us modify considerably these suppositions and add such notations as prograding, jumping, diffusive spreading, and so forth.

The principal conclusion deduced from the above material is the temporal and spatial instability of fracture zone systems, which can be changed for short periods, with sharp alternation of the principal tectonic boundaries (rifts, transforms). The principal structures of geodynamic system may migrate (jumping, prograding) as it evolves. However, we cannot conclude definitely about the mechanism of such instability of boundaries and dynamic environment. The cause seems to be lithospheric as well as lamination compositional and structural lateral inhomogeneity of the isolated lithospheric slabs. Relative displacement of subhorizontal lithospheric slabs may explain most of the described phenomena. The regularities we described here provide evidence for character of the Romanche fracture zone, which is the principal divide between the different geological history of the Central and Southern Atlantic. Despite complex variations in time of several geodynamic systems (Rom 1, Rom 2, etc.), the largest structure, the Romanche fracture zone, which extends from one continent to the other, was stable in space for at least the entire Cenozoic. Our data and analysis illustrate the need for a historical-geological approach to the study of oceanic fault structures similar to that applied to continental faults. So far, such an approach has been very limited and subordinated to pure geodynamic abstractions.

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