Morphology and tectonics of the Romanche transform fault: high-resolution mapping and precision sampling of the northern slope

Romanche transform fault
Seabeam
Glauconite
Tectonics
Faille transformante de La Romanche
Seabeam
Glauconie
Tectonique

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ABSTRACT

Precision positioning by means of seafloor acoustic transponders and high-resolution mapping using multi-narrow beam sounder, the Seabeam, enabled us during the Romancha cruise of the R/V Jean Charcot to construct a detailed chart of a section of the northern wall of the Romanche transform fault and to recover accurately located rock and sediment samples from selected sites. The main structural features encountered on the northern wall consist in : 1) elongated ridges having a general East-West orientation and bounded by steep scarps, and 2) discontinuous terraces covered by pelagic sediments. The thin sediment accumulation in the topographic lows, the presence of glauconite sampled *in situ* but at great depth, and the extreme variability of the outcropping rocks, often mylonitized, confirm the major importance of vertical motions in the studied area. Using the sediment stratigraphy and the morphology, we present a tentative chronology for the tectonic history of the area.

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RÉSUMÉ

Morphologie et tectonique de la faille transformante de La Romanche : cartographie Seabeam et échantillonnage précis de la paroi nord.

L'utilisation d'un système de positionnement par balises acoustiques mouillées sur le fond et du sondeur multifaisceaux à haute résolution Seabeam a permis au cours de la campagne Romancha du N/O Jean Charcot de cartographier très finement une section de la paroi nord de la faille transformante de La Romanche, et d'y prélever des échantillons de sédiment et de roches sur des sites choisis. Les grands traits structuraux rencontrés sur la paroi nord sont les suivants: 1) des chaînes allongées d'orientation générale Est-Ouest, délimitées par des escarpements à forte pente; et 2) des terrasses sédimentaires isolées. La faible accumulation de sédiment dans les creux, la présence de glauconie, trouvée en place à grande profondeur et l'extrême variabilité des roches affleurantes, souvent mylonitisées, confirment l'importance majeure des mouvements verticaux dans cette région. A partir de la stratigraphie des sédiments et de la morphologie de la zone étudiée, nous proposons une reconstitution partielle de l'histoire tectonique de la région.

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INTRODUCTION

The fracture zones in oceanic crust have been classically interpreted as having a very simple structure, being a slice or "window" showing the structure of the oceanic crust (Hess, 1962). However, studies of these zones have disclosed important topographic and petrologic anomalies, which indicate a more complex structure and imply significant vertical tectonic movement (Bonatti, Honnorez, 1976; Melson, Thompson, 1970; Thompson, Melson, 1972). Direct observation by diving saucer of a fracture zone in the Famous area near 37°N on the Mid-Atlantic Ridge has shown the existence of only small-scale fault block structures forming the walls of this transform fault (Arcyana, 1975; Francheteau *et al.*, 1976; Choukroune *et al.*, 1978). In these zones of very irregular relief, morphologic studies conducted by wide-beam sounders are extremely diffi-

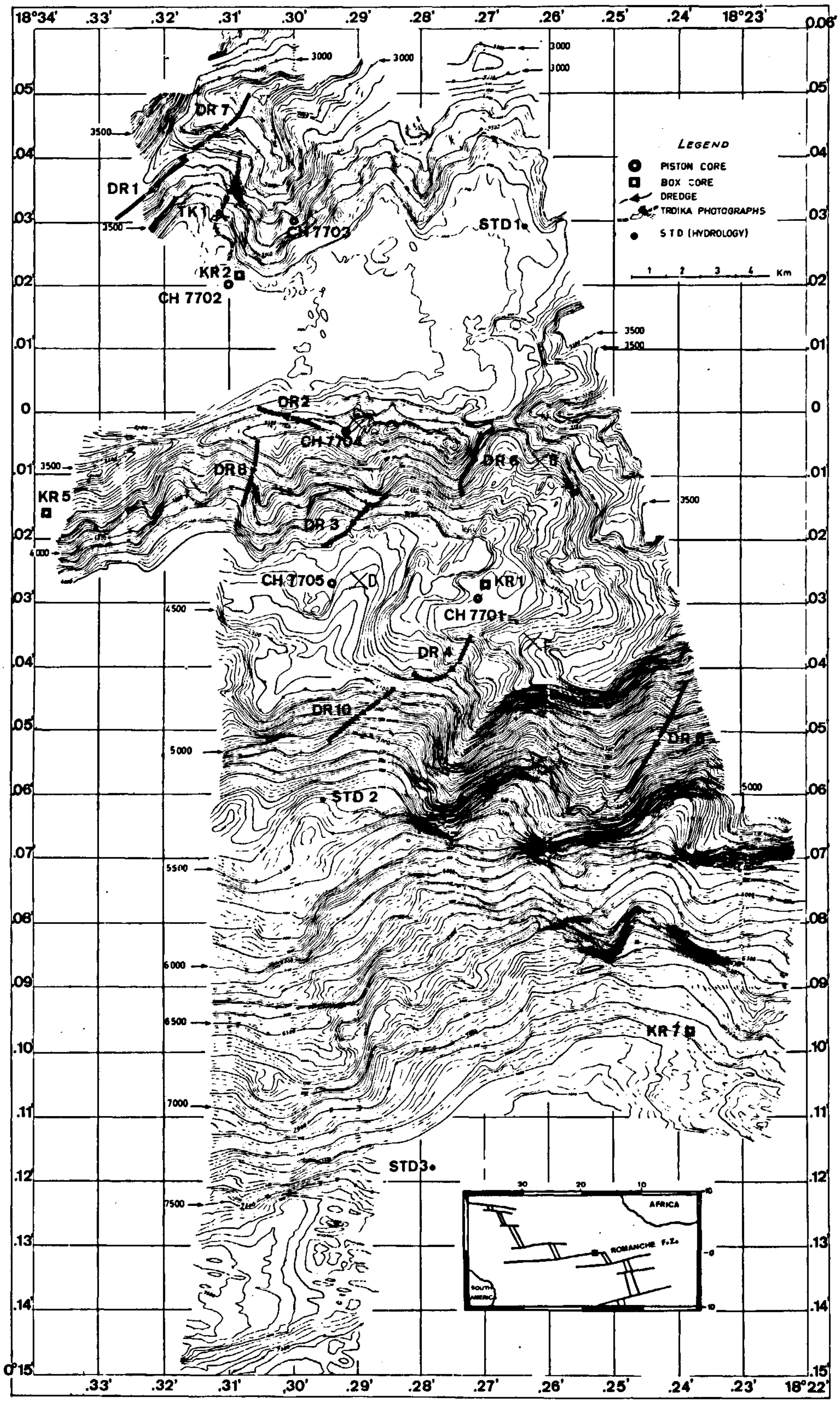

Figure 1

Reduced version of the original bathymetric chart (scale: 1/25,000) of the studied portion of the northern wall of the Romanche transform fault based on high-resolution, real-time, machine-contoured bathymetric strips produced aboard the R.V. Jean Charcot using the Seabeam swath sonar system. Locations of sampling sites are indicated for piston cores (CH 77..), box cores (KR..), dredges (DR..) and the bottom photographs survey (TK1). The four Atnav transponders are indicated by the letters G, B, D and F.

Réduction de la carte bathymétrique au 1/25 000^e représentant la partie étudiée de la paroi nord de la faille transformante de La Romanche, carte faite à partir des bandes bathymétriques dessinées automatiquement sur le N/O Jean Charcot par la table traçante de l'appareillage multifaisceaux Seabeam. L'emplacement des sites de prélèvement est indiqué par CH 77.. pour les carottes Kullenberg, KR.. pour ceux de grande section, DR.. pour les dragages et TK1 pour la série de photographies faites sur Troïka. Les quatre répondeurs ATNAV sont indiqués par les lettres G, B, D et F.

Table
Inventory of the material recovered during the 1977 *cruise of R. V. Jean Charcot on the northern wall of the Romanche transform fault near* 18°30' *W (CH 80-DR.. for dredges, CH 77.. for other samples) with, in addition, two cores (CH* 7108 *and CH* 7109*) sampled during the Harmattan cruise of the R. V. Jean Charcot in the same area in* 1971.
Inventaire du matériel prélevé au cours de la campagne Romancha du N/0 Jean Charcot sur la paroi Nord de la faille transformante de La Romanche vers 18°30' Ouest (CH 80-DR.. pour les dragages et CH 77.. pour les autres échantillons) auquel s'ajoutent deux carottes (CH 7108 et CH 7109) prélevées au cours de la campagne Harmattan du N/O Jean Charcot dans la même zone en 1971.

Ridge I				
CH 80-DR07	0°03.8'N	– 18°31.6'W	3,300 m	Weathered and metamorphosed basalts
	0°04.9'N	– 18°30.5'W	2,820 m	Thick (32 mm) Fe-Mn crust.
CH 80-DR01	0°03.1'N	– 18°32.6'W	3,640 m	One thick (25 mm) Fe-Mn crust.
	0°04.5'N	– 18°31.1'W	3,250 m	
CH 77-TK 1	0°02.4'N	– 18°31.0'W	3,760 m	Bottom photographs survey (Troika) showing pillow flows (3,670; 3,640-3,550; 3,390-3,270; 3,220-3,150). Ripple marks on sediments at 3,650 m.
	0°04.2'N	– 18°30.8'W	2,980 m	
Terrace A				
CH 7703	0°03.0'N	– 18°30.0'W	3,400 m	0.10 m of foraminifera ooze
CH 7702	0°02.0'N	– 18°31.1'W	3,780 m	5.50 m of foraminifera ooze, $CaCO_3$ = 80 %, regular sedimentation rate until late Pleistocene (1 cm/1 000 yr).
CH 77-KR02	0°02.1'N	– 18°30.8'W	3,787 m	0,35 m of foraminifera ooze.
Ridge II				
CH 80-DR02	0°00.3'N	– 18°30.7'W	3,660 m	One fragment of plagio-pyroxene gabbro.
	0°00.3'N	– 18°29.6'W	3,580 m	
CH 7704	0°00.3'S	– 18°29.2'W	3,470 m	5.77 m of foraminifera ooze, $CaCO_3$ = 80 %, Pleistocene age until 4.80 m, fossils of early Pliocene below.
CH 80-DR06	0°01.3'S	– 18°27.3'W	3,850 m	Diabasic rocks and weathered basalts coated with abundant Fe-Mn crusts interbedding of glauconite.
	0°00.3'S	– 18°27.0'W	3,680 m	
CH 80-DR08	0°01.6'S	– 18°30.8'W	4,100 m	Serpentinites, gabbros, pegmatites, breccias, anorthosites, metamorphics of the greenschist facies, Fe-Mn crusts and nodules.
	0°00.4'S	– 18°30.5'W	3,500 m	
CH 80-DR03	0°02.2'S	– 18°29.6'W	4,300 m	Basalts, breccias, metamorphics of the zeolite and greenschist facies, Fe-Mn coating and crusts.
	0°01.5'S	– 18°28.9'W	4,010 m	
CH 7109	0°01.6'S	– 18°36' W	3,650 m	3.60 m, pebbles with Fe-Mn coating, manganese nodules, reworked sediment, absence of fauna on 50 cm thickness, Oligocene below 3 m.
CH 77 KR05	0°01.6'S	– 18°33.8'W	3,670 m	Fe-Mn crust.
Terrace B				
CH 7705	0°02.7'S	– 18°29.4'W	4,350 m	5.92 m of foraminifera ooze, $CaCO_3$ = 56 to 90 %, constant remanent magnetization between 1.00 and 4.40 m, late Pliocene at the base.
CH 77 KR01	0°02.7'S	– 18°27.0'W	4,120 m	0.30 m of foraminifera ooze.
CH 7701	0°02.9'S	– 18°27.1'W	4,117 m	4.85 m of foraminifera ooze, $CaCO_3$ = 90 %, disturbed remanent magnetization, recent-Pliocene until 0.20 m, Pleistocene-Pliocene until 0.50 m, Mid-Pliocene below.
Steep slope				
CH 80-DR04	0°04.1'S	– 18°28.1'W	4,536 m	Serpentinite, abundant Fe-Mn encrusting.
	0°03.5'S	– 18°27.2'W	4,040 m	
CH 80-DR10	0°05.1'S	– 18°29.4'W	4,970 m	Pelite, breccia, serpentinite, mylonite, metamorphics of the greenschist facies, ophicalcite, rodingite, Fe-Mn crusts.
	0°04.4'S	– 18°28.4'W	4,650 m	
CH 80-DR05	0°05.8'S	– 18°24.7'W	4,950 m	A small serpentinite pebble with Fe-Mn coating.
	0°04.2'S	– 18°23.9'W	4,200 m	
Bottom bench				
CH 7108	0°14'S	– 18°37'W	7,500 m	7.60 m, reduced sediment with 2% of organic carbon, without carbonates except 5.10-5.90 m and 7.10-7.60 m, sedimentation rate: 50 cm/1 000 yr.
CH 77 KR07	0°09.7'S	– 18°23.8'W	7,350 m	Several pebbles of very altered serpentinite.

cult, the recovery of rock samples by dredging has often been imprecise, and core sampling for representative sediment sections from the flanks of the fracture zone valleys (Arcyana, 1975) has often been impossible. During the "Romancha" cruise of the research vessel "Jean Charcot", a recent equipment gave us new capabilities to study the largest and most rugged fracture zone of the Mid-Atlantic Ridge, the Romanche Fracture Zone. A high-resolution, multi-narrow beam sounder, the Seabeam, coupled with four acoustic transponders moored at the corners of a 5 km square grid enabled us to know the position of the vessel at all times with an accuracy close to 90 m.
Likewise, towed sampling gear (dredges, camera) were equiped with transponders providing the same precision for sample location. The Seabeam bathymetric survey system allowed us to produce a detailed real-time contour chart of an area 15 km × 35 km covering a section of the northern wall of the transform fault (Berthois, Réauté, 1978; Renard, Allenou, 1979). These systems allowed us to recover representative samples from selected sites, in particular to study the sedimentary deposits on the flanks of the transform fault, in order to evaluate vertical tectonic movement. Nine dredges (CH80 DR..), five piston cores (CH77..), four box cores (CH77-KR..) and a bottom photographic survey were used for this study. Additional informations were given by two piston cores (CH7108 and CH7109) taken during a previous cruise in the area (Table, Fig. 1).

MORPHOLOGY

The Romanche Fracture Zone, the largest offset in the Mid-Atlantic Ridge shows the largest scarp of oceanic crust known in the Atlantic Ocean, descending from 1 000 to 7 850 m depth (Heezen *et al.*, 1964; Gorini, 1977). We selected for detailed study of the Romanche transform fault an area along a corridor (15 km × 35 km) perpendicular to the fault trend, on the northern wall, between 18°24' and 18°32' West. The surveyed area slopes from 2 800 m at the crest down to 7 600 m near the Vema Depth.

Figure 1 shows at reduced scale the topographic map of the survey area. Figure 2 is a block diagram based on Seabeam contour map. Profiles have been digitized and computer drawn on a drum plotter (Berthois, Froidefond, 1978).

The area encompassing the crest is composed of an East-West trending ridge (Ridge I) ranging in depth from 2 900 to 3 700 m, with irregular small scale features such as several isolated peaks as shallow as 2 740 m (about 200 m above the surrounding reliefs).

A bottom photographic survey was made using a "Troïka" system towed across that ridge. The photographs revealed alternating steps of relatively smooth sediment bounded by steeper scarps with rocky outcrops. In several instances, pillow lavas and isolated massive structures, which could be interpreted as being dikes or thick flows, were observed. Many of these appeared to be coated by Fe-Mn encrustations. Fragmented lava was observed at the base of the scarps.

This top ridge slopes southward with a grade of 25% terminating in "Terrace A", a large shelf (3 km × 7 km) at 3 760 m depth. This terrace may be enclosed to the East by a junction between Ridge I and a deeper ridge, "Ridge II", lying between the Equator and 0°02' South.

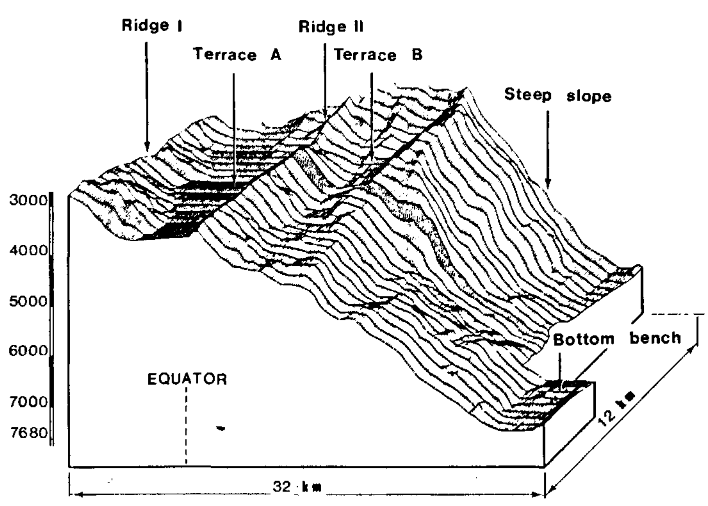

Figure 2
Block diagram of the northern wall of the Romanche transform fault based on Seabeam contour maps, from Berthois and Froidefond (1978). *The vertical exaggeration is about* 4.
Bloc diagramme de la paroi nord de la faille transformante de La Romanche construit à partir de la carte Seabeam, par Berthois et Froidefond (1978). Exagération des profondeurs: environ 4 fois.

Ridge II rises 300 m above Terrace A and then descends to 4 300 m depth. Like Ridge I, Ridge II exhibits a general East-West trend with isolated peaks as shallow as 3 400 m along the crest. Two transverse valleys penetrate Ridge II (Fig. 1 right and left of the center) resulting in extremely contorted topographic contours especially at 3 500-3 600 m depth and in the eastern portion of the studied area.

Another terrace, "Terrace B", is located at the base of Ridge II and gently slopes (5%) from 4 300 m down to 4 500 m depth. This terrace is much more complicated than Terrace A, and features tentatively interpreted as erosion channels (e.g. around transponder D) can be observed. This is particularly notable to the East where Terrace B appears to be bounded by a southern extension of Ridge II.

From the edge of Terrace B, a long steep slope descends to the Vema Depth, the sea floor dropping from 4 500 m down to 7 600 m over a distance of about a dozen kilometers. This "Steep slope" is far from uniform (Fig. 1), exhibiting several breaks with major steps at 5 300, 5 900 and 6 600 m depth. Very abrupt slopes, reaching 100%, can be observed locally.

The southernmost and deepest part of our area of study, the "Bottom bench", has been described by Heezen *et al.* (1964).

All these structures dip gently to the West, towards the Vema Depth.

SEDIMENTS

High-resolution mapping and precision sampling allowed us to obtain representative sediment samples on each main structural feature of the northern wall of the Romanche transform fault (Table).

Core CH7702, sampling Terrace A, penetrated 5.5. m of undisturbed sediment indicating regular sedimentation since late Pleistocene. Nannofossils datum levels indicate a sedimentation rate of 1 to 2 $cm/10^3yr$. Core CH7704 (5.8 m long), recovered from the top of Ridge II, exhibits a much more complicate history. The base of this core contains well preserved micro and nannofossils of early Pliocene age. These are overlain by alternating sequences of broken eroded flora and fauna of mixed early-late Pleistocene ages, followed in turn by well preserved latest Pleistocene/Recent assemblages. Core CH7109, also on this ridge, revealed numerous manganese nodules buried in sediments characterized by an important dissolution, overlying a succession of apparently undisturbed Oligocene and Miocene sediments, only 3 m below the water-sediment interface.

The sediment in cores CH7701 and CH7705, taken on Terrace B, agree with the rugged topography of this structure, in that they indicate a complicated sedimentary history with erosion and/or slumping. The study of remanent magnetization indicates also for these cores disturbed sedimentation (Laj, pers. comm.). The lower 4 m of core CH7701 contain assemblages of Mid-Pliocene age (zone NN16) overlain by half a meter of sediment with mixed Pliocene-late Pleistocene micro and nannofossils. In contrast, core CH7705 shows half a meter of lower Pliocene sediments at the base, overlain by four and a half meters of well preserved undisturbed latest Pleistocene/Recent sediments.

Core CH7108, recovered from the bottom bench, indicates a very high sedimentation rate (50 cm/10^3yr) for the bottom of the Romanche trench (Bonté, 1981). This was established by radiochemical measurements (Ionium) and C^{14} dating of the abundant organic matter (2%) present in the core. Turbidites of mixed sediment were also observed in some of the carbonate sequences. Such high sedimentation rate is not surprising if we consider the funnel shape of the trench, the mean slope and the intense seismic activity of the area.

From the detailed stratigraphic studies of the sediment cores, an attempt is made to reconstruct the sequence of the main tectonic events which are summarized as follow:

— the occurrence of Oligocene sediments in core CH 7109 reflects the minimum age of the crust forming the northern wall of the Romanche transform fault in this area;

— seismic profiles by Bonatti *et al.* (1979), taken on both sides of the survey area (18°10' and 18°45' West) show that Ridge II and Terrace A constitute a regular feature of this part of the Romanche northern wall. They show a thickness of 200 to 300 m at most for the sediment infilling of the terrace. This thickness is compatible with the dip of the flanks of Ridges I and II. If we extrapolate the sedimentation rate of about 1.5 cm/10^3yr measured for the top 5 m of core CH7702 to the complete sediment sequence, an age of 10 to 20 million years is estimated for the formation of Ridge II/Terrace A structure;

— in the Vema Depth, the sediment cover is thin (about 300 m, Heezen *et al.*, 1964). The Romanche trench below 5 000 m is a closed basin; this precludes any significant current action in the bottom part, either scour or local accumulation of sediment. As the upper five meters of core CH7108 display a very high sedimentation rate (50 cm/10^3yr) of non carbonated, reduced sediment, we have to admit that the Vema Depth has a rather recent origin. A simple calculation leads to an age of 600,00 years. This age may not be taken to face value, as calculated from one core. However, taking into account the slumped carbonate material present at the base of core CH7108 would suggest an even faster mean sedimentation rate.

ROCK DESCRIPTION

A general description of the various rock types recovered from the northern wall of the Romanche transform fault near 18°26' West is given in the Table. A great variety of rock types was found at various depths: sedimentary rocks, altered basalts, gabbros, anorthosites, pegmatitic gabbros, rodingites, serpentinized peridotites, ophicalcites (serpentine and calcite) and mylonites are among the most commonly encountered (Table). The regional distribution of the rocks is shown

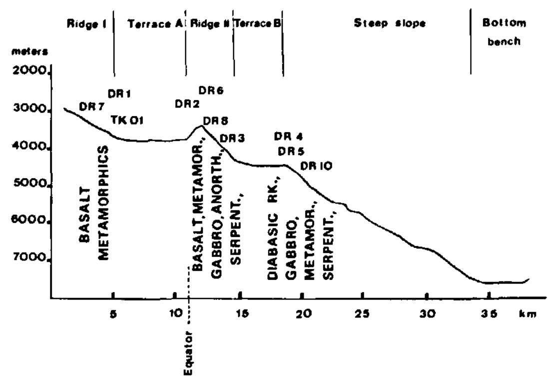

Figure 3

North-South profile along the northern slope of the Romanche transform fault at 18°29' *West showing the distribution of the major rock types recovered by dredging from the R.V. Jean Charcot (vertical exaggeration = 3).*

Profil Nord-Sud le long de la pente nord de la faille transformante de La Romanche à 18°29' Ouest, montrant la distribution des principaux types de roches prélevées au cours de la campagne Romancha (exagération des profondeurs: 3 fois).

on a profile across the northern wall of the transform fault (Fig. 1, 3). On Ridge I, we have definite evidence of pillow flows from the bottom protographs and dredge hauls. Some of the basaltic rocks are weathered and others are altered to a low grade metamorphic facies with a common albite-chlorite-epidote assemblage (Table). On Ridge II, the basaltic rocks are similar to those of Ridge I, the plagioclase-pyroxene bearing basalts also weathered and metamorphosed. However, on this ridge, in addition to the basaltic rocks, gabbros, anorthosites and serpentinized peridotites are found. Evidence of deformation was noted in some crushed gabbros found near the top of Ridge II. In addition, two dredges containing extremely sheared and mylonitized material associated with serpentinized peridotites and altered basaltic rocks were recovered from the flank of the same structure (Ridge II, Fig. 3, Table).

The lithological heterogeneity, with no clear evidence of stratigraphic succession within the rock sequences encountered, does not seem to agree with the simple layered structure proposed by Hess (1962) nor does it fit with the hypothesis of massive intrusive bodies of serpentinites raised diapirically from the mantle as described by Bonatti (1978). Previous studies (Francheteau *et al.*, 1976) have also shown the complexity and the heterogeneous nature of rocks encountered on major North Atlantic fracture zones. The amount of serpentinites encountered within each dredge haul from the slope of the Romanche Fracture Zone northern wall is low compared to the other extrusive and intrusive rocks recovered. Therefore, ultramafic material from deep crustal origin is probably not the main component of these ridges and could represent thin slivers injected between fault planes. The major part of the gabbros and pegmatitic units might represent cumulates differentiated during the ascent of a basaltic magma and exposed posteriorly to the surface by local faulting. This faulting must result from intense diastrophism prevailing in the transform fault area, due to shearing between two lithospheric plates and also due to localized compressions and/or extensions resulting from changes in plate relative motion. The possibility of uplift reaching depths as shallow as the photic zone is suggested by the recovery of corals from 1 000 m on the top of the northern wall near 17° West (Bonatti *et al.*, 1977), and by the recovery of glauconized foraminiferal ooze on Ridge II at 3 680-3 850 m depth (CH80 DR06) in the study area. Physico-chemical conditions for glauconite formation from globigerina ooze are very restrictive and seem to occur exclusively in shallow water environments (White, 1974). Thus Ridge II may have been near the sea surface in the past.

SUMMARY AND CONCLUSIONS

The northern wall of the Romanche transform fault near 18°30'West in the equatorial Atlantic consists of two major types of structures : 1) the elongated ridge systems with isolated peaks and a general East-West trend; 2) well defined sedimentary terraces bounded by the E-W trending ridges. The observed topography suggests that the northern wall of the Romanche transform fault in the study area results from a complex block faulted structure. The uplift of Ridge II is suggested by the occurrence of material from shallow water environment (glauconitic products). No unique process, such as diapirical raising of serpentinite or deep crust exposure by a major tectonic uplift can explain the heterogeneous nature of the rocks found in each scarp. We propose that part of the rock variability could be explained by differentiation of cumulates during ascent of basaltic magmas, exposed later by local faultings. Our stratigraphical results confirm a high activity of vertical tectonism for the last few million years in the area.

Acknowledgements

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