Observation of sections of oceanic crust and mantle cropping out on the southern wall of Kane FZ (N. Atlantic)

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ABSTRACT

The objective of the 20 *Nautile* dives of the recent Kanaut cruise was to study the southern wall of the Kane Fracture Zone from its eastern intersection with the Mid-Atlantic Ridge (MAR) to 5 Myr in age. The geological mapping shows four successive massifs, wrench faulted and slightly tilted. The transform-facing walls of these massifs exhibit outcrops of fresh and serpentinized peridotites, gabbros and basalts. The entire crustal exposure is cataclased and metamorphosed to greenschist facies.

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INTRODUCTION

Recent work in different oceanic environments has demonstrated that fracture zone (FZ) walls expose thick sections of oceanic lithosphere. Examples of such sections have been mapped and sampled on the southern wall of the Vema FZ in the Central Atlantic (Auzende *et al.*, 1989), at the intersection between the 15°20′N FZ and the MAR (Bougault *et al.*, 1993), at Hess deep in the South Pacific (Francheteau *et al.*, 1990) and in the Garret Transform Fault (Hékinian *et al.*, in press). Previous assumptions that the faulting in transform zones disrupted and obscured the original stratigraphy of the crust (Francheteau *et al.*, 1976) have now been discarded. Fracture zones and transforms are known to have abnormally thin crust, however, and may not be representative of the seismically defined oceanic crust (Raitt, 1963; Detrick and Purdy, 1980; Fox and Gallo, 1984; White, 1984; White *et al.*, 1984).

The Kanaut cruise using the submersible *Nautile* (15 November–16 December 1992) addressed two fundamental questions concerning the construction of the oceanic lithosphere in a slow-spreading ridge environment. The first question concerns the cyclicity of the accretionary processes. Cycles in the magmatic activity related to spreading processes in fast-spreading ridge environments have been suggested by a number of workers (MacDonald, 1982; Gente, 1987). Such cyclicity might be expected to be more pronounced at slow spreading ridges where large magmatic supply episodes would be followed by amagmatic extension (Harper, 1985). The second question concerns the processes by which deep levels of the oceanic crust and upper mantle are exposed at the sea floor, as observed at the intersection of Mid-Oceanic Ridges and large fracture zones. On the Kane FZ the variety of models proposed to account for these observations, from thermal processes and tectonic deformation to serpentinization, demonstrates the limited knowledge of this process.

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PREVIOUS WORK IN THE KANE FZ AREA

The Kane FZ and adjacent area are probably the most extensively surveyed areas of the Central Atlantic ocean, and over the last ten years more than 15 geological and geophysical cruises have been carried out in the area ranging from sea surface and deep-towed surveys to manned submersibles and crustal drilling.

The Kane FZ is located around 23°40′N in the Central Atlantic and offsets the Mid-Atlantic Ridge by about 150 km from 45°W to 46°C20′W (Fig. 1a). The motion along the transform segment is dextral and the measured full spreading rate in the area is close to 3 cm yr^{-1} (Schulz *et al.*, 1988). The eastern intersection between the Kane FZ and the MAR constitutes the MARK area and has been intensively surveyed by *SeaBeam* and *Simrad* (Detrick *et al.*, 1984; Pockalny *et al.*, 1988; Gente *et al.*, 1991). The rift valley in the MARK area is 10–17 km wide and 3500–4000 m deep, reaching 6100 m depth in the nodal basin at the Ridge-Transform Intersection (RTI). Studies carried out with the submersibles *Alvin* (Karson and Dick, 1983; Karson *et al.*, 1987) and *Nautile* (Mével *et al.*, 1991) delineated a serpentinitic massif cropping out on the western wall of the rift valley south of the RTI (i.e. at the inside corner high). Above these serpentinites there were successive sections of the gabbros, metagabbros, metabasalts and basalts. The 1991 British RRS *Charles Darwin* deep-towed sidescan (TOBI) survey of the western intersection between the Kane FZ and the MAR found that the transform valley floor had thin sedimentary cover and was cut by a fault system representative of the Present-Day Deplacement Zone (PDDZ) (J. Pearce, pers. comm.). In 1992, the Scripps deeptow cruise (Tow the MARK), using side-looking

Fig. 1. *(a) Location of the Kane FZ in the Central Atlantic. (b) Multibeam Bathymetry of the Eastern half of the Kane FZ. The contour interval is 100 m. The dives tracks are in heavy lines.*

sonar and photography mapped the southern wall of the Kane FZ from the eastern RTI up to 45°30'W (Karson *et al.*, 1992).

GEOLOGICAL SETTING OF THE KANE FZ AREA

Different domains can be recognized based on the *SeaBeam* and *Simrad* bathymetric maps (Fig. 1b) (Detrick *et al.*, 1984; Gente *et al.*, 1991) and from previous geological studies and sampling.

1 The MAR valley trends N20° and is bounded by asymmetrical walls. The western wall is steeper and about 500 m higher than the eastern wall. The average depth of the valley is 4000 m and its bottom is bisected by an elongated neovolcanic zone, 500 m high and 3–4 km wide. This neovolcanic ridge named Snake Pit was explored during the Hydrosnake cruise of the Nautile (1988) (Gente *et al.*, 1991).

2 The RTI nodal basin consists of a circular, more than 6000 m deep depression and corresponds to the deepening of the rift valley floor at the intersection with the Kane FZ. Similar features have been explored and described at the intersection of the MAR and large fracture zones elsewhere (OTTER, 1984, Auzende *et al.*, 1990; Mamaloukas *et al.*, 1991; Mével *et al.*, 1991; Lagabrielle *et al.*, 1992; Bougault *et al.*, 1993).

3 The transform valley varies from 6 to 8 km in width. It is composed of a series of 4500 m deep basins separated by shallower saddles. The main trend of the transform valley floor varies from E-W to N110–120°. The relatively disturbed topography of the valley floor suggests that the sedimentary cover is probably thin.

4 The northern wall of the Kane FZ shows an irregular pattern with a succession of 4500 m deep lows separated by N–S trending highs representative of the oceanic crust created along a N–S ridge axis. Toward the east the sedimentary cover attenuates the sharpness of the relief.

5 The southern wall of the Kane FZ consists of four successive massifs. They show different stages of vertical evolution from the RTI (zero age) to about the middle part of the FZ (4–5 Ma). The easternmost inside corner massif located at the RTI reaches to less than 1200 m depth, while the top of the westernmost massif is at about 2500 m depth. Each massif shows a convex shape with a steep wall toward the transform valley. Their width is remarkably constant, at about 20 km and they are separated by deep, N–S depressions several kilometres wide.

KANAUT CRUISE RESULTS

The Kanaut cruise had two main objectives. The first objective was a detailed study of the eastern RTI massif. The second objective was to make a series of geological sections of the southern wall of the fracture from the eastern RTI massif at 45°W toward the west up to 45°40'W, in order to observe variations in the crustal stratigraphy and thickness.

Ten dives were carried out on the eastern RTI inside corner massif (Fig. 1b) complementing earlier dives by Alvin (1981) (Karson and Dick, 1983) and Nautile (Mével *et al.*, 1991). The dives provided a framework for constructing a detailed geological and structural map of the RTI massif (Fig. 2). The

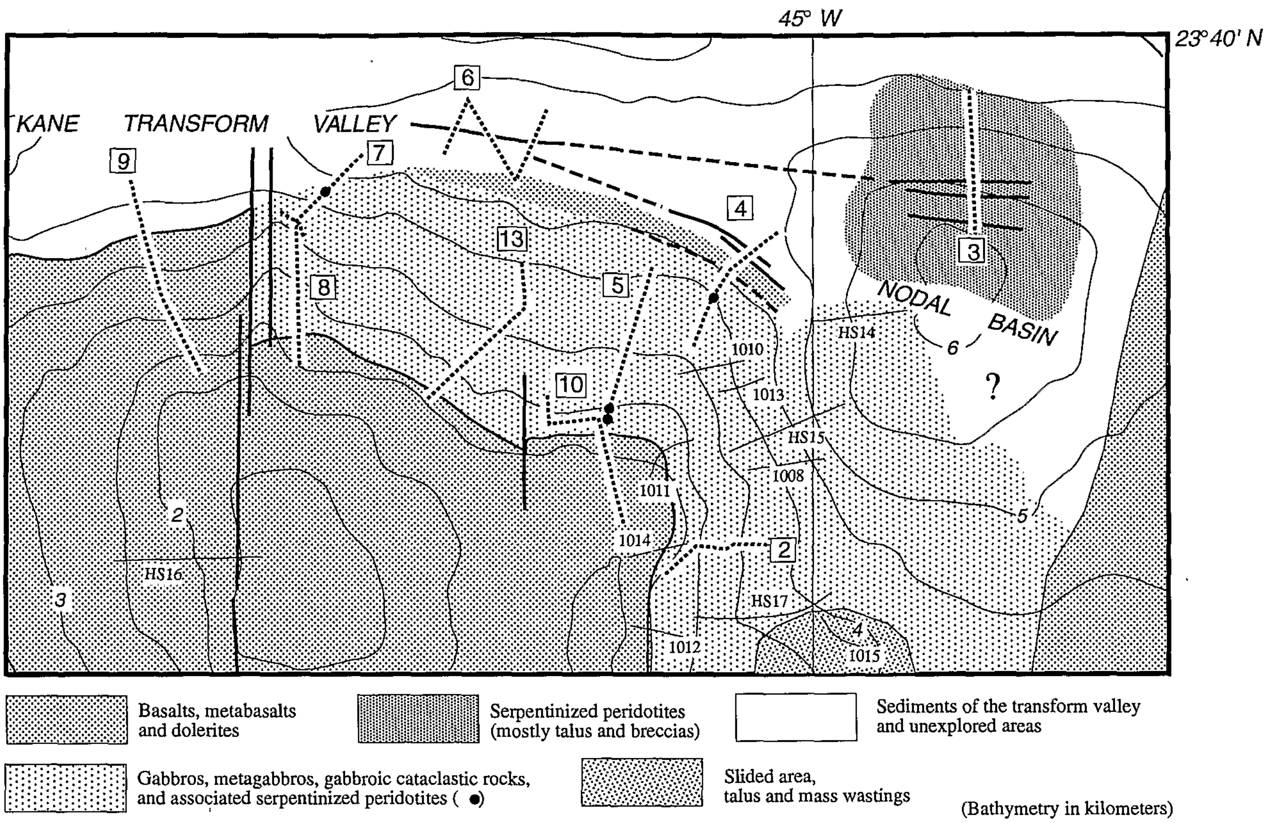

Fig. 2. *Geological map of the Eastern RTI massif. The Kanaut cruise, Nautile dives are in heavy dotted lines. The Alvin dives (Karson and Dick, 1983; Karson et al., 1987) are in thin lines. HS 14 to HS 17 are the Hydrosnake (Mével et al., 1991) Nautile dives. The main faults are underlined by continuous heavy lines.*

east-facing wall of the RTI massif constitutes the western side of the nodal basin and MAR valley floor. The Kanaut dives confirm previous observations of Mével *et al.*, 1991 and show that the massif consists of a thick layer of gabbros from the bottom of the nodal basin at 6100 m depth up to 2200 m depth on the slope. These gabbros can be differentiated into two main units: a massive unit in the lower part of the section and an intensively deformed unit in the upper part. Serpentinized peridotites have also been sampled. The entire gabbroic section is cut by normal faults, parallel to the gabbro foliation and trending N–S to NW–SE with a slight dip E to NE (25–50°). E–W strike-slip faults, parallel to the transform direction, with steep dips (more than 50°) were observed mostly at the foot of the wall, but have also been observed in some places on the slope. Above 2200 m the gabbros are overlain by basaltic layers showing doleritic dikes, lava flows and pillow lava. The dolerites are isolated dikes and do not constitute a dike complex as observed on the southern wall of the Vema FZ (Auzende *et al.*, 1989). The Central part of the RTI massif corresponds to the southern wall of the transform. Its structure is more complicated and can be summarized by a synthetic section (Fig. 3)—the lower part of the section shows basaltic formations constituted by lava flows, doleritic dikes and pillow lava in place or in talus. Close to the transform valley these different layers are cut by dextral strike-slip faults associated with the PDDZ. Above the basalts the slope between 3200 m and 2600 m depth is occupied exclusively by an E–W to NW–SE trending fault plane. This fault plane dips toward the transform valley with a 35–50° angle and is associated with a schistosity cross-cutting serpentinites, gabbros and basalts. The whole area is cataclased and metamorphosed giving metagabbros and metabasalts of greenschist facies. Spectacular mylonitic zones were observed at about 2800 m depth. Subvertical N–S and N110–120° faults dipping 80° to the south were also observed. The top of the massif above 2500 m is entirely composed of sediment-covered dolerites and basaltic flows. The western edge of the massif around 45°10'W shows a succession of lava flows, pillows and doleritic dikes cropping out from 3500 m depth up to the top of the massif at 1200 m. The dikes have a mostly N–S (between N182° and N35°) direction with dips varying from 50°W at 2600 m depth to 71°E at 2000 m. In the upper part of the section, from 2500 to 1100 m depth, the slope increases and is cut by numerous, recently active normal faults trending mostly E–W, but also N140° and N–S.

The remaining 10 *Nautile* dives were carried out toward the west on the massifs constituting the southern wall of the Kane FZ (Fig. 1b). Due to the increasing

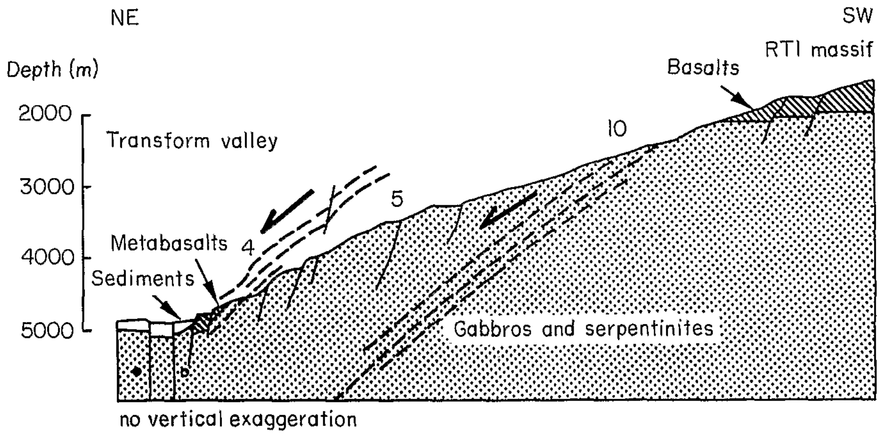

Fig. 3. *Geological section across the RTI massif south-west of the nodal basin. The heavy dotted lines indicate the major ductile faults. 4, 5, and 10 are the dives used to establish the geological section.*

thickness in sediment cover, the exploring outcrops are mainly located at the slope-breaks or on the N–S faults cutting the sections. The dives show crustal sections similar to those of the RTI massif with a succession from fresh to serpentinized peridotites to gabbros and basalt. The upper mantle and metagabbros (flasered gabbros and amphibolites) widely outcrop on ductile fault planes dipping 45° toward the transform valley. The peridotites are intensively deformed in places and are cut by numerous gabbroic dikes that increase in number upslope (Fig. 4). The section is crowned by basalts. Sub-horizontal schistosed serpentinites have been observed above the basalts at 3320 m depth during the dive 14 suggesting the existence of a major fault affecting the upper-mantle in this area. The whole succession is cut by faults with the same direction and type as the faults previously observed on the RTI massif.

In addition to the geological mapping and sampling, a magnetometer mounted to the submersible measured the magnetic field during each dive. Preliminary magnetic field results suggest that the crust exposed on the southern wall of the Kane FZ is only weakly magnetized. This is consistent with both the reduction in amplitude of the sea-surface magnetic field over the FZ and the dominance of highly metamorphosed crustal units. There are indications that a magnetization contrast exists between 3000 m and 3500 m on the RTI massif which may correlate with a lithological transition. Further analysis is underway to fully interpret these magnetic data in the context of the geological mapping results.

CONCLUSIONS

In summary, while these observations on the southern wall of the Kane FZ do

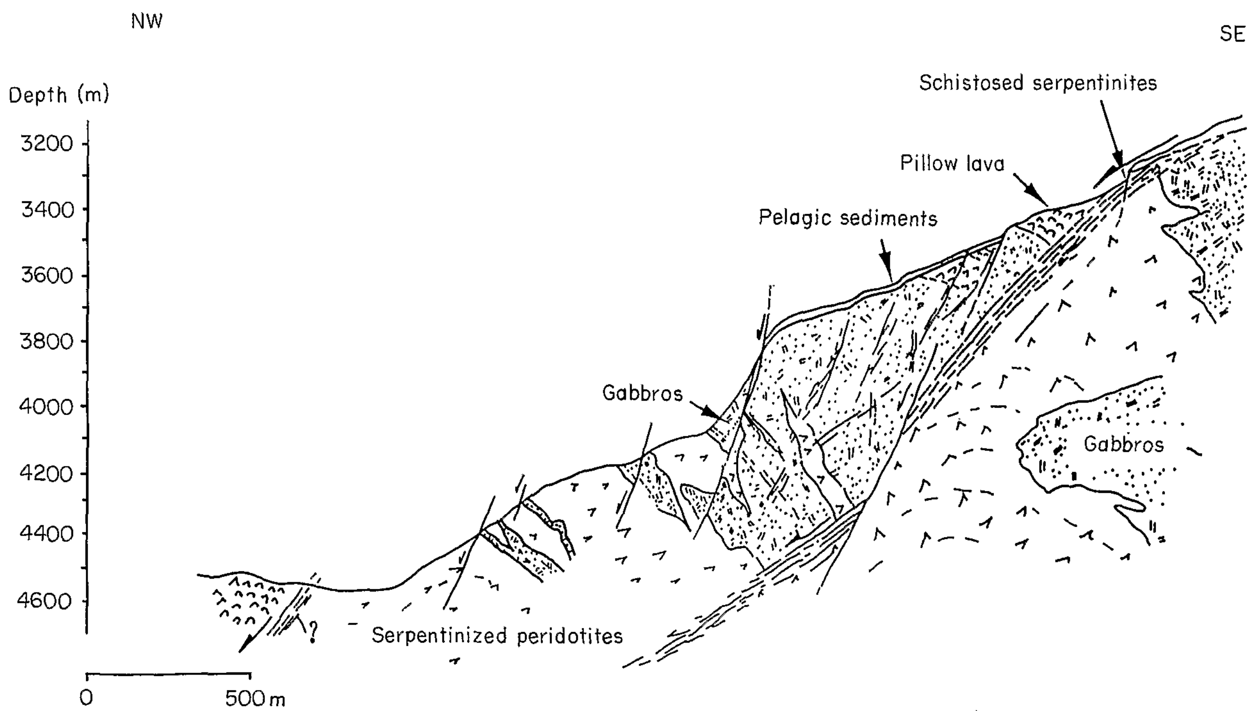

Fig. 4. *Geological section of the 45°15′W massif established with the observations made during dive 14. The heavy dotted lines indicate the major ductile faults.*

not show any alternation in the magmatic and amagmatic processes at the ridge axis, they do illustrate the tectonic processes at the RTI which induce the cropping out of deep levels of the crust and the upper-mantle.

The existence of deep crustal sections in abnormal topographic position along the walls of large fracture zones is well documented, especially in slow-spreading environments. Models to explain their emplacement are numerous with many different mechanisms, such as thermal effects (Forsyth and Wilson, 1984; Phipps-Morgan and Forsyth, 1988), tectonics (Sleep and Biehler, 1970; Sandwell and Schubert, 1982; Colette, 1986), or by the serpentinization of peridotites (Bonatti, 1976; Francis, 1981). The observations made during the Kanaut cruise confirm the predominance of tectonic effects in the emplacement and uplift of the RTI inside corner massifs on the southern wall of the Kane FZ. The observed faults suggest a wrench motion along the wall of the transform. This motion is probably the origin of the exposure of deep levels of the oceanic crust and upper mantle. This exposure on the wall and in the nodal basin could be accentuated by a slight tilting (few degrees) of the massifs. These observations demonstrate that the thickness of the oceanic crust close to transform zones in thinner than 'normal' oceanic crust defined by seismic experiments. The average thickness of the outcropping crust on the southern wall of the Kane FZ is about 1500 m. Other observations on the Vema FZ southern wall (Auzende *et al.*, 1989) give a thickness close to 3000 m. The recent fractures observed on the RTI massif are associated with the plate motion along the Kane FZ. The E–W faults are located mainly at the foot of the internal slope of the transform, while the N–S faults cut across the whole crustal section of the southern wall. A recent OBS seismic experiment (Wilcock *et al.*, 1990) found evidence of N–S seismic alignments across the Kane FZ southern wall. These N–S fractures could be localized at weak zones in the crust created at the ridge axis and reactivated in the vicinity of the transform.

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