

InRidge program: Preliminary results from the first cruise

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The first cruise under India's own Ridge research initiative, InRidge collected new data on bathymetry, free-air gravity and magnetic anomalies across the ridge axis between the Vema and Zhivago transform faults in the Central Indian Ridge. In addition, basalt and ferro-manganese nodules were collected from the Vityaz transform fault area. Basalts are fresh and phyric, containing plagioclase and olivine phenocrysts. Ferro-manganese nodules from the same areas show smooth textures, variable oxide thicknesses and fresh basaltic nuclei. Preliminary studies indicate a possible mixed hydrothermal and hydrogenous source for these nodules. The water column was also sampled at the Vema and Vityaz transform fault areas.

STUDY of the global ocean ridge system, which spans 70,000 km, is important to understand the processes of crustal accretion and the interactions that take place between the earth's mantle and crust. To date, most such studies have concentrated on the Pacific and Atlantic Oceans, parts of the South West Indian Ridge, and to a lesser extent the South East Indian Ridge. Knowledge of ridge processes along a substantial length of the Central Indian Ridge (CIR) is scanty (e.g. refs 1, 2 and references cited therein).

The InRidge program, the Indian initiative for ridge research, launched at the National Institute of Oceanography will focus on the Indian Ocean Ridge system. Two studies are currently being carried out on the Central Indian Ridge and the Carlsberg Ridge. A future project will study the biology of the Central Indian Ridge.

The InRidge project plans detailed geophysical and geological studies at four major intersections between the CIR and the transform faults Vityaz (5°44' S), Vema (8°45' S), Argo (13°45' S) and Marie Celeste (16°37' S), and the ridge segments between them (Figure 1). The programme envisages documentation of regional tectonic fabric, with special reference to growth and evolution of transform faults and near-axis seamounts. Determining the petrological implications of transform faults on generation of new crust and sub-crustal hydrothermal

budget are the other objectives of this programme.

To achieve the above objectives we carried out single beam bathymetric, magnetic and gravity surveys in the Vema area which includes the CIR axis between the

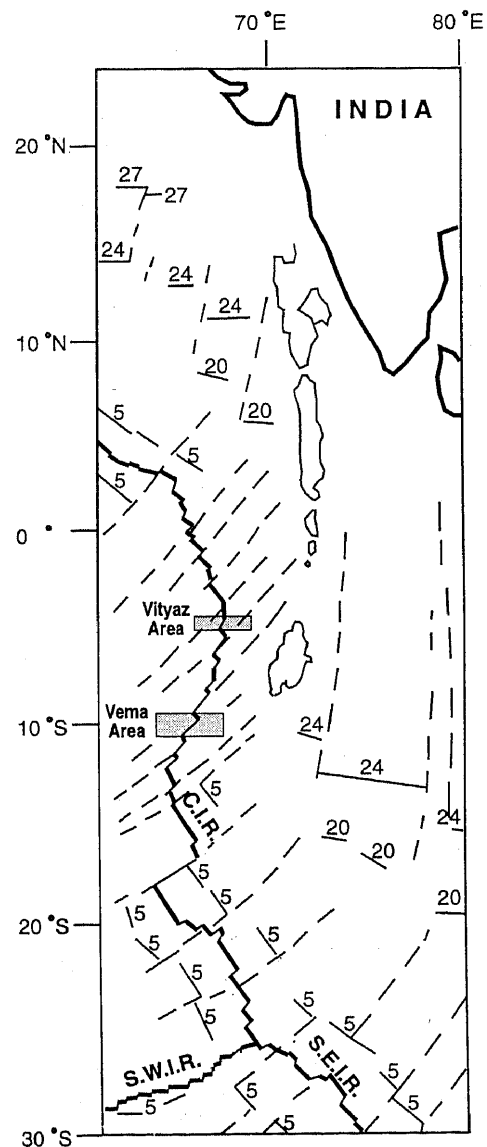


Figure 1. Generalized map of the Indian Ocean basin showing the study area²⁰.

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Zhivago and Vema transform faults and across the transform fault. Moreover, dredging operations for geological sampling were carried out at the Vema (VM area) and Vityaz transform faults (VT area). The water column was sampled at the Vema and Vityaz transform faults. At the ridge axis and the seafloor, elements from the sea are either added onto or removed from the basalt, thereby bringing about significant changes in the chemistry of seawater. This paper presents the preliminary observations and interpretations of these areas from new data collected during the ORV *Sagar Kanya* cruise 125 (July–August 1997).

Geophysical observations and interpretation

The CIR is presently spreading at 40–60 mm per year (full rate³). The ridge offsets at these four major transform faults are variable, being of the order of 110 km at the Argo fracture zone to 300 km at the Vema transform fault³. The reliefs associated with the transform faults are also large, ranging from more than 2800 m at the Argo transform fault to 4600 m at the Marie Celeste transform fault⁴.

The geophysical surveys, aimed at understanding the spreading history of the ridge segments and the formation of transform faults, were conducted across the NW–SE oriented ridge segment and NE–SW oriented Vema transform fault (Figure 2).

The survey in the VM area indicates that sea floor depth along the ridge axis varies from 1500 m to 6200 m, but is generally of the order of 2500–3800 m (Figure 3). The north-eastern part of the ridge is generally deeper. The topography is rugged with relief ranging from a few hundred to 2700 m. The average width of the axial

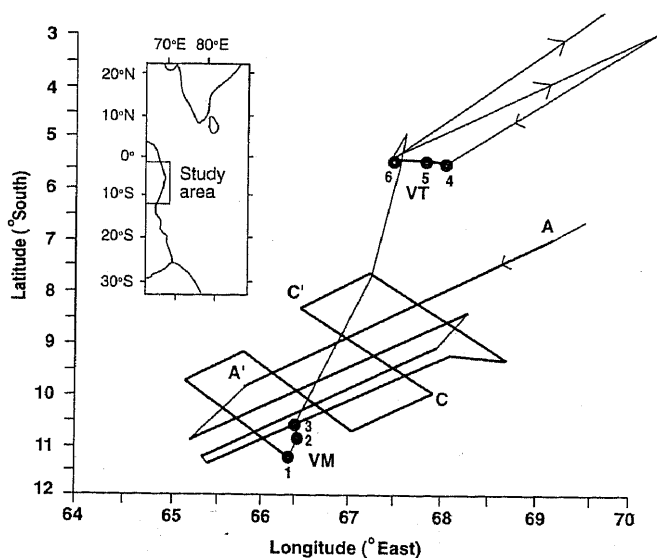


Figure 2. Cruise tracks and sample locations for ORV *Sagar Kanya* cruise 125.

valley is of the order of 15 km. The transform valley depth ranges from 2000 m to 6000 m, with the deepest parts being in the centre of the transform fault. The transform fault is about 35 km wide (Figure 4).

The steep valley walls and elevated topography along the ridge axis in the VM area are associated with magnetic anomalies of a few hundred (up to 400) nT (Figure 3). Magnetic anomalies along the northernmost profile across the ridge axis appear to indicate that the ridge axis in that area is an active spreading centre and can be traced up to anomaly A3. The north-eastern side of the ridge, which is deeper, is associated with more conspicuous magnetic anomalies. Magnetic anomalies associated with the transform fault are more subdued. The anomaly associated with the central part of the Vema transform fault is of the order of 200 nT and appears to be offset to the south-east (Figure 4).

Free air gravity anomalies measured along the axial valley in the VM area are of the order of 150 mGal (Figure 3). The trend of these values is in accordance with the bathymetric and magnetic anomaly observations. Across the Vema transform fault the free air gravity anomalies are variable with a maximum of 200 mGal recorded in the steepest part of the transform fault (Figure 4).

Geological observations and interpretation

Five dredging operations were carried out, of which two were successful (Figure 2). One dredge was across the axial valley walls near the Vityaz transform fault (VT 4) and the other along the ridge-transform intersection between the Vityaz transform fault and the ridge axis (VT 5). Both the dredges recovered mainly basalts. Other materials like ferro-manganese (Fe–Mn) nodules and encrustations, and calcareous material were also recovered from the ridge transform intersection (VT 5).

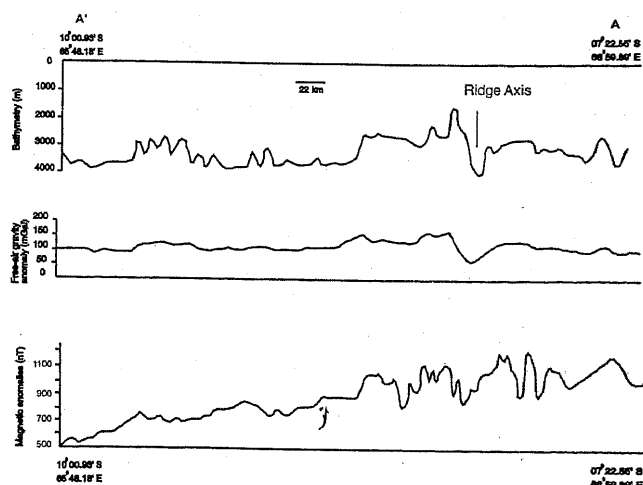


Figure 3. Bathymetry, free-air gravity and magnetic anomaly profile across the ridge axis.

Basalts recovered from the ridge axis (VT 4) are fresh and phyrlic, containing abundant plagioclase phenocrysts. The basalts are capped by a layer of glass between 0.5 and 5 cm thick and Fe–Mn crusts of variable thickness (up to 3 cm). The groundmass of the basalts is made up mainly of glass, with acicular plagioclase and olivine in some samples. Plagioclase phenocrysts, which are acicular at times, are sometimes zoned (sector) and contain abundant melt/host inclusions, and have corroded margins. Olivine phenocrysts are rarer and are often altered. They are irregular in shape but euhedral crystals are also present. The irregular crystals contain numerous cracks. Textural relationships indicate that plagioclase was the first mineral to crystallize.

The dredge haul from the ridge-transform intersection (VT 5) yielded variably altered basalts. They occur as substrates for the deposition of ferro-manganese oxides and also serve as nuclei for these deposits. These basalts, which resemble those dredged from the ridge axis, are medium to coarse grained and phyrlic with abundant phenocrysts of plagioclase. Olivine is more scarce and microphenocrysts of olivine, when present, are invariably altered to iddingsite.

White calcareous material, which contain extensive bioturbation channels was recovered from the ridge-transform intersection (VT 5). The calcareous material form the substrate for ferro-manganese oxide deposits. Buff white calcareous clayey sands were also recovered from this dredge haul. These sands occur as substrates for Fe–Mn deposits. Other samples recovered in this

dredge are porous red-black slabs which contained calcareous clayey sands and Fe–Mn deposits. X-ray diffraction (XRD) studies show that calcite makes up the major portion of these samples, with minor phillipsite, and in the red-black samples, goethite. Samples resembling corals, which are flat and tubular and at times showing honeycomb structures, were also dredged.

Manganese nodules of variable sizes and shapes were recovered from the ridge-transform intersection (VT 5). This is interesting as most nodules recovered in the Central Indian Ocean basin (CIOB) are from south of the 10° S latitude⁵. The surfaces of the nodules are mainly smooth, but in some cases botryoidal textures can also be seen. These nodules are clearly different from other Fe–Mn encrustations seen in the dredge haul. The nuclei for these nodules are mainly basaltic rocks. These basalts are very fresh, which is uncommon but not unique in the CIOB⁶. Previous studies to the east of the study area⁵ have correlated the surface texture of the Fe–Mn nodules to their origin, with smooth surfaced nodules being hydrogenetic, while those with rough surfaces being diagenetic. Using this crude classification scheme, the Fe–Mn nodules from our study area would appear to be hydrogenetic in origin. The presence of weak δMnO_2 reflection peaks and the absence of todorokite seem to support this assumption.

While we were unable to collect any sediment samples in the study area, they would seem to be calcareous, as such material has been recovered in dredge VT 5. Earlier mapping in the area indicates that bottom sediments are high calcareous foraminiferal and coccolitho-foraminiferal, containing 30–50% CaCO_3 (ref. 7).

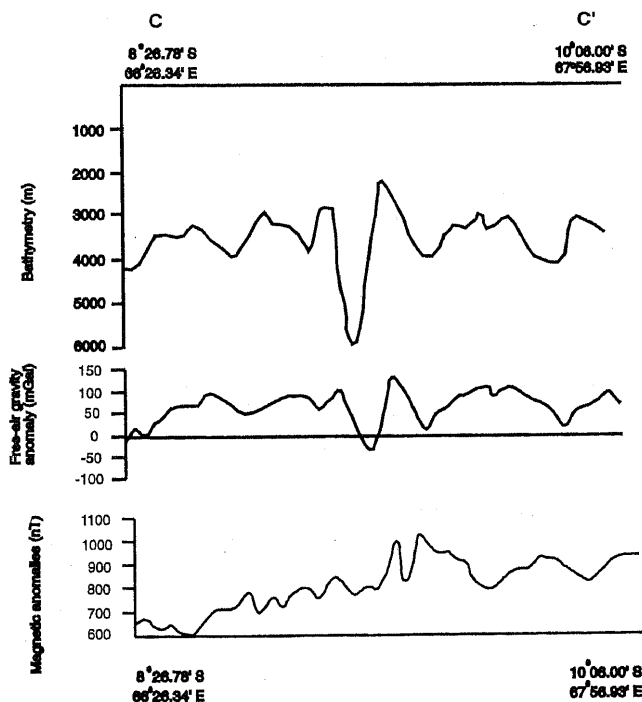


Figure 4. Bathymetry, free-air gravity and magnetic anomaly profiles across the Vema fracture zone.

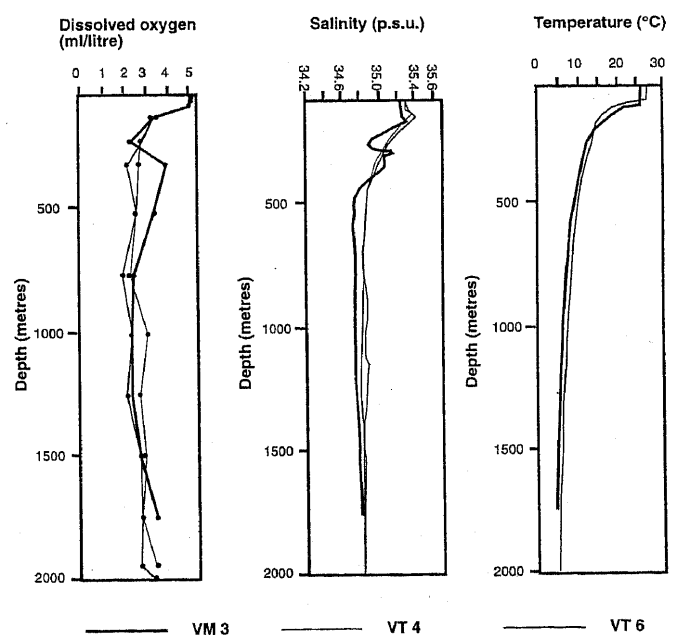


Figure 5. Water column temperature, salinity and dissolved oxygen profiles as a function of depth at the Vema and Vityaz fracture zone areas.

Nodules from areas with a calcareous-red clay sediment composition (from 14°S, 72°E at water depths of 4700–5000 m) show high concentrations of iron (FeO between 5 and 6%)⁸. X-ray diffractograms of these nodules show a distinct lack of crystallinity, which can be attributed to the presence of goethite in our samples. The oxide thickness of the nodules (up to 3 cm) coupled with the fact that the basalt nuclei are very fresh could be indicative of very rapid nodule growth. These rates would be much higher than basinal nodules which grew by diagenetic processes. Hydrogenetic growth rates are very slow as well and thus the growth of these nodules from hydrothermal processes linked to ridge volcanism can be evoked. Fe–Mn nodules which are hydrothermal in origin, but which contain a variable but significant (~40%) hydrogenetic component have been reported from north of the Rodrigues Triple Junction⁹. Rocks altered by high-temperature hydrothermal alteration have been reported from the Vityaz transform fault^{10,11}, just to the east of our sample sites. Preliminary chemical analyses of these Fe–Mn nodules indicate a Mn/Fe ratio less than 1 and Cu, Ni and Co concentrations lower than typical diagenetic nodules (Banerjee and Ghose, in prep.). These values indicate the possibility of a mixed hydrothermal–hydrogenous origin for these Fe–Mn nodules.

The Vityaz transform fault may have acted as a conduit and facilitated the movement of water masses, from the adjacent Somali basin into the Arabian basin. Such water movement probably facilitated the uninterrupted precipitation of trace metals from the water column to the nodules studied by removing their overlying sediment cover. The movement of deep water masses has been demonstrated earlier in the CIOB^{12,13}. Kolla *et al.*¹⁴ have demonstrated the entry of Antarctic bottom waters into the Mozambique basin and thence to the Somali basin. Thus, transform faults in the CIR can act as conduits for deep water circulation and water mass exchange between the Somali and Arabian basins. Future deep CTD observations will confirm this circulation pattern in the study area.

Observations of the water column

In order to get first hand information of the water characteristics in the Ridge area, water samples were collected from 3 stations (ridge crest area of the Vema area; the axial valley in the Vityaz area and the Vityaz transform fault). The water samples were collected at standard depths using a CTD rosette sampler fitted with Niskin samplers. However, the sampling could be done only up to 2000 m depth.

The samples collected were studied on board the ship for hydrographic parameters such as temperature, pH, salinity and dissolved oxygen. The data showed the

presence of two distinct water layers; the upper 200 m layer with high temperature and salinity followed by a layer of low temperature and salinity. In the Vityaz area, the surface waters were warmer (>27°C) than in the Vema area (<26°C) with a continuous decrease of temperature downwards where the lowest temperature is in the range of 2.6–2.8°C at 2000 m.

The salinity profiles, however, are almost similar at the Vema and Vityaz areas. Salinity ranges from 35 to 35.3 psu in the upper 200 m layer and 34.68–34.94 psu at 2000 m (Figure 5). The upper water mass can be identified as the Central Indian Ocean Water while the lower water mass can be attributed to the Antarctic Intermediate Water¹⁵.

Dissolved oxygen (DO) concentrations are uniform in the upper 50 m layer at all the stations, indicating homogenization due to prevailing winds. Thereafter there is a gradual decrease with an oxygen minima at 750 m, followed by a slight increase till 2000 m (Figure 5). However, the oxygen maxima at 300 m in the Vema area is associated with a salinity minima and corresponds to the South Atlantic Mode Water^{15,16}. The vertical extent of this water mass is restricted.

The 200 m depth seems to be a boundary, for the physico-chemical parameters of the water mass which vary widely in the first 200 m but remain more or less constant at depth. The temperature, salinity and DO profiles therefore indicate that the water movement at depths up to 2000 m in these regions is from south to north and the southern waters are less saline and more oxygen-rich than the northern waters.

Perspectives for future work

The second cruise of the project will carry out detailed geophysical surveys, including seismic studies of the Argo and Marie Celeste transform faults. Geological sampling in the ridge axis and the ridge-transform intersection at the Vityaz transform fault recovered only basalts, although lower crustal and/or upper mantle rocks can also be expected at ridge-transform intersections¹⁷. The presence of gabbros and serpentinized peridotites have been reported from the Marie Celeste, Argo and Vema transform faults and other CIR transform faults^{18,19}. Dredging operations to recover these mantle and deep crustal rocks are also planned. Deep water CTD surveys will characterize the water chemistry at various depths as well as confirm the hypothesis that transform faults are conduits for the flow of deep-water between the Somali and Arabian basins. Collection of long sediment cores will enable us to decipher the palaeo-climate signatures of the study sites.

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