^{210}Pb, ^{230}Th, and ^{10}Be in Central Indian Basin seamount sediments: Signatures of degassing and hydrothermal alteration of recent origin

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[1] Isotopic (^{210}Pb, ^{238}U-^{230}Th, ^{10}Be), major and trace elements, and micromorphological and microchemical data, were used to identify recent (~100 yrs) hydrothermal alteration of a >200 kyr sedimentary record from the flank of a seamount in the Central Indian Basin located at the edge of the 75°30′E fracture zone. Alteration effects are also reflected in 1) the depleted sedimentary organic carbon, 2) dissolution features of radiolarian skeletons, 3) the presence of altered minerals such as smectite and zeolites, and 4) distinctly different magnetic properties in the altered sediments. We interpret a predominant influence of neutral chloride type hydrothermal fluids. This is the first report of recently occurring sediment alteration by shallow circulating sub-surface fluids along the Indian Ocean intra-plate seamount environment. **Citation:** Nath, B. N., D. V. Borole, A. Aldahan, S. K. Patil, M. B. L. Mascarenhas-Pereira, G. Possnert, T. Ericsson, V. Ramaswamy, and S. M. Gupta (2008), ^{210}Pb, ^{230}Th, and ^{10}Be in Central Indian Basin seamount sediments: Signatures of degassing and hydrothermal alteration of recent origin, *Geophys. Res. Lett.*, *35*, L09603, doi:10.1029/2008GL033849.

1. Introduction

[2] Although there are several reports on the occurrence of hydrothermal activity at the intra-plate seamounts in the Pacific Ocean such as Macdonald, Loihi [*Karl et al.*, 1988], Vailulu'u (Samoan Hotspot related) [*Staudigel et al.*, 2004], signatures of hydrothermal mineralization have been reported in only one intra-plate seamount area in the Indian Ocean [*Iyer et al.*, 1997]. This is despite the fact that a number of seamounts and abyssal hills are known to exist in the Indian Ocean [*Das et al.*, 2005; *Kamesh Raju*, 1993; *Mukhopadhyay and Khadge*, 1990]. Deep-sea hydrothermal venting may provide an important source of trace elements to the ocean water [*von Damm et al.*, 1985] and thereby needs to be considered.

[3] We have identified signatures of recent hydrothermal fluid flow through the sediments on the flank of a seamount in the Central Indian Basin through several geochemical and isotopic tracers in a core located close to the southern end of 75°30'E fracture zone (Figure 1), which defines the trace of Indian Ocean triple junction movement [*Kamesh Raju*, 1993].

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2. Geological Setting and the Analytical Methods

[4] During the 61st cruise of R.V.A. A Sidorenko in 2003, a 50 × 50 × 20 cm sediment box core (#BC 8) was recovered from the flanks of a seamount in the Central Indian Basin from a water depth of 5010 m (Figure 1). The seamount is one of the many topographic highs aligned along the fracture zone (Figure 1) [*Kamesh Raju*, 1993]. The corer could not penetrate deeper than 20 cm due to the hard nature of the substrate. Details of the analytical procedures are given in the auxiliary material[1].

3. Results

[5] The sediments investigated are composed of light brown radiolarian ooze containing pelagic clay in the top ~6 cm of the core overlying the dark brown to grey-colored semi-indurated pelagic clays containing volcanoclastic material. Sediments deeper than 6 cm are devoid of radiolarians. Two late Quaternary radiolarian index fossils, Buccinosphaera invaginata (Haeckel) and Collosphaera tuberosa (Haeckel) were identified in the top part of the core. B. invaginata first appeared at the ~180 kyr datum [*Johnson et al.*, 1989] which imply that the sediments deeper than 6 cms bsf can be older than 180 kyr [*Mascarenhas-Pereira et al.*, 2006]. The sediments also contain volcanic glass, palagonite, pumice, micronodules and other lithic grains in the sand-sized fraction [*Mascarenhas-Pereira et al.*, 2006].

[6] The systematics of $^{230}Th_{excess}$ (portion of total ^{230}Th not supported by the decay of ^{234}U in the sediment) decreases exponentially with depth down to about 12 cm which is underlain by sediments with variable $^{230}Th_{excess}$ values (Table S1; Figure 2). Furthermore, sedimentation rate in the top 6 cm, estimated from $^{230}Th_{excess}$ least square line regression (^{230}Th $t_{1/2}$ = 75.2 kyr), is 0.32 mm/kyr corresponds to an age span of about 175 kyr which is in very good agreement with the biostratigraphy [*Mascarenhas-Pereira et al.*, 2006]. The sediments deeper than 6 cm show higher ^{210}Pb activity over both ^{238}U and ^{230}Th (Table S1; Figure 2). $^{238}U/^{210}Pb$ values are markedly lower in these sediments. $^{210}Pb/^{230}Th$ values below unity in the top 6 cm, and values between 1.19 and 3.84 in the deeper part point to a significant enrichment of $^{210}Pb_{excess}$ relative to its parent ^{230}Th, while no $^{210}Pb_{excess}$ is seen in the top 6 cm (Table S1).

[7] ^{10}Be concentrations are extremely low (0.4 to 1.3 × 10^9 atoms/g; Figure 2; Table S1) compared to several surficial sediments from the Central Indian Basin (^{10}Be up to 5 × 10^9 atoms/g [*Nath et al.*, 2007]).

[1]Auxiliary materials are available in the HTML. doi:10.1029/2008GL033849.

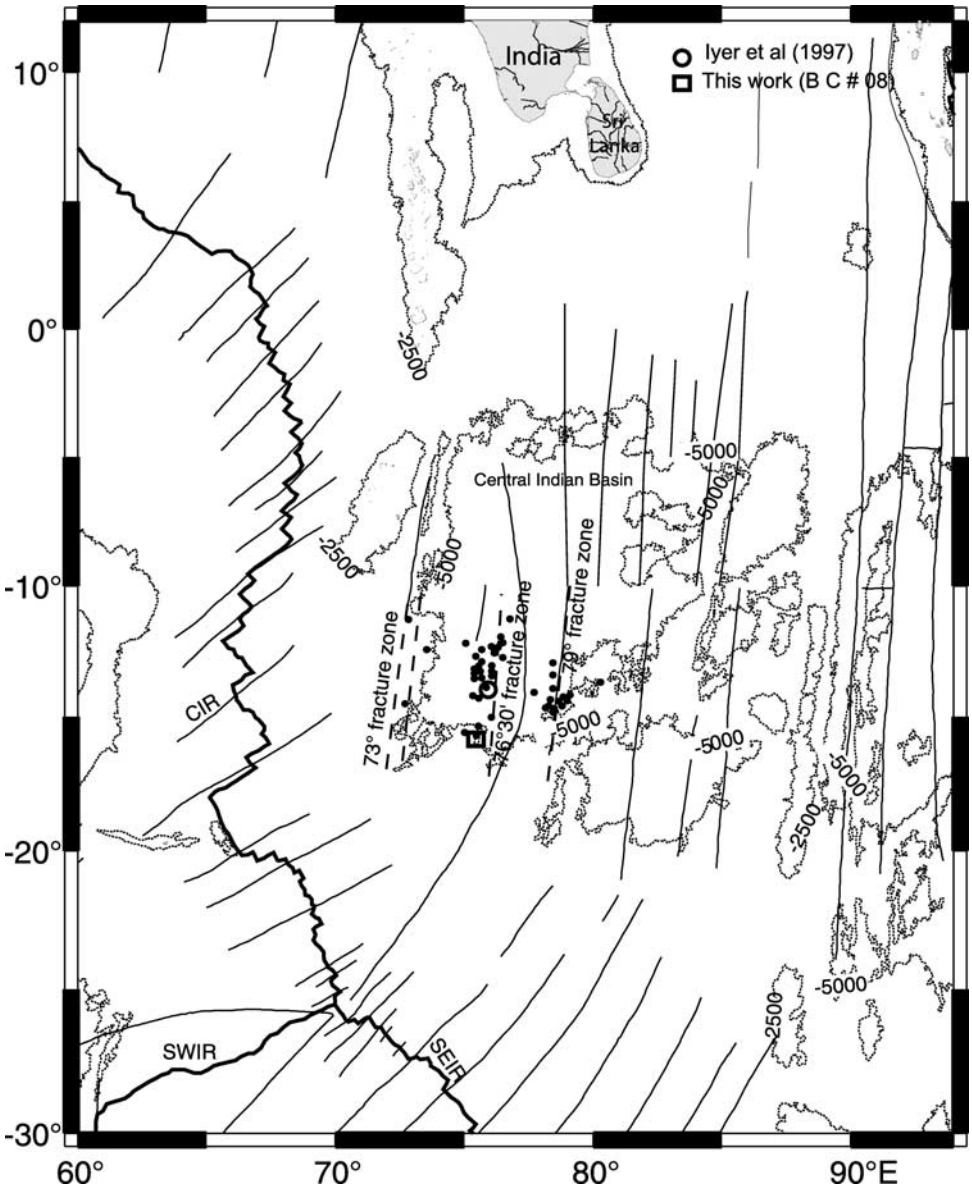

Figure 1. Sample location map. Also shown are India, Indian Ocean ridge system and the Rodriguez Triple Junction. All the dots denote the seamounts. Note the occurrence of seamounts mostly along the fracture zones. The fracture zone at 76°30′E represents the trace of movement of Rodriguez Triple Junction [*Kamesh Raju*, 1993]. Sediment core studied here (#BC 8) and that of *Iyer et al.* [1997] which had volcanogenic-hydrothermal material are shown is shown with different symbols.

[8] Scanning electron microscopy of radiolarians has shown intense dissolution features occurring predominantly in the 6 to 20 cm sediment section (Figure S1 in auxiliary material). In the same depths, sedimentary organic carbon is extremely low (Figure 2).

[9] Compared to the pelagic clays occurring in the Central Indian Basin, distinct enrichment in Fe, Ti, P, and depletion in Si, and Mg was seen (Figure S2 in auxiliary material).

[10] Lithic grains with extremely high Al (Al_2O_3 ~90 %), Cu and Zn contents as well as EDS detectable Ag and S concentrations, and also high Cl contents were recovered. Some of these grains (rich in Al, S and Cl) are spheroidal aggregates of irregular size as well as glassy blebs (Figure S1 in auxiliary material).

[11] Magnetic Properties: Relatively higher χ_{LF}, SIRM, χ_{ARM} (ARM representing anhysteretic remanent magnetization), SIRM/χ_{LF}, SIRM/ARM and S-ratio values indicating higher ferrimagnetic content of stable single domain (0.03–0.15 μm) magnetite are found in the sediment core studied here in detail (BC#8). Conversely, samples from a sediment core in the adjoining area have exhibited lower χ_{LF}, χ_{ARM}/SIRM, χ_{ARM}/χ_{LF}, S-ratio values and higher χ_{fd}%, χ_{ARM}/SIRM and χ_{ARM}/χ_{LF} values (Figure S3 in auxiliary material) indicating that the magnetite of superparamagnetic (<0.03 μm) size would be the major magnetic component in the samples. Isothermal remanence magnetization experiments (Figure S4 in auxiliary material) along with temperature dependent magnetic susceptibility varia-

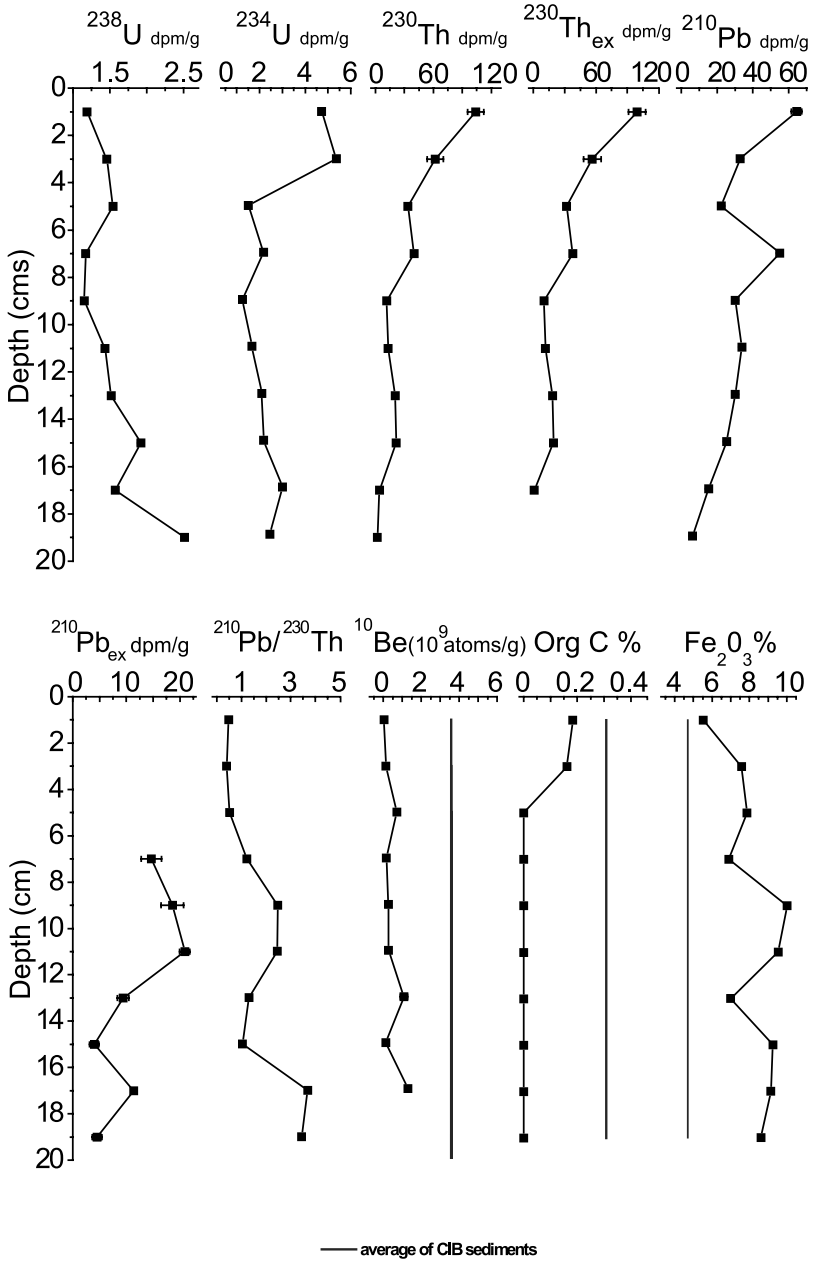

Figure 2. Downcore variation of isotopes of U-series and ^{10}Be along with the sedimentary organic carbon and iron content. Error bars are shown for critical parameters (^{230}Th, ^{230}Th$_{excess}$, ^{210}Pb$_{excess}$). Iron content is very high compared to the average composition of CIB sediments (average data [from *Nath et al.*, 1989]). Exponential decay is seen in ^{230}Th$_{excess}$ profile more clearly down to 12 cm. ^{210}Pb$_{excess}$ is only seen in the sediments deeper than 6 cm. ^{10}Be and C$_{org}$ content in this core are very low compared to other CIB sediments [*Nath et al.*,1989, 2007]. C$_{org}$ is extremely low in sediments deeper than 4 cm.

tions unambiguously suggest 'magnetite' as the dominant magnetic mineral in the altered and unaltered samples.

[12] Mössbauer spectroscopy studies of bulk and HCl-treated residues show that all the iron is in ferric state (Figure S5).

4. Discussion

[13] The sediments studied here have distinctly different geochemistry compared to those generally occurring in the Central Indian Basin. In particular, silica depletion and higher Fe stand out, suggesting a ferruginous nature. Compared to usual yellowish to light brown color seen in most of the CIB surficial sediments, one of the two sediment facies in the core studied here shows dark brown to grey colored semi-indurated sediments. These two primary differences have prompted us to look into the origin of this core. The isotopic data shows an excess of ^{210}Pb over its parent in the semi-indurated sediments (6 cm bsf) (Figure 2). Bioturbation cannot be responsible for the ^{210}Pb$_{excess}$ in the deeper sediment section since the sediments lacked benthic biota and are depleted in organic matter. Slumping of older sediments from the shallower portions of the seamount also may not be a reason for the ^{210}Pb$_{excess}$ in the

deeper sediments, as the entire core is of siliceous clay nature with no detectable carbonate content. The upper slope and seamount top sediments are composed of carbonate-rich foraminiferal sands and on slumping, they would have deposited over the sediments with $^{210}Pb_{excess}$ content. Alternatively, higher ^{210}Pb activity over both ^{238}U and ^{230}Th indicates a likely magmatic origin [e.g. *Krishnaswami et al.*, 1984]. $^{238}U/^{210}Pb$ values are also markedly lower in these sediments suggesting a magmatically influenced fractionation. Further, unsupported ^{210}Pb is found only in the deeper sediments, which suggests recent (about a century old) hydrothermal emanations considering the relatively short (22.3 yr) half life of ^{210}Pb. ^{210}Pb excesses indicate the presence of a deeper degassing reservoir supplying volatiles to shallow stalled magma [*Berlo et al.*, 2004]. A radioactive disequilibrium between ^{210}Pb and ^{210}Po (half life = 138.4 days) was noticed in several hydrothermal areas such as Macdonald Seamount, EPR, Gorda Ridge and Loihi Seamount and was related to nearly complete removal or degassing of the more volatile Po [*Rubin*,1997].

[14] The low ^{10}Be (half life 1.5 myr) values of the sediment suggest that leaching by emanating hydrothermal fluids can be the reason. Observation of selective leaching of ^{10}Be by hydrothermal fluids was documented in sediment covered hydrothermal systems in the Guaymas Basin and Escanaba Trough [*Bourlès et al.*, 1991]. Low ^{10}Be cannot be due to exposure of older sediments on the surface, as both the radiometric ($^{230}Th_{excess}$ based) and the biostratigraphic (radiolarian assemblages) dating methods have consistently yielded younger ages ($\sim$165 kyr) for the top 6 cm. Slumping of sediment from the seamount top is not a possible cause for the observed low ^{10}Be because two sediment cores collected near the top of the seamount which lies well above the CCD (core ABP26/SVBC#37, lat. 16°06.943′S; long. 75°25.083′E, water depth: 3992 m and core ABP4/BC#37; lat. 16°06.031′S, and long. 75°26.040′E, water depth: 4252 m;) have very high carbonate contents ($CaCO_3$ between 77 to 92% in first core and 48 to 76% in second core; unpublished data) compared to the non-carbonate (<1%) sediments on flank. The seamount top cores also have relatively higher sedimentation rates (AMS ^{14}C date of 12,315 ± 70 yr for the 0–2 cm subsection of core ABP-4/BC#37; dating of foraminifera at Uppsala Tandem laboratory — unpublished data with authors). Both these parameters suggest that the sediments from the seamount top and flank sediments are dissimilar ruling out the possibility of slumping as a reason for low ^{10}Be values noticed in the studied core located on the flanks near the base of the seamount.

[15] With the given average ^{10}Be concentration of the CIB sediments at about 3×10^9 atoms/g [*Nath et al.*, 2007], the low concentrations noticed here would account for non-deposition of sediments for a time period of about 1.5 to 6 myr (one to four half lives), which is however unlikely. We prefer selective leaching during the hydrothermal alteration as the reason for low ^{10}Be content. This is because the concentrations would have been higher if it were due to precipitation, as the hydrothermal scavenging can lead to significant net removal of dissolved ^{10}Be onto the bottom sediments [e.g., *German et al.*, 1997]. Enhanced scavenging of ^{230}Th over that of ^{10}Be was found during hydrothermal Mn oxide deposition [*Frank et al.*, 1994]. Further, one would see a correlation between Fe content and $^{230}Th_{excess}$ [*German et al.*, 1997] if it was due to enhanced hydrothermal plume fall-out.

[16] Another finding that further supports considerable hydrothermal influence is the presence of grains having native Al° in the same sediment core (BC#8), considered to be of hydrothermal origin [*Iyer et al.*, 2007]. Morphologically and compositionally, the Al-rich specimens are similar to those reported from the EPR hydrothermal sediments. During progressive melting of magma, a basaltic magma is produced which has high contents of reductants such as methane and hydrogen, and a low oxygen fugacity. It was hypothesized that during the upward migration of such magma, reduction to metallic Al and the formation of native Al° particles has taken place [*Iyer et al.*, 2007, and references therein].

[17] Grains of comparable morphology and chemistry to the ones described here (rich in Cu, Zn, Al, S, Cl, Ag) were observed in the Manus back-arc basin associated with a hydrothermal system [*Yang and Scott*, 1996]. Particles within buoyant hydrothermal plume at East Pacific Rise were enriched in Cu, Ag, Zn, Al and other elements by a factor of 4–20% relative to Fe [*Mottl and McConachy*, 1990], which has been explained as a degassed input overprinted upon a hydrothermal input [*Rubin*, 1997].

[18] Alteration of sediment is also evident from the radiolarian dissolution features and depleted organic carbon. Dissolution of amorphous silica and organic matter degradation were found to be wide spread in ridge-flank hydrothermal systems compared to non-hydrothermal settings [*Wheat and McDuff*, 1994] suggesting an intense hydrothermal effect. Opal dissolution can also occur during early diagenetic processes [*Cole*, 1985], though such process cannot explain the lack or organic carbon. The sediments also contain typical alteration minerals smectites (including nontronite) and zeolites. Iron in the sediments studied here is entirely of ferric nature (Figure S5), which is typically seen in hydrothermal clays [*Singer et al.*, 1984].

[19] Mineral magnetic data also support sediment alteration. The altered (core BC#8) and unaltered samples (different core from the same Basin) displayed difference in the relative quantity of magnetic mineral and their grain sizes. Altered sediments are enriched in secondary magnetite of SSD size (0.03–0.15 μm) and appear to be the result of hydrothermal alteration. The relatively lower ferrimagnetic (magnetite) component of SP grain sizes (<0.03 μm) in the unaltered sediments, on the other hand is characteristic of pelagic deep-sea sediments. Binary plots of χ_{LF} versus χ_{ARM} and χ_{ARM} versus χ_{ARM}/SIRM parameters show distinct grouping of altered and unaltered sediments (Figure 3; core A and core B representing altered and unaltered sediment cores).

[20] Shale-normalized rare-earth element patterns of both the bulk sediments and the selectively leached Fe-Mn oxides show distinct anomalies at cerium and europium (Figure S6). While Ce shows negative anomalies, Eu displays positive anomalies compared to their trivalent REE neighbors. Both these characteristics are typical of seawater influenced hydrothermal fluids [e.g., *Sherrell et al.*, 1999]. Negative Eu anomalies (shale-normalized values) in hydrothermal Fe-Mn oxide precipitates were attributed to contribution from low temperature (<220°C) hydrothermal fluids

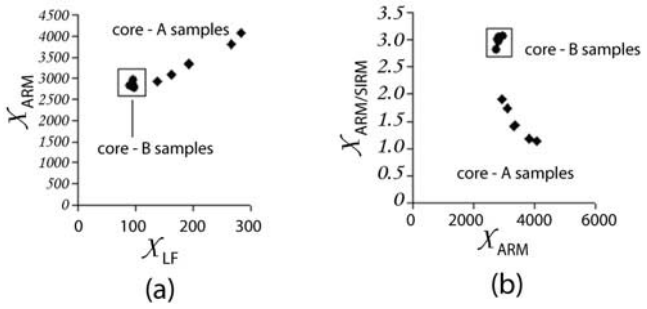

Figure 3. Scatter plots of magnetic parameters (a) χ_{LF} vs χ_{ARM} and (b) χ_{ARM} vs χ_{ARM}/SIRM indicative of magnetic concentration and grain sizes in the altered and unaltered sediments (represented by Core -A and Core -B respectively). The terms χ_{LF}, χ_{ARM}, and SIRM are described in text.

due to the non-dissolution of plagioclase during the fluid-rock interaction [*Frank et al.*, 2006]. Thus, significant positive Eu anomalies of our sediments probably imply the role of fluids, with temperatures higher than 220°C, in altering the sediment.

[21] Relatively high S and Cl concentrations together with low S/Cl values (0.09 to 0.54) found in some of the individual grains suggest that they could be derived from neutral hydrothermal fluids with temperatures at nearly 200 to 350°C in areas of abundant water supply with upwelling of chloride rich fluids above an active magmatic source [*Nicholson*, 1993; *Newsom et al.*, 1999]. However, some grains also have relatively high S content (12 %) with near absence of chlorine. Both through ascent and advection, the magmatic fluids would have altered the primary signal of the sediments imparting hydrothermal signatures.

[22] Occurrence of recently altered sediments at the seamount flank area reported here and the earlier report of *Iyer et al.* [1997] on the occurrence of semi-indurated metalliferous sediments of Holocene period at the base of other seamount in the Central Indian Basin (Figure 1), both close to the fracture zone suggest that the hydrothermal activity must be occurring at several places along the fracture zones in the Central Indian Basin. Reactivation of tectonic faulting at the fracture zones [*Kamesh Raju*, 1993] would probably be responsible for the observed hydrothermal alteration. While the Fe-oxides generally precipitate in the hydrothermal systems, a part of precipitated Fe would probably be removed to the overlying waters during the hydrothermal alteration, as solid $Fe(OH)_3$ would be in a metastable form at the Eh-pH conditions prevalent in seawater [*Glasby*, 2006]. A part of leached Fe in the deep-sea hydrothermal systems may be available for incorporation into the manganese nodules and may play a role in the oceanic iron cycle.

5. Conclusions

[23] Isotopic data (^{210}Pb, ^{238}U-^{230}Th, ^{10}Be) together with major and trace elements, mineralogy and magnetic properties of seamount flank sediments in the Central Indian Basin show evidence of alteration due to the degassing and circulation of hydrothermal fluids. Although the earlier studies have reported the occurrence of hydrothermally derived sediments at intra-plate seamounts in the Central Indian Basin, degassing events of recent origin as reported here are not known. Emanation of hydrothermal fluids and consequent alteration of the sediments may be a widely prevalent phenomenon in the Central Indian Ocean than that is known currently, in view of possible fluid ascent along the conduits in the faulted areas of the well defined fracture zones.

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