Near-seafloor magnetics of off-axis volcanism near the Kairei and Yokoniwa hydrothermal fields of the Central Indian Ridge

Masakazu Fujii[1]

[1]National Institute of Polar Research/SOKENDAI

November 21, 2022

Abstract

The Kairei and Yokoniwa hydrothermal fields are hosted in mafic as well as ultramafic rocks distributed at an off-axis volcanic knoll of the Central Indian Ridge. Despite intensive investigations, their geological and geophysical background is still debated. Here, we show results of near-seafloor magnetic field measurements using a submersible. We investigated crustal magnetization of the hydrothermally altered zone and surrounding lava flows, and evaluated their intensities compared to previously reported values at axial areas of a spreading environment. The Kairei hydrothermal field is characterized by low coherence between observed and modeled anomalies and low values of magnetization. This result suggests that magnetic minerals within basaltic lava flows were likely altered by hydrothermal fluid circulation. The variation pattern in the observed magnetic anomalies above the lava flows is in phase with that of modeled magnetic anomalies for a simple assumption with a magnetization direction parallel to the geomagnetic field. This result suggests that these lava flows preserve normal magnetic polarity corresponding to the Brunhes chron. The estimated magnetization intensity reaches 20 A/m in this area, which is clearly greater than that of the general off-axis crustal magnetization. This study provides new insight into the distribution of highly magnetized lava flows and indicates the distribution of recent off-axis volcanic activity, which is potentially linked to sub-seafloor hydrothermal circulation.

Near-seafloor magnetics of off-axis volcanism near the Kairei and Yokoniwa hydrothermal fields of the Central Indian Ridge

Masakazu FUJII (National Institute of Polar Research (NIPR) / SOKENDAI), Kyoko OKINO (AORI, UTokyo) **E-mail: fujii.masakazu@nipr.ac.jp**

Fujii and Okino *Earth, Planets and Space* (2018) 70:188
https://doi.org/10.1186/s40623-018-0959-5

Earth, Planets and Space

FULL PAPER Open Access

Near-seafloor magnetic mapping of off-axis lava flows near the Kairei and Yokoniwa hydrothermal vent fields in the Central Indian Ridge

Masakazu Fujii[1,2*] and Kyoko Okino[3]

Available online

Introduction

Japanese Team has investigated the Central Indian Ridge (CIR) near the Rodrigues ridge–ridge–ridge triple junction to understand volcanic and hydrothermal processes within oceanic lithosphere (Gamo et al., 2001; Kumagai et al., 2008; Nakamura et al., 2009; Okino et al., 2015; Fujii et al., 2016a; 2016b). We found the Kairei (KHF) and Yokoniwa hydrothermal fields (YHF), which are distributed at an off-axis volcanic knoll. They are characterized by hosted mafic as well as ultramafic host rocks and unique vent fluids with high H2 and CH4 contents. Despite intensive investigations, their geological and geophysical background is still debated. Here, we show the results of near-seafloor magnetic anomaly surveys conducted using a submersible.

Remained Question:
Why do vent sites exist in off-axis region?

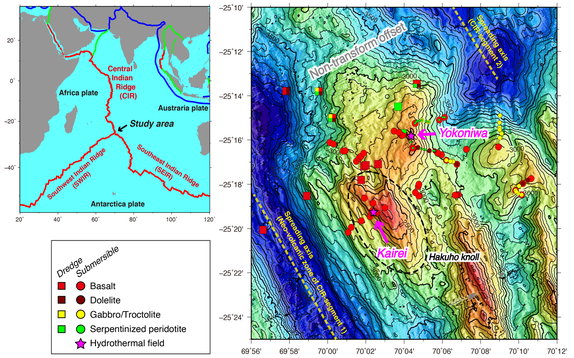


Figure 1. Geological background and seafloor bathymetry of the study area.

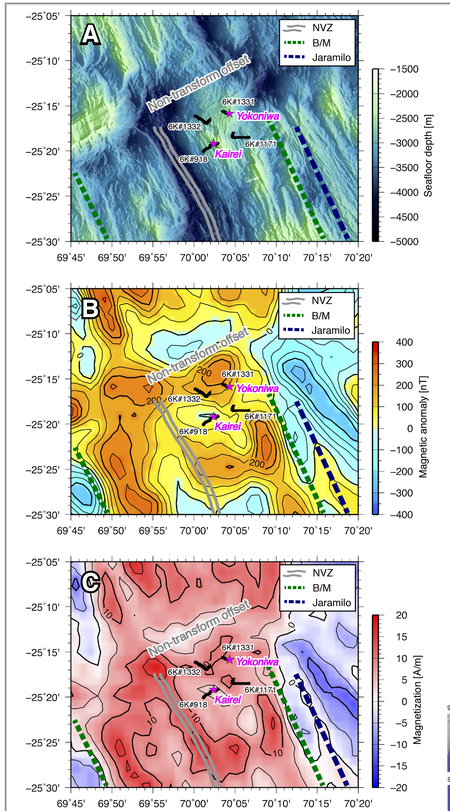
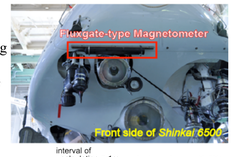


Figure 2. Survey tracks overlaying (A) bathymetry, (B) magnetic anomaly, and (C) magnetization distribution maps. NVZ: neo-volcanic zone; B/M: Brunhes–Matuyama boundary (0.78 Ma); Jaramilo: magnetic isochron of Jaramilo chron 1r.1 (0.99–1.07 Ma).

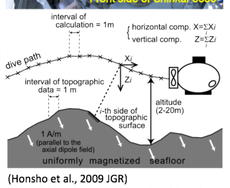
Method

We investigated the bulk magnetization of the hydrothermally altered zone and the surrounding lava flows and evaluated their intensities compared with previously reported values at axial areas of seafloor spreading environments. We performed near-seafloor magnetic surveys using submersible *SHINKAI6500* during 3 research cruises of R/V *Yokosuka*; YK05-16, YK09-13, and YK13-03.

Three components of the magnetic field were successfully measured by using a three-axis fluxgate type magnetometer that was rigidly fixed to the front side of the submersible.



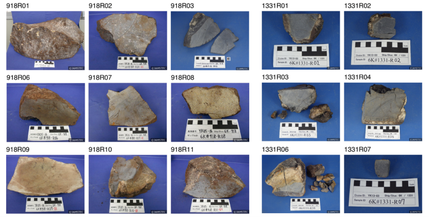
The two-dimensional forward method combined with frequency analysis was applied to estimate the absolute magnetization under consideration of topography and altitude variation (Fujii et al. 2015; Fujii et al. 2016a; Honsho et al. 2009).



(Honsho et al., 2009 JGR)

The upper boundary of the magnetized layer was constrained by the topographic surface, which was defined by the depth and altitude of the vehicle. The magnetized layer was assumed to be uniformly magnetized with infinite half-space and a magnetization direction parallel to the geocentric axial-dipole field, showing an inclination of -43° and a declination of 0° in study area.

We measured grain density and rock magnetic properties of natural remanent magnetization (NRM) and magnetic susceptibility for lava samples. Samples were divided into cubic sub-samples (2-cm cubic), which were utilized for measurements of a spinner magnetometer (Natsuhara Giken DSPIN), an AGICO KLY-3 Kappabridge, and a gas-pycnometer (AccuPycTM 1330 Pycnometer).



Results

The KHF is characterized by low coherence between observed and modeled anomalies and low values of magnetization. This result suggests that magnetic minerals within basaltic lava flows were likely altered by hydrothermal fluid circulation. The variation pattern in the observed magnetic anomalies above the lava flows is in phase with that of the modeled magnetic anomalies for the simple assumption that the magnetization direction is parallel to the geomagnetic field. This result suggests that these lava flows preserve normal magnetic polarity corresponding to the Brunhes Chron. The estimated magnetization intensity reaches 20 A/m in the study area, which is clearly greater than those of previously reported off-axis areas, suggesting that recent volcanic eruption may have occurred in these off-axis areas.

Dive at Kairei hydrothermal field (KHF)

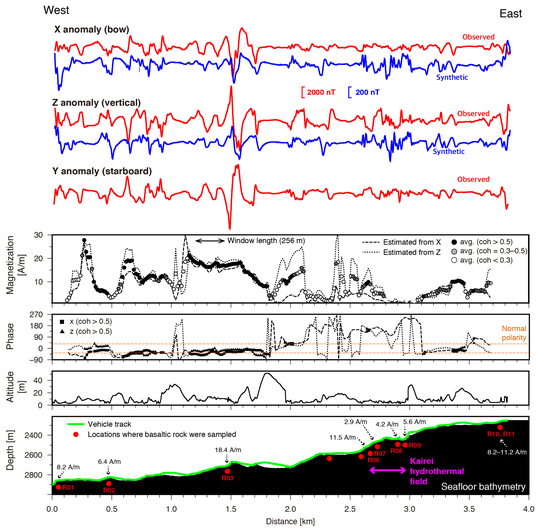
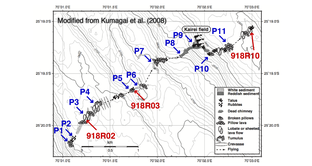


Figure 3. Analysis x (bow) and z (downward) components of observed magnetic anomaly along the 6K#918 track. From top to bottom: observed (red line) and synthetic (blue line) magnetic anomaly intensity, magnetization, phase, vehicle altitude, and seafloor/vehicle geometry. Black and gray circles are those with high coherency of >0.5 and from 0.3–0.5 on both the x and z components, respectively. The location of collected basaltic rock samples are shown in the bottom figure.



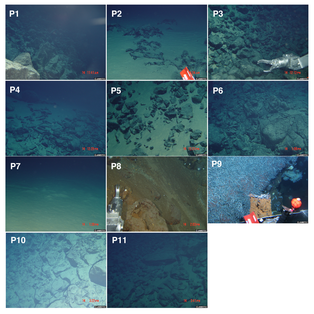


Figure 4. Seafloor surface geological signatures along the dive track of 6K#918 modified from Kumagai et al. (2008) (dive observer: H. Kumagai).

Dive at Yokoniwa hydrothermal field (YHF)

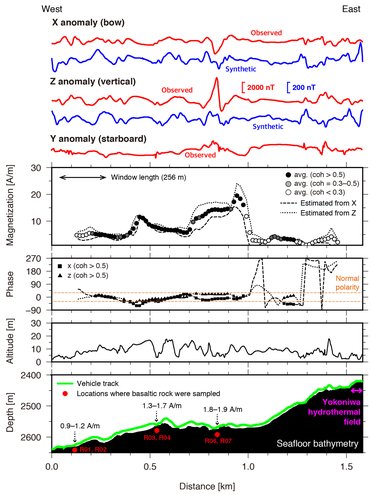


Figure 5. Analysis x (bow) and z (downward) components of observed magnetic anomaly along the 6K#1331 track (reanalyzed after Fujii et al. 2016a). Details are same as Figure 3.

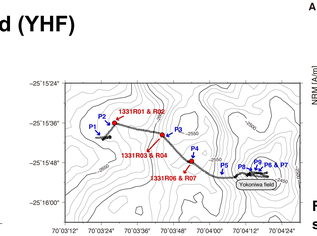


Figure 7. Log-log plot of susceptibility (K) and NRM.

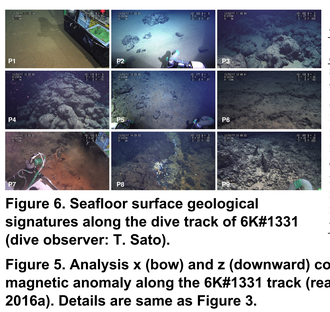


Figure 6. Seafloor surface geological signatures along the dive track of 6K#1331 (dive observer: T. Sato).

Table. Whole rock chemistry of collected lavas

(wt%)	918R02 (n = 19)	918R03 (n = 13)	918R10 (n = 12)
SiO_2	50.9	51.5	50.9
TiO_2	1.11	1.19	1.06
Al_2O_2	16.3	16.0	16.1
FeO	8.2	8.4	8.1
MnO	0.16	0.17	0.15
MgO	8.7	8.4	8.7
CaO	11.8	11.5	11.9
Na_2O	2.7	3.0	2.8
K_2O	0.03	0.05	0.02
P_2O_5	<0.1	0.11	0.07
Total	99.8	100.4	99.9

Discussion

The estimated magnetic-anomaly-derived absolute magnetizations (MADAM) show a reasonable correlation with the natural remanent magnetizations of rock samples collected from the seafloor of the same region; their relationship is consistent with previously reported datasets from the Mariana Trough (Fujii et al., 2015) and Mid-Atlantic Ridge (Honsho et al., 2009).

The highly magnetized lava flow zones (~20 A/m) in the study area are in a seafloor approximately 250 kyr old if a constant half-spreading rate of 30 mm/yr is assumed. This intensity of ~20 A/m is too high for off-axis areas in case of an exponential reduction in the NRM intensity with a time constant of 20,000 to 100,000 years (Gee and Kent 1994; Johnson and Tivey 1995).

It is considered that paleointensity variation could not be a significant factor to provide the seafloor magnetization intensity of 20 A/m on off-axis seafloors over the effect of low-temperature oxidation base on the evidence of Cordier et al. (2010), in which continuous across-axis distribution of absolute magnetization of the CIR covering the last 800 kyr period was reported.

The geochemical data for lava samples do not contradict our interpretation that the estimated high magnetization intensity of 20 A/m here is indicative of a recent eruption because of low Fe and high Ti contents..

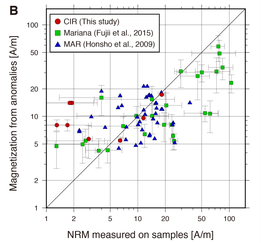
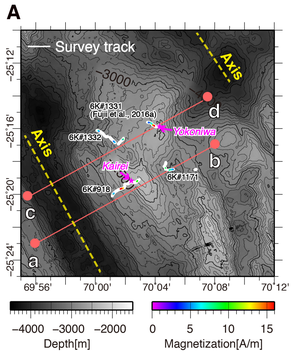
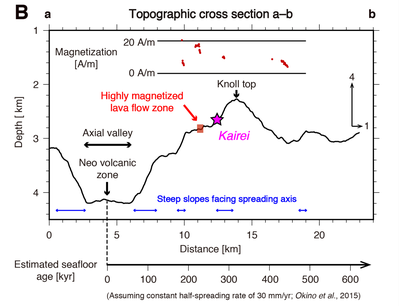


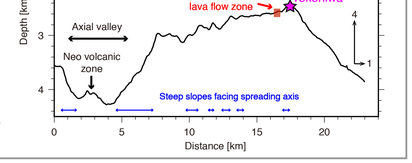
Figure 8. Comparison between reliable magnetic-anomaly-derived absolute magnetization (MADAM) with high coherency (>0.5 and >0.3 for 918R06) and NRM measured on rock samples.





The high magnetization distributions are commonly observed at the bottoms of the western slope from the KHF and YHF. This finding provides new insight into the distribution of highly magnetized lava flows in the off-axis areas and indicates the distribution of recent off-axis volcanic activities, which is potentially linked to the sub-seafloor hydrothermal circulation.

Figure 9. Distribution of highly magnetized lava flows with normal polarity.



Conclusion

We conducted near-seafloor magnetic field measurements and rock magnetic and geochemical studies of seafloor lava flows using the submersible SHINKAI 6500 near the Kairei and Yokoniwa hydrothermal fields of the Central Indian Ridge. The integrated analysis of the magnetic anomaly and comparison with the rock magnetic properties led to the following conclusions:

1. The Kairei hydrothermal field is associated with a lack of magnetization and it extends several hundred meters toward the western slope. The hydrothermal alteration of magnetic minerals present in extrusive lavas and in deposits of nonmagnetic hydrothermal material are likely responsible for the reduced magnetization.
2. The MADAM estimates are generally consistent with the NRM intensities of collected rock samples from the corresponding seafloor lava, although the NRM values are partly smaller than the MADAM estimates for low values. This discrepancy can be explained by the heterogeneity in magnetic grain size distribution as well as the spatial difference in the degree of low-temperature oxidation.
3. The magnetization intensity from magnetic anomalies reaches 20 A/m in the study area, which is clearly greater than that of previously reported off-axis areas. This result suggests that a recent volcanic eruption may have occurred in the off-axis areas. High magnetization distributions are commonly observed at the bottoms of the western slopes of the KHF and YHF. This finding provides new insight into the distribution of highly magnetized lava flows in off-axis areas and indicates the distribution of recent off-axis volcanic activities, which is potentially linked to the sub-seafloor hydrothermal circulation.