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39. PALEOGENE COUNTERCLOCKWISE ROTATION OF THE CELEBES SEA--ORIENTATION OF ODP CORES UTILIZING THE SECONDARY MAGNETIZATION[1]

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ABSTRACT

Experiments with thermal demagnetization of the samples from Site 770 of Ocean Drilling Leg 124 indicate that the samples have two magnetic components. An assumption that the low-temperature component, which is removed between 100°C and 200°C, is the secondary magnetization acquired in Brunhes normal chron, gives a core orientation. The oriented high-temperature component directions were tightly clustered around a pair of antipodal directions. The change of declination of the high-temperature component shows that the Celebes Sea was rotated counterclockwise about 60° during Eocene and Oligocene time.

INTRODUCTION

The Celebes Sea is a small marginal basin whose origin is not clear (Bowin et al., 1980; Lee and McCabe; 1986). In this paper we discuss the paleoposition of the Celebes Basin on the basis of the paleomagnetism of ODP Site 770 (Fig. 1).

Paleomagnetic measurements on sediment cores have long been performed, and they have contributed significantly to the Earth sciences. A limitation of paleomagnetism on cores is the difficulty of horizontal orientation. In the Ocean Drilling Program the advance piston cores (APC) were oriented by means of a multishot core orientation tool, which is essentially a magnetic compass, although the accuracy is not sufficient for all aspects of paleomagnetism. For rotary drilling operations using the extended core barrel (XCB) or rotary core barrel (RCB), no method has been shown to be useful for the horizontal orientation of each sample. The cores recovered with XCB or RCB are usually not continuous but segmented by rotary cutting, thereby the orientation of the core barrel does not indicate that of core sample itself. In this paper we will demonstrate that the Brunhes secondary magnetization is useful for the orientation of XCB and RCB samples under certain conditions, and we will present tectonic implications of the results. There were a few studies using the secondary magnetization as the reference of the orientation (Van der Voo and Watts, 1978; Kodama, 1984), but no result has been reported with soft sediment, which appears most commonly in paleomagnetic studies of core samples.

METHODS

Samples used in this study are from Leg 124, Site 770. The site was drilled to supplement Celebes Sea Site 767, and the drilling was focused on the basement rocks, and sediment just above basement. The upper 340 m were washed except for spot cores every 50 m, and all coring was with RCB. The lithology of the samples is different by horizon. At least one sample was taken from each 1.5 m section. Some of the samples were demagnetized with alternating field (a.f.) and measured using on-board 2-G Enterprises' pass-through cryogenic magnetometer. Forty-eight additional samples were thermally demagnetized and measured at Kyoto University using an SCT cryogenic rock magnetometer. The residual magnetic field in the demagnetization furnace was less than 10 nT.

RESULTS

Figure 2 shows examples of Zijderveld diagrams (Zijderveld, 1967) for progressive thermal demagnetization. It is clear that the magnetization consists of two components, namely low-T component eliminated from 100°C to 200°C and high-T component erased over 200°C. The equal-area plot of the magnetic direction for both the low-T and high-T component shows scattered declination and low inclination (Fig. 3, left), indicating rotation of the core by rotary cutting and the low latitude of the Celebes Basin, respectively. By taking the difference of the declination of the two components instead of the raw values of the declinations of each component, it is restricted to the very narrow range between north and northeast and its antipodal direction (Fig. 3, right). This result is explained well assuming the low-T component as the Brunhes secondary magnetization.

The experiments happened to be performed in two periods, April to May 1989, and July, 1989. All the specimens processed during the earlier period had straight alignment of 100°C, 150°C, and 200°C points on the Zijderveld diagram (Fig. 2A). However, we found that some specimens have a 150°C point off the line connecting 100°C and 200°C points, during processing of the first several specimens in the later period. Thus, we made additional demagnetization steps of 125°C and 175°C on the remaining specimens (Fig. 2B) and determined the direction of the low-T component as any straight portion including more than three points between 100°C and 200°C. However, a few specimens have no straight part, thus the directions of their low-T component could not be determined.

Meanwhile, the direction of the high-T component was obtained by the linear fitting of the points between 250°C and 620°C for the former group, and represented by the direction at 350°C for the later group. All the results were listed in Table 1.

DISCUSSION

Although we tried progressive AF demagnetization on board to identify the Brunhes secondary magnetization, we were not successful, probably because the cleaner nature of

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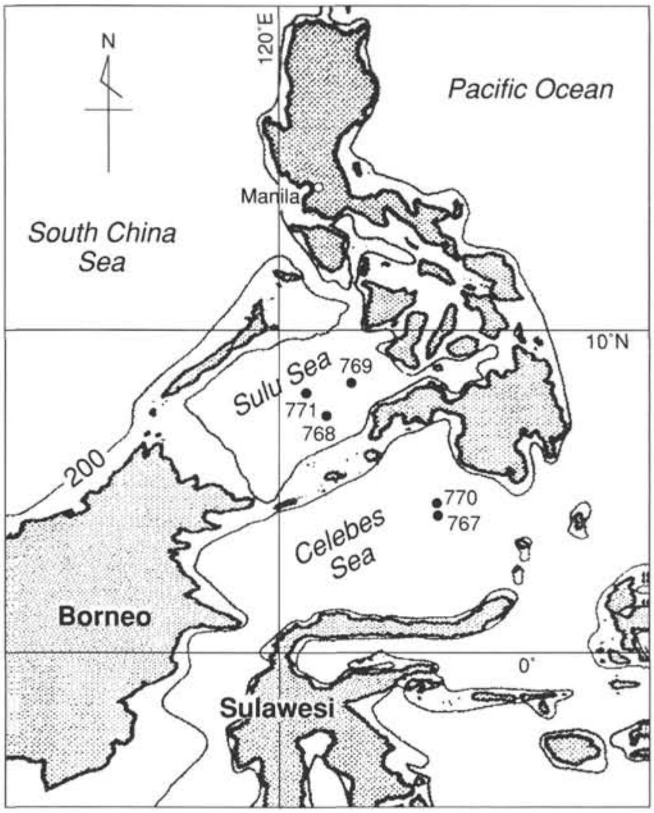

Figure 1. Map showing location of the drill sites.

the thermal treatment. DRM is so ineffective in acquiring the magnetization that the sediment has very small NRM compared to the amount of magnetic mineral contained. Thus, a very small imbalance of the AF may be the origin of the noise in the Zijderveld diagram. Preventing the noise in thermal treatment is achieved by simply shielding the furnace, which is less difficult than to make a perfect balance of the AF.

Because all the experiments were made more than 5 months after the sampling, the difference between the two periods of experiments does not seem due simply to the storage effect. The temperature may be critical for overwriting the secondary component; it rises significantly from May to July in Japan.

We tried to orient samples from Site 769, in the Sulu Sea, using equipment situated at Texas A&M University. The Brunhes secondary magnetization was not recognized. As the NRM directions of these samples tend to be close to vertical, the drilling secondary magnetization problem in these samples seems to be more severe than those from Site 770. Although five sites were situated and thirteen holes were drilled on the cruise, samples from the other sites are not useful for the component analysis because the on-board measurements indicate that they were affected by the drilling remagnetization more than the Site 769 samples. To make use of this method regularly, avoiding the secondary magnetization at or after the drilling procedure, is very important.

The stratigraphic plot of the corrected declination and the inclination is shown in Figure 4. The open circles indicated the antipodal direction for the reversed samples. It is easily seen from the figure that the declination is westerly deflected at the bottom of the core, and the deflection decreases gradually to zero at about 360 mbsf. The directions of the normal samples are less scattered than those of the reversed samples, probably because the same amount of contamination of the primary magnetization at the low-temperature range more greatly affects the reversed direction than the normal one. Taking the direction for normal samples, the declination can be said to change linearly.

The deflection of the declination is usually explained as a result of rotation of the block that includes the site. Because no major fault is reported around the site, the block of the rotation must be the whole Celebes Sea Basin. The ages of the bottom of the sedimentary column and the end of the deflection are 42 Ma and 20 Ma, respectively. The Celebes Sea had been rotated 60 degrees within 22 m.y.

Lee and McCabe (1986) correlated the magnetic lineations and argued that the Celebes Sea originated from the Indian Ocean. The present result does not support their model, because the inclination of Site 770 stayed low throughout the sedimentary column. On the other hand, the Leg 124 Scientific Party concluded that the Celebes Sea did not originate by back-arc spreading, but as a part of a larger spreading system in an open ocean (Rangin, Silver, von Breymann, et al., 1990). The only remaining large basin around the Celebes Sea is the west Philippine Basin. The results of ODP Leg 124 reveal several similarities between the west Philippine Basin and the Celebes Basin. They showed the age of the Celebes Sea as 42 Ma, which is within the range of the opening of the west Philippine Basin (40–48 Ma; Seno and Maruyama, 1984). The low latitude of the Celebes Sea at the time of its generation coincides with the low paleolatitude at the base of DSDP Sites 290–294 (Kinoshita, 1980). After the correction of the counterclockwise rotation of the Celebes Sea, the azimuth of its magnetic lineation is about NW70°. That of the west Philippine Basin is now about NW60°.

There are a few studies of the rotation of the west Philippine Basin. They claimed a considerable amount of clockwise rotation, though all the evidence is indirect or not accurate enough. The paleomagnetic results from the islands at the east fringe of the Philippine Plate (Keating et al., 1982; Kodama et al., 1983; McCabe and Uyeda, 1983) all show clockwise rotation, but the amounts of rotation do not coincide with each other. They also can be explained by rotation of each island. The rotation drawn from anomaly skewness data from the west Philippine Basin (Louden, 1977; Shih, 1980) also is not a solid conclusion. The skewness analysis is highly dependent on the assignment of the magnetic anomaly, and the skewness factor only gives us a half of the great circle on the globe on which the paleopole can exist.

The most reliable models of the reconstruction of the Philippine Plate are those given by Seno and Maruyama (1984). They introduced two models and concluded that the "trench retreating model" is preferable to "anchored slab model" because of several indications of the rotation of Philippine Plate. If we assume that the Celebes Basin was formed as a part of west Philippine Basin, the direction of the magnetic anomaly for the "anchored slab model" fits with that in the Celebes Sea at the time of its generation. On the other hand, if we assume clockwise rotation of the west Philippine Basin, we find two large basins both spreading in different directions in the Southeast Asian equatorial area, in Oligocene time.

CONCLUSIONS

1. Orientation of the sediment cores utilizing the Brunhes secondary magnetization was successful at Site 770.
2. The Celebes Sea had been rotated 60° counterclockwise through Oligocene time.
3. Paleolatitude stayed low throughout the history of the Celebes Sea.
4. Paleomagnetic inclination along with the basement age of Site 770 suggests a relationship between the Celebes and west Philippine basins.

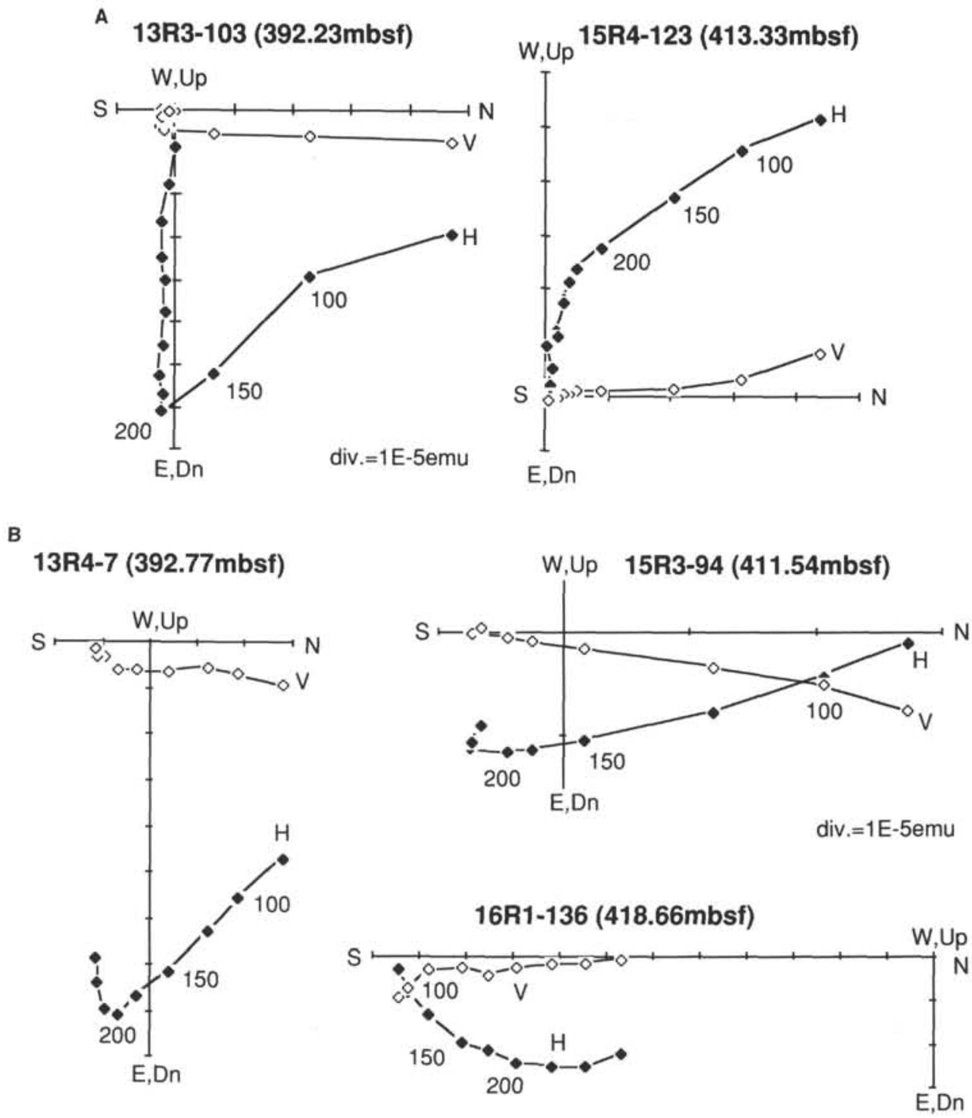

Figure 2. Orthogonal demagnetization diagrams for typical samples. Double component nature of these magnetizations are easily recognized. **A.** April and May 1989 experiments. **B.** July 1989 experiments.

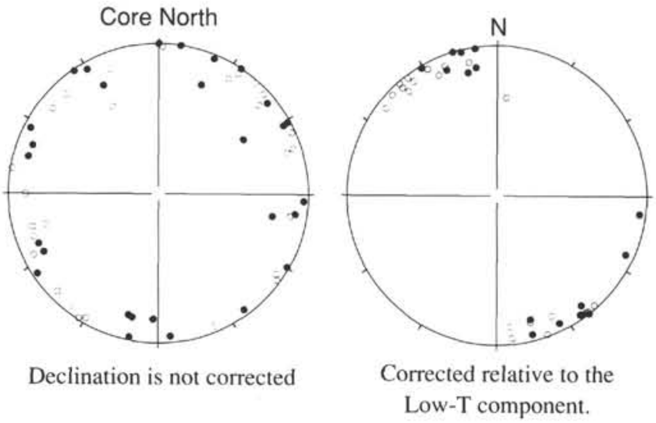

Figure 3. Magnetic direction of the high-temperature component relative to core north (left), and relative to the low-temperature component (right).

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Table 1. Directions of the low-T and high-T components and the difference of the declination (dDec). All angles are in degrees. Samples designated * and # were processed in April and May 1989, and in July 1989, respectively.

Specimen		SBD(m)	Low-T component		High-T component		
			Dec	Inc	Dec	Inc	dDec
Hole 770B							
5R1-17	#	195.97			48.6	-11.4	
5R2-79	*	198.09			-105.2	-22.7	
6R1-3	*	244.13	-152.7	9.1	-166.0	17.1	-13.3
6R1-23	#	244.33			-177.9	17.4	
7R1-6	#	292.46			100.9	23.5	
7R3-38	*	295.78	-21.7	8.5	143.6	4.8	165.3
7R7-25	#	301.65			175.0	5.1	
8R1-46	#	341.06	-47.0	10.6	-69.0	11.4	-22.0
8R2-76	#	342.86	-26.2	1.0	-34.9	1.2	-8.7
8R3-102	*	344.62	-39.5	2.9	-51.3	-10.5	-11.8
9R1-54	#	350.14			46.2	-4.2	
9R2-12	*	351.22	85.9	-4.6	-109.3	-13.2	164.8
9R4-102	#	355.12			21.3	23.2	
10R1-108	#	360.38			-104.9	-14.5	
10R1-144	#	360.74	-103.5	-7.3	-112.8	14.7	-9.3
10R2-27	#	361.07	-32.7	1.3	-27.3	-35.1	5.4
10R3-113	*	363.43	165.1	0.3	-21.0	-12.9	173.9
10R4-32	#	364.12			-123.7	3.2	
11R1-30	#	369.20			72.0	-11.7	
11R1-79	#	369.69			61.2	5.5	
11R2-103	*	371.43	-139.9	7.6	33.6	-4.4	173.5
11R3-96	#	372.86	-83.1	13.0	61.1	2.3	144.2
11R4-61	#	374.01	114.7	-2.2	-89.9	-12.1	155.4
12R1-18	#	378.78			57.2	33.5	
12R1-57	#	379.17	-154.3	2.5	-168.5	2.1	-14.2
12R2-23	*	380.33	150.3	1.1	119.6	1.6	-30.7
12R3-99	#	382.59			156.9	-3.8	
13R1-59	#	388.79	-94.2	3.4	-116.1	-7.9	-21.9
13R3-103	*	392.23	-52.4	1.7	92.6	3.5	145.0
13R4-7	#	392.77	-44.2	0.9	98.3	8.3	142.5
13R5-59	#	394.79			-74.1	11.0	
14R1-27	#	398.17	78.8	9.5	-116.8	15.4	164.4
14R1-131	#	399.21	25.5	2.1	8.5	0.0	-17.0
14R2-126	#	400.66	125.6	4.0	99.6	-11.8	-26.0
14R3-6	*	400.96	153.2	5.6	124.4	-5.1	-28.8
14R4-27	#	402.66			-27.2	20.4	
15R1-22	#	407.82	-2.8	-1.8	-43.2	-10.3	-40.4
15R2-75	#	409.85	107.6	0.5	71.2	-6.4	-36.4
15R2-127	*	410.37	39.0	6.6	1.5	-2.5	-37.5
15R3-94	#	411.54	-16.2	9.9	126.2	-2.2	142.4
15R4-123	*	413.33	-38.9	-4.2	-80.3	-1.8	-41.4
15R5-31	#	413.91	-101.1	0.0	-142.5	-5.6	-41.4
16R1-13	#	417.43	-82.7	4.0	-134.6	-6.7	-51.9
16R1-36	*	417.66	-103.2	-1.5	-149.7	-4.4	-46.5
16R3-30	*	420.00	-160.0	11.5	-62.7	4.7	97.3
Hole 770C							
1R1-27	*	384.07	176.2	-3.7	-30.1	5.5	153.7
1R2-6	#	385.36	52.6	6.4	-147.5	-1.4	159.9
1R2-81	#	386.11			-168.2	16.6	
1R3-120	#	387.93	-64.2	22.1	50.3	6.5	114.5
1R3-142	#	388.15			31.0	-11.6	
1R4-123	#	389.46	-73.1	7.1	65.1	-2.6	138.2
1R5-19	*	389.92	-100.3	4.2	41.2	-2.0	141.5
1R5-132	#	391.05	-108.3	9.1	33.5	0.1	141.8
1R6-101	#	392.24			22.4	3.0	

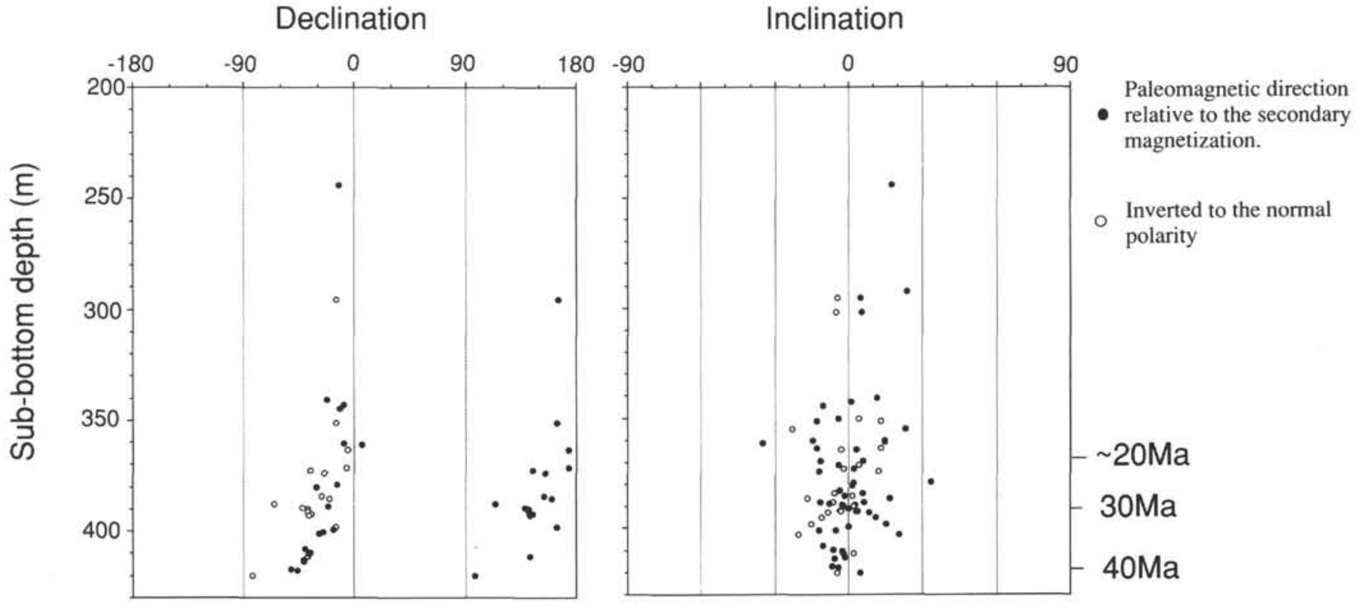

Figure 4. Stratigraphic plot of the declination and inclination of the high-temperature component. The declination is relative to the low-temperature component. Open circles are antipodal directions for the reversed samples.