PALEOMAGNETIC STUDY IN ANDEAN PERU : CRETACEOUS SEDIMENTS AND VOLCANICS

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1. Introduction

Rock samples were taken for paleomagnetic study in 1980 and 1981 as a part of the work titled "Geophysical study of the Central Andes". On these samples, paleomagnetic measurements have been in progress, from which several results are reported here.

Paleomagnetic poles of South American Plate are available for the entire Phanerozoic age, but they are usually based of the rock formations of the cratonic area such as Precambrian shields or intracratonic basins (e.g. Creer, 1970). On the other hand, there have been reported several paleomagnetic works on the rock formations of Andean orogenic belts, some of which suggest some "anomalous" paleomagnetic poles inconsistent with the "standard" polar wonder path. Andean orogenic belt has several "deflections" where the trend of the structure abruptly changes within its whole length of more than 7,000km (Fig.1), and anomalous paleomagnetic results were often attributed to the "oroclinal bending" occurred around these deflections. For example, Palmer et al.(1980a) reported 30°-40° counterclockwise rotation of Jurassic Camaraca Formation, Arica at the Peru-Chile border. MacDonald and Opdyke (1972) and Burns et al.(1980) reported the anomalous declination in the Northernmost and Southernmost parts of the Andes respectively. Palmer et al's (1980) attempt was to compare the paleomagnetic declination between the northern and southern regions of the Santa Cruz deflection, at the Peru-Chile border and to test the orocline hypothesis with paleomagnetic techniques. They, however, failed to derive any reliable paleomagnetic results from Peru due to the "unstability" of the remanent magnetization of the rock samples. Our original objective was the same as that of Palmer et al.(1980a) and we succeeded in getting several reliable paleomagnetic records of Cretaceous age from sediments of Northern Peru and volcanic rocks of coastal Central Peru.

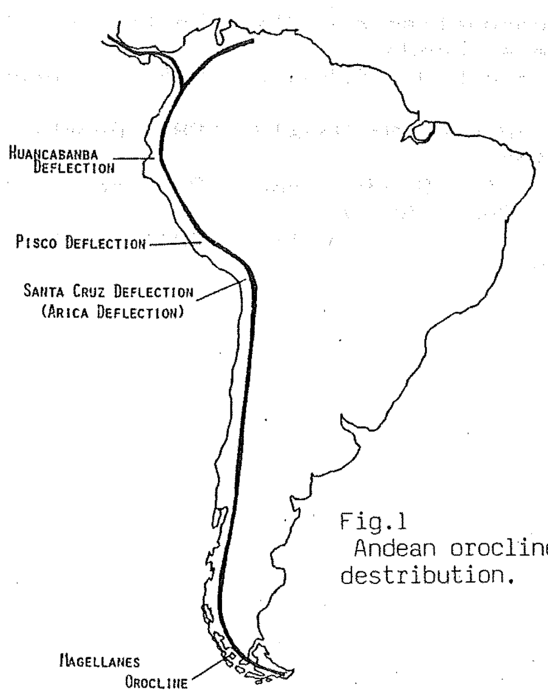

Fig.1
Andean orocline destribution.

2. Geology

Peruvian continental

margin is characterized by Mesozoic geosynclinal pair which roughly comprises of what we call eugeosyncline and miogeosyncline, the former consists of both volcanics and sediments and the latter consists mainly of sediments. Subsidence in the eugeosyncline was most rapid during the Albian, Middle Cretaceous, and the total thickness amounts to about 7,000m. In the miogeosyncline, the age of the greatest subsidence is the Tithonian, Late Jurassic, but its subsidence continued throughout the Cretaceous to accumulate a total thickness of about 6,000m (Cobbing, 1976).

From the miogeosyncline, sedimentary samples were collected for paleomagnetism (CM,BG series) from Middle Cretaceous rock formations near Cajamarca, Northern Peru, with the time span covering from the Albian to the Turonian. Rocks are mainly composed of shallow-sea limestone and marl and contain many fossils. Their stratigraphy and geology are reported in Reyes (1980), Bellido (1979) and some others. Rock types and sampling site localities are given in Table 1 and Fig.2.

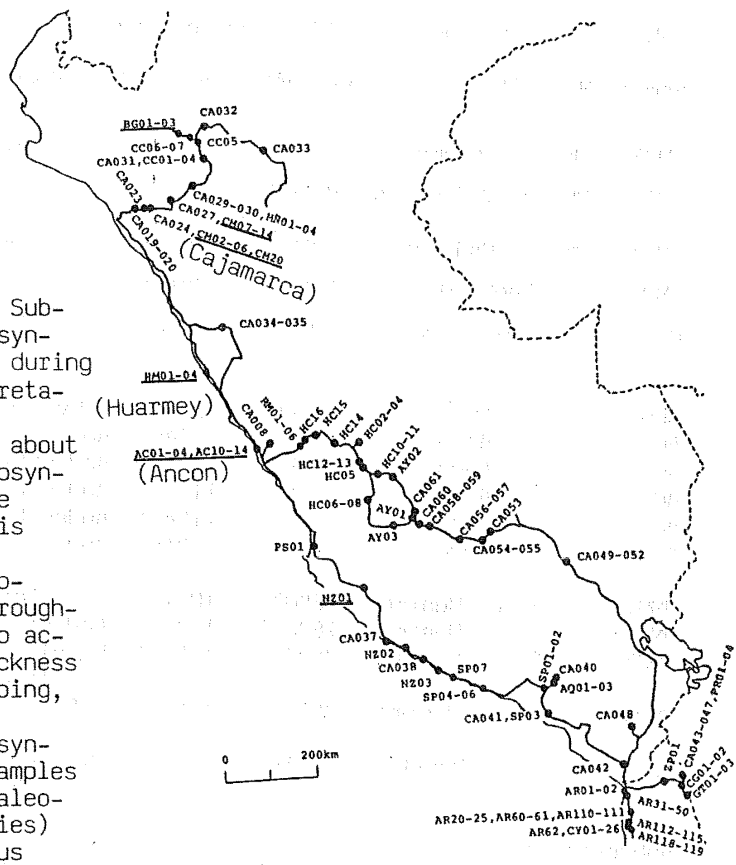

Fig.2 Localities of the sampling sites. Site numbers reported in this article are underlined.

From the eugeosynclinal area, volcanic rocks such as lava flows or dike rocks were collected (HM,AC,NZ series) along the coast between Huarmey and Nazca, Central Peru. Volcanic rocks in this region are reported to range in their composition from high-alumina basalt to andesite (Webb, 1976), which demonstrates these volcanisms are of island-arc type. Direction of maximum horizontal stress axis suggested by the dike orientation is almost north-south, which is nearly perpendicular to the present compression axis. Some lava flows show pillow structure indicating their submarine genetic environment. Geology of this region are reported by Myers (1974), Bellido (1979) and others. Rock types and sampling site localities are also given in Table 1 and Fig.2.

3. Experimental Procedure and Paleomagnetic Results

Sedimentary rocks

Each sample was taken from an outcrop as an oriented block and was cut into a core specimen in the laboratory. A cliogenic magnetometer of University of California, Santa Barbara was used in the measurement

Table 1. Sampling localities and rock types.

Sample No.	Place	Long.(°W)	Lat.(°S)	Rock name	Formation(Age)
CM08	W. of Cajamarca	78°26'	7°09'	Limestone	Chulec Fm.(Al.)
CM10	NW. of Cajamarca	78°20'	7°05'	Limestone	Pariatambo Fm. (Al.)
CM13	NW. of Cajamarca	78°16'	7°03'	Limestone	Chulec Fm.(Al.)
CM20	Tembladera	79°07'	7°15'	Andesitic dike	Cretaceous?
BG01	Bagua Grande	78°09'	5°54'	Limestone	Cajamarca Fm. (Tur.)
AC02	Ancon	77°11'	11°46'	Pyx. Andesite	Cretaceous
AC10	Ancon	77°11'	11°46'	Andesitic dike	Cretaceous
AC11	Ancon	77°11'	11°46'	Andesitic dike	Cretaceous
AC12	Ancon	77°11'	11°46'	Andesitic dike	Cretaceous
AC13	Ancon	77°11'	11°46'	Andesitic dike	Cretaceous
AC14	Ancon	77°11'	11°46'	Andesitic dike	Cretaceous
HM01	S. of Huarmey	78°03'	10°19'	Andesite	Cretaceous
HM02	S. of Huarmey	78°03'	10°19'	Andesitic dike	Cretaceous
HM03	S. of Huarmey	78°01'	10°21'	Basalt pillow lava	Cretaceous
HM04	S. of Huarmey	78°01'	10°21'	Basaltic dike	Cretaceous
NZ01	Rio Grande	75°14'	14°31'	Pyx. Andesite dike	Cretaceous

Abbreviations
W.:west, NW.:northwest, S.:south, Pyx.:pyroxene, Al.:Albian, Tur.:Turonian.

of these sedimentary rocks. Some number of the samples had natural remanent magnetization (NRM) of the order of 10^{-7} Am²/kg, but typical NRM intensity was of the order of 10^{-8} Am²/kg, which is the weakest possible intensity to measure even with a cliogenic magnetometer. Stepwise alternating field (AF) demagnetization was performed up to 80mT in peak intensity on each specimen.

Rock magnetic study of marine limestone have been very difficult owing to the low concentration of magnetic minerals, but current knowledge was recently summerized in Lowrie and Heller (1982). According to them, both magnetite and hematite are thought to be the most popular carrier of the NRM of marine limestone, in which magnetite is generally of depositional origin while hematite is thought to grow during diagenesis (see also Channel et al., 1982). Dominance of these two magnetic component is determined by their relative percentage of contribution to the total NRM. Limestone whose NRM is carried mainly by hematite can be, in general, characterized with its pinkish color and shows higher coercivity and blocking temperature than the limestone with magnetite-carried NRM. Peruvian limestone studied here ranges in its color from gray to pinkish gray and purely gray limestone specimens were found to be demagnetized considerably during stepwise AF demagnetization as far as 80mT while ones with pinkish color hardly change their direction nor intensity throughout the AF demagnetization. It suggests bimodal remanence carried by magnetite and hematite. In this study, we preferred magnetization component carried by magnetite because hematite of

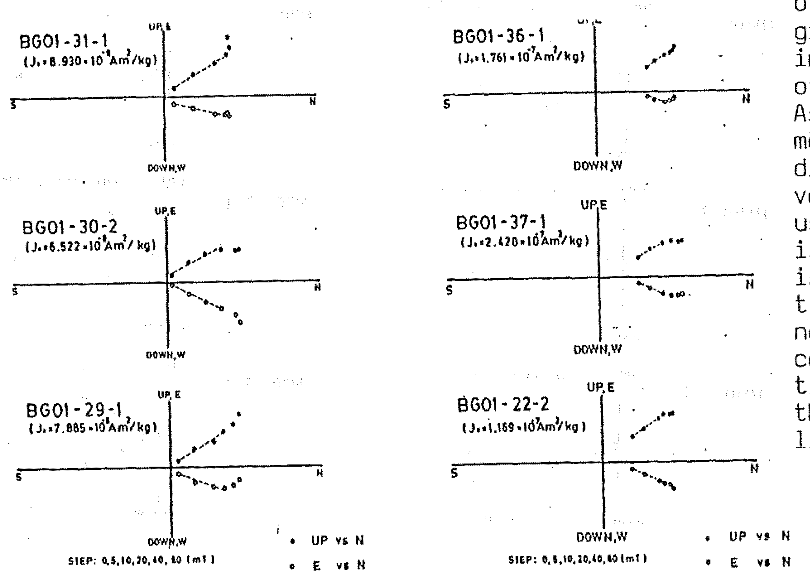

Fig.3 Zijderveld diagram plot (Zijderveld, 1967) of the AF demagnetization of Peruvian limestones. Characteristic remanence direction was determined from the gradient of the linear portion (dashed line) of the diagram.

of diagenic growth might delay in its acquisition of the remanence. As a practical method, Zijderveld diagram (Zijderveld, 1967) was used because it is convenient to isolate the direction of the remanence from multi-component magnetized specimen by the application of linear regression to the linear portion of the diagram (Dunlop, 1979). The "demagnetizability" of the remanence as far as 80mT was not uniform even within a single outcrop reflecting the degree of the dominance of the magnetite in the total NRM. Paleomagnetic direction was determined by the gradient of the linear portion of the diagram as far as 80mT irrespective of the proportion of the destroyed remanence (Fig.3). Obtained field directions are structurally corrected and plotted on equal area projections in Fig.4. Only CM20 is of reversed polarity and the others are normal and no field directions showed the coincidence with the present axial dipole field direction but deviates by 20°-50° in their declination counterclockwisely. Statistical parameters and mean field directions by Fisher's (1953) method are given in Table 2.

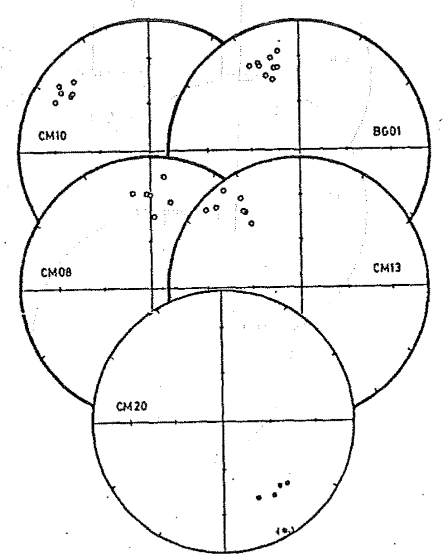

Fig.4 Equal area projection of characteristic remanence direction of sedimentary rocks. Open circle: upward, solid circle: downward.

Volcanic rocks

NRM of the volcanic rock was measured using a Schonstedt spinner magnetometer of University of Tokyo. Stepwise AF demagnetization was also performed and most samples showed relatively hard remanent magnetization with their median destructive field (MDF) of more than 30mT. Their Zijderveld diagrams indicate univectorial nature of the remanence (Fig.5) and paleomagnetic field direction was also obtained from the gradient of the diagram. Equal area projection of the field directions are given in Fig. 6. Paleomagnetic results are tabulated in Table 2. Paleohorizons were not observable at the outcrops in many cases, although for HM03 bedding plane was found to be nearly parallel to the present horizontal plane from

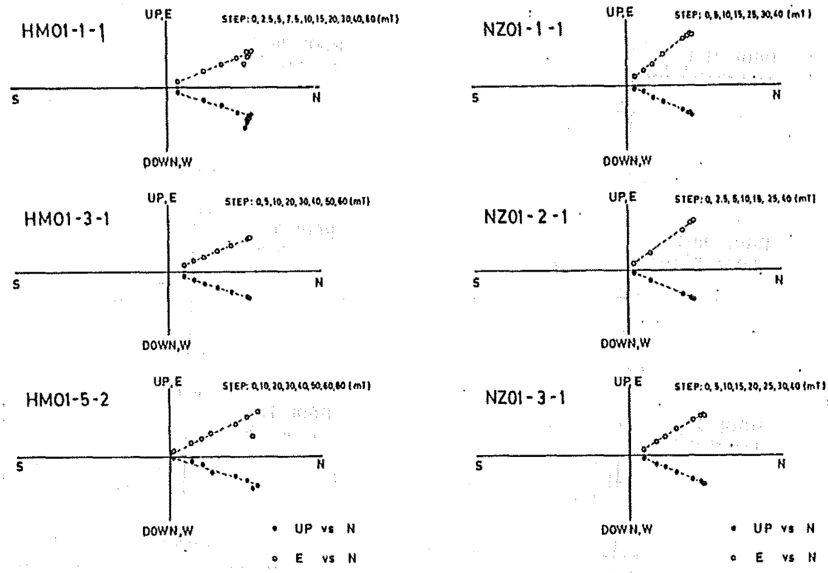

Fig.5 Zijderveld diagram plot of the AF demagnetization of Peruvian coastal volcanic rocks.

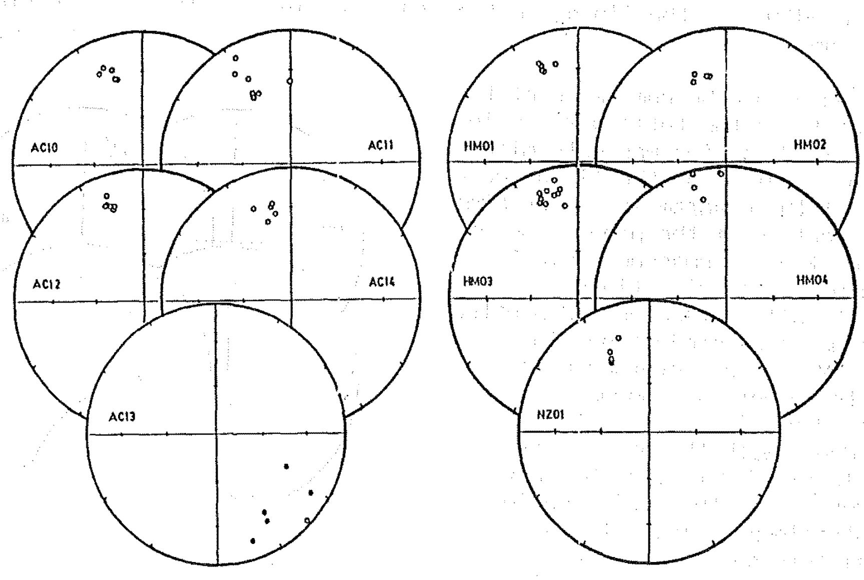

Fig.6 Equal area projection of remanent magnetization of Peruvian coastal volcanic rocks. Open circle: upward, solid circle: downward.

the shape of the pillow structures. In this report, no structural corrections are made on the paleomagnetic field directions of volcanic rocks.

Paleomagnetic field directions were almost of normal polarity with only one exception of AC13 which is of reversed polarity and showed 20°-30° counter clockwise deviation of the declination from axial dipole field direction, which is concordant with the results from sedimentary rocks but

Table 2. Paleomagnetic results of the sedimentary rocks and volcanic rock of the Andean Peru.

Site No.	N	Incl.	Decl.	R	k	Alpha 95	Bedding collection
CM08	7	-31.8	4.7	6.7824	27.6	11.7	o
CM10	6	-24.7	-54.7	5.9676	154.4	5.4	o
CM13	7	-22.6	-38.3	6.8328	35.9	10.2	o
CM20	4	34.6	145.0	3.9776	134.1	8.0	o*
BG01 (30-42)	9	-32.3	-20.6	8.9220	102.6	5.1	o
AC02	6	-38.8	-26.8	5.8504	33.4	11.8	x
AC10	5	-28.4	-20.4	4.9729	147.3	6.3	x
AC11	7	-33.1	-23.8	6.8011	30.2	11.2	x
AC12	6	-24.4	-19.2	5.9867	375.7	3.5	x
AC13	6	21.9	140.0	5.6136	12.9	19.3	x
AC14	5	-31.1	-14.4	4.9715	140.3	6.5	x
HM01	5	-26.2	-20.0	4.9892	370.6	4.0	x
HM02	4	-34.2	-16.7	3.9886	262.2	5.7	x
HM03	10	-20.5	-14.7	9.9014	114.5	4.5	x
HM04	5	-8.9	-9.8	4.8854	34.9	13.1	x
NZ01	5	-33.0	-26.4	4.9600	100.1	7.7	o*

N: number of samples, Incl.: inclination (degree), Decl.: declination (degree)
R: length of the resultant vector, k: precision parameter, Alpha 95: diameter of 95% confidence circle, *Bedding plane of the country rock was used.
(in degrees)

the amount of the deviation seems a little smaller than that derived from the sedimentary rocks.

4. Discussion

Phanerozoic polar wonder path of South American Plate was established by Creer (1970), which demonstrates that paleomagnetic pole during Mesozoic time should approximately coincide with the present geographic pole, in other words, Mesozoic paleomagnetic field direction should not present serious deviation from today's axial dipole field direction. Paleomagnetic results of Cretaceous sediments and volcanics in Peruvian Andes yield, however, several tens of degrees of counterclockwise declination shift (paleomagnetic declination is almost parallel to the Peruvian coastline, see Fig.7), which significantly differ from axial dipole field.

Cretaceous paleomagnetic data of South America is plainly reviewed in Palmer et al. (1980b), where Cretaceous poles were divided into two groups, that is, poles from stable platform and those from Andean orogenic belts. Note that Palmer et al.'s (1980b) paleomagnetic pole from Chilean Andes at the latitude of about 30°S is almost consistent with that of stable area and does not indicate any rotational movement of that region, which is also true for the pole of Colombian Andes (Creer, 1970). If

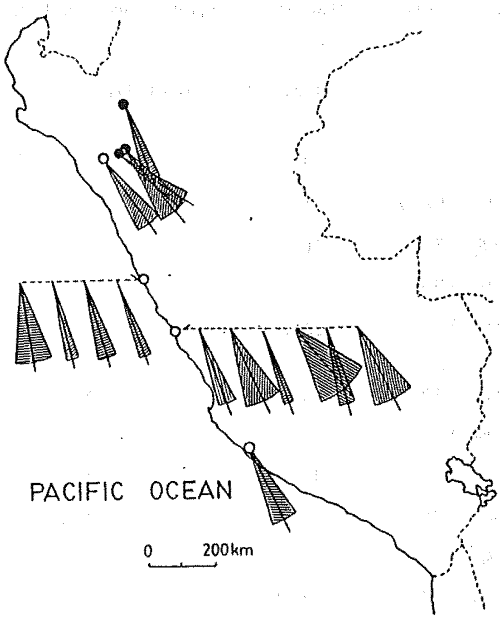

Fig.7 Paleomagnetic declination with their 95% confidence intervals of Cretaceous rock formations of Andean Peru. All the declinations are converted to "reversed" directions for the sake of visual simplicity. Open circle indicates volcanic rock, solid circle indicates sedimentary rock.

such declination anomaly are confined between Huancabamba deflection and Santa Cruz deflection (Fig.1), this can be explained with counterclockwise rotation of Peruvian region as the origin of these two deflections (Fig.8). Paleomagnetic study of younger Neogene and Quaternary volcanic rocks is in progress by the authors but no anomalous paleomagnetic declination have been coming out, which gives younger limit of the timing of the bending. It suggests that the bending occurred between Middle Cretaceous and Neogene times. Palmer et al.'s (1980a) report of 30°-40° counterclockwise rotation of Arica region after Jurassic time does not conflict with out results if Arica region is assumed to be just on the hinge of Santa Cruz deflection.

The mechanism of the bending process of the Andean mountain chain is still unclear due to its ambiguity of the timing. Tectonic evolution history of the Andes suggests major folding began in Late Eocene (Noble et al., 1979). It is important to know at what stage of the evolution history of the Andes the bending actually occurred; in the pre-folding stage of the sedimentary troughs, in the early stage of the compressional deformation, or longer-term phenomenon covering the whole history of the orogeny. Further paleomagnetic study, especially of Paleogene rocks, would be necessary to reduce the ambiguity of the timing of the bending.

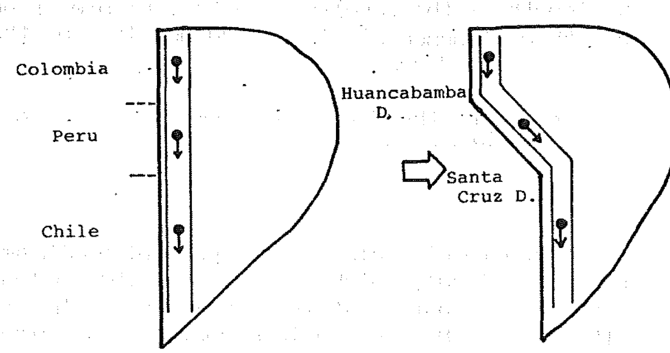

Fig.8 A cartoon illustrating the bending of the Andes and anomalous declination of the Peruvian Andes. D.: deflection.

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