PALEOMAGNETISM OF NEOGENE OCROS DIKE SWARM NEAR AYACUCHO, PERUVIAN ANDES

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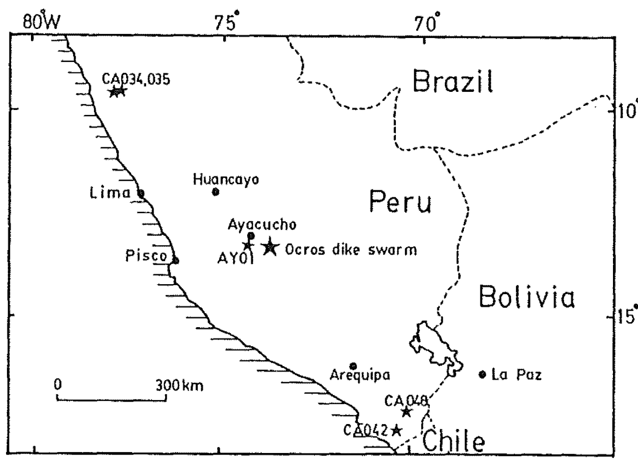
1) Introduction

Paleomagnetic studies on the rocks of the Peruvian Andes and the northernmost Chile have revealed post-Cretaceous oroclinal bending (Carey, 1955) of the Central Andes around an axis at the Peru-Chile border (Heki et al., 1983; Heki, 1983). It was also showed that Tertiary Ocros dike swarm shows about a half of the rotation angle of those of Mesozoic rocks. Recently, Hayashida et al. (in press) reported the counterclockwisely deflected declination of the Eocene red sediments of Salla Group in the Bolivian Altiplano and suggested the occurrence of the bending to be after the Eocene. Such Tertiary paleomagnetic studies will reveal the detailed chronology of the bending of the Central Andes. Here we report the full paleomagnetic description of Ocros dike swarm.



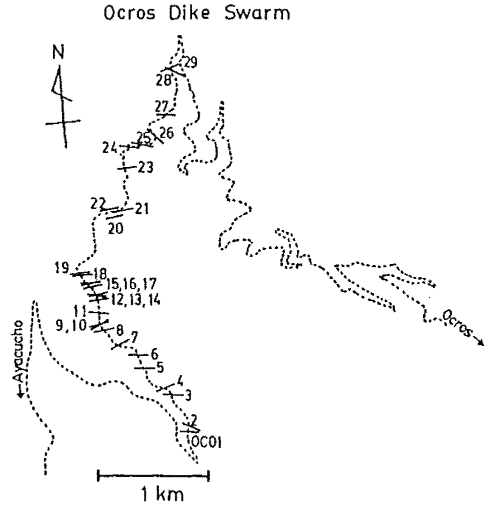


Fig.1 Sampling site of Ocros dike swarm. Direction of the bar indicates the strike of the dike.

2) Geology

Upper Cretaceous to Quaternary volcanic formations are widely distributed in Peru over the highland of the Cordillera Occidental (Western Cordillera). These formations are composed of lava flows, volcanic breccias, agglometes and tuffs and their compositions are mostly andesitic. These are divided into several stratigraphical groups from their degrees of the influences of the compressive pulses in the Andean orogeny. The youngest volcanic formations which were formed after the last compressive deformation (Quechuan orogeny; Bellido, 1979) is generically called Barosso Group. Plio-Pleistocene age is assigned to these volcanics but radiometric age determination studies often revealed that even the volcanic rocks whose ages were assumed to be Quaternary show the age of the Upper Miocene (Bellon and Lefèvre, 1976; Kaneoka and Guevara, 1983). This implies the importance of radiometric age determinations on these rocks.

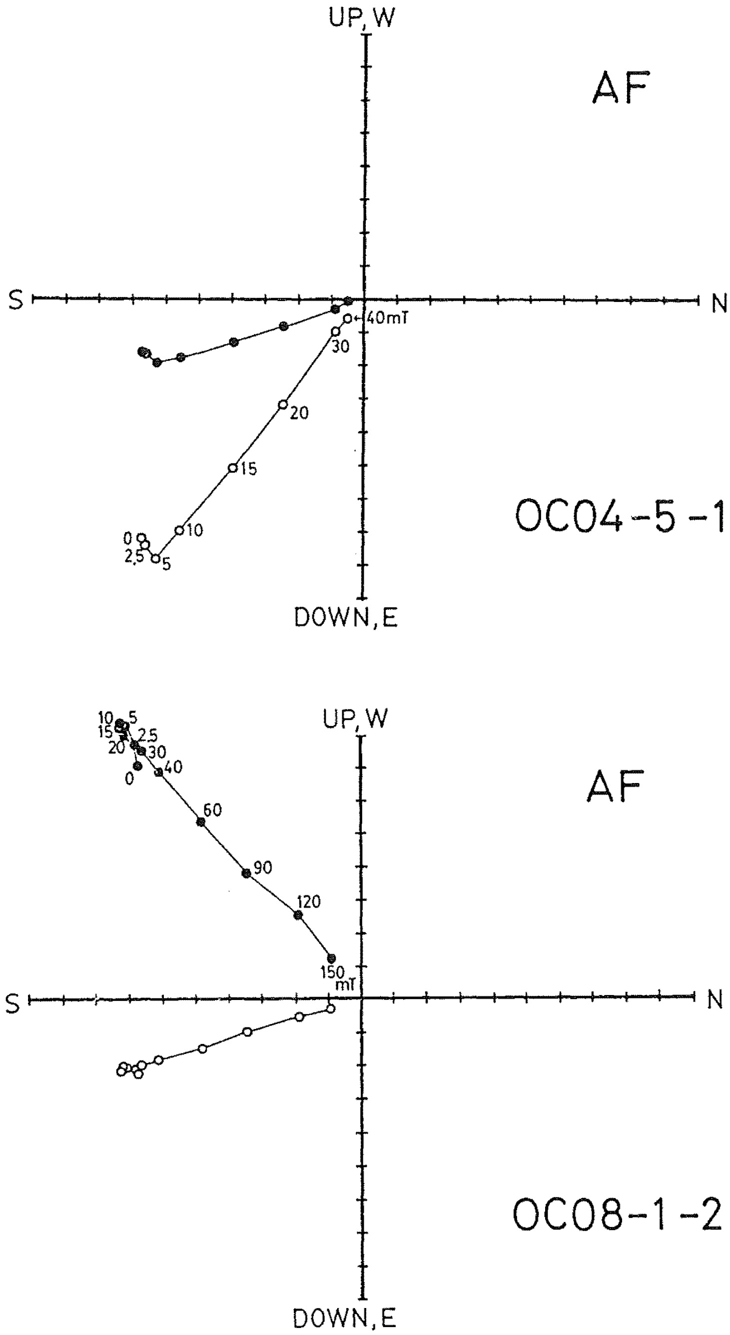


Fig.2 Zijderveld diagrams in AF demagnetization of the specimens of Ocros dike swarm. Open and solid symbols indicate projections onto vertical and horizontal planes respectively.

A dike swarm was found within a volcanic formation which is described as Barosso Group (Bellido, 1979) (Fig.1). The sampling route spans about 4km extending approximately north to south, along which we collected about two hundred oriented samples from 29 dikes intruding into alternation of lavas and pyroclastics (Fig.1, OC01-29). At several sites (OC03,05,06) lava flows adjacent to the dikes were also sampled. General trend of the dikes is N80°E which is consistent with present direction of maximum horizontal stress axis determined by focal mechanism solution of earthquakes in central and northern Peru (Stauder, 1975). Although Peruvian geologic map indicates Plio-Pleistocene age of the formation, our preliminary K-Ar dating suggested slightly older age, say Late Miocene (6-8Ma). Detailed geologic and petrologic descriptions are given in Ui et al. (1983).

3) Experimental Procedures

A Schonstedt spinner magnetometer in University of Tokyo was used for paleomagnetic measurements and alternating field (AF) demagnetization was carried out on each specimen stepwisely as far as most part of the original remanence was destroyed. NRM intensity ranged from 10^{-4} to 10^{-2} Am^2/kg. NRM directions are fairly stable against AF demagnetization and median destructive fields (MDF) in most cases were more than 20mT. In Fig.2 are shown demagnetization diagrams (Zijderveld, 1967) of typical specimens. Paleomagnetic field direction was determined as the gradient of the linear portion of the diagrams by least square fitting. Thermomagnetic analyses were performed on several specimens using an automatic Curie balance and approximately reversible Js-T curves were obtained with Curie temperatures mainly of magnetite (580°C). Initial susceptibility was measured using Bison AC bridge and natural Königsberger ratios (Qn ratio) were calculated to be ranging from 2 to more than 100. Susceptibility anisotropy measured by spinner magnetometer yielded no serious values as to affect the remanent magnetization directions.

4) Results and discussion

All paleomagnetic results are listed in Table 1 and illustrated with 95% confidence circles (Fisher, 1953) in Fig.3. We got four normal polarity dikes (OC12,15,16,17) and twenty-one reversed polarity dikes and lavas (OC01-07,13,14,18,22-29) which are almost antipodal and deviate counterclockwisely in its mean declination by about 15° from axial geocentric dipole field. Seven intermediate polarity dikes (OC08-11, 19-21) were also found. The angular standard deviation (ASD) was calculated using twenty-five normal and reversed polarity VGPs which are converted to a single polarity. The contribution of the within-site dispersion to the total ASD was corrected and the between-site ASD was isolated. The 95% confidence interval of the ASD was calculated from the table presented by Cox (1969). We got an ASD of 14.2° with the 95% confidence interval of 11.9°-17.7°. The ASD of Ocros dike swarm shows good agreement with global trend of Plio-Pleistocene ASD presented in McElhinny and Merrill(1975).

There are two groups in intermediate polarity dikes, that

Table 1. Paleomagnetic directional data of Ocros dike swarm.

Dike (lava)	N	Incl.** (°)	Decl.** (°)	R	k	α_{95} (°)	Pole Lat. (°N)	Pole Long. (°E)
OC01	4	3.9	176.5	3.9786	242	5.9	-78.0	88.9
OC02	6	0.8	-163.1	5.9209	63	8.5	-68.8	159.6
OC03	6	52.5	160.3	5.8739	40	10.8	-63.4	-34.9
OC03*	6	44.8	168.5	5.9649	142	5.6	-73.1	-36.0
OC04	5	42.4	179.3	4.8687	31	14.1	-78.8	-70.7
OC05	6	32.4	164.7	5.9578	118	6.2	-74.7	-1.8
OC05*	13	32.0	174.0	12.8808	101	4.2	-83.0	-18.6
OC06	6	24.7	170.2	5.8422	32	12.1	-80.5	17.6
OC06*	5	39.4	172.9	4.9244	53	10.6	-78.8	-37.9
OC07	6	17.5	164.4	5.9724	181	5.0	-74.1	30.6
OC08	5	17.2	-120.6	4.7201	14	20.9	-31.7	-161.8
OC09	6	13.1	-140.2	5.8151	27	13.1	-50.3	-169.7
OC10	6	9.5	-125.5	5.9375	80	7.5	-35.6	-167.7
OC11	6	8.8	-108.6	5.9755	204	4.7	-19.1	-163.9
OC12	6	-36.4	-32.5	5.9611	129	5.9	58.2	179.2
OC13	6	34.4	154.9	5.9335	75	7.8	-65.3	-0.1
OC14	6	34.6	167.7	5.9420	86	7.3	-76.9	-11.1
OC15	7	-34.6	-21.6	6.9315	88	6.5	68.5	178.0
OC16	6	-38.6	-30.7	5.9482	97	6.9	59.6	175.7
OC17	6	-41.6	-32.9	5.9043	52	9.4	57.2	172.5
OC18	7	38.4	-179.6	6.9192	74	7.1	-81.8	-76.6
OC19	4	-79.5	-37.0	3.8513	20	21.0	29.2	119.9
OC20	5	-75.4	-43.0	4.8872	36	13.0	32.3	127.9
OC21	6	-74.2	2.1	5.8976	49	9.7	42.9	104.6
OC22	6	31.2	150.5	5.9762	210	4.6	-61.3	5.4
OC23	6	43.8	176.1	5.9440	89	7.1	-77.2	-57.8
OC24	6	2.9	176.3	5.9655	145	5.6	-77.5	88.7
OC25	6	1.3	169.3	5.9709	172	5.1	-73.4	65.5
OC26	3	35.4	160.3	2.9963	545	5.3	-70.2	-4.7
OC27	5	41.9	168.1	4.9908	434	3.7	-74.4	-29.4
OC28	7	22.1	157.9	6.9487	117	5.6	-68.3	18.7
OC29	8	20.7	152.0	7.9520	146	4.6	-62.5	18.6

N:number of samples studied, R:length of resultant vector, k:precision parameter (Fisher, 1953), α_{95}:radius of 95% confidence circle.

**All directions are determined by least square fitting to the demagnetization diagram.

*lava flows (the others are dikes).

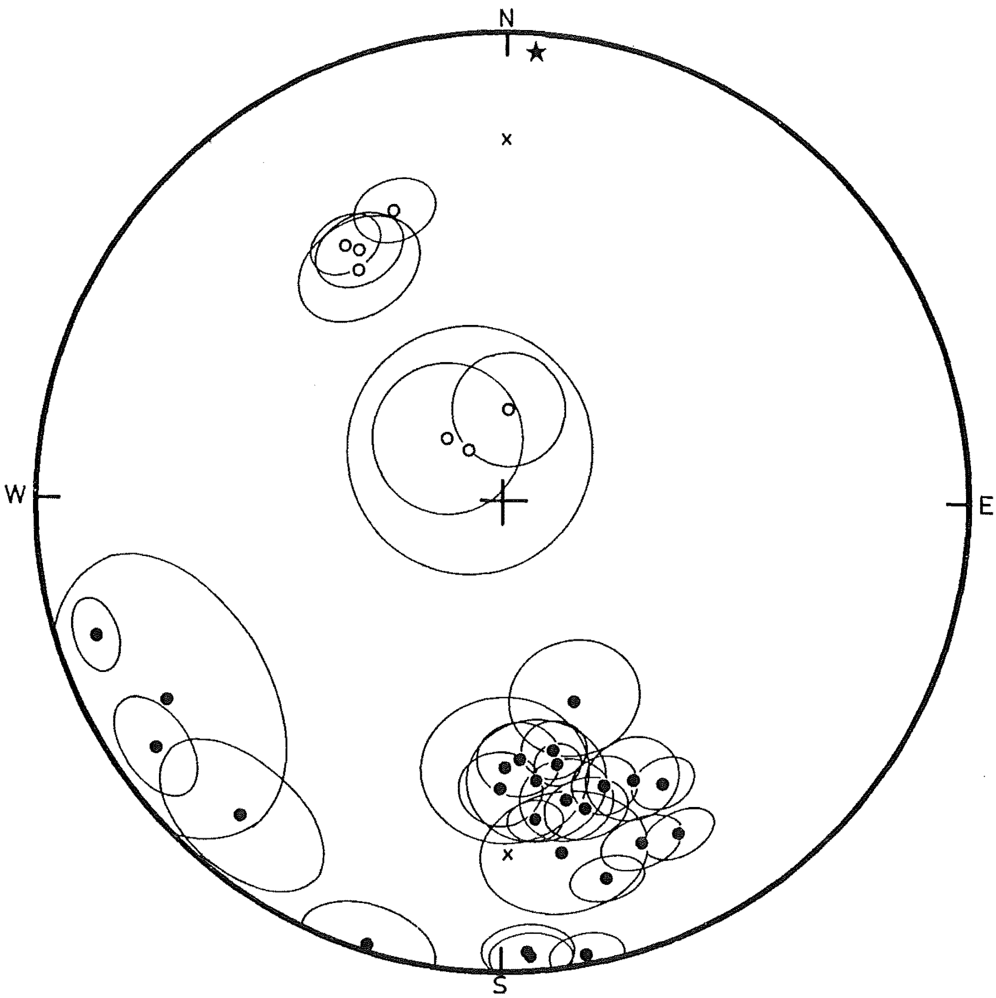


Fig.3 Equal area projection of dike-mean field directions of Ocros dike swarm. 95% confidence circles are also illustrated. Open and solid symbols denote negative and positive inclinations respectively. Star indicates present field direction and X indicates present axial dipole field.

is, almost horizontal and west-southwest seeking dikes (OC08,09,10,11) and almost vertical and upward seeking dikes (OC19,20,21). The former corresponds to VGP transition path to the west of the site about 90° apart and the latter corresponds to far-sided transition path. There are many short polarity events in Late Miocene time (e.g., La Brecque et al., 1977) and whether these two groups belong to a single polarity transition or represent multiple polarity transitions is unknown with present data only. It is, however, quite interesting that definite far-sided transitional VGPs were observed in southern hemisphere sites.

Dipole hypothesis predicts that geomagnetic field almost

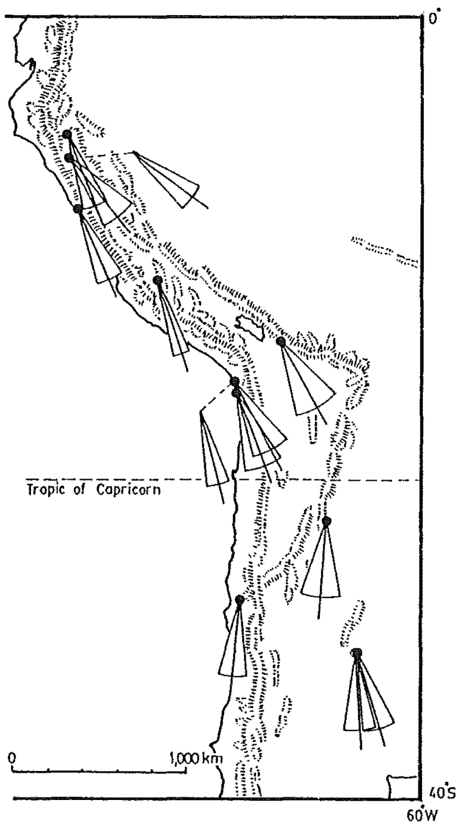


Fig.4 Rotations observed in the Central Andes after Heki (1983).

coincides with that of an axial and almost geocentric dipole when being averaged over a certain time range covering the whole periods of secular variation. Mean field direction obtained from Ocros dike swarm show about 15° of counterclockwise declination shift although paleosecular variation seems sufficient (ASD=14.1°) as to include the whole periods of secular variation. Paleomagnetic study of late Tertiary age in other area does not show a paleomagnetic pole significantly different from today's geographic pole (Creer and Valencio, 1969; Valencio et al., 1975) and this declination shift appears to be the results of the tectonic rotation of the region of Ocros dike swarm. It is also possible to explain it by assuming some undetected tilt. However, in order to convert axial dipole field direction to that of Ocros mean field, nearly 30° westward dip with a strike of N30°W is necessary. Observed contacts of Ocros dikes are almost vertical and so Plio-Pleistocene tilting up to 30° is quite unlikely.

It is more plausible to interpret that the large-area counterclockwise rotation is responsible for the declination shift. As already shown in Heki et al. (1983), paleomagnetic results suggest post-Cretaceous occurrence of oroclinal bending of the Central Andes (Fig.4). Paleomagnetic results of Ocros dike swarm give a strong constraint to the timing of the bending that about a half amount of the rotation still occurred after the time of the intrusion of Ocros dike swarm.

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