GEOPHYSICAL STUDIES OF THE CENTRAL ANDES

Masaru KONO(1), Yoshio FUKAO(2), Yozo HAMANO(3), Kosuke HEKI(3), Hajimu KINOSHITA(4), Yoshio ONUKI(5), Asahiko TAIRA(6), Tadahide UI(7) and Leonidas Ocola(8)

1. Department of Applied Physics, Tokyo Institute of Technology, Ookayama 2-12-1, Meguro-ku, Tokyo 152
2. Department of Earth Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464
3. Geophysical Institute, University of Tokyo, Yayoi 2-11-16, Bunkyo-ku, Tokyo 113
4. Department of Earth Sciences, Chiba University, Yayoi-cho 1-33, Chiba City, Chiba 260
5. College of General Education, University of Tokyo, Komaba 3-8-1, Meguro-ku, Tokyo 153
6. Department of Geology, Kochi University, Akebono-cho 2-5-1, Kochi City, Kochi 780
7. Department of Earth Sciences, Kobe University, Rokkodai-machi 1-1, Nadaku, Kobe, Hyogo 657
8. Instituto Geofisico del Peru, Apartado 3747, Lima, Peru

1. Introduction

The Andes is a huge mountain chain running along the western border of the South American continent and having a length of more than 10,000 km. Except the Central Asia, where the Himalayas and other mountains form the 'roof of the world', the Andes is the only mountain chain which attains a height of nearly 7,000 m in a considerable area. The Andes is a place of plate subduction, just as the Japan and other island arcs in the North-western Pacific are, but differs from the latter in the fact that they form a margin to a stable continent.

The Central Andes constitutes the middle part of the Andes chain, ranging from Peru to northern Chile, and is characterized by many features typical of the subduction zones such as trenches deeper than 5 km, deep-focus earthquakes occurring at depths greater than 300 km, and existence of a numerous active and Quaternary volcanoes.

In the years 1980 and 1981, we carried out a series of field works in the Central Andes region, with a grant-in-aid for overseas scientific researches from Mombusho (the Ministry of Education, Science and Culture, Grant Nos. 504204 and 56041015). The ultimate aim of this research was to clarify and understand the processes involved in the formation of the great mountain belts such as the Andes, and in particular, to make comparisons with other collision type boundaries (such as the Himalayas) and with island-arc type consuming boundaries (such as Japan). To make an effective approach to this ultimate aim, and to perform other useful studies, we decided to make the following specific researches on the rock samples and other data collected by the field works:

(1) Determination of the paleomagnetic polar wander curve for the area of the Central Andes, especially for Peru.
(2) Comparison of the polar wander curves from the Central Andes and from the stable, cratonic area of the South America.
(3) Study of paleointensities and paleosecular variation of the geomagnetic field.
(4) Crustal structure of the Andes based on terrain corrected Bouguer gravity anomalies.
(5) Seismotectonic study using seismicity, mechanism solutions, and wave propagation data.
(6) Correlation between the distances of active volcanoes from the trench axis and major element chemistry of the volcanic rocks.
(7) Change with time in the sedimentaion environment and its bearing to the tectonics.

The items (4) and (5) are carried out with the participation of Instituto Geofisico del Peru (IGP), which is contributing to the project with unpublished gravity and seismic data.

2. Field Works

A reconnaissance survey of Peru was carried out in the autumn of 1980 by Kono, Onuki and Ui, with the help of Crisolfo Perales and Isaias Vallejos of Instituto Geofisico del Peru (IGP). The route taken was Lima-Trujillo-Cajamarca-Chachapoyas-Moyobamba-Tarapoto-Juanjui in the northern Peru, and Lima-Pisco-Arequipa-Tacna-Arica-Tacna-Puno-Cuzco-Ayacucho-Huancayo-Lima in the southern Peru and Northern Chile.

In the northern route, gravity survey by LaCoste-Romberg gravimeter G-375 (curtesy of Prof. Yokoyama, Hokkaido University) was carried out at about 200 bench marks between El Cruce (near Pacasmayo) and Juanjui. Gravity connection was also done at 14 national and international standard stations including Tokyo, Los Angeles, Lima, Arequipa and Arica.

Preliminary sampling of volcanic and metamorphic rocks were also carried out in the reconnaissance trip. The route taken is shown in Figure 1. Some Pre-Inca potsherds from Cajamarca region was also collected in 1980.

The field works of 1981 were mostly dedicated to the collection of rock samples from various geologic strata in Peru and northernmost Chile. The sampling was carried out by a series of field trips starting from Lima:
(i) Northern Chile, near Cajamarca and Bagua. Kinoshita, Taira and Heki sampled extensive outcrops of limestones, shales, silts, and sandstones. Jose Machare and Julio Melgar from IGP also went to this trip to help them.
(ii) Central Peru, Lima-Huancayo and near Ayacucho. Kono, Ui and Hamano sampled "Quaternary" andesite dykes near Ocros, southwest of Ayacucho. Felix Monge and Franklin Moreno of IGP helped in this trip. They also collected various metamorphic and sedimentary formations ranging from Eocene to Precambrian in age.

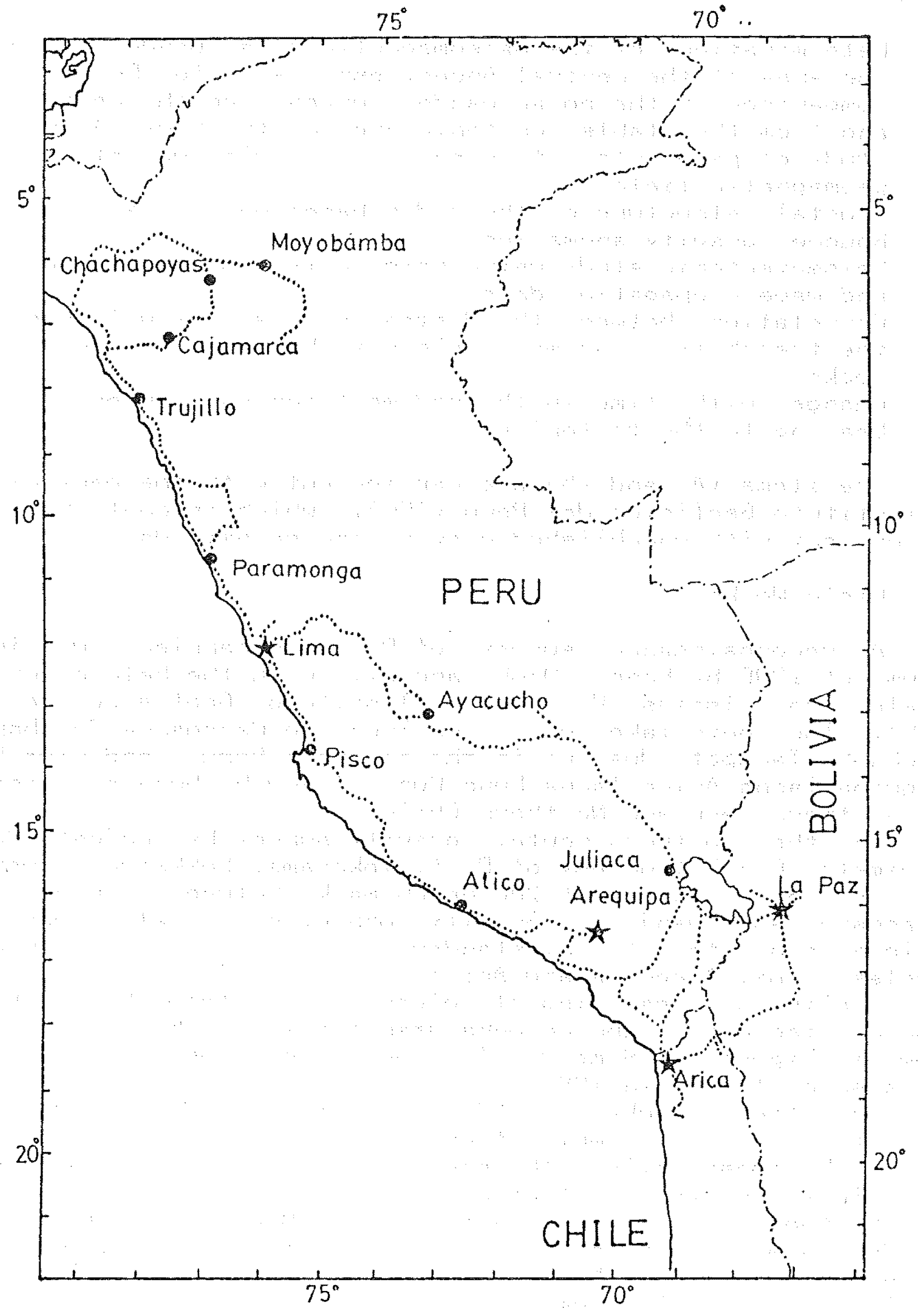

Fig. 1. The routes taken in the field works of "Geophysical Studies of the Central Andes" in 1980 and 1981. Stars and closed circles indicate IGSN71 international refernce gravity stations and IGP national reference points. The total distance traveled is 30,000 km and 1.5 tons of rock samples are collected.

(iii) Northernmost Chile, near Arica. Ui, Taira, Fukao, Hamano and Heki collected Tertiary and Jurassic volcanic rocks (welded tuffs and dykes) and sediments (dolomites, sandstones and shales) in cooperation with Hugo Moreno of Departamento de Geologia, Universidad de Chile (Santiago) and Konosuke Sawamura of JICA and Departamento de Geociencia, Universidad de Norte (Antofagasta). Kono and Kinoshita sampled Jurassic dyke swarm at Cuya, south of Arica.

(iv) Central and southern Peru. Volcanic, sedimentary and metamorphic rocks of various ages near Huarmay, Nazca, Arequipa and Moquegua were collected in various occasions.

3. Previous Works in Paleomagnetism

We shall give here a very brief review of the previous paleomagnetic works in South America. Data reported in 1972 or earlier are summarized in McElhinny (1973).

Before 1970, paleomagnetic studies were mainly done to obtain the polar wander curve for South America. The samples were therefore collected from the stable, cratonic area; that is, mostly from southeastern part of the continent. Creer performed extensive studies in this period and his results are summarized

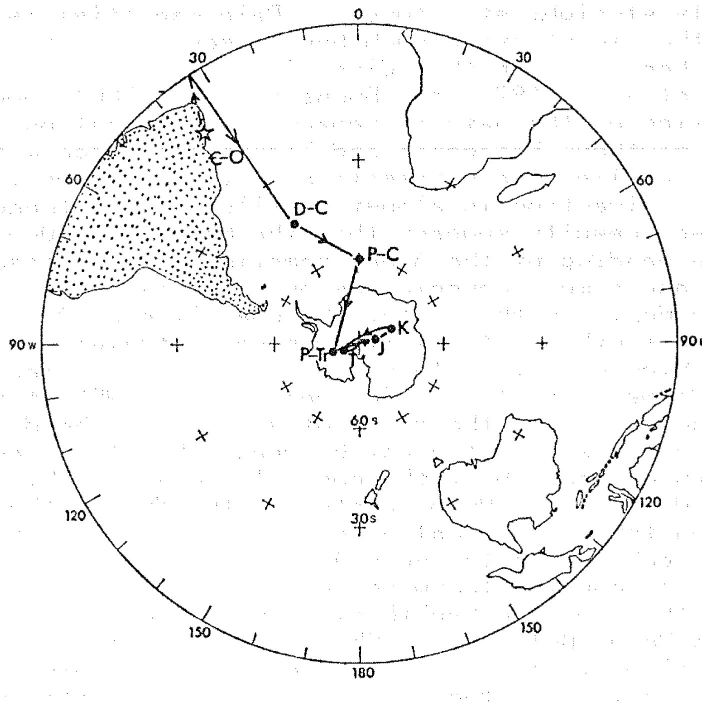

Fig. 2. Phanerozoic Apparent polar-wander path for South America. Star indicates a pole lying in the northern hemisphere. Polar stereographic projection. Reproduced from McElhinny (1973).

in Creer (1970). Figure 2 shows the polar wander path for South America, reproduced from McElhinny (1973). A very prominent feature of this curve is that the paleomagnetic pole was located near the equator in the first half of Paleozoic, but that there was a large shift of the pole before Permian, and after Permian period, the pole was quite near the present geographic pole.

With the advent of new paleomagnetic laboratories in South America, a much wider age range and more specific problems were studied especially by the workers of Argentine. For example, Valencio et al. (1980) obtained a polar wander path for the period of 400 to 1000 Ma, and Valencio et al. (1977) applied the paleomagnetic data to the problem of the opening of the South Atlantic. The idea was to see if the position of South America determined from the reconstruction based on sea-floor spreading data is compatible with the paleomagnetic directions near the time of the breakup of Gondwanaland. These studies are very promising in the future, but at present, data are only available from somewhat restricted region of Argentine, and are therefore to be substantiated by further studies.

Recent investigations are more and more directed to clarify the process in tectonically active regions. There are several places in the Andes where the general trend of the mountain chain changes rather abruptly (called oroclines). Carey (1958) was the first to suggest that these features were formed by the bending of originally straight structures. Paleomagnetism is the most effective method in studying such hypotheses, and some researches have already been done in this direction.

Dalziel et al. (1973) and Burns et al. (1980) reported that the declination of the natural remanent magnetization (NRM) in the rocks of southern Patagonia and Tierra del Fuego with ages of Cretaceous or earlier are systematically turned to west, so that the magnetic direction is almost parallel to the trend of the Andes. These results suggest that the Magellanes Orocline was formed by the bending of the Andes sometime after Cretaceous.

Another and a more conspicuous orocline is situated near the Peru-Chile border. In the north, the coastline of Peru is almost NW-SE, while south of Arica it runs very straight in the N-S direction (Figure 1). This is generally called Bolivian Orocline. Palmer et al. (1980) measured the NRM of the rocks both to the north and to the south of Arica. If the direction of NRM is systematically different between the two regions, an inference can be made about the possible rotation which produced the Bolivian Orocline. Unfortunately, the NRM of the northern rocks was unstable, and Palmer et al. (1980) report only the results form rocks collected near Arica. Their result suggest a 30 to 40 degrees counterclockwise rotation of Arica region. To substantiate the orocline hypothesis, much more studies covering wide areas in Peru, Bolivia and Chile are necessary.

A special mention should be made about paleointensity and paleosecular variation studies. paleomagnetic data are heavily biassed to the northern hemisphere. The latitude dependence of the paleosecular variation appears to have been well established (e.g., Cox, 1970). Yet, on closer examination, it is apparent that these models and conclusions are based primarily on the data obtained in the northern hemisphere. Given the large asymmetry in the distribution of the present day non-dipole field in both hemispheres, there is no a priori reason to suppose that the model based on the northern hemisphere data are applicable to the entire earth. Studies of paleosecular variation in the southern continents should be encouraged.

Paleointensity data from South America are entirely from the potsherds and other remains of Inca and Pre-Inca civilizations in Peru. Earlier results were given by Nagata et al. (1965) and Kitazawa and Kobayashi (1968). Some new data were reported by Games (1977), Gunn and Murray (1980) and Kono and Ueno (in preparation). The availability of well dated bricks and potteries from old civilizations of Peru makes this area very attractive place to work on the archeomagnetic intensity changes. Future efforts should include volcanic rocks, so that intensity variation in a much longer time span can be studied.

References

Burns, K.L., M.J. Rickard, L. Belbia and F. Chamalaun (1980) Tectonophysics, 63, 75.

Cox, A. (1970) Geophys. J. Roy. Astron. Soc., **20**, 253

Carey, S.W. (1958) Proc. Roy. Soc. Tasmania, **89**, 255.

Creer, K.M. (1970) Phil. Trans. Roy. Soc. Lond., **A267**, 457.

Dalziel, I.W.D., R. Krigfield, W. Lowrie and N.D. Opdyke (1973) in "Implications of Continental Drift to the Earth Sciences" vol. 1, p. 87.

Games, K.P. (1977) Geophys. J. Roy. Astron. Soc., **48**, 315.

Gunn, N.M. and A.S. Murray (1980) Geophys. J. Roy. Astron. Soc., **62**, 345.

Kitazawa, K. and K. Kobayashi (1968) J. Geomag. Geoelectr., **20**, 7.

McElhinny, M.W. (1973) Palaeomagnetism and Plate Tectonics, 358p. Cambridge University Press, London.

Nagata, T., K. Kobayashi and E.J. Schwarz (1965) J. Geomag. Geoelectr., **17**, 399.

Palmer, H.C., A. Hayatsu and W.D. MacDonald (1980) Geophys. J. Roy. Astron. Soc., **62**, 155.

Valencio, D.A., E. Mendia, A. Giudici and J.O. Gascon (1977) Geophys. J. Roy. Astron. Soc., **51**, 47.

Valencio, D.A., A.M. Sinito and J.F. Vilas (1980) Geophys. J. Roy. Astron. Soc., **62**, 563.