PALEOMAGNETIC STUDY OF JURASSIC SEDIMENTARY AND VOLCANIC ROCKS IN NORTHERN CHILE

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1) Introduction

Palmer et al. (1980) reported that paleomagnetic results of Jurassic Camaraca Formation, Arica Group, northernmost Chile shows about 25° counterclockwise rotation with respect to the stable South American platform. Heki et al. (1983) and Heki (1983) showed that the rotation of the whole Peruvian block is responsible for this counterclockwise rotation. Here we report paleomagnetic description of our Jurassic results in Arica region. Our data consist of one dike swarm near Cuya and shale strata of Camaraca Formation in the city of Arica.

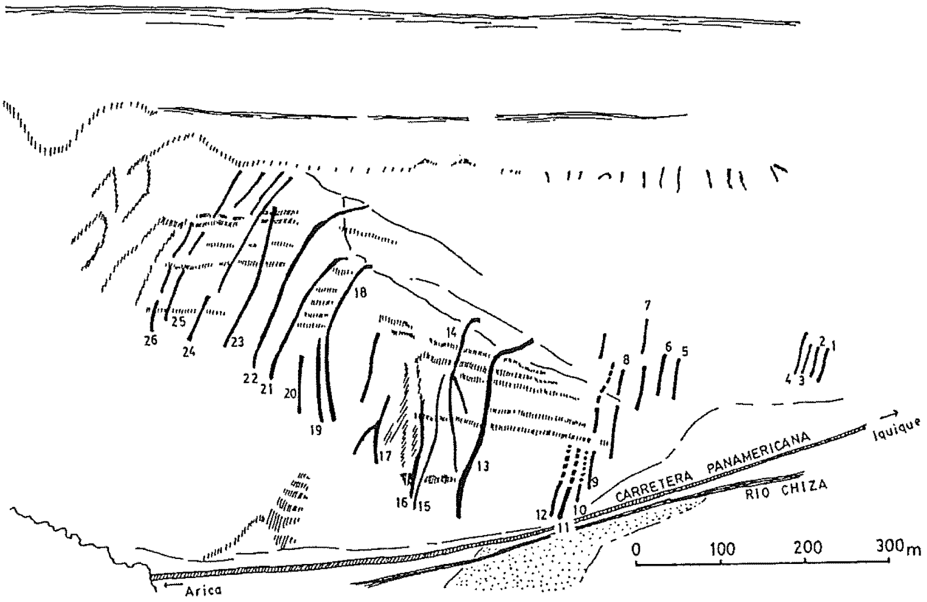

Fig.1 Sketch map of Cuya dike swarm intruding into sedimentary rocks of Jurassic Arica Group. Numbers attached to the dikes indicate serial number of dikes studied here.

2)Geology

The department of Arica covered by the geologic map of Salas et al. (1966) is mostly occupied by Mesozoic and Cenozoic sedimentary and volcanic rocks with the total thickness up to 8,000m. The oldest rock is Middle Jurassic Arica Group which consists of lower Camaraca Formation (upper Bajocian to Calovian) and upper Los Tarros Formation (Oxfordian). Camaraca Formation is made of dark color andesitic volcanics accompanied with some intercalations of marine sediments, and Los Tarros Formation is composed of the alternation of lutite, limestone, quartzite and minor amount of andesitic volcanic rocks. Arica Group is uncomformably overlain by Neocomian Atajaña Formation, Vilacollo Group.

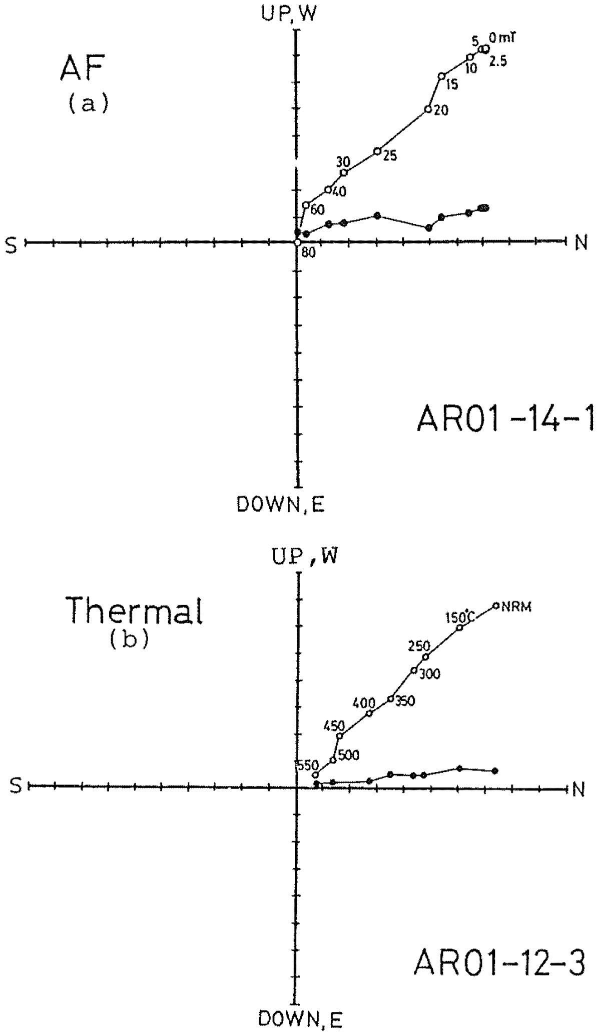

Fig.2 Zijderveld diagrams of progressive AF(a) and thermal(b) demagnetization. Open and solid symbols denote projections onto vertical and horizontal planes respectively.

Sedimentary paleomagnetic samples were taken from the shale layer exposed exposed at the northern face of the cliff called "Morro de Arica" which corresponds to the lower member of the Camaraca Formation. More than 20 samles were taken from four different horizons (AR01; 31-36, 11-15, 21-25, 41-47,51, in ascending order, for the locality, see Fig.1 of Heki et al. (1984, in this volume)). Their bedding plane dips by about 10° northward. The uppermost horizon (AR01;41-47, 51) is just under the boundary between these shale layers and overlying pillow lava layer. 10 samples were taken from this andesite pillow lava (AR02) for comparison. In this pillow lava, one sample was taken from the center of a pillow block. This pillow lava corresponds to the site "AR-1" in the table 1 of Palmer et al. (1980).

A dike swarm was found along the Panamerican Highway some

70km south of Arica, near the boundary between the departments of Arica and Pisagua (named "Cuya dike swarm"). Dikes range in their thicknesses from 0.5m to 7m and generally trend north-south. Most dikes are made of porphyritic andesite and the country rocks (Los Tarros Formation) are made of calcareous sandstone and limestone which dip northeastward by about 30°-50°. Their top is eroded and is horizontally overlain directly by Tertiary ignimbrite of Oxaya Formation. Generally six hand samples were taken from each of 26 dikes (CY01-26, Fig.1) and adjacent sedimentary rocks were also sampled at CY08 (CY08; 11-13, 21-23) and CY09 (CY09; 11-17, 21-27) with various distances from the contacts to carry out baked contact test.

3)Experimental procedure and paleomagnetic results

Shale and pillow lava (AR01,02) Natural remanent magnetization (NRM) intensities of samples of AR01 and AR02 are generally of the order of 10^{-5}-10^{-6} Am^2/kg and a Schonstedt spinner magnetometer was used for the measurement. Stepwise alternating field (AF) demagnetization was carried out for each specimen as far as the original remanence was mostly destroyed. Thermal demagnetization was also performed on several specimens to infer the blocking temperature distribution. Median destructive fields (MDFs) were usually between 20-25mT for AR01 and stable and single-component remanent magnetizations were suggested from demagnetization diagrams (Fig. 2a) of Zijderveld (1967). Thermal demagnetization (Fig.2b) showed that the blocking temperature is distributed from less then 150°C continuously up to about 550°C

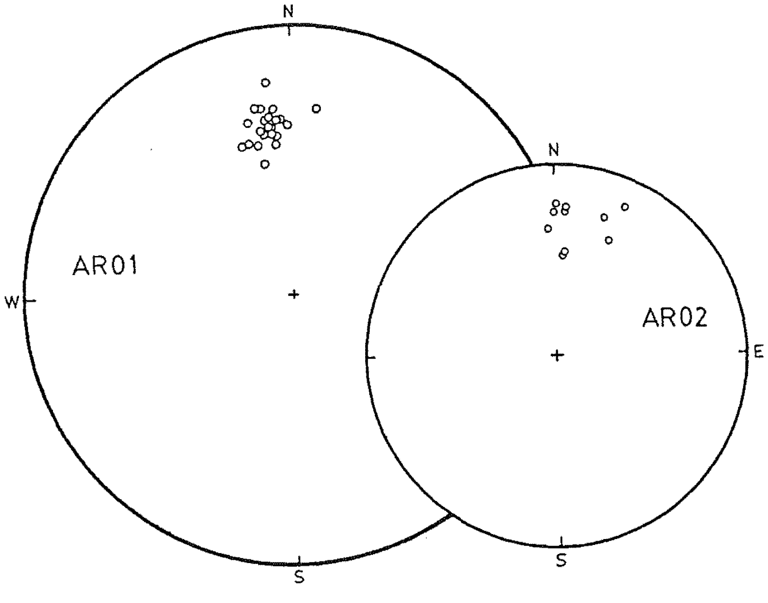

Fig.3 Equal area projection of the field directions of AR01 and AR02. All inclinations are negative (upward).

and no blocking temperature higher than the Curie temperature of magnetite was observed suggesting the inexistence of hematite. Paleofield directions were determined by the least square fitting (LSF) to the linear portion of the diagram. Paleomagnetic field directions were obtained from 22 shale specimens in total. All specimens showed normal polarity magnetization with slight counterclockwise declination shift from north. Pillow lava samples (AR02) were also AF demagnetized and measured with a Schonstedt spinner magnetometer in the same way as AR01. Obtained field directions are not well grouped but show declination of about 10° which is significantly different from those of shales (Fig.3) suggesting that shale layers sampled here did not suffer any thermal effects from the overlying pillow lava. Structurally corrected paleomagnetic directions are listed in Table 1 and illustrated in Fig.3.

<u>Dikes (CY01-27) and their country rocks (CY08,09)</u> NRMs of the country rocks (limestones and calcareous sandstones) were measured using a cryogenic magnetometer in the National Institute of Polar Research and a Schonstedt spinner magnetometer in University of Tokyo. NRM intensities of these rocks have various values (vary in the order of two) in spite of their lithological similarities. NRM intensity is strongly dependent on the distance from the dike contact: NRM intensities of the order of 10^{-5} Am^2/kg at the baked part abruptly decrease at the distance of 50-100cm down to the order of 10^{-7} Am^2/kg indicating the diminishing of the thermal effects of the dikes (Fig.4). Baked part seems to have thermoremanent magnetization (TRM) acquired in times of the intrusions of CY08 and CY09 dikes and unbaked part seems to have pure detrital remanent magnetization (DRM) acquired

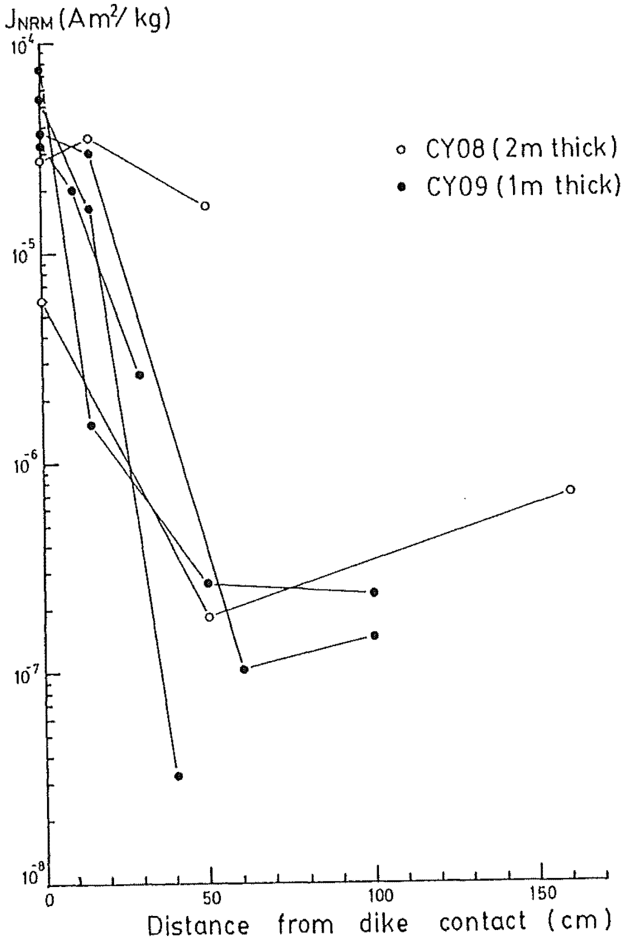

Fig.4 NRM intensity of country rocks versus distance from dike contact at CY08 and CY09.

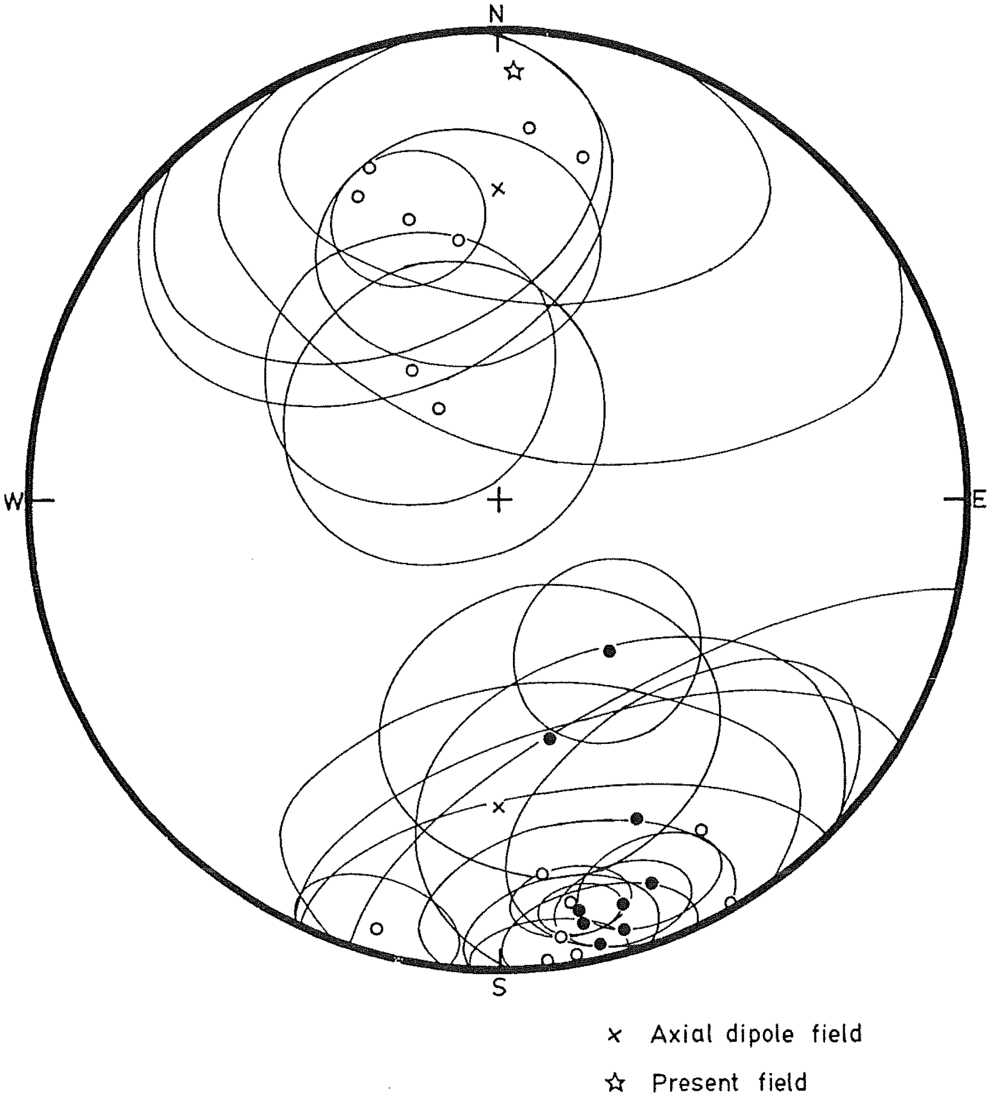

Fig.5 Equal area projection of dike-mean field directions of Cuya dike swarm. 95% confidence circles are also illustrated. Star indicates present field direction and X indicates present axial dipole field direction. Open and solid symbol denote negative (upward) and positive (downward) inclinations respectively.

in time of or soonly after the time of deposition of the country rocks. The existence of the unbaked part guarantees that this dike swarm did not suffer wide-region thermal remagnetization and that the TRMs of individual dikes are independent.

NRMs of the dike samples were measured using a Schonstedt spinner magnetometer in University of Tokyo as a bachelor thesis by Nomura and Morikawa (1983) and detailed paleomagnetic and rock magnetic descriptions are avialable in their thesis. NRM intensities of dikes were small (typically $10^{-5}Am^2/kg$-$10^{-7}Am^2/kg$) in comparison with ordinary igneous rocks and are almost comparable with those of country rocks (CY08,09). On the other hand, initial susceptibilities are not so small making consequent natural Königsberger (Qn) ratios quite small (mostly less than unity). This may be due to some kind of alteration of magnetic minerals such as low temperature oxidation ubiquitously observed in microscopic analyses (Nomura and Morikawa, 1983). Js-T curves measured by a Curie balance often showed the existence of two phases: the lower one around 300-350°C and the higher one almost that of magnetite. About four fifths of the dikes showed irreversible Js-T characteristics suggesting the existence of low-temperature oxidation. Stepwise AF demagnetization was performed on each specimen. Several specimens showed stable magnetization direction in demagnetization process but for most specimens, remanent magnetization directions were too unstable to present linear portion in the Zijderveld diagrams. Hence, certain optimum demagnetizing step was determined by the objective criterion of minimum dispersion and remanent magnetization direction at that step were adopted. Several specimens were discarded due to their complete unstabilities against AF demagnetization. MDFs were widely distributed from 10mT to 80mT.

From 25 dikes, tolerably clustered paleofield directions were obtained as illustrated in Fig.5. Dike-mean field directions present bimodal and almost antipodal distribution, which are interpreted to represent normal and reversed polarities. Both distributions deviate a little counterclockwisely from present axial dipole field in their declinations. Bedding corrections were made on all these directions according to the structure of the country rocks. There are several dikes whose polarities appear to be intermediate (e.g., CY04) but it is not certain due to their large confidence angles (Fig.5). After all, all directions were classified into normal or reversed polarities by whether virtual geomagnetic poles (VGPs) are on the northern hemisphere or on the southern hemisphere and 8 normal and 17 reversed polarity directions were obtained. Paleomagnetic results are listed in Table 1.

4) Discussion

As for AR01 samples, because no external thermal effects were found in all four layers, paleofield directions of all 22 specimens were avgeraged irrespective of their horizons and the mean direction was obtained. The corresponding pole is thought to cancel out paleosecular variation and to be a paleomagnetic pole. 25 VGPs of Cuya dike swarm may include intermediate or transitional ones but all VGPs showed latitudes higher than 45° and were used for the calculation of the paleomagnetic pole. They were converted to southern hemisphere poles and the paleomagnetic pole was obtained by averaging them. Cuya dike swarm pole, AR01 pole and that derived by Palmer et al. (1980) on 33 lava flows of Camaraca Formation are listed in Table 2.

Arica region paleomagnetic poles were compared with Jurassic platform pole and are illustrated together in Fig. 6. Platform poles are roughly coincident with present geographic pole while

Table 1. Paleomagnetic directional data of Chilean Jurassic rocks

Site	N	Incl. (°)	Decl. (°)	R	k	α_{95} (°)	ODF (mT)	Pole Lat. (°N)	Pole Long. (°E)
(sedimentary rocks)									
AR01									
11-15	4	-34.7	-0.9	3.9853	204	6.4	LSF	89.0	164.6
22-25	4	-40.3	-7.9	3.9860	215	6.3	LSF	81.4	167.1
31-36	6	-39.7	-9.3	5.9927	688	2.6	LSF	80.4	173.2
41-47, 51	8	-35.8	-10.5	7.9055	74	6.5	LSF	80.0	190.4
total	22	-37.6	-7.9	21.8261	121	2.8	LSF	82.1	179.4
AR02	10	-30.4	9.4	9.7351	34	8.4	LSF	80.8	7.7
(volcanic rocks)									
CY01	4	8.6	168.6	3.8483	20	21.2	30	-71.4	71.6
CY02	4	-1.8	170.2	3.6321	8.2	34.3	40	-67.7	83.2
CY03	6	13.1	158.2	5.8864	44	10.2	30	-65.4	47.6
CY04	6	-71.5	-32.8	5.2570	6.7	27.9	5	45.6	135.4
CY05	4	-26.1	14.5	3.2212	3.9	54.2	0	75.1	0.7
CY06	5	-30.1	-24.6	4.2125	5.1	37.7	0	66.4	-156.7
CY07	6	-37.7	-17.5	5.8298	29	12.6	30	73.5	-166.9
CY08	5	46.8	167.8	4.5341	8.6	27.7	7.5	-75.8	-20.8
CY09	4	-18.3	148.4	3.7440	12	28.0	12.5	-47.7	59.6
CY10	4	-20.8	173.3	3.5543	6.7	38.3	20	-59.3	96.9
CY11	4	5.2	163.7	3.4694	5.7	42.5	15	-67.0	64.0
CY12	4	26.8	156.5	3.6616	8.9	32.7	10	-67.0	28.8
CY13	5	-14.1	169.8	4.9536	86	8.3	20	-61.8	88.0
CY14	6	11.8	168.9	5.9627	134	5.8	30	-72.9	69.1
CY15	4	-22.0	5.1	3.6096	7.7	35.5	0	80.8	-37.1
CY16	5	56.9	143.3	4.8273	23	16.2	10	-53.2	-17.8
CY17	4	-25.4	-21.0	3.6314	8.1	34.3	0	69.0	-147.2
CY18	4	-0.3	149.9	3.3317	4.5	49.0	30	-54.7	49.6
CY20	4	3.3	167.1	3.9439	53	12.7	20	-68.4	72.6
CY21	4	10.8	162.7	3.9673	92	9.7	20	-68.3	56.8
CY22	4	-0.6	173.9	3.9660	88	9.8	60	-69.6	92.1
CY23	5	-5.9	-164.4	4.9210	51	10.9	40	-63.1	146.2
CY24	3	-43.7	-8.3	2.9344	30	22.7	5	80.0	158.7
CY25	3	-63.4	-33.8	2.9188	25	25.4	10	52.0	149.6
CY26	3	-6.6	171.7	2.9786	93	12.8	5	-66.1	89.0
--country rock--									
Baked (CY08)	2	23.3	164.0	1.9804	51	35.7	LSF	-73.1	42.1
Baked (CY09)	9	31.0	160.6	8.8730	63	6.5	LSF	-71.4	24.4
Unbaked part	5	3.8	161.6	4.7965	20	17.7	LSF	-65.0	61.5

N:number of samples studied, R:length of resultant vector, k:precision parameter (Fisher, 1953), α_{95}:radius of 95% confidence circle, ODF:optimum demagnetizing step (LSF means that the directions are determined by the LSF to the diagram).

those of Arica region listed in Table 2 show similar deviations as northern Chilean Cretaceous poles (Heki et al., 1984). Valencio et al. (1983) attributed the Camaraca Formation discordant pole (Palmer et al., 1980) not to the tectonic movements but to the hairpin motion of the South American paleomagnetic pole from the observation that the distribution of the VGPs contained in individual Jurassic paleomagnetic poles are not circular but are elongated toward the longitude of about 30°. However, Mesozoic paleomagnetic pole of the Arica region all deviate in a similar sense and the original interpretation of Palmer et al. (1980) of tectonic rotation appears more plausible.

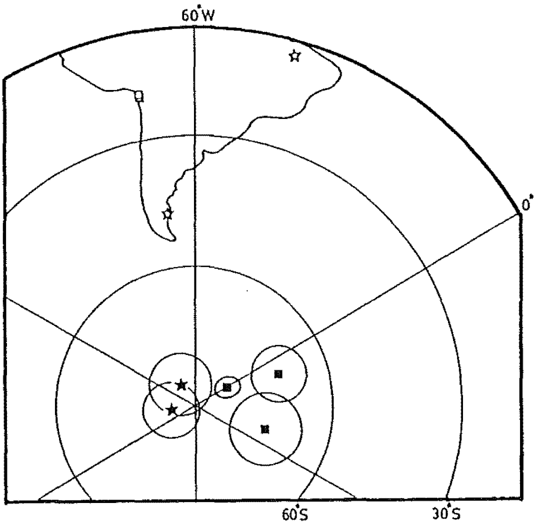

Fig.6 Paleomagnetic poles of Jurassic rock units in Arica region (squares) and stable platform (stars). After Heki (1983).

Table 2. Jurassic poles in the northern Chile.

Rock unit	Locality		Age	Pole				
	Lat. (°S)	Long. (°W)		Lat. (°S)	Long. (°E)	dp (°)	dm (°)	A_{95} (°)
Camaraca Fm. shale (AR01)	18.6	70.3	Jm	82.1	-0.6	1.9	3.3	
Camaraca Fm. lavas*	18.6	70.3	Jm	71	10			6
Cuya dike swarm (CY01-26)	19.2	70.2	J	74.1	49.1			7.8

dp:radius of confidence oval measured in the direction from site to pole, dm:radius of confidence oval measured perpendicular to dp, A_{95}:radius of 95% confidence circle, J:Jurassic, Jm:Middle Jurassic.

*Palmer et al. (1980)

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