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PALEOMAGNETISM OF PERMIAN AND TRIASSIC ROCKS, CENTRAL CHILEAN ANDES

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Abstract. The first paleomagnetic data from Permian and Triassic formations west of the Andean divide are presented. Four formations of Permian or Triassic age in the central Chilean Andes have been investigated: two are located in the coastal ranges, and two are in the main cordillera. Of the formations in the main cordillera (Pastos Blancos and Matahuaico formations), only the Pastos Blancos Formation has yielded characteristic directions. While a fold test is absent, magnetizations are most likely secondary and yield pretilt corrected concordant inclinations, but yield declinations discordant 30° clockwise in comparison to the South American apparent polar wander path. Both formations from the coastal ranges (Cifuncho and Pichidangui formations) yielded stable directions. Postfolding magnetizations in the Cifuncho Formation also show declinations discordant 30° clockwise and concordant inclinations. The Pichidangui Formation has two stable components: one of postfolding age is concordant to apparent polar wander path data, and one of probable prefolding (Late Triassic) age is concordant in declination, but discordant in inclination. Further work is needed to better define the prefolding magnetizations in the Pichidangui Formation, but at present these preliminary results are the first paleomagnetic signs of displaced terranes along the Pacific margin of Chile. If correct, the results suggest that the Pichidangui Formation was some 15° of latitude farther south during the Late Triassic and had likely moved northward to its present latitudinal position with respect to cratonic South America by Middle to Late Jurassic.

Introduction

Through paleomagnetic studies of late Paleozoic and Mesozoic sequences from the more stable platform or cratonic regions of South America [e.g., Creer, 1970; Valencio and Vilas, 1972], one can argue that much of the South American landmass was an integral portion of the Gondwana supercontinent during the late Paleozoic and early Mesozoic, until the opening of the South Atlantic in the Early Cretaceous. Thus far, paleomagnetic studies of rocks from the Andean Cordillera have yielded results both concordant and discordant with the South American and Gondwana apparent polar wander (APW) paths [e.g., Palmer et al., 1980a, b; Heki et al., 1983]. Most of the studies made thus far, especially in sequences exposed west of the Pacific/Atlantic drainage divide, have been in units of post-Early Jurassic age. Here, we report on magnetizations acquired by principally Permian and Triassic formations from the western flanks of the Andes between 25°S and 31°S in Chile (Figure 1).

The paleomagnetism of rocks west of the Andean divide, particularly in the coast ranges and from units of pre-Jurassic age, is important for two reasons. First, in recent years, the geologic community has become increasingly aware of the unique character of the western forearc region of the central Peruvian and Chilean Andes, which is dominated by metamorphic and plutonic rocks of Precambrian to late Paleozoic age. The proximity of these pre-Jurassic crystalline rocks to the Peru-Chile trench has led to speculations that the forearc either was truncated via a cryptic process of "subduction erosion" [Rutland, 1971; Scholl et al., 1977; Kulm et al., 1977; and von Huene et al., 1985] or was the site of the accretion of exotic microplates [Nur and Ben-Avraham, 1978, 1982; Nur, 1983]. Acquiring paleogeographic data is an important step for testing such hypotheses. Second, attempts to make Paleozoic paleogeographic reconstructions for the regions of South America affected by later "Andean" orogenic events must rely on isolated outcrops of pre-Jurassic rocks that are often poorly fossiliferous and variably affected by Andean orogenic events.

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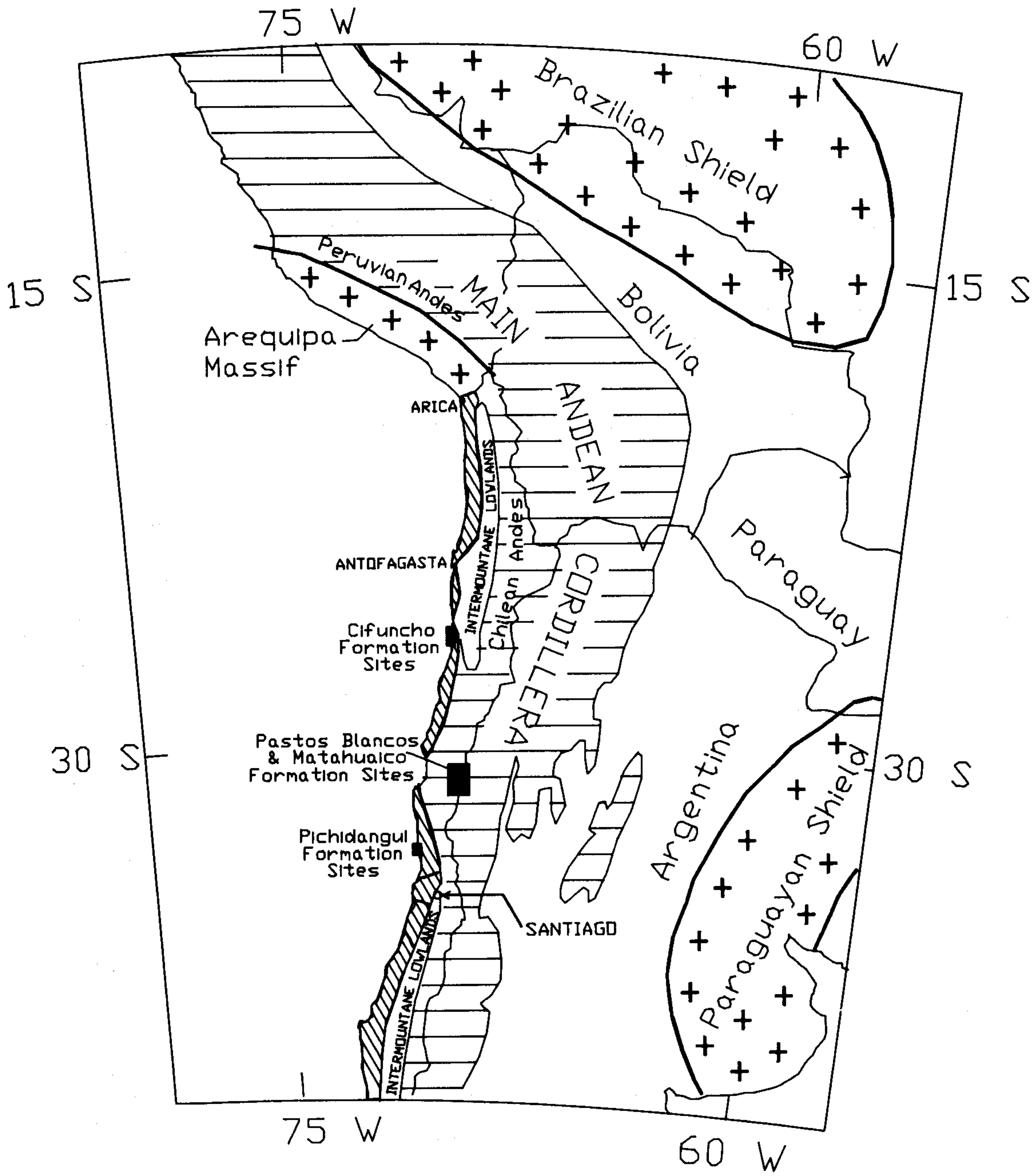

Fig. 1. Location map of the three sampling areas (enlarged in Figures 2, 3, and 4) of Permian and Triassic rocks in north central Chile.

Paleomagnetic data for these isolated complexes, as well as younger units, are necessary to build confidence that such complexes form part of a unified history of the southwest margin of Gondwanaland, rather than a collage of "terrane" elements which might have been brought into juxtaposition by the "docking" of various exotic continental or oceanic microplates during the Mesozoic and Cenozoic.

Outcrops of pre-Jurassic rocks in central and northern Chile are found either in the coastal cordillera or in the western ranges of the main cordillera that form the border between Argentina and Chile. In the coast ranges, rocks of Triassic age tend to be of distinctly different facies from those in the main cordillera, and most of the coast ranges are separated from the main cordillera by fault systems. Thus paleogeographic at-

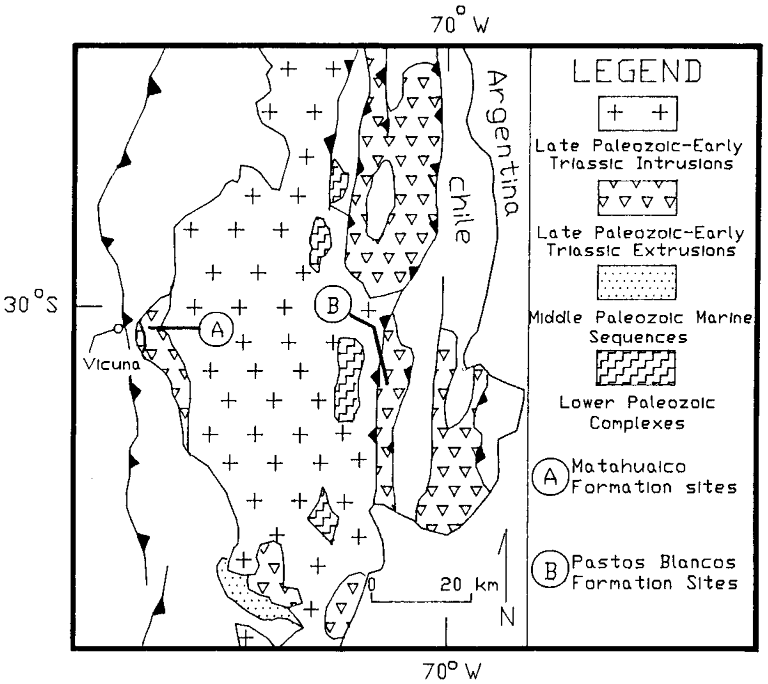

Fig. 2. Paleozoic and Early Mesozoic units in the western Chilean flanks of the main cordillera east of Vicuña. The two sampling localities in the Pastos Blancos and Matahuaico formations are shown.

tempts to reconstruct the pre-Jurassic framework of the central Andes are tenuous on either stratigraphic or tectonic grounds. To determine the tectonic relationships between pre-Jurassic units of the western flanks of the main cordillera and those of the coastal cordillera, we have sampled a number of late Paleozoic, Triassic, and Jurassic units between latitudes 25°S and 31°S. Here, we report on results from four formations: two in the main cordillera and two in the coastal cordillera. We briefly discuss first the geology of the four units sampled in the main and coastal cordilleras and then the paleomagnetic data and their ramifications.

Geology of the Units Sampled

Main Cordillera

Two formations of late Paleozoic to possibly Triassic age were sampled in the main cordillera in the upper reaches of the Elqui River valley (31°S). These are the Pastos Blancos Formation, sampled in the La Laguna River area, and the Matahuaico Formation, sampled east of Vicuña (Figure 2).

Pastos Blancos Formation. The Pastos Blancos Formation [after Thiele, 1964; Maksaev et al., 1984; and Mpodozis and Cornejo, 1986 is a sequence, thousands of meters thick, of rhyolitic ignimbrites and lavas, pyroclastic beds, a few intercalations of andesite, and continental sedimentary rocks. It is thought to be equivalent to the Choiyoi Group of the Frontal Cordillera of Mendoza and San Juan, Argentina [Rolleri and Criado Roque, 1969; Caminos, 1979] that forms an extensive magmatic belt from the North Patagonian Massif [Llambias et al., 1984] toward Iquique, Chile [Coira et al., 1982]. In the La Laguna river valley the Pastos Blancos Formation is formed of ignimbrites, breccias, and rhyolitic lavas intercalated with red continental sediments. The exact age of the formation is uncertain, and the base is not exposed in this area. In the Hurtado River valley, 30 km to the southwest, it rests with angular discordance over the Hurtado Formation, a sequence of graywacke and shale of probable Devonian age [Mpodozis and Cornejo, 1986]. It is intruded by numerous plutons (leucocratic granites) of Permian and Triassic age [Cornejo et al., 1984]. The oldest date obtained is 276 ± 4 Ma (biotite-K/Ar) for a pluton sampled south of the La Laguna reservoir. This date suggests that the Pastos Blancos Formation in the La Laguna area is no younger than Early Permian, but it could be substantially older (Carboniferous). The Choiyoi Group, exposed in Argentina, has always been considered younger, i.e., post-Early Permian, since it rests in the Frontal Cordillera over Upper Carboniferous to Lower Permian marine strata (Tupungato, El Plata, and Cerro Agua Negra formations [Polanski, 1970]). In the valley of Huasco in Chile (29°S), the Pastos Blancos Formation rests over the Las Placetas Formation, which contains Carboniferous plant remains [Reutter, 1974; Nasi et al., 1986]. It seems most likely that the Pastos Blancos Formation is Carboniferous

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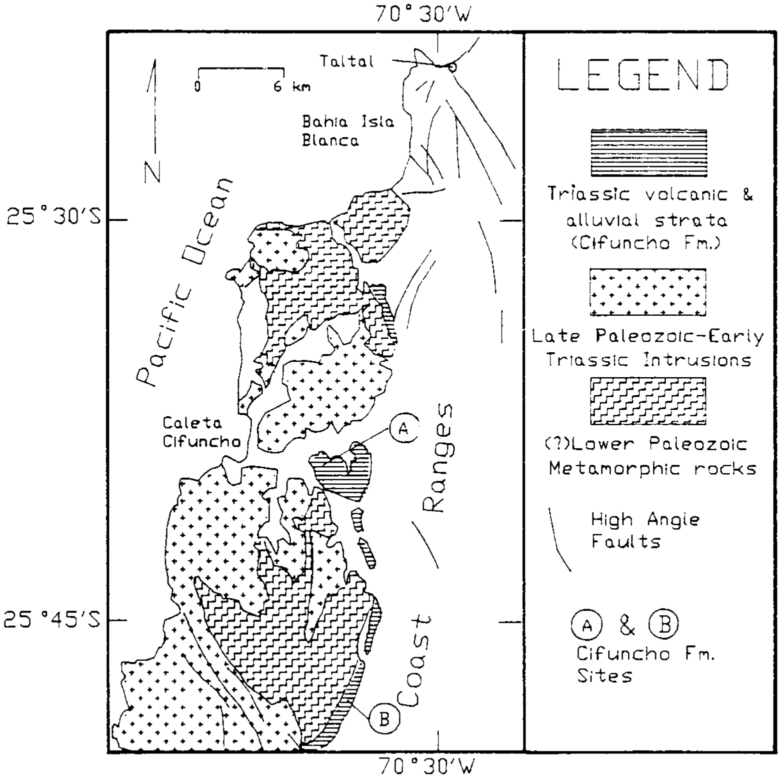

Fig. 3. Paleozoic and lower Mesozoic units in the coast range south of Taltal, near Caleta Cifuncho, with sampling localities indicated.

to Lower Permian. In the sampling area the sequence is homoclinally dipping about 60° to the north-northwest; thus no fold tests were feasible.

Matahuaico Formation. The Matahuaico Formation [after Dedios, 1967], exposed in the Elqui River valley east of Vicuña, is formed of acidic pyroclastic breccias, vitreous lavas, finely laminated tuff, and red sandstones and conglomerates. Its base is not exposed. It is covered by Upper Triassic continental sequences and intruded by leucocratic granite bodies of Permian and Triassic ages [Cornejo et al., 1984]. It can be considered the equivalent to the Pastos Blancos Formation. According to Letelier [1977], it contains plant remains (*Cordaites hislopi* and *Noeggerathiopsis hislopii*) attributed to the Permian. The formation is folded at the sampling locality into an upright syncline, with a hinge plunging approximately 40° to the west.

Coastal Cordillera

Two units of Triassic age, the Cifuncho Formation and the Pichidangui Formation, were sampled in the coast ranges (Figures 3 and 4).

Cifuncho Formation. The Cifuncho Formation (25°30'S; after García [1967]) rests with angular discordance over the Paleozoic basement of the coast ranges which here is composed of a deformed sequence of turbidites thought to be of forearc origin [Bell, 1982]. The Cifuncho Formation is concordantly overlain by fossiliferous marine strata of Hettangian age. Following Suarez et al. [1984], the formation is a thick sequence of red conglomerates, sandstones, and shales that were deposited in alluvial fans and braided streams within basins limited by faults in the beginning stages of the "Andean Cycle." It includes scarce remains of plants similar to the classic "flora de la Ternera" attributed to the Upper Triassic [Naranjo and Puig, 1984]. Its precise pre-Jurassic age is uncertain. It is the only Triassic sequence known in the coast ranges of the Antofagasta region of Chile.

Pichidangui Formation. The Pichidangui Formation (latitude 32°S, longitude 71°30'W [after Vicente, 1976]) is composed of 4000 to 5000 m of breccias, tuffs, and keratophyric lavas that were deposited in fluctuating subaquatic continental conditions. The formation extends in the coast from Caleta el Quereo in the north, south of Los Vilos, to the village of Los Molles (Figure 4). It also probably includes some associated intrusions and sills.

The base of the formation rests over Anisian sandstones of the El Quereo Formation with *Daonella* fauna and scarce ammonites (*Gymnites*, *Ptychites*, *Sturia*, *Ceratites*, *Gryphoceras*, and *Trematoceras*) [Cecioni and Westermann, 1968]. The upper part of the Pichidangui Formation contains intercalations of black shales carrying *Esteria* and rich in plant remains with *Dicroidium*, *Yabeil-*

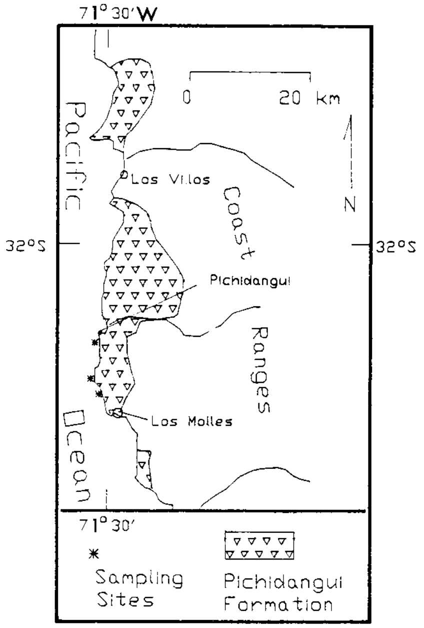

Fig. 4. Distribution of the Late Triassic Pichidangui Formation in the coast ranges near Los Molles along with the sampling locations.

la, Podazamites, Chiropteris, and Neoggerathiopsis attributed to the upper Carnian [Fuenzalida, 1937, 1938; Cecioni and Westermann, 1968].

Near the village of Los Molles, the formation is covered by black shales with plant remains and ammonites (Sandlingites) attributed to the upper Norian. Over these beds lies the Los Molles Formation with a complete sequence passing from the Triassic to the Jurassic in marine facies.

Paleomagnetic Results

Samples oriented by magnetic compass were obtained in the field with a gasoline-powered drill. Sampling was arranged according to sites, each represented by three or more independently oriented samples. At least one 2.2-cm-long specimen core was prepared from each core sample for magnetic measurement.

Natural remanent magnetization (NRM) was measured on either a computer-interfaced two-axis superconducting magnetometer [Goree and Fuller, 1976] or a flux-gate spinner magnetometer [Molyneux, 1971]. Detailed alternating field (AF) and thermal demagnetization studies were conducted initially on a pilot sample from each site. The sample demagnetization data were analyzed on orthogonal projections of vector end-point diagrams, and a progressive demagnetization schedule at a minimum of six levels was designed to isolate significant magnetization components for the remaining available samples from each site. Magnetization components were calculated by least-squares line fitting to the demagnetization trajectories [Kirschvink, 1980]; component mean directions were averaged according to standard paleomagnetic statistical analysis [Fisher, 1953; Watson and Irving, 1957].

Main Cordillera, Pastos Blancos Formation

A total of 39 samples from 10 sites were available for paleomagnetic study. The NRM directions tend to fall in the northeast quadrant with negative inclination, away from the present-day field direction. The inferred stability of the magnetizations is confirmed by demagnetization studies. AF treatment generally defines a demagnetization trajectory that converges toward the origin (Figure 5a). Up to 60% of the NRM, however, can remain after 100 mT, and subsequent thermal treatment to 670°C and higher is required to remove the remaining fraction. Evidently, high-coercivity, high-blocking-temperature hematite is an important remanence carrier in these rocks. The sample magnetizations can, in any case, be regarded as essentially univectorial, origin-seeking trajectories defining characteristic directions that are usually upward and northerly (e.g., Figure 5a), but in two sites are more southerly and downward.

Characteristic directions were isolated in 33 samples representing all 10 sites (Table 1). The northerly and upward (normal polarity) directions from eight sites are well clustered, with a mean of declination (D) of 33°, a mean of inclination (I) of -44.4°, and an alpha 95 of 6.9°, before correction for tectonic tilt (Table 1). After correction for tilt, the directions become northwesterly and shallower. These eight sites represent a variety of rock types, including rhyolites, welded tuffs, and fine-grained dikes.

The downward directions from the two rhyolite flows can be interpreted as of reversed polarity, but they neither are closely grouped (even though from adjacent lava beds) nor collectively or individually appear to be antipodal to the eight normal-polarity site directions. The age of magnetization of the poorly represented reversed polarity directions may therefore differ significantly from that of the normal polarity directions. Although no fold test was possible at the sampling locality, we note that the reversed polarity directions go from westerly to the more expected southerly declination with application of tilt correction.

Main Cordillera, Matahuaico Formation

Of the 24 samples from six sites available for paleomagnetic study from the Matahuaico Formation, 18 were subjected to demagnetization treatments. The sampling locality of this unit, thought to be correlative to the Pastos Blancos Formation, afforded the opportunity of a fold test to help constrain the age of magnetization. Upon demagnetization, most samples showed evidence of multicomponent magnetizations, often with seriously overlapping stability spectra. Despite attempts to isolate characteristic directions for each site (with a preference for the high-temperature component that converged on the origin), site directions failed to group either before or after tilt correction. Unfortunately, the magnetizations of the Matahuaico Formation at the sites sampled are

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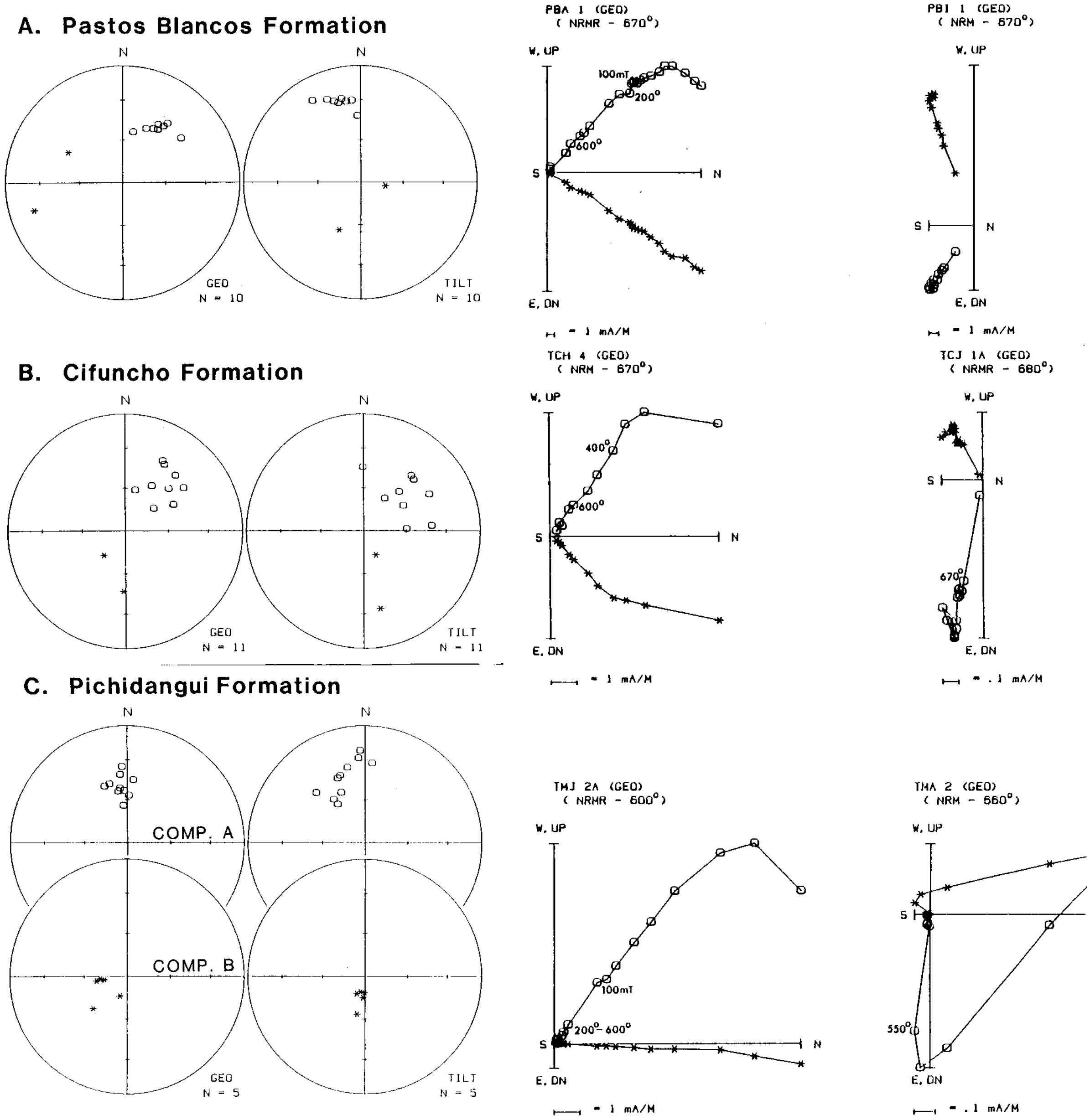

Fig. 5. Paleomagnetic data from the (a) Pastos Blancos, (b) Cifuncho, and (c) Pichidangui formations. At left are equal area plots of site mean directions in geographic (GEO) and tilt corrected coordinates (TILT) for the components isolated in each rock unit. At right are vector end-point diagrams of principally thermal (in degrees Celsius) sometimes preceded by AF demagnetization for representative specimens from each formation. Open circles (stars) are projections on vertical (horizontal) planes.

very complex with no convincing definition of characteristic directions for the formation.

Coastal Cordillera, Cifuncho Formation

The sample collection included sandstones (six sites), basic dikes (three sites), and lava flows (three sites) for a total of 53 samples. Redbed samples were thermally demagnetized up to 680°C, and dike and lava samples AF demagnetized up to 100 mT, although some of the lava samples required subsequent thermal treatment up to 680°C for complete demagnetization. Complex demagnetization trajectories were commonly encountered, although a sufficient number of sites yielded relatively straightforward univectorial decays of consistent

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TABLE 1. **Paleomagnetic** Data From Permian and Triassic Rocks, Chile

			Before Tilt Correction				After Tilt Correction			
Sites	Samples	Polarity	Declination	Inclination	k	alpha 95	Declination	Inclination	k	alpha 95
Pastos Blancos Formation (Late Carboniferous-Early Permian, 31.1°S, 70.1°W)										
8	29	N	33.1[a]	-44.4	65	6.9	344.7	-29.8	65	6.9
2	4	R	272.4	36.3	--	---	174.9	71.2	--	---
Cifuncho Formation (Late Triassic, 25.6°S, 70.6°W)										
9	28	N	40.1	-47.6	29	9.8	50.7	50.8	16	13.3
2	5	R	196.0	59.0	--	---	163.6	52.2	--	----
11	33	N, R	36.6[b]	-50.0	24	9.6	40.3	-53.8	10	15.1
Pichidangui Formation (Late Triassic, 31.2°S, 71.5°W)										
10(A)	33	N	353.1[c]	-50.0	69	5.8	341.5	-40.9	24	10.1
5(B)	14	R	242.7	71.1	50	11.0	191.7[d]	74.6	134	6.6

N is normal; R is reversed. Dashes indicate only marginally significant data.
[a] The pole is 60.7°S, 200.3°E; dp = 5.5°, dm = 8.7°.
[b] The pole is 57.5°S, 217.1°E; dp = 8.6°, dm = 12.8°.
[c] The pole is 84.1°S, 20.7°E; dp = 5.2°, dm = 7.8°.
[d] The pole is 59.0°S, 277.5°E; dp = 10.9°, dm = 12°.

orientation from sample to sample, as illustrated in Figure 5b, to allow meaningful averaging of what we regard as the characteristic direction. One lava site, however, failed to yield at least one interpretable sample demagnetization diagram.

The site-mean characteristic directions fall predominantly into a normal polarity, northwesterly, and up grouping (nine sites), but two sites (sediment and a lava) have nearly antipodal (reversed polarity), southerly, and down directions (Table 1). After tectonic tilt corrections (assuming the dikes are feeders for the lavas), scatter in the site-mean directions increases. The precision parameter decreases with tilt correction by a factor of 2.4, which is significant at the 95% confidence level. It therefore appears that the directions are of postfolding origin, and the in situ mean for the 11 sites (D=36.6°, I=-50°, and alpha 95=9.6°) can be regarded as a good estimate of the geomagnetic field in which the secondary magnetization was acquired.

Coastal Cordillera, Pichidangui Formation

Basaltic and rhyolitic lavas and tuffs were sampled at 13 sites (47 samples). The NRM directions tend to fall near the present geomagnetic field. AF and thermal demagnetization reveal the presence of two components of magnetization. The most common and dominant component (labeled A) is northerly and up and can be isolated in 10 sites. In six of these sites, it is the only consistent component of magnetization present as shown by linear trajectories that converge toward the origin by 100 mT AF or 600°C thermal treatment (Figure 5c). In four sites, however, the A component trajectory does not go toward the origin, and further temperature treatment up to 680°C reveals a southerly and downward magnetization (component B) of high stability (Figure 5c). One additional site shows the B component even though the A component cannot be well resolved.

Component A fails the fold test at the 95% confidence level; for these normal polarity sites the in situ mean is D=353.1°, I=-50°, with alpha 95=5.8° (Table 1). The precision parameter improves by a factor of 2.7 after tilt correction for the B component, and therefore this reversed polarity direction may be of pre-folding origin. For the five sites, the mean B component direction after tilt correction is D=191.7° and I=74.6°, with alpha 95=6.6° (Table 1), which may possibly represent a Late Triassic direction.

Discussion

For comparison with the paleomagnetic directions reported here from northern Chile, we use the apparent polar wander path for South America determined by Irving and Irving [1982]. They compiled 34 paleopoles representing the time interval 380 Ma to the present. These paleopoles, thought to provide reference directions for the stable interior of South America, were averaged through a 30 Ma time window, moved in 10 Ma steps, and assigned confidence circles. These poles are used to define a 300 to 120 Ma polar wander path shown in Figure 6 along with the results obtained from the two coastal localities.

We note that for virtually all of Mesozoic and Cenozoic time, and even in the Late Permian (i.e., 260 Ma to the present), the mean paleopoles for South America as calculated by Irving and Irving [1982] are not significantly different from the present dipole field (geographic axis). Only a Late Triassic (200 Ma) mean shows a departure (16°) which exceeds the associated 95% confidence level (11°). Therefore, if these references poles are taken at face value, predicted directions from 60 Ma to the present should have declinations near

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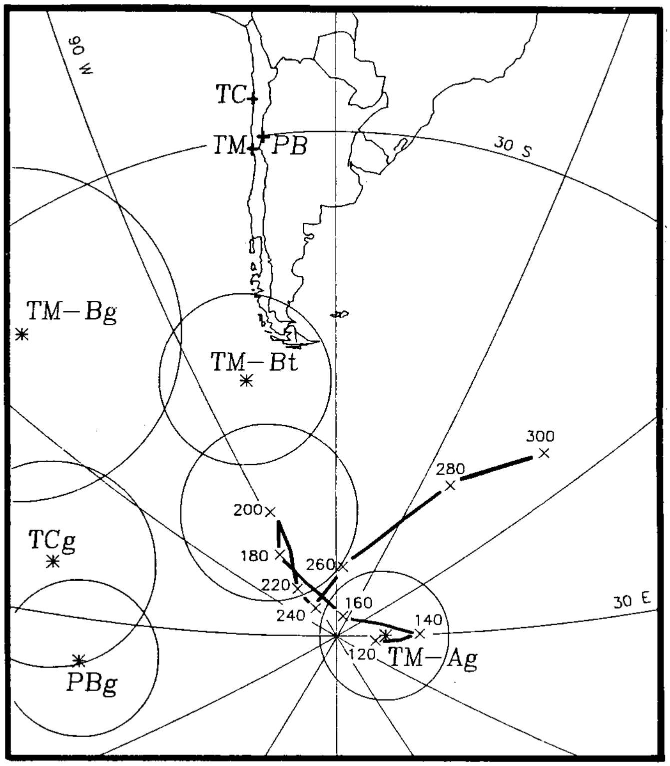

Fig. 6. Averaged APW path for South America [Irving and Irving, 1982] along with the poles and their 95% confidence limits for the localities reported here (TCg is Cifuncho Formation without tilt correction; TM-Bg and TM-Bt are Pichidangui Formation B component, without and with tilt correction, respectively, TM-Ag is Pichidangui Formation A component without tilt correction; and PBg is Pastos Blancos Formation without tilt correction). The confidence circle for the 200 Ma position of the APW is shown for comparison with the poles derived from the sampled formations. Formation confidence circles are calculated from virtual geomagnetic poles determined for each site mean.

0° (180° for reversed polarity) and inclinations (negative for normal, positive for reverse polarity) conforming to the present latitude of the sampling locality according to the dipole formula. For Late Carboniferous and Early Permian times (300 Ma to 270 Ma), the mean paleopoles for South America show significant departures from the present field axis, and would predict in north-central Chile (~31°S, 71°W) northwesterly declinations (e.g., 322° for a 300 Ma mean pole) and inclinations somewhat steeper than at present (e.g., -58.5° for a 300 Ma mean pole, compared to -50° for the present dipole field).

The reference pole data set for South America is admittedly not very satisfactory because of the general absence of fold and other field tests to demonstrate that the magnetizations are not seriously contaminated by more recent overprints. However, some support for the hypothesis that can be drawn from these data, that South America in fact occupied, since about the late Permian, an orientation not very dissimilar from today's position, comes from comparison of paleopoles from Africa and the other southern continents when they are reconstructed to their past positions relative to South America [e.g., Van der Voo and French, 1974; Irving and Irving, 1982; Norton and Sclater, 1979].

In the absence of a fold test, it is uncertain whether the paleomagnetic results from the Pastos Blancos Formation represent primary or secondary magnetizations. We believe that at least the normal polarity directions that are dominant in our collection do not represent primary magnetizations because this would conflict with the predominantly reversed polarity Kiaman Interval of Late Carboniferous and Permian age [Irving and Pullaiah, 1976], the time interval in which the Pastos Blancos Formation is thought to have formed. If the normal polarity magnetizations are of secondary origin, we find that the mean northeasterly declination calculated without tilt correction does not correspond to predicted Mesozoic or Cenozoic field directions, even though there is no notable discrepancy in the mean inclination. Therefore the data would suggest a clockwise rotation of about 30°, but no discernible latitudinal motion of the Pastos Blancos Formation since acquisition of its postfolding characteristic magnetizations. If the secondary magnetizations were acquired after the Kiaman Interval but were still prefolding, we must conclude the opposite: no significant discordance in declinations but more than 15° of latitudinal discrepancy, a result placing the Pastos Blancos Formation at much lower latitudes with respect to cratonic South America. As is discussed below, the former alternative implies a rotation that is consistent with that seen in the Cifuncho Formation, while the latter implies a latitudinal shift that is inconsistent with that seen in the Pichidangui Formation. Thus secondary acquisition of the characteristic directions in the Pastos Blancos Formation appears to be the more reasonable alternative. Unfortunately, one cannot exclude the possibility that the directions may have been subsequently affected by local tilting. The poorly defined reversed directions at two sites in the formation might record an earlier, possibly primary, magnetization.

The stable directions from 11 sites in the Cifuncho Formation are apparently of secondary origin because of a negative fold test, even though two of the sites have reversed polarity. As for the Pastos Blancos Formation secondary magnetizations, the Cifuncho Formation mean direction without correction for bedding tilts is rotated by about 30° clockwise, but there is no significant discrepancy in the mean inclination with respect to available post-Late Triassic reference directions for South America. The clockwise discordance is significant regardless of what available Late Triassic or younger reference direction is chosen for comparison. Of course, one cannot exclude the possibility that there may be errors in the APW data or, for that matter, that small

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amounts of block tilting about horizontal axes could be present. However, below we show that the clockwise discordance seen here is part of a broad regional pattern along the western flank of the Chilean Andes, leaving the alternative of local block tilting seemingly ad hoc.

The paleomagnetic results from the Pichidangui Formation show two components of magnetization. The normal polarity A component fails the fold test. However, unlike the secondary magnetizations in the Pastos Blancos and Cifuncho formations, the A component mean direction conforms in both declination and inclination with a younger (post-Late Triassic) paleomagnetic field direction for South America. We do not know the age of the secondary magnetizations, but we know that it must be younger than the ages of the rock units and their time(s) of deformation. If the secondary magnetizations of the Pastos Blancos, Cifuncho, and Pichidangui formations are all of the same age, the Chilean Andes have a complex regional pattern of apparent rotation, with clockwise rotation in the main cordillera and the Cifuncho region, but apparently no rotation in the more southerly Pichidangui coastal area. Alternatively, the A component of the Pichidangui Formation may be significantly younger, acquired after the clockwise rotation was recorded in the Pastos Blancos and Cifuncho formations.

The reversed polarity B component in the Pichidangui Formation may represent an original (i.e., Late Triassic) magnetization. It is the only magnetization component found in any of the rock units reported here which shows better grouping after tilt corrections. The south pole position for the tilt-corrected direction falls at latitude 59.0°S, longitude 82.5°W (dp=10.9°, dm=12°). This is closest to the 200 Ma (Late Triassic reference pole of Irving and Irving [1982], but still some 15° of arc different. The 200 Ma reference pole predicts a declination of 187° and an inclination of 64.5° at the Pichidangui sites; in contrast, the observed declination and inclination were 191.7° and 74.6°, respectively. The good agreement between predicted and observed declinations suggests that there have been few significant rotations; however, the difference between predicted and observed inclinations is statistically significant and implies that almost 15° of northward latitudinal transport occurred sometime after the Late Triassic. Because most samples were dominated by the secondary A component, additional sampling will be necessary before the B component can be better documented. If the secondary A component was acquired as a thermochemical overprint during the peak of arc activity in the Pichidangui area in the Late Jurassic or Early Cretaceous, the concordance of the A component with the South American reference APW path would suggest that the apparent northward translation of this coastal block was completed in the Jurassic. Note that by considering the B component to also be secondary, the amount of directional discordance increases in comparison with younger reference poles, so that about 30° of latitudinal motion would be required to reconcile the observed with predicted paleomagnetic directions.

Recently, paleomagnetic results from Jurassic and Early Cretaceous intrusions in this coastal region, including bodies which cut the Pichidangui Formation, have been reported [Irwin et al., 1985] and show no major discordance with respect to Jurassic or Cretaceous reference positions. These results clarify interpretations of the magnetizations recorded in the Pichidangui Formation. First, since intrusive units of Jurassic age that intrude the Pichidangui Formation show no apparent rotations with respect to reference directions, folding in the Pichidangui Formation must have been completed prior to emplacement of the intrusions. This suggests that a period of deformation occurred not previously reported elsewhere in Chile and that the B component of magnetization in the Pichidangui Formation is likely of pre-Late Jurassic age. Since the directions of the A component are consistent with the directions recorded in the Jurassic and Early Cretaceous intrusions, it is not unreasonable to suppose that the A component was acquired as a secondary thermochemical overprint during emplacement and initial cooling of the intrusions. While further work is clearly needed, it appears that structural and magnetic data support the existence of a microplate of Late Triassic age represented by the Pichidangui Formation, which had moved northward with respect to cratonic South America and been deformed (during "docking"?) between the Late Triassic and Late Jurassic, after which it was intruded by the initial plutonic elements of the Andean arc system in the Late Jurassic and Early Cretaceous.

Further comparision of results obtained in Pastos Blancos, Cifuncho, and Pichidangui formations to other published results from the Andes between 10°S and 32°S brings out several interesting relationships. In Figures 7a and 7b, observed declinations and inclinations from these studies (including the four reported here) are plotted against predicted declinations and inclinations for the various sampling sites from regions north of 19°S and regions south of 19°S, respectively (assuming sites are fixed with respect to stable South America). Looking first at results reported from the western flank of the Andes in Peru, we find that observed inclinations show no consistent patterns of discordance with respect to the expected (cratonic reference) inclinations. While one could say that the majority of the observed results are consistent with no latitudinal discordance of coastal terranes, some of the inclinations are too steep and others are too shallow. That inconsistency arises even in units of similar age sampled from one general region leads to the suspicion that errors may be present. However, the observed declinations plotted against expected declinations show a surprising consistency (given the inconsistency in the inclinations) in their general counterclockwise discordance. This pattern has been noted by Heki et al. [1983], May and Butler [1985], and Beck [1985]. Heki et al. have pointed out, following the suggestion of Carey [1955], that it may reflect oroclinal bending from Peru to Chile (Arica orocline). In Figure 7b, data for the western flank of the Andes south of 19°S is plotted. First, note that with the excep-

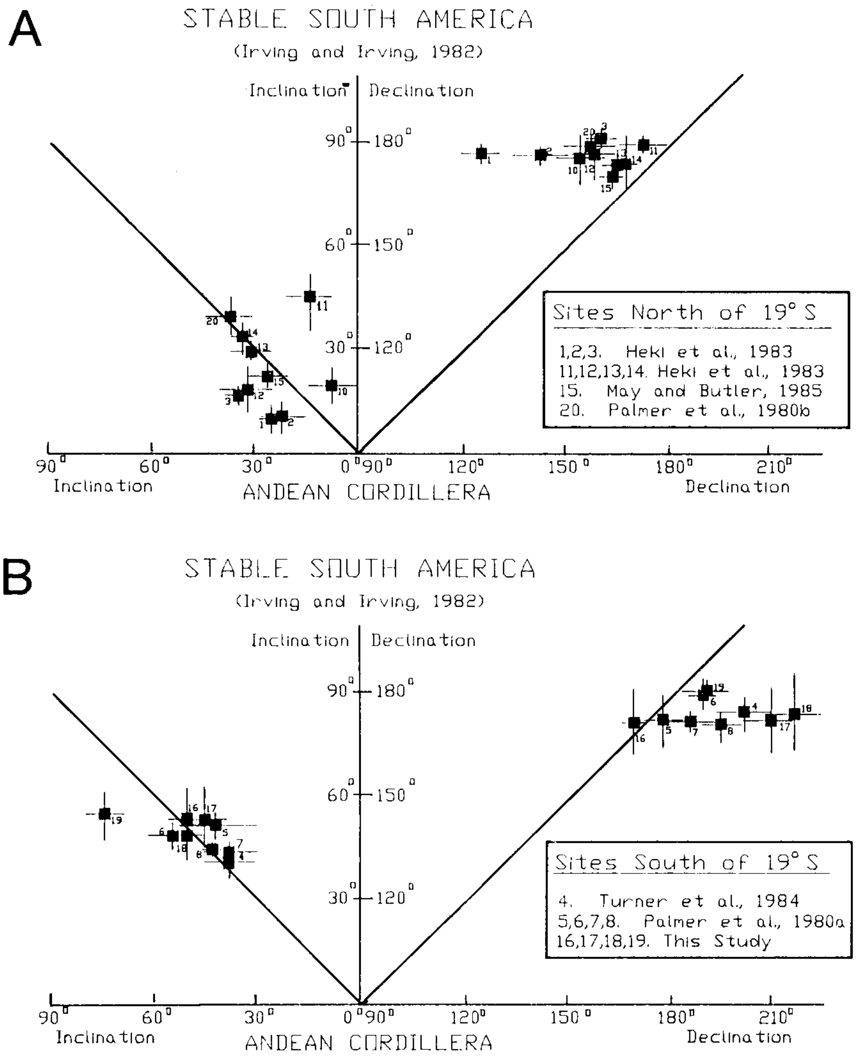

Fig. 7. Predicted versus observed declinations and inclinations for a number of units that have been sampled between 10°S and 32°S in the Andes: (a) sites north of 19°S and (b) sites south of 19°S. The predicted values for each locality assume no relative motion between the Andean ranges and "stable" or cratonic South America when APW data published by Irving and Irving [1982] are used. Vertical bars represent a range of predicted values based on the uncertainty of the age of the units sampled or the time of NRM aquisition. The horizontal bars reflect confidence limits of mean directions determined for the various units. All reported paleomagnetizations are believed to be Jurassic or younger with the exception of the B component from the Pichidangui Formation (site 19) reported here.

tion of the B component of the Pichidangui Formation (which is the only magnetization direction plotted of likely pre-Jurassic age), none of the reported inclinations are significantly discordant from their expected inclinations. Thus we first conclude that these data contain no evidence of latitudinally displaced terranes of Late Jurassic or younger ages. Second, observed declinations show the opposite pattern of discordance from that recorded from the Peruvian Andes. While the tectonic mechanism responsible for this systematic shift or discordance is debatable, we note that simple hypotheses of oroclinal bending are unlikely to explain the observed variations in amounts of discordance, for example, that seen between the Cifuncho and Pichidangui formations of the Chilean coast ranges. Other hypotheses, such as systematic block rotations of border terranes in association with oblique plate convergence [Beck, 1980], are difficult to reconcile with rotations seen in the units from the main Cordillera, e.g., Pastos Blancos Formation.

Much more work, including better refining of the APW data for stable South America, is needed to define the extent and timing of the apparent rotations before a tectonic agent can be isolated.

Finally, evidence for latitudinal displacements revealed in the paleomagnetic results from the Late Triassic Pichidangui Formation emphasizes the need to isolate primary components in pre-Jurassic units of the Andes.

Acknowledgments. Support for this work comes from National Science Foundation grants INT 83-00521, EAR 82-12549, and EAR 85-07046, and from the Servicio Nacional de Geología y Minería. We thank reviewers for their comments and criticisms. This is Lamont-Doherty Geological Observatory Contribution No. 4075.

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