Paleomagnetic evidence for rapid vertical-axis rotation in the Peruvian Cordillera ca. 8 Ma

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ABSTRACT

Paleomagnetic results from 31 Neogene sites in the Peruvian Andes yield primary magnetizations, as demonstrated by positive fold and reversal tests. Strata dated as 18–9 Ma record a significant counterclockwise rotation (−11° ± 5°), whereas unconformably overlying younger strata (7–6 Ma) are not rotated. The age of rotation thus is between 9 and 7 Ma, a period that coincides with the widespread Quechua 2 deformation phase. Moreover, eight independent studies on 107–9 Ma rocks from Peru between 9°S and 15°S reveal similar and significant rotations (−15° ± 6°). This suggests that the region rotated during a 2 m.y. period of deformation ca. 8 Ma, when the Andes underwent rapid uplift and important deformation commenced in the Subandean zone.

Keywords: Andes, Neogene, orogenesis, paleomagnetism, Peru, rotation.

INTRODUCTION

Since pioneering work in the 1970s, paleomagnetic studies on Cretaceous to Pliocene rocks have shown that magnetic declinations roughly parallel structural trends along strike of the Andean chain. Counterclockwise rotations are found north of the Arica deflection (∼19°S, Fig. 1A) where structures are northwest oriented, while south of the bend, where the regional fabric strikes north-northeast, rotation sense is mainly clockwise. Models proposed to explain this pattern range from wholesale oroclinal bending with large-scale rotations and/or differential shortening (>1000 km), to smaller block rotations via local partitioning of strike-slip and thrust-related tectonics (see reviews in Beck, 1998; Randall, 1998). The obliquity of convergence relative to the South American margin likely influences the pattern of paleomagnetic rotations. The Nazca–South America plate convergence direction has remained fairly constant since ca. 50 Ma (Pardo-Casas and Molnar, 1987) and currently trends N76°E (Norabuena et al., 1998). Convergence is margin normal at the Arica deflection but oblique to the north and south. This obliquity may induce counterclockwise rotations in Peru and slightly clockwise rotations in Chile; rotation sense, however, becomes unpredictable where the convergence direction is trench normal (Beck et al., 1994). The relatively high obliquity of the Peruvian margin relative to convergence, coupled with the continuous geologic structures of the Peruvian Andes, provides an excellent setting to study the link between mountain building and paleomagnetism, and eventually to discriminate between scale-dependent tectonic models.

From 9°S to 15°S, the major structures (e.g., fold axes, thrust faults) of the Peruvian Andes trend north-northwest, parallel to the coast (Fig. 1B). Several orogenic episodes have been recognized in this region: a Late Cretaceous Peruvian phase (Mégard, 1984), an Oligocene-Miocene Incaic phase (Sempere et al., 1990) that Mégard (1987) considered the major shortening phase, and three Miocene-Pliocene Quechuan phases (ca. 20, 8, and 5 Ma, Mégard et al., 1984). Paleomagnetic studies on Cretaceous and Tertiary rocks, mostly conducted near the coast, demonstrate a broad pattern of significant counterclockwise rotations on the order of −15° (Fig. 1B). A study on the Ocros dike swarm (Heki et al., 1985), within the interior of the Cordillera, exhibits a similar rotation (−12° ± 6°). Although the age of the Ocros dikes is poorly defined as Neogene, these data suggest consistent paleomagnetic rotations over a broad area. To better define the timing and spatial extent of these rotations, we carried out a paleomagnetic study on Neogene rocks in the Ayacucho basin of the Peruvian Cordillera.

GEOLOGIC SETTING

We drilled 262 cores at 31 sites in the Sallalli (6 sites), Huanta (13 sites), and Ayacucho (12 sites) Formations. The Sallalli Formation (called the Larampuquio volcanics by Mégard, 1984) consists largely of basaltic andesite interbedded with conglomerate deposits. Plagioclase and sanidine extracted from tuffs from the upper and lower parts of the formation yielded K-Ar dates of 18.3 ± 0.6 Ma and 17.3 ± 0.2 Ma, respectively (McKee and Noble, 1982). The overlying Huanta and Ayacucho Formations consist mainly of fluviolacustrine sediments intercalated with volcanics. Rocks collected near the base of the Huanta Formation yielded K-Ar dates from 12.1 to 9.7 Ma, the weighted mean being 11.4 ± 0.5 Ma; sanidine from a tuff collected in the formation's upper part gave a 9.3 ± 0.3 Ma K-Ar date (Mégard et al., 1984). K-Ar dating on the Ayacucho Formation indicates deposition mainly from 7.0 to 6.5 Ma (Mégard, 1984).

Mégard et al. (1984) recognized a marked angular unconformity between the Huanta and Ayacucho Formations and suggested that the Huanta and older formations were folded during Quechua 2 deformation. Bedding-plane data from this study define a fold axis trending 169° for the Huanta Formation (Fig. 1B); the Sallalli Formation fold axis, however, is poorly defined because only one limb was sampled. Combining bedding data from these two formations yields a trend of 168°, orthogonal to the Nazca–South America maximum compressive stress direction. The fold axis of the gently deformed Ayacucho Formation (strike 124°) is quite different from the older rocks, consistent with the existence of an angular unconformity.

PALEOMAGNETISM

Samples were measured with a three-axis 2G DC-SQUID magnetometer and demagnetized thermally or with an alternating field (AF) using 14–22 steps. Magnetic susceptibility was measured after each thermal step to monitor potential changes in magnetic mineralogy. Unblocking temperatures >580 °C indicate the presence of hematite, but Curie point experiments also show the presence of titanomagnetite. We used mainly thermal or hybrid demagnetization for the Huanta and Ayacucho Formations and AF demagnetization for the Sallalli volcanics. Data were evaluated by using principal component analysis (Kirschvink, 1980) and Fisher (1953) statistics.

Most samples had one or two magnetization components (Fig. 2, A–D). Two Huanta sites were rejected due either to noisy demagneti-

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