TECTONIC EVOLUTION OF THE CENTRAL ANDES SINCE THE CRETACEOUS

Simon LAMB, Lorcan KENNAN, Leonore HOKE

Department of Earth Sciences, Parks Road, Oxford, OX1 3PR, UK.

RESUMEN

Los Andes Centrales de Bolivia y Norte de Chile forman parte de un límite de placas entre Sudamérica continental y la placa subductante de Nazca. Desde el Cretácico, esta región ha sido solevantada hasta formar la parte más ancha de los Andes. La deformación ha sido contínua durante este período, aunque su localización ha cambiado marcadamente. Se incluye un esquema de la evolución terciaria de los Andes de Bolivia, basada en un estudio de las secuencias sedimentarias cretácicas y terciarias, y en datos paleomagnéticos

KEY WORDS: Central Andes, tectonic evolution, palaeomagnetism.

INTRODUCTION

The Central Andes of Bolivia and northern Chile form part of the plate-boundary zone between the continental South American and subducting oceanic Nazca plates. Since the Cretaceous, this region has been uplifted to form the widest part of the Andes, reaching an average elevation of ca. 4000m in a region 700 km wide. Though deformation has occurred throughout this period, its locus has changed markedly. The following description briefly outlines the Cretaceous and Tertiary evolution of the Bolivian Andes, based on extensive field work, K-Ar dating (Kennan et al. in preparation) and palaeomagnetic studies, as well as information from unpublished oil company reports and seismic sections. The Central Andes is viewed as a continuously growing mountain belt, rather than the product of discrete tectonic events.

PRE-CRETACEOUS AND CRETACEOUS DEFORMATION

There is a marked angular unconformity at the base of the Cretaceous. Open to tight folding, with limb dips up to 50°, a weak axial planar cleavage and extensive quartz veining are found in Palaeozoic flysch deposits beneath the Cretaceous throughout the Cordillera Oriental which are truncated by basal Cretaceous conglomerates. At least 5 km of pre-Cretaceous rocks were stripped off by erosion prior to Cretaceous deposition. In places the pre-Cretaceous deformation appears to have influenced the style and orientation of Tertiary structures.

Thin Cretaceous sequences (usually <1 km) of lacustrine and possibly marine deposits are preserved throughout the Bolivian Andes, and demonstrate that most of the present region of the Andes was at or near sea level at that time. Local mafic volcanism, including pillow lavas, suggest a small amount of extension concomitant with subsidence of the Cretaceous basin. Interestingly, the depocentre of the Cretaceous basin coincides with the region of most intense pre-Cretaceous shortening. The active plate margin at this time was a relatively narrow zone much further west, with a wide back arc region of slow subsidence and limited extension several hundred kilometres wide.

EARLY TERTIARY DEFORMATION

Cretaceous sandstones, often containing fossilised dinosaur tracks, pass conformably into thick red-bed sequences. For instance, in the Camargo area of southern Bolivia, this transition can be traced along strike for over a hundred kilometres and is perfectly conformable. The basal part of the red-bed sequence consists of red siltstones with thin medium sandstone interbeds. However, within 150 m stratigraphically of the base of the sequence, conglomerates and thick coarse sandstones are well developed.

In both the Altiplano region and Cordillera Oriental, the basal few hundred metres of the Tertiary red-bed sequence shows a large dispersion in sediment transport directions, but then these become essentially unidirectional further up the sequence. This is interpreted as a transition from a highly meandering fluvial environment in a region of low topographic gradient, to a more uniform flow regime down a steeper gradient, representing the onset of deformation in this part of the Andes in the earliest Tertiary.

The uplifting regions can be defined with some precision from the pattern of sediment transport directions. The centre of the Cretaceous basin was inverted, so that the deepest part formed a narrow uplifting region in the earliest Tertiary, which shed sediment both to the east and west. This proto-cordillera developed as a narrow isolated range in what is today the western part of the Cordillera Oriental, separated from the active arc by a region several hundred kilometres wide. The intervening region formed a large intermontane basin which is now preserved in the Altiplano region of the Bolivian Andes, where up to 5 km of Early Tertiary continental sediments were deposited.

MIDDLE AND LATE TERTIARY DEFORMATION

Underformed Early Miocene ignimbrites show that north of the latitude 22°S, significant shortening deformation in northern Chile ceased in the Middle Tertiary. Deposition also continued in the Altiplano basin to the east, which received sediment both from the west and east. The distribution of Oligo-Miocene sedimentary sequences in the Bolivian Cordillera Oriental show that many local structural basins formed at this time, which locally sit with angular unconformity on older sequences. Shortening here also extended much further east than in the Early Tertiary. However, the nature of the eastern front of the Andes is not understood, but there is no evidence for a region of intense Middle Tertiary shortening similar to the present SubAndean zone. However, sedimentation in the SubAndean zone suggests a foreland basin began to form at this time. Shortening throughout the Cordillera Oriental was accommodated by km to 10's km scale folding and relatively high angle reverse faulting, with changes in vergence. No evidence for nappe-style deformation has been observed in the Cordillera Oriental. The best estimate of Tertiary crustal shortening comes from crustal thickness balancing, as much of the structure in the Cordillera Oriental is pre-Cretaceous in age.

In the Late Miocene, during a period of a few million years, the Altiplano basin started to shorten internally. Essentially undeformed Late Miocene to Pliocene sedimentary basins, which are found throughout the Cordillera Oriental, suggest that shortening in the Cordillera Oriental, except for local conjugate strike-slip deformation, effectively ceased. However, in the Pliocene, the locus of deformation again shifted to the frontal parts of the Andes in the east, in what is today the Subandean zone. This forms an active thin-skinned fold and thrust belt which has accommodated ca. 100 km of shortening. Also, no evidence for either active normal faulting or significant Plio-Pleistocene extension has been observed in the Bolivian Altiplano.

The present drainage pattern in the Cordillera Oriental, including deep valleys with a vertical relief reaching several kilometres, is the product of erosion during the last 3 Ma. Prior to that, the topography in the Cordillera Oriental was relatively subdued with the development of regional peneplains.

TECTONIC ROTATIONS

Deformation since the middle Miocene (ca. 15 Ma) has been responsible for substantial rotations about a vertical axis in the Central Andes, relative to the South American plate. Palaeomagnetic work has defined three principal zones which can be characterised by particular rotations about a vertical axis.

In the north, the Bolivian Andes is characterised by small anticlockwise rotations between 0 and 10°, observed in Cretaceous to Late Miocene sediments and volcanics, right across the width of the Andes. Further south, a zone can be defined, also extending right across the Andes, in which clockwise rotations between 0 and 10° are typical, observed in Cretaceous to Early Miocene sediments. And even further south, there is a zone, which again extends right across the width of the Andes, characterised by clockwise rotations between 20° and 30°, observed in Cretaceous to Late Miocene sediments and volcanics. These three principal zones can be ascribed to along strike gradients in the shortening in the Subandean zone, which has resulted in 'bending' of almost the entire width of the Central Andes since the Late Miocene.

In the Cochabamba area, in a region ca. 100 km by 100 km, local clockwise rotations, between 20° and 30°, have been detected in Cretaceous sediments, within the general area of anticlockwise rotations. These are related to block rotation accommodated by sinistral strike-slip on ESE-trending faults, active in the Miocene-Pliocene and accommodating the divergence in shortening round the pronounced bend in the Bolivian Andes. In addition, a local zone of large anticlockwise rotations, up to ca. 50°, is found in Middle Miocene rocks at the southern end of Lake Titicaca. This may be related to along strike sinistral shear in the northern Altiplano, which is partly accommodating the component of plate motion parallel to the trend of the Andes. In general, zones of tectonic rotation can be correlated with the general structural trend. However, regions of anomalous strike orientation, for instance in the Otavi syncline near Potosi, are not always associated with significant Cenozoic tectonic rotation and probably reflect the reactivation of pre-Cretaceous trends which differ from prevailing Andean trends.