1. Tectonica de placas - Peru
2. Cordillera de los Andes (Peru) - Tectonica

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Plate Tectonics and the Peruvian Andes

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We describe and discuss geological evidence which does not accord with simple Plate Tectonic models of the development of the Peruvian Andes.

DURING recent developments of the Plate Tectonics hypothesis the Andes seem to have become a type example of a fold-belt developing at the edge of a continental plate by a process of subduction[1-3]. There is, however, some real geological evidence which is not entirely in accord with simple models based on this attractive hypothesis.

Gansser[4] has recently assembled much of what is known concerning the Andean belt as a whole, concluding that, during the Mesozoic, the troughs of deposition in Colombia and Venezuela were likely to have been floored by oceanic crust, whilst in Peru and Chile they were intra-cratonic. We explore this finding by summarizing salient points from the rapidly growing knowledge of Peruvian geology[5].

The General Geological Structure of Peru

The Andes of Peru and Bolivia consist of two sub-parallel fold belts[6]: one of Mesozoic–Tertiary age makes up the Western Cordillera and another of late Palaeozoic age constitutes the Eastern Cordillera. These two fold belts (Fig. 1) are separated by the Altiplano, a broad intermontane plateau filled with Tertiary molasse. This plateau is present in Bolivia and occupies the southern part of Peru as far north as Abancay where a swing in the trend of the Palaeozoic fold-belt brings the two belts together and eliminates the Altiplano as a structural unit.

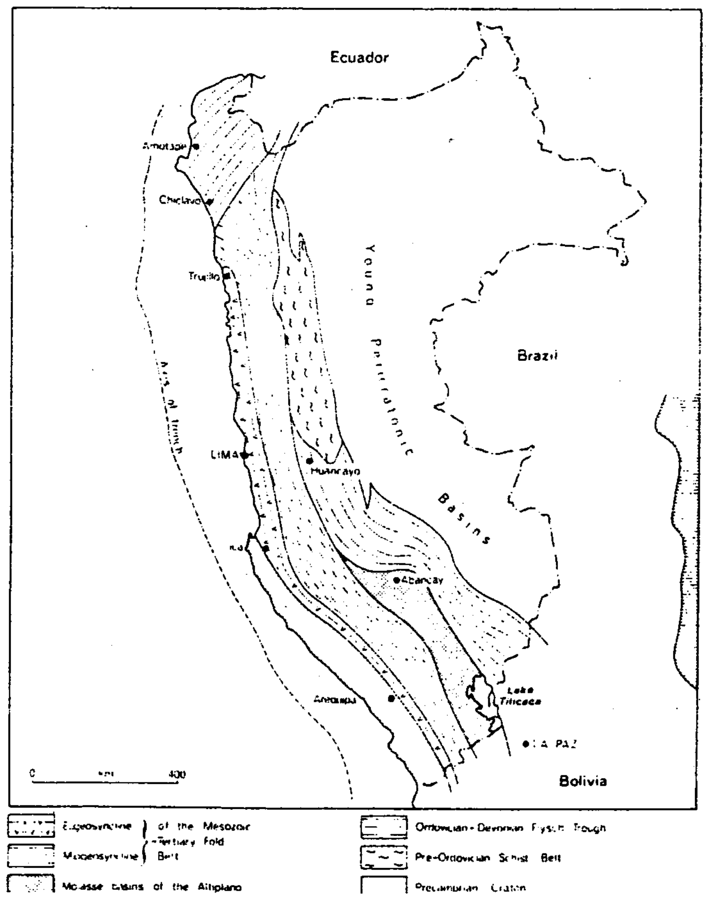
The Palaeozoic fold-belt[7] is readily divisible into two parts. A thick, black shale-quartzite assemblage to the south of Huancayo (Fig. 1) contrasts with pre-Ordovician green-schist facies pelites to the north. It is important to note that the latter are associated with gneisses which may represent re-worked Precambrian basement[8,9].

The Mesozoic-Tertiary fold-belt is also clearly divisible into two, this time more conventionally into an eastern miogeosynclinal belt of folded clastics and carbonates and a western eugeosynclinal belt of relatively undeformed volcaniclastics. From Ica in the south to Trujillo in the north (Fig. 1) these deposits are so thick that no floor is seen, but between Trujillo and Chiclayo, Cretaceous sediments rest upon andesites of Triassic age which in turn rest upon schists and phyllites of Lower Palaeozoic or Precambrian age (J. J. Wilson, personal communication). South of Ica regionally metamorphosed rocks, including augen gneiss and migmatite, form faulted inliers within the belt of younger rocks (B. Amos and J. W. Stewart, personal communication). Thus the Phanerozoic rocks are at present floored by old crystallines which probably craton and, to the west, along the western seaboard of Peru, by equally old rocks forming the Arequipa massif and possibly also a great part of the continental shelf of Peru.

The Arequipa Massif

So far little detailed work has been done on these particular rocks, though their gneissic character has been frequently commented on[7,10-13]. We have examined them briefly and collected samples for radiometric analysis: these are not yet determined but a K-Ar date of 642 ± 16 m.y. was obtained by Stewart and Snelling[14], from gneisses in association with the Mesozoic batholith in the Arequipa area.

The massif consists essentially of grey gneisses (migmatites of semipelitic host) and granite gneisses together with coarse potash feldspar-bearing granites and pegmatites of anatexitic origin: locally dark mylonitic crush zones cut all these rocks. The grey gneisses contain garnet and coarse prismatic sillimanite, and pyroxene has also been reported[12], so that a high amphibolite or granulite facies of metamorphism is



represented. A further component of the massif is a sequence of pelites, psammites and amphibolites exposed in the valley of the Rio Ocona and these probably overlie the gneisses. Thus the typically Archean aspect reported by Douglas[10] and Jenks[11] has been amply confirmed.

Exposures of the old crystalline rocks extend some 700 km along the coast of southern Peru and are therefore likely to make up a considerable part of the 200 km wide continental shelf. In the north, according to newspaper records, "basement" rocks have been reached at comparatively shallow depths in an offshore drilling programme in the latitude of Trujillo, though here we might expect schists of Lower Palaeozoic age of similar type to the Amotape hills at the frontier with Ecuador. Such general evidence concerning the sialic composition of the shelf would fit with the finding of velocities of 5 to 6 km s^{-1} to considerable depths[3].

blocks and the trench, are the sites of deep faults operating as linear structures throughout the whole of the Phanerozoic.

Comparison of the Two Fold Belts

The two fold belts are very different in terms of their internal composition. The Palaeozoic flysch belt[7], folded during the Upper Devonian, takes the form of an anticlinorium (Fig. 2). The structures are fan shaped with a flow cleavage in the axial region giving way to fracture cleavage at the margins: they are overturned towards these margins which are approached through outwardly directed high-angle fault zones. This structural symmetry suggests that the fold belt was formed between cratonic forelands: thus a sub-Andean fault zone gives way to the Brazilian shield on the east while the La Paz–Lake Titicaca fault zone gives way to the Altiplano on the west.

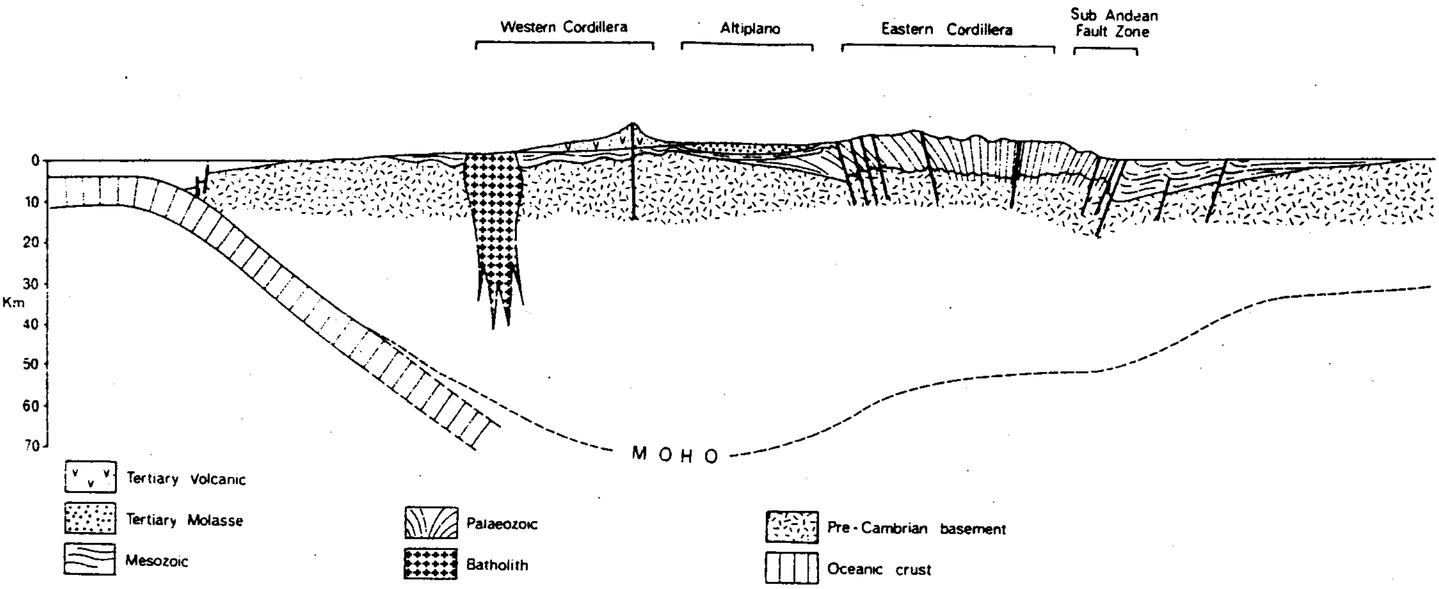


Fig. 2 A schematic section through the Andean Belt at the latitude of Arequipa incorporating data from refs. 3, 7, 11, 19.

In terms of Plate Tectonics this massif is embarrassing because it is widely considered that at such continental margins thick sequences of marine volcanics accumulate upon oceanic crust, which is impossible in this instance if the massif were in place during the Mesozoic. The stratigraphic evidence is clear on this point: Mesozoic volcanics and sediments rest unconformably on the gneiss[11]. Moreover, sediments of the Macoma (Mississippian), Tarma (Pennsylvanian), Mitu (Upper Permian) and Copacabana (Lower Permian) groups have all been reported as unconformably resting on the gneiss[15–17], yet are indistinguishable from representatives of these groups in the Central Andes. Further, Devonian strata are recorded as resting on the gneiss[7,12] and similarly a small outlier of Lower Palaeozoic age was noted[18]. Clearly the Arequipa massif has occupied its present position with respect to the Andean mobile belt since the Devonian and probably earlier. Thus the Mesozoic–Tertiary fold-belt is known to be contained within and underlain by sialic crust both at the present time and during that of the deposition of its constituent rocks: a conclusion in accord with Mégard's section across the Peruvian Andes[20].

The structure of both schist and gneiss generally strike inland at right angles to the Andean orogenic trend so that spatially and chronologically these metamorphic structures are cut both by the trench and the Andean folding. Taking An implication of this is that the Altiplano block is an integral part of the Arequipa massif overlain by relatively thin Lower Palaeozoic sediments which thin rapidly towards the west (Fig. 2). Because of its simplicity in sedimentary and structural history, with no hint of lateral polarity, this Palaeozoic fold belt has been considered to be intercratonic in character by Mégard *et al.*[7].

The Mesozoic–Tertiary fold belt in southern Peru is contained within gentle warps in the Precambrian Arequipa massif (Fig. 2). Further north the basement is not seen but with increasing thickness the polarity between the miogeosynclinal and eugeosynclinal troughs is enhanced. The structure within the miogeosyncline involves symmetrical, often tight, concentric folds continuous in outcrop over long distances and closely associated with major vertical faults. Within the eugeosyncline, however, the volcanics are generally very openly folded, except in narrow zones, though vertical faults are still important, and possibly controlled the emplacement of the associated intrusives[5]. In neither situation, however, is there marginal under or over-thrusting.

Implications for Plate Tectonics

The Palaeozoic belt of clastic flysch was intracratonic and even though it trends approximately parallel to the existing marked polarity and with an andesitic volcanic flysch concentrated in a narrow belt near the continental margin and intruded by great volumes of closely related tonalitic magmas.

Andesitic volcanicity began during the Lias in Southern Peru and the Trias in Northern Peru (J. J. Wilson, personal communication) and has continued with few interruptions up to the present. If we assume that this volcanicity was associated with subduction of oceanic crust at a plate margin we can say that subduction has been an active process since this period. The andesitic rocks so produced, however, were laid down upon a pre-existing sialic crust: no ophiolite belts or suture zones are present and we disagree with the view of James[3] that a great proportion of the crustal thickness in the fold belt is composed of Mesozoic volcanics and their high pressure equivalents. Further, the sialic crust on which the volcanics were deposited was not formed by accretion from oceanic crust, nor is there much evidence of underthrusting, for in the Peruvian Andes steep faults form a central feature of the overall structure.

If true oceanic rocks are indeed absent along this part of the continental margin, as we believe, then the assumption that this is an active subduction zone between plates requires that everything oceanic has been carried down under the continent. The direct evidence for this is certainly not to be found on land.

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LETTERS TO NATURE

Optical Identification of GX 17 + 2

A SYSTEMATIC search is being made for the optical counterparts of the better localized X-ray sources. Here we report a preliminary result of the study of GX 17+2 (2U 1813−14).

This X-ray source has thermal spectrum and shows variations both in intensity and temperature. Tananbaum *et al.*[1] note that "there is a striking resemblance in the X-ray emission of GX 17+2 and Sco X-1". There is evidence also for absorption effects at low X-ray energies, the cutoff energy (E_a) being 2.0±0.2 keV.

Kunkel *et al.*[2] searched for optical counterparts down to a blue magnitude $B=17$ within the error box associated with GX 17+2 given by Schnopper *et al.*[3]. They found no candidate for the identification.

Recently Hjellming and Wade[4] have found a weak variable radio source which can be associated with GX 17+2. On the basis of the assumption that GX 17+2 and the radio source are the same object, we have searched for optical candidates in the much smaller error box furnished by the radio observations

RA (1950) = 18 h 13 min 10.82 s ± 0.2 s
Decl. (1950) = −14° 03′ 13.00″ ± 3.0″

On the Palomar Sky Survey prints, only one optical object, numbered 28 on the identification card of Fig. 1, is present within 3σ of the most probable position of the radio source, its position being

RA (1950) = 18 h 13 min 10.90 s ± 0.02 s
Decl. (1950) = −14° 03′ 14.69″ ± 0.60″

and that the absorption of X-rays at the lower energies is due to interstellar absorption between the source and the observer, we can estimate the apparent magnitude of its optical counterpart. Without absorption effects, the similarity with Sco X-1 would lead to an optical counterpart of visual magnitude $V \approx 15.3$ and colour indices typical of a flat spectrum: $B-V \approx 0.1$ and $U-B \approx -0.91$. But the cutoff energy in X-rays indicates a gas density in the direction of the source

$$N_H = 2.9^{+0.9}_{-0.4} \times 10^{22} \text{ atom cm}^{-2}$$

using the photoelectric cross-section of Brown and Gould[5].

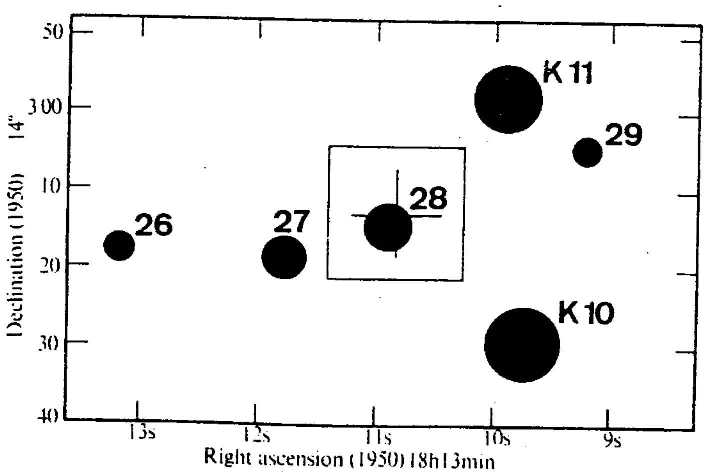

Fig. 1 The identification card of GX 17+2 shows all the optical objects visible on the Palomar Sky Survey prints in the region of