Geologische Rundschau 79/1 | 111–120 | Stuttgart 1990

Sedimentation, tectonism and volcanism relationships in two Andean basins of southern Peru

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With 5 figures

Zusammenfassung

Die Bildung der intermontanen Becken der Zentral-Anden erfolgte in der ältesten Phase der Andentektonik (Peruvia-Phase des Santons). Die Beckensedimentation wird von klastisch-kontinentalen Ablagerungen mit vulkanischen Einschaltungen unter kompressiver Tektonik bestimmt.

Die beiden Becken, die hier besprochen werden, unterscheiden sich in Alter und geodynamischen Zusammenhang:

1) Das Cusco-Sicuani-Becken aus dem Mastricht bis Paläozän ist ein Back-Arc-Becken. In diesem Becken tritt zeitgleich mit synsedimentären tektonischen und vulkanischen Vorgängen des Schüttungsgebietes die Sedimentation grobkörniger Rotsedimente ein.

2) Das Moquegua-Becken ist ein oligozänes Fore-Arc-Becken. Dieses Becken entwickelte nach einer kompressiven Phase an seiner nordöstlichen Grenze eine hohe Mobilität, die anhand von alluvialen Schuttfächern zu erkennen ist.

Die beschriebenen Phänomene der Tektonik, des Vulkanismus und der Rotsedimentation verliefen in beiden Becken zeitgleich. Dabei wird das Vorkommen der Rotsedimente nicht auf klimatische Veränderungen, sondern auf höhere Instabilität des Schüttungsgebietes zurückgeführt. Das Verhältnis zwischen Tektonik und Vulkanismus in Becken und Liefergebiet ist Inhalt dieser Arbeit.

Abstract

The intermontane basins of the Central Andes, formed from the first episode of the andine tectonic (peruvian phase, Santonian), are characterized by a clastic continental sedimentation, settled in a compressive tectonic context and containing volcanic intercalations.

The two basins presented in this paper, have distinct ages and a different geodynamic context, each:

1) The Cuzco-Sicuani Basin, Maestrichtian-Paleocene in age, is a back-arc basin. A coarse grained red bed sedimentation appeared at the same time as the synsedimentary tectonic and volcanic activity increased in the source area.

2) The Moquegua Basin, Oligocene in age, is a fore-arc basin. After a compressive phase, the northeastern border of the basin shows high mobility, characterized by superposed alluvial fans. Within the basin, the coarse grained sediments are associated with volcanic tuffs.

In the two basins, the tectonism, the volcanism and the coarse grained sedimentation occured simultaneously. The coarse grained sedimentation does not appear to be linked with climatic changes, but with the increasing mobility of the source area. The relationship between tectonic regime and volcanic activity in the basin and in the source area is considered.

Résumé

Les bassins intramontagneux des Andes Centrales, formés à partir du premier épisode tectonique andin (phase péruvienne du Santonien), sont caractérisés par une sédimentation continentale mise en place en contexte tectonique compressif dans laquelle s'intercalent des produits volcaniques.

Les deux bassins présentés ici ont des âges et des contextes géodynamiques distincts:

1) Le bassin de Couches Rouges de Cuzco-Sicuani, d'âge Maestrichtien-Paléocène est en position d'arrière-arc. Dans ce bassin, une sédimentation grossière apparaît en même temps que des émissions volcaniques sur les zones d'apport et que s'accentue la déformation synsédimentaire compressive.

2) Le bassin de Moquegua, Oligocène, est en position d'avant-arc. Aprés une phase de compression, le bord NE du bassin devient mobile, des cônes alluviaux s'y superposent envoyant au bassin de grandes quantités de matériel grossier dans lesquelles s'intercalent des tufs volcaniques.

Dans les deux bassins, la tectonique, le volcanisme et la sédimentation grossière, sont des phénomènes simultanés. Ces apports grossiers n'apparaissent pas liés à un changement climatique mais à une plus grande mobilité des zones d'apport.

Les relations entre le régime tectonique et l'activité volcanique des bassins et des zones d'apport sont envisagées.

Краткое содержание

Образование межгорных бассейнов в центральных Андах произошло при древнейшей фазе тектоники Анд (фаза Перувиа сентонского века). Тектоника сжатия, регулировала осадконакопление в этих бассейнах кластическо-материковых отложений с вулканическими включениями. Оба бассейна, исследованные здесь, отличаются по возрасту и по геодинамическим процессам:

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1. Бассейн Куско-Сикуани, возраста от маастрихта до палеозоя, является бассейном тыловой дуги. Причем в этом бассейне отлагались грубозернистые красные седименты, которые были принесены из зоны сноса, где одновременно происходили, как тектонические, так и вулканические процессы.

2. Бассейн Мокегуа является олигоценовым бассейном фронтовой дуги. У него после некой фазы сдавления появилась на северо-восточной границе значительная подвижность, которую можно установить по аллювиальным веерам отложений. В бассейне грубозернистые седименты перемешаны с вулканическими туффами.

Описанные феномены тектоники, вулканизма и отложения красных седиментов в обоих бассейнах протекало одновременно. При этом появление красных седиментов связывают не с изменениями климата, а с большой нестабильностью областей сноса. Данное опубликование посвещено описанию взаимоотношений между тектоническими процессами и вулканизмом в бассейнах и областях сноса.

The continental clastic sedimentation in intermontane basins of the Central Andes, generally controlled by compressive tectonics, is an important aspect during Uppermost Cretaceous and Lower Tertiary. In these basins, tectonism and volcanism are frequently linked together with coarse grained sedimentation.

The purpose of this paper is to give an explanation for these concomitant phenomena. So, two andean basins in southern Peru having different ages and geodynamic patterns were analysed (Fig. 1):

– the Maestrichtian to Paleocene Cuzco-Sicuani Basin in a back-arc position;

– the Oligocene Moquegua Basin in a fore-arc position.

The Fig. 2 illustrates the general tectonic and stratigraphic setting of southern Peru during Upper Cretaceous and Cenozoic times.

1. The Cuzco-Sicuani Basin

The Cuzco-Sicuani Basin is located in Southern Peru, between the towns of Cuzco and Sicuani, at the northern end of the Altiplano of Peru and Bolivia, and at the southwestern side of the Eastern Cordillera (Fig. 1). The Cuzco-Sicuani Basin, filled by Maestrichtian-Paleocene red beds, is the northernmost one of a series of highly subsiding red bed basins, known from Argentina (SCHWAB & SCHÄFER, 1976) to Peru (MEGARD, 1978; DALMAYRAC et al., 1980; CORDOVA, 1986; NOBLET et al., 1987). North of the Abancay Deflection, red bed basins of the same age, do not show such a subsidence rate.

In addition, this basin is confined by major faults trending E-W and NNW-SSE (Fig. 1).

1.1. Stratigraphic setting

The Cuzco-Sicuani red beds, conformably overlie the marine deposits of the Moho Group at Sicuani (AUDEBAUD, 1967) and of the Yuncaypata Formation at Cuzco (MAROCCO, 1971; 1978). Both lithostratigraphic units are of Albian to Turonian in age (NEWELL, 1949; KALAFATOVITCH, 1957).

Red beds are overlain by thick conglomerates of the Puno Group (NEWELL, 1949). In the Lake Titicaca region, CHANOVE et al. (1969) proved an Oligocene age for the lower part of the Puno Group on the base of charophytes. At Cuzco, any elements for dating the Puno Group have not been found. At Sicuani, there are no deposits above the red beds; the sandstones and conglomerates, belonging to the Puno Group as defined by AUDEBAUD (1967), in fact correspond to the upper part of those red beds (NOBLET, 1985).

MAROCCO (1971), MEGARD (1978), DALMAYRAC et al. (1980), assign an Uppermost Cretaceous-Upper Eocene age to the red beds of South Peru and Central Peru, which is based on charophytes and lithostratigraphic correlations. The red beds are considered to be continental sediments and accumulated in intermontane basins, formed by tectonics of the peruvian phase (roughly 80 ma) (MEGARD, 1978; NOBLE et al., 1974; DALMAYRAC et al., 1980). The recent discovery of vertebrate footprints in the upper part of the Cuzco-Sicuani red beds (NOBLET, 1985; CORDOVA, 1986; NOBLET et al., 1987) allow to revise the age of the series. Some of these footprints are tridactyl and probably could be formed by dinosaurs (NOBLET et al., in progress). In this case, the whole Cuzco-Sicuani red beds could be Santonian to Maestrichtian or Paleocene in age.

1.2. Description of the series

The whole unit is formed by red continental sediments of fluvial origin and is composed of two principal sequences (sequence I and II in Fig. 3).

The lower sequence (I)

Sequence I is 3000 m thick and consists of reddish fine-grained quartzose sandstones and red clays. The stratas are arranged in several sequences, thickening and coarsening upward and correspond to the accumulation of fluvial distal sediments in a subsiding basin. The source areas are quite remote and located somewhere in the West and in the South.

There is no evidence of magmatic activity in the source areas nore in the basin. The tectonic activity in the basin is mainly an intense subsidence.

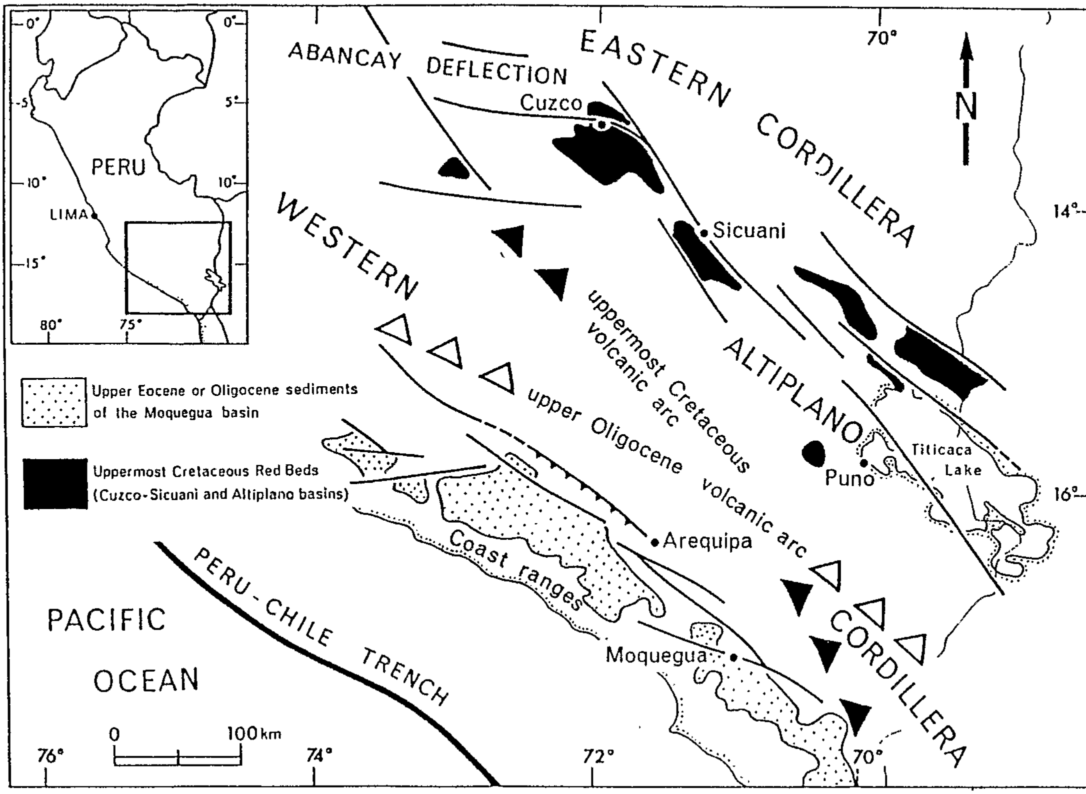


Fig. 1. Location and geodynamic setting of the Cuzco-Sicuani Basin and the Moquegua Basin in Southern Peru.

The upper sequence (II)

Sequence II is 3000 m thick and fundamentally different from the sequence I. Its lower part shows a bed of carbonates and oxides of copper having a synsedimentary origin. There are associated with abundant plant remains. The whole sequence is coarsening upward (from mainly siltstones at the base to conglomerates at the top). As the Cuzco region is probably closer to the source area, its sediments are more conglomeratic than in Sicuani.

There is a lot of evidence for volcanic activity throughout the sequence:

- microdiorite monogenic clasts associated with clastic magmatic minerals (feldspars, pyroxenes, amphiboles);
- monogenic volcanic pebbles of greenish andesite;
- brecciated volcanic tuffs.

The amount of volcanic fragments increase from the bottom to the top of the sequence. They really correspond to a contemporaneous magmatic activity and not to an anterior volcanism which supplied volcanic fragments.

The stratas of sequence II are arranged as coarsening and thickening upward sequences of minor order. Although the Cuzco-Sicuani Basin is characterized by a rapid subsidence; the vertical evolution suggests that this subsidence is less important than the sedimentation within the basin. A progradation of a very proximal fluvial system and alluvial fans is to be interpreted.

The dynamics of that sedimentation style is different from that of sequence I. The source areas are close and show high mobility.

1.3. Compressional synsedimentary tectonics of the Cuzco-Sicuani red beds

The structural analysis of the Cuzco Basin clearly establishes the presence of synsedimentary folded structures in the upper part of the red beds (Fig. 4). These structures are related to N-S, E-W and NW-SE trending fault systems. CORDOVA (1986) and NOBLET et al. (1987) determined these faults to be formed by synsedimentary movements respectivelly dextral, sinistral and reversal, resulting in a NE-SW shortening.

1.4. Geodynamic context

The analysis of the Cuzco-Sicuani red beds permits to determine two successive tectonic-magmatic patterns during Upper Cretaceous-Paleocene times. The transition between the two patterns is progressive and fast.

Sequence I (Santonian-Maestrichtian) corresponds to the beginning of the Andean uplift consecutive to the Peruvian tectonic phase (80 ma). This uplift first affected the regions close to the Pacific Ocean. From there came down a fluvial system that carried sediments to an alluvial plain which was located at the southwestern side of the actual Eastern Cordillera. In the basin, an incipient compressive synsedimentary deformation can be linked with this uplifting.

Sequence II (Maestrichtian-Paleocene) is characterized by the increase of coarse grained sedimentation in the basin, proving the vicinity of the source areas. Volcanic rock fragments dominate in the sandstones. In the basin, the accumulation rate and the synsedimentary compressive tectonic increase.

Based upon paleocurrent analysis, CORDOVA (1986) & NOBLET et al. (1987) suggest that the Eastern Cordillera did not have an important relief in these times.

The uplift of the western regions was linked to a extensional period following the compressional peruvian tectonic phase. However, VICENTE et al. (1979) & MEGARD (1984) showed that one of the main effects of this Peruvian phase was the overthrust of the andine Mesozoic western basin on its eastern foreland. The coarsening-upward and thickening-upward evolution of sequence I and II, the compressional synsedimentary deformations, and the direction of sediment transport are coherent with a compressive uplifting of the Western Cordillera.

Up to now it was admitted, that the Uppermost Cretaceous-Paleocene volcanism was localized at the Coast, forming the Toquepala volcanics (BELLIDO & GUEVARA, 1963; BELON & LEFEVRE, 1976; VATIN et al., 1982). The activity, close to the Cuzco-Sicuani Basin, on the other hand, indicates that in Maestrichtian-Paleocene times an important magmatic centre was active 350–400 km off the trench (fig. 1). In the same region (eastern borders of the Western Cordillera) an important magmatic activity occured during Upper Eocene-Oligocene (NOBLE, et al. 1985).

2. The Moquegua Basin

The Moquegua basin, located in the coastal region of Southern Peru and Northern Chile (Fig. 1), is generally considered as Oligocene. However, present studies consider the possibility of an Eocene age, for the lower part of the basin filling (MAROCCO, 1984; NOBLE et al., 1985). The northeastern edge of the basin is a NW-SE trending fault system (Fig. 1). According to the position of the volcanic arc during Oligocene, the Moquegua basin is a continental fore-arc basin.

2.1. Description of the series

The Moquegua Basin (Fig. 5) is essentially filled with fluvial, lacustrine and evaporitic sediments (the Moquegua Group). They are arranged in two separate sequences (Lower Moquegua Formation, Upper Moquegua Formation), both separated by a regional angular unconformity.

The Moquegua Group unconformably overlies different units from Precambrian (Coastal Basal Complex) to Paleocene (Toquepala volcanics). The top of the group is formed by pyroclastics (Huaylillas volcanics) of a Late Oligocene-Early Miocene age: 22 to 17 ma (BELON & LEFEVRE, 1976; NOBLE et al., 1974; TOSDAL et al., 1981; VATIN et al., 1982). The age of the basal unconformity is probably Paleocene (MAROCCO, 1984; NOBLE et al., 1985). The angular unconformity between the Lower and the Upper Moquegua Formation is considered by NOBLE et al. (1985) as the result of the 43 ma Incaïc phase. However, this unconformity can be also interpreted as the result of a 30 ma tectonic event (MAROCCO, 1984; SEBRIER et al., 1979). This last interpretation seems to be the more coherent with regard to the stratigraphic and the tectonic correlations in the Central Andes (NOBLET et al., in progress). In a recent publication, SEBRIER et al. (1988), in base on news radiometric studies realized on Bolivians rocks, suggest an age of 26–28 ma for this tectonic phase.

The Lower Moquegua Formation (Fig. 5a)

This is 150 to 300 m thick; its vertical evolution corresponds to the filling of a stable depression. From bottom to top, we note a progressive transition from coarse-grained sediments (debris flows and proximal braided rivers) to fine-grained sediments (distal braided rivers and freshwater lakes and saline lakes). This evolution constitutes a fining and thinning upward sequence. Where the Lower Moquegua Formation is thickest, two superimposed fining and thinning up-

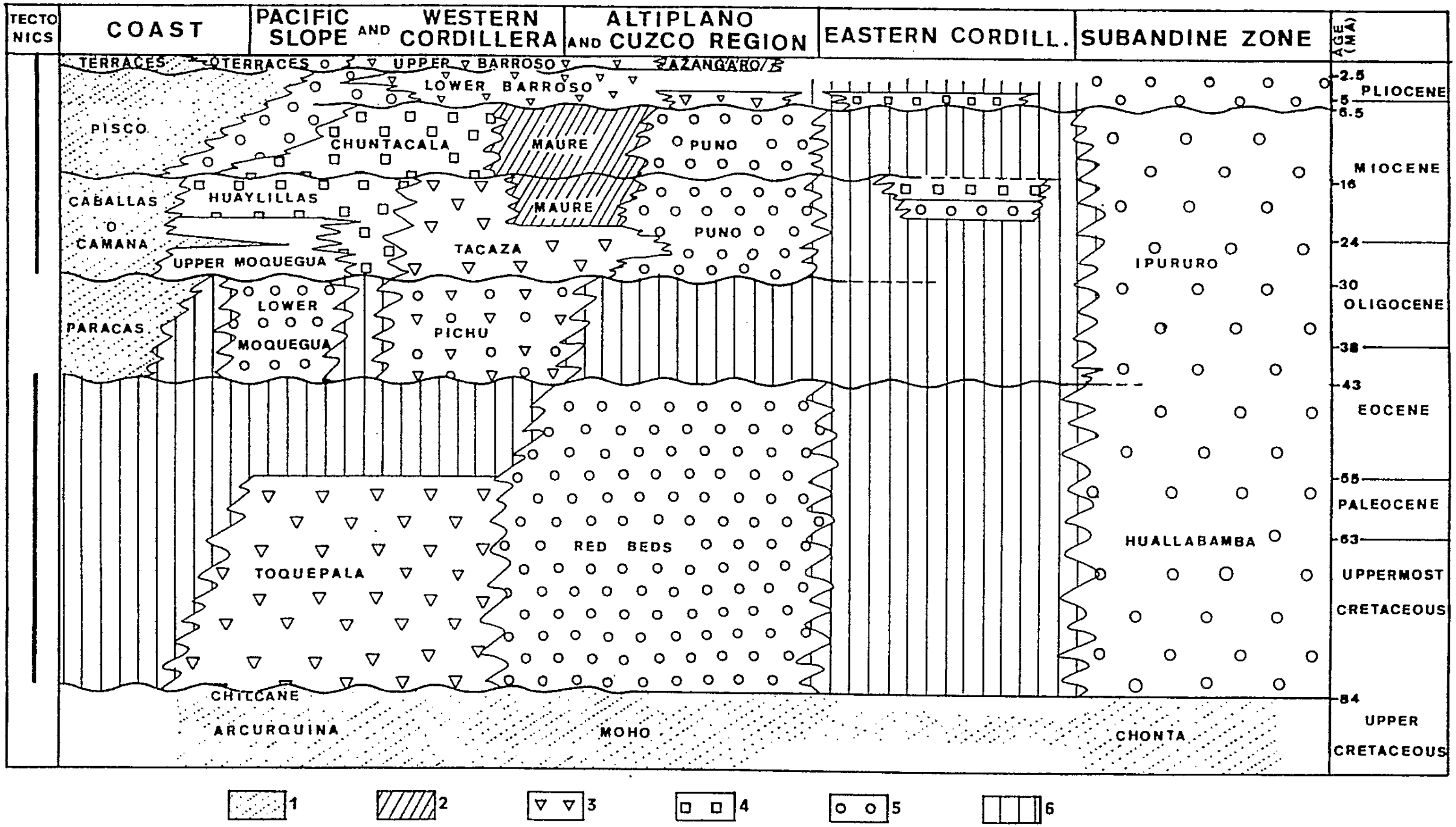


Fig. 2. Stratigraphic and tectonic correlations of Upper Cretaceous-Cenozoic times in Southern Peru. 1: Marine deposits; 2: Lacustrine deposits; 3: Volcanics (lavas); 4: Volcanics (pyroclastics); 5: Fluvials deposits; 6: Erosion or no deposition. The black vertical lines in the column »Tectonics« indicate the duration of the tectonic continuum.

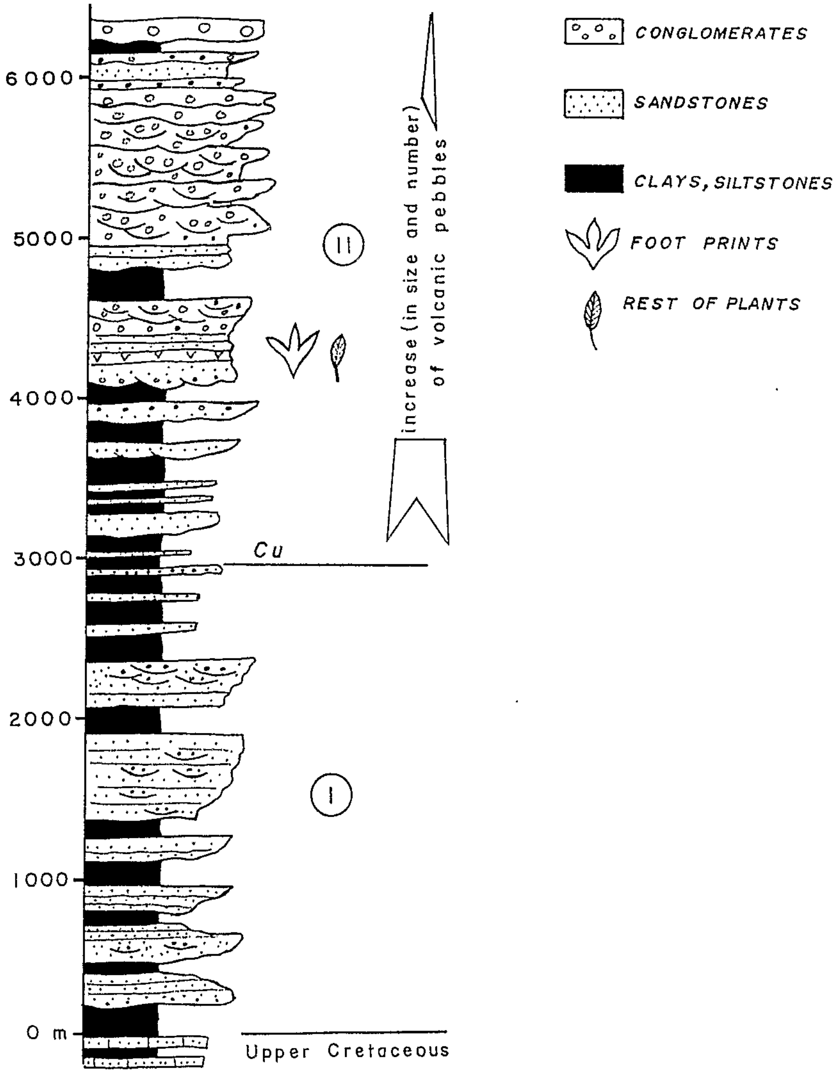


Fig. 3. Synthesized lithologic section of the Cuzco region Red Beds as compiled from different localities (after CORDOVA, 1986).

ward sequences, can be observed. They altogether indicate a pulse of subsidence in the area located close to the faults, for example in the Caraveli region (HUAMAN, 1985) and in the Moquegua region (Fig. 5d).

The Upper Moquegua formation (Fig. 5b and 5c)

The Upper Moquegua Formation overlies the Lower Moquegua Formation by an angular unconformity. Its lithology is very different as well as the sequential disposition.

In the central part of the basin (Fig. 5c), the formation corresponds to a superposition of a number of fining and thinning upward fluvial sequences. They all begin with tens of metres thick conglomerates beds and end with fine-grained lacustrine or evaporitic sediments.

In the northeastern margin of the basin, 100 to 200 m thick conglomerate beds coarsen and thicken upward (Fig. 5b). These are interpreted as alluvial fans linked to the mobility of the NW-SE trending fault system that limits the northeastern margin of the basin (MAROCCO & DELFAUD, 1985). The southwestern

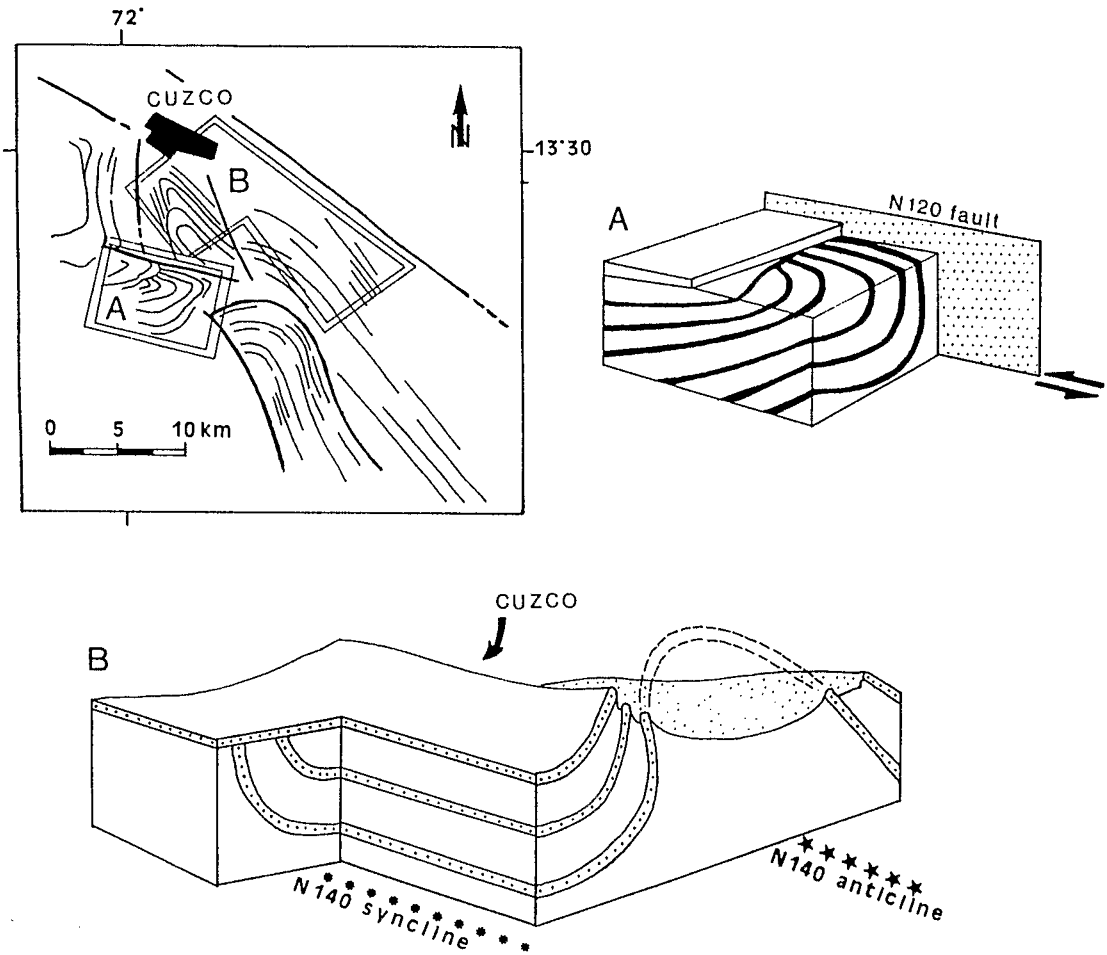


Fig. 4. Example of the synsedimentary tectonic structure in the Cuzco-Sicuani Basin.

margin is often covered by eolian deposits of the recent desertic pediment. However, along some valleys perpendicular to the basin axis (for example Rio Sihuas, Fig. 5d), the Upper Moquegua sediments reveal a decreasing granulometry from NE to SW: this margin was inactive, during the sedimentation: neither volcanism, nor tectonics, nor erosion.

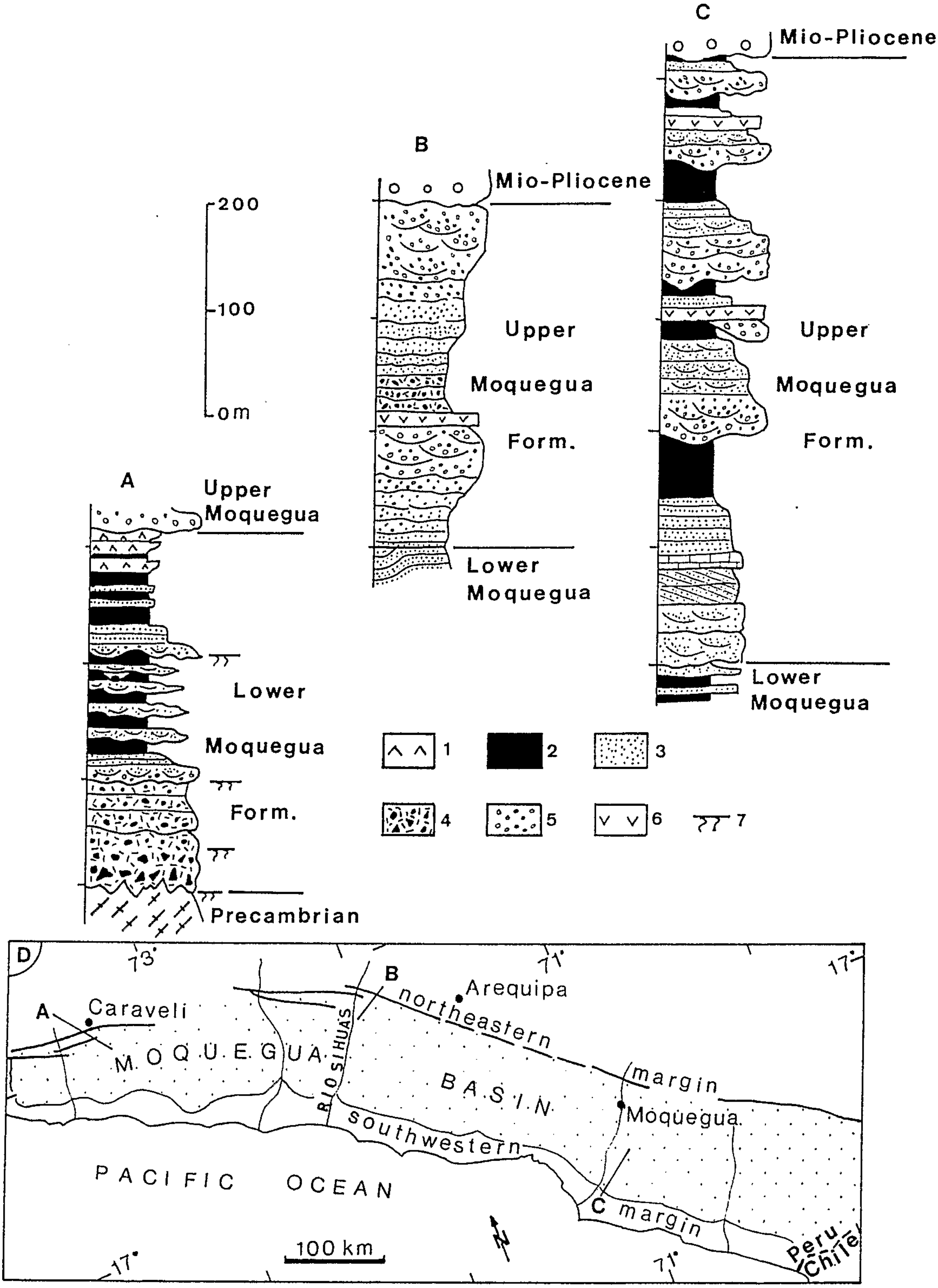
The whole unit shows evidence of an intense volcanic activity: feldspars in sandstones, floating pumices, water-lain and ash-flow tuffs. The amount of volcanic products increase from bottom to top of the formation.

In the northern part of the basin (Caraveli region), NOBLE et al. (1985) obtained K-Ar ages of 25.5 ± 1.0 and 24.5 ± 0.8 ma from floating pumices and water-lain tuff respectively. In the vicinity of Moquegua (southern part of the basin), K-Ar ages of 25.3 ± 0.4, 23.3 ± 0.4 and 22.7 ± 0.4 ma were obtained from ash-flow tuffs interbedded in the Upper Moquegua formation (TOSDAL et al., 1981).

2.2. Geodynamic context

The initial depression of the Moquegua Basin was probably formed by a Paleocene tectonic event; this depression was elongated and parallel to the pacific coast. A more or less continuous structural high (»coast ranges« in Fig. 1), separates that depression from Pacific Ocean. The geodynamic evolution of the Moquegua Basin presents two different periods.

The first period (Eocene and probably Lower Oligocene), is characterized by a lack of tectonic and



C
Mio-Pliocene
Upper
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Precambrian
1
2
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5
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73°
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B
Arequipa
A
Caraveli
northeastern
MOQUEGUA
RIO SIHUAS
BASIN
margin
Moquegua
southwestern
PACIFIC OCEAN
C
margin
100 km
N
Peru
Chile
17°
71°

volcanic activity within the basin as well as in the source areas.

The second period (Upper Oligocene), begins after the 30 ma tectonic event. The dynamics of the source area and within the basin completely changes. In the northeastern margin of the basin, a superposition of alluvial fans proves a tectonic activity of the border faults. This tectonic activity induces periodical breaks of the topographic equilibrium. Correspondingly, in the central part of the basin, the fine-grained sequences were superposed by several conglomeratic filling-up sequences (Fig. 5c).

HUAMAN (1985) showed – at least in the Caraveli region (northern part of the basin, Fig. 5d) – that the continental sedimentation of Upper Moquegua Formation was linked with a compressive stress (synsedimentary reverse faulting). In the southern part of the basin, the synsedimentary tectonic seems to be localized to the NW-SE fault system, of a probable reverse-dextral motion, that limits the basin to the northeast.

The volcanism of the source area (actual Western Cordillera, NE of the basin) began during Oligocene (Fig. 1), and increased gradually. So, the upper part of the basin infilling is constituted by the pyroclastic deposits of the Huaylillas Volcanics of WILSON & GARCIA (1962).

3. Conclusions

In the Cuzco-Sicuani Basin, as well in the Moquegua Basin there is a close relationship between tectonism, volcanism and the resulting coarse-grained sedimentation. This relationship does not constitute a rule for the formation of andean intermontane basins but is not of casual nature either. In fact, the same relationship exists in others basins of the Central Andes, for example:

- in the Eocene red beds of the southern Bolivian Altiplano (MAROCCO et al., 1987; SEMPERE verb. comm);
- in the continental Oligo-Miocene basin of Cuenca, in Ecuador (NOBLET et al., 1988);
- in the continental Rumichaca basin in Central Peru (MEGARD et al., 1983);
- in the Upper Permian volcano-clastic Basin of Southern Peru, CANDIA & CARLOTTO (1985) which emphasize the contemporaneous occurence of coarse grained continental sedimentation and volcanism;
- in the Cretaceous to Recent Rio Toro Basin of NW Argentina (SCHWAB & SCHÄFER, 1976).

The relationship between tectonism or volcanism and coarse-grained sedimentation is obvious. If the source areas are submitted to a tectonic stress, uplift occurs which induces erosion and consequent coarse-grained sedimentation in the basin. A volcanism in the source area can result in coarse-grained in the deposition of volcaniclasts in the basin.

The relationship between volcanism and tectonism is more difficult to understand. Two geodynamic regimes have been determinated from out the deposits of the basins:

- Periods of relative tectonic stability, corresponding to fine-grained sedimentation and lack of volcanism;
- Periods of tectonic mobility which correspond to coarse-grained sedimentation and volcanic activity.

The volcanic products in the sedimentary basins can only be derived from the Upper Cretaceous and Eocene or Oligocene magmatic arcs (Fig. 1). In both basins, the synsedimentary deformation corresponds to a compressive tectonic stress.

However, volcanic and tectonic phenomena must be considered in the scale of global geodynamics. So, the evolution of the andean active margin shows periods of tectonic and magmatic quietness alternating with long periods of active tectonism associated with an increase of the magmatism.

Acknowledgements

We thank the Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM) for its logistic assistance. We are grateful to D. C. NOBLE & A. LAVENU for their suggestions and criticism, to Mr. and Mrs. SOYER for correcting our English. For critical review we gratefully acknowledge the two anonymous reviewers.

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◀Fig. 5. Stratigraphic sections of the Moquegua Group (after MAROCCO, 1984). a) Lower Moquegua Formation; b) and c) Upper Moquegua Formation; d) sketch map of the Moquegua Basin with location of the sections a, b, c.
1: Evaporites; 2: Clays and fine-grained lacustrine deposits; 3: Sandstones; 4: Debris flows and mud flows; 5: Conglomerates; 6: Volcanic tuffs; 7: Paleo-soils.

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Band 79, 1990 · Heft 1, Februar 1990

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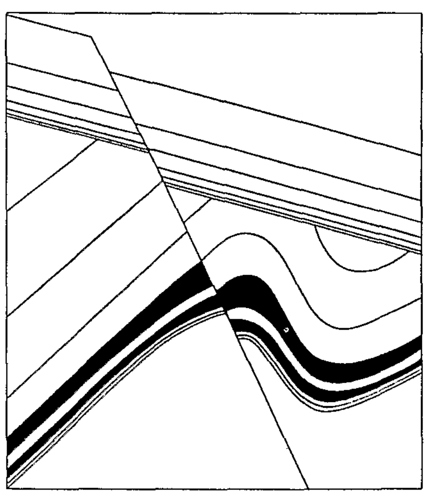
Sedimentation, tectonism and volcanism relationships in two Andean basins of southern Peru



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