GEOPHYSICAL RESEARCH LETTERS, VOL. 13, NO. 10, PAGES 1023-1026, OCTOBER 1986

ON CRUSTAL SEISMICITY OF THE AMAZONIAN FOOTHILL OF THE CENTRAL PERUVIAN ANDES

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Abstract. A microearthquake survey of crustal seismicity conducted in 1985 on the Eastern Cordillera and the Amazonian foothills in Central Peru gives a description of the present tectonic activity related to the uplift of the Andes. Hypocenters on the Huaytapallana fault are shallower than 10 km, and their focal mechanism is in agreement with the fault trace corresponding to the earthquakes of 1969 and suggests a reverse strike slip movement on a plane striking N130°. An active tectonic zone is evidenced along a NW-SE direction passing through the Amauta Subandean region. The vertical distribution of hypocenters and the comparison of shallow and deep focal mechanisms suggest a reverse fault dipping to the west. Depths vary between 0 and 20 km. and never exceed 32 km. The Huaytapallana Cordillera is uplifted by thrust faults on both sides.

Introduction

The Andean chain, south of 5°S, is considered as the classical example of a Cordillera due to oceanic-continental subduction. A characteristic feature is the absence of ophiolitic belts and of sutures due to accretion of allochtone material during Mesozoic and Cenozoic times, that is to say, during its formation. Deformations are simple, without nappes. Metamorphism is weak and calcalkaline volcanism is abundant.

Even though these properties are found all over the chain, the longitudinal structure is not uniform. Segmentation characterized by different tectonic styles, landscapes and volcanic activity, coincides with changes of the subduction slope from normal (30°) to subhorizontal.

The Peruvian Andes show subhorizontal subduction to the north of 15°S and normal to the south, and has been the subject of much recent geological and geophysical work (Megard, 1978; Dalmayrac et al.,1980; Cobbing et al., 1981;Grange et al.,1984a,1984b among others). Some open questions remain or have been raised by these papers:

-The crustal and upper mantle structure is not well known.

-The origin and mechanism of the crustal thickening is not certain.(A 70 Km. crust is proposed by Ocola and Meyer (1972) for the Altiplano).

-The nature of present crustal deformation should be given in detail.

Paper number 6L6182.
0094-8276/86/006L-6182$03.00

The latter problems are closely dependent on the knowledge of the location and mechanism of active faulting. The high Andes are subjected to a NS extension due to the compensated high topography (Lavenu et al.,1980; Mercier,1981; Sebrier et al.,1985). Seismic activity is very scarce on the Altiplano and the High Andes, even though some strong earthquakes may occur such as the Ancash event of 1946 that shows a normal fault with surface rupture (Silgado, 1951). Nevertheless, there is an exception to regional extension in Central Peru. The Huaytapallana Cordillera is higher than 5000 m. and it is bordered to the west by reverse faults that were activated during the 1969 earthquakes (Philip and Megard, 1977). Previous studies (Suarez et al.,1986) showed that most of the deformation and crustal seismicity is concentrated in the eastern part of the Andes and the Subandean region, where focal mechanisms suggest high angle reverse faulting (Suarez et al.,1983; Chinn and Isacks,1983). The orientation of the P-axis is consistent with the direction of plate convergence (Stauder,1975). Suarez et al. (1983) studied P-waveform from long period WWSSN data and obtained focal depths up to 38 Km. Hence, they proposed a model of growth of the Andes by eastward migration of reverse faulting affecting the whole crust, thus explaining crustal thickening and the active margin of the Andes overthrusting the Brazilian shield.

This paper gives some results from recent field work in the Eastern Cordillera and the Subandean region, carried out in order to obtain precise information about active faulting.

Description of the Microearthquake Survey

A field experiment in 1980 showed the approximate position of the subandean seismicity (Suarez et al.,1986). It was clear thereafter that it was necessary to set up a local network to the east of the previous one in order to have precise hypocenter control. Such a network was operational during July and August 1985 (Figure 1). Twenty short period, autonomous seismic stations were distributed, half of them over the Eastern Cordillera and the other half over the Subandean region in the jungle. They consisted in paper recorders (11 Sprengnether MEQ 800) with vertical L4C seismometers, and digital 3-component magnetic tape recorders (9 GEOSTRAS) with L22 sensors. Time signals were provided by the WWV station and OMEGA receivers tuned to Argentina. The stations located on the Cordillera had gains of 84 or 90 db, while those in the Subandes were between 78 and 90 db. It was possible to obtain good recording conditions in the Subandes in spite of the scarcity of outcrops and the abundance of vegetation.

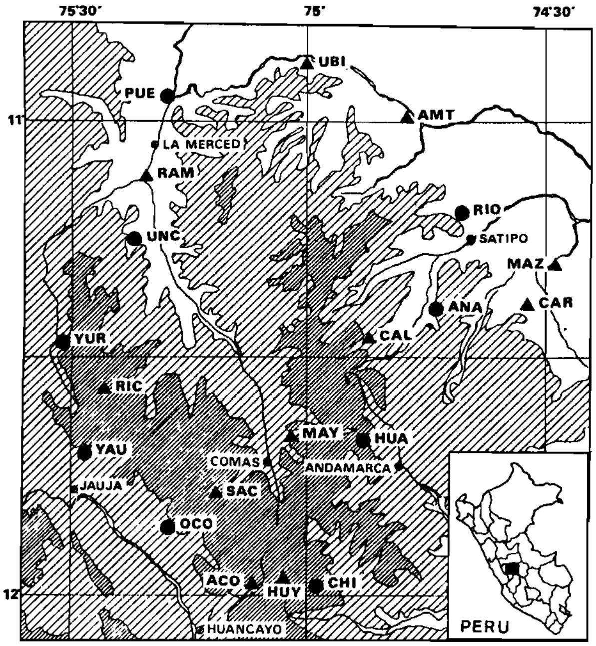

Fig. 1. General view of the network with the topography in the background. The inset shows the situation of the map within Peru. Lighter hatched lines indicate elevations between 2000 m and 4000 m, while darker regions correspond to altitudes over 4000 m. Circles are GEOSTRAS digital stations and triangles are Sprengnether MEQ 800 analog stations.

We present here partial results from analog data about crustal events recorded during a week period. Hypocenters were obtained by using the HYPOINVERSE routine (Klein,1977). Several models have been tested in order to establish the stability of results. The model (Table 1) adopted by Grange (1983) gives the smallest residuals, though other models produced rather similar values. A Wadati diagram gave a Vp/Vs ratio of 1.75 that was used to compute S velocities. Altitude corrections were significant since some stations differed by more than 4000m.

Figure 2 shows epicenters of 128 well determined earthquakes. Most of the activity is concentrated within a 30 km wide band parallel to the foothill of the Andes. No seismicity is observed further to the east. Figure 3 shows 80 events that are located with a RMS<0.4 s, calculated horizontal error ERH<10 km and vertical error ERZ<10 km. All of them have more

Table 1: Velocity Models

Mountain		Jungle	
0 km		0 km	
	6.0 km/s		6.0 km/s
25 km		20 km	
	6.8 km/s		6.8 km/s
55 km		45 km	
	8.0 km/s		8.0 km/s

Stations in the mountain:
CHI,HUY,ACO,OCO,SAC,MAY,HUA,YAU,RIC,YUR
Stations in the jungle:
UNC,RAM,PUE,UBI,AMT,RIO,MAZ,CAR,CAL,ANA

than seven arrival times with at least one S, and they are situated within or near the network. In fact 92% have ERH<5 km and 80% have ERZ<5 km. The main tectonic features of the region are taken from Megard (1978). The epicenters form several clusters, one of them on the Huaytapallana fault zone (12°S,75°W), and another one near the AMT station (11°S,74°50'W). This last cluster seems to continue to the NW and to the SE along a mapped fault zone.

Figure 4 shows three vertical cross-sections (see Figure 3 for locations) orthogonal to the structures. The Huaytapallana group is shallower than 10 km and most of the other hypocenters are between 10 and 20 km. A few shocks are located below 20 km but not exceeding 32 km. Chinn and Isacks (1983) found that most teleseismic locations of crustal events in the South American Plate had depths between 10 and 20 km. Our data do not favor the continuation of the brittle crust below 30 km. However this thickness is greater than what is usual for crustal seismicity.

Some composite focal mechanisms were obtained for these crustal earthquakes. Figure 5 gathers data for events from the Huaytapallana fault. The mechanisms of the 1969 earthquake and of its largest aftershock correspond to a reverse fault dipping to the east, with a left lateral component (Stauder,1975; Suarez et al.,1983). The fault plane and slip vector were well established by Philip and Megard (1977) and by Blanc et al. (1983) and Blanc (1984). Our solution, even if not well constrained, is compatible with their mechanisms.

A new finding is that of the Amauta cluster

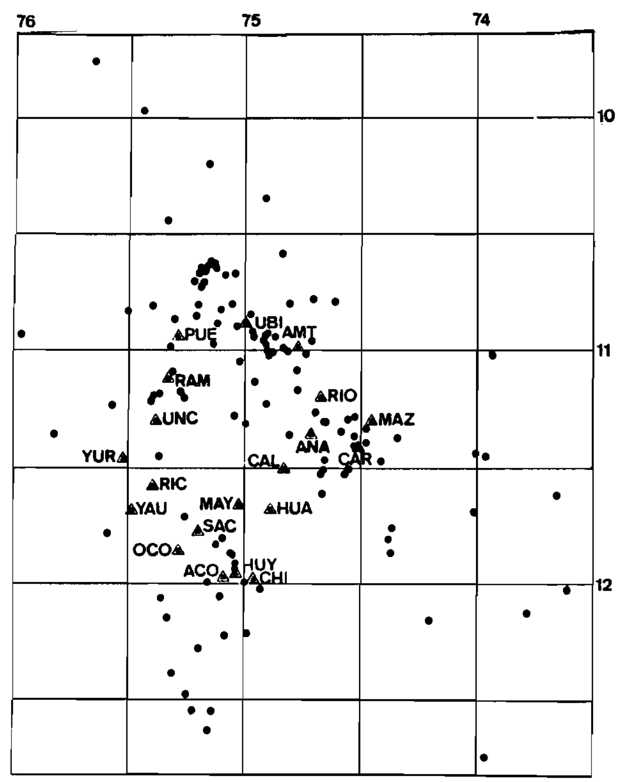

Fig. 2. Epicenters recorded during the second week of August, 1985. A hundred and twenty eight shocks with magnitudes between 0 and 3 are plotted as black dots. Triangles are seismic stations.

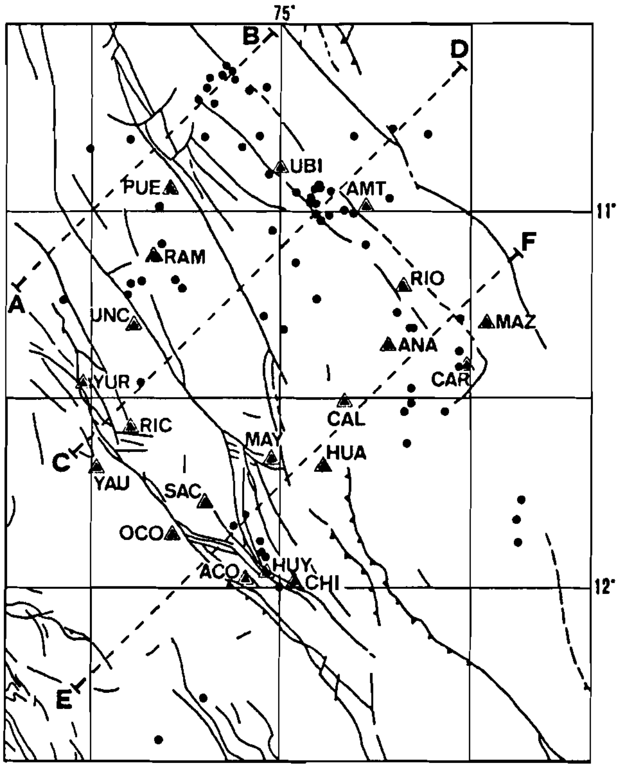

Fig. 3. Eighty best determined epicenters are shown as black dots. Triangles are seismic stations. Solid lines are faults after Megard (1978). Cross-sections A-B, C-D and E-F refer to Figure 4.

(section C-D, near the station AMT), where hypocenters lay on a surface dipping west. Special attention was given to depth control for this cluster. Each event was processed several times with fixed depths. Depths were allowed to vary from the surface down to 36 km. at 4km. intervals, and the RMS of residuals was plotted against depth for each shock. The error bars in the figure correspond to the hypothesis that arrival times may be wrong by 0.1 s.

Composite focal mechanisms were computed automatically (Udias et al. 1982) and show reverse faulting with a fault plane trending between 137°N and 153°N, if one selects the direction parallel to the local structures (Figure 6). We have separated the data into three independent groups: shallow (h<10 km.), intermediate (10<h<20 km.) and deep (20<h<32 km.). Even though the shallow events show some inconsistencies,the intermediate and deep solutions are good. The P-axis strikes between 45°N and 62°N and differs from that obtained at Huaytapallana (EW). Similar composite mechanisms were found for shocks to the NW and SE of Amauta.

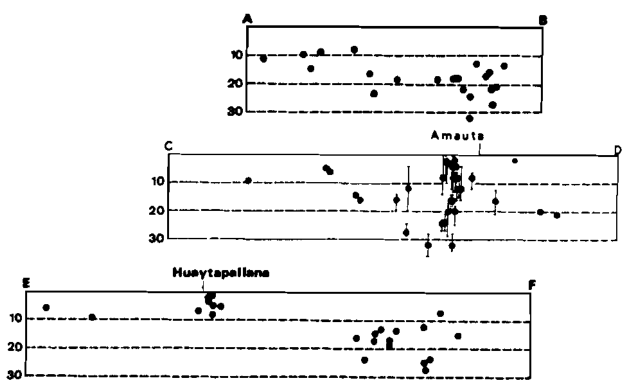

Fig. 4. Cross-sections orthogonal to the structures of Figure 3. Depth is given in km. Horizontal and vertical scales are equal. Error bars in the Amauta cluster take into account nonlinearity in the calculations.

Conclusions

Present crustal tectonic activity observed in the Andes is mainly confined to the Subandean region. Preliminary results based on 128 well located microearthquakes in this region show that seismicity is important and forms clusters that align themselves in the direction of some of the mapped faults. No events were observed to the east of the Amauta active zone, even though our network was able to detect them.

Depths of hypocenters related to the Huaytapallana fault are shallow (h<10 km). The Amauta cluster shows depths shallower than 32 km, and the foci lie on a surface dipping to the west. Most other hypocenters lie between 10 and 20 km and only a few fall below 20 km but never exceeding 32 km. Thus the brittle region of the crust does not seem to be as thick as thought before.

A composite focal mechanism for the Huaytapallana events is consistent with the solutions proposed for the strong 1969 shocks, with a fault plane oriented 142°N and dipping 50° to the east. The composite focal mechanisms obtained for the Amauta events correspond to a reverse fault with azimuth between 137°N and 153°N and dip between 34° and 43°.

The direction of the fault planes is parallel to the local Andean structures, and the pressure axis varies between 60°N and 90°N hence being close to the direction of plate convergence (80°N at this latitude).

The Huaytapallana Cordillera is bounded to the west and to the east by active reverse

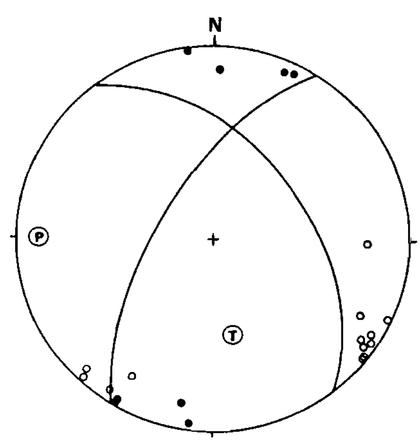

Fig. 5. Composite focal mechanism of the Huaytapallana events (Schmidt projection). Open circles are dilatations and solid ones are compressions. The pressure (P) and the tension (T) axis are indicated. The fault plane has a strike of 142°N, it is compatible with that of the 1969 strong earthquake, and it dips 50° to the east. It has a small left lateral component.

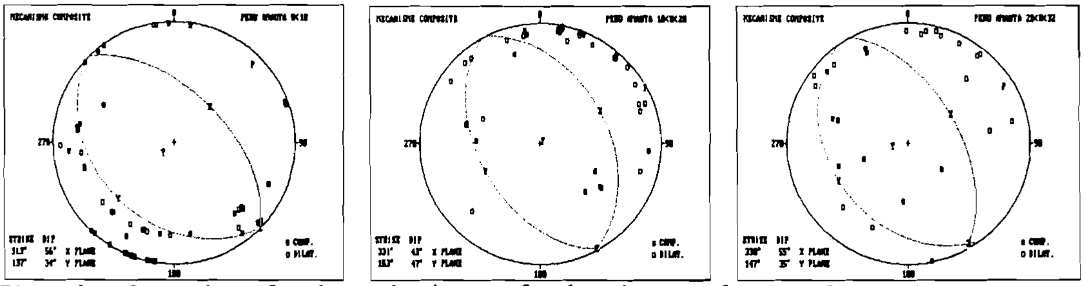

Fig. 6. Composite focal mechanisms of the Amauta cluster. Conventions are as in Figure 5. Fault planes (Y Planes) are chosen along faults shown in Figure 3. Earthquakes are divided into three classes according to depth.

faulting. It follows then that it is thrusting at the same time over the Brazilian shield and over the Huancayo basin. This observation explains its relief above the neighbouring mountains. An alternative view point is to consider the Huaytapallana Cordillera as a pressure ridge generated by a deflection of the left lateral Huaytapallana strike slip fault (Blanc et al., 1983).

Acknowledgements. We wish to thank the help we received during the field work from M. Chang, O. Veliz, L. Ponce, J. Tavera from the Observatorio Geofisico de Huancayo, J. Berrospi from ORSTOM, H. Arjono and A. S. De Bievre from Orsay. This research makes part of a French-Peruvian Cooperation Project.

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(Received May 8, 1986;
revised August 20, 1986;
accepted September 1, 1986.)