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Subduction geometry in central Peru from a microseismicity survey: first results

Ruben Lindo [a,c], Catherine Dorbath [b,c], Armando Cisternas [c], Louis Dorbath [b,c],
Leonidas Ocola [a] and Miguel Morales [a]

[a] *Instituto Geofisico del Peru, Apartado 3747, Lima 100, Peru*
[b] *ORSTOM, 213 Rue La Fayette, 75480 Paris Cedex 10, France*
[c] *Institut de Physique du Globe de Strasbourg, 5 Rue René Descartes, 67084 Strasbourg Cedex, France*

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ABSTRACT

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Preliminary results from a seismic survey done over the coastal region of Central Peru from April 7 to May 22, 1986 and from previous surveys (1980, 1985) are presented. The synthesis of these three data sets permits an accurate study of Central Peru, starting from the coast, across the Altiplano and into the Subandean region. The Wadati-Benioff zone is geometrically well constrained. Subduction near the trench dips at 30° down to a depth of 100 km and then it changes to subhorizontal. Seismicity is noticeable below the western zone but is scarce beneath the Altiplano. Crustal activity in the Subandean region is clearly established.

Introduction

The uplift of the Central Andes is in close relation with the subduction of the Nazca Plate beneath the South American continent. It has been shown (Kausel and Lomnitz, 1968; Jordan et al., 1983) that the changes in tectonics along the Andean chain correspond to changes in the geometry of the subducted plate. A segmented view of the Andes was thus possible, with normal (30°) subduction under regions with central valleys and volcanic alignments, and subhorizontal subduction below regions without volcanoes.

Several studies were devoted to determining the geometry of the Wadati-Benioff zone in Central Peru, where active volcanism is absent. Barazangi and Isacks (1976, 1979) used data from ISC catalogs, carefully screened through rigorous criteria, and proposed a model where shallow subduction dips with a constant 10° angle to the east. Later on, James (1978) and Hasegawa and Sacks (1981) from the Carnegie group, using data from a local network (in Peru) and converted phases such as ScSp from teleseismic events, concluded that the slab has a 30° dip down to a depth of 100 km, then it bends and continues at a nearly horizontal angle. A French–Peruvian–American expedition (Suarez et al., 1990) monitored the seismic activity in the Altiplano and the Eastern Cordillera of Central Peru in 1980, and described a quasi-horizontal subduction below their network, thus favoring the model of the Carnegie group, but without control of the seismicity near the trench, below the coastal region and the western Cordillera.

Another French–Peruvian joint experiment performed in 1985 (Dorbath et al., 1986), extended the observations of Suarez et al. (1990) towards the east into the Subandean zone, and continued this work towards the west in 1986,

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Correspondence to: R. Lindo, Instituto Geofisico del Peru, Apartado 3747, Lima 100, Peru.

into the coastal region of Central Peru, in order to determine with precision the geometry of the subducting slab and its implications on the tectonics of the Peruvian Andes.

The present work describes preliminary results of the 1986 survey, taking advantage at the same time of the previous knowledge and data sets already obtained during the expeditions of 1980

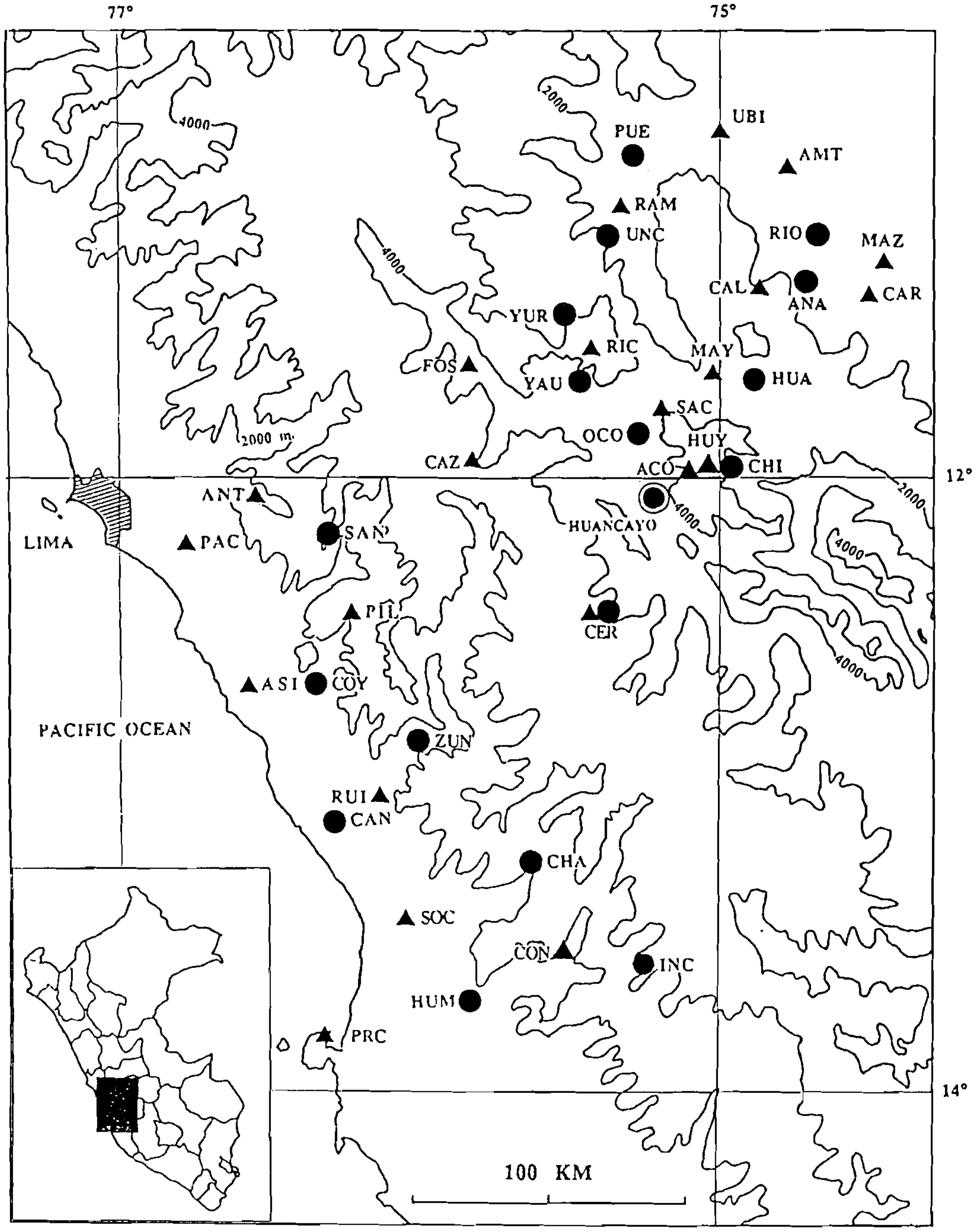


Fig. 1. Topographic map of the area under study and general view of the networks corresponding to the surveys of 1985 and 1986. The inset shows the situation of the map within Peru. Closed circles and triangles are GEOSTRAS digital stations and Spregnether MEQ-800 analog stations, respectively. The network of 1986 was at the Coast, the Western Andes and the Altiplano.

and 1985. In particular, it was possible to incorporate the accurate data from the different surveys into a single, self-consistent file. Thus, we are able to construct a very precise seismic traverse starting from the coast, going across the Altiplano and into the Subandean regions.

Data acquisition and hypocenter locations

A microseismicity survey of western Central Peru has been performed from April 7 to May 22, 1986 with a local network (Fig. 1) of 19 short-period, autonomous seismic stations. Eleven of them were smoked-paper Sprengnether MEQ 800 recorders with vertical MARK PRODUCTS L4C seismometers, and the remaining were 3-component magnetic-tape GEOSTRAS digital recorders with L22 sensors, the signals from the latter being digitized using a sampling rate of 150 sps. The analogue stations had gains ranging from 78 to 96 db depending on the sites, the typical value being 84 db. The filters were set up from 0 to 30 Hz except for those few stations situated next to the coast where a 5-30-Hz filter was necessary to eliminate microseismic noise. Timing was provided by the WWV signals entered every two days on the analogue records, together with internal time marks recorded every second. Accurate time on digital stations was provided by the global Omega system. The drifts were linear and smaller than 0.05 s per day. The uncertainties in picking P and S arrival times were 0.02–0.05 s for the digital stations and 0.2–0.5 s for the analogue stations, respectively.

We located hypocenters using an algorithm of direct searching. Our approach is comparable to Nelson and Vidale's (1990) algorithm but the subroutine that computes theoretical travel times comes from the HYPOINVERSE computer program (Klein, 1978). Our program works in two steps: during the first one, the searching is done on a coarse grid of trial hypocenters below the network in order to find the node of the grid where the mean quadratic residual is minimum; the second step consisted in defining a finer grid around this first location, the process being repeated. We selected grid dimensions of 5 and 1 km, respectively.

TABLE 1

Velocity model

Velocity (km s^{-1})	Depth range (km)
Model 1	
6.0	00.0–30.00
6.8	30.0–65.00
8.0	> 65.0
Model 2	
6.0	00.0–25.00
6.8	25.0–55.00
8.0	> 55.0
Model 3	
6.0	00.0–20.00
6.8	20.0–40.00
8.0	> 40.0

The estimated origin time T_{org} is assumed to be:

$$T_{org} = \frac{1}{N} \sum^{N} (T_{obs} - T_{calc}), \tag{1}$$

where T_{obs}, T_{calc} and N are respectively the real arrival time, the calculated travel time and the number of observations (see Nelson and Vidale, 1990).

We have performed simple tests with synthetic data to which random (gaussian) noise with a standard deviation of 0.1 s has been added. The computed errors were lower than 2.5 km in hypocentral location, 0.25 s in origin time, and RMS values were lower than 0.1 s for typical events.

Since the velocity model in Central Peru is not well resolved due to the absence of refraction profiles in the region, we used one similar to that proposed by Grange et al. (1984) in Southern Peru (see Table 1). The model uses three different velocity structures in order to simulate the Moho variations across the network.

The magnitude for each earthquake was calculated from the duration of the coda, and for convenience we used the coefficients of the magnitude formula that were established in Alaska in a quite similar geodynamical region (Lee and Wetmiller, 1976). The events used in this paper have magnitudes ranging from 1.8 to 4.5.

Results

A synthesis was made of the results obtained from the 1980, 1985 and 1986 surveys, and 200 earthquakes with RMS values inferior or equal to 0.4 s were selected. Figure 2 shows the epicentral distribution of these events, and we notice two dense linear clusters of epicenters between the trench and the coast, and separated by a gap. Such a pattern has been already noticed by Grange (1984) and by Comte et al. (1992- this issue) in other sectors of the coastal region of South America. The cluster located near the coast is particularly active under Lima at more than 50 km depth, the other one is concentrated in the south at a depth smaller than 50 km. The clusters and the gaps around them seem to be real, since our location algorithm samples the space of all possible solutions.

Seismicity below the Altiplano is not as important as that of the western zone. Even though this might be attributed to the heterogeneity of the data from different surveys there are reasons to think that it is a real effect. In fact, similar configurations had already been obtained from teleseismic events (Isacks and Barazangi, 1977) with more homogeneity in space and time though with less precision than in the present work. In addition, no recent strong earthquake has been located in this region.

A general cross-section normal to the trench is shown in Figure 3, on which the trench is marked by the letter T. The slab dips at approximately 30° near the trench and then it changes slope to a subhorizontal one at a depth of about 100 km. Activity is still present at the place where the curvature changes. There is a gap beneath the Eastern Cordillera and then the slab possibly goes down as shown by Hasegawa and Sacks (1981). Crustal activity is related to important reverse faults of the Subandean region (Dorbath et al., 1990).

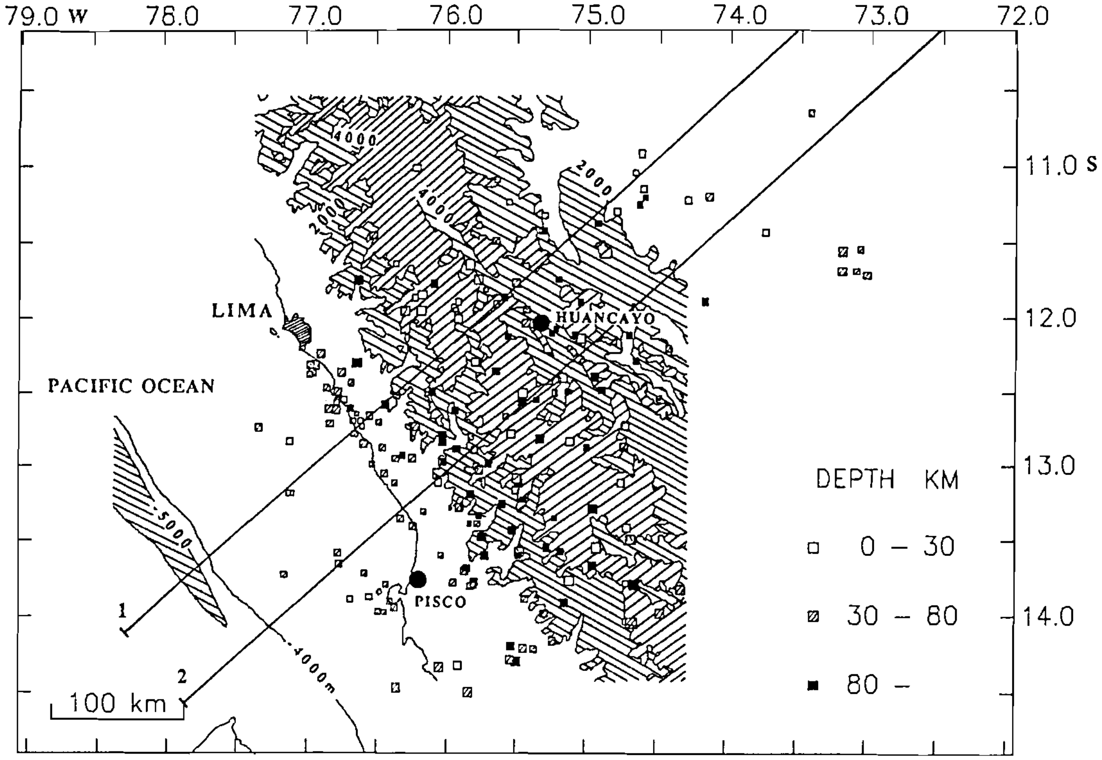


Fig. 2. Epicenters of 200 earthquakes recorded during the fields experiments of 1980, 1985 and 1986 (not all). The size of squares indicates the magnitude. The lines show the sections of Fig. 4. Continuous lines show the 2000 and 4000 m topographic contours of the Central Andes. Trench topography is also shown.

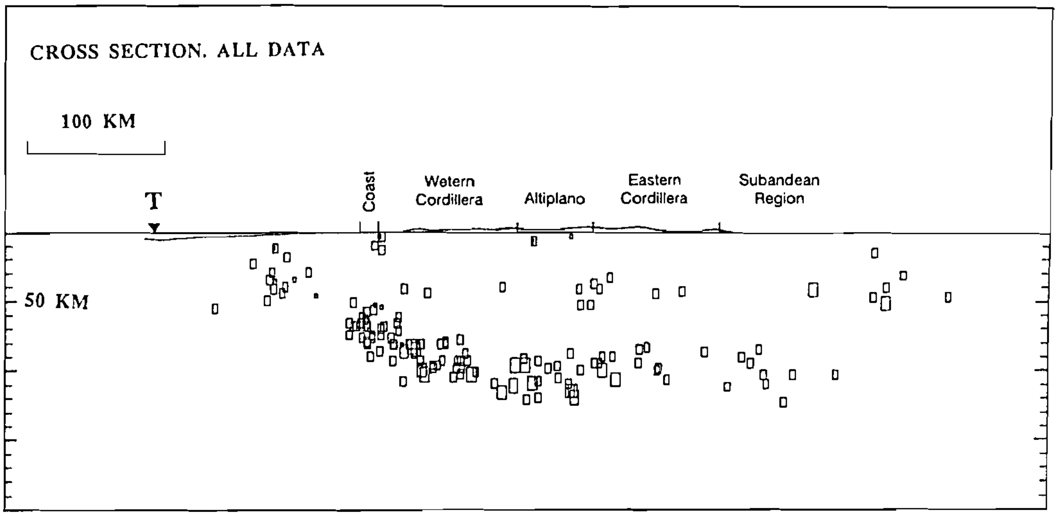
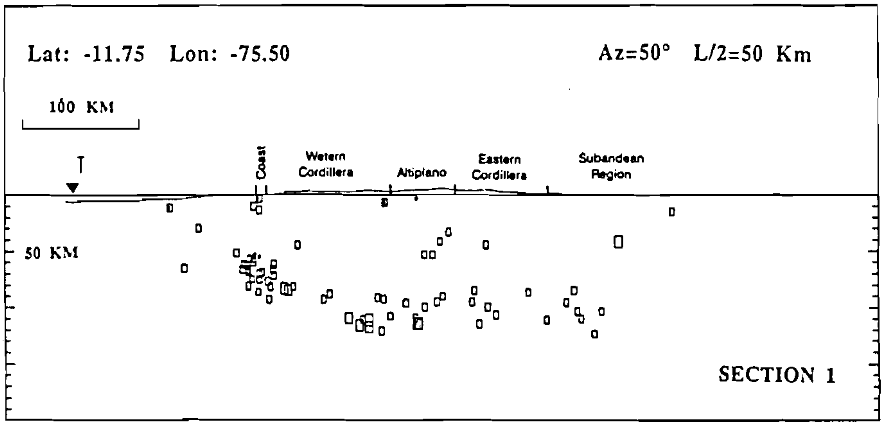


Fig. 3. Transverse composite of all events in Fig. 2, perpendicular to the trench. The trench is marked by *T*. Morphologic structures in Central Peru are also indicated.



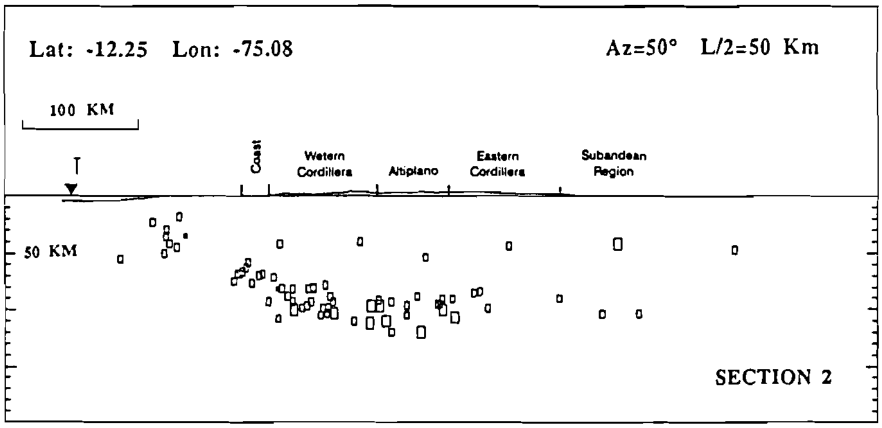


Fig. 4. Cross-sections 1 and 2 (see fig. 2) of well-located earthquakes. The geographic coordinates belong to the cross-section center. *T* indicates the position of the trench. Az and L/2 are the azimuth and half-width of the cross-section, respectively.

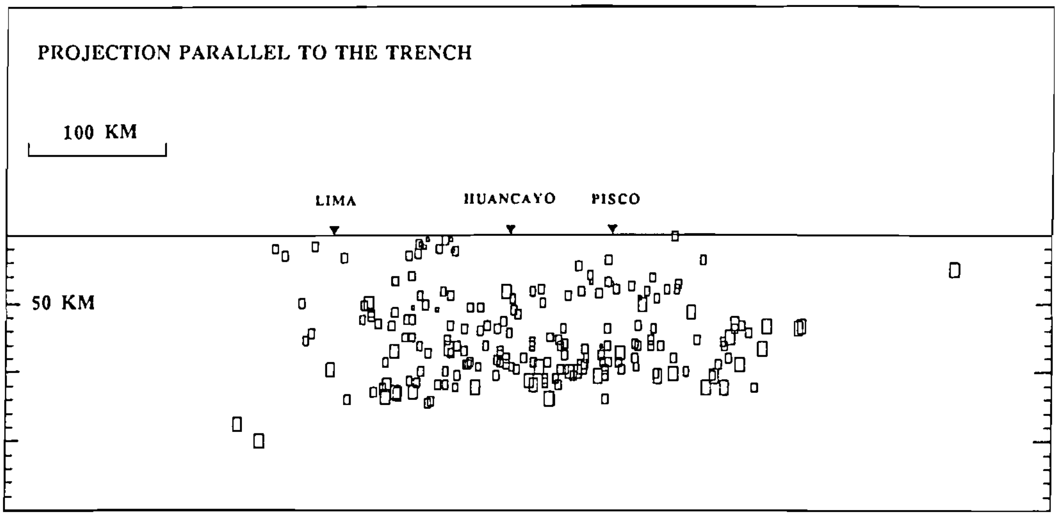


Fig. 5. Section parallel to the trench for all events in Fig. 2. Seismicity is present down to 100 km approximately. Two hypocenters with depths of about 140 km are present here but not in Fig. 3 because of the different regions sampled by the projections.

Figure 4 shows two cross-sections, perpendicular to the trench, the axes are 70 km apart and the semi-width is 50 km. Even though there is an overlap between the neighbouring sections, we may conclude that they reflect the rather precise geometry of the subhorizontal subduction and their lateral homogeneity. The geometry of the Wadati-Benioff zone is uniform and well established by data that is more precise than that of previous studies. We also observe well-defined crustal activity at intermediate depths. A cross-section parallel to the trench (Fig. 5) shows that seismicity occurs down to 100 km approximately and that is quite well distributed all along the orientation of the structures.

Conclusions

Seismicity from the 1980, 1985, and 1986 (partially) surveys in the Central Andes has been analyzed and preliminary results were presented. An accurate seismic traverse has been constructed across Central Peru, going from the desertic coastal region (Lima to Pisco) towards the northeast into the Altiplano (Huancayo to Jauja) and down to the Subandes and the jungle (San Ramon, Satipo). The geometry of the Wadati–Benioff zone is continuous and uniform in this region. The subduction starts under the trench and dips at 30° approximately up to a depth of 100 km. Then it changes to subhorizontal as far as the Subandean region. Seismicity near the coast forms elongated clusters; it is scarce beneath the Altiplano region; crustal seismicity is also associated with reverse faults of the Subandean region.

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