SEISMOTECTONIC FEATURES OF THE WADATI-BENIOFF ZONE IN THE ANDEAN REGION

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INTRODUCTION

The interaction among the South American and Nazca plates forms one of the most typical Wadati-Benioff (W-B) zones existent on Earth. However, a detailed examination of that zone shows some peculiarities that cause controversies in the interpretation of its own structure, both in depth and laterally, and in the satisfactory explanation of some related phenomena, such as the origin and the mechanism responsible for the deep earthquakes in South America, among others. Some seismotectonic features of the W-B zone in the Andean region, based on the spatial distribution of hypocentres of selected earthquakes and the space-time distribution of the deep earthquakes, are presented with the purpose of contributing in the solution of some of the controversies mentioned above.

The data used in this work have been selected from the International Seismological Centre (ISC) Bulletin Data Base (BDB) CD-ROM, for the time interval January 1964 - August 1987, and from the Global Hypocenter Data Base (GHDB) CD-ROM, for the periods earlier than 1964 and after August 1987 up to December 1988. This data was complemented with hypocentre data contained in magnetic tapes furnished by the National Earthquake Information Center (NEIC/USGS), of earthquakes occurred up to June 1990. The selected earthquakes for the present work were past through a selection procedure using as reference the method of Barazangi & Isacks (1979). From a total of 9132 earthquakes with $m_b \geq 4.0$ compiled from those catalogues, only 2236 (24%) were selected as hypocentral determinations of good quality to be used in this work.

RESULTS

The spatial distribution of the selected hypocentres is made through epicentral maps and profiles corresponding to portions of the Andean region with the seismic foci projected into vertical sections that follow the assumed direction of the Nazca plate subduction. These projections clearly show several known seismotectonic features of this W-B zone, as for instance the flat portions of W-B zone located at around 30°S in Central Chile/NW Argentina and in Central/Northern Peru and the absence of seismic activity among 300 and 500 km of depth, as discussed in Barazangi & Isacks (1976, 1979), James (1978), Hasegawa & Sacks (1981), Boyd et al. (1984), Smalley & Isacks (1987), among others.

The seismic sections also show some evidences of a twisted W-B zone, specially beneath the Peru-Chile-Bolivia-Argentina borders region, as shown by Schneider & Sacks (1987), and the existence of some probable lateral discontinuities between portions of the W-B zone, that have different behaviour.

This can be seen in the sections for the portion 25°S-32.5°S where the flat slab in Central Chile does not seem to correlate with the deep earthquakes of NW Argentina. The continuity of the slab in depth is more evident in the sections corresponding to the portion 20°S-25°S. The last sections suggest the presence of two kinds of slab with different characteristics: 1) a 25 km thick slab dipping from the trench with an angle of near 20° down to a depth of no more than 150 km, as a continuation of the slab portion near the trench in Central Chile, and 2) a 40 km thick slab dipping with an angle that increases from 30°, near the trench, to almost 45° at 300 km of depth, that apparently continues dipping through the aseismic gap, up to meet the deep focus earthquakes. These features suggest the existence of a lateral discontinuity that begins near the Arica elbow and passes through the southern extreme of the deep earthquakes epicentral area in NW Argentina as proposed by Berrocal (1974). The transverse sections in the other portions of the Andean region do not show conspicuous profiles of the W-B zone, specially in the northern latitudes.

The longitudinal S-N section shown in Fig. 1, permits to correlate the deep earthquakes with features of the slab suggested by the spatial distribution of shallower seismicity, mainly in the central portion of the Andean region, suggesting the continuity of the W-B zone, both in depth and laterally. The depth of the W-B zone gradually increases from around 50 km in its southern extreme (45°S) up to depths of the order of 200 km at 27.5°S. Then comes a gap of intermediate depth activity in 27.5-26°S, followed by a decrease on the depth of the slab to around 100 km up to 25°S. The characteristics of the W-B zone following to the north, clearly change between 25°S and 24°S. Here the seismic activity gets deeper, going rapidly from 150 km to almost 300 km of depth at 23°S. This block of the W-B zone, located beneath northern Chile and southern Peru, is extended up to latitude 14.5°S and seems to correlate well with the almost S-N oriented Southern Segment of deep earthquakes located in northern Argentina and southern Bolivia, as shown in Fig. 1. That interpretation suggests that the Nazca plate subducting between 23°S and 14.5°S, is being twisted relatively to the South, in such an amount that the deep extremes of this portion of the slab are beneath latitudes 29°S and 17°S, respectively. This interpretation may explain the suggested existence of two different slabs in Northern Chile.

After 14.5°S the seismic activity gets shallower from 250 km to around 100 km of depth and increases a little up to around 150 km just to the North of 10°S. This forms a block of the W-B zone beneath Central Peru that seems to correlate with the Central Segment of the deep portion of the slab with scarce seismicity, where occurred the M_w 8.3 deep event of June 1994 under the Peru-Bolivia border region. The surface projection of the Central Segment of deep earthquakes follows the SE-NW direction, suggesting that the slab is still twisted to the South, in a smaller amount than the southern portion, but bent to the NW. Then come a small gap of intermediate depth activity followed by a sudden increase of activity among 150 and 200 km of depth beneath 9°S that keeps constant until around 1°S, where it ends abruptly, with the slab bent northwards. That forms another block of sallower activity that can be correlated with the Northern Segment of deep earthquakes located between latitudes 11°S and 1.5 °S, beneath the Peru-Brazil border region and southern Colombia. The Northern Segment of deep earthquakes is fairly active only in its southern portion, between 11°S and 6.5°S, then follows a large inactive portion up to its northern extreme where have occurred the M_w 8.2 deep earthquake of July 1970 and other two large deep events, in 1911 and 1922. This portion of the W-B zone related to the Northern Segment of deep events is less twisted to the South than the portions related to the Southern and Central segments of deep earthquakes, specially its northern extreme.

The space-time distribution of deep South American earthquakes (h>500 km), using all data existent in the catalogues mentioned above covering the interval from 1911 to present, shows that consistent data for this type of events exists only since the 1960's. The three segment of deep earthquakes are evident in the latitude/time distribution, showing the following peculiarities: 1) the activity in terms of the number of events, is higher in the Southern Segment and very low in the Central one; 2) the southern portions of the Southern and Northern segments of deep earthquakes are the most active within each segment; 3) the activity in the portion between 27°S and 29°S is continuous along the last 35 years, whereas the other portions of deep earthquakes present large periods of inactivity, some of them of several years; 4) the activity in the northern portion (18°S-22°S) of the Southern Segment has increased from six events in the interval 1960-1980, to ten events in the last 15 years; and 5) the scarce activity in the Central Segment increased from three earthquakes occurred in 1958 (2 events) and 1969 (1 event) to

three important earthquakes occurred in the last two years, including the M_w 8.3 deep event of June 1994 and its aftershocks.

Time correlation between reliable hypocentral determinations for deep South American earthquakes is possible for events occurred since 1964. There is a clear correspondence among events in the Southern Segment with the earthquakes of the Northern Segment suggesting an interchange of energy from south to north, that during the 1964-1968 period use to occur with an interval of a few days to a few weeks. During the second half of 1968 that interchange suddenly stopped, the deep activity in the Northern Segment also stopped, a few months later occurred in the Central Segment of deep earthquakes an unusual event at around 13°S in the Peru-Bolivia border region, and the suggested flux of energy apparently inverted its direction, modifying completely the seismicity behaviour in the Southern and Northern segments, in relation to that observed in the 1964-1968 period. After this inversion, that lasted up to the end of 1969 or beginning, the M_w 8.2 deep earthquake of July 1970 occurred in southern Colombia. It was a milestone event in South American seismotectonic activity, because its occurrence was preceded and followed by clear changes in the seismic behaviour of the entire deep portion of the W-B zone beneath the Andean region, but specially in the Northern Segment, that presented very low rates of activity up to the end of 1982.

During the last five years, deep activity in South America has been very high, reaching very unusual rates, including the Central Segment. This, together with the changes occurred before and after the July 1970 deep event in the northern extreme of the Northern Segment, and the probable time correlation between the events of the Southern and Northern segments of deep earthquakes in South America, suggests the lateral continuity of the slab under the central portion of the Andean region.

CONCLUSIONS

The space-time correlation of deep South American earthquakes, and its apparent correlation with shallower seismic activity in the W-B zone, beneath the central portion of the Andean region, suggests the continuity of the slab, both in depth and laterally, in the central portion of that region. They also suggest the slab being twisted to the South, with more intensity in its southern deep extreme and almost nothing in the northern extreme, with its central portion bent to the West. This new model of the W-B zone under the Andean region may help to solve some of the existent controversies.

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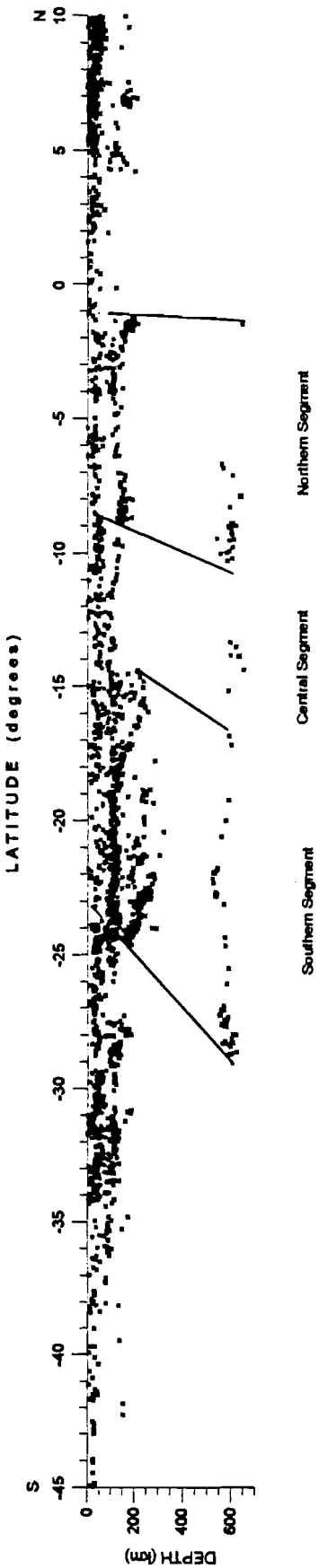

Figure 1.- South-North longitudinal section of Andean seismicity, showing only selected hypocentres in the time interval 1964 - 1990, except for the Central Segment where are included the deep earthquakes occurred after 1994.