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A shallow double seismic zone beneath the central New Hebrides (Vanuatu): evidence for fragmentation and accretion of the descending plate?

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Abstract. A shallow double seismic zone (SDSZ) has been found in the descending Australian plate beneath the central part of the New Hebrides island arc, directly above a large gap in intermediate depth seismicity and between two seismic boundaries. Ambient seismicity occurs mostly in the upper part of the SDSZ, while earthquakes in the lower part occur in clusters (swarms or aftershocks of large earthquakes). The distance between the upper and lower levels of the SDSZ is 50-70 km, and they are joined at 80 km depth by a near-horizontal band of seismicity. Thrust-faulting mechanisms predominate for earthquakes in the upper level of the SDSZ. Those in the lower level, however, appear to be normal faulting, despite their being aftershocks of large thrust events. We suggest that with the absence of a pull from the detached lithosphere the upper part of the Australian plate in the region of the SDSZ is resistant to subduction, and thus the downward displacements caused by large earthquakes in the adjoining regions result in a localized rebound. The location of the aftershocks within the plate suggests that a new plate boundary is forming, which will eventually replace that outlined by the residual seismicity in the upper level. Thus the leading edge is decoupling , and the boundary will eventually shift back to the lower level of the SDSZ.

Introduction

On a regional scale, the New Hebrides Wadati-Benioff zone appears uniform down to a depth of about 300 km [Dubois, 1971; Isacks and Molnar, 1971; Pascal et al., 1978]. However, the central part of the arc between about 16.5°S-17.5°S contains several peculiar features. First, earthquake locations from both worldwide [Pascal et al., 1978] and local [Marthelot et al., 1985; Prévot et al, 1991] networks show a sizable gap in the intermediate depth seismicity of the Wadati-Benioff zone. Previous authors have interpreted this feature as evidence of a detachment of the lower part of the downgoing slab [Chatelain et al., 1992,1993; Choudhury et al., 1975; Louat et al., 1982; Pascal, 1973, Pascal et al., 1978]. Second, there appear to be strong lateral variations in seismicity, characterized by two barriers to aftershock development by Chatelain et al. [1986] (Figure 1). Third, there are a number of anomalous surface features in this region: a seamount is heading toward the trench near 17.2°S, and the strike of the trench changes from nearly N-S to NNW-SSE. The trench itself becomes less well defined north of this region.

An additional anomalous feature discussed in this paper is the clustered seismic activity (i.e., swarms and aftershocks of main events) which, along with the ambient seismicity of the region, makes up a shallow double seismic zone (SDSZ) in the upper 80 km of the lithosphere. We suggest that this SDSZ is a result of the fragmentation of a portion of the downgoing Australian plate which, because of detachment, has lost the pull of the lithosphere that preceded it. The upper level of the SDSZ is thus the residual activity of an old, nearly defunct plate boundary, while the lower level outlines a new boundary where the leading edge of the Australian plate is presently breaking off and rebounding to the surface. The decoupled fragment will perhaps be accreted onto the Pacific plate as an ophiolite.

Data and Observations

A network of 19 telemetered seismograph stations (Figure 1) was operated from 1978-1990 in the New Hebrides as a joint project between the Institut de Recherche pour le Développement en Coopération (ORSTOM) and Cornell University. For this study, 2422 of the best locations were selected from a network catalog of about 30,000 local events. Many of these events were located previously in a variety of one- and three-dimensional structures [e.g., Roecker et al., 1988, Prévot et al., 1991] and the patterns they reveal are robust. Therefore we are confident that the trends discussed here are not simply artifacts of the location procedure or of poor data quality.

To characterize seismicity outside of the network, the data set of locally recorded hypocenters was supplemented by 383 well-recorded earthquakes reported in the International Seismological Center (ISC) catalog. Clusters and swarms were distinguished from ambient seismic activity using the second order moment technique [Reasenberg, 1985].

Ambient activity in the central New Hebrides occurs largely within a single contiguous zone (Figure 1). Clustered activity oc-

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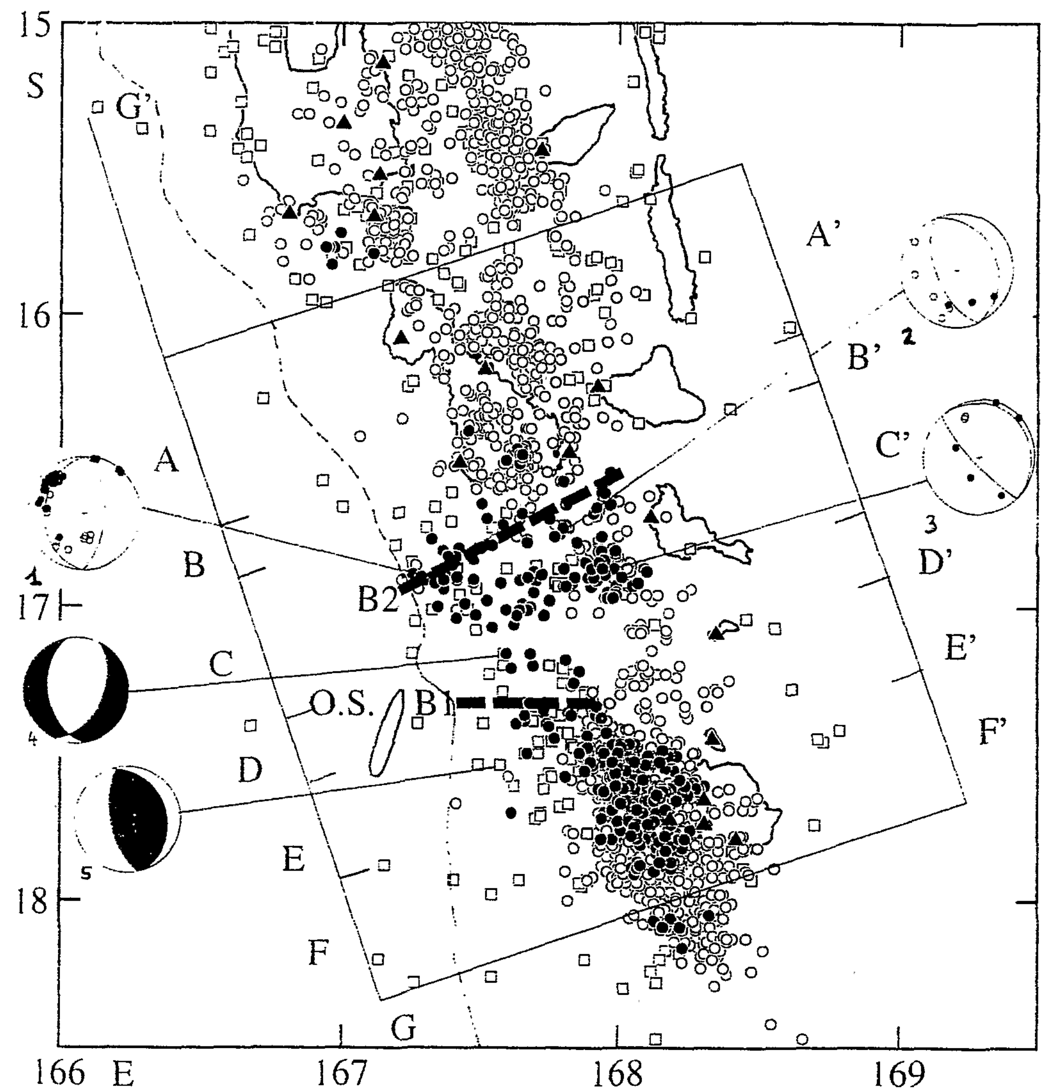

Figure 1. Map view of the central New Hebrides island arc. Solid triangles denote seismic stations of the local network. The two heavy dashed lines are the seismic boundaries (B1 and B2) identified by Chatelain et al. [1986]. The ORSTOM seamount is denoted by O.S. South of the O. S., the trench is shown by a solid line, while to the north its inferred position (after Collot et al., 1985) is shown by a dashed line. The ORSTOM seamount is denoted by O.S. Numbers on focal mechanisms denote the following: (1) composite mechanism from lower level clustered events, (2) best constrained individual mechanism from an upper level event, (3) best constrained individual mechanism from an event located at the eastern edge of the clustered activity, (4) CMT solution for the large 81/07/15 thrust and (5) CMT solution for the 81/07/19 aftershock. Data used to construct mechanisms 1-3 are show in Figure 4. Open squares are events taken from ISC catalog (1968-1988). The activity located by the ORSTOM-Cornell network (1978-1991) is divided into clustered seismicity (solid circles) and background seismicity (open circles). Letters A-G locate the cross sections shown in figures 2 and 3.

curs within this zone as well in the regions north and south of the seismic boundaries identified by Chatelain et al. [1986] (Figures 1-3), but between these boundaries it occurs in distinct zones separated from the ambient seismicity by about 50 km, thus defining a SDSZ (sections CC' and DD' in Figure 2). These two zones are connected at a depth of about 80 km by a nearly horizontal zone of seismicity that outlines the top of the seismic gap in the deeper Wadati-Benioff zone (section CC' in Figure 2 and Figure 3). We note that nearly all of the clustered activity defining the lower part of the SDSZ are either aftershocks of the 26 August 1979 (M_W = 6.2) and 15 July 1981 (M_W = 7.1) earthquakes or are part of a swarm that occurred in April 1986. Both of the mainshocks were thrusts with the probable rupture planes dipping about 30 degrees ENE (Figure 1). Focal mechanisms for events in the upper level of the SDSZ typically show thrust faulting (e.g., mechanism #2 figures 1 and 2), while those in the eastern lower part of the SDSZ suggest nearly horizontal slip (e.g., mechanism #3 in figures 1 and 2). Mechanisms of events in the lower level, however, appear to be the reverse of those in the upper. A centroid-moment tensor (CMT) solution (Dziewonski et al., 1983-1990) for one of the larger aftershocks in this area (mechanism #4 in figures 1 and 2) shows normal faulting, and while the station spacing is not amenable to constraining individual mechanisms, a composite

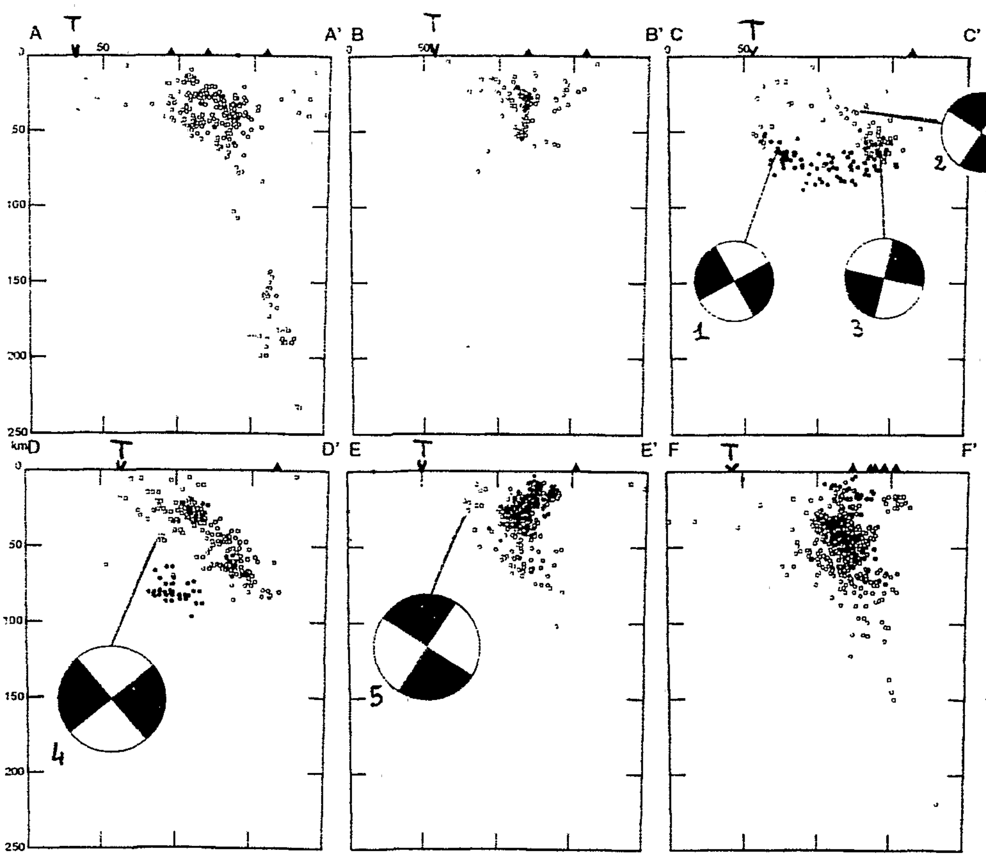

Figure 2. Cross sections of the Wadati-Benioff zone beneath the central part of the New Hebrides island arc. Meaning of symbols same as in figure 1. T denotes the location of the trench. Note that the steeply dipping zone in A-A' is not present in the next cross section to the south (B-B'). The shallow double seismic zone is prominent in section C-C' and appears to a lesser extent in sections D-D' and E-E'. Back-hemisphere projection of the focal mechanisms are shown in section C-C', with numbers corresponding to those in figures 1.

mechanism (mechanism #1 in figures 1 and 2) suggests normal faulting as well.

Discussion and Conclusions

Double seismic zones have been observed in several Wadati-Benioff zones [e.g., Fujita and Kanamori, 1981; Kawakatsu, 1986; Smith et al., 1993] but the SDSZ in the central New Hebrides appears to be different from all of these. For example, most double seismic zones occur at greater depths (65-85 km), the distance between the upper and lower zones is generally less than about 20 km, and the characteristic pattern of upper level mechanisms with P axes parallel to the dip of the zone and lower level mechanisms with T axes parallel to the dip of the zone appears to reflect changes in the internal stress field of the subducted lithosphere ("sagging" or "unbending"). Like the New Hebrides, the DSZ in the Mendicino subduction zone reported by Smith et al. [1993] is shallow (10-40 km depth), but has thrust mechanisms on both the upper and lower levels with fault planes parallel to the seismicity, and they interpret this SDSZ as the boundaries of a sliver of lithosphere trapped when the trench there stepped back. The SDSZ in the central New Hebrides is distinguished by being shallow, by having the two zones separated by a large distance (at least 50 km), and by fault plane solutions indicating shallow thrust faulting and deeper normal faulting. The New Hebrides SDSZ is thus unlike any other DSZ in most respects, and therefore is likely to be caused by a different mechanism.

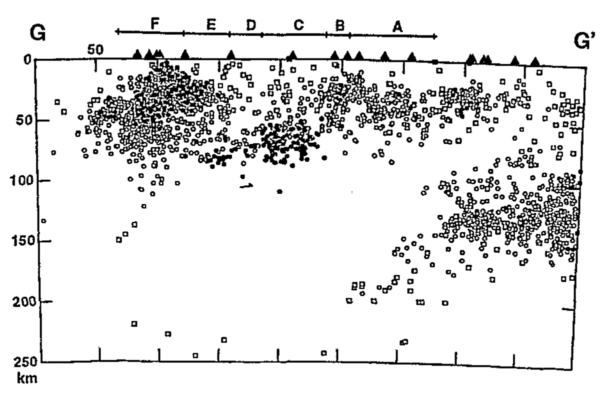

Figure 3. Cross section taken along the strike of the seismic zone (GG' in figure 1). Meaning of symbols same as in figure 1. Note the gap in the intermediate depth seismicity directly beneath the deeper clustered events (solid circles) that are part of the lower level of the shallow double seismic zone.

Several lines of evidence, including elastic wave attenuation [Marthelot et al., 1985], elastic wave velocity structure [Prévot et al., 1991], and uplift rates on the islands of Malekula and Santo [Mitchell and Warden, 1971; Taylor et al., 1985; Chatelain et al., 1992], suggest that the deeper part of the subducted Australian plate has detached at about 80 km depth, removing a substantial pulling force from the upper part of the plate and

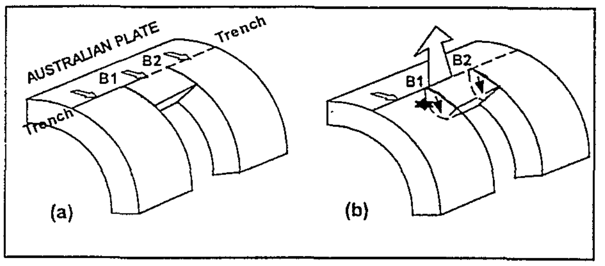

Figure 4. Cartoon illustrating the proposed mechanism for the generation of the New Hebrides SDSZ. (a) The shallow slab above the detachment is pulled down by longer slabs on either side. (b) The overextension of the shallow slab by large thrust event (black star) near the boundary B1 causes a readjustment in the form of normal faulting within the plate.

causing at least part of it to rebound [Chatelain et al, 1992]. We appeal to this detachment to explain the occurrence of the SDSZ. Clearly, subduction continues in a normal fashion along most of the arc, but in the region of shallow detachment there are no large thrust events and those large thrusts (such as the 81/07/15 event) that occur near the boundaries of the region trigger swarms of normal faulting events within the lower level of the SDSZ. This reversal of motion suggests that this part of the plate is resistant to subduction, in that it attempts to rebound after being displaced downward (Figure 4).

Interestingly, this rebound occurs not along the original plate boundary (as outlined by the upper level events of the SDSZ) but along a new boundary (the lower level of the SDSZ) some 50 km further back into the descending plate. It therefore appears that a consequence of slab detachment at depth is a fragmentation of the downgoing plate at the surface. We suggest that this portion of the leading edge of the Australian plate, as outlined to the east and west by the SDSZ and to the north and south by the seismic boundary zones of Chatelain et al. [1986] eventually will completely decouple and accrete onto the Pacific plate, perhaps as an ophiolite.

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