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Tonga-Lau System: Deep Collision of Subducted Lithospheric Plates

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Abstract. Deep collision of the presently subducted Pacific plate with activated remaining parts of the buried Lau paleoplates was found on the basis of a detailed investigation of the morphology of the Wadati-Benioff zone in the Tonga region. The position of two centres of deep collision was determined and the extent of activation of the Lau paleoplates was delineated.

Key words: Seismicity – Plate tectonics – Tonga island arc – Lau Ridge.

Introduction

The plate tectonic interpretation of the distribution of earthquake foci in the Tonga region implies a complicated pattern of subducted lithospheric plates (Hanuš and Vaněk, 1978a). In this aspect the most remarkable feature seems to be the deep collision of the recently subducted Pacific plate with buried remnants of Lau paleoplates causing the highest deep seismicity in the world. The aim of the present paper is to give a description of this new phenomenon based on a detailed investigation into the morphology of the Wadati-Benioff zone in the interacting Tonga and Lau systems of subduction.

Tonga System

For studying the morphology of the Wadati-Benioff zone in the Tonga region the ISC data (Regional Catalogue of Earthquakes) for the seven years' period 1967–73 were used. In some areas with low intermediate and deep seismicity the ISC data for selected shocks from 1964–66 were also included. The Tonga region (14°–27.5° S, 170° W–178° E) was covered by a system of 22 sections approximately perpendicular to the axis of the Tonga-Kermadec trench, the scheme of which is given in Figure 1, see also Hanuš and Vaněk (1978a).

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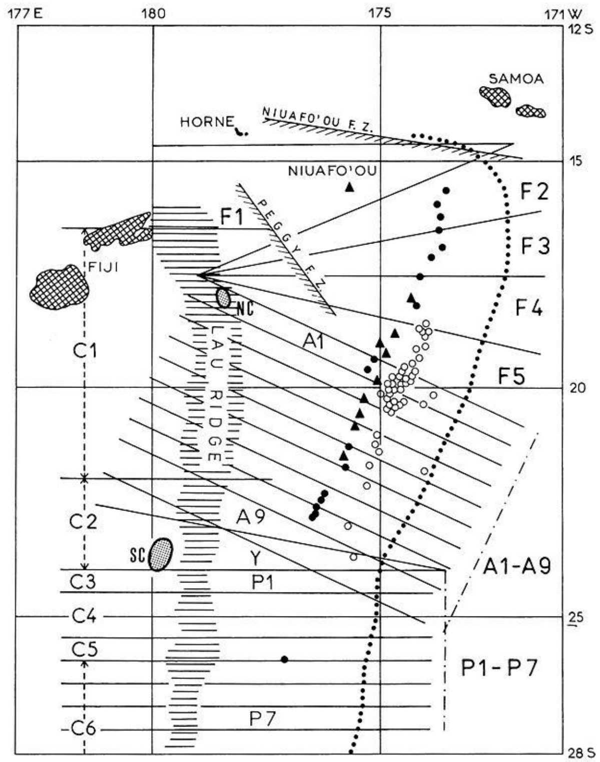

Fig. 1. Geographic scheme and position of sections used for the study of the Tonga-Lau deep collision; the Tonga-Kermadec trench is denoted by a dotted line, active volcanoes by full triangles, islands and submarine elevations associated with active volcanic chain by full circles, coral islands and reefs with associated submarine elevations by open circles, centres NC and SC of deep collision by dotted areas. Scheme compiled on the basis of Cullen (1970) and World Map (1968)

From the sequence of the vertical sections, showing the depth distribution of earthquake foci in dependence on the distance from the trench, four sections F5, A1, Y, and P1 are selected in Figures 2 and 3. The analysis of the complete set of vertical sections (Hanuš and Vaněk, 1978a) reveals that the complicated geometry of the earthquake foci distribution is caused by an interplay of different systems of lithospheric plates. If we omit the northern closure of the Tonga subduction zone, two different systems can be delineated: the presently subducted Tonga system including the plates T 1 and T 2 in the east, and the remnant Lau system composed of plates L 1 and L 2 in the west.

The well-defined Wadati-Benioff zone T 1, representing the presently active subduction of the Pacific plate, begins in the vicinity of the Tonga-Kermadec trench and is divided by an intermediate aseismic gap into two distinct seismically active parts (see Figs. 2 and 3). The gap appears to be spatially connected, similarly as in the Andean region (Hanuš and Vaněk, 1976), with the occurrence of active andesitic volcanism and can be interpreted as a zone of partial melting in the subducted plate. The depth penetration of the zone T 1 changes along the trench in a considerable range between 185 and 565 km.

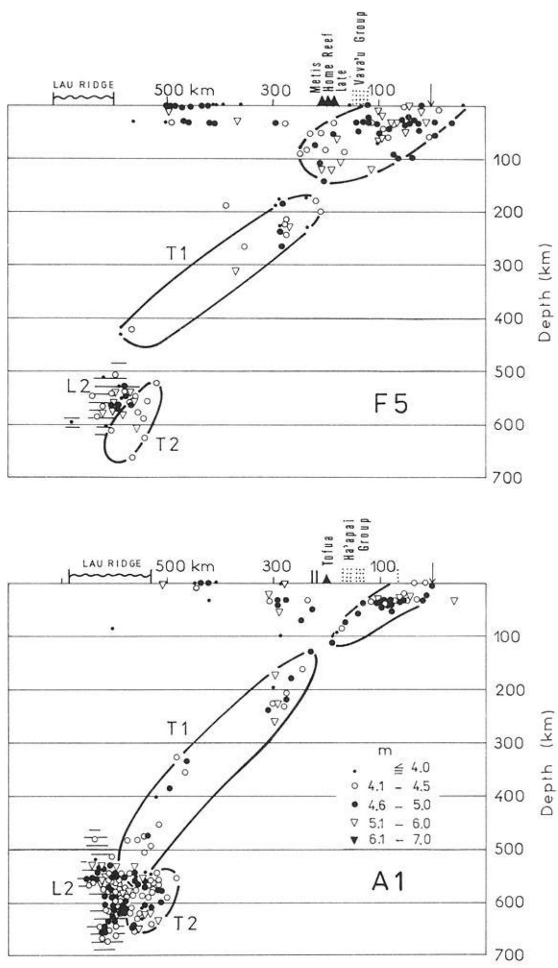

Fig. 2. Vertical sections F5 and A1 giving the distribution of earthquake foci in dependence on the distance from the Tonga-Kermadec trench; *m:* ISC magnitude; active volcanoes are denoted by full triangles, islands and submarine elevations associated with active volcanic chain by short vertical lines, coral islands and reefs with associated submarine elevations by short dotted lines, position of the trench by arrows, the Lau Ridge by a wave-line, Wadati-Benioff zones T 1 and T 2 by full-line contours, zones L 1 and L 2 by vertical and horizontal hatching. For position of sections see Figure 1

In most vertical sections a clearly separated group of deep earthquakes, shifted eastwards in relation to the zone T 1, can be observed. In analogy with our interpretation of deep Andean shocks (Hanuš and Vaněk, 1978c) this zone, denoted as T 2, is interpreted as the remaining active part of the foregoing cycle of subduction. The shape of T 2 itself and the existence of isolated intermediate shocks (see, e.g., Fig. 3) show that the zone T 2 runs in an approximately parallel strip below the present Wadati-Benioff zone T 1. The bottom of T 2 reaches the depths between 495 and 690 km. The interpretation of the zone T 2 as a remaining active part of the foregoing cycle of subduction is strongly supported by the position of the extinct volcanic line appearing now as a chain of coral islands, reefs and submarine elevations in the Tonga island arc (Hanuš and Vaněk, 1978b).

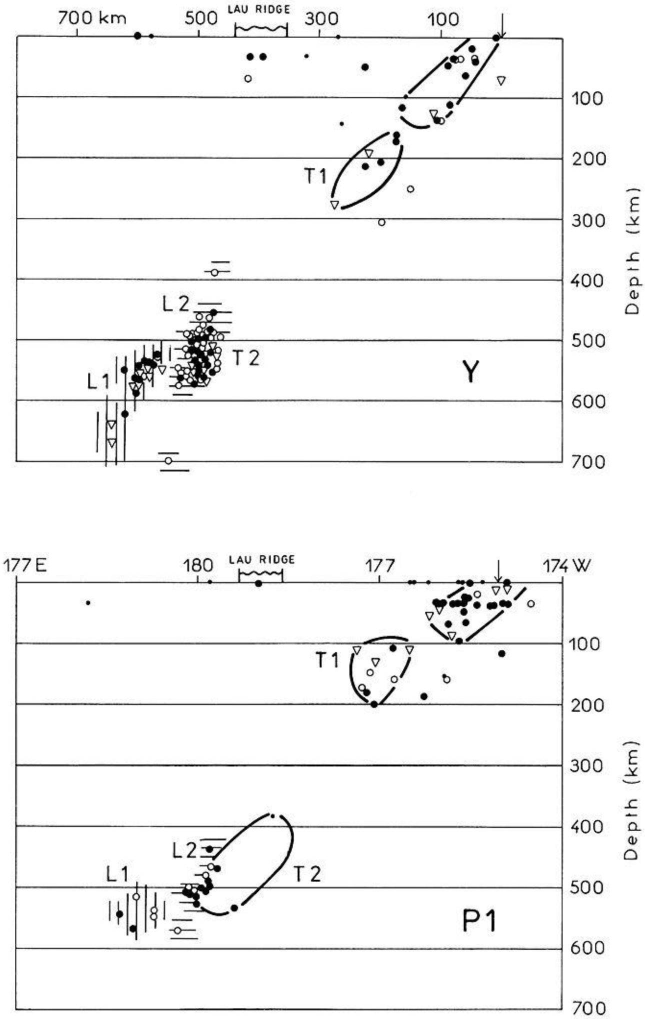

Fig. 3. Vertical sections *Y* and *P1*. For key see Figure 2 and for position of sections see Figure 1

Lau System

In the western part of the region investigated numerous deep earthquakes occur, which can be simply associated neither with the Tonga zone T 1, nor with the zone T 2 (see Figs. 2 and 3; Hanuš and Vaněk, 1978a). They are interpreted as a contorted part of the Tonga slab by Oliver et al. (1973). However, the epicenters of these deep earthquakes are arranged into a meridional belt, the course of which substantially differs from that of the Tonga-Kermadec trench. These earthquakes may be coordinated to the Lau Ridge, a remnant arc according to Milsom (1970) and Karig (1972), which has the same meridional strike and is situated above the belt of deep earthquakes in question.

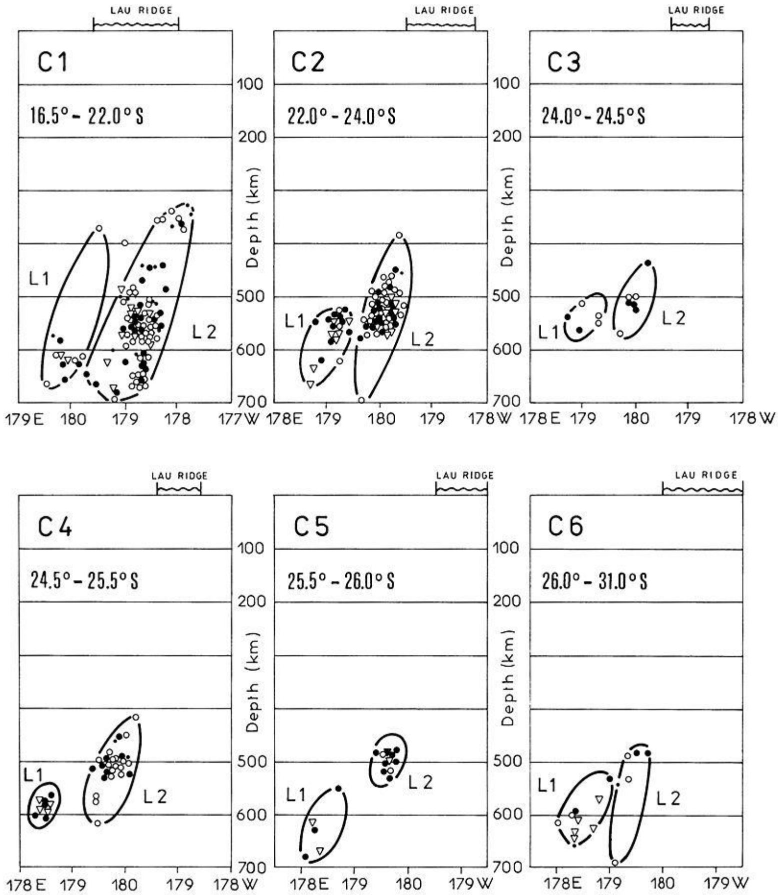

Fig. 4. Vertical sections C1–C6 for the Lau system giving the distribution of earthquake foci in dependence on longitude; symbols as in Figure 2, zones L 1 and L 2 are denoted by full-line contours. For position of sections see Figure 1

In order to demonstrate the reality of this interpretation, the depth distribution of the above foci was constructed and plotted together with the position of the Lau Ridge in a system of six parallel sections (see C1–C6 in Fig. 1). The resulting vertical sections, given in Figure 4, show that the earthquakes can be divided into two separated zones denoted arbitrarily as L 1 and L 2. They are very steeply dipping, the present average dip appearing to be about 70° to the west. It seems that the zones L 1 and L 2 represent two buried paleoplates activated by a deep collision with the recently subducting zones T 1 and T 2.

The top of the activated zone L 1 ranges from 370 to 565 km (sections C1, C4), the bottom of L 1 reaching depths between 565 and 685 km (sections

C3, C5). The thickness of the active part of L 1, measured perpendicularly to the dip, varies from 50 to 75 km with the prevailing value of 70 km. The corresponding parameters for L 2 are as follows: depth of the top between 325 and 485 km (sections C1, C6), depth of the bottom between 535 and 695 km (sections C5 and C1, C2, C6), thickness variable between 50 and 100 km.

Deep Collision and Activation of Buried Paleoplates

Deep collision of subducted lithospheric plates is a new phenomenon in the plate tectonic hypothesis. It is characterized by an anomalous clustering of deep earthquake foci in a relatively limited space, which cannot be interpreted by a simple model of one subducted plate. The geometry of the earthquake distribution gives an impression that smoothly downgoing slabs of recent subduction meet an obstacle during their penetration through the upper mantle. An analysis of the geometry of earthquake distribution and the position of remnant island arcs reveals that these obstacles can be interpreted as activated remaining parts of buried paleoplates belonging to ancient zones of subduction.

The above phenomenon is demonstrated in Figures 2 and 3, where the deep collision of the recently subducting Pacific plate with buried remnants of Lau paleoplates is shown. In the Tonga region two main centers of collision can be identified: the northern centre, appearing in the vertical section A1 (see Fig. 2), is produced by the collision of the Tonga zones T 1, T 2 with the Lau zone L 2; in the southern centre, which can be observed in the vertical section Y (see Fig. 3), the Tonga zone T 2 and the Lau zones L 1 and L 2 take part in the collision. In the southern centre T 1 is not involved in the collision because its depth of penetration is not sufficient to reach the Lau zone L 2 (for details see the complete sequence of vertical sections in Hanuš and Vaněk, 1978a).

The clustering of earthquake foci in the northern centre of collision is very intensive; therefore an enlarged picture of this region is shown in Figure 5, where we attempt to coordinate the individual earthquake foci to the interacting zones assuming that all the zones preserve their simple plate-like shape: zone T 1 is delineated by full-line contour, zones T 2 and L 2 are denoted by vertical and horizontal hatching, respectively, and the centre of collision by cross-hatching. The position of the centre of gravity of the northern collision is at 18.0° S and 178.4° W, its depth is at 600 km. The corresponding parameters of the southern collision are 23.6° S, 179.8° W, and 540 km depth. Both centres of collision are also shown in the geographic scheme of the Tonga region given in Figure 1.

By the deep collision with the Tonga zones T 1 and T 2 the buried Lau paleoplates L 1 and L 2 were activated not only in the centres of collision. The activation takes place also between both centres of collision and the earthquake foci belonging to L 1 can be observed up to the latitude of 31° S southwards of the southern centre and those belonging to L 2 up to the latitude of 16.5° S northwards of the northern centre of collision. This means that the Lau system of paleoplates is activated for a length of about 1600 km.

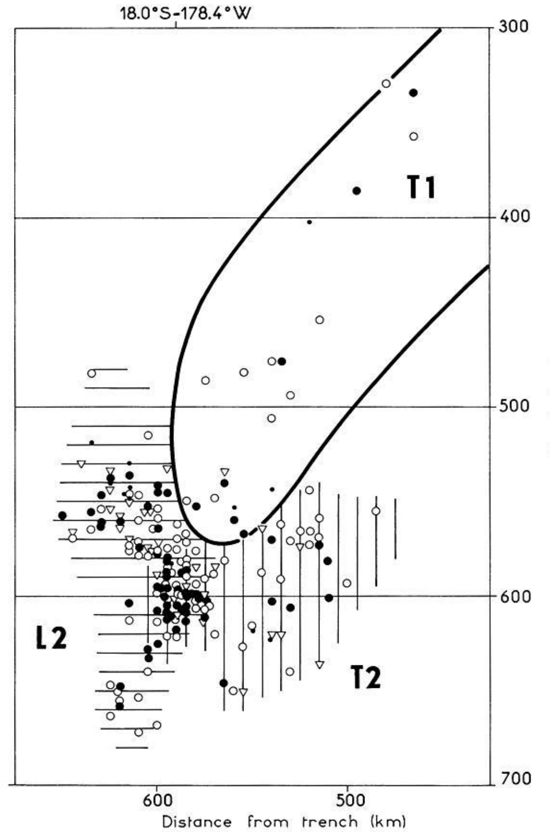

Fig. 5. Detailed picture of the northern centre of the Tonga-Lau deep collision; zone T 1 is denoted by full-line contour, zones T 2 and L 2 by vertical and horizontal hatching, centre of collision by cross-hatching

It appears that the earthquake foci are not distributed randomly in the paleoplates but that they are arranged in an orthogonal system with a specific orientation with respect to the possible direction of subduction. A detailed discussion of this phenomenon will be published in a separate paper. It must be also noted that the present dip of the zones L 1 and L 2 need not correspond to the original dip of the Lau subduction and can be substantially influenced by the deep collision with the zones T 1 and T 2.

One of the most specific features of the Tonga region is the highest deep seismicity in the world. The deep collision of lithospheric plates may be the decisive factor in explaining this phenomenon.

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