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A TELESEISMIC ARRAY STUDY IN FRENCH POLYNESIA; IMPLICATIONS FOR DISTANT AND LOCAL STRUCTURE

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Abstract. We analyze slowness and azimuth anomalies, as recorded in the French Polynesia Seismic Network. The network can be considered as an array in its whole, or can be split into two subarrays, 350 km apart. In the former case, it is found that, contrary to Canadian VASA results, no anomaly is apparent for rays bottoming under Hawaii. In the latter case, a model of the crust is attempted under Tahiti as well as under the atoll of Rangiroa.

In the so-called "hotspot" theory, Morgan (1971) postulated that there exist vertical lines of upwelling which are fixed with respect to the mantle and which extend deep into the Earth, presumably down to the core-mantle boundary. These hotspots would represent thermal and/or chemical heterogeneities which should, in turn, affect the propagation of seismic body waves. Recently observed anomalies in the propagation of P and S waves bottoming deep under Hawaii may be interpreted in terms of the presumed Hawaiian hotspot (Davies and Sheppard, 1972; Kanasewich et al., 1973; Sengupta and Julian, 1974). However, the accumulated evidence seems as yet unconvincing. Kanasewich et al. (1973) link the existence of a hotspot with a slowness anomaly, whereas Davies and Sheppard (1972) link it with an azimuth one. Furthermore, Capon (1974) showed that the anomalies observed at LASA may actually be fully explained by variations in the structure of the crust and upper mantle under the receiving array. On the other hand, Capon and Berteussen (1974) show that this last approach fail to explain NORSAR anomalies, leaving the question wide open. In this study we analyze teleseismic P waves recorded by the French Polynesia Seismic Network. Along with possible interpretation of local structures, these data provide an additional test on whether the proposed Hawaii and Easter Island hotspots should produce anomalies in the propagation of seismic waves. No such anomaly is observed. Although this does not constitute definite evidence that the proposed hotspots do not exist, it indicates that they may not necessarily be reflected through observable seismic propagation anomalies.

The French Polynesia Seismic Network is made of 9 major stations, distributed in two subarrays, one on the volcanic islands of Tahiti and nearby Moorea, the other on the atoll of Rangiroa (see Fig. 1). Each of them is equipped with a short period vertical seismometer (Talandier, 1971). In this study, we analyze teleseismic slowness and azimuth as observed in our stations, and compare them with values computed from PDE data. For this purpose, we use records from 160 events, with epicentral distances from 24 to 90 degrees. For every event, we make a least-square computation of the observed slowness and azimuth over i) only the 5 Tahiti stations, ii) only the 4 Rangiroa ones, and iii) the whole 9-station network. In each case, we obtain a mean residual over the used stations. We eliminate about 50 events for which such residual is larger than 1.8 sec in i) or ii) and 2.5 sec in iii). This means eliminating events for which an observed plane wave across the used array is difficult to define; the residuals of the events kept usually being of the order of .3 to .5 sec. For every event we keep, we also compute slowness and azimuth from PDE data, for each of the used array. In this way for each event, we define an "arrow", whose head points towards the computed value of slowness and azimuth, and whose tail gives the observed values. Comparable arrows were drawn at LASA by Davies and Sheppard (1972). The arrows are shown on Figs. 2, 3 and 4.

The fundamental observations from the three diagrams is that the whole network gives very good results, whereas each of the two subarrays exhibits strong trends of anomaly. Having this in mind, we make the assumption that the anomalies present in the subarray diagrams are due to local structure, whereas those for the whole network can be associated with distant phenomena (source or path effects). This assumption seems reasonable because the Tahiti and Rangiroa diagrams are clearly uncorrelated and the arrows on them are very much larger than on the whole array diagram. Figs. 2 and 3 shows the array diagrams for Tahiti and Rangiroa. It appears at once that the two islands behave very differently.

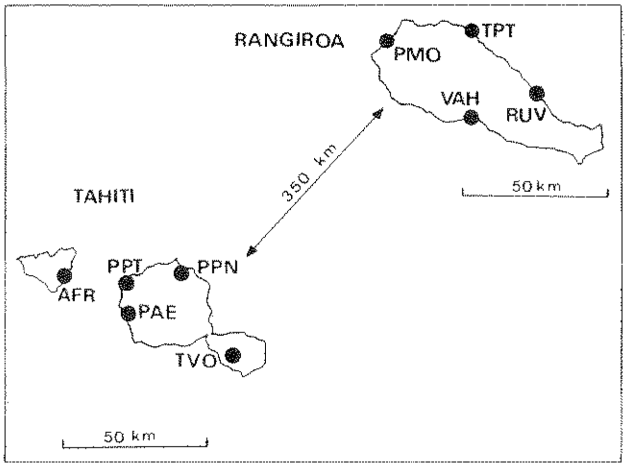

Figure 1. Map of the French Polynesia Seismic Network. The dots indicate stations. For clarity, the distance between the two subarrays is not scaled.

Most of the Tahiti arrows point inwards, with smaller azimuthal anomalies than in the case of Rangiroa, for which the general trend is Northwards, except for the events in Western Pacific. In order to solve the inverse problem from the arrows to the local structure, we made the assumption that variation in the depth and shape of the Mohorovičić discontinuity (Moho) is solely responsible for the observed anomalies, which seems reasonable as a first approach, given the size of the two subarrays and the volcanic origin of the Society and Tuamotu Island chains. However, we must emphasize it as an assumption.

In the case of Tahiti, the pointing of most arrows inwards leads us to think of a Moho basin under the island. Interpretation of local refraction data from quarry blasts and underwater explosions provides similar results (Talandier and Kuster, unpublished data). The dip along the edges of the basin is computed from the size of the arrows, yielding values of 6° for bearings 260-280°, 13° for bearings 310-350°, and 11° for bearings 70-90°. However, the smaller anomalies in observed azimuths must be analyzed as well. It is remarkable that they are directed towards a line bearing 110-290°, which represents the main tectonic direction in the region. This indicates a further dipping of the Moho towards this line, and leads to an image of the Moho under Tahiti featuring a basin of slightly anisotropic shape, so as to create a rift along the tectonic direction. The basin would be a few km deep, this being consistent with isostasy under a Hawaii-type volcano.

In the case of Rangiroa, the major feature of the diagram is its separation across a line bearing 110-290°. Most of the arrows North of the line point North-Northeast, whereas the other ones point Southwest. The corresponding dipping angles are calculated from the size of the arrows. The resulting feature is a "roof" whose axis is directed along the main tectonic direction, and which dips 15 degrees to the North-Northeast and 10 degrees to the Southwest. This "roof-shaped" Moho may seem contradictory to isostasy. However, a refraction profile made along this line bearing 110-290° reveals a Moho depth of so 25 km (Talandier and Kuster, to be published). This is clearly a thicker crust than for the average oceanic plate. The resulting picture may thus be a very broad Moho basin on which a smaller roof-type feature is superposed in the main tectonic direction. It must be emphasized that our interpretation is only a tentative one, whose main purpose is to show that one can find reasonable local structures which explain the observed anomalies in each subarray. This conclusion brings some support to our earlier assumption that the whole network diagram, which integrates local anomalies over larger distances, is associated with distant phenomena whereas the subarrays reflect local effects.

On the whole network diagram shown on Fig. 4, the arrows are clearly of small magnitude, except for the Mexico-Central America and Colombia seismic regions. However, in these cases the standard deviation of the anomalies around their mean value is itself large, i.e. of the order of 6° in azimuth. It might be that due to its shape, our array is badly "beamed" in this direction; it might also be a source or path effect in the tectonically disturbed region close to the Pacific-Nazca-Cocos triple junction. Further monitoring of Central America earthquakes may improve understanding of this point. For events in the Western Pacific, the magnitude of the anomalies is very small, even smaller than their standard deviation, for both slowness and azimuth. In this respect, we can state that the network in its whole does not reveal any distant slowness or

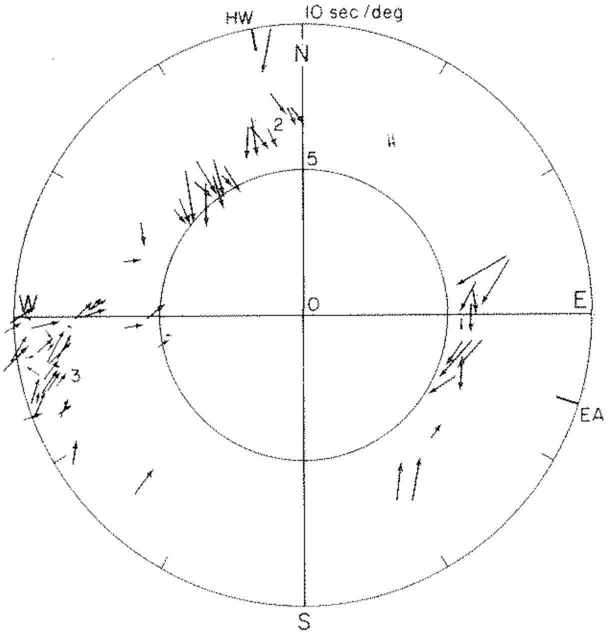

Figure 2. Array diagram for the Tahiti subarray. The heads of the arrows are for the computed values, the tails for observed ones. Numbers on diagram stand for so many arrows similar to adjacent ones and too close to be plotted. Labels HW and EA indicate azimuth of Hawaii and Easter Islands presumed hotspots.

zimuth anomaly for these epicentral regions. [illegible] events in the Aleutian and Alaska, the anomaly is of the order of 1° in azimuth and a few hundredths of p units. Most of these rays bottom in the vicinity of the presumable Hawaiian hotspot, one of them missing the vertical of the 1973 earthquake epicenter by only 18 km. Therefore no significant anomaly associated with the Hawaiian hotspot is recorded, in contradiction with observations by Kanasewich et al. (1973), at VASA, Western Canada, and by Davies and Sheppard (1972), at LASA. One possible reason for the discrepancy may be that VASA (160 km wide) and LASA (200 km wide) are not large enough to completely cancel out local effects; this interpretation is substantiated by the results of Capon (1974) and by the data reported in this study: when using only one subarray, we do observe large arrows, which disappear when using the whole network, extending over 350 km. Another possible reason for the discrepancy is that the mean ray paths we used bottom some 400 km shallower than those used at VASA or LASA, the epicentral distances used at VASA and in the present study being respectively 84-96° and 75-85°. However, the discrepancy remains consistent at an identical distance of 85°. Furthermore, under such an interpretation, the vertical extent of the anomaly is limited, and thus the anomaly can no longer be related to the presence of a hotspot, which should extend from the deep mantle all the way up to to the surface, since it is held responsible for the formation of volcanic island chains. It must be noted that no consistent anomaly is found for ray paths bottoming under Easter Island, a proposed location for another hotspot, which is approached 60 km by rays from northern Chile.

In conclusion, slowness and azimuths anomalies are substantial on the subarray scale and their inversion leads to reasonable crustal structures.

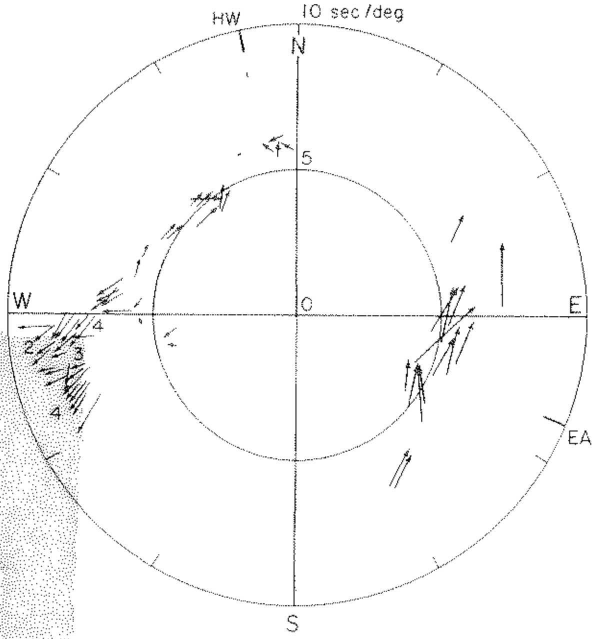

Figure 3. Array diagram for the Rangiroa subarray. Numbers and labels as in Figure 2.

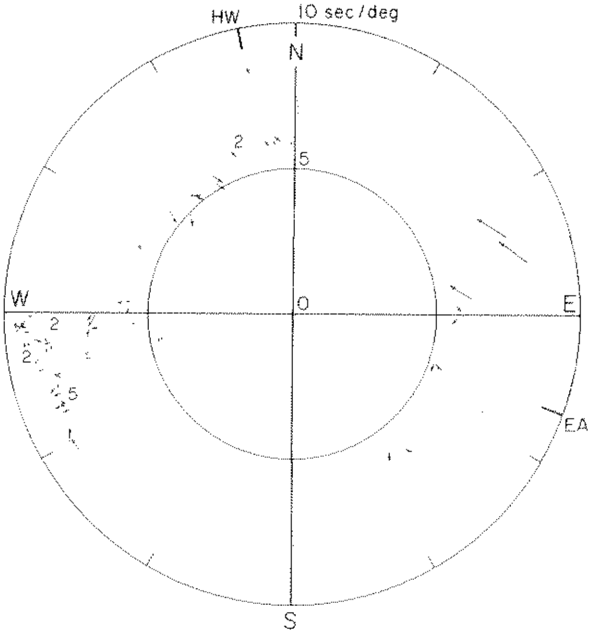

Figure 4. Array diagram for the whole network. Labels as in Figure 2. Numbers stand for so many arrows too small to be plotted.

On the whole network scale, slowness and azimuth anomalies are very small. This indicates that arrays to be used to study distant structures should be of large aperture and possibly spread over varied geological regions. Better results would certainly be obtained outside an ocean plate, where stations are restricted to island locations.

Also, there is no evidence for significant anomalies for rays bottoming under presumable hotspot locations, such as Hawaii and Easter Island. If carried further, this conclusion suggests that hotspots, if they exist, are not necessarily responsible for anomalous zones of propagation of seismic waves.

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