Note on New Zealand Crustal Structure

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Abstract

ATTENTION is drawn to implications of Gutenberg's new interpretation of southern Californian near-earthquake data and his suggestion that indications of velocities near 5.6 km./sec. may arise from the presence of a low-velocity layer near a depth of 16 km. rather than immediately below the sediments. It is shown that Gutenberg's new model for southern Californian crustal structure fits remarkably well an earlier interpretation of data for the New Zealand region when allowance is made for a possible decrease of velocity with increase of depth. It is possible that the average focal depth of normal earthquakes may be a little less in the New Zealand region than in California. It is shown that there is now no evidence of significant differences of crustal structure below the sediments in the Californian, New Zealand and Japanese regions. Thus the suggestion arises that regions bordering on the Pacific basin may have common structural features which deviate from the structure of more specifically continental regions.

1. Gutenberg (1951a, 1951b) has recently suggested a new interpretation of Southern Californian near-earthquake data, and the purpose of the present paper is to relate this work to work that has been done on New Zealand near earthquakes.

Gutenberg's new interpretation has emerged from his attempt to remove an apparent discrepancy between the indication of near-earthquake and explosion records on velocities just below the sediments. The discrepancy is that in several regions where near-earthquake studies have indicated P_g (or $\overline{P}$) phases corresponding to velocities of 5·5–5·6 km./sec., the P velocities indicated by explosion data have been not much less than 6·0 km./sec. in the first 10 km. or so below the sediments.

In almost all regions of the Earth there remain unresolved differences of interpretation of near-earthquake data. Some writers attribute complexities to the existence of serious deviation from horizontal layering below the sediments. Gutenberg, however, continues to adhere broadly to the postulate of horizontal layering, and makes the suggestion that the main difficulties arise from the existence of a significant decrease of velocity with increase of depth in part of the crustal layers. He offers, as a possible explanation of the decrease, the influence of temperature on rocks with an appreciable quartz content, and points out that a transition from α– to β–quartz would occur at the temperature prevailing in the Earth near a depth of 25 km. Taking into account the effects of possible variations of composition with depth, and the likelihood that the elastic parameters would start to decrease before the transition to β–quartz was complete, Gutenberg then infers that there could be a minimum velocity above the 25 km. level.

Whether the details of this suggested mechanism are substantiated or not, it leads to the idea that a low-velocity layer in the crust may be of wide-spread occurrence and not confined to the Californian region—a possibility to be taken into account in interpreting data in other regions.

Following the above suggestion, Gutenberg finds that his data on explosions and near earthquakes in southern California can be reconciled with a structure in which the P velocity ranges from 5 8 to 6 8 km./sec. between depths of about 5 and 11 km., and then decreases so that the average velocity along P rays which leave foci at depths near 16 km. and do not penetrate below this level is about 6 35 km./sec. The data do not enable Gutenberg to estimate the velocity decrease precisely, but he suggests that observations of the phase $\overline{P}$ may arise from the presence of a low-velocity " channel " near a depth of 16 km., and that these observations occur in California only with earthquakes whose foci are near this depth.

In earlier near-earthquake discussions, it has mostly been assumed that the phases P_g or $\overline{P}$, when observed, apply to a granitic layer. Gutenberg now regards it as more likely that "granitic layers" in California are associated with velocities of 6 to 6 5 km./sec. which, in his new crustal model, occur in the uppermost 10 km or so.

2. Turning now to near-earthquake data in New Zealand, a central point of interest related to Gutenberg's new interpretation is that observations of P_g in New Zealand have been remarkably scanty.

In the Wairoa earthquake of 1932 September 15 (Bullen, 1938a) which, of all New Zealand earthquakes studied by the writer, gave the most self-consistent information on crustal structure, there was no indication at all of either P_g or S_g phases, although there were good observations of a phase, denoted $P_{5\,0}$, that would correspond to the smaller velocity of 5 0 km./sec. in an outermost layer of greywacke. Some P_g and S_g onsets appeared to be recorded in aftershocks of the 1931 Hawke's Bay earthquake (Bullen, 1938b), but these were few in number. It was stated (Bullen, 1939) that " it appears that P_g and S_g were sometimes recorded from a few of the stronger shocks which presumably had a very favourably situated focus "

The data available in 1939 did not make it possible to locate the range of depth of a layer corresponding to the phase P_g In a picture (1939) of the New Zealand crustal structure (between latitudes of 38° 5 and 43°·5, S), a layer of some 4 km thick, corresponding to P_g, was inserted immediately below the greywacke layer for the sake of a tentative model The sole considerations brought to bear in the placing of this P_g layer were that, in the absence of evidence to the contrary, a tentative model should conform with the results given by seismologists for other regions and with the view then prevailing that velocities in the Earth's crust are essentially monotonic functions of the depth.

The new interpretation of Gutenberg now makes it desirable to contemplate a model for New Zealand in which the P_g layer is lowered to a depth agreeing with Gutenberg's suggested low-velocity channel in California. If this simple adjustment is made—an adjustment which does not conflict with the available New Zealand data at any point—the interesting result emerges that the 1939 findings for New Zealand are remarkably similar to Gutenberg's new pattern for southern California.

In the first place, some support is given to the earlier expressed view that P_g and S_g phases may appear only in a limited number of shocks with foci at favourable depths. The existence of a low-velocity layer is a sufficient and satisfactory explanation of the paucity of P_g and S_g observations in New Zealand.

Secondly, there is the clear evidence found (1938a, 1939) of the existence of phases, denoted as P^*, with velocities ranging from 6·0 to 6·55 km./sec in the New Zealand region. The standard deviations were such that it had not been possible to decide whether these observations corresponded to a single homogeneous layer or to a composite layer. These P^* readings are in fair accord with Gutenberg's new results for the first 10 km. below the sediments in California and are compatible with the average P velocity of 6·35 km./sec. found by him for earthquakes leaving foci at depths near 16 km In addition, the observed velocity of 3·7 km./sec. for S^* in New Zealand agrees well with Gutenberg's new figure of 3·67 km./sec. for the average S velocity in the first 10 km. below the sediments.

Thirdly, Gutenberg suggests that the P velocity jumps suddenly to 7·1 km./sec. at a depth of 28 km., a velocity near that of Stoneley's phase (1931). This finding is possibly relevant to certain New Plymouth readings of the Hawke's Bay aftershocks (1938b, p. 516).

A fourth and striking result is that the similarity between the results for California and New Zealand extends below the Mohorovicic discontinuity. Professor Gutenberg informs me that preliminary results based on records of the Kern County earthquake of 1952 July 21 give a P_n velocity of 8·17 ± 0·18 km./sec. for distances between $1\frac{1}{2}$ and 4 degrees, while " beyond 4 degrees the amplitudes decrease very rapidly, and one record at a distance of 6 degrees shows a barely perceptible P_n phase with this velocity. Between distances of 4 and 12 degrees, the velocities scatter around a straight line with an apparent velocity of $7\frac{3}{4}$ km./sec ". These new P_n observations of Gutenberg are quite remarkably in agreement with the solution (1938a) for the Wairoa earthquake, in which the best fit was obtained by assuming a P_n velocity of 8·1 km./sec. for distances up to 4 degrees and 7·8 km./sec. beyond 4 degrees.

3. It may be remarked that, on the crustal model contemplated in section 2, it would be possible to estimate the thickness of the greywacke layer given sufficiently precise data connecting the travel-times T with the epicentral distances Δ for the phases $P_{5\cdot 0}$ and P^* Let

$$T = \Delta/v + a,$$

where v denotes the velocity and a the " apparent delay of starting " for a given phase Then, applying the usual near-earthquake theory to data from the Wairoa earthquake, and taking the velocity of P^* as 6·3 km./sec., it is found that the difference in the values of a for the phases $P_{5\cdot 0}$ and P^* is approximately 2 sec This formally yields a thickness of $(8 + \frac{1}{2}\,d)$ km. for the greywacke layer, where d is the focal depth, and so implies that the thickness is at least 8 km. Because of the spread of values of the apparent velocity of P^* and of imprecision in the estimate of a, this estimate is, however, uncertain by at least 4 km. Data on later earthquakes may serve to increase the precision of this estimate.

4 The important feature of the comparison made in section 2 is that it shows that Gutenberg's new interpretation has removed all evidence of differences between the crustal structures of New Zealand and California, apart

from such as may occur between the New Zealand greywacke layer and the Californian sedimentary layers.

It is now possible to attribute the apparent earlier evidence of greater differences between the two crustal structures to differences in the focal depths of earthquakes studied in the two regions. Whereas the focus of the Wairoa earthquake appears to have been in a greywacke layer, the focal depths of many of the earthquakes studied by Gutenberg appear, on his interpretation, to have been in a low-velocity channel near 16 km. The disparity between the numbers of apparent observations of P_g and S_g in New Zealand and in California, and the frequency of observations of $P_{5.0}$ in general in the New Zealand region, suggest, further, that the average normal earthquake may originate at a somewhat shallower depth in New Zealand than in California. Additional evidence is of course needed to establish this point, and account needs to be taken of Californian earthquakes such as the Eureka earthquake of 1932 June 6 studied by Sparks (1936), which resemble the Wairoa earthquake in showing no evidence of P velocities near 5 6 km./sec.

It needs to be remarked also that, in drawing inferences from the above data and comparisons, the cautions referred to in the writer's 1939 paper in interpreting the New Zealand near-earthquake data still apply, and the conclusion should not be pushed too far. The recent work of Gutenberg has led to a removal of obstacles in the way of agreement between the Californian and New Zealand crustal structures rather than to providing strong positive proof of similarity. The removal of these obstacles is, however, of special interest in relation to similarities already suggested (Bullen, 1939) between the New Zealand and Japanese regions. The Japanese region shows strong evidence of phases with velocities in fair agreement with the New Zealand $P_{5\,0}$ and P^*, and only slight evidence of velocities near 5·6 km./sec. It has been pointed out that this contrasts strongly with the evidence stated by Jeffreys (1952) on P velocities near 5·6 km./sec. immediately below the crustal layers in a large section of the European region.

The suggestion therefore arises that regions bordering on the Pacific basin, as do California, New Zealand and Japan, may all show common structural features which deviate from the crustal structure in more specifically continental regions, an essential difference being the slightness of the indications of a 5·6 km./sec. layer in the part just below the sediments. In view of the current wide divergences in interpretation of near-earthquake data, there are obvious advantages in considering hypotheses which can lead to the co-ordination of results in this way, and it is suggested that the notion of a common structure be tested wherever possible in other regions bordering on the Pacific.

It is desirable finally to mention that, at the time this paper was completed, I received a communication from Dr. C. B. Officer kindly informing me in advance of publication of current work of Dr. E. I. Robertson and himself on the problem of New Zealand crustal structure. This work, which is based on new data, appears to be in broad agreement with a number of the indications of the present paper. In addition, the suggestion is made that there exists in the Wellington region a layer some 3 km. thick in which the P velocity just below the sediments is about 5 54 km./sec.; the tentatively suggested total crustal thickness in this vicinity is of the order of 20 km.

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