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VII.2 Determination of the 3-dimensional Seismic Structure of the Lithosphere under Montana LASA and under the USGS Central California Seismic Array

The novel 3-dimensional earth-modelling technique presented by Aki, Christoffersson and Husebye (1976) has been used for detailed investigations of the seismic structures beneath the LASA and Central California arrays. The characteristic feature of the above technique is flexibility in modelling the lithosphere. The starting point is the layered medium of classic seismology but each layer is divided into many blocks and assigned a parameter to each block which describes the velocity perturbation from the average for the layer. The data used are teleseismic travel time residuals observed at the LASA array in Montana and USGS Central California array. By isolating various sources of errors and biases, we arrive at a system of equations to determine the model parameters, i.e., the velocity perturbations within the individual blocks. The final solutions were obtained by the use of the generalized inverse and stochastic methods including analysis of resolution and errors of the estimated parameters.

A. The lithosphere beneath LASA

The seismic velocity structure beneath LASA has intrigued seismologists ever since this large aperture array was established in Montana in 1965. A commonly adapted model here is one where material properties within layers are homogeneous but in which the crust thickens sharply from approx. 50 km to approx. 60 km towards northwest near the center of the array. Our results, (Aki et al, 1976) a 3-dimensional seismic image of the lithosphere, are displayed in Figs. VII.2.1 and VII.2.2 in the form of two cross-sections for both the stochastic inverse and generalized inverse solutions respectively.

The most conspicuous feature of the seismic structure under LASA is a low velocity anomaly in the central and NE part of the array siting area with a N60^{o}E trend and persisting from the upper crust to depths greater than 100 km. We are tempted to associate this low velocity zone with wrench faulting and shearing during the Nevadan and Laramide orogenies. The sharp change in crustal thickness proposed in earlier studies is likely to be significantly overestimated because the upper crust and the lower lithosphere appear to share the same anomaly pattern as the proposed Moho topography.

B. The lithosphere beneath Central California - San Andreas fault

We have also studied the seismic structure of the lithosphere beneath central California using data from the 26 U.S. Geological Survey stations which are shown in Fig. VII.2.3 together with the major tectonic features of the area (Husebye et al, 1976).

The San Andreas fault system is a part of the present boundary between the North American and Pacific plates and expresses their relative motions as a transform fault. Between 29 and 21 m.y. the Farallon plate broke up between the Mendocino and Murray fracture zones and the small pieces under-thrust the west coast of North America (Fig. VII.2.4). The Pacific Ocean floor, which came in contact with the North American plate 10-20 m.y. ago, was very young so that the lithosphere was weak and susceptible to deformation. As the eastern margin of the Pacific lithosphere cooled, thickened and grew stronger, it probably became strong enough to bite off a piece of California from North America.

With this background information, let us look at our results for discussion. We start with Layer 1 or the crust with an assumed thickness of 25 km. The trends in the velocity anomalies in Layer 1 (Fig. VII.2.5) run nearly parallel to the direction of the major fault lines in the area; high velocity to the west of the fault zone and low velocity to the east. The maximum velocity contrast between the two sides for both solutions is around 10%, which is generally consistent with seismic profiling results on velocity differences between the granitic rocks of the Gabilan Range and the Franciscan rocks of the Diablo Range. We also notice that the velocity variation across the fault becomes gradual where the San Andreas fault system branches and sharpens where the faults merge to a narrow zone near Hollister.

The slowness anomalies in Layer 2 (25-50 km) directly beneath Moho are shown in Fig. VII.2.6 for the generalized inverse solution which is different from the stochastic inverse solution. Because of the difference in the two solutions, we shall refrain from any serious attempt to interpret Layer 2 anomalies, but if the general trend in the generalized inverse solution is correct, we find high velocity on the east and low velocity on the west side of the fault, a reversed picture as compared to Layer 1.

The slowness anomalies for Layer 3 (50-75 km) are given in Fig. VII.2.7 showing a definite trend parallel to the fault zone. Just like Layer 1, Layer 3 has high velocity to the west of the fault zone, and low velocity to the east. The remarkable correlation of velocity anomalies in Layers 1 through 3 with the San Andreas suggests that the fault zone penetrates to a depth of at least 75 km.

The slowness anomaly patterns for Layer 4 (75-100 km) and Layer 5 (100-125 km) no longer correlate clearly with the fault zone, as shown in Figs. VII.2.8 and VII.2.9. The similarity of their patterns to Layer 3 is only retained in the northern part of the area, where the velocity is still high to the west and low to the east. This suggests that these layers may not belong to the lithosphere, which is consistent with the average thickness of the lithosphere of around 80 km in the western United States as obtained by Lee and Solomon (1975) from surface wave attenuation data.

One of the most interesting aspects of the 3-dimensional velocity anomalies is the possibility that the shape of the anomaly may indicate the past or present mode of stress in the lithosphere. We see an indication of a sheared structure in the velocity anomaly pattern along the NW-SE profile in the Pacific plate west of the San Andreas fault. It is expressed in a north-westward migration of a high velocity anomaly along the Pacific coast with increasing depth. The pattern is clearer in the stochastic inverse than in the generalized inverse solution. The direction of shear implied by this pattern may support the hypothesis that the convection current in the asthenosphere is driving the plate motion. We cannot, however, forward a definitive answer to this problem because the profile runs through the peripheral region where the resolution is poor in the stochastic inverse solution and the random error effect is strong in the generalized inverse solution. Additional data currently being collected will hopefully give more definitive results.

Synopsis prepared by E.S. Husebye.

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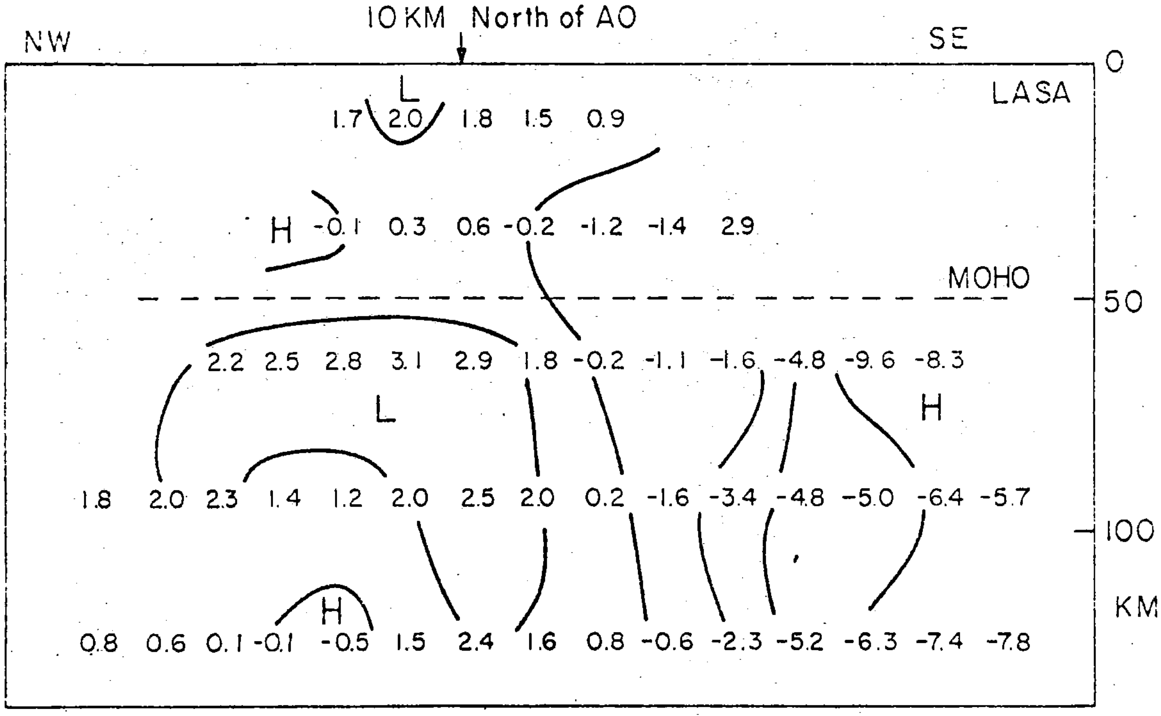

Fig. VII.2.1 Generalized inverse solution for a vertical cross section of the LASA array. The numbers show the fractional velocity perturbation in per cent of the average layer velocity. The letters H and L refer to high and low velocity anomalies.

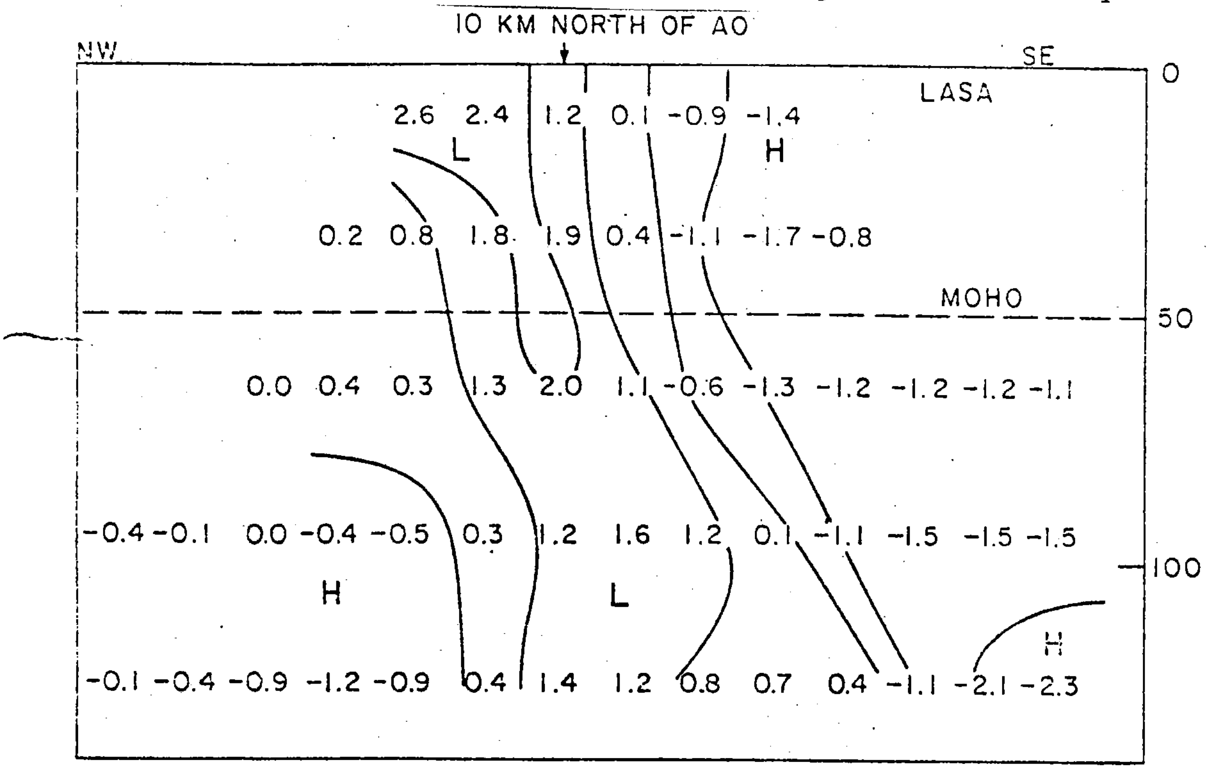

Fig. VII.2.2 Same as in Fig. VII.2.1 for the stochastic inverse solution.

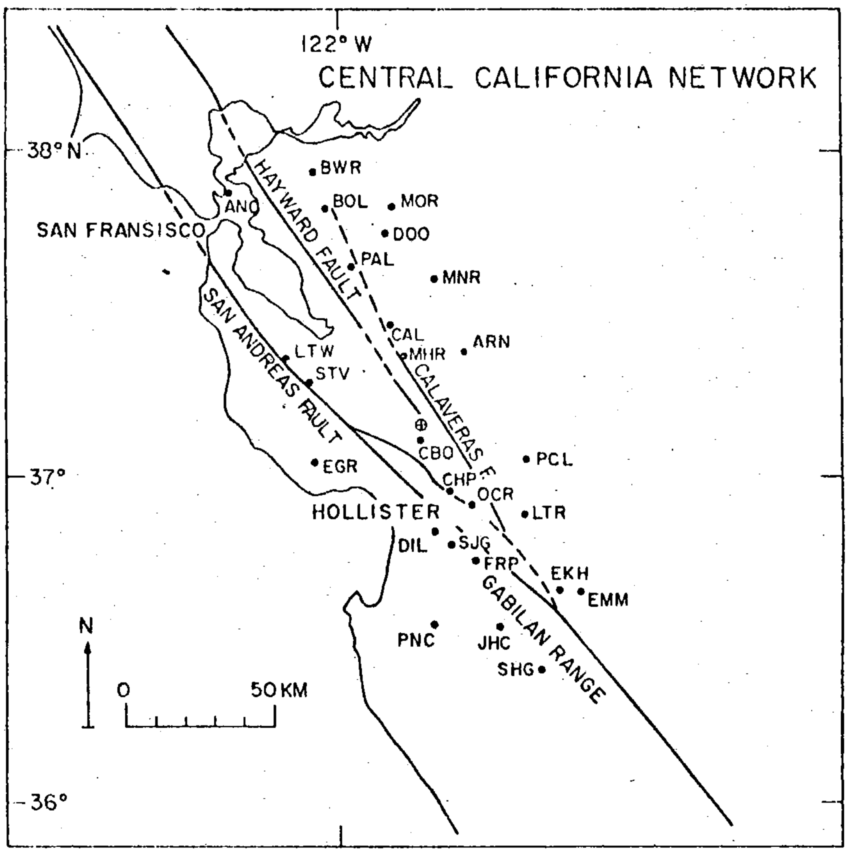

Fig. VII.2.3 U.S. Geological Survey Central California Seismograph stations used in the present analysis.

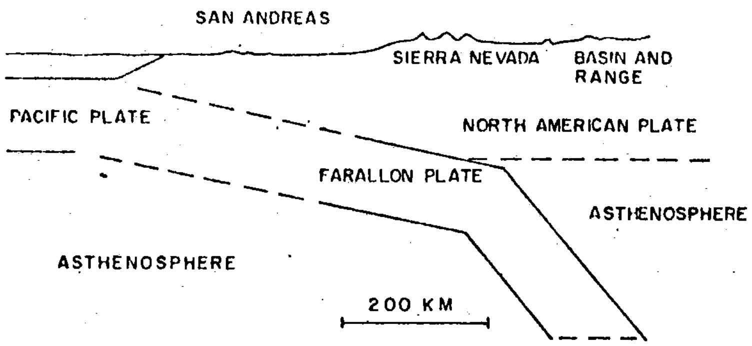

Fig. VII.2.4 A schematic cross-section of hypothetical plate boundaries reproduced from Solomon and Butler (1974).

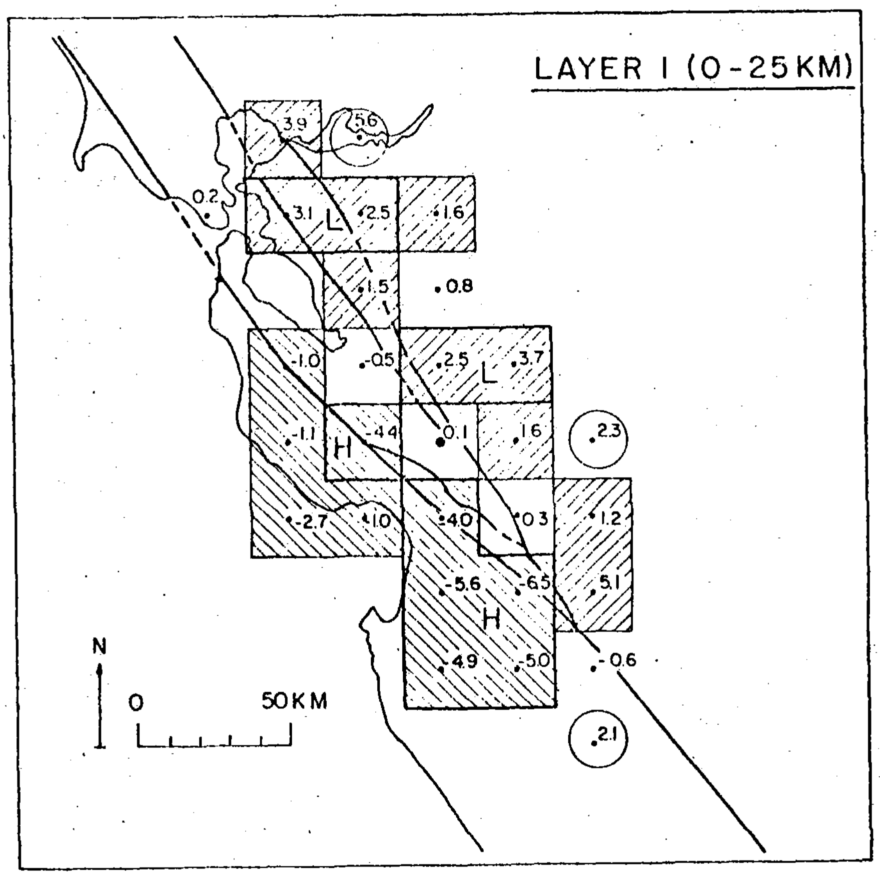

Fig. VII.2.5 Generalized inverse solution for Layer 1. The numbers show the fractional slowness perturbation in per cent of the average layer slowness. The heavy shaded areas correspond to the magnitude of solution greater than twice the standard error. The letters L and H refer to low and high velocity anomalies respectively. Blocks not properly resolved are encircled. The network center is marked by a larger solid circle.

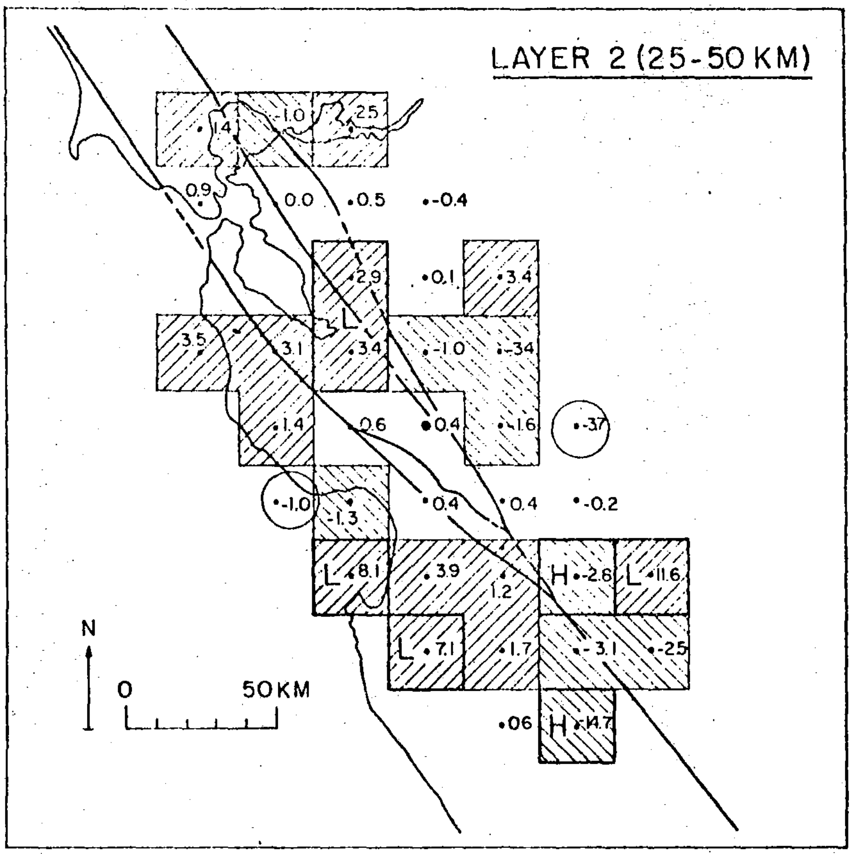

Fig. VII.2.6 Generalized inverse solution for Layer 2. See Fig. VII.2.5 for explanation of symbols.

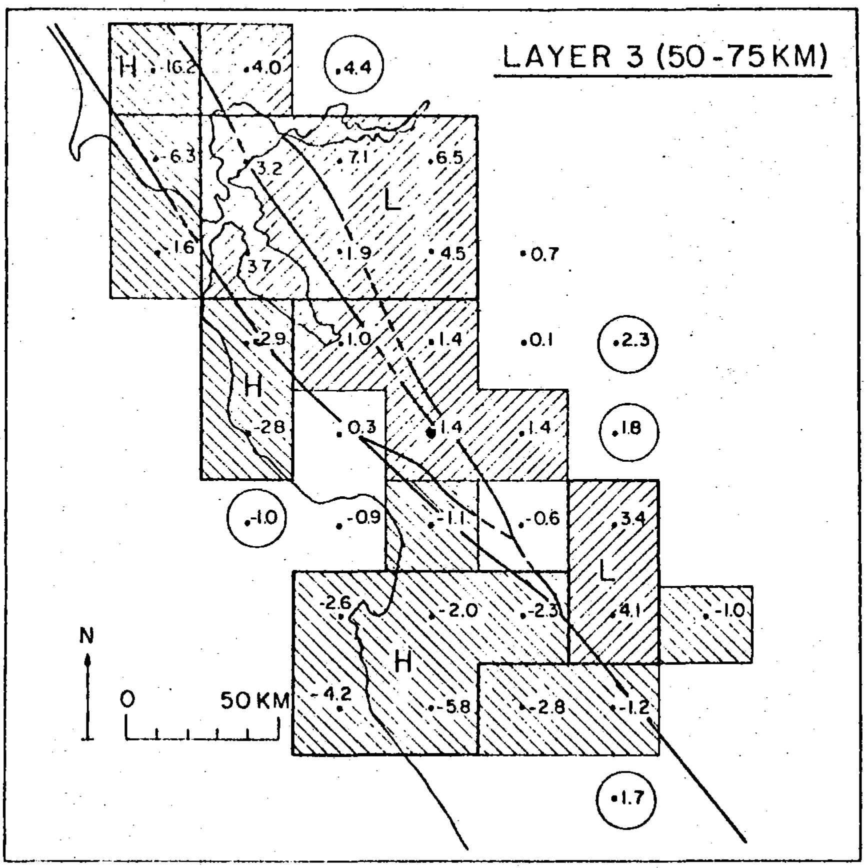

Fig. VII.2.7 Generalized inverse solution for Layer 3. See Fig. VII.2.5 for explanation of symbols.

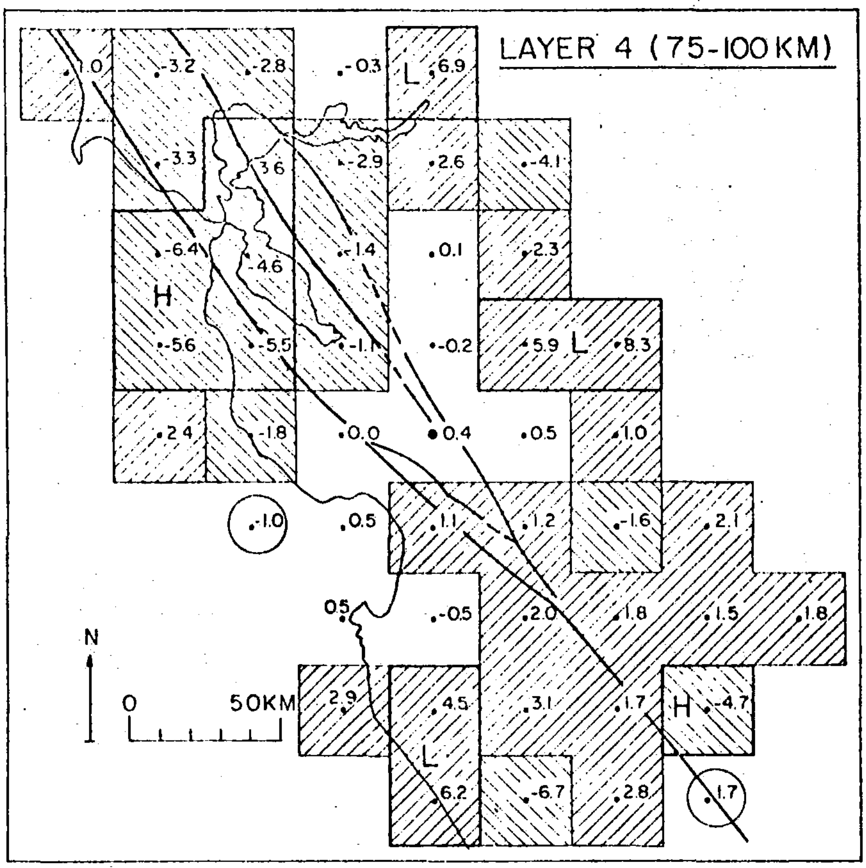

Fig. VII.2.8 Generalized inverse solution for Layer 4. See Fig. VII.2.5 for explanation of symbols.

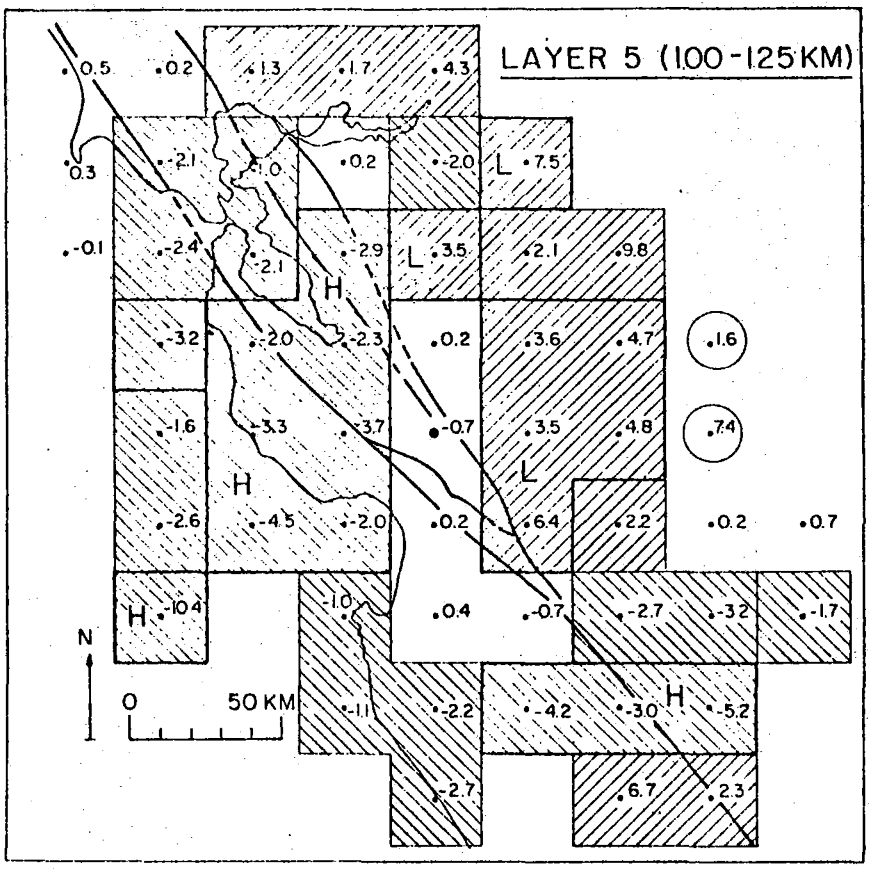

Fig. VII.2.9 Generalized inverse solution for Layer 5. See Fig. VII.2.5 for explanation of symbols.