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TEM Mapping Along the Longitudinal Valley in Eastern Taiwan and Their Tectonic Implications

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ABSTRACT

The Transient Electromagnetic (TEM) method was used to map geoelectric structures beneath the Longitudinal Valley, eastern Taiwan. Coincident loop configurations with square transmitting loops 90 to 200 m on each side were used for this survey. More than 300 soundings were conducted in this valley during 1991-1993. Field data were inverted by the adaptive nonlinear least-squares technique. The sounding depths were more than 200 m beneath the Longitudinal Valley. A 3D resistivity image of the Longitudinal Valley was obtained. The resistivity patterns in the western part of the Longitudinal Valley are apparently higher and relatively more heterogeneous, in contrast with a resistivity which is on average lower and relatively less homogeneous in the eastern part of the Longitudinal Valley. This feature correlates well with the surface geology of the area. Moreover, the TEM soundings show that one predominant NNE-trending electrical transition in the Longitudinal Valley agrees well with the known suture trace on surface between the Philippine Sea and the Eurasian plate. On the basis of the resistivity pattern at different depths, the crust in this area is subject to a horizontal compressional stress oriented preferentially along the NWW-SEE direction. That the Longitudinal Valley is undergoing severe compression by the Philippine Sea plates can also be recognized. However, due to the limited depth of exploration, deeper investigations are needed to completely resolve the actual tectonic features.

(Key words: The Longitudinal Valley, TEM mapping, Plate boundary)

1. INTRODUCTION

Taiwan is located on the convergent boundary between the Eurasian plate on the west and the Philippine Sea plate on the east (Figure 1a). The Longitudinal Valley of eastern Taiwan is believed to be the suture zone between these two plates (Chai, 1972; Biq,1972; Ho,1982; Angelier *et al.*, 1986). This long and narrow valley separates the Central Range

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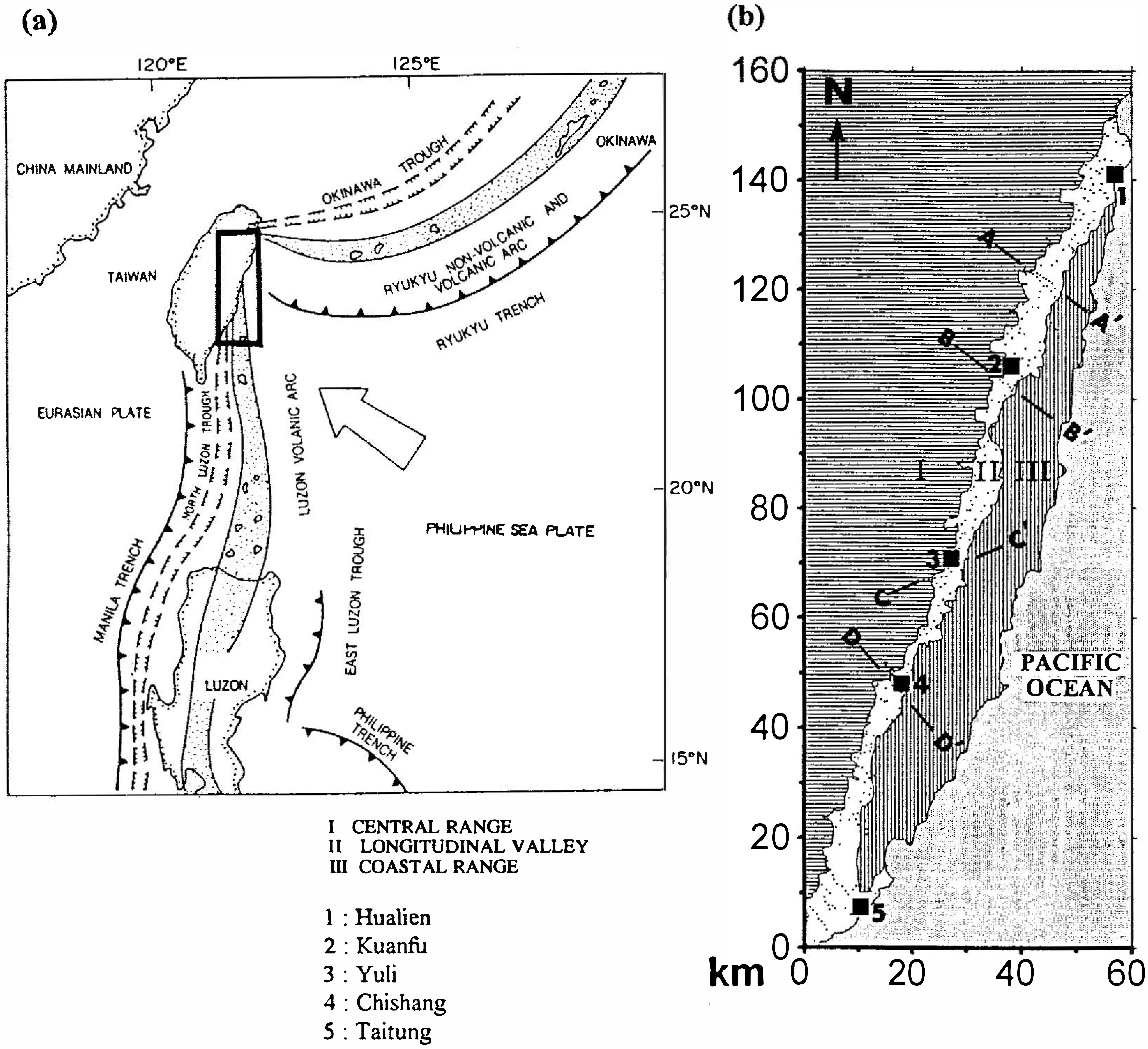

Fig. 1. (a) Plate tectonic setting of Taiwan and its environs (Ho, 1988). The TEM survey area is indicated in the box. (b) Location map of study area showing more than 300 TEM sounding locations as indicated by the black dots and four profiles AA', BB', CC' and DD'.

from the Coastal Range between the cities of Hualien and Taitung in eastern Taiwan (Figure 2).

The Longitudinal Valley is approximately 150 kilometers long and 3 to 6 kilometers wide, averaging 4 kilometers in width. The Valley contains about a 2-km thickness of a alluvium as measured by seismic refraction studies (Tsai *et al.*, 1974). The fault origin of the Longitudinal Valley has been recognized for a long time. Active faulting is indicated by high seismicity, many historical great earthquakes and fault scarps that cut the alluvial deposits of the valley floor (Allen, 1962). Nevertheless, due to the rapid erosion rate and thick alluvial cover, exposures of the actual fault surface can rarely be observed. Although several outcrops of the Central Range fault have been found and reported by Hsu (1976), gravity and magnetic surveys were conducted by Hu and Chen (1986), Yeh and Yen (1991);

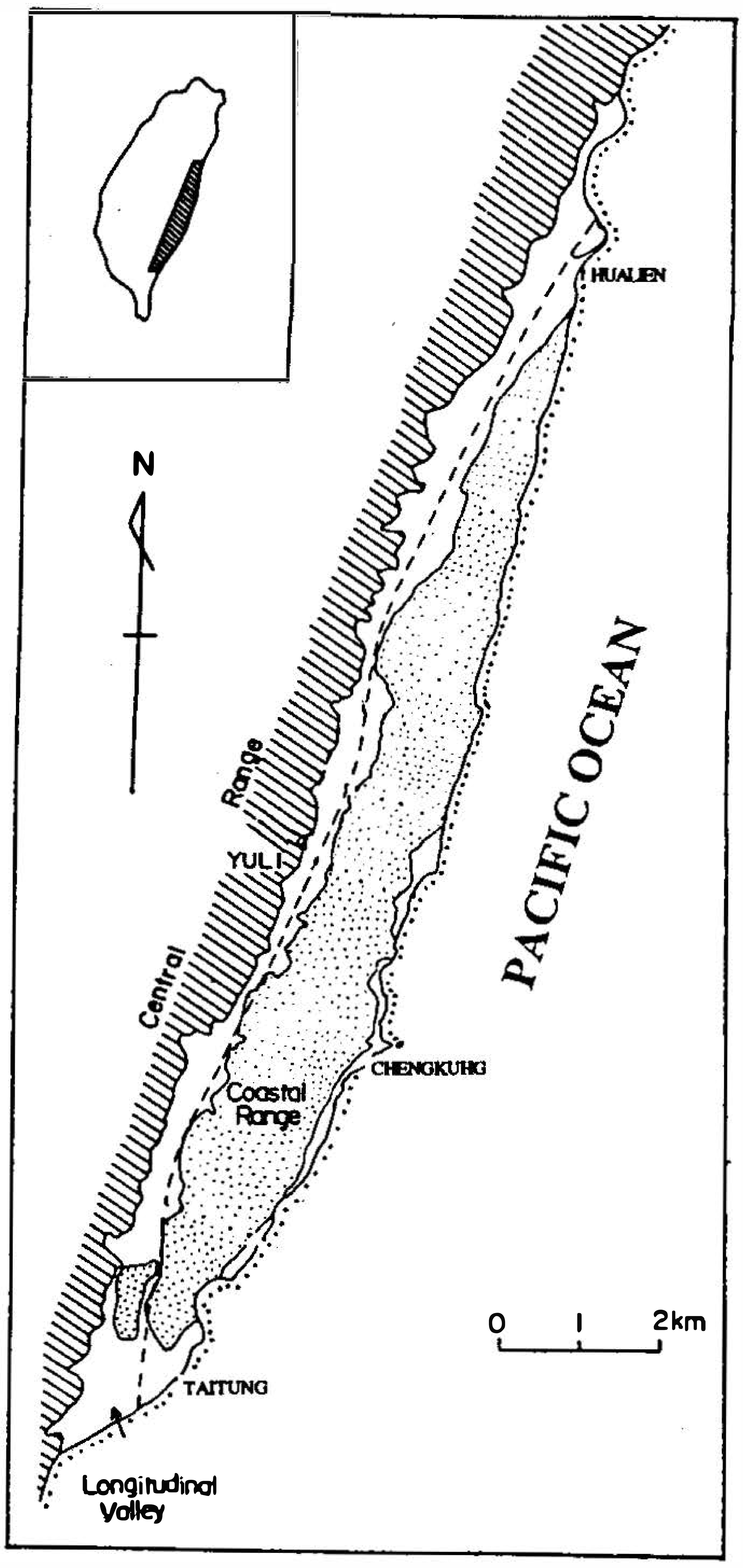

Fig. 2. Location map of the suture line along the Longitudinal Valley as indicated by dashed line. (after Ho, 1988; Teng *et al.*, 1988).

trilateration and leveling networks traversing the Longitudinal Valley have been surveyed by Yu and Liu (1989); and the suture line and plate boundary along the Longitudinal Valley was discussed by Ho (1982) and is mapped in Figure 2 with the dashed line. This has been widely quoted when geologic observations in the Longitudinal Valley have been interpreted.

The purpose of this study is to detect the subsurface structure and locate the Longitudinal Valley fault by using a new geophysical technique, the Transient Electro-magnetic (TEM) method. The TEM was originally used to locate massive sulfides. Its fast parametric soundings with considerable resolution allow for its use in situations where knowledge of the geoelectric section is required.

2. TEM DATA ACQUISITION AND PROCESSING

The principle behind the TEM method of geophysical prospecting is a very simple one (Figure 3). The driving current flowing in a transmitter loop sets up a magnetic field (solid line in the transmitter loop in Figure 3) and induces eddy currents which flow in any electrical conducting layers in the ground when the driving current is switched off. These eddy currents set up a secondary magnetic field (dashed line in the receiver loop in Figure 3) which can be detected by a receiver loop. The recording of the transient voltage is a means of detecting conducting layers in the ground. The decaying transient voltage can be recorded at various delay times during the quiet time between current pulses. The character of this decayed transient voltage (duration, amplitude, etc.) mainly depends on the conductivity and depth of the conducting layers. TEM sounding is unlike other geoelectric soundings in that the receiver-transmitter array does not need to widen to get deeper subsurface information. The depth of investigation for the TEM method is mainly a function of the recorded transient time.

For mapping structures in the Longitudinal Valley and its surrounding area, a detailed TEM survey was carried out in the Longitudinal Valley. SIROTEM TEM (Buselli and O'Neill, 1977) with the capability to measure the response in a delay time range of 0.049 to 160 ms was used. The measurements were made using a coincident-loop geometry with a transmitter loop measuring 90 to 200 m on each side depending on site space. More than 300 soundings were conducted in this valley (Figure 1b) during 1991-1993.

To aid in the qualitative interpretation and inversion, transient voltages of each sounding were transformed into apparent resistivities (Spies and Raiche, 1980). Apparent resistivity is the resistivity of a homogeneous earth which would produce the measured transient voltage at a single time. All of the TEM soundings were then inverted by nonlinear least-squares curve fitting for quantitative interpretation (Dennis *et al.*, 1981; Anderson, 1982). A good result fits all of the field data by using two to four layer models. Some of the typical apparent resistivities and their inverted results are shown in Figure 4. Consequently, in the absence of other geophysical or geologic information strongly suggesting the use of models with more layers, this model for interpretation was used in this research.

3. RESULTS

To assess the subsurface structures qualitatively, four apparent resistivity contour maps with a selected delay time equal to 1, 3, 5 and 10 ms respectively were drawn in time slice maps and then organized into a 3D plot. Furthermore, in order to interpret the subsurface structure quantitatively, four profiles AA', BB', CC' and DD' were prepared from the inversion results of the TEM data.

3.1 Time Slices

Theoretically, TEM is a time sounding tool; the response of early time reflects the shallow strata while the late time reveals the deep structures. This means that time slices are analogous to depth slices. Each time slice in the Longitudinal Valley (Figure 5) displays the tendency for resistivity to decrease toward an easterly direction. Such tendencies may be associated with the regional geologic change from the continental crust (high resistivities) to the oceanic crust (low resistivities).

For the sake of greater clarity, the trend surface analysis technique (Davis, 1973) was used to separate each time slice map into two components – those regional nature and those local fluctuations. Figure 6 shows the results of a 1 ms slice map after being processed by trend surface analysis techniques. Here the observed data (Figure 6a) are used to compute, by

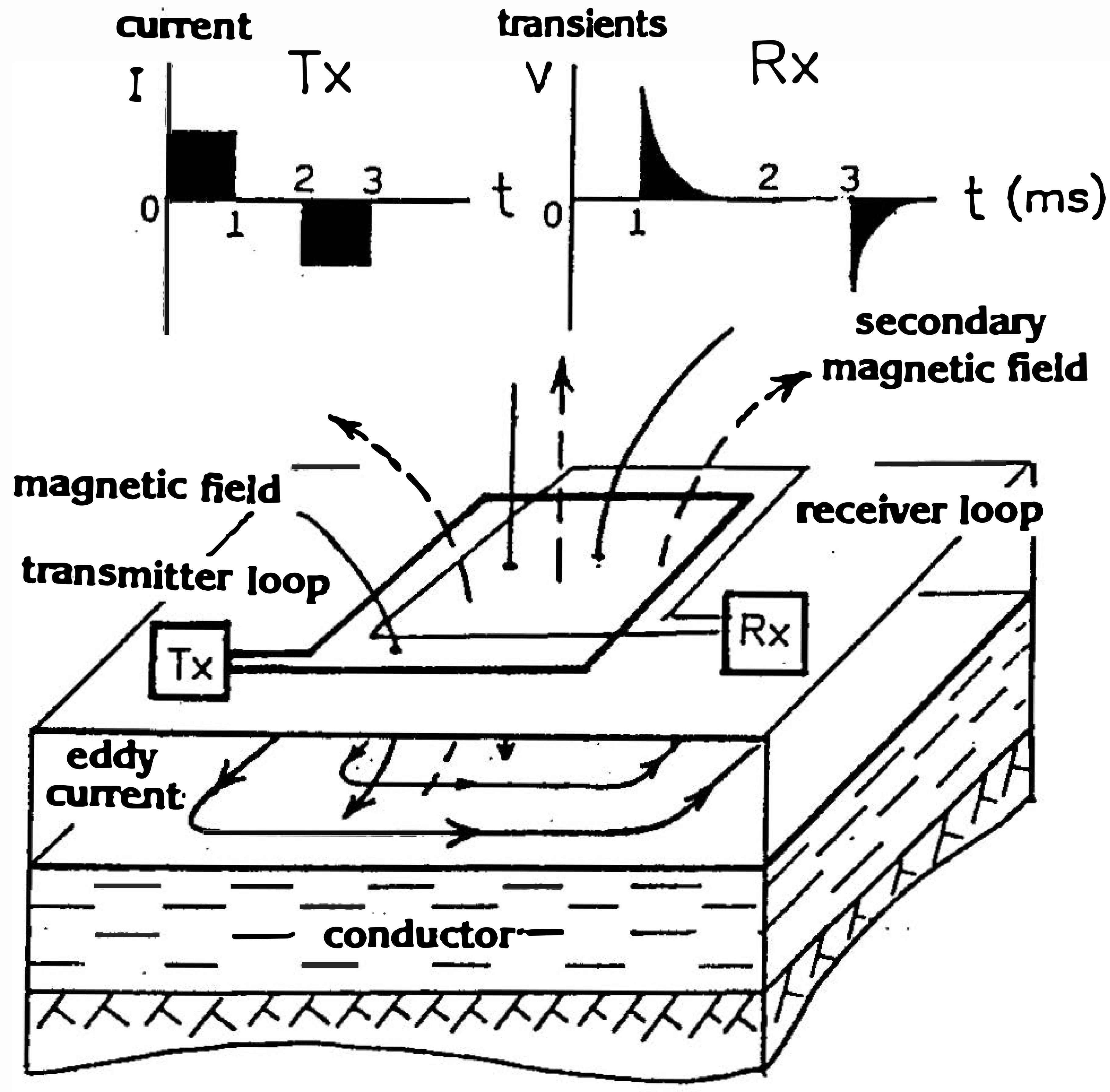

Fig. 3. Principle of the TEM sounding: The driving current flowing in a transmitter loop sets up a magnetic field (solid line in the transmitter loop) and induces eddy currents to flow in any electrical conducting layers in the ground as the driving current is switched off. These eddy currents set up a secondary magnetic field (dashed line in the receiver loop) which can be detected by a receiver loop. The recording of the transient voltage is a means of detecting conducting layers in the ground.

least squares, the mathematically describable surface (first order trend surface for this case) giving the closest fit to the resistivity field that can be obtained within a specified degree of detail. This surface is considered to be the regional resistivity (Figure 6b), and the residual (Figure 6c) is the difference between the resistivity field as actually mapped and the regional field thus determined.

After the removal of the local anomalies (Figure 7), the regional resistivity of each time slice was organized in a 3D plot as shown in Figure 8. Figure 7 shows remarkable irregularities which may have resulted from local complexities or even from measuring noise. To better understand the whole idea of the Longitudinal Valley, the regional patterns are the focus in this study. The SSW-NNE trend of the resistivity contours in the Longitudinal Valley (Figure 8) is rather clear in each time slice. The regional diagram when compared to the diagram before the trend surface analysis reveals clear information about the structure's identification; that is, the resistivity patterns in the Longitudinal Valley reveal the transition from the continental crust on the west to the oceanic crust on the east. The refinement of images of the TEM data by proper filtering is of significance especially for the complicated structures frequently met near the plate boundary.

The suture line and plate boundary along the Longitudinal Valley which was discussed by Ho (1982) is also drawn in the 3D time slices (Figure 9) to facilitate correlation. It is clear that at the deepest slice (i.e. a 10-ms slice which is about 300 m by skin depth approximation)

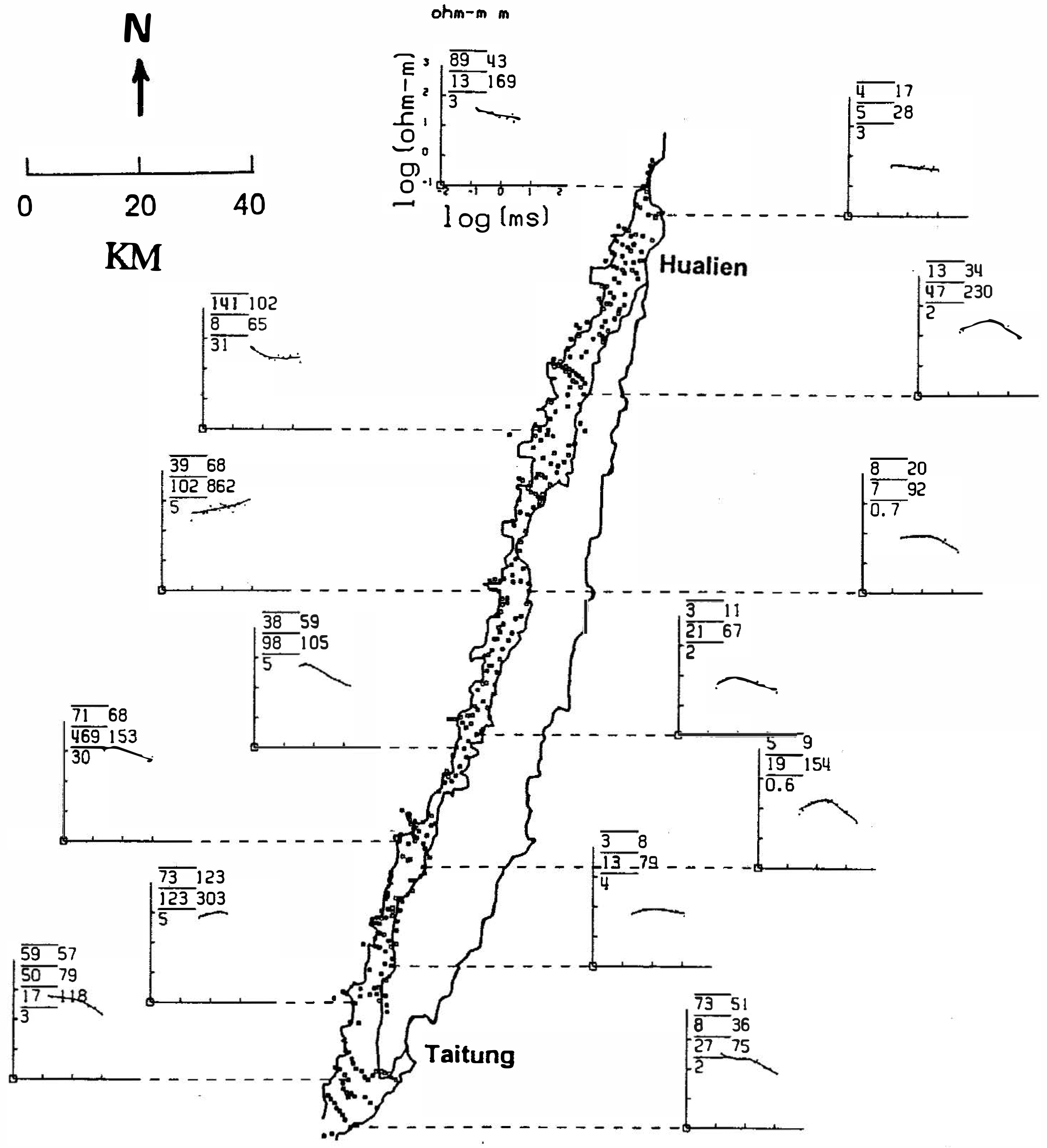

Fig. 4. Some typical field data and their inverted results of the TEM soundings in the Longitudinal Valley, Taiwan. In each sounding, dots are field data; the curve is the model value.

the isoresistivity line of approximately 25 ohm-m correlates with the suture line better than with others. Consequently, this isoresistivity line may be selected as geoelectric suture line. The suture line detennined by the TEM is situated along the eastern flank of the Central Range in the southern Longitudinal Valley, and it systematically changes along the western flank of the Coastal Range in the northern Longitudinal Valley. However, different locations between the geoelectric and geologic suture lines in the southern part of the Longitudinal Valley do exist. One of the most probable explanations is that the ground water distributions mask the suture anomaly as the electrical resistivity is more sensitive to variations in the earth pore fluid, and the Taitung plain abounds in ground water resources.

Moreover, the direction of the compressional stress of the Longitudinal Valley, the SE-NW direction, originating from the collision between the Eurasian plate and the Philippine Sea

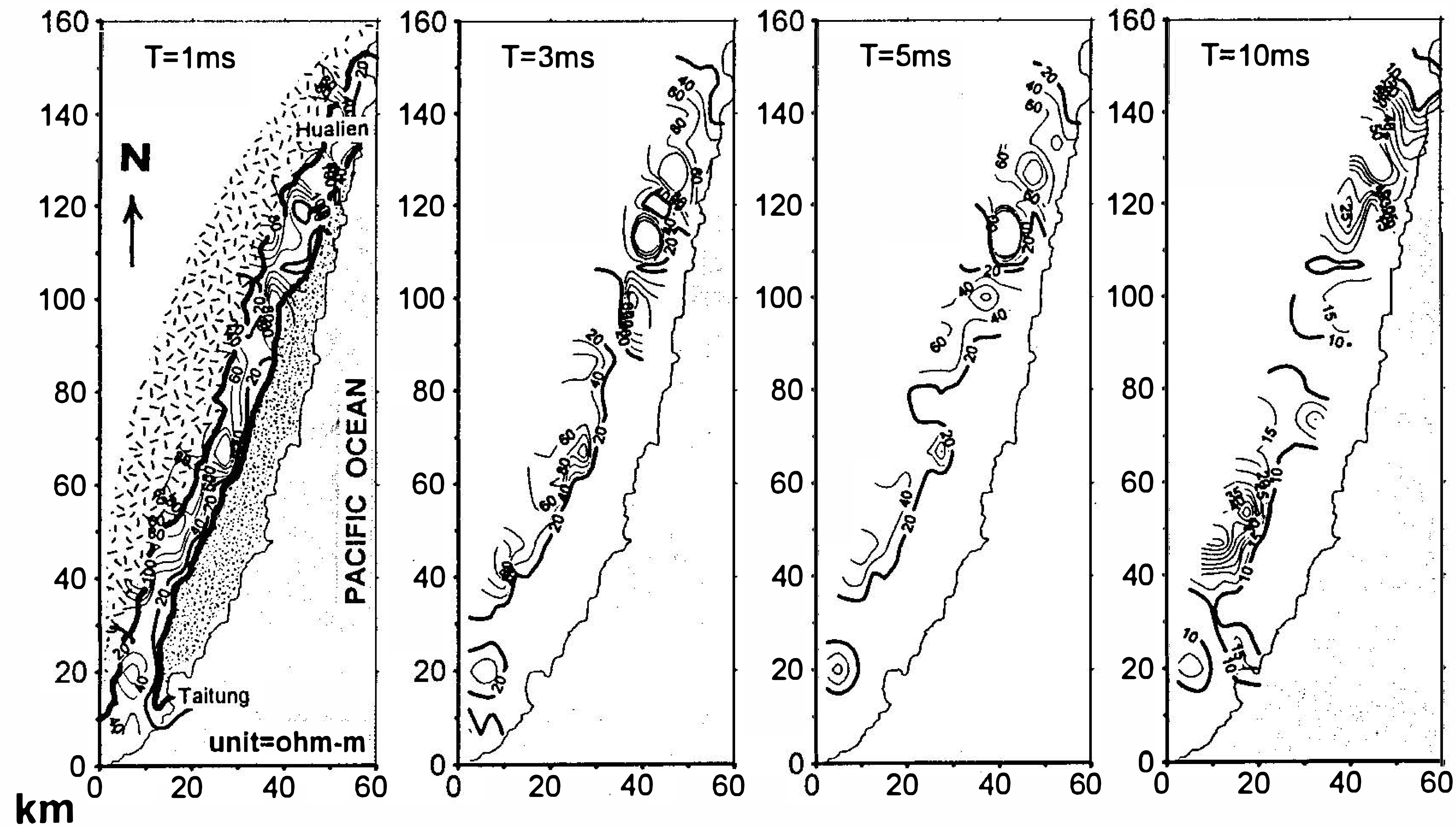

Fig. 5. Apparent resistivity contour maps of delay times T=1, 3, 5 and 10 ms in the Longitudinal Valley, Taiwan. The bold lines (20-10 ohm-m) indicate low resistivity boundaries.

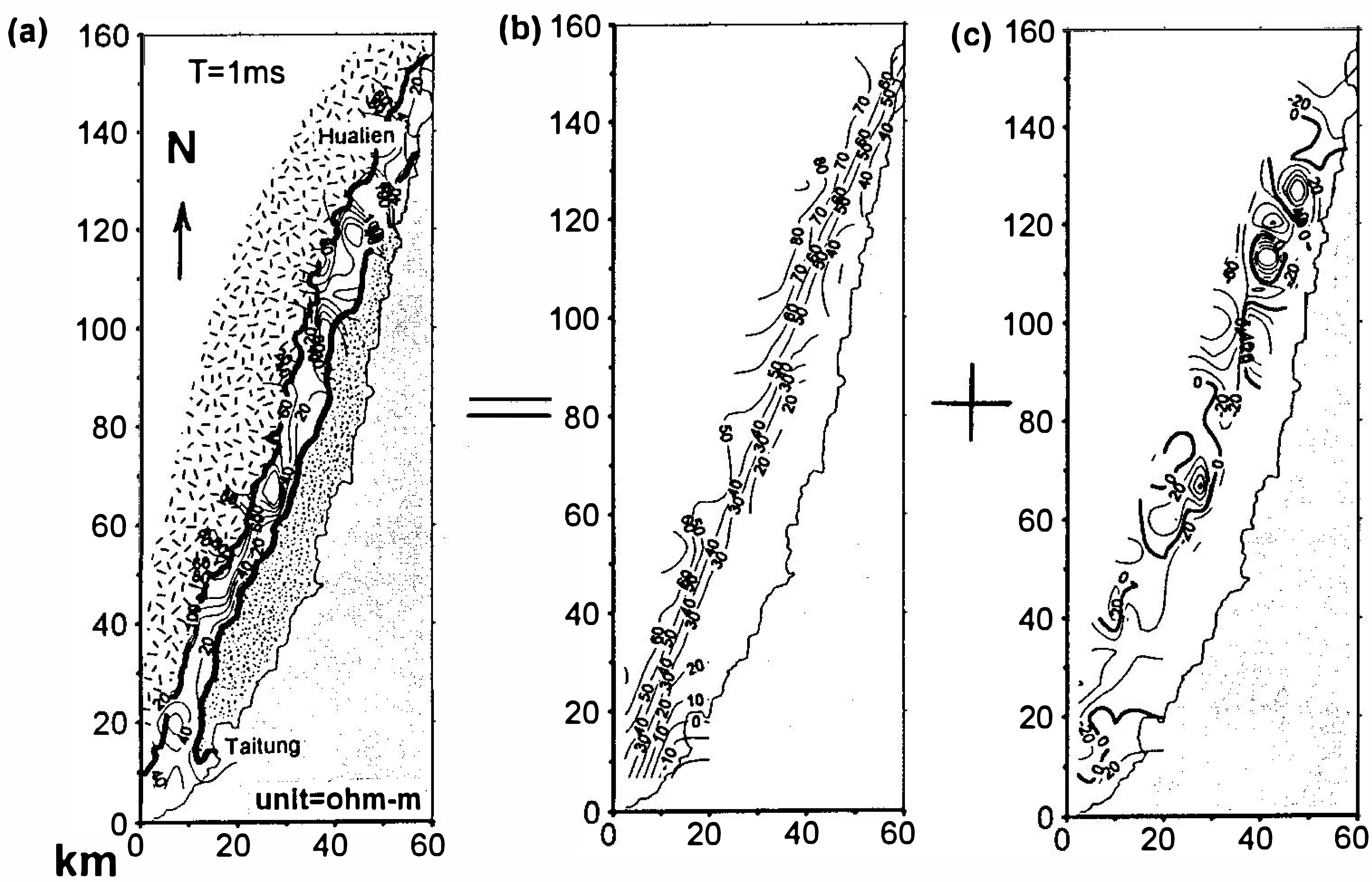

Fig. 6. (a) Resistivity contour map at the delay time of 1 ms in the Longitudinal Valley area. (b) First-degree trend surface. (c) Contoured residuals from the first-degree trend surface. Regional trend apparently shows the resistivities of the NNE trend which are hardly discernible on the observed resistivity map in (a).

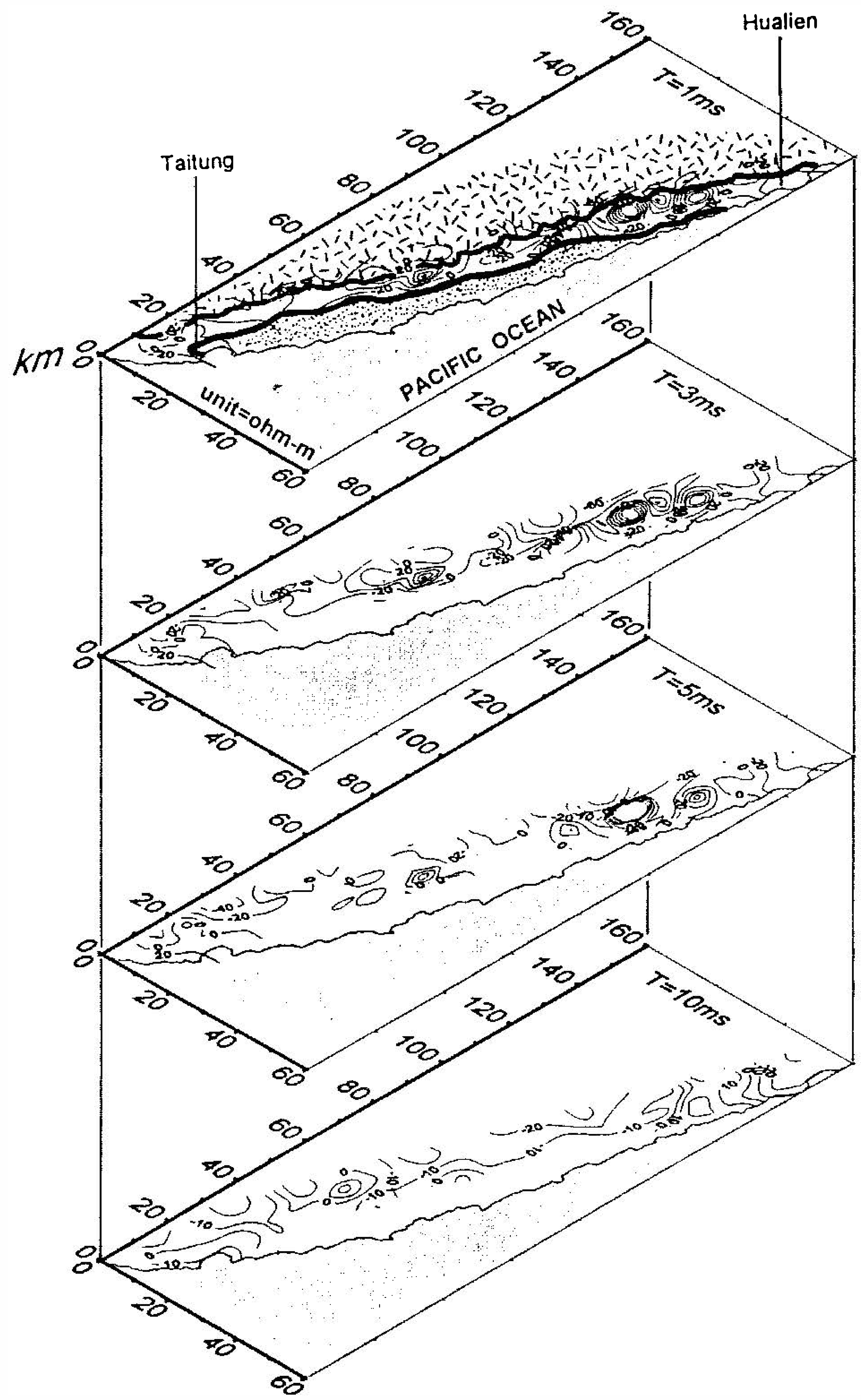

Fig. 7. Residual apparent resistivity contour maps at the delay times (a) 1 ms, (b) 3 ms, (c) 5 ms and (d) 10 ms after trend surface analysis.

plate was determined by using focal mechanisms of earthquakes (Barrier, *et al.*, 1982; Tsai, 1986; Suppe,1981). Because continued stress pushes both the oceanic and continental crusts to collision which eventually becomes the present resistivity patterns (Figure 9), the normals to the resistivity contour lines might be used to trace the paleostress in the Longitudinal Valley.

3.2 Profiles

In order to interpret the subsurface structure quantitatively, four profiles AA', BB', CC' and DD' were prepared from the inversion results of the TEM data, and then organized in Figures 10(a), (b), (c) and (d), respectively. The locations of the profiles in the Longitudinal Valley can be referred to in Figure 1b.

The AA' profile, 7 km in length, trending approximately SE crossed the northern Longitudinal Valley. Figure 10a illustrates the results of TEM sounding on this profile and the

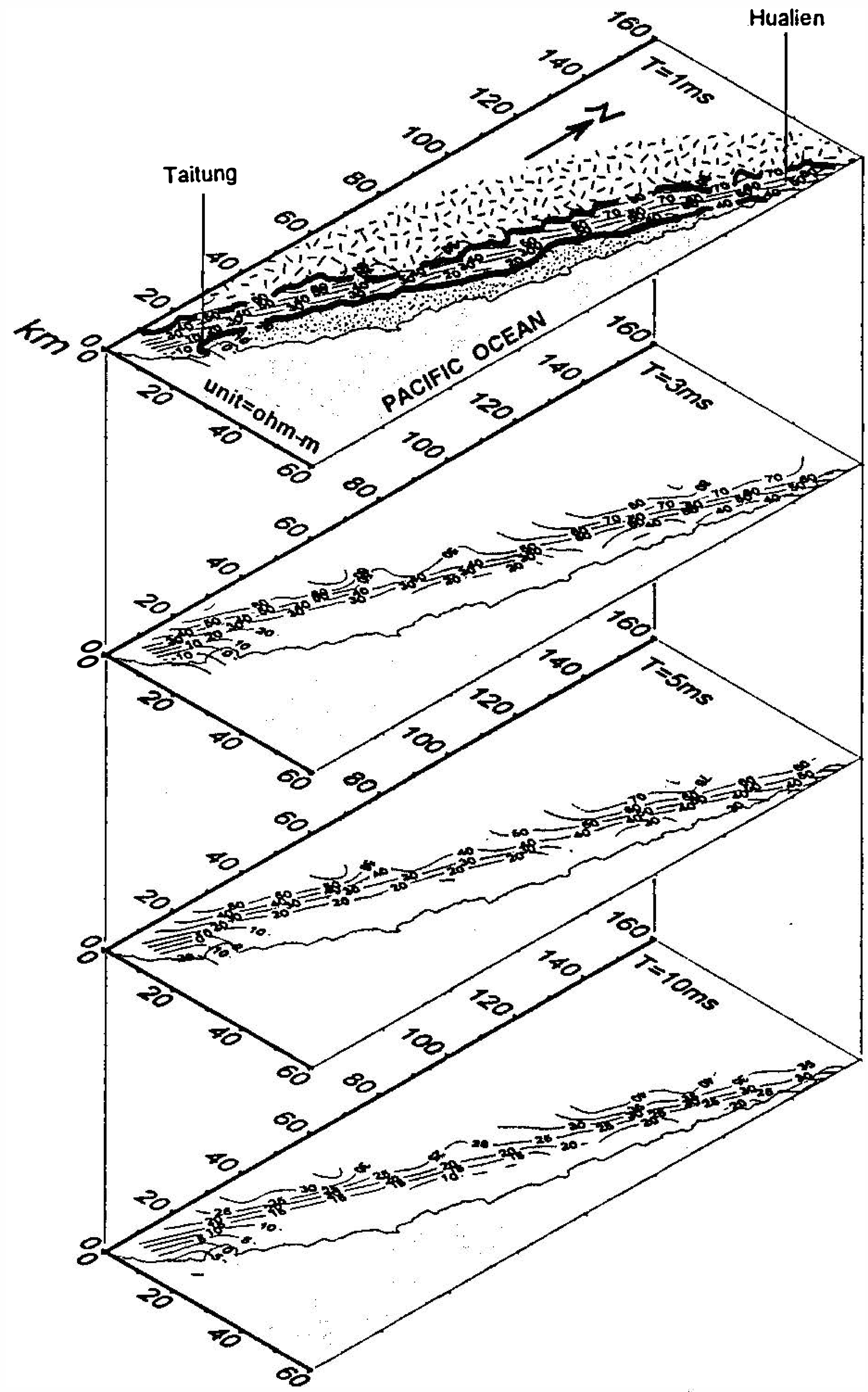

Fig. 8. Apparent resistivity contour maps at delay times (a) 1 ms, (b) 3 ms, (c) 5 ms and (d) 10 ms after the removal of residuals by trend surface analysis.

surface topography. The triangles indicate the sounding points. The interpreted positions of the layers and their resistivities in ohm-m are shown in Figure 10a. As expected, the TEM results show the presence of distinct resistivity discontinuities in the valley. This valley contains alluvium (high resistivities) with a thickness more than 300 m in the middle which is bounded by oceanic crust (low resistivities) on the eastern side and continental crust (medium resistivities) on the western side. Both contact lines are parallel and extend to depths of more than 400 m.

The BB' profile (Figure 10b), 6 km in length, trending approximately SE crossed Kuanfu. Generally speaking, the geologic section of this profile is the southern extension of profile AA'. High resistivity alluvium is in the middle and is bounded by low resistivity oceanic crust on the eastern side and medium resistivity continental crust on the western side. Again the two contact lines are parallel and extend to depths of more than 200 m. It should be noted that the alluvium resistivities when deeper than 200 m become extremely low, less than 1 ohm-m in this case, which is warning of a too low signal to noise ratio; therefore

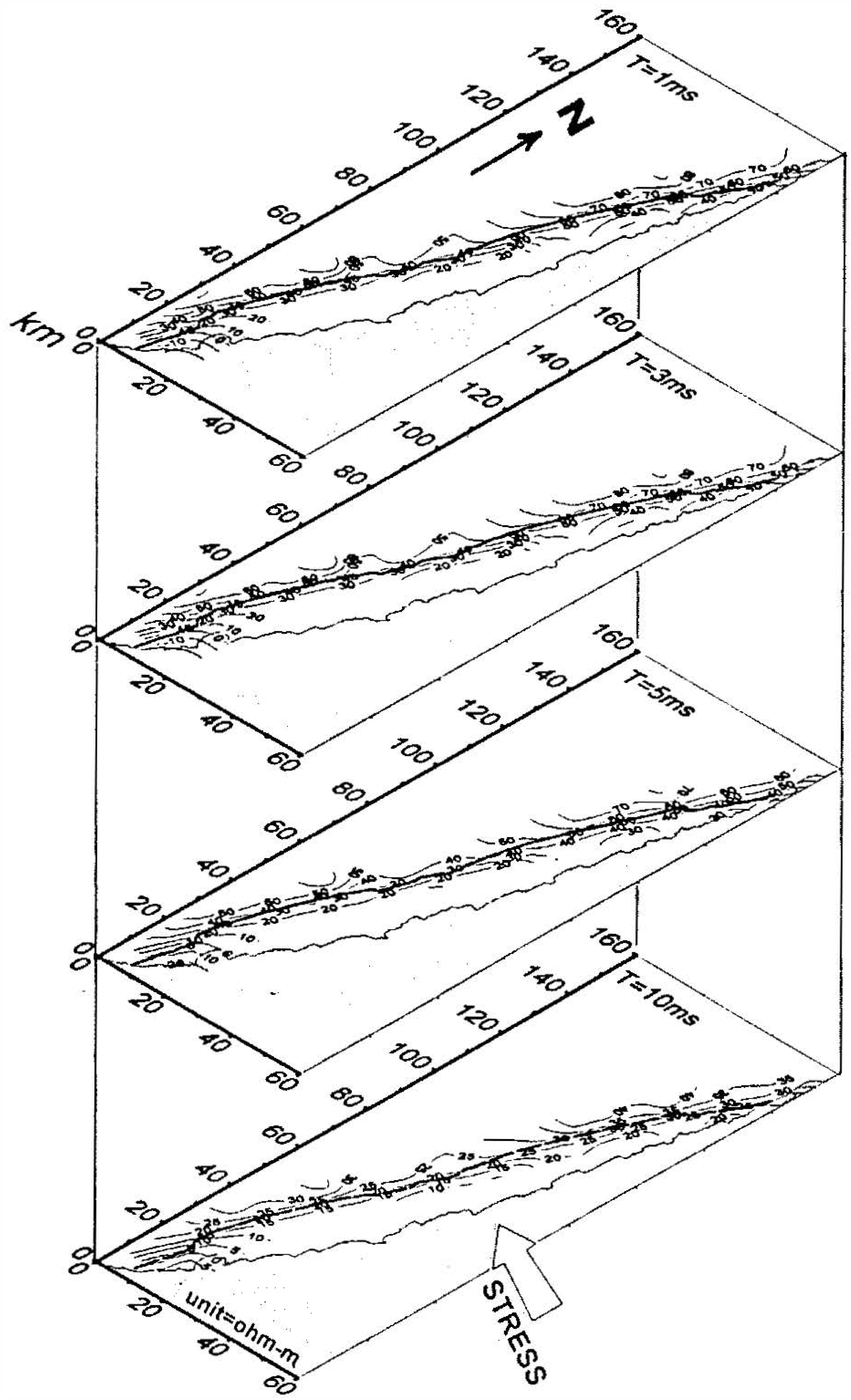

Fig. 9. 3D apparent resistivity regional map superimposed by the known suture line (bold line) of the Longitudinal Valley indicated in Fig. 2. A geoelectric suture line (approximately 25 ohm-m at 10 ms) between the two crusts is suggested from this study; the crusts being subject to a stress oriented in the NWW direction is also inferred.

these kinds of low resistivity values are incorrect. A larger loop was needed to improve the signal strength. The resistivities correlated to this alluvium layer in the AA' profile, where bigger loops were employed, and resulted in normal resistivity values at great depths, thereby proving these arguments.

The CC' profile(Figure 10c), 8 km in length, trending approximately NE crossed Yuli. There is marked difference from the above sections; both contact lines were pushed westward. Judging from these geoelectric features, the crust here had been subject to a severe horizontal westward stress in the past.

The DD' profile (Figure 10d), 9 km in length, trending approximately SE crossed Chihshang. This southernmost profile is the key section witnessed the collision of the two plates. Other than the three distinct resistivity regions and the two contact lines aforementioned, the two contact lines were merged together which is clearly visible in the central area of this profile at a depth about 200 m near Chihshang. This phenomenon is most probably related to the fact that the Longitudinal Valley has undergone the most severe compression-closure action in this region. However, due to the limited data distributed in the whole valley, the resolution of those boundaries could not be accurately estimated. The results are in reconnaissance stage. More studies are required to refine and correct the present knowledge of the behavior of plate boundary and the history of the tectonic evolution of this region.

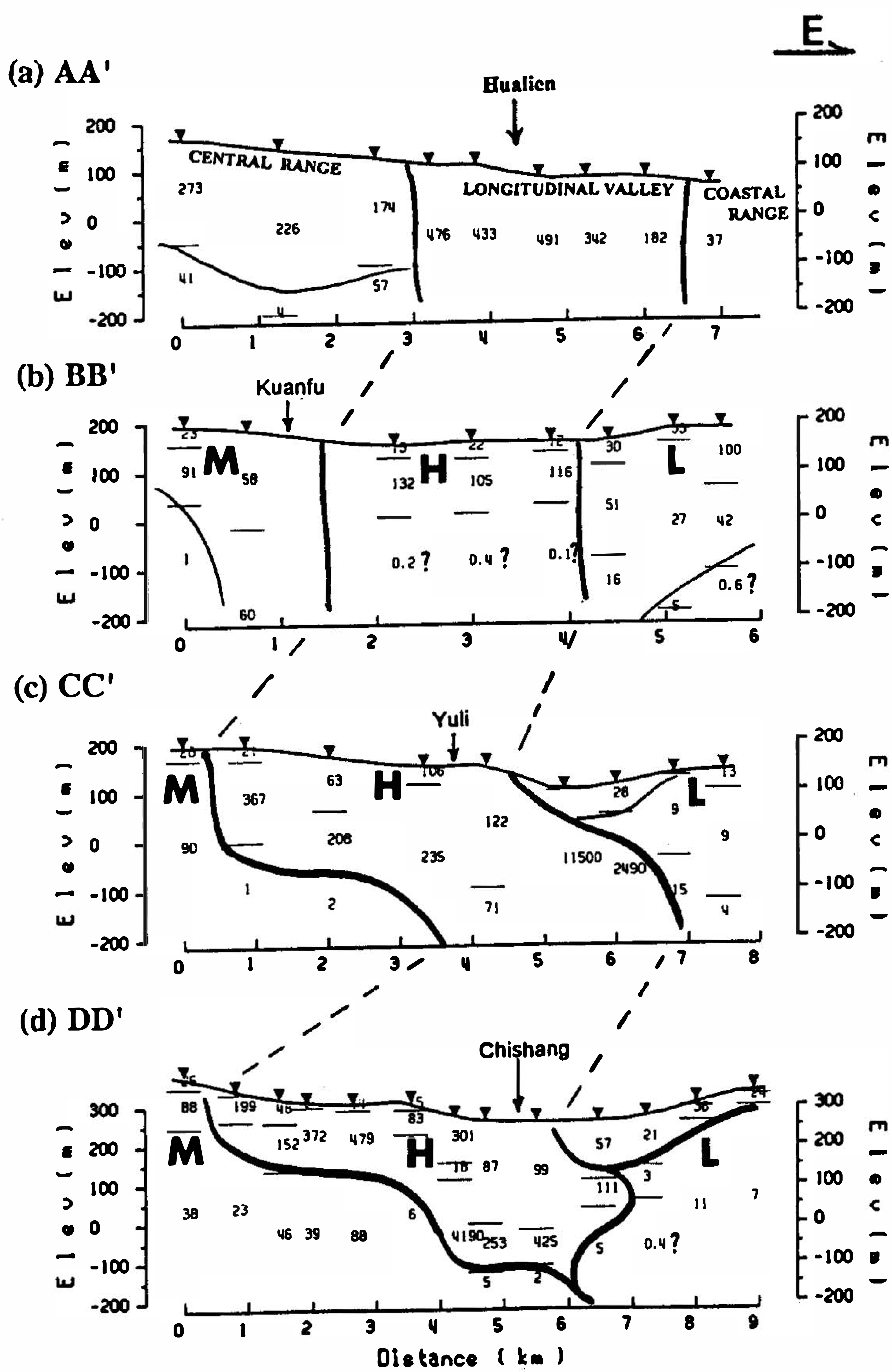

Fig. 10. Geoelectric section of profiles AA', BB', CC' and DD' in Fig. 1a. The triangles indicate the sounding points. The interpreted positions of the layers and their resistivities in ohm-m are also shown. Dashed lines connect geoelectric boundaries among sections for reference.

4. CONCLUSIONS

Based on the results, more than 300 TEM soundings carried out in the Longitudinal Valley, eastern Taiwan, a 3D resistivity image and four profiles of the geoelectric sections were obtained. The resistivity patterns in the western part of the Longitudinal Valley are apparently higher and relatively heterogeneous, in contrast with an average lower resistivity and relative homogeneity in the eastern Longitudinal Valley. This feature correlates well with the surface geology of the Longitudinal Valley. Moreover, the TEM soundings also suggest tectonic implications. For example, one predominant electrical transition trending NNE can be delineated in the Longitudinal Valley, and it agrees well with the known suture trace on surface between the Philippine Sea and the Eurasian plates. On the basis of the resistivity pattern at different depths, it can be inferred that the crust in this area is subject to a horizontal compressional stress oriented preferentially about the NWW-SEE direction. It can also be recognized the Longitudinal Valley is being undergone the most severe compression-closure action of the Philippine Sea plates.

The results presented in the paper did show that the TEM sounding method is useful for deep geologic mapping, especially for the detection of lateral boundaries, such as contacts and faults, where no detailed geological information is available. Such techniques will be helpful in the areas of complicated structures frequently met in Quaternary geology near earthquake belts.

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