Z-99 Interpretation of data of shallow refraction seismic by homogeneous functions method: structure of the 1912 ignimbrite, Alaska

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Abstract

Method of inversion of refracted traveltime curves by homogeneous function is very effective. This is fully automatic method of 2-D simple inversion and it has no limitations in respect to variations of velocity in horizontal and vertical directions and also in respect to existence of seismic boundaries - lines of sharp changes of velocity. This method is applicable to any system of observation: from minimal - (two reversal traveltime curves) to maximal when sources and receivers are spaced with equal intervals. In respect to details the resulting cross section always corresponds to the system of observation. Process of inversion consumes little time and thus this method is very useful for interpretation of data of shallow refraction seismic as well as for reinterpretation of old seismic data. In this paper we show efficiency of the method reinterpreting data (originally obtained in the 1970) of seismic investigations of geological structure of ignimbrite sheet of the Valley of Ten Thousand Smokes (Alaska).

Interpretation method

Progress in interpretation of data of refracted waves is commonly associated with two methods: tomography and modifications of the method of ray tracing. The first one demands very detailed system of observations, which usually cannot be applied in the case of shallow seismic. The interpretation by methods of ray tracing is very time-consuming. Thus data of engineering seismic are usually interpreted by traditional methods. These methods postulate that the geological cross section consists of homogeneous layers that is not always in case. The traditional methods of interpretation are interactive and cannot be completely automatic Method of homogeneous functions (Piip 2001) is completely automatic procedure exercising simple inversion of traveltime curves of the first arrivals to 2-D inhomogeneous velocity cross section, which contains seismic boundaries as well as both steep and gentle faults. Method is based on local approximating of real velocity distribution by homogeneous functions of two coordinates. For each pair of reversal time curves a homogeneous function is calculated. Common cross section is a superposition of different homogeneous functions and in a whole it is practically arbitrary velocity function. Such interpretation consumes little time and the system of observations usually used in shallow seismic is sufficient. The resulting seismic cross sections are very detailed and informative. This method is very effective for reinterpretation of old data of engineering seismic.

Seismic refraction profiles across the 1912 ignimbrite sheet in the Valley of Ten Thousand Smokes, Alaska

The 1912 Katmai eruption in Alaska deposited giant pyroclastic flow (ignimbrite) in the valley that later was named as Valley of Ten Thousand Smokes. To investigate thickness of the ignimbrite, seismic investigations were carried out by researchers from both the University of Alaska and the Geophysical Institute (L. Gedney et al. 1970). Length of A A' refraction profile across south branch of the valley (fig. 1, 2) was about 2300 m. In general, geophone spacing was 30 m. Shot to shot distance varied from 300 to 680 m.

Observed traveltime curves along profile A A' are shown in the fig.3. The original interpretation was produced by Wyrobek method that considers the medium to be built from homogeneous layers determined by the interpreter with approximation of the traveltime branches by straight lines. The resultant profile is represented in fig. 4. Velocity in pyroclactic deposits was determined as 0.58 km/s, velocity in bedrock was determed as 2.8 km/s. Thickness of the ignimbrite was determined as 45 - 50 m. The authors critically evaluated their interpretation. They considered that in reality the discontinuity between the base of the ignimbrite and the underlying sedimentary rock is relatively smooth and also that indications of a second layer within the flow deposit exist.

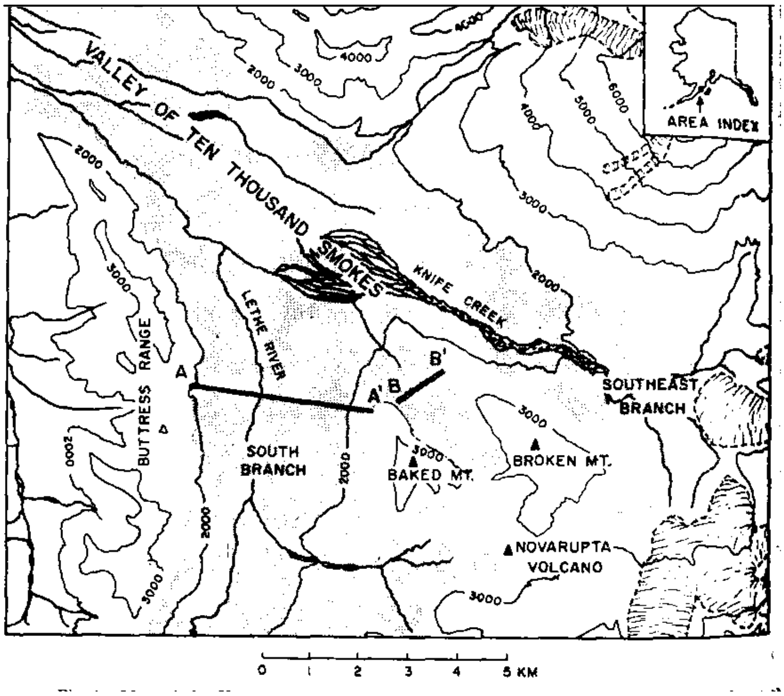

Fig.1 Map of Katmai area, showing distribution of the ignimbrite in the Valley of Ten Thousand Smokes, and location of the seismic profiles . (from Larry Gedney et al ,1970)

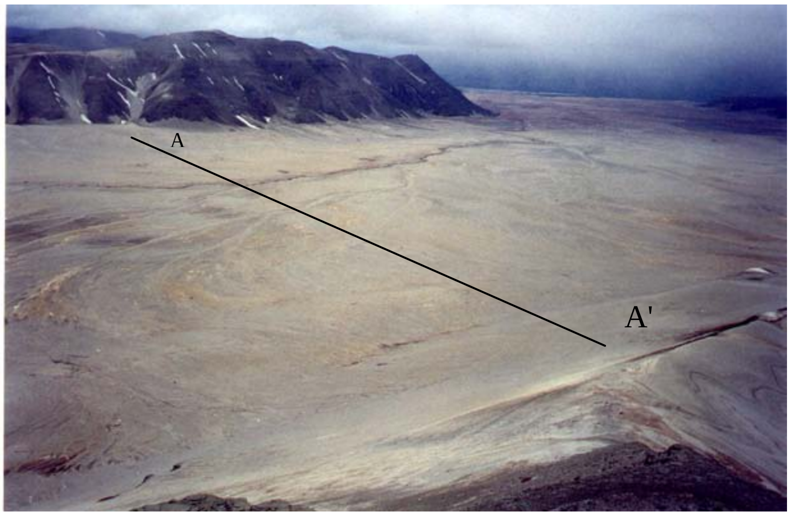

Fig. 2. Present-day view of the Valley of Ten Thousand Smokes from the Baked Mountain and location of the profile.

The traiveltime curves shown in the fig. 3. were inverted by homogeneous function method into velocity field represented by grid. The size of grid was 250 by 101 with sell size of 10 m in horizontal and of 2 m in vertical direction. To interpolate the observed traveltime curves and to compare the structures on the cross section obtained with the corresponded features on the traveltime curves we represent the traveltime curves as time section of equal distances between source and receiver (fig.5A). The main features of a cross section at depth are revealed in such a time section.

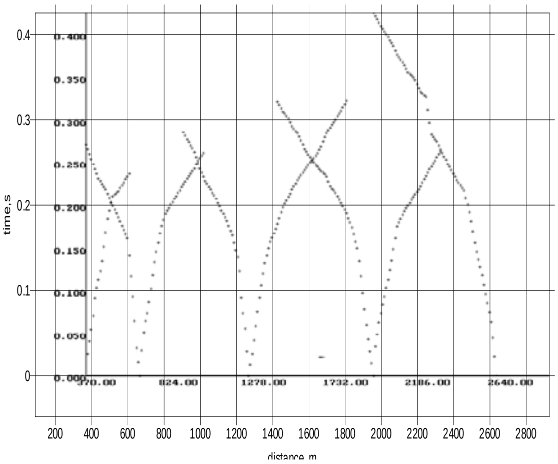

Fig.3. Traveltime curves along profile A A'

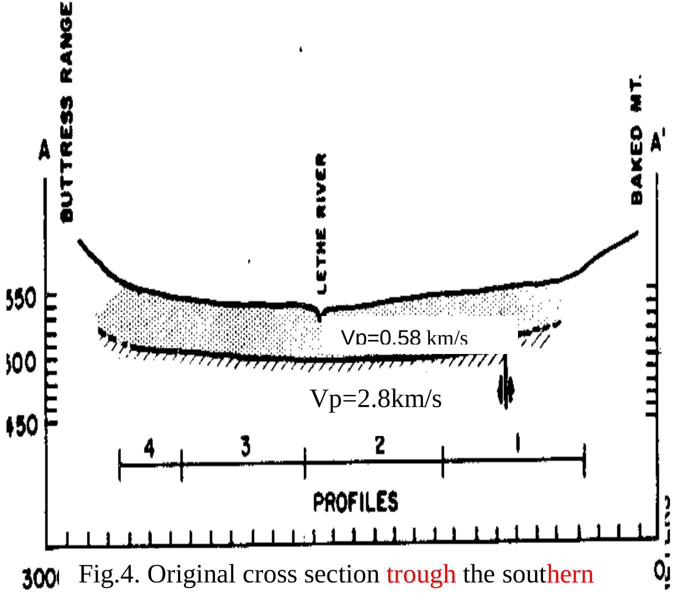

Fig.4. Original cross section trough the southern branch of the Valley of Ten Thousand Smokes along profile A A' produced in 1970.

Geological structure of the region includes bedrock represented by Jurassic-Cretaceous sandstone (Naknek Formation), which in valleys is covered by moraine of the last glaciation. The 1902 ignimbrite was probably emplaced on the surface of the moraine; layers with considerable variation in compaction and degree of welding exist within the flow deposit, as it seen in several deep ravines.

In result of inversion the velocity cross section was received (fig. 5 C). Seismic boundaries are lines where velocity changes abruptly. To distinguish seismic boundaries we calculated vertical component of gradient of velocity field and then represented the received grid as a half-tone picture (fig. 5B). In this cross section, the velocity contours are shown also.

On the fig 5 we can see thick (100 – 150 m), layered deposit in which velocity gradually increases with depth from < 600 to 3500 m/s. The deposit is dissected by a set of 4 – 5 normal faults with displacements up to several meters each. The faults form small-scale graben structure in the central part of the cross section. In the lower right (eastern) part of the cross section there is an irregular area with anomalously low velocity (2500 m/s). Our interpretation is that the layered deposit represents compound cooling unit of the 1912 pyroclastic flow deposit (ignimbrite). Layers with different velocities represent pyroclastic material with different degrees of welding, which increases with depth from non-welded to strongly welded. We think that the substrate of the 1912 pyroclastic flow deposit (moraine and sandstone of Naknek Formation) lays deeper than 150 m in the western (left) and central part of the cross section and thus was not detected by the 1970 survey. The anomalous low-velocity zone in eastern part of the cross section probably represents buried deposit of lateral moraine. Thus total thickness of the 1902 pyroclastic flow deposit in the western-central part of the profile exceeds 150 m and in the eastern part decreases to 50 - 100 m. Normal faults dissecting the layered deposit are the result of post-depositional compaction of the ignimbrite.

Conclusion

Reinterpretation of the old seismic data of the Valley of Ten Thousand Smokes allowed to understand the detailed geological structure of the 1912 ignimbrite. Total thickness of the pyroclactic flow deposit exceeds150 m. The deposit consists of several layers with different degrees of welding and is dissected by several normal rootless faults formed during post-depositional compaction. In the east part of the profile the ignimbrite is thinner and is underlined by moraine. This example demonstrates revolutionary efficiency of the method of homogeneous functions.

References

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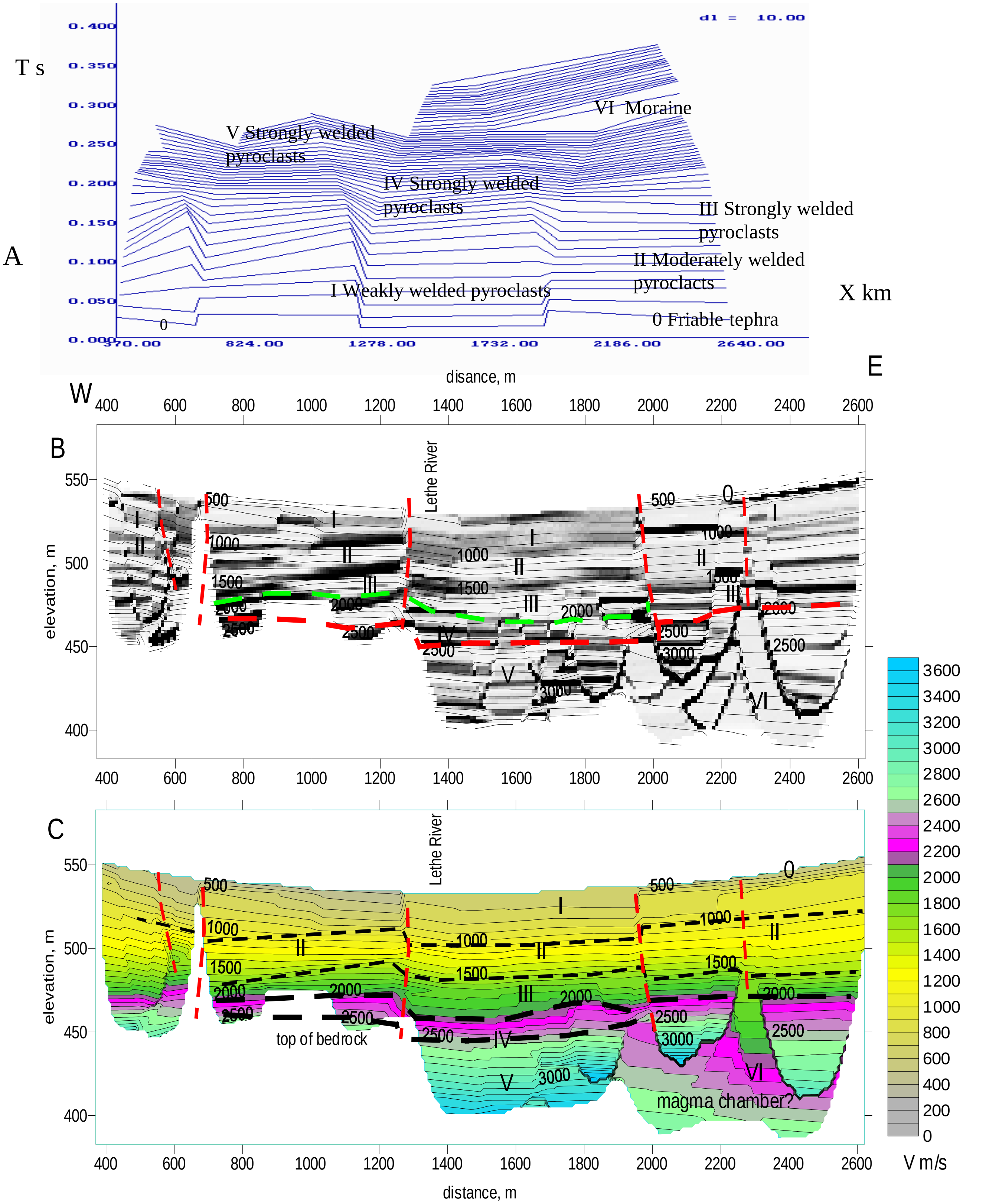

Fig.5. A - Time section of equal distances between shot and receiver. (contours are drawn with interval 10 m). This section images the main structures of real geological section. Layers here and below are designed: 0- friable tephra, I - weakly welded, II and III strongly welded pyroclastic deposits, IV - glacio-fluvial deposits, V - bedrock, VI - probably magma chamber. B - depth section with refractors (shaded relief section). Thin lines are velocity contours. Thick gentle layers (I, II, III) are pyroclacic deposits, lower disturbed layer is bedrock. C - velocity cross section with seismic boundaries.