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INTEGRATED INTERPRETATION OF GEOPHYSICAL ANOMALIES IN THE WESTERN ROSS SEA (ANTARCTICA)

Abstract. In the present paper, a seismic and magnetic profile recorded in the Western Ross Sea, near Coulman Island, is analyzed. The seismic line is characterized by some buried structures whose origin is not fully understood. Automatic bidimensional velocity analysis and tomographic inversion, as well as inversion of the magnetic data over the examined profile were performed. Analysis of the velocity field identified a local inhomogeneity whose depth is comparable to that of the seismic structure. The quantitative analysis of the magnetic data, on the other hand, supports the presence of magmatic bodies whose depths and shapes are in fairly good agreement with the structure and the velocity inhomogeneity. We concluded that the observed structures are due to magmatic intrusions (sills and dikes) which caused the deformation of the upper sedimentary sequences and the consequent anticlinal structure, successively remodelled by the erosional action of the Antarctic glaciers.

INTRODUCTION

The West Antarctic rift is a wide asymmetric rift system which extends over 3000 km across Antarctica (LeMasurier, 1978). It is comparable in size to the other major rift systems like the East African and the Basin and Range rift systems. The Ross Sea continental shelf (Fig. 1) is part of the system. Two main riftig phases (Cooper et al., 1987) can be recognized: an early rifting of pre-Oligocene age, probably Upper Cretaceous-Lower Eocene, which caused the formation of the main depocenters, and a late rifting phase, ranging from Miocene to present, which determined the formation of the Terror Rift in the Victoria Land Basin.

Widespread magmatic events are associated with the West Antarctic rift: in the Western Ross Sea (Fig. 1) active volcanic centers are present (Mt. Erebus and Mt. Melbourne), and Cenozoic magmatic rocks outcrop along the Victoria Land coast (Cape Hallett, Cape Adare and Cape Washington) and in the Ross Sea islands (Beaufort, Franklin and Coulman). The age of the magmatism ranges from Miocene to the present. The rocks are formed mainly by combinations of alkaloid basalt and trachite (Hamilton, 1972; Kyle and Muncy, 1983).

SEISMIC DATA

The analyzed seismic and magnetic data were collected by the R/V OGS Explora during the 1987/88 Antarctic summer. The seismic acquisition was with a Sercel 348 and a streamer with 96 traces for a total length of 2400 metres. The fold coverage was 2400%.

The seismic data (Fig. 2a) are characterized by some well defined seismic facies:

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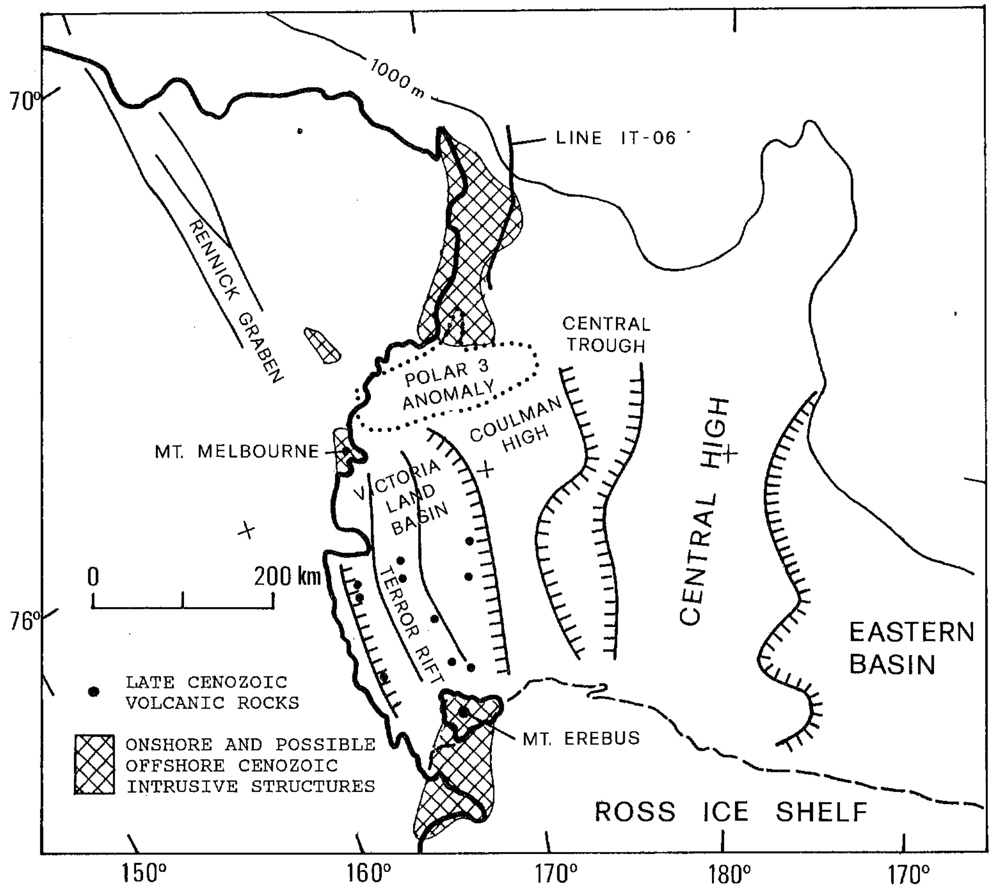

Fig. 1 - Map of the Ross sea region showing the position of line IT88A-06 offshore Cape Hallet and the locations of Cenozoic intrusive and sedimentary basins (modified from Cooper et al., 1987).

Facies I.

This is the upper one, from the sea bottom to horizon U3 (the horizon nomenclature follows Hinz and Kristoffersen, 1987). The sea bottom is a rough surface formed by the erosive action of grounding glaciers and by deposition of ice rafted debris. Facies I shows sub-horizontal, high amplitude and high continuity seismic character. The internal patterns are concordant with the lower boundary.

Facies II.

This ranges from horizon U3 to U4. The internal configurations present low amplitude, middle continuity characteristics and show on-lap termination against the lower boundary U4. In this area, U4 is a major erosional surface marking a widespread advance of the Antarctic glaciers over the Ross Sea continental shelf.

Facies III.

This ranges from U4 to the basement. The horizon U4 and the upper part of the sequence show some pseudo-anticlinal structures whose origin is not completely clear. Erosional or tectonic processes could not have generated the observed features: the partial involvement of the upper portion of facies III in the structure, in fact, excludes simple erosional processes; on the other hand, a tectonic origin is also excluded because the lower portion of facies III is only partially involved in the structure, showing much gentler folding compared to the top.

The only process that takes into account all the observed features is the emplacement of magmatic intrusions, forming sills and dikes, and cutting the lower part of sequence II and partially deforming the uppermost part. A further grounding ice erosion shaped the U4 unconformity and the upper part of the observed structures.

The goal of the present work is to verify the consistency of this hypothesis by means of an integrated analysis of seismic and magnetic data.

REMARKS ON THE SEISMIC DATA PROCESSING

Seismic data are usually processed and interpreted to extract the geometrical relationships between different groups of homogeneous reflections (seismic facies). In this way, it is possible to estimate the structural and depositional setting of the area, i.e., produce a macro-model consisting of a few main physical units (as sets of layers) distinguished by different physical properties or geological histories.

Stacking velocities are hardly considered in this approach, mainly due to the little physical meaning that can be attributed to them. The main source of discrepancies arises from the structural complexities of the strata and from the fact that the velocities are interpreted with the only aim of giving the best stack. Dip moveout correction can help in overcoming the first point whereas a geologically driven interpretation will partially solve the second.

In the present work, the analyzed area is structurally simple, and velocity analysis and interpretation was done by continuous velocity analysis along several interpreted horizons.

Starting from the hypothesis that sills and dikes are present, it follows that local inhomogeneities in the propagation speed of elastic waves determine variations in the traveltimes of the seismic signals passing through them.

The first step for localizing the postulated inhomogeneities is an appropriate processing to enhance the primary reflections, eliminating the strong multiples from the ice water bottom, and the spatially incoherent noise. In this paragraph, we describe the results obtained by applying some non-conventional processing tools to the considered zone. A detailed methodological description (and other examples) may be found in another paper of this monograph.

Fig. 3 shows a particular zone of the profile depicted in Fig. 2. Very strong multiples are noticed below 1.3 s, which almost hide any other useful signal. In Fig. 4 we see the effect of a double pre-stack f-k domain filtering, which removed fairly well the long period multiples. Several primaries can now be distinguished (e.g. at 2.1 and 2.5 s), which display a characteristic low frequency content and a geometrical shape that is uncorrelated with that of the other reflectors. Some organized noise has been introduced, nevertheless, in the form of dipping diffraction-like events.

Fig. 5 displays the result of a pre-stack f-x deconvolution applied to the data in Fig. 4. We see better now the laterally continuous reflectors, especially the deepest and weakest ones. The noise introduced by f-k filtering is partially reduced. To totally eliminate it, a final post-stack weighted mix has been applied (Fig. 6) to reinforce the practically sub-horizontal primary reflections.

Fig. 7 and 8 display enlarged detailes of Figs. 3 to 6. We see the increased quality after each processing step applied in cascade to the seismic data.

The final section (Fig. 6) shows a noticeable improvement over to the initial one (Fig. 3), and furnishes a satisfying image in time of the examined zone. It is also the starting point for a depth converted image of the investigated structures, which requires accurate velocity analysis and an inversion scheme.

TOMOGRAPHIC INVERSION OF STACKING VELOCITY ANOMALIES

Several tomographic methods (see e.g. Nolet, 1987) allow us to image the spatial distribu-

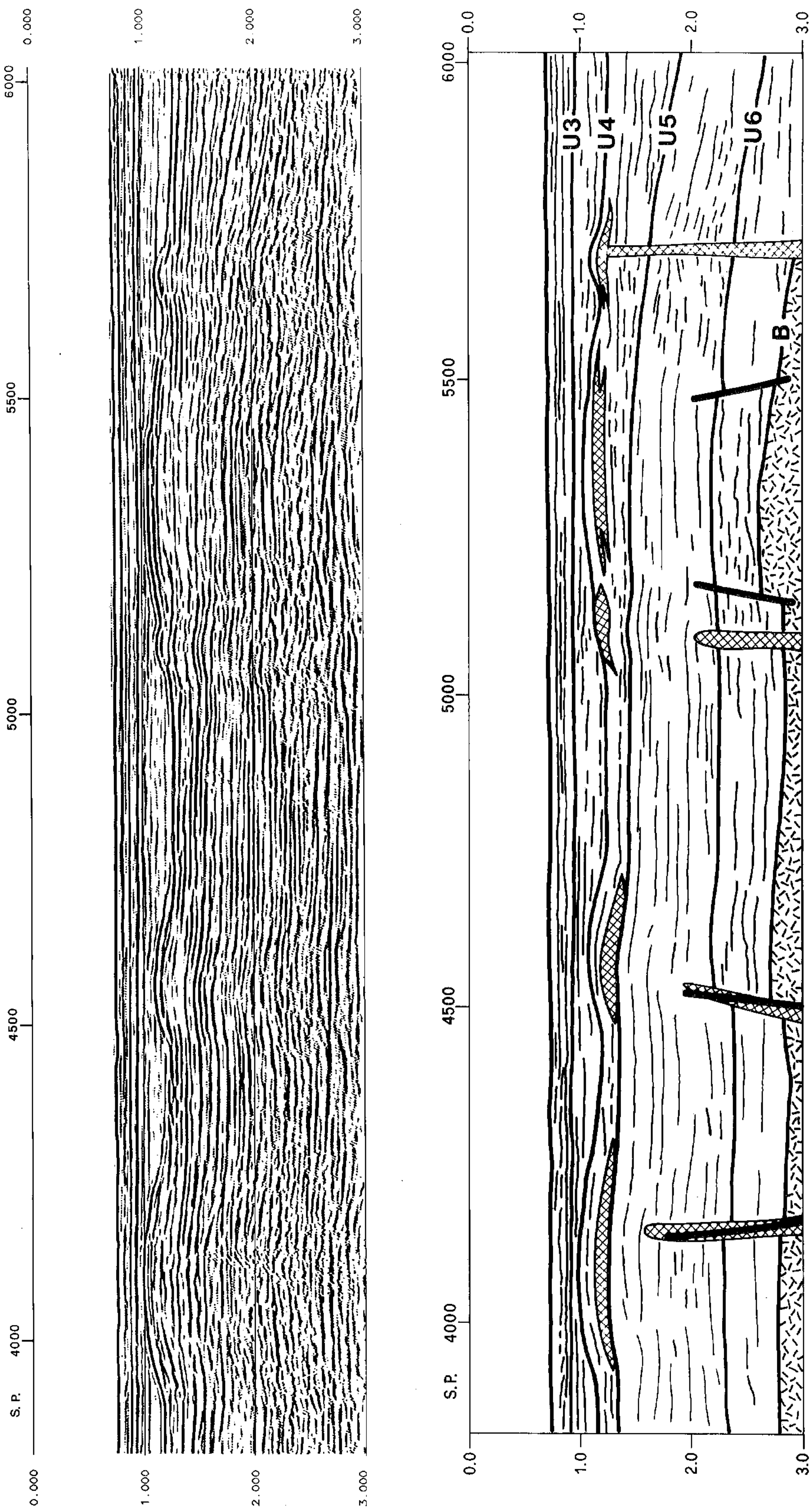

Fig. 2 - Final version of seismic profile IT88A-06 (a) and corresponding geological section (b).

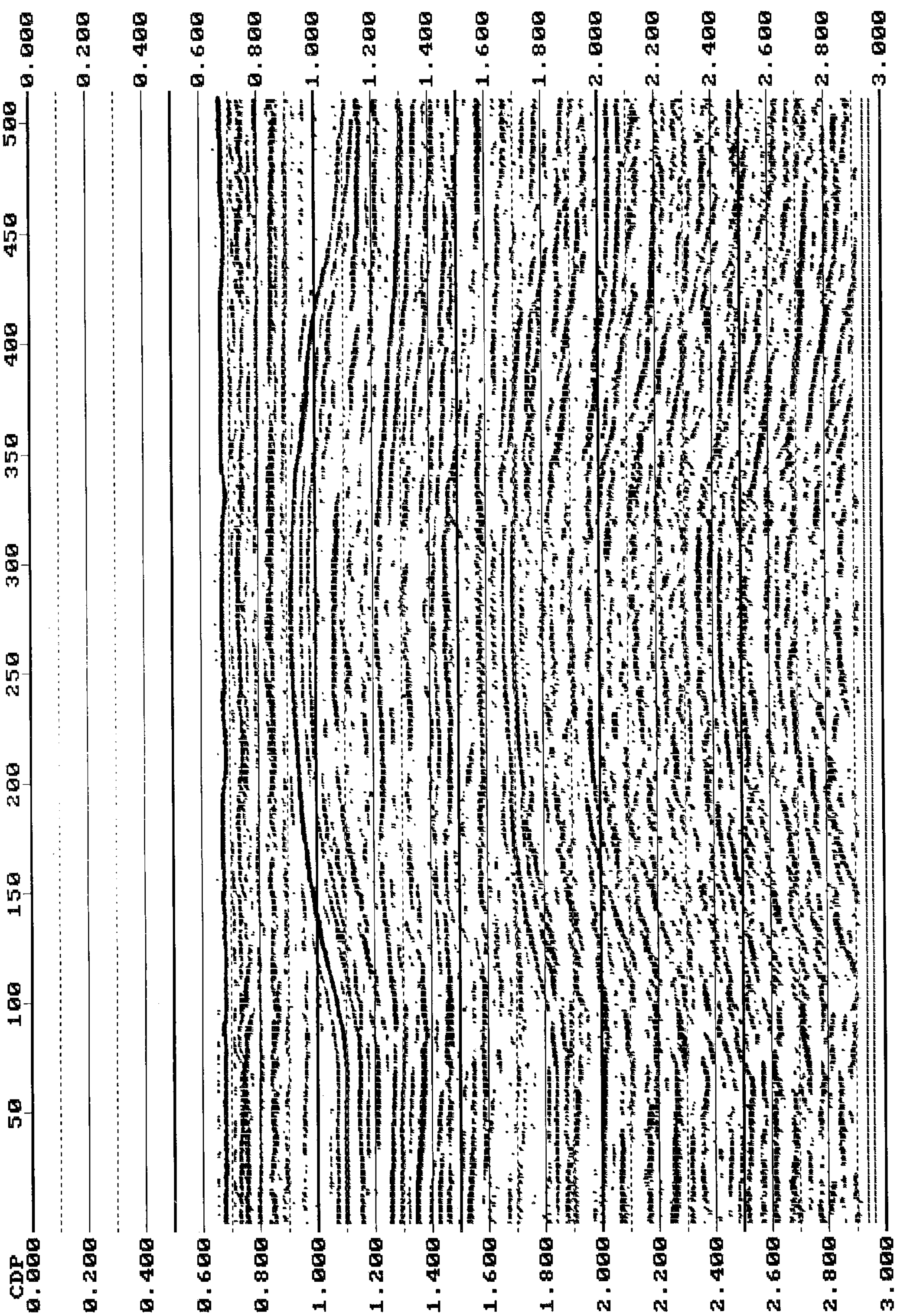

Fig. 3 - Stacked section of part of the line IT88A-06.

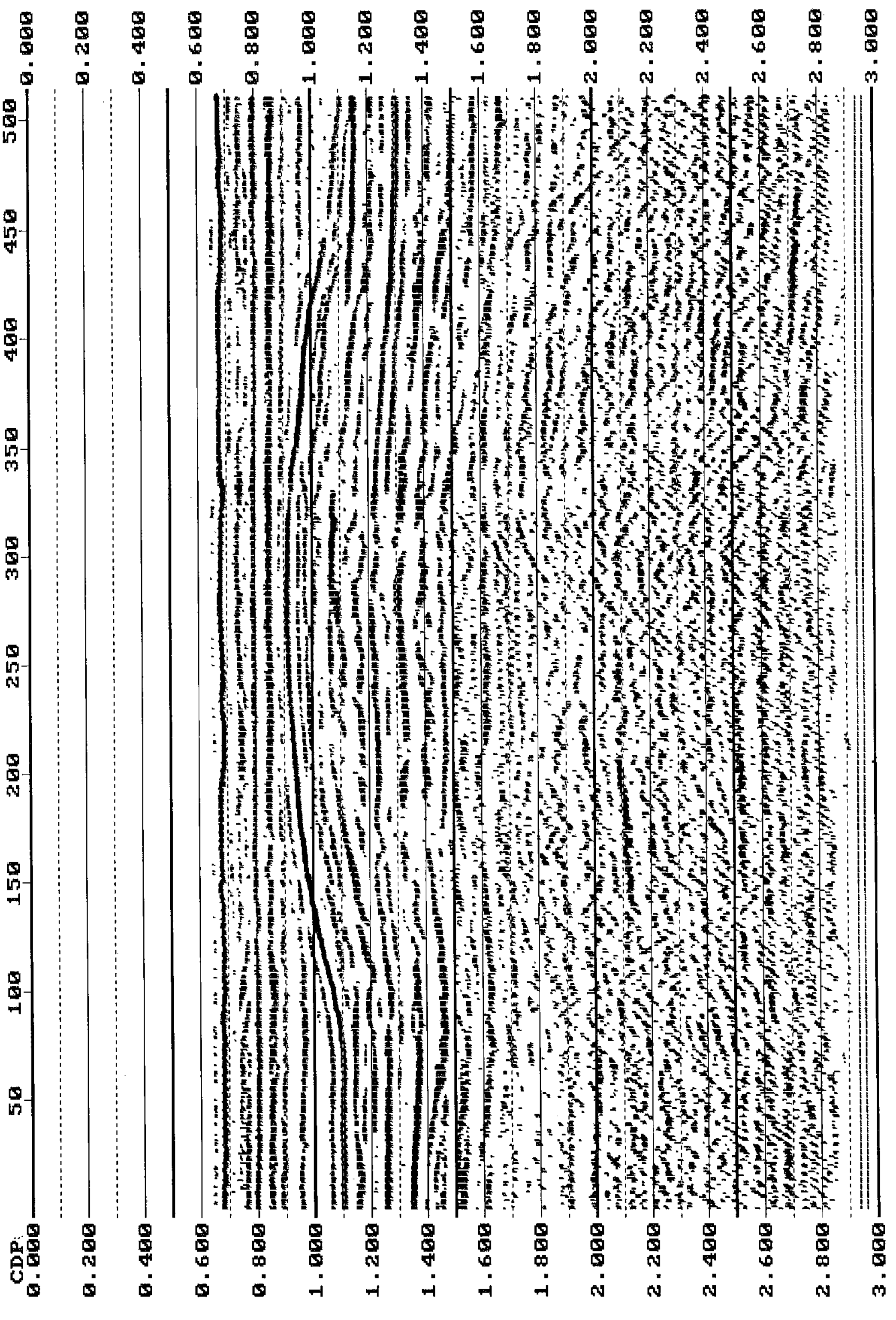

Fig. 4 - Seismic section obtained by a double pre-stack f-k filtering of data in Fig. 3.

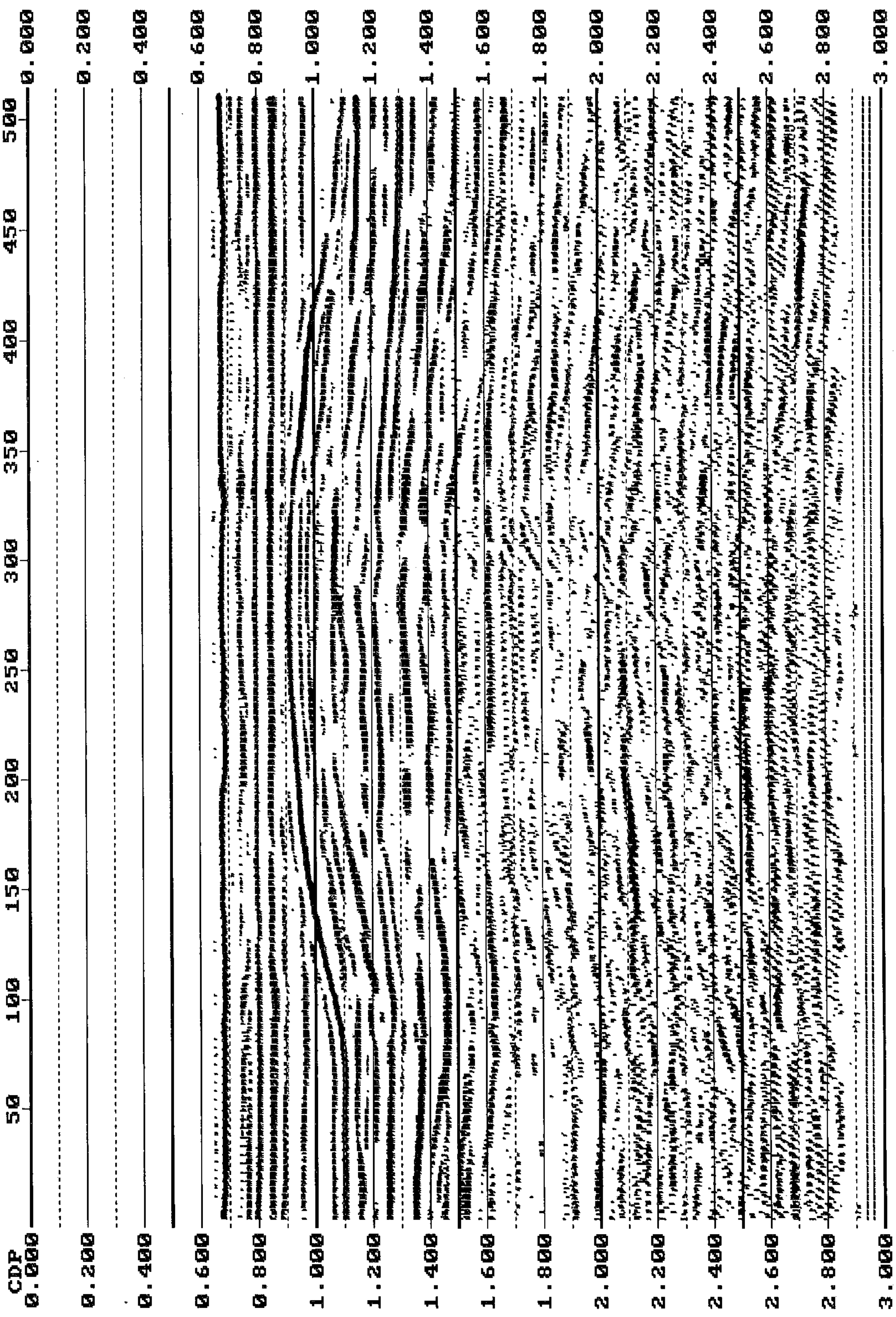

Fig. 5 - Seismic section obtained by a pre-stack f-x deconvolution of data in Fig. 4.

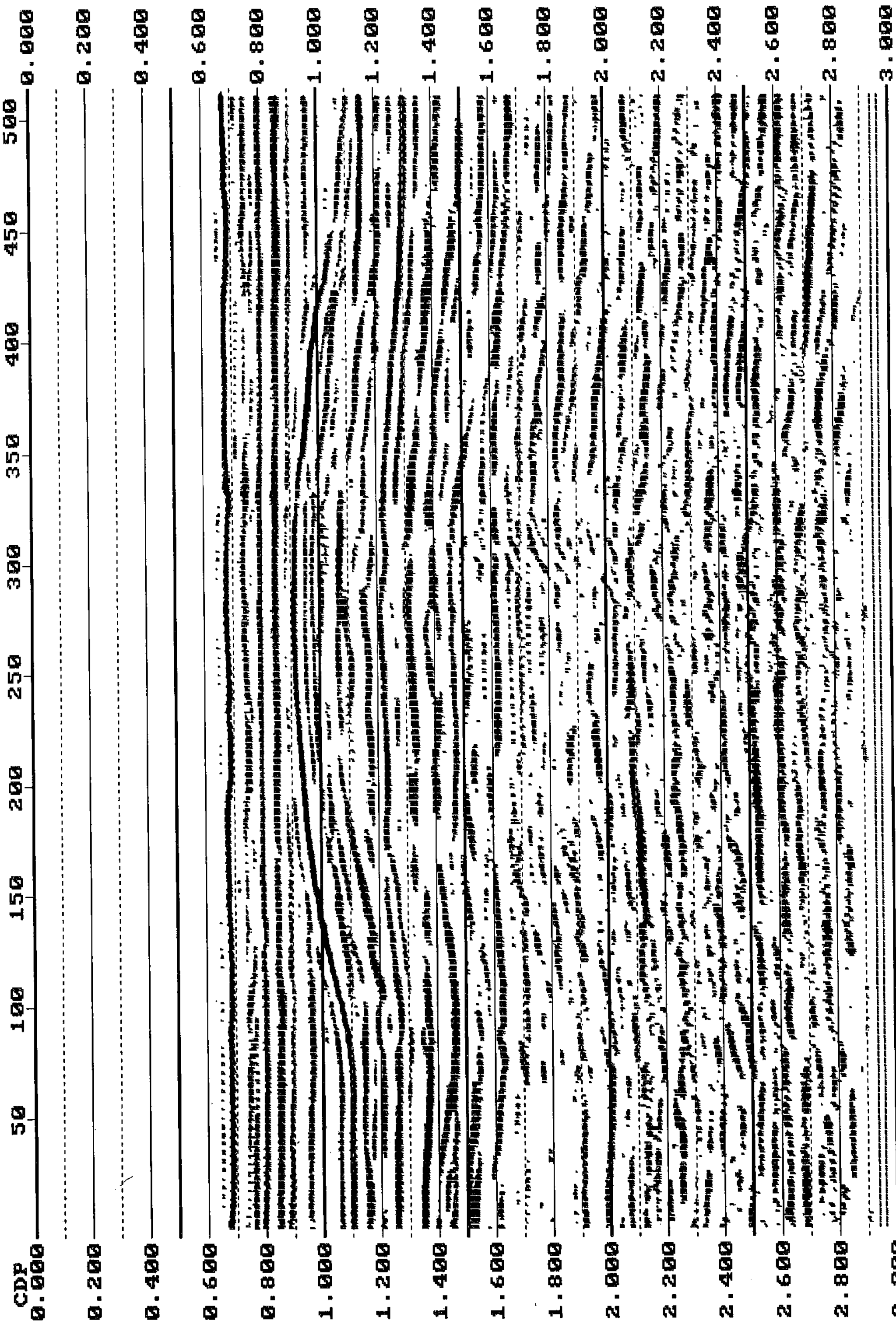

Fig. 6 - Seismic section obtained by a post-stack weighted mixing of data in Fig. 5.

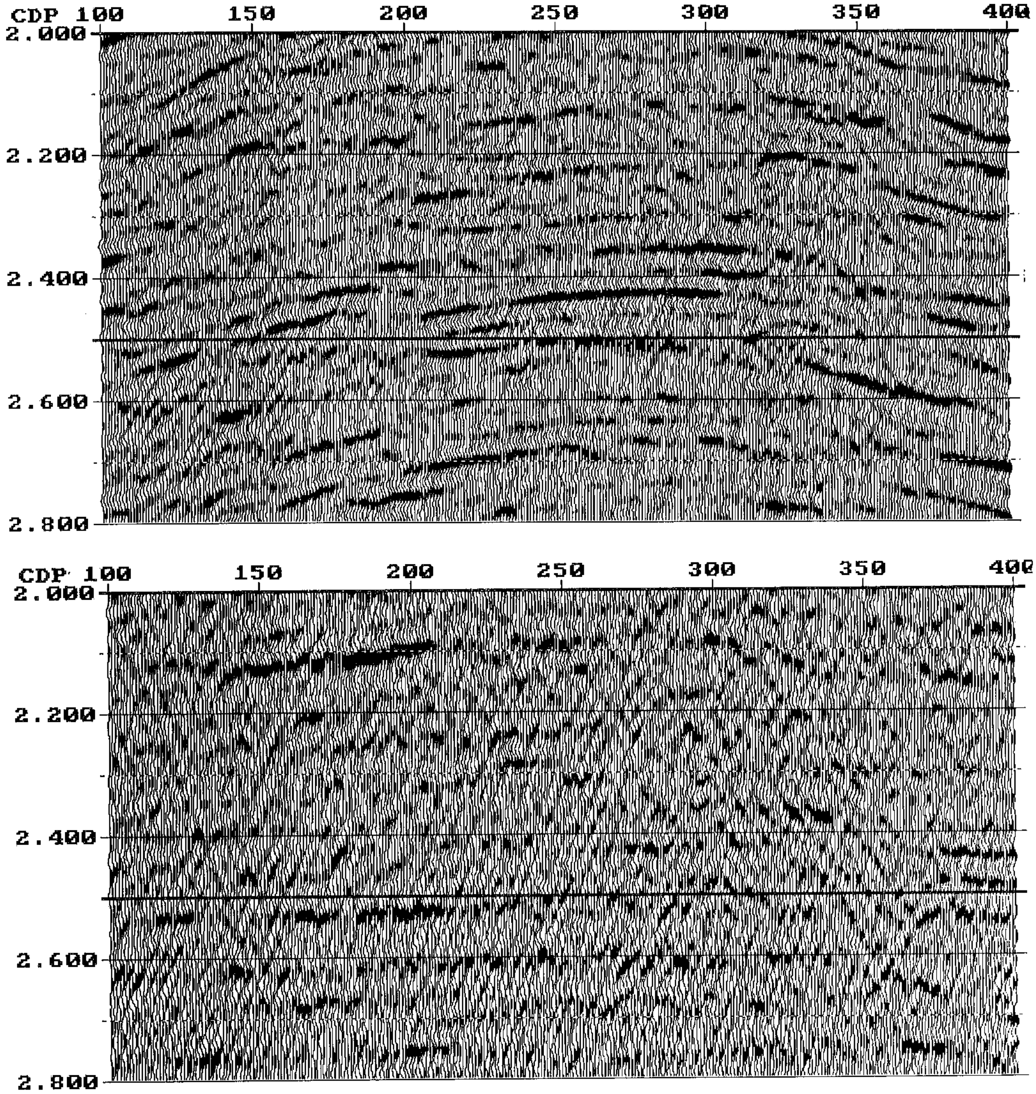

Fig. 7 - An enlarged detail of Fig. 3 (at the top) and of Fig. 4 (at the bottom), i.e. the stacked section and the f-k filtering.

tion of velocities exploiting these variations and a proper acquisition geometry. Usually, it is the picked traveltimes of selected events which are considered for the inversion but (more rarely) also the corresponding amplitudes, if an image of the energy absorption is sought.

In this paragraph, a different approach is followed: stacking velocities interpreted along continuous velocity spectra are employed instead of traveltimes. The main advantage of this alternative method is that it does not require the effort of manual picking of seismic reflections, which is time consuming (and therefore costly) especially if high fold data are considered. In our case, we only have to interpret a number of conventional and continuous velocity spectra, i.e., nothing more than is usually done in the standard processing sequence to get a good quality stacked section.

We will not describe here in detail the method, which is presented elsewhere (Rocca and Toldi, 1982; Harlan, 1989; Carlini et al., 1989; Vesnaver et al., 1990). We would like to

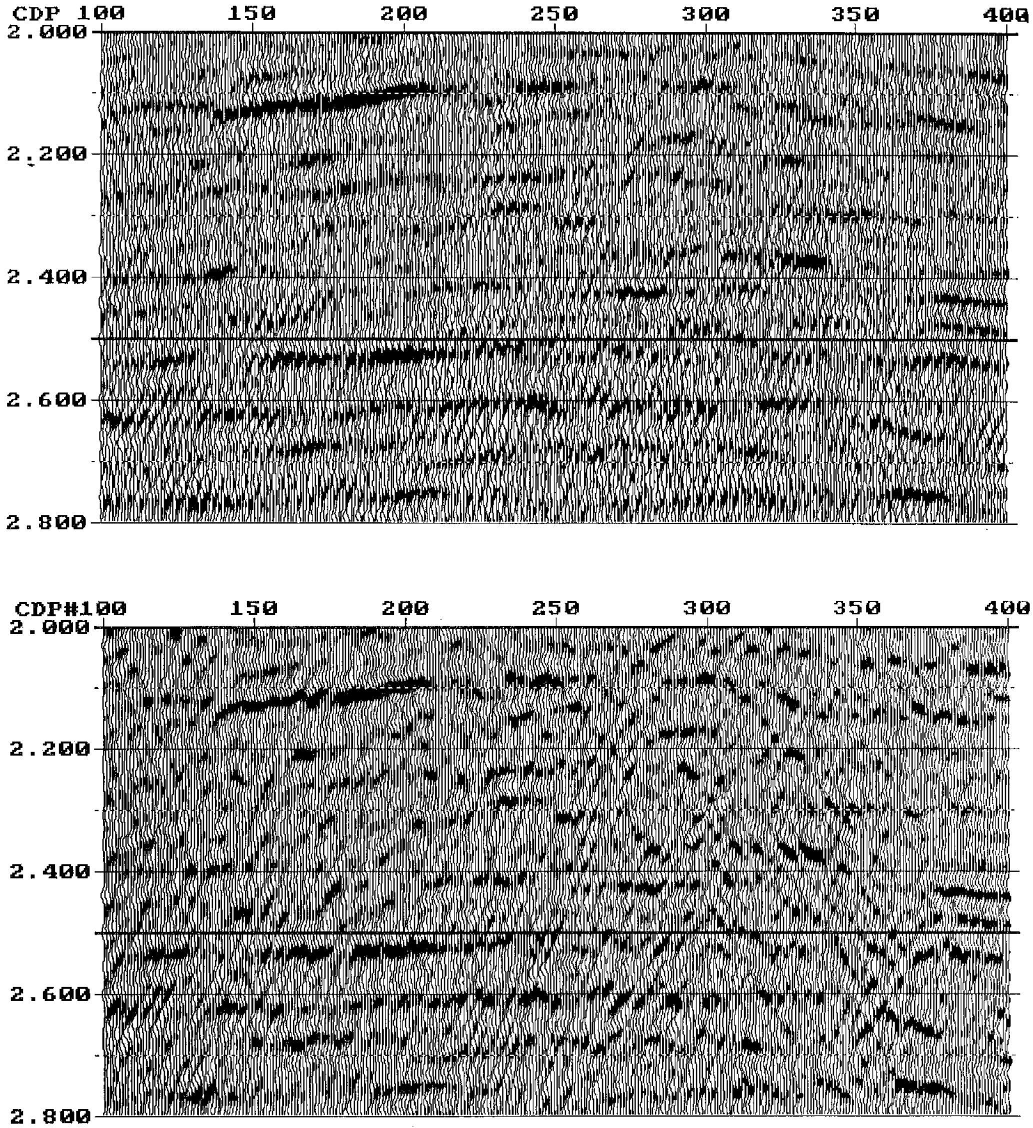

Fig. 8 - An enlarged detail of Fig. 5 (at the top) and of Fig. 6 (at the bottom), i.e. the f-x filtering and the weighted mixing.

recall only that local anomalies cause oscillations in the stacking velocity with a characteristic spatial pattern, displaying an increasing amplitude and width as we go deeper below the anomalous zone. Although this typical pattern is often sufficient to reveal its presence, we need a complete inversion procedure for a quantitative estimate of it. In any case, the resolution we can achieve by this method is of the order of the length of the seismic spread.

Fig. 9 shows the field of conventional stacking velocities. It appears fairly smooth, except for a small perturbation in the central part, around CMP 4000. The related interval velocities (Fig. 10) display a relatively small velocity anomaly (i.e., an increase) in correspondence to the perturbation, together with some other similar features (between CMP 4200 and 4300), which suggest the presence of a high velocity layer of variable thickness overlying rocks of different origin.

Fig. 11 displays the depth migrated local velocity field estimated by a tomographic inver-

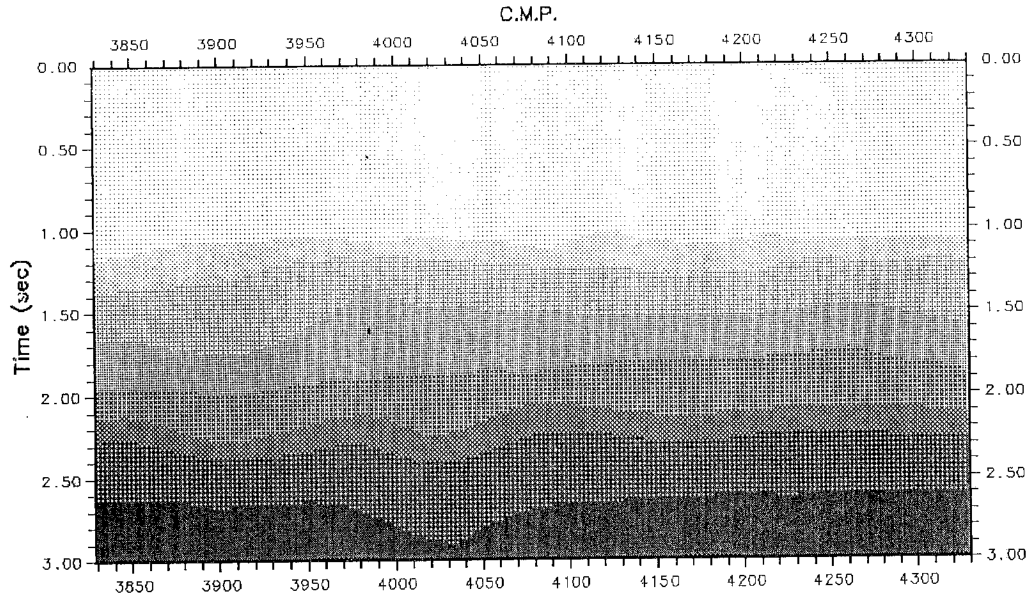

Fig. 9 - Stacking velocity contour map of the considered zone.

sion of stacking velocity anomalies. A high velocity layer is now clearly visible, which is in tight correspondence to the structure shown in Fig. 6 between 0.9 and 1.5 s. A low velocity zone separates this structure from the underlying layers.

MAGNETIC DATA

The acquisition of the magnetic data was by a Geometrics G 801-811. A comparison with

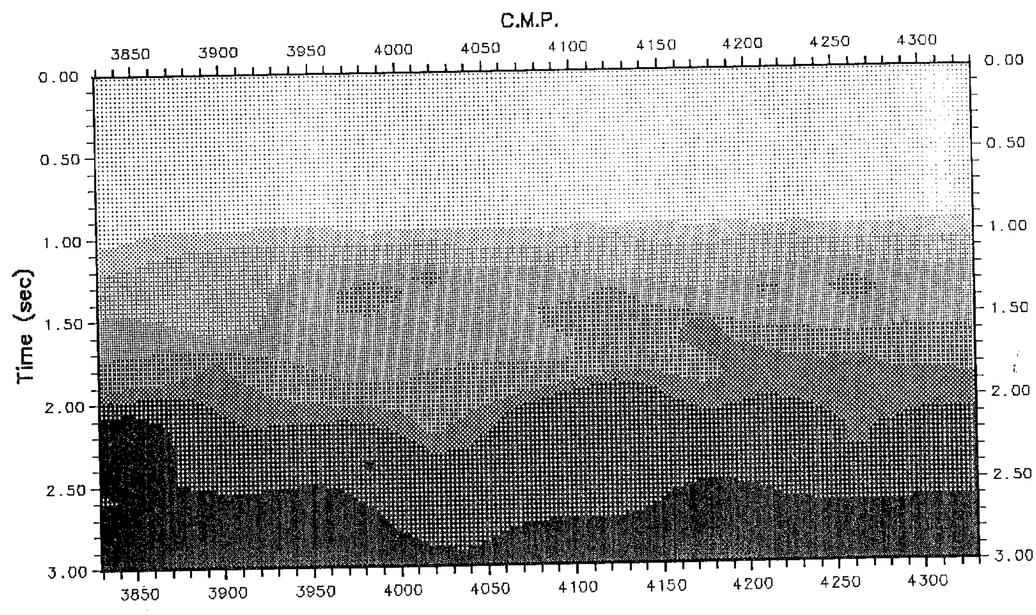

Fig. 10 - Interval velocity contour map corresponding to Fig. 9.

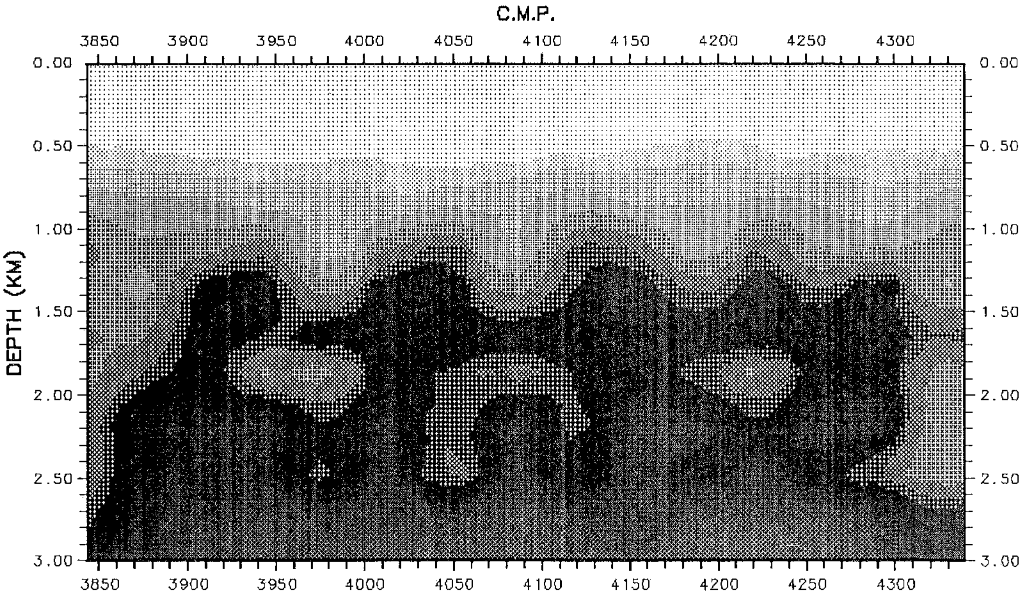

Fig. 11 - Field of the local anomalies of the depth migrated interval velocities estimated by a tomographic inversion of stacking velocities.

the aeromagnetic survey by the Ganovex V was done to be sure that the data were not disturbed by magnetic storms.

The interpretation of the data was by an integrated application of analytical signal methods (Green and Stanley, 1975) and the Werner deconvolution technique (Werner, 1953; Hartman et al., 1971) to determine the horizontal location and depth of susceptibility contrasts. Unlike most other methods, no knowledge of susceptibility values are required.

The amplitude of the analytic signal curve is characterized by its maxima located directly above the anomalous magnetic contacts (Fig. 12). The non-perfect symmetry of the analytic signal curve indicates the presence of interference between nearby anomalies.

The analytic signal was used to locate horizontally the anomalous magnetic contacts and to define the parameters used for the Werner deconvolution. A systematic application of this algorithm along the profile gives many solutions from which the most representative can be extracted using statistical criteria.

CONCLUSIONS

Integrated analysis of geophysical data allowed a more consistent and convincing interpretation of some structural features on seismic line IT88A-06. Both automatic bidimensional velocity analysis and tomographic inversion show, inside the seismic structures, a high velocity layer which causes a noticeable increase in the interval velocities. There is no definitive answer about the thickness of the layer but, considering the shape of the anomaly, it probably exceeds 100 m.

There is a good agreement also between magnetic and seismic data. The inversion of the magnetic data, in fact, reveals quite strong susceptibility contrasts inside the seismic structures that overlie the tomographic anomaly.

The most realistic hypothesis which takes into account the above mentioned constraints is that the seismic structures are caused by intrusions of magmatic bodies in the form of sills inside the glacio-marine sequences. The intrusions would have been taken place after the deposition of seismic facies III and before facies II and should be Upper Miocene in age. They

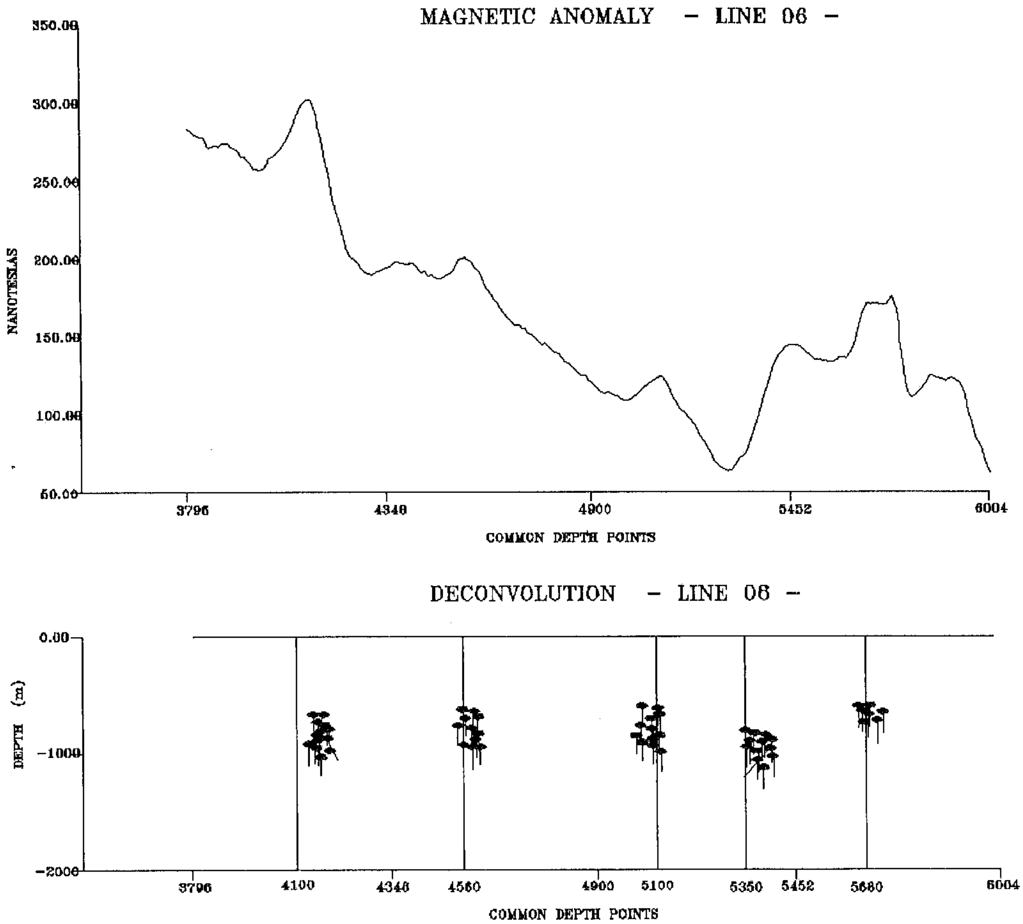

Fig. 12 - Magnetic data.

are probably part of the Cape Hallet magmatic province.

Magnetic data inversion support also the presence of narrow sub-vertical dikes associated to the sills.

Erosional processes induced by the dynamics of the Transantarctic Mountain glaciers remodelled the structural high. In fact Horizon U3, the upper boundary of facies III, is a notable erosional surface.

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