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Reconstruction of Antarctic Ice Shelf Expansion in the Ross Sea from Tomographic Analysis

F. Accaino*, G. Böhm & G. Brancolini

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), Trieste - Italy

**Corresponding author* (faccaino@ogs.trieste.it)

INTRODUCTION

The Ross Sea is part of the West Antarctic Rift System, which has evolved in different stages since the break-up of Gondwana in the Jurassic (Behrendt et al., 1992; Cooper et al., 1991). It is composed of three basins; the Eastern Basin, the Central trough and the Victoria Land Basin (see Fig. 1; Hinz & Block, 1984; Davey, 1981; Davey et al., 1982; Davey 1983, Cooper & Davey, 1987).

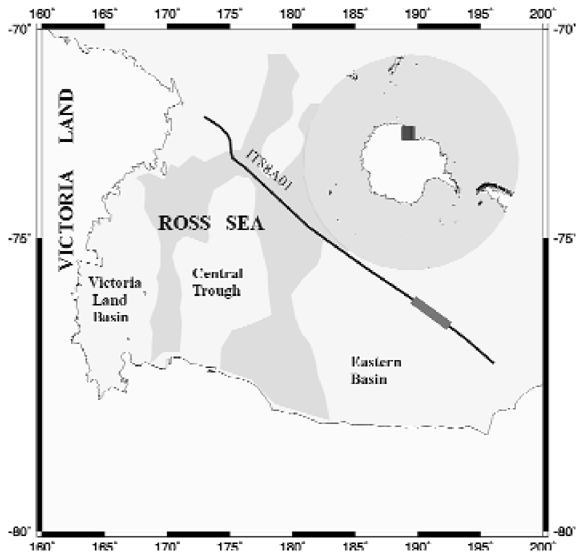

Fig. 1 – Location map of the investigated area. The thick segment corresponds to the location of inverted seismic data.

The Eastern Basin contains a thick sedimentary sequence that provides a direct record of the evolution of the West Antarctic Ice sheet. Alternate layers of over-compacted and less consolidated sediments in the shallowest offshore formations reveal different ice loads during expansion and retreat of the ice sheet.

Marine sediments of the West Antarctic Ice shelf record the history of the ice sheet, but all reconstructions suffer from two main limitations: the fragmentary character of stratigraphic boundaries and ambiguities in the interpretation of seismic data. The former can only be addressed through new borehole data, the latter through more accurate processing and evaluation of seismic data and better integration with well data.

This paper presents a quantitative analysis of the velocity field from multi-channel seismic data in order to better understand the processes that produced seismic unconformities in the Eastern Basin of the Ross Sea (Antarctica).

The velocity field was obtained using a joint inversion of reflected and refracted travel times. The resulting field was improved and tested through residual velocity analysis of the common image gathers by performing pre-stack depth migration.

The final velocity field was used to perform pre-stack depth migration, thus improving the seismic section and providing a qualitative estimate of sediment porosity. We aimed to identify the presence of over-compacted layers, which might indicate that a grounded ice sheet covered the area after sediments deposited over the unconformity.

SEISMIC INVERSION

The analysis of seismic data first involved accurately determining the velocity field. We performed a joint tomographic inversion of refracted and reflected data (Vesnaver et al., 1999). The travel-time inversion allowed us to obtain a satisfactory reconstruction of the velocity field and of lateral velocity variations.

For checking and fine-tuning the velocity model obtained by seismic tomography, we analysed various Common Image Gathers (CIGs) along the whole profile. Liu's perturbation method (Liu, 1995) was used to compute the residual-moveout semblance for the CIGs and estimate velocity corrections. To better constrain lateral variations, we also estimated the residual move-out along selected interpreted interfaces in pre-stack sections. This approach allowed us to better define geological structures and control the residual interval velocities in structures.

To improve the seismic image, we performed pre-stack depth migration. Figure 2 shows the pre-stack depth-migrated sections of the analysed section, while figure 3 shows the final velocity model obtained by tomographic inversion and velocity corrections.

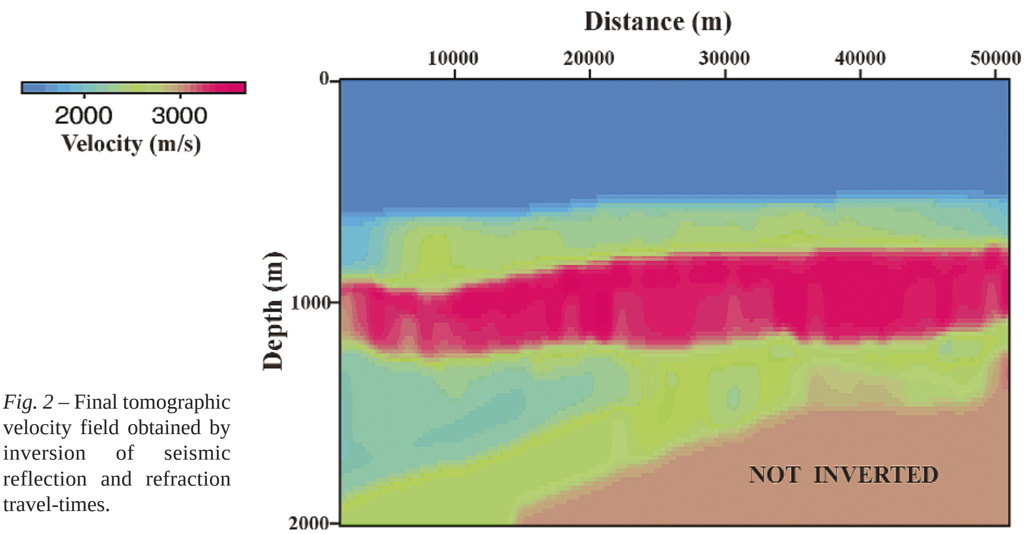

Fig. 2 – Final tomographic velocity field obtained by inversion of seismic reflection and refraction travel-times.

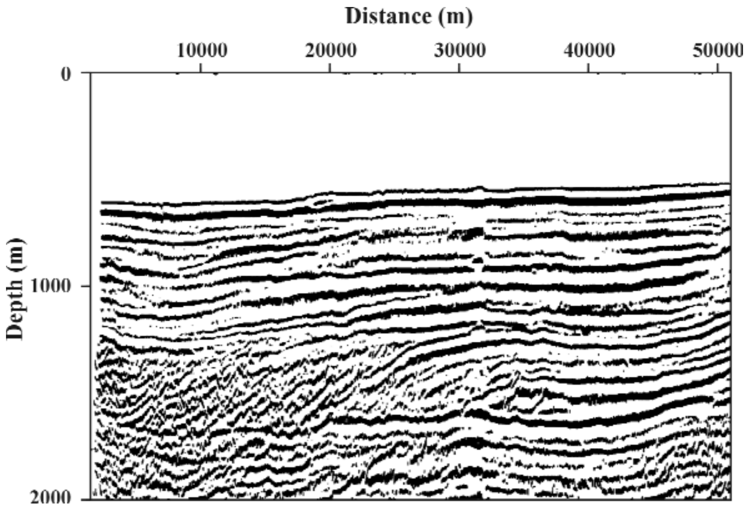

Fig. 3 – Pre-stack depth migrated section obtained using the tomographic velocity field.

The velocity model presents lateral and vertical variations. In particular, anomalous high velocities are present at depths of 800 m to 1000 m. This supports the hypothesis of differential compaction in the different layers due to glaciation history.

RESULTS

With the exception of a high velocity anomaly at about 800-1000 m, the velocity field obtained by inverting the selected part of the seismic line highlights velocities that are those of normal consolidated sediments. The thickness of the anomaly varies along the seismic line and increases to the SE**.** The base of this high velocity layer is characterised by an inversion in the velocity profile.

To investigate the effects of over-compaction in our study area, we compared our velocity profile, obtained by inversion at a distance of 10 000 m (see Fig. 3), with the velocity profile based on well data for post-Eocene sands and shales reported in Bourbie et al. (1987), and with that of normal compacted sediments of the Gulf of Alaska, which have a similar depositional environment (Cochrane et al., 1995). Using empirical formulas, and translating the velocity profile in terms of porosity, we found that the high velocity anomaly differs by 15-20% with respect to the reference curves. This confirms the hypothesis that the increase in velocity is caused by over-compaction.

Analysis of pre-stack depth migration (Fig. 3) highlighted an unconformity about 500 m below the sea floor, which can related to glacial erosion during ice expansion. The sediments deposited on this unconformity were over-compacted by the load of ice during a subsequent expansion of the ice sheet.

CONCLUSIONS

The joint tomographic inversion of reflected and head waves confirmed our geological interpretation of seismic profiles in the Antarctic offshore. The expansion and retreat of the ice shelf created characteristic erosion surfaces and alternating layers of over-compacted and normal-consolidated sediments, which correspond to higher and lower seismic velocity anomalies.

For an accurate analysis of lateral and vertical velocity variations, we jointly inverted reflected and refracted arrivals, and tuned our estimates by coherence of (according to some Common Image Gathers along the seismic profile.

A major velocity anomaly corresponding to a basin-wide seismic unconformity (RSU2) is interpreted as the first evidence of a major advancement of the West Antarctic ice sheet on the continental shelf. The best age attribution from DSDP leg 28 for RSU2 is early Pliocene (Hayes & Frakes, 1975). We speculate that before this age the West Antarctic ice sheet was not able to ground below sea level due to the warmer climate. RSU2 may represent the transition from a temperate to a polar West Antarctic Ice Sheet. This model is in agreement with borehole data, which indicate that sediments on the continental rise and in the abyssal plane around Antarctica experienced greater sub-glacial sediment transport during the early Pliocene than in more recent periods, suggesting greater accumulation and outward flow of ice.

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