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Seismic Reflection Experiments on the Ross Ice Shelf: 1985-1991

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Abstract - Three seismic reflection experiments on the Ross Ice Shelf are briefly described. Seismic reflection exploration on a thick, floating ice shelf presents a unique challenge in terms of both acquisition and data processing. Conventional acquisition methods were used in the 1985 survey including drilled shot holes and moving cables and geophones by skidoo. In the latest experiment, the SERIS project of 1990/91 at 82.5o S, thermal drilling of shot holes and a towed ice streamer were used. Results are variable and appear to be dependent on the intensity and character of intra-ice and seafloor multiples that are created by the dynamite shots. Some of the features we observe in the geology beneath the ice shelf includes unconformities, basement faulting, bottom simulating reflector and a possible base of the crust (Moho) reflector.

INTRODUCTION

Marine seismic surveys have been conducted in the Ross Sea (Fig.1) since the 1960's (e.g. Davey, 1981) and a reasonably dense network of data has now been collected. Development of seismic methods on the Ross Ice shelf (Fig.1) has been slower and more difficult for both logistical and technical reasons (Robertson et al., 1982; Blankenship et al.,1986; Beaudoin et al.,1992; ten Brink et al., 1993).

From a logistic standpoint, seismic acquisition on the ice shelf is hindered by crevassing, poor snow conditions and the need to move large volumes of equipment either by ski-equipped aircraft or by oversnow vehicles. On the other hand, seismic work on the ice shelf offers several operational advantages above that of land acquisition: a mostly flat and even surface; rapid shot hole drilling with hot water techniques; and cultural noise is possibly the lowest found anywhere in the world. Furthermore, a new advance has been the adaptation of a snow-streamer device, similar to that of marine streamers used behind ships, for seismic acquisition on the ice shelf. Eiken et al. (1989) report the first such use of snow streamers in Antarctica and ten Brink et al. (1993) described the use of an ice streamer for the SERIS project of 1990/91 (Fig. 1).

Multiples generated in the floating ice, and in the water column beneath the ice, are the most significant processing problem associated with seismic data collected from a floating ice shelf. Factors influencing multiple generation are the ice shelf thickness, roughness of the ice water contact, hardness of sea floor and thickness of the water column. Intra-ice multiples exhibit periods between 100 and 300 msec depending on ice thickness. In contrast, multiples generated at the sea floor typically have a period of about 1 sec and can be exceptionally strong in regions where moving ice has scraped soft sediment from the sea floor. Techniques that have been applied to suppress both sea-bottom and intra-ice multiples include predictive deconvolution, inverse velocity stack filtering and regular time-varying frequency filtering.

Compounding the treatment of both intra-ice and water layer multiples is that the maximum P-wave seismic velocity of ice is around 3.8 km/s, so that rays having a portion of their travel path through ice may acquire

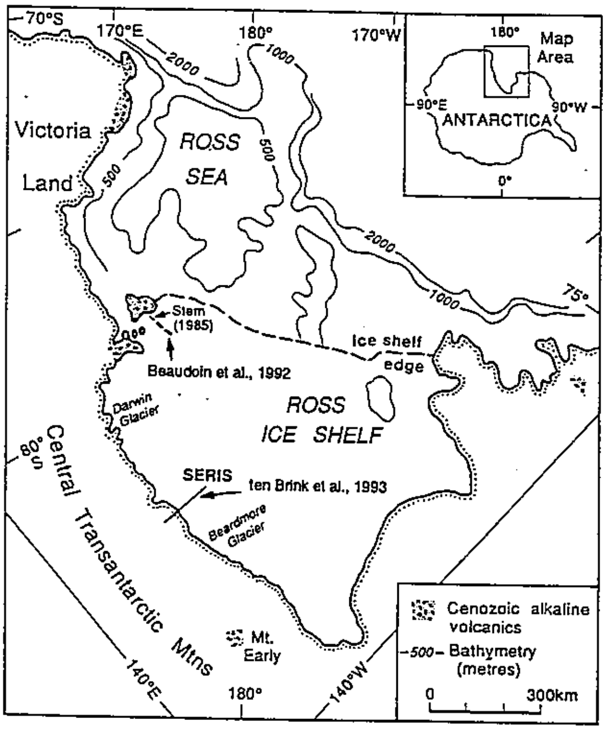

Fig. 1 - Location map for the Ross Ice Shelf and seismic lines discussed in text.

normal moveout velocities of 2-3 km/s. This range overlaps that for most sediments and makes the suppression of multiples awkward with standard normal moveout and stacking techniques.

SPECIFIC PROJECTS AND RESULTS

ROSS ICE SHELF, PRE 1985:

Initial seismic work on the Ross Ice Shelf was carried out by Bentley and his colleagues (e.g. Bentley & Clough, 1972). This work provided an initial picture of the sedimentary and basement velocity structure at about 150 stations distributed over the Ross Ice Shelf. Blankenship et al. (1986) used high resolution reflections from single shot gathers to infer the fine structure at the base of the West Antarctic Ice sheet.

ROSS ICE SHELF 1985

A short 5 km line shot in 1985 by Stern et al. (1991) used the conventional multichannel techniques to produce a 6-fold stack with a 17.5 m CDP spacing. This survey produced a high resolution image of sedimentary structure beneath the Ice shelf (Fig. 2). Predictive deconvolution proved the more effective tool in the elimination of short period multiples generated within the ~ 250 m thick ice shelf. The principal feature of these data is the dip of strata towards Ross Island and the unconformity at about 1.3 s. Stern et al. (1991) argue that this unconformity marks the loading, and hence "birth", of Ross Island at about 5 Ma.

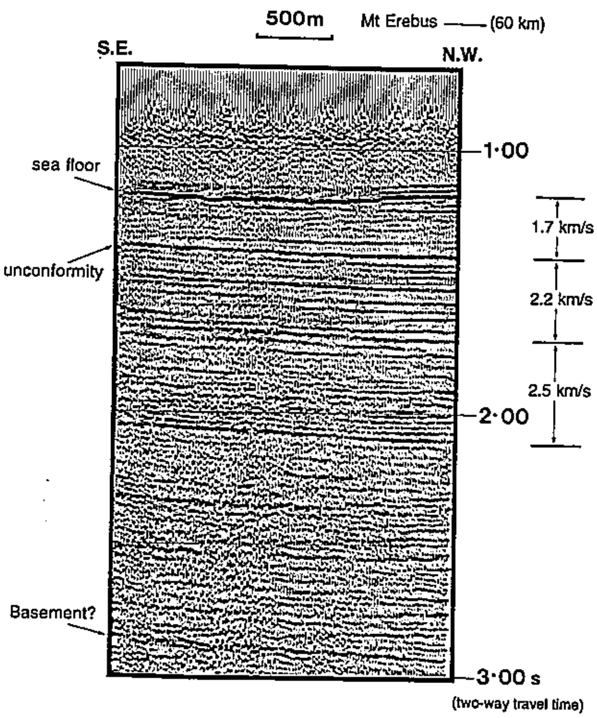

Fig. 2 - Processed stack from the 1985 survey described in Stern et al.(1991). Note well stratified section with an unconformity at about 1.3 secs of two-way travel-time. Velocities are based on best-fit stacking velocities. Basement pick is only approximate and is based on correlation with section of Beaudoin et al. (1992)(see Fig.3).

ROSS ICE SHELF, 1988

A regional multichannel line was carried out by a joint Stanford University (USA) - DSIR (NZ) team in 1988 (see Beaudoin et al., 1992). This line was about 60 km long and directed to identifying deformation of the lithosphere due to the volcanic load of adjacent Ross Island. The data (Fig. 3) were shot with a 24 channel DFS-V and shot and receiver spacings of 200 and 100 m, respectively.

A well stratified sequence can be observed dipping towards Ross Island and a strong erosional unconformity is observed at the sea floor. Dips on the upper reflectors are similar (about 27 msec/km) to that recorded closer to Ross Island (Fig. 2) by Stern et al. (1991).

Single shot gathers at the southeast end of this line show a pronounced reflection at 7.2 s that has been interpreted (Beaudoin et al., 1992) to be the Moho at a depth of about 21 km. This proposed Moho event could not, however, be tracked right across the profile.

A Moho at a depth of about 20 km concurs, however, with other work in the Ross Sea to the north (McGinnis et al., 1985; Behrendt et al., 1991) and on the Ross Ice Shelf to the south along the SERIS line (ten Brink et al., 1993).

SERIS LINE 1990-91

Imaging of crustal structure across the Transantarctic Mountain Front (TAM) was the objective of the SERIS project at 82.5° S during the 1990/91 season (ten Brink et al., 1993). Location of the SERIS project is shown in figure 1. This location, via the Robb Glacier, was found to be the most suitable option from the point of view of crevasse-free travel and satisfying the scientific objectives of SERIS.

A mixed reflection/wide-angle reflection experiment was carried out along a 140 km long line from the Lowery Glacier, down the Robb Glacier then out across the Ross Ice Shelf. Figure 4 shows the overall plan and seismic coverage for the profile. Both seismic reflection, refraction and wide-angle reflection data were collected. A variety of acquisition systems were attempted including regular cable and geophone configurations, and a "seismic streamer", as described by Eiken et al. (1989), for the vertical incidence reflection work. As shown in figure 4 regular seismic cable acquisition was used between camps Mike and Lima, and the streamer between Lima and Kilo. Independent "Reftek" seismic recording units were used for the refraction - wide angle acquisition. Aspects of the data acquisition and preliminary processing are given in Melhuish et al.(1993).

Interpretation of the SERIS experiment is given in ten Brink et al. (1993). A dipping Moho "ramp" at the boundary between East and West Antarctica is one of the most prominent features seen in the wide-angle seismic reflection data. Using gravity data to augment the seismic, they deduce that the crustal thickness changes from about 20 km beneath the Ross Ice Shelf to at least 35 km beneath the Transantarctic Mountains.

A surprising result from the SERIS survey was the lack of deformation in sediments adjacent to the uplifted

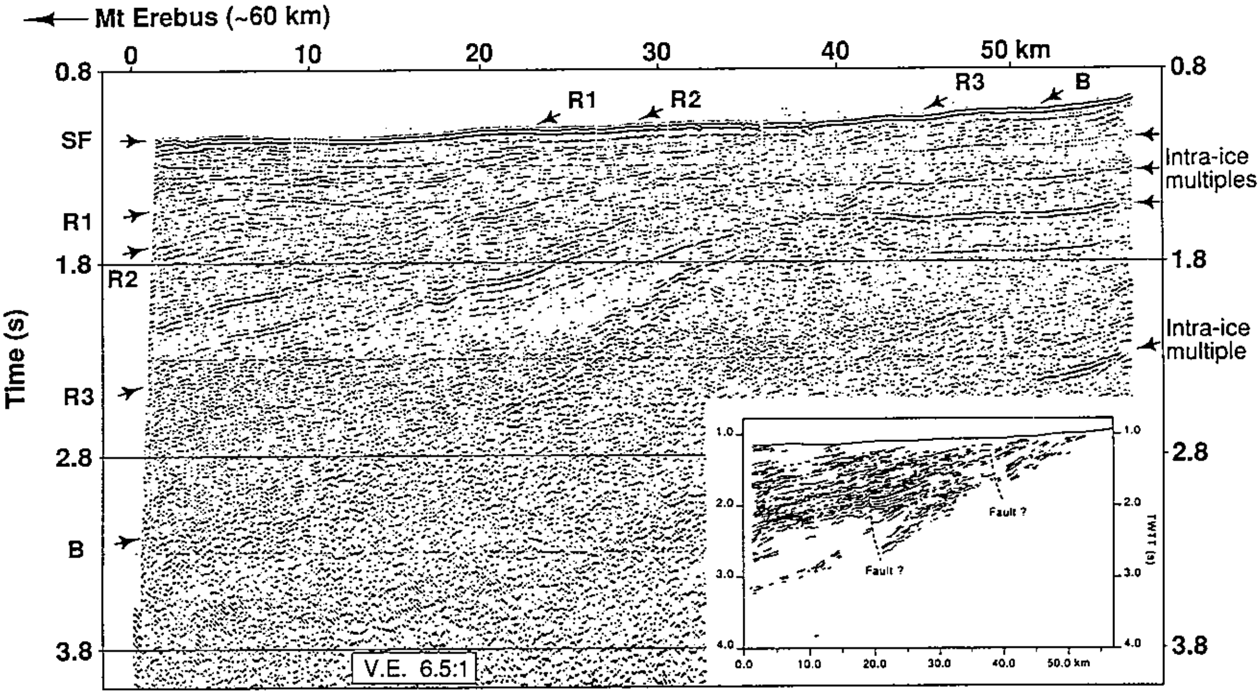

Fig. 3 - Final stack from the 1988 survey of Beaudoin et al. (1992). Southeast end is at 0 kilometre. Note strong intra-ice multiples at SE end of line where the ice is thick (400 m) compared to NW end of line where it is thin (200 m).

Transantarctic Mountains. Seismic reflection data (Fig.5) show subhorizontal layering out to distance of 100 km east of the mountain front. The only structures seen are some indication of mild normal faulting and a bottom simulating reflection due to a proposed gas hydrate (ten Brink et al., 1993). The lack of deformation is surprising in that at the adjacent mountain front there has been at least 5 km of uplift sometime in the Cenozoic. Possible explanations for this could be either an early Cenozoic uplift for this part of the Transantarctic Mountains, or an uplift mechanism that is largely driven by thermal conduction in the upper mantle (ten Brink et al., 1993).

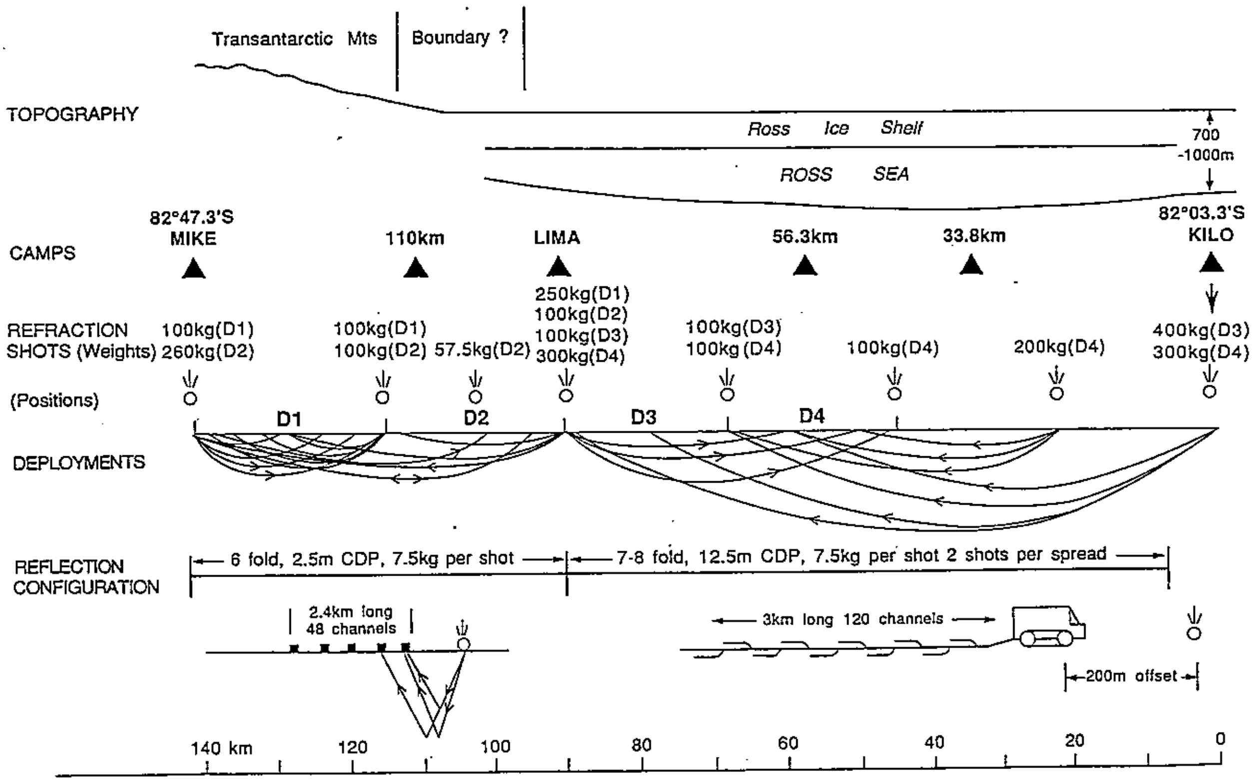

Fig. 4 - Geometry and layout for the SERIS seismic experiment. Positions of the three principal camps (Kilo, Lima and Mike) and minor camps (110 Km, 56.3 Km and 33.8 Km) are shown. Refraction shot weights and deployments are shown. Only enough dynamite was available for four deployments. Reflection data was collected in two modes as shown. Results of survey given in ten Brink et al. (1993).

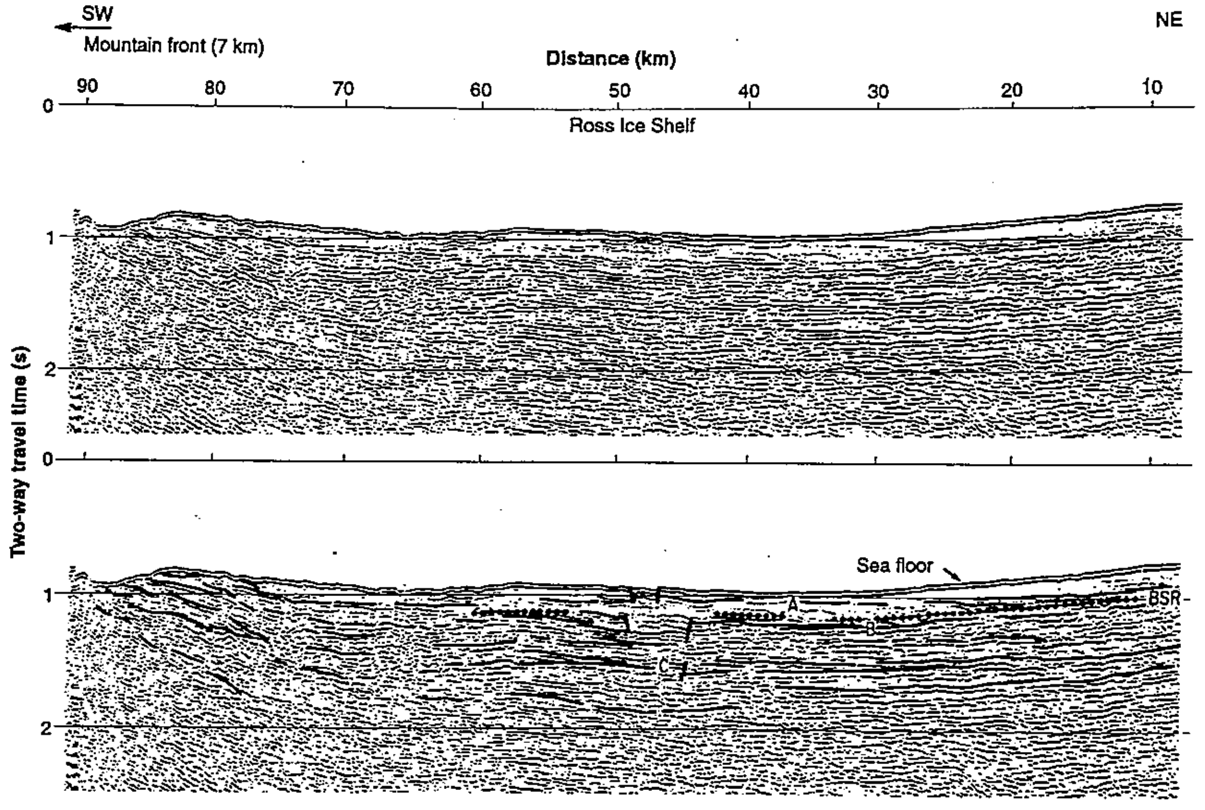

Fig. 5 - Seismic reflection profile and interpretation (after ten Brink et al., 1993). BSR refers to a Bottom Simulating Reflection marking the base of a gas hydrate layer. A, B and C are unconformities.

SUMMARY

Seismic reflection exploration on the Ross Ice Shelf is still in an early stage of development. Because of the degrading effect of multiples mixed results have been reported from the few surveys of multichannel seismic reported thus far. The clarity of the sub ice-shelf image appears to depend on the relative thicknesses of the overlying water and ice layers. Therefore the largest hurdle facing seismic surveys on the Ross Ice Shelf probably occurs at the processing stage where first and second order multiples can dominate the data. In particular, long-period multiples that contain a mixture of water and ice paths are resilient to modern processing techniques. Until a new processing strategy is developed for multiple removal the best defence against them is to increase fold of seismic surveys and at the same time maintain long aperture arrays so that differential moveout between multiple and primary, even when small, may be resolved.

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