Geophysical survey of the thick, expanded sedimentary fill of the new-born Crane fjord (former Larsen B Ice Shelf, Antarctica)

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Summary Integrated geophysical data recorded during cruise NBP0603 revealed the setting and the infill history of the newly-created Crane Glacier Fjord (Exasperation Inlet, Eastern Antarctic Peninsula). Originated by the 15 km retreat of the Crane Glacier after the Larsen B ice shelf collapse, the fjord shows three ponded basins at its floor, imaged in detail by a 12 kHz multibeam echosounder. In the lowest basin, sub-bottom profiling and single channel seismic revealed a 40 m thick, well-layered and unconsolidated fill. Its upper part, as confirmed by a 2.7 m core collected in the area, was interpreted as the result of the accelerated ice discharge from the glacier during the ice shelf break-up. The rest of the fill was regarded as the result of 30 years long sub-glacial lake sedimentation, suggesting that the glacier behaviour was affected not only by the Larsen-B ice shelf collapse, but also by regional ice shelves dynamics.

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Introduction

Over the past fifty years, mean air temperatures in the Antarctic Peninsula have increased by 2 to 4°C (King and Comiso, 2003; Skvarca et al., 1999). Floating ice shelves and their tributary glaciers are responding rapidly to this climate warming. The ice shelves in the region have decreased in area by >13,500 km^2 in the past 30 years, in some cases with the sudden collapse of large areas (Vaughan and Doake, 1996; Scambos et al., 2003). Following the collapse, the tributary glaciers flowing into the former sections of the Larsen A and B ice shelves have shown a two- to six-fold velocity increase according to satellite data (Rott et al., 2002, Scambos et al., 2004). Nevertheless, precursory accentuated glacier dynamics is suggested in the same data by seasonal variations in speed preceding the large post-collapse velocity increases (Scambos et al., 2004).

The Larsen Ice Shelf has undergone a rapid, catastrophic, retreat since 1995. Geophysical and geological exploration of the seafloor previously covered by the ice shelves allows direct access to the sedimentary record associated to the current global warming. The project "Understanding Larsen Ice Shelf: Seismic Evidence" (ULISSE) funded by the Italian Program of Researches in Antarctica (PNRA) allowed the acquisition, processing and interpretation of single channel seismic reflection data on board the R/V *Nathaniel B. Palmer* during cruise NBP06-03 (Punta Arenas 11 April 2006 – Punta Arenas 6 May 2006). The research was included within the framework of the United States Antarctic Program (USAP) project "Paleohistory of the Larsen Ice Shelf: Evidence from the Marine Record", initiated in 2000 and funded by National Science Foundation (NSF). It is within this project that sub-bottom profiles collected onboard R/V *LM Gould* during cruise LMG0502 (February 2005) imaged the complex sedimentary filling of the Hektoria Basin.

Three main themes have been addressed by these surveys: 1) the general structural setting of Larsen B area; 2) the characterization of the cold seep basin where a chemotrophic ecosystem was discovered during cruise LMG05-02 (Domack et al, 2005); 3) the setting and infill history of the Crane Glacier fjord.

Methods

The seismic source, consisting of one GI-gun shot in true GI mode (150 cubic inches in total) and pressured at 1850 psi, guaranteed a good compromise between resolution and penetration. Two single channel, 10-hydrophone streamers, 9.5 m and 30 m long respectively, simultaneously and independently collected the data with slightly different performances. Two parallel, independent digitizing systems (ELICS DELPH 2X SCS and OYO DAS-1) allowed two redundant records (to improve data protection from possible system failure) from both streamers. We also utilized hull mounted 3.5 kHz Chirp systems for higher (meter scale) resolution (BATHY2000W on the *N.B. Palmer* and Knudsen on the *L.M. Gould*), and the 12 kHz multibeam swath data as a bathymetric base.

New geophysical data from the inner shelf deposystems

The Hektoria and Crane tributary glaciers of the former Larsen B Ice Shelf have shown a landward retreat of several km, leaving the inner shelf deposystems at their mouths exposed. The Hektoria Basin infill is several tens of millisseconds thick and exhibits cyclical alternations of parallel continuous reflections and chaotic discontinuous reflections, representing up to 5 cycles and suggestive of glacial interglacial oscillations, as supported by five initial radiocarbon ages (Leventer et al., 2005).

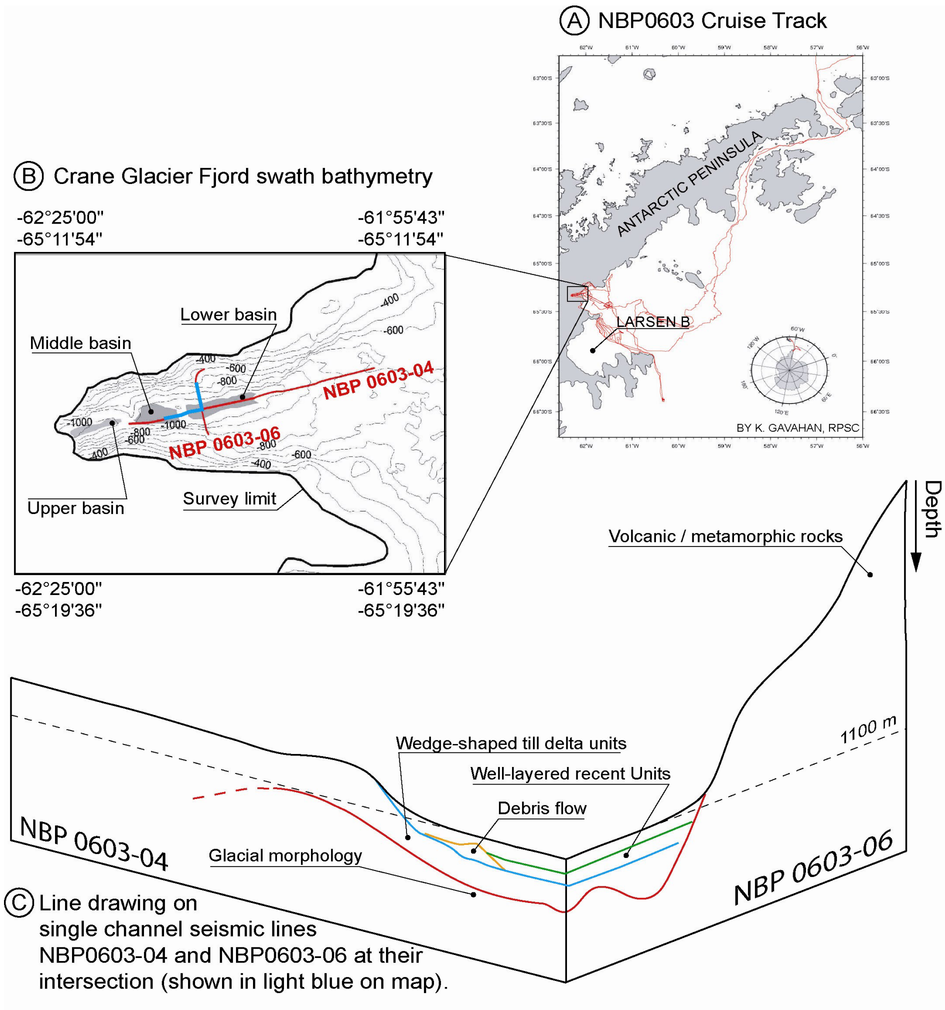

Figure 1. A. NBP0603 Cruise Track. B. Bathymetric contour from multibeam echosounder data within Crane Glacier Fjord: the complete track of seismic profiles NBP0603-04 and NBP0603-06 are indicated in red, the interpreted segments shown in the fence diagram in light blue. C. Fence diagram of interpreted line drawings.

Following the ice shelf collapse, the front of the Crane Glacier retreated by 15 km leaving behind a deep, newly-created fjord. The multibeam data imaged three ponded basins of varying depths, separated by more elevated thresholds (Fig. 1-B).

The sub-bottom profiles from the lowest basin show recent sediment fill of over 40 m thickness divided in two well layered, sub-parallel sub-units, laterally continuous and with a typical fill geometry onlapping the flanks of the basin.

The base of the basin and its fill are resolved in detail by profile NBP0603-04 (Fig. 1-C), which trends SSW-ENE parallel to the axis of the fjord and profile NBP0603-06 (Fig. 1-C), which trends SSE-NNW, normal to the axis and crossing the central part of the fjord (in the inner part of the lowest ponded basin). These data confirm the existence of the two fill sub-units accounting for over 40 m thickness. Moreover, they show that this fill is underlain by another seismic unit of variable thickness and complex geometry. Profile NBP0603-04 shows that the western part of the unit is wedge-shaped, with some dipping, prograding reflectors. Its upper boundary is landward dipping beneath the middle basin and rapidly outward dipping and subsequently flattening beneath the subparallel fill of the lower basin. The lower boundary of this unit has a similar trend in profile NBP0603-04, but is much more complex than the upper boundary in the strike profile NBP0603-06, showing alternating ridges and troughs.

Additional significant information that derives from the analysis of the single channel data is the sound velocity of the imaged seismic units. In the general case, when dealing with single channel (common offset) data, the information on the sound speed is inevitably lost, because no offset range is available to perform velocity analyses. In the case of profile NBP0603-06, however, a coarse and indirect estimation of sediment velocities was attempted by simply analyzing the diffraction hyperbolas that severely affected the raw data.

Among the profiles recorded in the area, line NBP0603-06 was in fact considered the best candidate to perform this kind of analysis, as it crossed the fjord perpendicularly. Hence it does not exhibit out-of-vertical plane reflections and diffractions typically encountered in topographically rough areas. At first, we considered the hyperbolas generated along the steep flanks of the basin, finding, as expected, a velocity of 1455 m/s (the sound of speed in water, normally attributed to the seafloor reflection). The internal velocity within the upper well-layered unit is not directly measurable because no hyperbolas are present within it. Proceeding downward, we analyzed the boundary separating the base of the underlying wedge-shaped unit. In this case, we found diffraction hyperbolas velocities of about 1700 m/s.

Thick expanded unconsolidated fill

The multibeam data reveal that the Crane Glacier fjord, the base of the former Crane Glacier, is over 1100 m deep, much deeper (over 600 m) than previously estimated on the basis of airborne echosounder data (Rignot et al, 2004). This discovery suggests that the amount of meltwater discharge following the retreat of this glacier (and likely also other similar tributary glaciers) is underestimated.

The present day morphology of the threshold between the middle and lower basin as shown by the multibeam data matches that of the alternating ridges and troughs at the base of the wedge-shaped unit shown by the single channel seismics. We notice that this morphology resembles that of the subglacial flutes observed elsewhere on the Antarctic margin (e.g. Canals et al., 2000) and in the Northern Prince Gustav Channel to the north of the Larsen Ice Shelf area (Camerlenghi et al., 2001). We hence interpret this morphology as the result of deposition of subglacial till at the base of grounded ice. This inference is further supported by the high sound velocity (1700 m/s) of this seismic unit.

The geometry and the internal prograding reflectors of the overlying wedge-shaped unit suggest that this unit developed as a sub-glacial delta. This delta may have developed in a "sub-glacial lake" setting similar to that inferred for the sub-glacial deltas in the Northern Prince Gustav Channel (Camerlenghi et al., 2001) and in the Palmer Deep basin (Domack et al., 2006).

We interpret the thick, layered fill of the lower basin as an expanded, unconsolidated fill resulting from accelerated ice discharge from the Crane Glacier related to the break-up of Larsen B ice shelf. This interpretation is supported by the high penetration shown by the sub-bottom acoustic profiles. Considering that the CHIRP data show good penetration down to the reflector at the base of the 40-m thick layer, and that this reflector represents the first downward appreciable variation in the acoustic facies, we infer that a low sound velocity may be assigned to this unit, which may extend down to its base with a slight increase. In fact, a substantial increase of velocity would be related to grain size variation, which would prevent penetration down to 40 mbsf, or to sediment compaction, which would originate a distinct reflection and a change in the acoustic facies.

Moreover, the inference that this layered fill has a low sound velocity and that this results from accelerated deposition is further supported by the high water content of kasten core NBP06-03 KC08 collected near the crossing of profiles NBP0603-04 and 06. This 2.7 m core is interpreted to represent just two year of deposition (summer 2004 to summer 2006), with a very high sedimentation rate (about 1.5 m/year).

This deposition took place after the collapse of the of remnant Larsen B ice shelf, which occurred in the summer of 2003. However, if the age model is correct, it would imply that the rest of the 40 m thick, layered fill took place in just one year. This would lead to unrealistic sedimentation rates. The only viable alternative option before a long core is available, is to consider that the rest of the fill took place in a sub-glacial lake setting, before the collapse of the ice shelf. By extrapolating the sedimentation rate of the upper 2.7 m of sediment downward, we estimate an age of about 30 years ago for the base of the layered fill. This age is roughly coincident with the onset of the decrease in the extent of the ice shelves in the region. We hence infer that the Crane glacier, and possibly other tributary glaciers, are not only heavily affected by the collapse of the nearby Larsen B ice shelf (e.g. Rignot et al., 2004), but also highly sensitive to the regional dynamics of the ice shelves, to long-period waves (Domack, 2007) and to mean air temperature variation.

Following the same reasoning, similar conclusions could be drawn with respect to the Hectoria Basin infill hystory, although seismic data are not yet available in that area.

Summary

Geophysical exploration revealed the setting and the recent infill history of the newly-created Crane Glacier Fjord (Exasperation Inlet, Eastern Antarctic Peninsula), originated by the retreat of the Crane Glacier after the Larsen B ice shelf collapse. The integration of multibeam echosounder, sub bottom profiling and single channel seismic data collected during cruise NBP0603 imaged in detail the fjord, that not only appears much deeper than previously estimated, but also exhibits an unexpected thick (more than 40 m) sedimentary fill in the lowest of its three basins.

This lattest information is particularly significant as it suggests that the glacier behaviour was affected not only by the Larsen-B ice shelf collapse, but also by regional ice shelves dynamics.

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