Géographie physique et Quaternaire

Sediment Content in Antarctic Iceberg Fragments Sufficient to Sink the Ice
Fragments d'icebergs de l'Antarctique au contenu sédimentaire suffisant pour entraîner leur dépôt sur le fond marin

Robert Gilbert, Eugene W. Domack et David Tewksbury

Volume 58, numéro 1, 2004

URI : https://id.erudit.org/iderudit/013115ar
DOI : https://doi.org/10.7202/013115ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Résumé de l'article

Des fragments d'icebergs recueillis sur le fond océanique, près du glacier de Swift, en Antarctique, contenaient suffisamment de sédiments pour couler à une vitesse de 0,13 à 0,35 m/s. La collision de tels fragments avec le plancher marin entraînerait un brassage important des sédiments mous. Au contraire de celle de sédiments délestés par les icebergs, la stratigraphie de ces sédiments gelés résultant de processus glaciaires peut être préservée au sein des dépôts marins après la fonte des fragments de glace dans lesquels ils sont emprisonnés. Ces fragments, dont la densité est supérieure à celle de l'eau, pourraient être communs dans les régions polaires et causer, sous l'action des courants, un labourage ascendant et descendant des pentes des fonds marins, contrairement aux glaces flottantes.

Géographie physique et Quaternaire, 2004, vol. 58, nº 1, p. 147-149, 2 fig.

SEDIMENT CONTENT IN ANTARCTIC ICEBERG FRAGMENTS SUFFICIENT TO SINK THE ICE

Robert GILBERT*, Eugene W. DOMACK* and David TEWKSBURY*: first author: Department of Geography, Queen's University, Kingston, Ontario K7L 3N6; second and third authors: Department of Geology, Hamilton College, Clinton, New York 13323, U.S.A.

ABSTRACT Iceberg fragments recovered from the sea floor near Swift Glacier, Antarctica, contained sufficient sediment to sink the ice. Sediment concentrations in the samples would have caused them to settle at 0.13 to 0.35 m/s through the water column. Impact with the sea floor would significantly turbate soft sediments. Unlike sediment dumped from icebergs, the stratigraphy of the frozen sediments created by glacial processes may be preserved in the marine sedimentary record after melting of the ice. Negatively buoyant berg fragments may be common in polar regions, and when driven by currents may scour the sea floor up and down slopes unlike floating ice.

RÉSUMÉ *Fragments d'icebergs de l'Antarctique au contenu sédimentaire suffisant pour entraîner leur dépôt sur le fond marin*. Des fragments d'icebergs recueillis sur le fond océanique, près du glacier de Swift, en Antarctique, contenaient suffisamment de sédiments pour couler à une vitesse de 0,13 à 0,35 m/s. La collision de tels fragments avec le plancher marin entraînerait un brassage important des sédiments mous. Au contraire de celle de sédiments délestés par les icebergs, la stratigraphie de ces sédiments gelés résultant de processus glaciaires peut être préservée au sein des dépôts marins après la fonte des fragments de glace dans lesquels ils sont emprisonnés. Ces fragments, dont la densité est supérieure à celle de l'eau, pourraient être communs dans les régions polaires et causer, sous l'action des courants, un labourage ascendant et descendant des pentes des fonds marins, contrairement aux glaces flottantes.

INTRODUCTION

Rafting of terrestrial sediment by sea ice and icebergs has long been documented as an important glacimarine process in arctic (Bischof, 2000) and antarctic waters (Anderson *et al.*, 1980). Sediment is actively incorporated in ice by basal freezing of sea ice to sediment in the nearshore zone (Gilbert, 1983), by frazil and anchor ice scavenging from the water column and sea floor (Reimnitz *et al.*, 1990; Smedsrud, 2002), or into glacier ice by basal processes, especially associated with freezing (Iverson, 1993). Passive loading onto sea ice occurs associated with tidal (Gilbert, 1990), colluvial, fluvial (Reimnitz and Bruder, 1972) and aeolian (Gilbert, 1983) processes, and onto glacier ice principally by colluvial processes on the lateral valley sides (Small, 1987).

Although it is known that the loads of these sediments may be large, there is very little evidence whether loads sufficient to increase the bulk density of the ice and sediment to greater than that of sea water occur commonly (*cf.* Goldschmidt, 1994), and of the significance of this in the character of the glacimarine sedimentary record.

The concentration, C, of sediment necessary to make the ice neutrally buoyant at the surface is

$$C = (\rho_w - \rho_i)/(1 - \rho_i/\rho_s)$$

where ρ is the density of seawater (w), ice (i) and sediment (s), respectively. As little as 170 to 200 g/L of sediment in the ice may be sufficient to render the ice negatively buoyant in seawater (Gilbert, 1990). Sediment incorporated into the ice either at the time of formation or subsequently, by melting and refreezing, will be more effective than sediment passively loaded on the ice surface, because the latter is likely to be washed from the ice as it submerges, allowing the ice to re-float. Variable concentration through the ice offers a means to raft frozen-in sediment to sea and subsequently allow a portion to sink due to breaking off of relatively dirtier ice, or by melting. This is especially so if the ice is oriented with the area of higher concentration submerged in cold sea water while the cleaner, less dense region is exposed to warmer air and solar radiation.

ANTARCTIC SEDIMENT-LAIDEN ICE

Grab samples from the sea floor in an embayment in front of Swift Glacier, James Ross Island, western Weddell Sea (Fig. 1) collected during a U.S. Antarctic Programme cruise on *RVIP N.B. Palmer* in January 2002 provide the first documentation of iceberg fragments submerged by their sediment content. This is a region that has experienced rapid climate warming (Vaughan *et al.*, 2001) and associated disintegration of the Larsen A Ice Shelf, principally in January 1995 (Scambos *et al.*, 2001), and the Larsen B Ice Shelf in February 2002. Bergs from the Swift Glacier were heavily laiden as a result of the development of large medial moraines (Fig. 1) associated with rapid erosion of the weakly indurated and heavily weathered upper Cretaceous sedimentary and igneous volcanic rock of James Ross Island.

The sea water in the vicinity of Swift Glacier consisted of four layers on January 3, 2002 (mid summer): (1) from 0-15 m depth, temperature increased from -0.58 to -0.39 °C, salinity decreased from 33.25 to 33.67 ‰, and density assessed from the UNESCO International Equation of State for Seawater (IES80) increased from 1026.72 to 1027.06 kg/m^3; (2) by 60 m depth temperature decreased to -0.75 °C, salinity increased to

Manuscrit reçu le 16 février 2005 ; manuscrit révisé accepté le 15 avril 2005 (publié le 2e trimestre 2006)
*E-mail addresses: gilbert@lake.geog.queensu.ca; edomack@hamilton.edu; dtewksbu@hamilton.edu

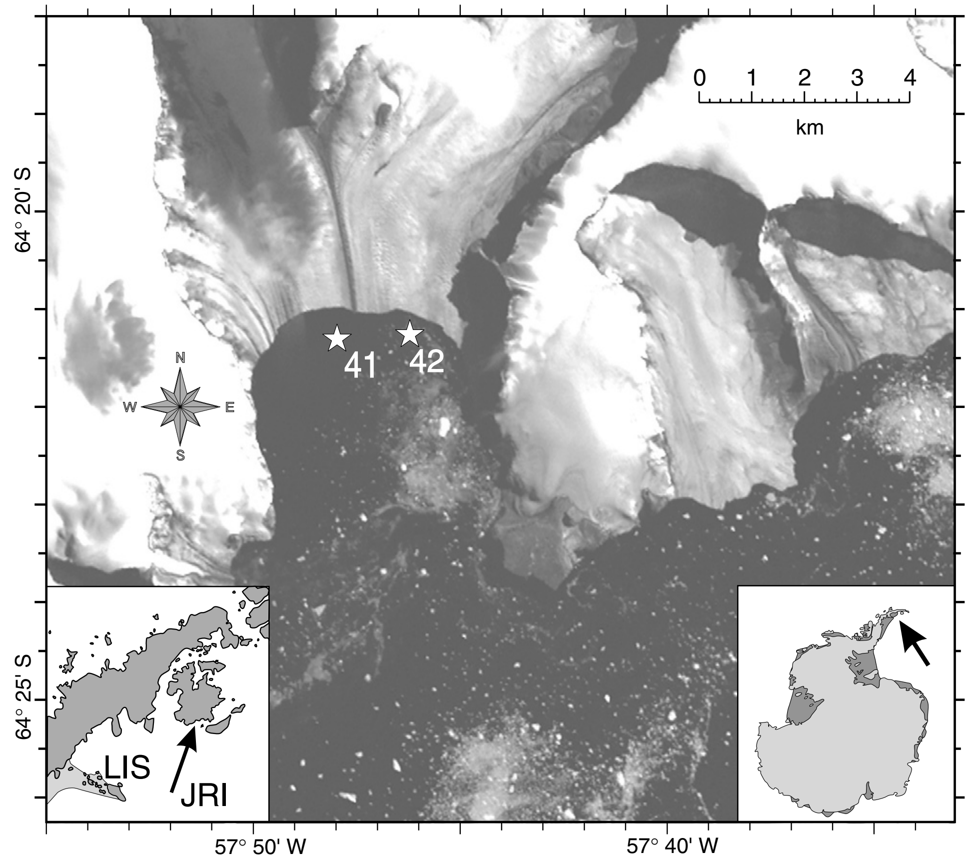

FIGURE 1. Landsat image from 1 February 2001 showing the terminus of Swift Glacier on James Ross Island (JRI) and the location of sampling stations discussed in text. Inset maps show the location with respect to the Antarctic Peninsula (at left) and the Antarctic continent (at right). The present northern edge of the Larsen Ice Shelf (LIS) is shaded.

Image Landsat prise le 1er février 2001 montrant l'extrémité du glacier Swift, sur l'île James Ross (JRI), et la localisation des stations d'échantillonnage mentionnées dans le texte. Les cartons indiquent la position du site par rapport à la péninsule Antarctique (à gauche) et au continent Antarctique (à droite). La limite nord actuelle de la plate-forme Larsen (LIS) est en gris.

33.865 ‰ and density increased to 1027.25 kg/m^3; (3) by 120 m depth temperature decreased to -1.69 °C, salinity increased to 34.43‰, and density increased to 1027.77 kg/m^3: and (4) by 185 m (the sea floor), temperature decreased slightly to -1.83 °C, salinity increased slightly to 34.47 ‰ and density increased slightly to 1027.84 kg/m^3.

In grab sample 42 (Fig. 1), collected in 23 m of water, were two fragments of sediment-laiden ice. One (Fig. 2a) contained a concentration of banded sediment of 396 g/L (57 % gravel, 23 % sand, and 20 % silt and clay size by weight), generating a negative buoyancy in sea water of about 134 g/L. The other (Fig. 2b) contained a single large fragment (672 g) of vesicular basalt for a concentration of sediment of 795 g/L, and a negative buoyancy in sea water of about 381 g/L. In grab sample 41 a fragment of sediment-laiden ice had a density of 1 470 g/m^3. Compare these values with concentrations of up to 57 g/L in arctic sea ice (Nürnberg *et al.*, 1994) and up to 68 g/L in Antarctic icebergs (Anderson *et al*, 1980).

According to the nomograph presented by Deitrich (1982), these fragments would have fallen through sea water described above at about 0.13, 0.27 and 0.35 m/s, respectively, assuming they were then as they were when recovered. Thus, they may have struck the sea floor with sufficient force to re-suspend a cloud of the highly under-consolidated, rapidly deposited, fine-grained sediment that dominates the sea floor in this region, and they may have become partially buried in this material.

CONCLUSION

Rafting over large areas of polar oceans and delivery to the seafloor of frozen sediment may be more widespread than previously understood. The implications for glacimarine sedimentation are significant. Sediment is delivered to the sea floor as it was incorporated into the ice, significantly preserving sedimentary structures such as foliation, lamination and layering. It may be encapsulated in fine hemipelagic sediment during impact or as deposited subsequently but before melting occurs, thus preserving the sedimentary structures (Gilbert, 1990). Because these fragments are slightly to moderately negatively buoyant, some may not be implanted in the sediment, especially on relatively hard sea floors. Thus, they may be easily moved across the sea floor by currents, leaving furrows that go up and down slopes (Josenhans and Woodworth-Lynas, 1988) unlike scours created by floating ice which only occur at and just less than depths corresponding to the draft of the ice keel. The samples we recovered were very small (limited to several decimetres by the size of the grab sampler) but it is likely that much larger, negatively buoyant bergs and berg fragments occur in the vicinity of calving glaciers.

ACKNOWLEDGMENTS

Funding was provided by the Natural Sciences and Engineering Research Council of Canada and by the U.S. National Science Foundation, Office of Polar Programmes

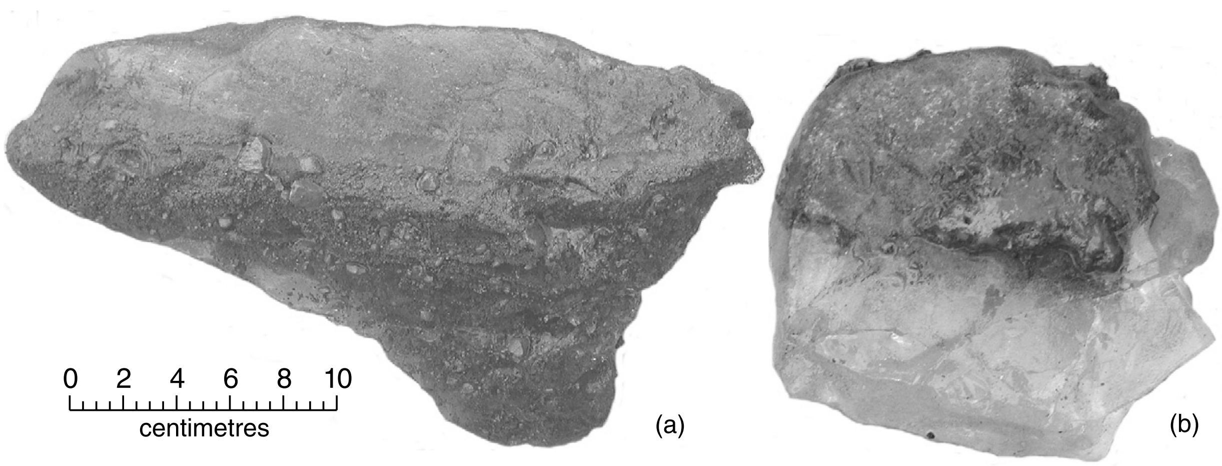

FIGURE 2 Photograph of iceberg fragments recovered in grab 42.

Photographies des fragments d'icebergs de l'échantillon 42 recueillis à l'aide de la benne.

(OPP-0003060). The diligence and skill of captain, officers, and crew of *RVIP N.B. Palmer* made the work possible. The first author thanks Foreign Affairs Canada and the University of Copenhagen, Institute of Geography, for the opportunities provided by a research chair during which this paper was written. We also thank Michel Parent who reviewed the manuscript.

REFERENCES

Anderson, J.B., Domack, E.W. and Kurtz, D.D., 1980. Observations of sediment-laiden icebergs in Antarctica waters: implications to glacial erosion and transport. Journal of Glaciology, 25: 387-396.

Bischof, J., 2000. Ice Drift, Ocean Circulation and Climate Change. Springer-Praxis, Chichester, 215 p.

Dietrich, W.E., 1982. Settling velocity of natural particles. Water Resources Research, 18: 1615-1626.

Gilbert, R., 1983. Sedimentary processes of Canadian arctic fjords. Sedimentary Geology, 36: 147-175.

_____ 1990, Rafting in glacimarine environments, p. 105-120. *In* J.A. Dowdeswell and J.D. Scource, ed., Glacimarine Environments: Processes and Sediments. The Geological Society Special Publication 53, London, 380 p.

Goldschmidt, P.M., 1994. Armoured and unarmoured till balls from the Greenland Sea floor. Marine Geology, 121: 121-128.

Iverson, N.R., 1993. Regelation ice through debris at glacier beds: implications for sediment transport. Geology, 21: 555-562.

Josenhans, H. and Woodworth-Lynas, C., 1988. Enigmatic linear furrows and pits on the upper continental slope, northwest Labrador Sea: are they sediment furrows or feeding traces. Maritime Sediments, 24: 149-155.

Nürnberg, D., Wollenburg, I., Dethleff, D., Eicken, H., Kassens, H., Letzig, T., Reimnitz, E. and Thiede, J., 1994. Sediments in arctic sea ice: implications for entrainment, transport and release. Marine Geology, 119: 185-214.

Reimnitz, E. and Bruder, K.F., 1972. River discharge into an ice-covered ocean and related sediment dispersal, Beaufort Sea, Coast of Alaska. Bulletin of the Geological Society of America , 83: 861-866.

Reimnitz, E., Kempema, E.W., Weber, W.S., Clayton, J.R. and Payne, J.R., 1990. Suspended-matter scavenging by rising frazil ice, p. 97-100. *In* S.F. Ackley and W.F. Weeks, ed. Sea Ice Properties and Processes. U.S. Army Cold Regions Research and Engineering Laboratory Monograph M90-01, Hanover, 148 p.

Scambos, T.A., Hulbe, C., Fahnstrock, M. and Bohlander, J., 2001. The link between climate warming and break-up of ice shelves in the Antarctic Peninsula. Journal of Glaciology, 154: 516-530.

Small, R.J., 1987. Moraine sediment budgets, p. 165-197. *In* A.M. Gurnell and M.J. Clark, ed., Glacio-fluvial Sediment Transport: An Alpine Perspective. Wiley, Chichester, 486 p.

Smedsrud, L.H., 2002. Frazil ice entrainment of sediment: large-tank laboratory experiments. Journal of Glaciology, 47: 461-471.

Vaughan, D.G., Marshall, G.J., Connolley, U.M., King, J.C. and Mulvaney, R., 2001. Devil is in the detail. Science, 293: 1777-1779.