Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient

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Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient

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Preface

Twenty years ago, the international marine community brought together a first *Atlas of Acoustic Images* of the high-latitude geo-marine environment (Davies *et al.* 1997). The present *Atlas of Submarine Glacial Landforms* presents a new attempt to summarize the state of knowledge of these high-latitude glacier-influenced systems, focusing in particular on high-resolution seafloor imagery derived mainly from multibeam swath bathymetry and associated acoustic-stratigraphic data. It is timely to provide a compilation of the variety of submarine glacial and related landforms, together with their stratigraphic setting where possible, for several scientific, technological, environmental and economic reasons. First, new-generation techniques have revolutionized the high-resolution imaging of the modern seafloor over the past two decades and these instruments have now been deployed widely in polar waters, providing vast quantities of new data. Secondly, palaeo-shelf surfaces, buried in glacial-sedimentary depocentres, can now be imaged better than ever before using 3D seismic-reflection methods, providing novel insights into sedimentary architecture and past environmental conditions. Thirdly, it is now widely recognized that the polar regions and their changing ice cover are both a key driver of global change and important responders to it, making their understanding of enhanced significance (e.g. IPCC 2013). Finally, industry is increasingly interested in understanding the dimensions and architecture of glacial sedimentary depocentres on present and past continental shelves because of the considerable potential of some glacial-sedimentary facies as hydrocarbon reservoirs.

The *Atlas of Submarine Glacial Landforms* presents a comprehensive series of contributions by researchers from 20 countries that describe, illustrate and discuss the full variability of landforms found on the high-latitude glacier-influenced seafloor. The distribution and geometry of these submarine landforms provide key information on past ice-sheet extent, the direction and nature of ice flow and dynamics, and a well-preserved window on the detailed form and composition of former ice-sheet beds. The development of ice-breaking research vessels and high-resolution imaging technologies has allowed seafloor mapping at water depths from tens to thousands of metres across high-latitude continental margins.

The 180 or so contributions to the *Atlas* are organized in terms of their positions on a continental margin into those from: (1) fjords; (2) continental shelves and plateaux; and (3) the continental slope, rise and deep-sea basins beyond. Two-page papers focus on *individual* seafloor landforms from the polar seas, whereas four-page papers describe and discuss *assemblages* of submarine glacial landforms. Entire fjord–shelf–slope systems of submarine landforms on high-latitude margins, sometimes referred to as *landsystems*, are outlined in 12 eight-page contributions, encompassing a continuum of glacimarine climatic settings from relatively mild (e.g. Gulf of Maine, Norway, Svalbard) to extreme (e.g. Arctic Basin, East Antarctica) and timescales from the modern margins of tidewater glaciers, through Quaternary examples, to the ancient glaciations of northern Africa in the Late Ordovician.

References

DAVIES, T.A., BELL, T. *et al.* (eds) 1997. *Glaciated Continental Margins: An Atlas of Acoustic Images*. Springer, Berlin.

IPCC (Intergovernmental Panel on Climate Change) 2013. *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge.

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