Modern Glacimarine Environments

by Ross D. Powell

Glacial systems produce one of the largest sediment volumes on the continental shelves and slopes, and their study provides another way of reconstructing paleoenvironments. Because of the interactions between the sea and ice of various kinds (icebergs, sea ice, tidewater fronts and ice shelves), the glacimarine setting is one of the most complex and least understood sedimentary environments. There is a continuum of diamictic deposits and a range of controls from tectonic to oceanic. This article reviews many facets of current work on this modern setting. (Ed.)

Modelling Sedimentary Systems

Current trends in sedimentology emphasize modelling the Earth's major depositional systems. Glacial environments are no exception, and recent models have been constructed from studies of modern processes under different climatic regimes as well as from facies analyses of sedimentary rocks. These models are initial working hypotheses, and much more information is required before they can be generally applied with confidence. Nevertheless, expressing current knowledge in this way is valuable for predictions and planning studies of modern environments and as guides for interpreting successions of older sedimentary basins.

What are Glacimarine Sediments?

The glacial marine (glacimarine) environment includes all sediment deposited in the sea after release from grounded or floating glacial or sea ice. The glacimarine setting remains one of the most complex and least understood of common sedimentary environments, despite recent studies

of both ancient and modern deposits, (e.g. Vanney and Dangeard, 1976; Boulton and Deynoux, 1981; Andrews and Matsch, 1983; Molnia, 1983; Elverhoi, 1984; Powell, 1984; Eyles et al., 1985; Drewry, 1986; Edwards, 1986). The physical processes in shallow water (to shelf and slope depths) by which glacimarine sediment is produced, distributed and laid down have received relatively little attention, no doubt partly due to the difficulties of sampling and monitoring appropriate variables over extended time periods in remote, harsh environments.

Glacimarine conditions prevail in different climatic-glacial settings from frigid polar to cold temperate regimes and in settings ranging from open shelf and coast to estuarine fjord. A broad range of information is required from common non-glacial processes such as fluvial and oceanic; these are complicated by modifications as well as new processes due to ice. Multidisciplinary research can now be helpful, with direct glacial controls being evaluated by glaciologists, hydrologists, sedimentologists and geomorphologists to provide data on source processes and modes of sediment genesis. Marine controls can be assessed by oceanographers, geophysicists, biologists, paleontologists and sedimentologists who provide data on glacier-sea water interaction, the primary marine contribution, and subsequent modification of glacimarine sedimentary facies by marine processes.

Delivering Sediments to the Sea

In general, four types of ice introduce sediment to the sea: tidewater fronts, ice shelves, icebergs and sea ice. Ice shelves are floating slabs of thick ice that calve icebergs, perhaps hundreds of kilometres from where they begin to float at their grounding lines. Tidewater fronts, ending as nearly vertical cliffs, calve icebergs coincident with their

ground lines (Fig. 1). Among the important glaciological issues here are how rapidly a glacier can advance into the sea, what controls the advance, what sedimentological processes occur and what products result. Exactly the same questions need to be addressed for grounding-line retreat. Can grounded glaciers detach from their bed over large areas and catastrophically disintegrate (Thomas and Bentley, 1978; Meier et al., 1980), and if so, what type of sedimentary record does that produce? How does that compare with processes and facies deposited during gradual retreat?

Sediment from beneath ice shelves has been obtained so far only from the Ross Ice Shelf, Antarctica. However, this was from a non-depositional regime where the ice shelf had no debris and modern bottom sediment was thin or absent. Indeed, most sediment appears to be deposited within a few kilometers or tens of kilometers from the grounding line of an ice shelf (Orheim and Elverhoi, 1981; Barrett et al., 1983). Are such deposits similar to those close to tidewater fronts? If that question can be answered, then climatic regimes may be closely defined. Extreme climates are required for ice shelf formation and maintenance. If ice shelf deposits are defined, then a polar climatic regime may be inferred.

Tidewater fronts may exist under any climatic regime. Detailed models for ice shelf deposition have been suggested by several workers after an original paper by Carey and Ahmad (1961), which was based on interpretations of ancient successions, with the assumption that all glacial marine sediment is deposited from ice shelves. Given the requirements for ice shelf formation, and that fifty percent of the present Antarctic coastline and most other glacial marine coastlines are glaciated by tidewater fronts or short floating glacier-tongues, such an assumption is very questionable.

Glacial marine Deposits

Glacial marine diamicts comprise a continuum from compound sediment where particles originate from two sources (e.g. meltwater streams and ice rafting) to residual sediment

Figure 1: Iceberg calving from Margerie Glacier, a tidewater front at Glacier Bay, southeast Alaska. Ice cliff is about 60m high.

Figure 2: A - Laminites and ice-rafted clasts in glacial marine sedimentary rocks of the Gowganda Formation (>2.1 Ga), Ontario, Canada. B - Two cores of recent sediment from Glacier Bay, Alaska showing ice-rafted clast and interlaminated sand and mud, which, though neither lacustrine nor annual, commonly have similar characteristics to "varves." These are comparable to the sedimentary rocks of Figure 2A but were deposited within 2 km of a grounding line at rates up to 15.4 cm per day. Core width is 7.5 cm.

where particles are removed during depositional winnowing from a source of poorly sorted debris (Powell, 1984; Anderson, 1985). The type of product depends on the ratios of coarse to fine particles. The proportion of coarse components is dependent upon the rate of ice rafting, which is in turn a function of volume of debris in the ice, the rate of ice dispersal, and the rate of melting. The fine components are controlled by ice rafting, degree of winnowing during fall through the water column, fluctuation in sediment discharge from meltwater streams and the amount of flux from oceanic currents. The state of knowledge about how these variables interact to produce different facies is still poor, especially if we want to distinguish facies of a tidewater front from that of an ice shelf or of a valley glacier from that of an ice sheet source.

The relative importance of meltwater stream sediment and that from direct meltout from ice is also unknown, and the related matter of the effectiveness of iceberg rafting in different glacial and marine settings is likewise poorly understood. Nearshore processes and annual sea ice can also contribute, under certain conditions, significant volumes of sediment to the sea, and a few studies have evaluated its contribution to sedimentary facies (Reimnitz and Barnes, 1974; Dionne, 1985). Investigations of biogenic production and its contribution to these sediments are still in their infancy.

Controls on Glacial marine Systems

Among all sedimentary systems, the glacial marine can be one of the most productive of sediment volume. Many modern continental shelves and slopes have received much of their sediment from ice sources, and the glacial system is one of

the world's greatest silt producers. Yet we are still in the dark when it comes to assigning sediment budgets to the glaciomarine system.

Tectonic control on glaciomarine sedimentation is also poorly understood. Are different facies produced under different tectonic regimes? In general, glaciomarine depositional systems cannot be characterized by individual facies, nor by typical facies sequences; facies associations need to be known in three dimensions in order to be useful for interpretations. Can settings such as epeiric seas, passive margins, and early intercontinental rifts create conditions for unique glaciomarine facies?

High-resolution seismic reflection studies are being used increasingly for seismic facies analysis, determining relative sea level and isostatic fluctuations, and establishing sequences of glacial advances and retreats across continental shelves. Side-scan sonar surveys are being applied to the study of iceberg scours, sediment gravity flow processes and facies mapping (e.g. Fossum et al., 1982; Vorren et al., 1983; Josenhans et al., 1986). Remote-control vehicles are needed to continue and expand these studies in the future to ice-proximal and sub-ice locations.

Oceanic influences on sediment transport and deposits also need to be studied. Sediment transport mechanisms on glaciated continental shelves and slopes, current patterns, water mass structure and mixing at glaciated margins and under ice shelves, and iceberg movements are all areas of concern for physical oceanographers and marine sedimentologists (Coachman and Aagaard, 1974; Jacobs, 1985; Syvitski et al., 1987).

Chemical oceanographers and marine biologists and paleontologists are acquiring data on a wide range of topics. These include nutrient fluxes; the fluxes, decay rates and accumulation rates of biogenic matter; food webs; the

abundances, diversities and distributions of organisms; ecosystems and biogeographic analyses; animal-sediment interactions; bottom-water production and sea-ice formation; water mass residence times; and turnover and upwelling processes (Lipps et al., 1979; Echols and Armentrout, 1980). However, most of these studies are in their infancy, and long term, time-series monitoring is required for all of these oceanographic studies.

Increased interaction between scientists of different specialties and researchers working in different modern climatic and tectonic regimes is clearly needed. Such exciting developments should continue the momentum and heightened level of interest that the glaciomarine environment has received in recent years. The results obtained from our better understanding of modern systems should also be of great value for those involved in basin analysis of successions in the rock record.

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