
Chapter 1

Introduction

Until recently, investigations of the sedimentation processes were restricted to the study of marine and continental deposits within continental sequences. Only during the last decades, geologists started investigations of the seas and oceans which occupy the largest part of the Earth's surface (about 2/3). The latter represent a natural laboratory of diverse sedimentation processes occurring throughout the world – from poles to equator. Besides significant expanding of the spread of work and appearance of possibilities to introduce the comparative-lithological method, new original instruments and methods have been involved into the study, thus resulting in development of new lines of investigations of sedimentation process and geochemistry.

It is reasonable that all this resulted in radical alterations in the usual data base. So the scientists were forced to revise many concepts previously considered as the salient ones but poorly supported with data.

It is especially important that the range of the studied oceanic territory extended significantly (including the former “uncharted territories”).

The “uncharted territories” include the high latitudinal Arctic and Antarctic areas, which are the most hardly accessible regions due to their glacial and meteorological conditions. These very territories are the main areas where a special type of lithogenesis is performed. The author suggested it be given the name of glacial-marine sedimentogenesis (Lisitzin 1961a–d, 1996).

It is generally recognized that ice is one of the most active agents of sediment preparation, transportation and accumulation. Its transportation activity is surprisingly high: large icebergs travel a distance of 4–6 thousand kilometres from the place where they originated, and while melting they lay down to the sea floor the involved sedimentary load.

Both icebergs and marine ice (formed on marine water freezing) are able to transport sedimentary load significantly ranging in size – from boulders (more than 10 m in diameter) to fine pelite particles (“glacial milk”).

The hoisting force of ice is large: depending on density one cubic metre of ice can transport more than 100 kg of sediment.

At present, different types of ice are spread in the World's Ocean over the area of 20 mio. km², i.e. about

7% of its surface, while icebergs cover 63 mio. km², i.e. about 20% of the ocean surface. This closely corresponds to the area of the present continental glaciation. During the recent geological epochs (Late Cenozoic and Quaternary glaciations) the area of both continental and marine glaciations increased considerably and glacial sedimentation became the main component of the sedimentation process on the Earth. It should be noted that as applied to the World Ocean, the new concept on glacial sedimentation appeared during the last decades due to the data obtained in the high latitudes of the Northern and Southern Hemispheres. True enough, many investigators (Drygalski 1897; Mushketov 1888; Andree 1920; Strakhov 1960 and others) gave special attention to the important role of sea, river and glacier ice in preparation, transportation and accumulation of sedimentary material and formation of the continental relief.

Various scientists give different meanings to the term “glacial sedimentogenesis”. It appeared more than 100 yr ago, when the first investigations of the Quaternary glacial deposits and their modern continental analogues were started. N. M. Strakhov (1960) gave the same meaning to this term, when recognizing main types of lithogenesis within continental block of the Earth. N. M. Strakhov thought the glacial sedimentation to be absent in seas and oceans, since it was typical only of the continental block. The glacial sedimentation includes only one stage of the sedimentation process – the sedimentation itself, while the other one – diagenetic changes – is absent. This was assigned to the low temperatures, which suppress microbiological and chemical processes.

Later Yu. A. Lavrushin (1976) and other Russian and foreign investigators showed, that glacial sediments of the continent are subjected to diagenetic changes; carbonate neogenic forms (regeneration rims around mineral grains, authigenic segregation of ferrum and goethite, structural transformations of clayey minerals) being of special importance for the subglacial process (Lavrushin et al. 1986). As shown above, N. M. Strakhov (1960) denied the possibility of accumulation of marine glacial deposits. He believed them to be the common kind of the humid zone deposits containing coarse detritus brought by ice. So, it was established in lithology,

that only continental type of glacial sedimentogenesis existed. Ice is the only agent of the sediment preparation, transportation and accumulation within the vast areas of sea and ocean bottom. Unique environmental conditions exist here along with special biogenic processes, special diagenesis and profound transformation of the sediments.

Temperature drop below the water freezing point, i.e. climatic variations, results in transition of liquid water into solid state. This process takes place in the atmosphere, continental and marine basins, rivers and sedimentary formations (lithosphere), thus forming snow, ice and permafrost.

Distribution of the main accumulations of solid water (ice-sedimentary rock) depends upon favourable combination of low temperature and atmospheric precipitation, i.e. humidity.

The greatest accumulations of ice on land – ice sheets with the thickness of up to 3 000–4 000 m – appear in the places where cryogenic conditions correlate well with sufficient supply of water in a solid state (snow). Thus, continental glaciated areas are restricted to the regions where snow accumulation exceeds ablation.

No ice caps appear in those continental areas where anticyclones are dominant and air is dry. Thus, continental glaciation is replaced by an underground one (permafrost areas of northeastern Asia, Alaska, Canada). Permafrost is also typical of many Arctic shelves (submarine type of underground glaciation).

Thick ice sheets cannot appear in oceans where intensive vertical circulation exists even under cryogenic conditions. The total thickness of ice and snow cover of the ocean surface does not exceed 4–6 m. Ice is preserved for the whole year or for its main part (6 months and more). In the pack ice area, ice is preserved all year round. This is an area of the modern sea ice glaciation. Along the outer boundary of this zone ice is preserved for a shorter period. This is a sea ice analogue of periglacial zone.

From the author's point of view, all kinds of on-land glaciation (ice sheets and permafrost) were accompanied by marine glaciation when ocean surface was occupied with constantly renewed ice all year round (arctic pack ice).

Accumulation of ice on land depends upon humidity (continental glaciation or permafrost) but sea ice cover formation is not influenced by this factor. Thus, sea ice cover serves as a universal indicator of cryogenic environment and planetary ice zones. Thus, they accompany both on-land glaciation and permafrost.

The prevailing form of water determines location of the zones of glacial and temperate sedimentation. If during most part of the year water on land and over the ocean surface exists in solid state (ice), environmental conditions are referred to as cryogenic and glacial type of sedimentation dominates over other types of sedimentation (Fig. 1.1).

The single reason – temperature drop below the water freezing point – causes different consequences on land and in the ocean. Continental drainage areas are replaced by either ice-catchment or permafrost zones. Ice governs both transportation of sedimentary material and its discharge in the places of ice melting.

Specific processes of the sedimentary material preparation operate at low temperatures, since chemical weathering of mother rocks and biochemical processes demand water in liquid state.

The most drastic environmental changes (from glacial to temperate) have occurred in the middle (temperate) latitudes. For instance, vast ice sheets repeatedly appeared in the middle latitudes of the Northern Hemisphere (Europe, North America) during the Quaternary epoch. Hence, seas and oceans were also repeatedly covered with ice.

Glacial conditions of high latitudes did not undergo any sharp changes. For instance, sea ice glaciation of the central Arctic Ocean has an age of many million years and Antarctic glaciation 30–50 mio. yr.

So, glacial sedimentation giving evidence for past environmental conditions was considerably more extensive (spatially and temporarily) than it has been previously thought.

The term “marinoglacial” deposits (Philippi 1910) has been previously used in reference to diverse sediments occurring in sea ice zones including iceberg-rafting related to ice sheets and sea ice-rafting which is not related to continental glaciations. However, certain criteria for distinguishing these sediments (markers) in geological sections still remain unknown.

In the current work we tried for the first time to distinguish between sea ice-rafting (related to sea ice activity), iceberg-rafting (i.e. related to continental glaciation producing icebergs) and processes related to permafrost (Fig. 1.2). Moreover, the author established numerous facies characterizing the above subtypes of sedimentary processes occurring at low temperatures. These facies represent regional and local combinations of cryogenic environmental conditions in seas resulting in accumulation of certain sediments with specific regularities of spatial distribution and regular spatial and temporal successions in accordance with the Walter's rule.

As shown below, sea ice-rafted sediments are easily distinguished from iceberg-rafted ones. Besides this, the author managed to subdivide the Arctic sea ice-rafted deposits into three subtypes differing from each other in the preparation and transportation of sedimentary matter, distribution of sediments and their properties.

Contrary to the existing opinion, coarse ice-rafted debris (IRD), previously considered as an universal indicator of cryogenic environment, is practically insignificant for the most widespread Siberian type of sea ice sedimentation. That is why the sediments represented in geological sections by fine grained glacial material of

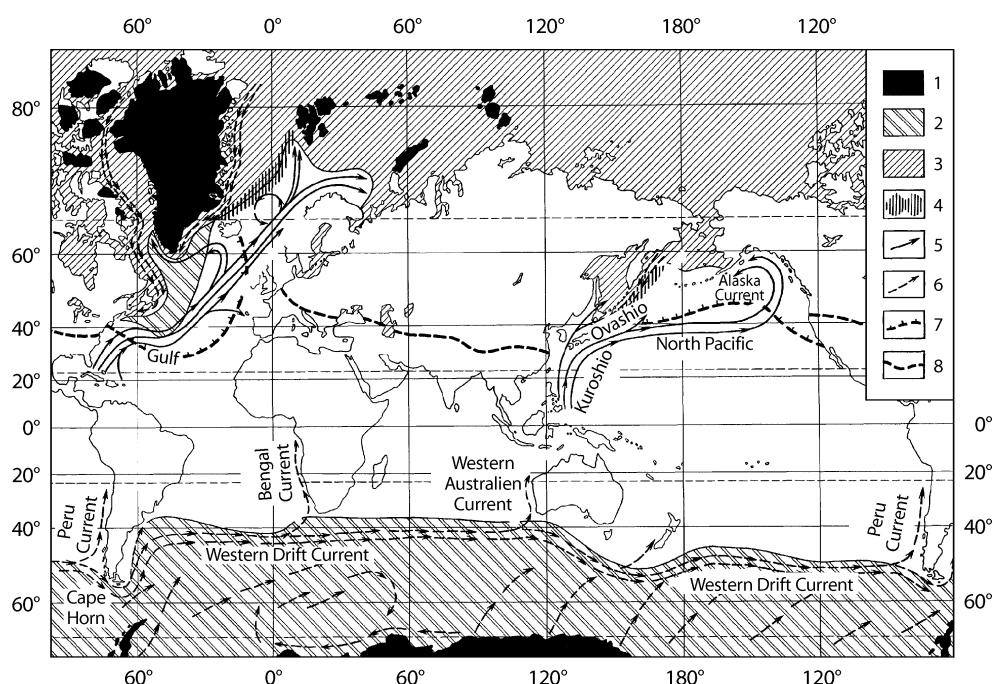


Fig. 1.1. Distribution of sea ice and correlative bottom deposits. 1: Modern glaciated areas with glaciers reaching sea level; 2: areas of iceberg distribution and correlative bottom sediments; 3: areas of drifting ice floes distribution with correlative bottom sediments; 4: areas of ice release at the contact of warm and cold currents; 5, 6: direction of main currents carrying ice floes and icebergs; 7: extreme southern limit of ice and correlative deposits in the Northern Hemisphere during glacial maximum; 8: modern limit of water freezing on continents

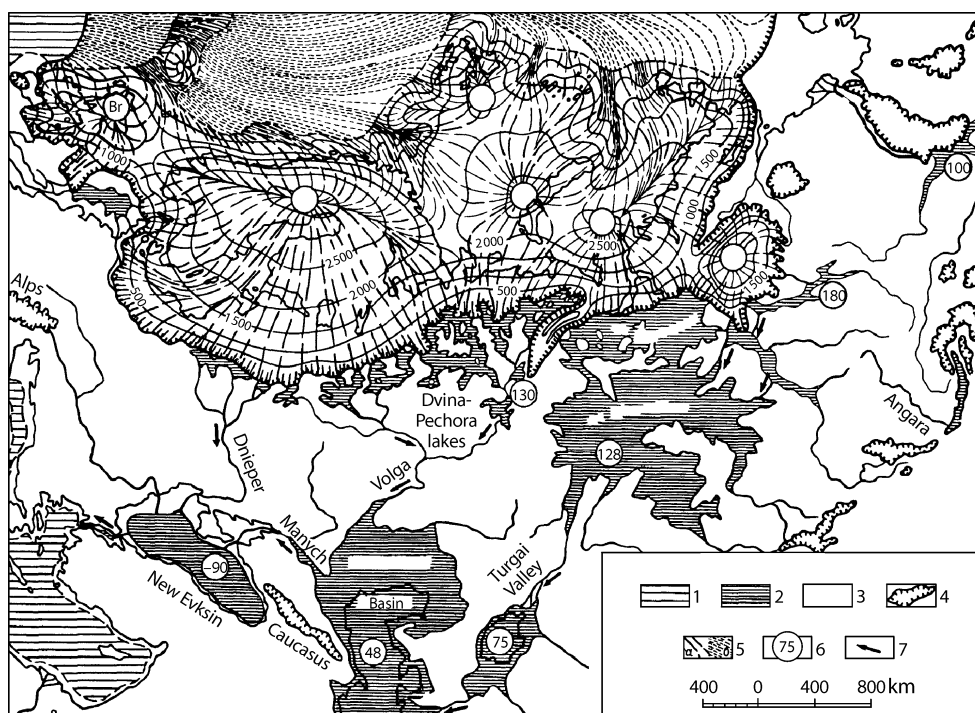


Fig. 1.2. Ice sheet extent in Eurasia during the last glaciation (Grosvald 1983a,b). 1: Ice-free ocean; 2: fresh-water basins; 3: ice-free land; 4: ice sheet extent; 5: spreading directions of onlapping (a) and floating (b) glaciers; 6: levels of intercontinental basins in m (relative to the present ocean); 7: outwash runoff.

Siberian type are mistaken for deposits of temperate humid zone.

Mixed sediments appearing due to coexistence of sea ice and icebergs (regions off Greenland and Labrador, and North Atlantic during glaciations) have been widespread since past epochs until recently. One of the goals of this monograph is to elaborate clearly defined criteria for distinguishing between different types of cryogenic sedimentation.

Another important component of the sea ice sedimentation, which is not usually taken into account, is the fact that removal of fresh water component of sea water (in course of evaporation or freeze-up) results in formation of brines. Thus, the remainder of sea water becomes denser and heavier. Two types of sea water distillation are typical of glacial zones, i.e. (1) evaporation with further transformation into snow and conservation in continental ice sheets or (2) ice freeze-up and formation of brines.

Widespread processes of water distillation cause gigantic changes in the system of vertical water circulation in oceans forming downslope flows of heavy deep-sea waters. The latter are comparable with katabatic winds rolling down from ice sheets. The system of deep-sea circulation with transportation of not only suspended matter (in the form of nepheloid layers) but dissolved forms of elements (including those released by recycling, nutrients and pollutants) is a unique system of circulation in ice zones. As shown below, it is of planetary importance since it determines environmental conditions of the World Ocean and the planet. Global transference of suspended matter goes on with global deep water conveyor triggered in the Arctic and Antarctic.

Upwelling of deep-sea waters rich in nutrients counterbalances downwelling of water in ice zones.

This is especially well manifested in the Southern Hemisphere (in the Arctic Ocean the zone of upwelling stretching along continental zone is usually hidden by pack ice). This results in accumulation of specific glacial deposits – biogenic (siliceous) – in high latitudinal regions of Antarctic. They occur together with iceberg-rafted deposits typical of this zone.

High latitudinal “ice pump” does not only activate and ventilate large masses of stratified deep-sea waters of the World Ocean but causes redistribution of nutrients, chemical elements and compounds. The Antarctic divergence is a striking example of this process operating nowadays. The global belt of silica accumulation is related to it.

Global sea level change is another important consequence of glacial processes, i.e. transformation of large amounts of water into ice with further accumulation on the surface of continents and oceans. It results from the fact that tremendous water masses are accumulated in the form of ice on continents (ice thickness up to 4–5 km), and the usual rapid return of water from con-

tinents with river runoff sharply slows down. Large water masses are gradually transferred from ocean to land. Hence, subsidence of continents is accompanied by sea level falls. During the last glaciation (about 18 ka) sea level fall reached 120 m. However, during previous glaciations it might have been even greater. Since glaciations were followed by interglacials, sea level also experienced different oscillations. During sea level falls all shelves emerged being later flooded again. Global vertical migrations of the depositional centres from river mouths and adjacent shelf areas to continental slope base (i.e. by 1–1.5 km for Siberian shelves) were especially important. During sea level falls waves and currents removed loose sediments from exposed shelves. In some places these processes were accompanied by a bulldozer effect of advancing glaciers.

Cryogenic environment gives rise to certain biogenic processes. Sea ice cover along with polar night event hamper phytoplankton development. Removal of nutrients beyond the limits of photic zone in course of decomposition of organic matter (recycling), makes Arctic environment more oligotrophic and even ultra-oligotrophic. Heavy waters formed at ice freeze-up also remove nutrients.

Biogenic sedimentation in the Antarctic is quite different. Narrow shelves and divergence zones (upwelling of waters rich in nutrients) correspond to the regions of open pack ice and phytoplankton bloom. The latter causes development of biofiltrators tying up sedimentary particles into pellets, which rapidly sink to the bottom.

The processes of sedimentary matter preparation in the glaciated and permafrost regions are discussed in later chapters. They describe the work of the frost weathering, chemical transformations of minerals and rocks, and transportation of newly formed matter from ice-catchment and drainage areas into the ocean.

As has been shown above, the fact that water is rather solid than liquid leads to specific cryosedimentation environment (sedimentosphere). It is also important for the other Earth's spheres (atmo-, hydro-, cryo-, biospheres) and their interactions.

That is why, in this monograph I tried, contrary to the common practice, to investigate regularities of sedimentary matter formation ice zones through study of not only bottom sediments but interactions between sedimentary matter of different spheres. This required elaboration of new equipment and methods. The regularities of quantitative distribution and composition of sedimentary matter in different components of the ice zones have been studied, i.e. in atmosphere, cryosphere (snow and ice cover of the seas, continental ice caps, permafrost) and hydrosphere (riverine and sea water). Processes operating in the high latitudinal biosphere are also discussed. Thus, bottom sediments reflect interactions between atmo-, cryo-, hydro-, bio- and lithosphere.

The author has been using this system approach for many years, i.e. study of all sedimentation systems and

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