ORIGIN OF GRAVELS FROM THE SOUTHERN COAST AND CONTINENTAL SHELF OF THE BEAUFORT SEA, ARCTIC ALASKA

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ABSTRACT

Gravel and larger sized materials from the seafloor of the continental shelf area of the Beaufort Sea, Arctic Ocean, as well as from adjacent onshore portions of northern Alaska, feature a variety of lithologic types: diabasic, volcanic, granitic, sedimentary clastic and carbonate, and high-grade metamorphic rocks. Presumably, fragments such as these were carried to their present collection sites by some mechanism involving ice-transport: via paleo/contemporary ice-rafting, or continental/subcontinental ice sheets. If this suite of samples represents an assemblage derived from a single general source area, the most likely source area would seem to be somewhere in the Canadian Arctic. However, if more than one source area furnished materials, the problem of ascertaining such sources becomes considerably more complex. Present interpretation leads to speculative sources in the Canadian Arctic, in particular the Coronation Gulf area or/and the Arctic Archipelago.

INTRODUCTION

It has been amply demonstrated that gravel fragments offer important clues on the sources, environments, and hydrodynamics and mechanisms of transport and deposition of sedimentary formations (see Pettijohn, 1957, and Reineck and Singh, 1980). Gravels of cobble to boulder sizes are commonly associated with glacial till; high-energy fluvial, beach, and gravity-flow environments; fluvial and glacial outwashes; unconformities; and ice-rafted diamictons. Consequently, they have a potential use in paleogeographic interpretation of depositional basins. Further, as many placer minerals are codeposited with conglomerates, understanding the origin of the associated gravels may be useful in resource exploration.

Along the Alaskan Beaufort Sea coast, cobble and boulder erratics have been deposited at elevations of up to 7 m above mean sea level (MSL), and at distances as far as 5 to 10 km into the hinterland (Leffingwell, 1919; MacCarthy, 1958; Naidu, 1974; Naidu et al., 1982; Rodeick, 1975; Hopkins, 1982). Boulders are also common within the southern Beaufort Sea continental shelf and adjacent Canada Basin (Hunkins and Kutschale, 1967; Hunkins et al., 1970; Naidu, 1974; Mowatt and Naidu, 1974, 1989). During the past two decades, there has been considerable debate on the origin of erratic gravel deposits of the coast and shelf. The elucidation of the origin of these deposits would seem to hold a key to better understanding of the late Quaternary history of the Alaskan Arctic. However, many of the ideas presented to date on the origin of these deposits are included in unpublished reports. We report here on the general petrology of some of these erratics, discuss possible sources of the gravels, and synthesize various ideas concerning the modes of transport and deposition of the erratics.

AREA OF STUDY, MATERIALS, AND METHODS

Although cobble and boulder erratics are interspersed along the shoreline of the Alaskan Arctic Coastal Plain extending from Demarcation Point to Point Barrow (Fig.1), our sampling of the erratics emphasized five localities where large concentrations were observed. These locations were the lagoonward shores of the Pingok, Bodfish, Bortocinni, and Flaxman Islands, and along the mainland beach extending 3 km westward from the East Dock of Prudhoe Bay (Fig.1). The above tundra-blanketed islands were carved out of the relict Beaufort coastal plain (Naidu et al., 1984). The gravel samples on or near the shoreline (Fig.2) were collected at random; however, they represented samples of the various lithological types encountered. Additionally, samples of gravels were collected from the modern Alaskan Beaufort Sea shelf at selected stations (Fig.3). The large sediment samples from the shelf were collected with Van Veen and Smith-McIntyre grab samplers and wet-sieved to separate gravels. To characterize the gravels, 105 representative specimens were selected for detailed study from the total suite of some several hundred samples. The selection was based on hand-specimen and binocular-microscope examination of the entire suite. The selected samples were studied in thin-section under the petrographic microscope, supplemented by X-ray diffraction analysis as appropriate. Two separate samples of pink/red granite were submitted to the Geochronology Laboratory, Geophysical Institute, University of Alaska, for K/Ar radiometric dating. Muscovite grains separated from these granites were dated at 2.43±0.07 and 2.08±0.06 billion years (b.y.).

PETROLOGY

The following lithologic types were identified:

(1) Diabasic igneous rocks; some olivine-bearing, others quartz-bearing.

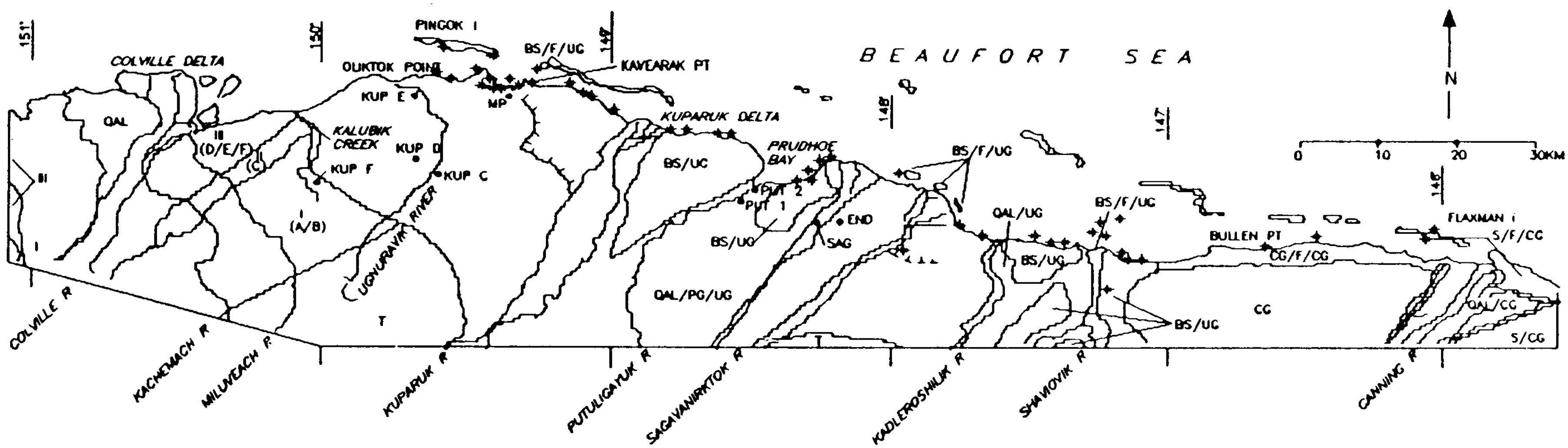

Fig 1. Locations of cobble and boulder erratics along the shoreline of the north Alaskan Coastal Plain.

Fig.2. Gravel deposits on or near the shoreline of the north Alaskan Arctic Coast (Beaufort Sea).

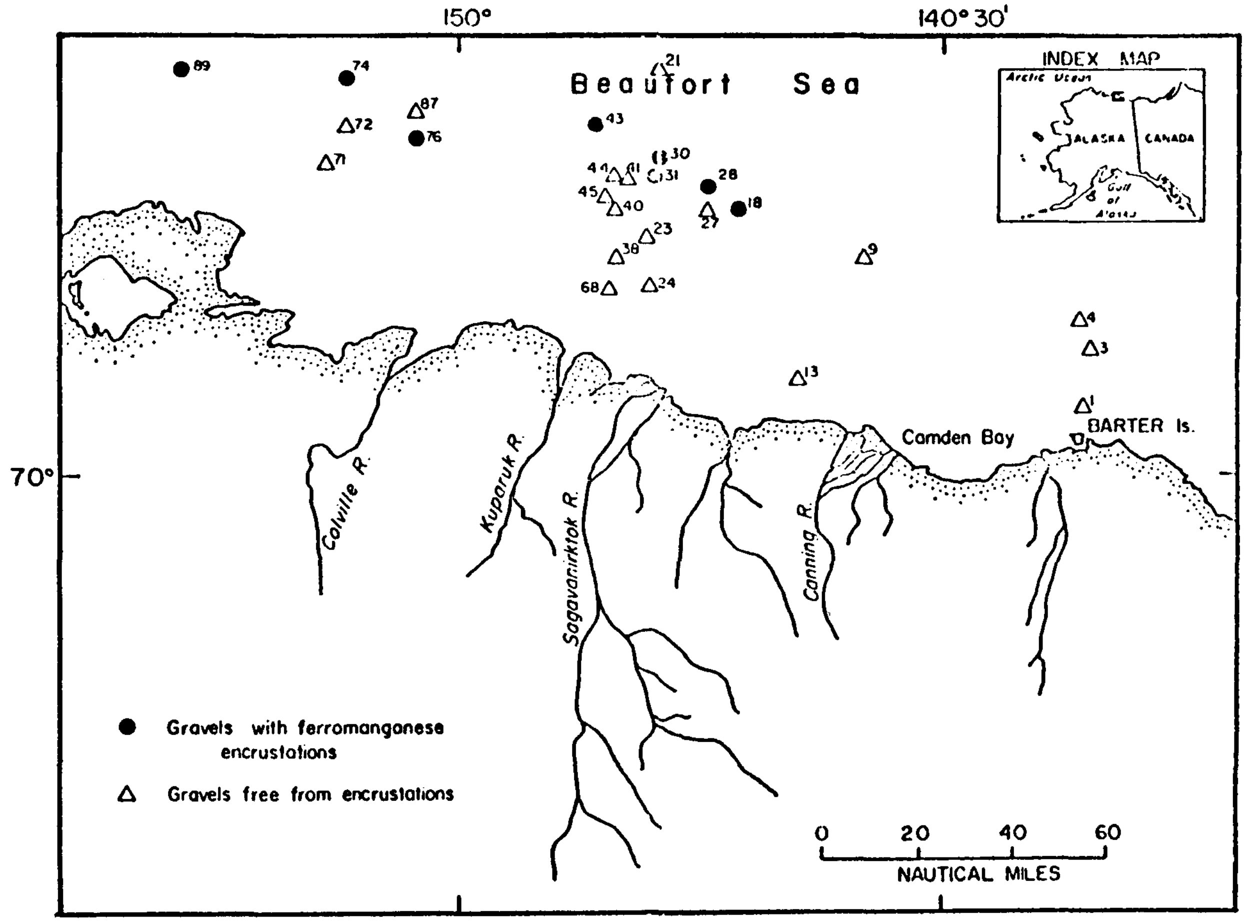

Fig. 3. Locations of gravel samples collected from the Alaskan Beaufort Sea shelf.

(2) Volcanic igneous rocks; fine-grained, moderately to intensely altered.

(3) Rocks of granitic aspect; principally granites, with some granodiorites, diorites.

(4) Clastic sedimentary rocks; principally medium- to coarse-grained arenites, litharenites, and lithic wackes. Some of the arenites are characterized by intergranular anhydrite and/or gypsum cements.

(5) Carbonate sedimentary rocks; dolomites, limestones of various kinds; some are cherty.

(6) Metamorphic rocks; particularly noteworthy is a garnet-sillimanite quartzo-feldspathic gneiss of medium-high regional metamorphic grade.

Table 1 presents a summary of localities and lithologies analyzed petrographically.

Table 1. Summary of lithologies of gravels described from the coast of southern Alaska and the Beaufort Sea shelf.

Lithology	Shelf	Flaxman Island	Bodfish Island	Pingok Island
Granitoid	20	2[a]	5	3
Quartz/ Granodiorite	6		2	3
Diorite	2			2
Diabase	28		7	5
Volcanic	6			1
Gabbro	2			
Metamorphic	1			
Sedimentary-Clastic	28		2	10
Limestone	3			
Dolomite	3			
Cherts	4			
TOTAL	105	2	16	24

[a]Muscovite- and biotite-bearing microcline granites. Potassium -argon radiometric analyses yield dates of 2.43 and 2.08 b.y., on Muscovite separates (K_2O = 10.7%; Na_2O = 0.4%).

DISCUSSION

Source(s) of Erratic Gravels

Gravel and larger sized fragments such as these presumably were carried to their collection sites off northern Alaska by some mechanism involving ice transport. Study of the bedrock geology of potential source areas within the circumarctic region indicates that the analyzed samples are not uniquely definitive of any one particular area.

If this suite of samples represents an assemblage derived from a single general source area (subsequently transported together to the present sites of occurrence), the most likely source area for the suite, *in toto*, would seem to be somewhere in the Canadian Arctic. However, if more than one source area furnished materials, the problem of ascertaining such sources becomes considerably more complex. In terms of elucidation of source terrane(s), the garnet-sillimanite gneiss is perhaps the most definitive lithology, and the anhydrite and/or gypsum-cemented arenites next, as well as perhaps the diabases (with or without the volcanic rocks as possible associates). The granitoids (with the exception of the age-dated boulders), the other clastic sedimentary rocks, and the carbonate rocks seem, by and large, to offer limited specificity solely on the basis of petrology.

The mainland south of Coronation Gulf, Northwest Territories, Canada, has the high-grade gneiss and the diabasic, volcanic, granitic, and perhaps sedimentary rocks possibly analogous to the Beaufort Sea gravel suite. This possible source area is consistent with the radiometric dates obtained from the Flaxman Island granite boulders.

The sillimanite-garnet quartzo-feldspathic gneiss has no known analog in northern Alaska and therefore represents a high-grade metamorphic terrane elsewhere, such as the Aphebian and Helikian of Northwest Territories, Canada (south of Coronation Gulf, south shore of Queen Maud Gulf, Baffin Island, or Ellesmere Island), or the Hadrynian of Ellesmere Island.

The diabasic rocks are somewhat less definitive, because their possible sources are more numerous. They may have been derived from northern Alaska, but many of the Alaskan diabasic rocks seem to be considerably more altered than the gravels studied. Alternative possible sources include the Hadrynian of the Coronation Gulf area (south shore), and/or Victoria Island, Northwest Territories, Ellesmere Island, or Ellef Ringnes Island.

The volcanic rocks in the gravels have few known analogs in feasible source areas in northern Alaska. They might have been derived from the De Long Mountains or the Southern Foothills of the North Slope sequence, as noted for the diabases described above, particularly if the basaltic rocks were associated with the diabases. However, a more likely source is in the Neohelikian and/or Aphebian volcanics south of Coronation Gulf, the Helikian volcanics of Victoria Island and/or Baffin Island, or the Ellesmere Island Ordovician or Devonian sequences.

The mineralogy of the granitic rocks is hardly unique. Possible granitic source terranes in the proximal Arctic Basin region include northern portions of Russia and areas of northern Canada. Of the latter, the most likely sources are the Devonian granitoids of Ellesmere Island and/or the Archaean granitoids of the south shore of Coronation Gulf (cf., the 2.43 and 2.08 b.y. dates from the Flaxman Island muscovite-bearing granites).

The clastic sedimentary rocks of the gravel suite do not seem to be amenable to absolute assignment regarding their source areas, in part because of the considerable extent of such rocks in the region. However, the anhydrite and/or gypsum-cemented arenites represent a lithology without known analogs in northern Alaska, but with occurrences of similar rocks to the east within the Canadian Arctic.

The carbonate rocks (some of which are dolomitic) in the suite could have been derived from northern Alaska, but they might have come from various source areas in the Canadian Arctic (the Archipelago and/or the continent).

In summary, a source in the Canadian Arctic seems most likely for at least some of the gravels studied; however, some of the lithologies might equally have been derived from other areas in the northern portions of the North American continent or elsewhere within the Arctic. Given the evidence presented here, the first choice appears to be the most reasonable one.

MODE OF TRANSPORT AND DEPOSITION OF GRAVELS

Presumably, the cobble and boulder fragments were carried to their collection sites along and off the northern coast of Alaska by some mechanism involving ice transport. Although possible, it appears most unlikely that the transport of the exotic cobbles and boulders to the Beaufort Sea shoreline and shelf occurred either by continental ice sheet(s) or fluvial action. That the transport was not by the present North Slope rivers or their ancient analogs arising from the Brooks Range is consistent with our earlier conclusion that the lithologies of some of the exotics are quite foreign to the drainage basins of the Brooks Range. Additionally, our surveys and examination of the bedloads of the major rivers of the North Slope did not yield any gravel samples matching the pink/red granite, sillimanite-gneiss, or dolomite fragments that were collected from the study area. Likewise, it is difficult to conceive that the transport of the gravels to the coast could have occurred during the Illinoian or the Wisconsinan by piedmont glaciers arising from the Brooks Range, since the northern coastal plain of Alaska had no glacial ice during the two glacial epochs (Coulter et al., 1965; McCulloch, 1967; Hamilton and Porter, 1975; Hamilton, 1986).

We have considered the hypothesis presented by Hughes et al. (1977) as a possible mechanism for the entrainment and deposition of large size gravel fragments in our study area. Hughes et al. (1977) have postulated that during global ice maxima, coinciding with the late-Wurm, thick-coalescing ice sheets with floating ice shelves had developed. These were centered on a number of domes encompassing portions of the Arctic Ocean and the North American continent. It is suggested that as these ice sheets thickened and spread onto the shallow seas, such as the Beaufort Sea, they were grounded. It was further alluded to by Hughes et al. (1977) that some of the erratics on the northern coast of Alaska (presumably on the adjacent shelf as well) were initially entrained within some of the above ice sheets and deposited in place on the coast subsequent to the ice melting.

The above hypothesis remains highly debatable; strong arguments have been presented both for and against it (Hughes et al., 1977; Williams et al., 1981; Hopkins, 1982; Clark, 1982). According to one view, it is unlikely that such massive and continuous ice sheets, even if they had formed, actually had extended onto the Beaufort shelf and adjoining coast. The lack of any local evidence in northern coastal Alaska (D.M. Hopkins, pers. commun., 1992) and the Beaufort Sea shelf (Foster, 1988) for large-scale regional ice scouring or dragging of substrate comprised of late Pleistocene sedimentary formations as well as the presence of microfossils within the boulder deposits reflecting present sea-water salinity (Hopkins, 1982) are factors that are inconsistent with the hypothesis of Hughes et al. (1977). Besides, it is doubtful that lobes of ice extending from the northwestern margin of the Laurentide ice sheet (a most likely medium of transport for the erratic gravels from the Canadian Shield area) had extended beyond the mouths of the Amundsen Gulf or the M'Clure Strait and onto the Alaskan Beaufort Sea shelf during the Early and Late Wisconsinan glaciation (Prest, 1969; Vincent, 1982). Detailed investigations of the late Pleistocene glacial history of the Canadian Northwest by Vincent (1982) suggest that the outer limits of the ice lobes probably were to the south-southeast and north-northeast of Banks Island. However, the strong arguments by Williams et al. (1981) in support of the Hughes et al. (1977) hypothesis cannot be ignored. We suggest that additional investigations be carried out to attempt to resolve the issue.

The alternative hypothesis to explain the origin of the erratic boulders relates to transport and deposition by ice rafting. The transport of boulders by floating ice and their release on the shelf as dropstones during high stands of sea levels is quite conceivable, although our surveys on numerous icebreaker cruises in the Beaufort Sea shelf region suggest that such a transport mode is uncommon at the present time. However, boulders presently are more frequently carried by ice islands over the Arctic Basin (Stoiber et al., 1956). Leffingwell (1919), who was the earliest to describe the boulder deposits, named them as Flaxman Formation. He suggested that the boulders were foreign to the Alaskan hinterland and probably were ice rafted to the present sites during the late Pleistocene, an idea that was subsequently resurrected and supplemented (MacCarthy, 1958; Naidu, 1974; Hopkins, 1978, 1982). Based on recent work, the Flaxman deposit with intercalated boulder diamictons was reclassified as a member of the Pliocene-Pleistocene Gubik Formation with an age of 70 to 80 Ka (Carter et al., 1979; Brigham, 1985). Hopkins (1982) speculated that the diamicton-bearing Flaxman sequences were deposited at the North Slope shoreline by small icebergs during a brief interstadial rise in sea level that coincided with d18O stage 5a. He further suggested that the event followed abortive glaciation involving formation of ice caps, and that the boulder source was Northern Keewatin or south central Queen Elizabeth Islands (Canada). Supporting Hopkins' ideas, it is further speculated that there may have been an abrupt rise in sea level 70 to 80 Ka ago in the Arctic caused by a surge of the West Antarctic ice sheet (Davies, 1981; Carter, 1988).

The model presented by Hopkins (1982) to explain the origin of the Flaxman diamicton seems quite credible with the exception of a few potential flaws. One of the problems that has to be explained relates to the rise in sea level at the postulated interstadial, and the elevation (up to 7 m above MSL) at which the Flaxman boulders presently occur. It is generally accepted that within the past 80 Ka, sea level was never higher than it is today. Does the presence, therefore, of the boulders at 7 m above MSL imply that the North Slope coast has been recently tectonically uplifted? All evidence gathered to date suggests that the above region has been tectonically stable during the past 125 Ka (Carter, 1988). The other drawback to the Hopkins model is the conspicuous absence of a transgressive sequence corresponding to the Flaxman Member (Brigham, 1985) in the Chukchi coastal plain region, south of Skull Cliff. How can this selective absence be explained if the marine transgression 70 to 80 Ka ago was of a eustatic nature as contended by Carter (1988)? A few years ago, we had doubted whether Beaufort Sea icebergs with deep drafts and carrying boulders could negotiate the 10-40-m-depth zone of ice ridges ("stamukhi zone"; Reimnitz et al., 1977) in the Beaufort Sea, as well as the beach ridges, and transfer boulders to the coast and adjacent hinterland. However, we are now convinced that icebergs of sufficient size occasionally can be drifted above the present shoreline of the North Slope during episodic storms (P. W. Barnes and E. Reimnitz, pers. commun., 1992). It would, therefore, seem quite possible that boulders occasionally could have been ice rafted to the shoreline, especially during the time when the sea level was postulated to be higher than today (Hopkins, 1982).

CONCLUSION

In conclusion, based on our petrographic investigations of a representative boulder suite, and on the age (over 2 b.y.) of associated pink/red granites, we suggest that the major source of the Flaxman boulders, *in toto*, is most likely the Canadian Archipelago and the Northwest Territories (south of Coronation Gulf). The mode of transport and emplacement on the North Alaskan Arctic shoreline still remains an enigma. Two stimulating but contradictory ideas have been postulated, one relating to the transport involving grounded thick arctic ice sheets during the late Wisconsinian glacial maxima and the other to ice rafting during a brief interstadial rise in sea level 70 to 80 Ka ago. Additional research must be carried out to resolve this debate.

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