# Orphan Arctic Ocean metasediment clasts: Local derivation from Alpha Ridge or pre-2.6 Ma ice-rafting?

**Article** *in* Geology · December 2000

DOI: 10.1130/0091-7613(2000)028<1143:OAOMCL>2.3.CO;2



**4 authors**, including:

Bart J. Kowallis
Brigham Young University - Provo Main Campus


Levi Gordon Medaris
University of Wisconsin–Madison


Alan Deino
Berkeley Geochronology Center

# Orphan Arctic Ocean metasediment clasts: Local derivation from Alpha Ridge or pre-2.6 Ma ice rafting?

David L. Clark
Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706, USA
Bart J. Kowallis
Department of Geology, Brigham Young University, Provo, Utah 84604, USA
L. Gordon Medaris
Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706, USA
A.L. Deino
Berkeley Geochronology Center, Berkeley, California 94704, USA

## ABSTRACT

**Phyllonite and metaquartzite clasts occur in early Pliocene or possibly Miocene sediment at the base of the University of Wisconsin Arctic Ocean core Fl-380. Single-crystal $^{40}Ar/^{39}Ar$ laser-probe ages derived from feldspars in sediment enclosing the clasts range from Middle and Late Proterozoic to Paleozoic. The clasts occur in sediment deposited 1–2 m.y. earlier than any previously reported central Arctic Ocean ice-rafted debris, and although an ice-rafted origin may be possible, a local source such as adjacent Alpha Ridge bedrock should also be considered.**

**Keywords:** submarine landslides, talus, Arctic tectonics, ice rafting, Alpha Ridge.

## INTRODUCTION AND ARCTIC OCEAN ICE-RAFTING

Core Fl-380, taken on ice island T-3, was recovered from a prominent slope on the eastern margin of Alpha Ridge (Fig. 1), an irregular and broadly fractured arch ~500 km wide and 900 km long and cited as "one of the few large-scale geological structures on Earth whose tectonic evolution is still unknown" (Weber and Sweeney, 1990, p. 330). The core includes the normal M to $A_2$ lithostratigraphic units (Holocene to Pliocene or Miocene?) for this part of Alpha Ridge (Clark et al., 1980), with the exception that the lowest part of the core contains phyllonite clasts (Fig. 2). The clasts range from a few millimeters to 3 cm in size and are associated with fragments of metaquartzite with a heavy iron-oxide crust. The clasts compose only a few percent of the total volume of sediment (~2%) in the lower 60 cm of the core. They occur in unconsolidated reddish silty sediment rich in quartz, albite, oligoclase, and K-feldspars. This association differs from sediment of the same stratigraphic interval that occurs in more than 200 cores recovered from adjacent areas of the Alpha-Mendeleyev Ridge complex and is analogous to the Northwind Breccia, a submarine talus derived from submarine weathering of Northwind Ridge, 1000 km distant in the Arctic

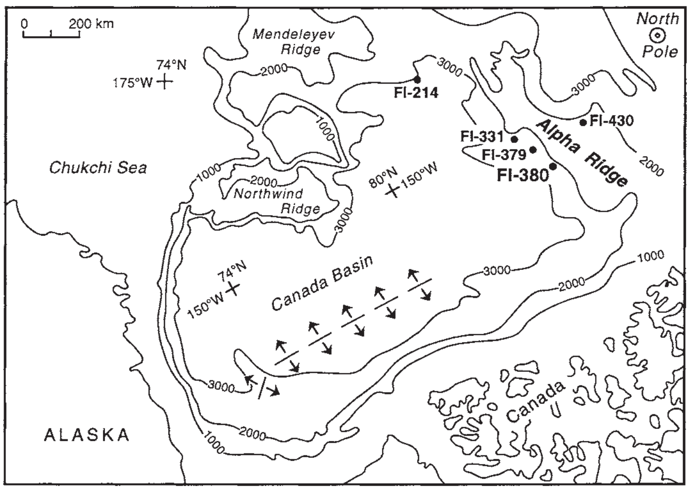


**Figure 1. Location and general bathymetry of Alpha Ridge and other Arctic Ocean structures. Specific core data include Fl-380, 84°37′02″N, 128°27′53″W, 2401 m, 345 cm; Fl-379, 84°38′11″N, 128°44′50″W, 2268 m, 342 cm; Fl-331, 84°16′01″N, 134°37′39″W, 2659 m, 348 cm; Fl-430, 85°59′27″N, 133°20′29″W, 1860 m, 324 cm; Fl-214, 80°17′26″N, 159°30′56″W, 3021 m, 335 cm. Site of possible early Canada basin spreading axis is indicated.**

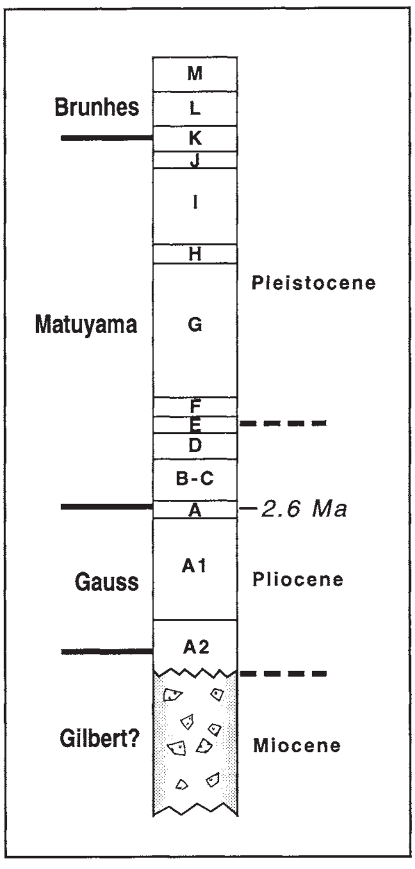


**Figure 2. Lithostratigraphy and chronology of core Fl-380 (345 cm) showing position of clasts in basal 60 cm of core. A2 to M stratigraphy is from Clark et al. (1980) and Clark (1996).**

TABLE 1. MINERALOGY OF SAMPLES AT BASE OF CORES

| Core | Qtz | Plg | Micr | Amp | Tour | Epi | Musc | Chrt | Carb | Bio | Zirc | Sphe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fl-380 | | | | | | | | | | | | |
| 1-4 | A | A | A | P | | | P | | P | | | |
| 4-1 | A | A | A | | | P | P | | | | | |
| 4-2 | A | A | A | | | | P | | | P | | P |
| 4-3 | A | A | A | | | | P | | | P | | P |
| 5-1 | A | A | A | | | | P | | P | P | | P |
| 5-2 | A | A | A | | | | P | | P | P | P | P |
| Fl-379 | | | | | | | | | | | | |
| 1-1 | A | A | A | | | P | | | P | | | |
| 7-1 | A | A | A | | | P | | | P | | | |
| Fl-430 | | | | | | | | | | | | |
| 2-4 | A | A | P | P | | P | P | P | | P | | |
| Fl-214 | | | | | | | | | | | | |
| 1-4 | A | A | P | P | P | P | P | P | P | | | |
| 3-1 | A | A | P | P | P | P | P | P | P | | | |

Sample numbers (e.g., 1-4) following core numbers refer to time equivalent intervals in lower 100 cm of cores. A = >25% of sample, P = <5% of sample. Qtz = quartz, Plg = plagioclase, Micr = microcline, Amp = amphibole, Tour = tourmaline, Epi = epidote, Musc = muscovite, Chrt = chert, Carb = carbonate, Bio = biotite, Zirc = zircon, Sphe = sphene.

Ocean (Grantz et al., 1998). The Northwind Ridge talus accumulated during deposition of lithostratigraphic unit A. However, Fl-380 sediment contains fewer clasts, which are not as lithologically diverse as the Paleozoic and Mesozoic clasts described from Northwind Ridge cores.

Glacial ice rafting was the most common mode of large size sediment transportation and deposition in the central Arctic Ocean during the late Pliocene and Pleistocene (Clark and Hanson, 1983; Bischof et al., 1996). To date, the earliest central Arctic Ocean ice-rafted debris is that identified in the upper part of lithostratigraphic unit A (Thiede et al., 1990; Clark, 1996). The upper part of unit A correlates approximately with the Matuyama-Gauss magnetic boundary (Clark, 1996), which is considered to be ca. 2.6 Ma (Cande and Kent, 1992) (Fig. 2). This is approximately the same time as initiation of significant ice rafting in the North Pacific (Rea et al., 1995) and the North Atlantic (Shackleton et al., 1984). Older North Atlantic Cenozoic ice-rafted debris is associated with more restricted ice sources and accumulated in coastal areas, not the deep ocean (Larsen et al., 1994). The clasts of Fl-380 occur 150 cm below unit A. Low sedimentation rates in this part of the Arctic Ocean (Clark et al., 1986) suggest that the clasts accumulated 1–2 m.y. prior to initiation of major glacial ice-rafting at 2.6 Ma.

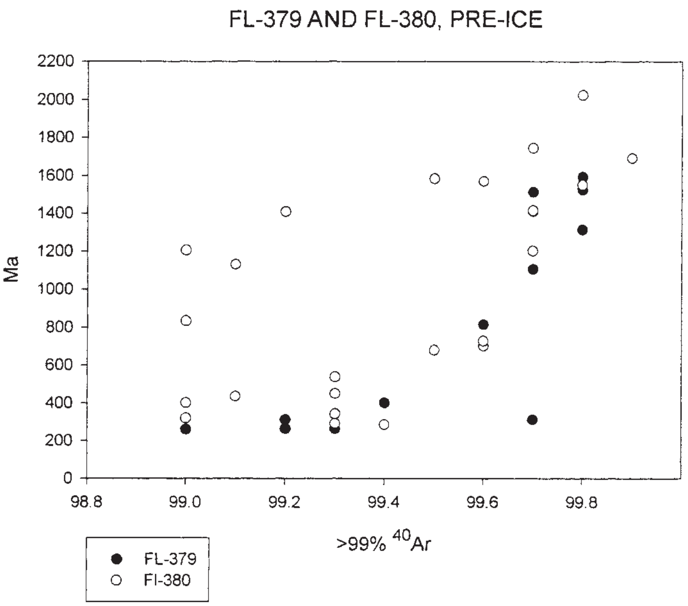


**Figure 3. $^{40}$Ar ages for feldspars in equivalent pre-2.6 Ma sediment at base of cores Fl-380 and Fl-379.**

## MINERALOGY AND Ar AGES OF CORES

The mineralogy of clast-bearing basal sediment of Fl-380 was compared to that of equivalent stratigraphic units in other Alpha Ridge cores (Table 1). Sediments of all cores at similar stratigraphic intervals contain predominately quartz, microcline, albite, and oligoclase. However, chert, not present at the base of Fl-380 or adjacent Fl-379, occurs in Fl-430, ~220 km from Fl-380 and Fl-379, and also is a common constituent in the same stratigraphic interval of Fl-214, taken ~800 km from the site of Fl-380. Another minor difference includes the presence of tourmaline in Fl-214 but not in Fl-380, and the presence of zircon, sphene, and biotite in Fl-380 but not in Fl-214, the most distant core from the Alpha Ridge. If the clasts of Fl-380 were locally derived, mineralogy of most distant cores should show the greatest differences. While there is an overall similarity of major mineralogy in all cores, the mineral assemblages of Fl-380 and adjacent Fl-379 suggest a granitic, igneous-metamorphic source.

In order to determine if there were more significant differences in sediment of different cores, we separated K-feldspar grains from several core intervals for single-crystal $^{40}Ar/^{39}Ar$ laser-probe ages. If Fl-380 grains were derived locally, their ages should be different from grains from cores farther away from Alpha Ridge. We analyzed 214 grains; only grains with more than 99% radiogenic $^{40}Ar^*$ were considered. Grains obtained from the base of Fl-380 and Fl-379 (Fig. 3) illustrate overlap in Paleozoic to Middle Proterozoic ages and may have originated from similar sources. In younger sediment deposited after initiation of major ice rafting (upper part of A and younger, Fig. 2), a similar range in ages was determined (Fig. 4). Although fewer grains were analyzed from more distant cores Fl-331 and Fl-214, a similar overlap in age is apparent (Fig. 5).

## INTERPRETATION

What appears at first to be the easiest explanation for the occurrence of clasts at the base of Fl-380, ice rafting, also raises important questions. Sea

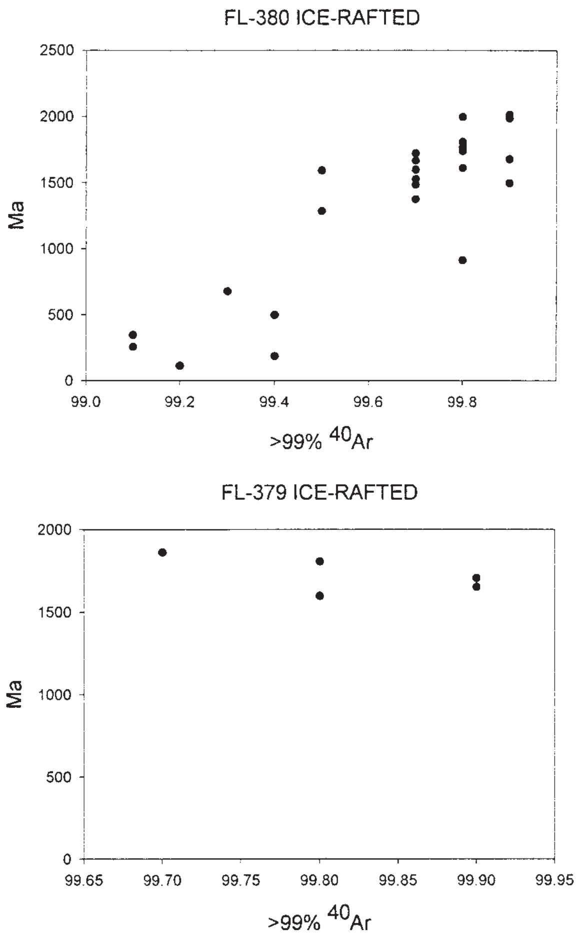


**Figure 4. $^{40}$Ar ages for feldspars from post-2.6 Ma sediment in cores Fl-380 and Fl-379.**

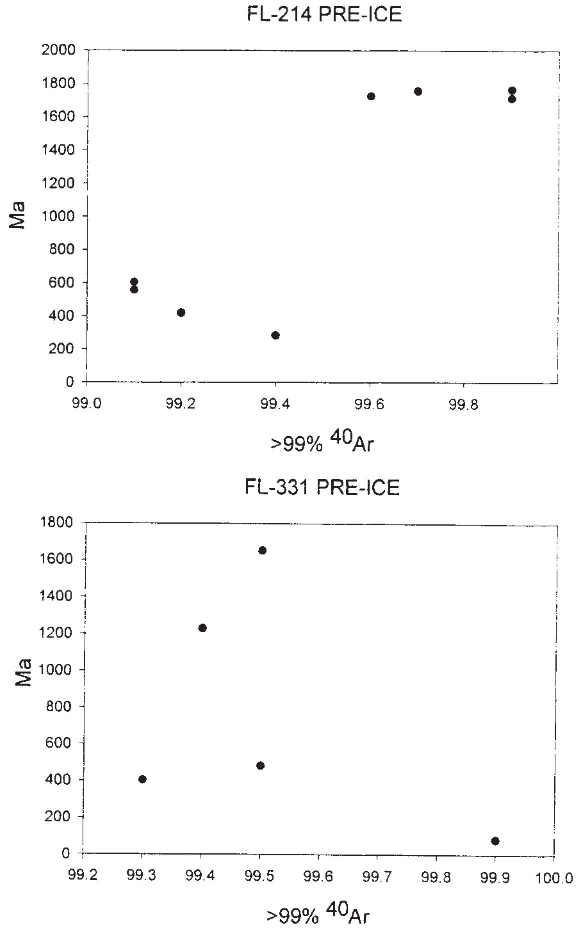


**Figure 5. $^{40}$Ar ages for feldspars from pre-2.6 Ma sediment in cores Fl-214 and Fl-331; both cores were taken at significant distances from Fl-380 (Fig. 1).**

ice is known to raft silt and clay-size sediment great distances in the Arctic Ocean (Bischof and Darby, 1997), but it is only under more unusual conditions that sea ice can pick up and raft particles the size of the largest phyllonite clasts at the base of Fl-380 (Reimnitz et al., 1992, 1994). In addition, fast ice, thought to be important for this process, commonly melts in place prior to spring breakup and drifting (Reimnitz et al., 1992). Glacial ice rafting is a better explanation than sea-ice rafting because of the large size particles that usually are transported (Clark and Hanson, 1983). However, it is important to note that the presence of either kind of ice in the central Arctic Ocean during the earliest Pliocene or possibly late Miocene, the age of the sediment-bearing clasts in Fl-380, has been questioned by many Arctic workers who argue that the Arctic Ocean was ice free at this time (Funder et al., 1985; Raymo et al., 1990; Cronin, 1991; Gladenkov et al., 1991; Brigham-Grette and Carter, 1992; Dowsett et al., 1992). Although we are uncertain about the ice cover from 3 to 5 Ma, we also note that Fl-380 was taken from a steep slope of a ridge escarpment that rises at least 1500 m to the top of the Ostenso Seamount, a good setting for the accumulation of submarine talus (Fig. 6). The mineralogy and, to some extent, the isotope ages are consistent with a local origin. If the clasts were derived from bedrock of Alpha Ridge, then at least one part of the ridge must include metasediment. If so, Alpha Ridge may be a complex of both basaltic rocks (Van Wagoner et al., 1986; Jokat et al., 1999) and metasediment. While geophysical evidence for an oceanic basaltic Alpha Ridge is substantial (Weber and Sweeney, 1990; Jackson et al., 1986; Tarduno et al., 1997), a continental origin also has been repeatedly suggested (King et al., 1966; Coles et al., 1978; Zonenshain and Natapov, 1989; Johnson et al., 1994). Although evidence presented here does not solve the problem, it suggests that future

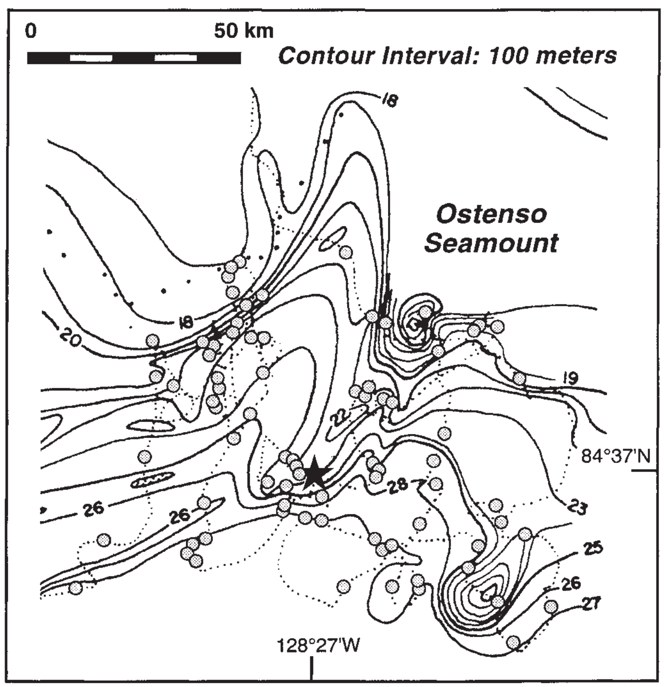


**Figure 6. Details of site of core Fl-380 (star symbol) on slope of Ostenso Seamount of Alpha Ridge. Drift track of ice-island T-3 and sites of other cores taken along track, none of which contain phyllonite clasts, are also shown.**

theories of the origin and structure of Alpha Ridge as well as the time of initiation of Arctic Ocean ice rafting must consider the orphan metasediment clasts at the base of core Fl-380.


## ACKNOWLEDGMENTS

Funding was provided by the Weeks Bequest, the Graduate School, and the Paleontology Research Fund of the University of Wisconsin. John Valley, R.H. Dott, Jr., and C.W. Byers helped with different parts of the study. Mary Diman provided several of the illustrations and David Tingey helped in separation of feldspars. Art Grantz, Peter R. Vogt, and Dennis A. Darby offered helpful reviews.


## REFERENCES CITED


Bischof, J., and Darby, D.A., 1997, Mid to late Pleistocene ice drift in the western Arctic Ocean: Evidence for a different circulation in the past: Science, v. 277, p. 74–78.

Bischof, J., Clark, D.L., and Vincent, J.-S., 1996, Origin of ice-rafted debris: Pleistocene paleoceanography in the western Arctic Ocean: Paleoceanography, v. 11, p. 743–756.

Brigham-Grette, J., and Carter, L.D., 1992, Pliocene marine transgressions of northern Alaska: Circumarctic correlations and paleoclimatic interpretations: Arctic, v. 45, p. 74–89.

Cande, S.C., and Kent, D.V., 1992, A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, v. 97, p. 13,917–13,951.

Clark, D.L., 1996, The Pliocene record in the central Arctic Ocean: Marine Micropaleontology, v. 27, p. 157–164.

Clark, D.L., and Hanson, A., 1983, Central Arctic Ocean sediment texture: A key to ice transport mechanisms, *in* Molnia, B.F., ed., Glacial-marine sedimentation: New York, Plenum Publishing Corporation, p. 301–330.

Clark, D.L., Whitman, R.R., Morgan, K.A., and Mackey, S.D., 1980, Stratigraphic and glacial-marine sediments of the Amerasian Basin, central Arctic Ocean: Geological Society of America Special Paper 181, 57 p.

Clark, D.L., Andree, M., Broecker, W.S., Mix, A.C., Bonani, G., Hofmann, H.J., Morenzoni, E., Nessi, M., Suter, M., and Woelfli, W., 1986, Arctic Ocean chronology confirmed by accelerator $^{14}$C dating: Geophysical Research Letters, v. 13, p. 319–321.

Coles, R.L., Hannaford, W., and Haines, G.V., 1978, Magnetic anomalies and the evolution of the Arctic: Arctic Geophysical Review, v. 45, p. 1–66.

Cronin, T.M., 1991, Pliocene shallow water paleoceanography of the North Atlantic based on marine ostracodes: Quaternary Science Reviews, v. 10, p. 175–188.

Dowsett, H.J., Cronin, T.M., Poore, R.Z., Thompson, R.S., Whatley, R.C., and Wood, A.M., 1992, Micropaleontological evidence for increased meridional heat transport in the North Atlantic Ocean during the Pliocene: Science, v. 258, p. 1133–1135.

Funder, S., Abrahamsen, N., Bennike, O., and Feyling-Hanssen, R.W., 1985, Forested Arctic: Evidence from north Greenland: Geology, v. 13, p. 542–546.

Gladenkov, Y.B., Varinov, K.B., Basilian, A.E., and Cronin, T.M., 1991, Stratigraphy and paleoceanography of Pliocene deposits of Karaginsky Island, Eastern Kamchatka: U.S.S.R. Quaternary Science Review, v. 10, p. 239–245.

Grantz, A., Clark, D.L., Phillips, R.L., and Srivastava, S.P., 1998, Phanerozoic stratigraphy of Northwind Ridge, magnetic anomalies in the Canada Basin, and the geometry and timing of rifting in the Amerasia Basin, Arctic Ocean: Geological Society of America Bulletin, v. 110, p. 801–820.

Jackson, H.R., Forsyth, D.A., and Johnson, G.L., 1986, Oceanic affinities of the Alpha Ridge, Arctic Ocean: Marine Geology, v. 73, p. 237–261.

Johnson, G.L., Pogrebitsky, J., and Macnab, R., 1994, Arctic structural evolution: Relationship to paleoceanography, *in* Johannessen, R.D., et al., eds., The polar oceans and their role in shaping the global environment: American Geophysical Union Geophysical Monograph 85, p. 285–294.

Jokat, W., Stein, R., Rachor, E., Schewe, I., and the Shipboard Scientific Party, 1999, Expedition gives fresh view of central Arctic geology: Eos (Transactions, American Geophysical Union), v. 80, p. 465, 472–473.

King, E.R., Zeitz, I., and Alldredge, L.R., 1966, Magnetic data on the structure of the central Arctic Ocean region: Geological Society of America Bulletin, v. 77, p. 619–646.

Larsen, H.C., Saunders, A.D., Clift, P.D., Beget, J., Wei, W., Spezzaferri, S., and ODP Leg 152 Scientific Party, 1994, Seven million years of glaciation in Greenland: Science, v. 264, p. 952–955.

Raymo, M.E., Rind, D., and Ruddiman, W.G., 1990, Climatic effects of reduced Arctic sea ice limits in the GISS II General Circulation Model: Paleoceanography, v. 5, p. 367–382.

Rea, D.K., Basov, I.A., Krissek, L.A., and the Leg 145 Scientific Party, 1995, Scientific results of drilling the North Pacific Transect, *in* Rea, D.K., et al., Proceedings of the Ocean Drilling Program, Scientific results, Volume 145: College Station, Texas, Ocean Drilling Program, p. 577–596.

Reimnitz, E., Marincovich, L., Jr., McCormick, M., and Briggs, W.M., 1992, Suspension freezing of bottom sediment and biota in the Northwest Passage and implications for Arctic Ocean sedimentation: Canadian Journal of Earth Sciences, v. 29, p. 693–703.

Reimnitz, E., Dethleff, D., and Nürnberg, D., 1994, Contrasts in Arctic shelf sea-ice regimes and some implications: Beaufort Sea versus Laptev Sea: Marine Geology, v. 119, p. 215–225.

Shackleton, N.J., Backna, J., Zimmerman, H., Kent, D.V., Hall, M.A., Roberts, D.G., Schnitker, D., Baldauf, J.G., Desprairies, A., Homrighausen, R., Huddlestun, P., Keene, J.B., Kaltenback, A.J., Krumsiek, K.A.O., Morton, A.C., Murray, J.W., and Westberg-Smith, J., 1984, Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region: Nature, v. 307, p. 620–623.

Tarduno, J.A., Cottrell, R.D., and Wilkison, S.L., 1997, Magnetostratigraphy of the Late Cretaceous to Eocene Sverdrup Basin: Implications for heterochroneity, deformation, and rotations in the Canadian Arctic Archipelago: Journal of Geophysical Research, v. 102, p. 723–746.

Thiede, J., Clark, D.L., and Herman, Y., 1990, Late Mesozoic and Cenozoic paleoceanography of the northern polar oceans, *in* Grantz, A., et al., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, Geology of North America, v. L, p. 427–458.

Van Wagoner, N.A., Williamson, M.-C., Robinson, P.T., and Gibson, I.L., 1986, First samples of acoustic basement recovered from the Alpha Ridge, Arctic Ocean: New constraints for the origin of the ridge: Journal of Geodynamics, v. 6, p. 177–196.

Weber, J.R., and Sweeney, J.F., 1990, Ridges and basins in the central Arctic Ocean, *in* Grantz, A., et al., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, Geology of North America, v. L, p. 305–336.

Zoneshain, L.P., and Natapov, L.M., 1989, Tectonic history of the Arctic region from the Ordovician through the Cretaceous, *in* Herman, Y., ed., The Arctic seas: New York, Van Nostrand Reinhold, p. 829–862.



Manuscript received May 15, 2000
Revised manuscript received September 15, 2000
Manuscript accepted September 20, 2000