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Title of article Quaternary History of Sea Ice and Paleoclimate in the Amerasia Basin, Arctic Ocean, as Recorded in the Cyclical Strata of Northwind Ridge

Author(s) R. Lawrence Phillips and Arthur Grantz

SEE: X *GSA Bulletin*

Geology

 GSA Today

v. 109, p. 1101 - 1115

Contents

9 pg.

The Geological Society of America
P.O. Box 9140 • Boulder, CO 80301-9140 U.S.A.
Phone 303-447-2020

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Lithostratigraphic sequence Northwind Ridge

Upper cyclic sequence

Unit 1. 5 to 10 cm of bioturbated dark yellowish brown (10YR4/2) sandy mud containing abundant benthic and planktonic foraminifers, echinoid spines, sponge spicules, ostracodes, pteropods, and rare large diatoms. The sand-size fraction can be as large as 11 weight percent. Up to 12 clasts/100 cc of sediment occur in this unit. The clasts include siltstone/sandstone (44%), limestone/dolostone (40 %), and quartz (11%). The uppermost dark brown bed was recovered in cores 5, 6, and 7 but was lost in core 4 during coring. Its former existence in the core is documented by the presence of dark brown burrow-fill mud containing abundant foraminifers found in olive gray mud directly beneath the uppermost sediment surface.

Unit 2. 71 to 103 cm of bioturbated basal dark yellowish brown (10YR4/2) sandy mud containing abundant ice-rafted clasts, abundant benthic and planktonic foraminifers, echinoid spines, sponge spicules, and ostracodes. Contains as many as to four yellowish gray to very pale orange (5Y7/2, 10YR8/2) clastic-rich beds with as much as 21 percent sand and interbeds of faintly laminated light olive gray (5Y5/2) sandy mud with ice-rafted clasts and abundant planktonic and benthic foraminifers. The unit contains up to 21 clasts/100 cc of sediment. Laminated medium to dark medium gray (N4-N5) silty mud and dark greenish gray (5GY3/2) mud lacking in foraminifers overlies the clastic-rich beds. The uppermost beds consist of faintly laminated to bioturbated grayish brown (5YR3/2) pebbly mud containing abundant siltstone clasts, lignite, coal, rare foraminifers, and have an organic carbon content of 0.8 to 1.2 percent. Sandstone and siltstone comprise 42 %, limestone and dolostone 37%, and CaCO₃ 43 percent of the clast-rich beds. The sequence is eroded in core 4

but is identified by dark brown burrows extending 24 cm into the underlying gray mud beneath an erosional surface.

Unit 3. 52 to 138 cm thick unit consisting of two basal distinct "white" very pale orange (10YR8/2) clastic-rich beds containing as much as 33 percent sand-size sediment (PW-2 beds of Clark, 1988) interbedded with faintly laminated and bioturbated light yellowish gray (5Y7/2) sandy mud containing abundant ice rafted clasts. The unit changes upsection into dark yellowish brown (10YR4/2) bioturbated sandy mud containing abundant benthic and planktonic foraminifers, echinoid spines, sponge spicules, and ostracodes. It contains abundant very small planktonic foraminifers and up to 56 clasts/100 cc sediment. Limestone and dolostone (51 %) are the most abundant clast type. The basal clastic beds contain as much as 62 % CaCO_3 whereas the foraminifera-rich brown bed contains no more than 10 % CaCO_3 . An altered andesitic tephra occurs at the top of the brown bed in core 9. Overlying the brown bed with a sharp contact in core 9 is as much as 99 cm of laminated olive gray (5Y5/2) mud containing a thin clast rich bed 10 to 15 cm above the brown bed. Very rare arenaceous foraminifers occur locally in the laminated mud sequence.

Unit 4. 15 to 50 cm thick unit consisting of a basal clast-rich bed containing 13 percent sand-size sediment changing upsection into bioturbated sandy mud to bioturbated dark yellowish brown (10YR4/2) mud and laminated light olive gray (5Y5/2) silt and clay. The unit thins eastward (down slope). The upper 10 to 15 cm of the brown bed contains abundant planktonic and benthic foraminifers and echinoid spines, but only rare arenaceous foraminifers occur in the lower part of the brown bed and underlying strata. The laminated gray mud above the brown bed contains rare arenaceous foraminifers. This unit contains up to 11 clasts/100 cc of sediment, and limestone and dolostone (45 %) are the most abundant clast type.

Unit 5. A lack of planktonic and calcareous benthic foraminifers and an intense coating of orange to orange-brown iron-manganese on all lithic clasts and most

quartz grains distinguishes this unit, which ranges from 18 to 72 cm in thickness. The unit consists of a dark yellowish brown (10YR4/2) bioturbated sandy mud containing a thin clastic bed with 21 percent sand-size sediment and it is overlain by olive gray (5Y5/2) laminated silt and clay. Rare arenaceous foraminifers are the only fossils found in the brown bed. This unit contains up to 9 clasts/100 cc of sediment, of which well rounded dark siliceous pebbles (39 %) are the most abundant clast type.

Unit 6. 32 to 112 cm thick, consisting of two distinctive pink basal clastic-rich beds of bioturbated pebble sandy mud changing vertically to dark yellowish brown (10YR4/2) foraminifer rich pebbly sandy mud. A sharp contact characterizes the top of the brown bed, which is overlain by well laminated to bioturbated light olive gray (5Y5/2) silty mud that lacks, or contains only rare arenaceous foraminifers. The basal pink clastic beds have been eroded in core 4. Altered white, blue, orange, yellow, to dark brown andesitic clasts up to 1 cm in diameter occurs in the mud above the dark brown bed in core 9, but not in any of the other cores. The CaCO_3 content ranges up to 70 percent in the distinctive pink clastic-rich beds, but is only 10 percent or less in the overlying foraminifer-rich brown beds. This unit contains up to 75 clasts/100 cc of sediment, of which limestone and dolostone, up to 50 percent, are the most abundant clast type.

Unit 7. 32 to 66 cm thick. A distinctive clast-rich bed up to 27 cm thick consisting of grayish orange pink (10YR7/2) bioturbated pebbly sandy mud with a sharp basal contact lies at the base of this sequence. A bioturbated dark yellowish brown (10YR4/2) bed overlies the clast rich bed in core 5. In core 9, the clast-rich bed is overlain by laminated silty mud that changes upsection first into well laminated sand containing 65 percent unimodal quartz and then into bioturbated pale yellowish brown (10YR6/2) sandy mud. Rare arenaceous foraminifers are found in the lower clastic bed and abundant planktonic foraminifers, echinoid spine, and

ostracodes in the overlying brown bed. This unit contains up to 43 clasts/100 cc. Limestone and dolostone, up to 69 percent, form the most abundant clast type. The CaCO_3 is as high as 68 percent in the basal clastic-rich bed.

Unit 8. 18 to 57 cm of laminated to bioturbated pale green (10G7/2) sandy mud that changes upsection into intensely bioturbated dark yellowish brown (10YR4/2) pebbly sandy mud. An olive gray (5Y5/2) mud lacking foraminifers that is 13 cm thick in core 9 and 2 cm thick in core 5 overlies the brown bed. Abundant planktonic and benthic foraminifers and echinoid spines are found in the brown strata. Sandstone and siltstone, 44 percent, forms the most abundant clast type for this unit, which contains as many as 12 clasts/100 cc sediment. The CaCO_3 content (less than 18 percent), is low.

The following depositional units are only found in cores 5 and 4.

Unit 9. 55 to 94 cm thick of a basal light olive gray (5Y5/2) sandy mud that grades upsection into intensely bioturbated and mottled dark yellowish brown (10YR3/2) sandy mud. Overlying the brown bed are mottled greenish gray (10YR6/2, 5GY6/1) sandy mud to mud beds. Abundant planktonic and benthic foraminifers, echinoid spines and ostracodes occur in the brown bed and in the bioturbated strata below the brown bed. This unit contains up to 22 clasts/100 cc of sediment of which limestone and dolostone (53 percent), are the most abundant clast type. The CaCO_3 content (up to 30 percent) is variable.

Transitional cyclic sequence

Unit 10. 29 to 38 cm thick. Bioturbated yellowish brown (10YR5/4) slightly sandy mud, which constitutes the basal bed, changes upsection into pale olive (10Y6/2) sandy mud to intensely bioturbated moderate brown (5YR3/4) sandy mud. Abundant planktonic and benthic foraminifers, echinoid spines, and ostracodes as well as abundant FeMn micronodules are found in the brown bed, and lesser quantities in the upper beds. The unit contains up to 9 clasts/100 cc of sediment, of

which limestone and dolostone (56 percent) are the most abundant. The Brunhes-Matuyama chron boundary is found at or near the top of the brown bed.

Unit 11. 7 to 15 cm of yellowish gray to light olive gray (5Y5/2-7/2) bioturbated sandy mud overlies a basal grayish orangish pink (5YR7/2) sand-rich (to 25 percent sand-size sediment) pebbly bed. The unit contains rare arenaceous foraminifers, and 88 clasts/100 cc of sediment. The CaCO₃ content of the basal clastic-rich bed is 40 percent.

Unit 12. 24 to 35 cm thick unit of olive gray (5Y5/2) bioturbated mud overlying one to three beds of grayish orange pink (5YR7/4) pebbly sandy mud with up to 46 percent sand-size sediment. Unit 12 contains rare arenaceous and calcareous benthic foraminifers, and 101 clasts/100 cc of sediment. The Jaramillo normal polarity subchron is found within this sequence in cores 4 and 5.

Limestone and dolostone, up to 49 percent, is the most abundant clast type in units 11 and 12.

Unit 13. 18 to 30 cm of bioturbated dark yellowish brown (10YR4/2) pebbly sandy mud overlain by olive gray (5Y5/2) laminated mud. The sand content decreases from 21 percent in the basal bed to 2 percent in the upper part of the unit. The unit contains rare arenaceous and calcareous benthic foraminifers and echinoid spines and 22 clasts/100 cc of sediment.

The following units are only found in core 4.

Unit 14. 19 cm thick consisting of a basal grayish orange pink (5YR7/4) sand-pebble-rich bed (23 percent sand) overlain by bioturbated brown (10YR4/2) sandy mud and a thin bed of yellowish gray (5Y5/2) mud or sandy mud. The unit contains rare arenaceous foraminifers and 10 clasts/100 cc of sediment.

Lower cyclic sequence

Unit 15. 18 cm thick, consisting of a basal grayish orange pink (5YR7/4) sand-pebble-rich bed (28 percent sand-size sediment) changing upsection to yellowish

brown(10YR5/2) bioturbated sandy mud containing rare arenaceous foraminifers. This unit contains 103 clasts/100 cc of sediment.

Unit 16. 9 cm thick, consisting of a basal grayish orange pink (5Y7/4) sand-pebble-rich bed (23 percent sand -size sediment) changing up to yellowish brown (10YR5/2) bioturbated sandy mud containing rare arenaceous foraminifers. A thin bed of yellowish gray (5Y5/2) sandy mud overlies the brown bed. This unit contains 40 clasts/100 cc of sediment.

Unit 17. 11 cm of bioturbated basal grayish orange pink (5Y7/4) sand-pebble-rich strata (24 percent sand-size sediment) grading upsection into yellowish brown (10YR5/2) sandy mud overlain by a thin bed of yellowish gray (5Y5/2) mud. The unit contains rare arenaceous foraminifers and 108 clast/100 cc of sediment.

Unit 18. 7 cm thick of bioturbated basal grayish orange pink (5Y7/4) sand-pebble-rich strata (sand fraction 18 percent) grading up to yellowish brown (10YR5/2) sandy mud containing rare arenaceous foraminifers. The unit contains 10 clasts/100 cc of sediment.

Unit 19. >5 cm of laminated yellowish gray (5Y7/2) sandy pebbly mud containing rare arenaceous foraminifers and 64 clasts/100 cc of sediment.

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Correlation with Standard Arctic lithostratigraphic units of Clark and others (1980)

A tentative correlation of the standard Arctic units M to I of Clark and others (1980) for Central Arctic Ocean cores is established for the NWR stratigraphic section (Phillips and others, 1992; Poore and others, 1993) and is presented in figure 5. The condensed cycles below unit 11 also fall in unit I. The correlations are tentative because they seek to relate expanded sediment sections on NWR to the condensed sections studies by Clark and others (1980). The determination of the lithostratigraphic boundaries in our cores were made by David L. Clark, University of Wisconsin.

Unit M Lithostratigraphic unit M is 473 cm thick in core 9 and consists of six dark brown bioturbated beds of which five contain abundant microfauna. Unit M also contains as many as nine distinctive clastic beds of which the upper seven are white or cream in color and the lower two are pink. The lowest pink clastic bed in NWR is correlated with PW2 of Clark and others (1980). PW2 lies at the base of unit M. Each clastic bed contains a sand fraction peak with the maximum percentage ranging up to 33. At least three major CaCO_3 peaks are identified in unit M with the basal pink sand bed ranging up to 65 percent. Unit M comprises our lithostratigraphic sequence 1 to 6.

Unit L Lithostratigraphic unit L is 145 cm thick and consists of two dark brown bioturbated beds with abundant microfauna separated by a distinctive pink, pebbly, coarse sandy pebbly clastic-rich bed as much as 27 cm thick. A unit of gray and tan mud, as much as 52 cm thick, contains minor sandy clastic-rich intervals underlies the lower brown bed. Locally, Unit L is characterized by current laminated very fine-grained unimodal quartz sand with the sand fraction as high as 65 percent. One major sand peak containing up to 27 percent sand and a CaCO_3 peak, up to 63

percent, characterizes unit L on NWR. Unit L comprises our lithostratigraphic sequences 7, 8, and part of 9.

Unit K Lithostratigraphic unit K, locally as thick as 63 cm, consists of upper and lower dark brown bioturbated beds with abundant microfauna separated by pale olive coarse sandy clastic-rich mud. Two beds, containing as much as 18 percent sand fraction, occur in the pale olive mud and at the base of the lower brown bed. A CaCO_3 peak, 26 percent, occurs in the upper sand bed within the pale olive mud between the two brown beds. The Brunhes-Matuyama magnetopolarity chron boundary is found at or just above the lower brown bed. Unit K correlates with the lower part of our lithostratigraphic sequence 9 and all of 10 on NRW.

Unit J Lithostratigraphic unit J, as much as 53 cm thick in core 4, consists of two distinctive, bioturbated, pink coarse clastic beds containing rare arenaceous foraminifers. In core 5 the lower pink bed contains interbeds of laminated sandy mud and in core 4 it is represented by three sandy pebbly clastic-rich beds. The upper clastic bed contains up to 26 percent sand and the lower clastic bed(s) contains up to 46 percent sand with both sands associated with as much as 40 percent CaCO_3 . The Jaramillo normal magnetopolarity subzone is found in cores 4 and 5 between the upper and lower sandy pebbly clastic-rich beds. Unit J comprises lithostratigraphic sequence 11 and 12 on NWR.

Unit I Only the upper part of lithostratigraphic unit I is found in cores 4 and 5, where it is at least 99 cm thick and consists as many as 7 fining-up sediment cycles. The cycles consist of thin-bedded, intensely bioturbated, coarse clastic rich, pebbly mud with as much as 28 percent sand. Some of the sandy clastic-rich intervals contain as much as 38 percent CaCO_3 . Foraminifers where present are arenaceous.

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FORAMINIFER OCCURRENCE IN NORTHWIND RIDGE CYCLES

Foraminifer	Lithostratigraphic cycles														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>Neogloboquadrina pachyderma</i>	X	X	X	X		X	X	X	X	X					
<i>Bolivina arctica</i>				X		X		X	X	X	X	X	X	X	
<i>Bulimina aculeata</i>			X	X											
<i>Cassidulina laevigata</i>		X													
<i>Cassidulina reniforme</i>										X	X	X	X	X	
<i>Cassidulina teretis</i>	X	X	X	X		X	X	X	X	X		X	X	X	
<i>Criboelphidium excavatum</i>						X	X	X	X	X		X			
<i>Epistominella exigua</i>			X					X		X				X	
<i>Eponides tumidulus</i>	X	X								X					
<i>Fontbotia wuellerstorfi</i>	X	X	X	X		X	X	X	X					X	
<i>Globocassidulina subglobosa</i>									X	X		X			
<i>Haplophragmoides obscurus</i>	X				X			X				X	X		X
<i>Oridorsalis</i> spp	X	X	X	X											
<i>Pullenia bulloides</i>										X					
<i>Stainforthia horvathi</i>		X	X	X		X	X	X		X	X	X	X	X	
<i>Triloculina frigida</i>	X		X										X		
<i>Valvulineria arctica</i>		X											X		

Note: Foraminifer occurrence in each lithostratigraphic cycle represents microfauna in the >150 μ m size fraction. The foraminifer occurrence data for lithostratigraphic cycles 1-4 and 6-10 are summarized from Foley and Poore, 1991, 1993; and Poore and others, 1993, 1994; the data for lithostratigraphic cycle 5 and 15 are from Phillips and others (1992). Sequence 16 to 19 in core 4 contained a few arenaceous foraminifers that have not been identified. Cores obtained in 1992 and 1993 on Northwind Ridge at shallower depths than core 4 contain a rich benthic microfauna in lithostratigraphic cycles 16-19.