MAASTRICHTIAN/DANIAN(?) OSTRACODE ASSEMBLAGES FROM NORTHERN ALASKA: PALEOENVIRONMENTS AND PALEOBIOGEOGRAPHIC RELATIONS

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ABSTRACT

Cretaceous and lower Tertiary rocks are exposed in bluffs that extend ~ 300 km along the Colville River, northern Alaska. Well-preserved, diverse Maastrichtian and Danian(?) ostracode assemblages were recovered from the northernmost outcrops near Ocean Point. High-latitude fossil faunas are uncommon in the geological record, and this locality provides the means to reconstruct an ancient arctic environment across a nonmarine to marine transition. Maastrichtian sediments examined represent nonmarine floodplain deposits with diverse terrestrial and aquatic fossils. The paleoenvironment was a broad, flat, water-saturated delta plain with diverse herbaceous ground cover and emergent and subaquatic vegetation. Nonmarine ostracodes indicate groundwater with elevated salinity of marine composition. Danian sediments examined are marginal marine and shallow marine with abundant, diverse invertebrates. The paleoenvironment was a mild- to cold-temperate shallow ocean with lowered salinity, terrestrial influence, and frequent storm activity. Danian(?) ostracodes show a gradual shift upsection from lagoonal and bay facies to inner-shelf facies. During the Maastrichtian and Danian, polar terrestrial and marine assemblages included a component of endemic taxa adapted to cool temperatures, seasonally low light regimes, and geographic isolation, all characteristic of northern high latitudes. Many of the nonmarine arctic ostracode genera recovered represent their geologic oldest occurrence, suggesting they evolved in Alaska during the Late Cretaceous. These "arctic" genera migrated southward in the Tertiary as lower latitude climates cooled. They comprise some of the common nearctic nonmarine genera of the temperate middle latitudes, some of which are still extant today.

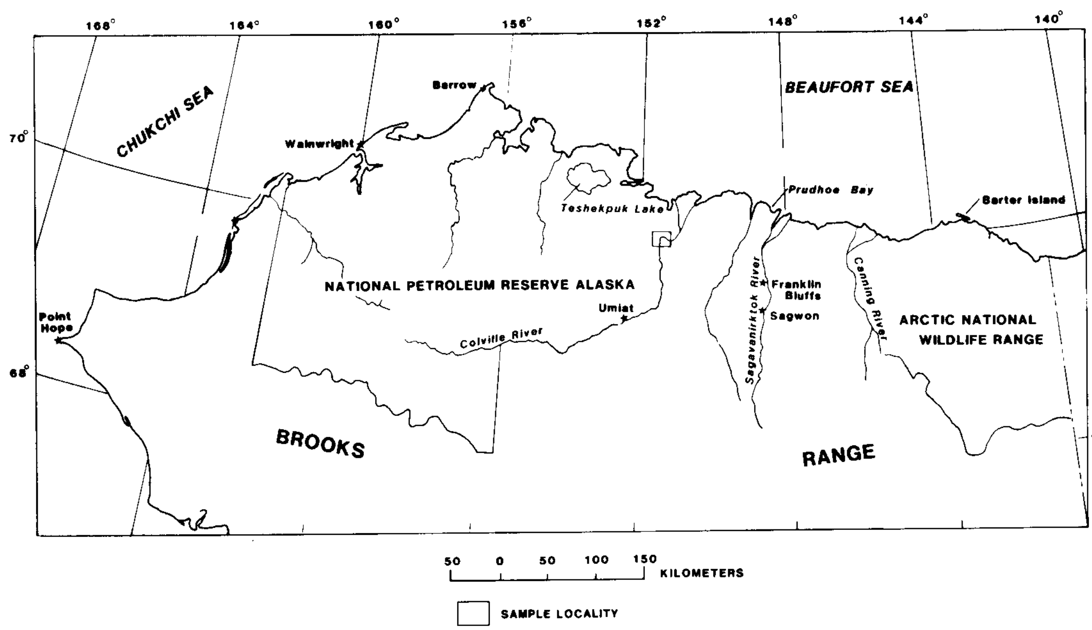

Fig.1. Location map of northern Alaska showing the region studied along the lower Colville River, at the eastern boundary of the National Petroleum Reserve of Alaska (NPRA).

STUDY AREA

Field studies were conducted by the senior author between 1983 and 1986 along the Colville River at 70° N. lat., 45 km south of the Arctic Ocean, along the eastern boundary of the National Petroleum Reserve of Alaska (NPRA; Fig.1). Extensive exposures of Cretaceous and Tertiary rocks form bluffs 30 to 50 m high. The sedimentary rocks studied belong to the Prince Creek and Schrader Bluff Formations of the Colville Group (Upper Cretaceous to Danian) and include claystone, siltstone, sandstone, coal or carbonaceous mudstone, and tephra (Brosge' and Whittington, 1966). A prominent unconformity separates the Cretaceous-lower Tertiary rocks from the overlying sands and silts of the Pliocene to Quaternary Gubik Formation (Carter and Galloway, 1985).

STRATIGRAPHIC DISTRIBUTION OF OSTRACODES

During 1986, 25 sections were measured, from the lowest known horizon containing dinosaur bones to the first occurrence of fully marine sediments (Marincovich et al., 1985; Phillips, 1988). Fieldwork was conducted to (1) collect dinosaur fossils and (2) collect micropaleontological samples to provide relative ages and paleoenvironmental data for the dinosaur fauna. The total sequence measured in 1986 is 180 m thick, of which 155 m were exposed in 1986. Of the 160 paleontological samples collected, 53 contain ostracodes. Four distinct ostracode assemblages can be recognized and represent the following aquatic environments (Fig.2): (1) lower nonmarine, (2) marginal marine, (3) upper nonmarine, and (4) shallow marine. The assemblages are distinguished by differences in genus and species composition and abundance and are believed to represent both environmental and temporal changes. Comparison of generic identification with other occurrences elsewhere on other continents permitted reconstruction of the environments of deposition.

The lower nonmarine assemblage occurring in the basal 135 m has been dated as late Campanian to late Maastrichtian based both on biostratigraphy (Brouwers et al., 1987; Frederiksen et al., 1988; Frederiksen, 1991; Brouwers and De Deckker, 1993) and on radiometric analysis (McKee et al., 1987; Conrad et al., 1990; J. Obradovich, oral commun., 1993). The marginal-marine, upper nonmarine, and shallow-marine assemblages occurring in the upper 45 m have been dated as Maastrichtian (McDougall, 1987; Frederiksen, 1990) and Paleocene (Marincovich et al., 1990; Marincovich, 1992, 1993; Brouwers and De Deckker, 1993) based on biostratigraphy; no material suitable for radiometric analysis is available in the upper sequence. Brouwers and De Deckker (1993) provide additional arguments based on ostracodes for the Danian age. For the purposes of this paper, which focuses on paleoenvironments, the age of the lower nonmarine sedimentary rocks is considered to be late Maastrichtian, and the age of the marginal-marine, upper nonmarine, and shallow-marine sedimentary rocks is considered to be Paleocene (Danian). Question marks throughout the text underscore the age controversy of the upper 45 m.

Maastrichtian Sequence

The basal 135 m represent floodplain environments and include fluvial sands and extensive organic-rich overbank silts with interbedded tephra deposits. Overbank sediments are the most abundant volumetrically and include crevasse splay, overbank

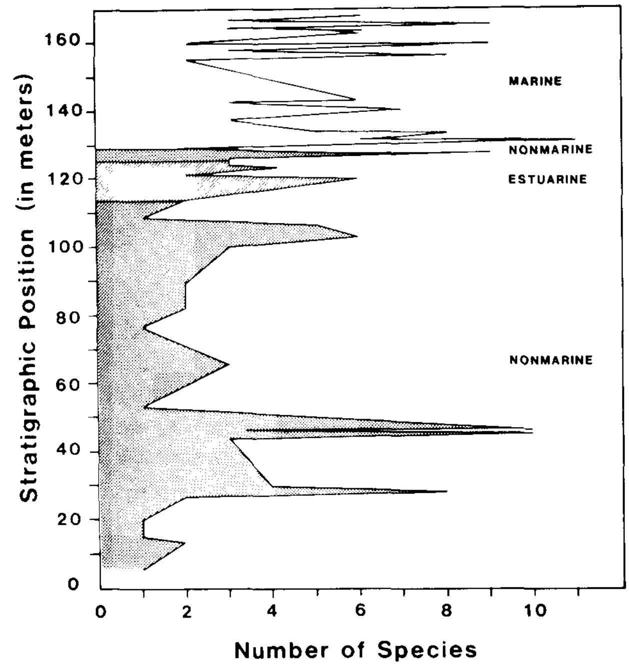

Fig.2. Plot of ostracode species diversity through the sequence studied. Patterns differentiate the four ostracode assemblages: lower nonmarine, marginal marine (estuarine), upper nonmarine, and shallow marine. Peaks in species diversity correlate with mollusk-rich lag sediments. The boundary between Maastrichtian and Danian(?) assemblages occurs at the contact between the lower nonmarine and estuarine assemblages.

sheet flood, and vertical accretion deposits (Phillips, 1988, 1990).

Ostracodes occur in discrete horizons through the nonmarine sequence, most commonly in the overbank siltstones. High species diversity and abundance are found in shell-rich beds, which represent lag deposits that are a consequence of accumulation and deposition from several marginal fluvial environments (e.g., temporary ponds, oxbows, and streams). The basal 135 m contain the lower nonmarine ostracode assemblage, which dominates the Colville River sequence studied here. Species are well preserved and include such genera as *Candona, Cytherissa, Mongolocypris, Bisulcocypridea*, and *Ziziphocypris*. Morphologic similarity between Cretaceous arctic taxa and Tertiary middle-latitude temperate to subarctic taxa suggest that middle-latitude genera originated in high-latitude environments in Late Cretaceous time and migrated southward to lower latitudes as global climate cooled during the Tertiary. The first two genera listed above have living representatives and hence ecologic comparisons are inferred from their known distribution.

The assemblage composition and associated sediments suggest that the ostracodes lived in marginal fluvia habitats such as oxbow lakes, ponds, marshes, and small streams adjacent to large distributaries. The abundance of root traces (Phillips, 1988, 1990) and high organic content of the siltstones (Brouwers et al., 1987) suggest that lush aquatic and terrestrial vegetation existed on the delta, which would have created a number of microhabitats and supported an abundant microfauna. The presence of cytherid taxa such as *Bisulcocypridea* and *Cytherissa* implies that water bodies must have been permanent at the time of life and reproduction of the ostracodes, because cytherid genera cannot withstand desiccation.

During the Maastrichtian and Danian, the study area was part of a large fluvial-deltaic complex that bordered the Arctic Ocean, located northeast of the delta. The region was dominated by a low-gradient, low-relief coastal plain that was occasionally flooded by marginal-marine waters. The water table was probably high, as evidenced by the lack of mudcracks, the abundance of aquatic invertebrates and plants, the presence of abundant organic-rich paleosols, and the presence of ostracode taxa that require permanent water. Several major rivers and many small streams meandered across the coastal plain, carrying suspended-load sediment and depositing large volumes of overbank silts. Rivers and streams had extensive vegetation along their banks, seen in the presence of abundant root traces in the overbank silts (Phillips, 1988, 1990). Herbaceous ground cover dominated the coastal plain and consisted mainly of ferns, *Equisetites* (horsetails), aquatic and subaquatic wetland plants, and some angiosperms (Ager in Brouwers et al., 1987; Frederiksen, 1991). An abundant palynomorph flora and abundant petrified and carbonized wood indicate that a diverse forest occurred in closely related and more distant upland regions.

Estimates of paleolatitude for the Colville River area during the Late Cretaceous, based on paleomagnetic data and tectonic reconstructions, range from 70° to 85° N. (Witte et al., 1987; Smith et al., 1981). The North Slope experienced profound seasonality of temperature as a consequence of several months of winter darkness. Reconstructions of paleogeography based on tectonics and faunal provinces show that the Late Cretaceous Arctic Ocean had narrow connections with the Western Interior Seaway of North America and with the Tethys Seaway through Turgai Strait (Marincovich et al., 1990). Late Cretaceous marine and nonmarine ostracodes of the Colville River sequence show taxonomic affinities with Late Cretaceous faunas of the Western Interior (Fouch et al., 1987) and northern China and Mongolia (Hao et al., 1982; Szczechura and Blaszyk, 1970). The affinity between Alaska and China suggests the existence of a nonmarine temperate province at high latitudes that also extended into northern China.

Paleocene (Danian?) Sequence

Three distinct ostracode faunas occur in the uppermost 45 m: a marginal-marine assemblage, a nonmarine assemblage, and a shallow-marine assemblage (Fig.2). Nonmarine rocks occur near the top of the sequence and consist of several fining-up overbank cycles, each capped by an organic-rich paleosol. Overbank sediments include rooted siltstones and fine sandstones. The depositional environment is interpreted to be a muddy marsh, minor distributary streams, or overbank deposits (Phillips, 1988, 1990).

Ostracodes occur throughout most of the sequence but vary in species diversity and abundance. Marginal-marine deposits make up the lower part of the 45-m sequence. Sediments grade upsection from a vegetated sand flat and channel sequence to a storm-dominated sequence; and fossils include benthic foraminifers, bivalves, ostracodes, and *Equisetites* roots. The marginal-marine ostracode assemblage includes nine species, dominated by *Paracyprideis* and *Cytheromorpha*, which are characteristic estuarine genera (Keen, 1978; van Morkhoven, 1963). The occasional presence of *Cytherissa* and *Bisulcocypridea* indicates very low salinities, being close to fresh (e.g., <3 o/oo).

The deltaic-fluvial complex shifted laterally-landward relative to its position during the Cretaceous, so bay and shallow-marine facies were being deposited during the Paleocene. The marginal-marine environment probably consisted of shallow bays that fronted the rivers and coastal regions. Salinities were low, indicated by the presence of salinity-tolerant nonmarine taxa and the absence of stenohaline marine ostracode and mollusk taxa. Low salinities are also indicated by the presence of abundant roots of *Equisetites* and other subaquatic plants.

Nonmarine rocks are sandwiched between the underlying marginal-marine rocks and the overlying marine rocks and suggest a paleoenvironment comparable to that inferred for the lower nonmarine rocks. Genera of the upper nonmarine assemblage indicate ponds, streams, and other habitats that form part of a fluvial-deltaic complex with an abundant supply of organic detritus. The lower and upper nonmarine assemblages differ in genus and species composition; of 21 nonmarine species that occur in the entire sequence, only 6 species are in both assemblages. Because the environments of the two nonmarine assemblages are inferred to be comparable, the change in composition is believed to be temporal.

The uppermost rocks consist of shallow-marine sandstones and siltstones with an abundant invertebrate fauna, including bivalves, gastropods, brachiopods, ostracodes, and benthic foraminifers. Sandstones and silty sandstones occur as hummocky cross-stratification and include local concentrations of shell lags; these sediments are probably storm-generated deposits. The finer sandy siltstones form low-angle cross beds and include bivalves in growth position; these sediments presumably are not storm beds.

Ostracodes occur in most samples collected from the marginal-marine and shallow-marine facies. Species diversity shows a number of peaks that probably are more related to sedimentation than to environmental changes. The sharp diversity peaks are believed to be a consequence of concentration and redeposition by storm events. The contact between the middle nonmarine facies and the basal part of the upper marine facies includes a peak in ostracode species diversity and abundance that corresponds to a lag horizon, evidenced by a pebble lag. The sample taken just above the contact contains nonmarine taxa together with marine taxa. This mixture of paleoenvironments is inferred to represent reworking of older nonmarine sediments during the erosive onset of a transgressive event. Repeated storm-generated deposition probably also contributed to the reworked elements. The marine ostracode assemblage occurring above the nonmarine/marine contact indicates normal marine salinity and inner-shelf water depths.

Based on the ostracodes and mollusks (Marincovich et al., 1985, 1990), the marginal-marine and marine paleoenvironments were dominated by mild- to cold-temperate marine climates. Ostracode taxonomic affinities are with coeval faunas from the Canadian Arctic Islands, northern Russia, and northern Europe. These similar high-latitude assemblages suggest the existence during the Paleocene of an endemic temperate faunal province that consisted of populations with low diversity and abundance and an absence of warm-water taxa.

Reconstructions of paleogeography show that by Paleocene time the Arctic Ocean was almost completely isolated from the other oceans (Marincovich et al., 1985). The marine ostracode assemblage consists of heterochronous genera, including forms previously documented from Cretaceous and Danian strata, from upper Paleocene to Oligocene strata, and from Neogene to Quaternary strata. The presence of relict Cretaceous taxa implies that terminal Cretaceous extinction processes were only partly effective at northern high latitudes. The Cretaceous holdovers are believed to have made up a marginal population that was adapted to a harsh physicochemical environment and was therefore more capable of surviving through an ecologic crisis. The precocious Paleogene genera presumably evolved in this high-latitude environment, which was unique in being geographically isolated and having a temperate climate.

SUMMARY

Extinction processes at the Cretaceous-Tertiary boundary apparently were only partly effective in northern Alaska. The nonmarine fauna shows a turnover across the boundary, with the disappearance of some ostracode genera and species at the end of the late Maastrichtian. The marginal-marine and shallow-marine ostracode faunas indicate that a number of "Cretaceous" genera persisted into the early Tertiary and coexisted with more typically Tertiary genera. The implication is that the northern high-latitude marine and nonmarine habitats were somewhat buffered from and not markedly affected by terminal Cretaceous events. This is because the environmental conditions that prevail in the Tertiary elsewhere in the world already existed in Alaska at the Cretaceous/Tertiary boundary. The early geologic appearance of ostracode taxa may be related to high UV penetration in the Arctic, which would induce genetic permutations and hence represent a "center of radiation" of new species and genera.

The presence of numerous marine endemic taxa is related to (1) progressive isolation during the Late Cretaceous of the Arctic Ocean from the world's oceans; (2) the temperate climate of the high latitudes, which was cold relative to the subtropical and tropical climates that existed at middle and low latitudes; and (3) the nearshore environment, characterized by low temperature and salinity, which supported populations adapted to marginal conditions.

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REFERENCES

Brosge', W.P. and Whittington, C.L., 1966. Geology of the Umiat-Maybe Creek region, Alaska. U.S. Geol. Surv. Prof. Paper, 303-H: 501-638.

Brouwers, E.M., Clemens, W.A., Spicer, R.A., Ager, T.A., Carter, L.D. and Sliter, W.V., 1987. Dinosaurs on the North Slope, Alaska: High latitude, latest Cretaceous environments. Science, 237: 1608-1610.

Brouwers, E.M. and De Deckker, P., 1993. Late Maastrichtian and Danian ostracode faunas from northern Alaska: Reconstructions of environment and paleogeography. Palaios, 8: 140-154.

Carter, L.D. and Galloway, J.P., 1985. Engineering-geologic map of northern Alaska, Harrison Bay Quadrangle. U.S. Geol. Surv. Open-File Report 85-256, 49 pp.

Conrad, J.E., McKee, E.H. and Turrin, B.D., 1990. K-Ar and $^{40}Ar/^{39}Ar$ ages of tuff beds at Ocean Point on the Colville River, Alaska. U.S. Geol. Surv. Bull. 1946: 77-82.

Fouch, T.D., Hanley, J.H., Forester, R.M., Keighin, C.W., Pitman, J.K. and Nichols, D.J., 1987. Chart showing lithology, mineralogy, and paleontology of the nonmarine North Horn Formation and Flagstaff

Member of the Green River Formation, Price Canyon, central Utah: A principal reference section. U.S. Geol. Surv. Misc. Inv. Ser. Map I-1797-A.
Frederiksen, N.O., Ager, T.A. and Edwards, L.E., 1988. Palynology of Maastrichtian and Paleocene rocks, lower Colville River region, North Slope of Alaska. Can. J. Earth Sci., 25: 512-527.
Frederiksen, N.O., 1991. Pollen zonation and correlation of Maastrichtian marine beds and associated strata, Ocean Point dinosaur locality, North Slope, Alaska. U.S. Geol. Surv. Bull. 1990E, 24 pp.
Hao Yi-Chun, Su De-Ying and Li You-Qui, 1982. Late Mesozoic nonmarine ostracodes in China. In: R.F. Maddocks (Editor), Applications of Ostracoda, Proceed. 8th Internat. Symp. Ostracoda. Univ. Houston, pp. 372-380.
Keen, M.C., 1978. The Tertiary-Palaeogene. In: R. Bate and E. Robinson (Editors), A Stratigraphic Index of British Ostracoda. Geol. Jour. Spec. Issue, 8: 385-450.
Marincovich, L., Jr., Brouwers, E.M. and Carter, L.D., 1985. Early Tertiary marine fossils from northern Alaska: Implications for Arctic Ocean paleogeography and faunal evolution. Geology, 13: 770-773.
Marincovich, L., Jr., Brouwers, E.M., Hopkins, D.M. and McKenna, M.C., 1990. Mesozoic and Cenozoic paleogeographic and paleoclimatic history of the Arctic Ocean Basin, based on shallow-water marine faunas and terrestrial vertebrates. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), The Arctic Ocean Region. Boulder, CO. Geol. Soc. Amer., The Geology of North America, L: 403-426.
Marincovich, L., Jr., 1992. Earliest Cenozoic (Danian) paleogeography of the Arctic Ocean. Internat. Conf. on Arctic Margins, Anchorage, Alaska. Abstracts: p. 3
Marincovich, L., Jr., 1993. Danian Mollusks from the Prince Creek Formation, Northern Alaska, and implications for Arctic Ocean paleogeography. Jour. Paleont. Memoir 35, 35 pp.
McDougall, K., 1987. Maestrichtian benthic foraminifers from Ocean Point, North Slope, Alaska. Jour. Paleont., 17: 344-366.
McKee, E.H., Conrad, J.E. and Turin, B.D., 1989. Better dates for Arctic dinosaurs. Eos, 70: p. 74.
Phillips, R.L., 1988. Measured sections, paleoenvironments, and sample locations near Ocean Point, Alaska. U.S. Geol. Surv. Open-File Report 88-40.
Phillips, R.L., 1990. Summary of Late Cretaceous environments near Ocean Point, North Slope, Alaska. U.S. Geol. Surv. Bull. 1946: 101-106.
Smith, A.G., Hurley, A.M. and Briden, J.C., 1981. Phanerozoic paleocontinental world maps. Cambridge Univ. Press, 102 pp.
Szczechura, J. and Blaszyk, J., 1970. Fresh-water Ostracoda from the Upper Cretaceous of the Nemegt Basin, Gobi Desert. In: Results of the Polish-Mongolian Palaeontological Expeditions, Part II. Palaeontol. Polonica, 21: 107-120.
Van Morkhoven, F.P.C.M., 1963. Post-Paleozoic Ostracoda, v. 2. Elsevier, Amsterdam.
Witte, W.K., Stone, D.B. and Mull, C.G., 1987. Paleomagnetism, paleobotany, and paleogeography of the Cretaceous, North Slope, Alaska. In: I. Tailleur and P. Weimer (Editors), Alaskan North Slope Geology, Soc. Econ. Paleont. and Mineral. and Alaska Geol. Soc., 2: 571-579.