northwest-central South Dakota is recorded in the off-lap sequence beginning with the Elk Butte Member (offshore shelf) of the Pierre Shale followed by the Trail City (bar-influenced shelf), Timber Lake (offshore bar), and Iron Lightning (deltaic) Members of the Fox Hills Formation. Well-preserved molluscan assemblages from these facies permit comparison with assemblages from analogous recent environments.

Factors controlling the distribution of Late Cretaceous mollusk assemblages are related to (1) sediment organic content, (2) sedimentation rate, and (3) sediment-water interface stability. These limiting factors closely control feeding adaptations and are reflected, therefore, in the distribution of feeding groups.

Bottoms dominated by deposit feeders.—Deposit feeders are limited to bottoms containing an organic food source. Shelf areas receiving deltaic sediments (Iron Lightning) or deeper offshore areas receiving settling fines (Elk Butte) were dominated by this feeding group. Mud bottoms extensively reworked by deposit feeders have a high water content and are suspended easily by weak bottom currents. High interface turbidity and instability may explain the low diversity of filter feeders from this bottom type as high concentrations of suspended silt-clay cause clogging of filtering mechanisms.

Bottoms dominated by filter feeders.—The clean-washed upper part of the Timber Lake sand bar and the distributary sands of the Iron Lightning were dominated by mobile filter-feeding bivalves burrowing into the shifting unstable sand bottoms. Interface instability excluded attached epifaunal forms.

Bottoms with mixed feeding groups.—Peak filter-feeding diversity was attained on bottoms during periods of low Trail City sedimentation. Physical stability of these bottoms provided a firm surface of attachment for epifaunal mollusks and interface turbidity was relatively low providing optimal conditions for filter feeders. Root structures and high gastropod diversity indicate that some parts of the bottom were covered with plants during Trail City deposition. The presence of small amounts of organic matter in the sediment also permitted the population of a few infaunal deposit feeders.

The distribution of the Fox Hills bivalves by feeding groups reflects the conditions of food source, sedimentation rate, and bottom stability. These relations are supported by independent evidence of lithologic and stratigraphic analysis. The recognition of feeding groups can provide a strong tool in environmental reconstruction and analysis of ancient community structure.

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Reefs and Reef Environments

Reefs are considered as largely unbedded or obscurely bedded, massive structures which are composed of solid, organically bound, *in situ* organisms, and which were at least potentially wave-resistant structures that rose topographically above the surrounding depositional surface. Reefs are somewhat unusual and quantitatively minor features in the geologic record, but they have received considerable attention because of their economic importance, biologic uniqueness, or distinctive facies relations.

Any model for recognition of reefs in the geologic record must allow for considerable variation in relief, size, shape, biologic composition, and facies relations. They are associated commonly with normal marine environments, but the associated complex may span from freshwater to hypersaline deposits or from euxinic to well-oxygenated conditions.

Relief and shape depend on several factors, principally the comparative rate of subsidence and growth, direction of prevailing currents, structural relation, and organic composition. Size and shape commonly are discernible, but demonstration of depositional relief is difficult in many places.

Textures of single outcrops, hand specimens, or thin sections, may be diagnostic of at least reef potential if the massive, bound relations of organisms are apparent, but commonly additional criteria are necessary. Recognition of biologic and lithologic facies relations are critical in investigation of reef and associated environments in the geologic record.

The term "reef" has been applied loosely to several structures by different workers. Locally, it has been used for merely a faunal association, even though the organisms are present as loose, discrete fragments and the rocks in which they occur are evenly bedded in moderately thin layers. The term also has been applied to carbonate lenses in noncarbonate sequences, even though these lenses are of bedded, unbound detritus, oölites, or crinoid columnals. It also has been applied to sheetlike deposits of *in situ* corals or algal crusts or other reef-associated organisms even though the deposit is widespread, thin, and with no demonstrable topographic expression. Massive tumbled blocks also have been considered to be reefs, particularly if the blocks are abundantly fossiliferous and occur in distinctly more thinly bedded rocks. The term "reef" also has been applied to large carbonate structures which may be truly of reef origin at their margins, but which are composed mainly of bedded, clastic debris.

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Comparison of Continental Margins off Northwest Africa and Cape Hatteras[1]

Pre-drift reconstructions of the Atlantic place the continental margin off the middle Atlantic region of the United States against the continental margin off northwest Africa. An implication of this reconstruction is that the opposing continental margins would be mirror images if the two margins formerly had been joined and then had separated and had undergone parallel development. Relevant sections of the outer continental shelf, continental slope, continental rise, and abyssal plain off northwest Africa between Point Durnford, the Spanish Sahara, and Cape Timiris, Mauritania, and off Cape Hatteras, United States, were investigated with continuous seismic reflection (air gun), magnetic, and bathymetric profiles.

Geophysical data and regional geology from the two continental margins disclose some similarity in their stratigraphic framework. Mesozoic through Cenozoic coastal-plain strata dip seaward at low inclinations ($<5°$) under much of the continental shelf of both continents. Paleozoic-Precambrian crystalline rocks are exposed along the landward margin of the coastal plain and apparently incline seaward as base-

[1] This work was supported by the Office of Naval Research under Contract Nonr-266(84). Reproduction in whole or in part is permitted for any purpose of the United States Government. It is Hudson Laboratories of Columbia University Informal Documentation No. 163.

ment beneath the coastal-plain strata. The continental rises are formed by a seaward-thinning wedge of sedimentary strata inclined nearly parallel with the sediment-water interface ($<1°$).

However, development of the two continental margins differs. Sedimentary strata of the northwest African margin are deformed by intrusive bodies and by structures which resemble horsts and grabens. An extensive offshore Triassic and/or Aptian salt-dome province extends from Morocco to Senegal. The eastern Canary Islands and the Cape Verde Islands are a strongly folded Jurassic through Eocene fold belt. Sedimentary strata of the Hatteras margin, in contrast, are relatively undeformed except for structures which can be explained by massive rotational slumping and gravitational gliding. The sedimentary strata of neither continental slope nor rise show the effects of compressive stresses expected in models of sea-floor spreading by convection currents that turn downward at the continental margins.

Thus, the opposing continental margins investigated are not mirror images as might be expected if the two margins had been joined and then had separated and had undergone parallel development. Although much of the stratigraphic framework of the two continental margins appears to be similar, their development differs.

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Arctic Margin of Canada

Recent investigations have added to knowledge of the northern margin of Canada and the structure of the Arctic Ocean. The geosynclinal belt rimming the North American craton has been deformed with a sequence and style of tectonism that in Paleozoic time were generally similar to those of the Appalachians and the Brooks Range, whereas the later history bears a resemblance to that of parts of the northwest cordillera.

Problems remain with regard to the possible extension of the geosynclinal belt and structures at each end of the present exposures in the Arctic archipelago. At its west end the belt trends beneath the continental shelf toward the Canada Basin; the magnetic and gravity patterns over the shelf and continental slopes are not clearly related to known structures. A major positive gravity anomaly along the outer edge of the shelf lies athwart the projection of known geologic trends, and possible explanations of this anomaly by crustal thinning or intrusions are not supported by available magnetic and seismic data. That this area is still active tectonically is suggested by the unusual depth of the shelf which appears to have been drowned since Quaternary time but is still isostatically overcompensated, by magnetic and seismic anisotropy, modern microseismicity, and other features.

At its northeast end the geosynclinal belt of Arctic Canada abuts the geosynclines of northeast Greenland, whose faunal content and deformational history show European rather than American affinities since Paleozoic time. The relationship between these two provinces appears to be related to the evolution of the structures of the Arctic Ocean. Present evidence appears compatible with the hypothesis that the trans-Arctic Alpha Cordillera was connected with the Mid-Atlantic Ridge, and that the connection has been dislocated by the widening of the Altantic basin, leading progressively to the development of Baffin Bay and the Nares rift valley, and to the extension of the Atlantic fracture into the Siberian crustal block, splitting off Lomonosov Ridge as a continental remnant that abuts against, but does not join, the structures of Arctic Canada.

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Selective Dolomitization of Stromatolites

Selective dolomitization of stromatolites occurs in the Boundary Member of the Schooler Creek Formation (Triassic) of British Columbia, Canada. The member is as thick as 34 ft and is a repetitive cyclic sequence of stromatolite-pelmicrite-micrite-pelmicrite-stromatolite.

Interpreted depositional sites are: (1) micrite—local basin center; (2) pelmicrite—nearshore to low intertidal; (3) stromatolite—intertidal; and (4) anhydrite beds—restricted intertidal. Lateral change within the member is slight except for coalescing of units toward the paleoshoreline. Landward, within the major stromatolitic interval, there are tongues of anhydrite; seaward there are tongues of pelmicrite containing composite oöliths.

The stromatolites and beds in contact with them are dolomite with abundant large anhydrite crystals and clots of crystals. The rest of the member is limestone, slightly dolomitic in part, with sparse euhedral anhydrite crystals. The amount of anhydrite and dolomite increases toward the stromatolitic intervals.

Three conclusions are drawn: (1) the association of anhydrite clots and crystals with desiccation features indicates that diagenesis was partly penecontemporaneous with stromatolite formation, (2) dolomite in the beds adjacent to the stromatolitic intervals indicates that some dolomitization occurred after shallow burial of the stromatolite, and (3) selective dolomitization of stromatolitic intervals suggests that these intervals originally had relatively high permeability. Brines from evaporating pans in the landward area refluxed through the permeable zones and dolomitized the stromatolites.

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Correlation Theory Between Thin-Section and Loose-Grain Arithmetic Mean Sizes on Number-Frequency Basis

Projection diameter (P, or p), the diameter of a circle having an area equal to that of the grain area, *long diameter* (A, or a), and *short diameter* (B, or b) can be measured for loose grains in a stable position in the gravitational field (capital letters) and for grains in the thin section. The stable position of an irregular loose grain in the gravitational field need not be a unique position, but generally the thickness of the loose grain (C) remains vertical. In such a situation $\overline{B}$ and $\overline{p}$ are the best estimators of the arithmetic mean nominal diameters B and p, respectively, on a number-frequency basis. However, $\overline{B}$ and $\overline{p}$ need not be unbiased estimators of the nominal diameters if some nonspherical grains are present either in the thin section or in the loose grains.

From Krumbein's theory of thin sectioning of spherical grains,

$$\bar{d}_n = (\pi/4)\overline{D}_n, \qquad (1)$$