conglomerate, although every gradation may be seen from mosaic brecciation of bedrock to moderately well-rounded material in the lag gravels.

The breccias and conglomerates are unconformably and diachronously overlain by Middle or Upper Permian clastic sedimentary rocks that were deposited in an evaporitic environment.

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TIDAL FLATS

Tidal flats are built of marine sediments intersected by runnels and channels in a specific vertical sequence. Bidirectional current marks and subaerial features complete the environmental indicators.

Sediments in the intertidal zone lie between high- and low-water line across a vertical distance of 1-4 m or more, depending on the tidal range. The tidal range causes tidal currents which in turn form numerous gullies and channels. Currents of a high tidal range erode deeper channels than currents of low tidal ranges. The current velocity on the flats may reach 1 knot; therefore, on sandy bottoms small-scale current ripple marks are formed. The current velocity in gullies and channels is 3 knots or more, so that megaripples and underwater dunes are common in the channels. The tidal flats are sheltered by barrier islands or sand bars or they are in a sheltered bay. Though wave action is not too strong, it is nevertheless an important factor.

The whole wedge-shaped tidal flat body is elongate, parallel with the shoreline for many miles, but is intersected by channels or river estuaries.

The clastic sediments are mud (clay and silt), and sand, which is mostly fine grained. Gravel is scarce but clay pebbles and shells are commonn on channel bottoms. The mineral content of clay and silt is mainly clay minerals, quartz, iron minerals, garnet, mica, feldspar, some heavy minerals, dolomite, and carbonate. The mineral content of sand is mainly quartz, feldspar, mica, heavy minerals, fecal pellets, broken shells, and Foraminifera.

Near the high-water line (mud flats) the mud content is high, especially on wind- and wave-sheltered coastlines. The mud content decreases in the mixed flats and is low near the low-water line in the sand flats. The mud content increases near channels and below the low-water line, especially in the lateral channel deposits (except in the channel-bottom sediments). Even in the mudflats, the channel-bottom sediments are very muddy.

The tidal flats in The Netherlands are less muddy than the tidal flats in the German bay. Most tidal flats in Great Britain are very sandy. South of San Felipe, Gulf of California, the tidal flats are built of skin sand; north of San Felipe the mud content increases markedly toward the Colorado delta, whence the silt is derived.

Cross-bedding of megaripples is rare on the flats but common in the channels. On sand flats cross-beds of small-scale current ripples are very common. Locally the cross-beds shows herring-bone structures in sections normal to the ripple-crest axis and festoon bedding in sections parallel with the ripples. Laminated sand is not common. Climbing ripple structures are very rare. Flaser bedding, wavy bedding, lenticular bedding, interbedding, and interlamination of mud and sand are common bedding types in the mixed flats and in the lateral channel deposits. In mud flats there are thick mud layers with thin strips of sand. None of these bedding types is restricted to tidal flats. Salt-marsh deposits are characteristically interfused by roots and by uneven noduled lamination.

In the microstructure there is graded bedding in thin laminae, mostly less than 1 mm thick. Some beds are graded from coarse to fine, and some from fine to coarse. Small-scale erosional features are common.

The origin of these bedding types commonly is related to the alternation of tidal currents and tidal slack water. In a vertical column there are thicker sets changing in the bedding type from set to set, resulting from changes of wind and wave direction and force. Most of the layers are deposited in shallow morphological depressions as flat erosional patches (shallow runnels), but some are deposited laterally in channel deposits (point bars) and others on sheltered, gently inclined places. On the flats above the depressions and channels, overall (net) sedimentation is small because of alternating erosion and sedimentation.

Tidal flat faunas are plentiful, but only a few species are present. Most parts of the tidal-flat surface layers are strongly bioturbated by bottom-living animals. Where layers are deposited rapidly, bioturbation is not as common. This is especially true of the lateral channel deposits and the channel-bottom sediments.

In some places there are units with bottom-living invertebrates in living positions. In a few layers, fecal pellets are concentrated. Rolled algal mats develop on tidal flats in certain climates.

The most common surface-structure features on tidal flats are ripple marks, mostly of current ripples, but also symmetrical oscillation ripples. Subaerial marks are important; small runnels and erosional depressions are abundant. The flat depressions are commonly sculptured by oscillation ripples whereas the surrounding bottom is covered by current ripples. Tracks of birds and other land animals, raindrop and hail imprints, and desiccation cracks are on the surface. Groove casts also are common.

Transgressive sequence on tidal flats may develop as follows (from top to bottom): *e'*, sand (sand-flat deposits); *d'*, mixed sediment (mixed-flat deposits); *c'*, mud (mud-flat deposits); *b'*, brackish and freshwater clay; and *a'*, sphagnum peat. Regressive tidal-flat sequence, from top to bottom, consist of: *f*, peat; *e*, freshwater and brackish deposits; *d*, salt-marsh deposits; *c*, mud-flat deposits; *b*, mixed flat deposits; and *a*, sand flat deposits.

This sequence is common only if there is an abundant sediment supply. If the sediment supply is not plentiful, meandering channels rework the sediments and the thick channel sediments directly overlie the transgressive sequence. Even where channels are developed, a regressive sequence sand, mixed sediments, mud, and salt-marsh deposits can develop, though they are deeply dissected by runnels and channels. In many examples of fossil and recent tidal flats, the sequences given here may not be fully developed.

Seaward from tidal flats, and parallel with the coast, sandbars or barrier islands may develop. The landward side of the tidal flats is the line where land soils develop by older sediments are exposed.

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SEDIMENT CONTROL OF FAUNAL DISTRIBUTION PATTERNS IN LATE CRETACEOUS MARGINAL MARINE DEPOSITS OF SOUTH DAKOTA

The recessional history of the Late Cretaceous sea in northwest-central South Dakota is recorded in the offlap 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 ($<5^\circ$) 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-

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