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Jurassic aeolian oolite on a palaeohigh in the Sundance Sea, Bighorn Basin, Wyoming

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ABSTRACT

Aeolian limestones are widespread in the Quaternary record and have been identified in outcrops and cores of late Palaeozoic strata. These rocks have been interpreted as a low latitude signal of glacio-eustatic sea level fluctuations and have not been previously reported from the Mesozoic or from other episodes of earth history generally believed to have been non-glacial. Numerous lenticular bodies of cross-stratified oolite lie near the contact between the lower and upper members of the mudstone-dominated lower Sundance Formation (Middle and Upper Jurassic) in the Bighorn Basin of north-central Wyoming, USA. The lenses, up to 12 m thick, contain sedimentary structures diagnostic of aeolian deposition. Inversely graded laminae within thick sets of cross-strata were deposited by climbing wind ripples. Adhesion structures and evenly dispersed lag granules are present in flat-bedded strata at the bases of several of the oolite bodies. Thin sections reveal abundant intergranular micrite of vadose origin. The lenses appear to represent virtually intact, isolated aeolian bedforms that migrated across a nearly sand-free deflation surface. When the Sundance Sea transgressed the dunes, a thin (<1 m thick), wave-rippled, oolite veneer formed on the upper surface of the aeolianite. Previous workers, primarily on the basis of sedimentary structures in the veneer, interpreted the oolite lenses as tidal sand bodies.

The dunes provide clear evidence of widespread subaerial exposure on the crest and north flank of the Sheridan Arch. This structural high was delineated by previous workers who demonstrated thinning of pre-upper-Sundance Formation strata and localized development of ooid shoals. Ooids that formed in shoals on the windward (southern) side of the palaeohigh were exposed and deflated during lowstand. Thin, scour-filling ooid grainstone lenses that crop out in the southern part of the study area represent remnants of the marine beds that sourced the aeolianites. Farther north (down-wind), oolitic dunes prograded over thinly laminated lagoonal silts. When relative sea level began to rise, the uncemented dunes were buried under fine-grained marine sediment as the lee side of a low-relief island was inundated.

INTRODUCTION

Although coastal dune ridges predominately composed of calcium carbonate are widespread at low latitudes, pre-Quaternary aeolian limestones were unknown from the rock record until very recently. Thin, laterally extensive aeolian limestones are now known from the Pennsylvanian of the southern Colorado Plateau (Loope & Haverland, 1988; Rice & Loope, 1991) and the Mississippian of Indiana and Kansas (Hunter, 1989, 1993; Handford, 1990). These studies affirmed the prediction by Fairbridge & Johnson (1978) that aeolian carbonates would be found within ancient strata deposited during periods of rapid, high-amplitude, glacio-eustatic sea level fluctuations.

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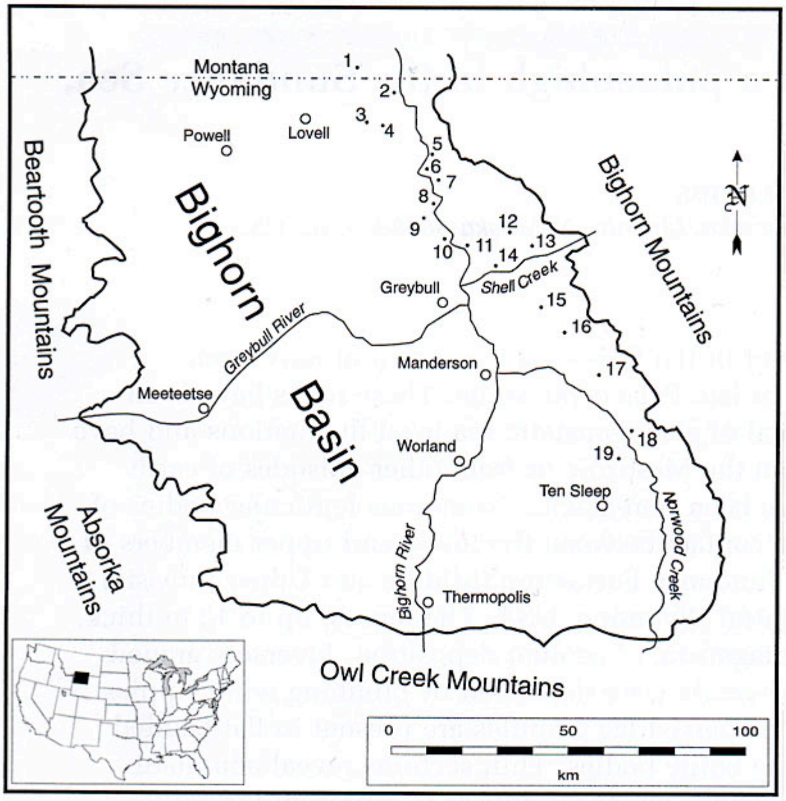

Fig. 1. Map of the study area with locations of measured sections.

In this paper, we describe the first aeolian limestones to be identified within Mesozoic strata. Like the Palaeozoic aeolianites, these Jurassic dunes are not part of a progradational wedge, but were derived from subtidal sediments that became subaerially exposed upon relative sea level fall. Unlike their Palaeozoic counterparts, the Jurassic aeolian strata described here are not laterally extensive; they are limited to a small area near the crest of a structural high. Although cross-bedded oolite is a common Jurassic facies (Hallam, 1975), we have so far failed to find aeolian structures in other Jurassic limestones. Aeolian oolite bodies in the Sundance Formation show that glacio-eustatic sea level fluctuations are not required for deposition and preservation of aeolian carbonates and that nearly intact, uncemented aeolian dunes can be preserved on the lee side of structurally high islands.

GEOGRAPHICAL AND STRATIGRAPHIC SETTING

The rocks we have studied crop out along the eastern margin of the Bighorn Basin of north-central Wyoming (Fig. 1) and are within the Jurassic Sundance Formation. We use the informal nomenclature developed for north-central Wyoming by Imlay (1956, 1980) and focus on the upper member of Imlay's (1956) 'lower Sundance' Formation (Fig. 2). On the basis of the presence of *Gryphaea nebrascensis*, and by stratigraphic relationships with ammonite-bearing strata in central Montana, Imlay (1956) considered the age of the lower Sundance Formation to be middle Bathonian to early Callovian. Peterson (1954a,b) recognized two different ostracode assemblages in the lower Sundance Formation rocks and suggested the presence of a palaeohigh – the Sheridan Arch (Fig. 3) – that prevented mixing of water masses west and east of the feature. Imlay (1956) demonstrated thinning of Jurassic rocks over the arch and West (1984) argued that ooid shoals preferentially developed over the crest of the structure.

Most previous studies have interpreted the contact between the upper and lower Sundance Formation in the Bighorn Basin to be unconformable. Imlay (1956; p. 591) interpreted the disconformity to represent the latter half of Callovian time and he considered chalcedony nodules within the thinly laminated limestones in the northern part of our study area to be evidence for subaerial exposure. Peterson (1954a,b) and Wright (1971) recognized differences between

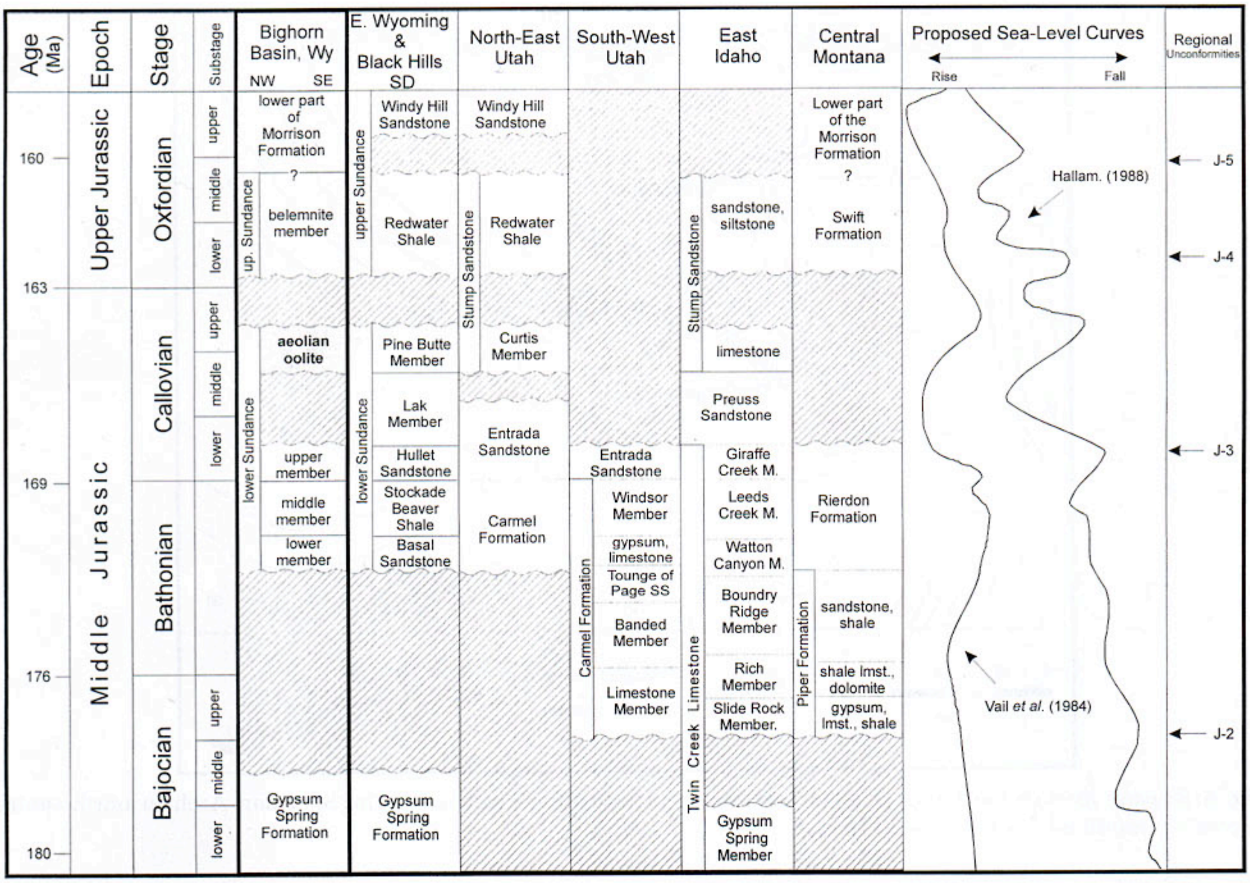

Fig. 2. Middle Jurassic stratigraphic nomenclature, correlation, and sea level curves (after Imlay, 1980; Pipiringos & O'Sullivan, 1978; Vail *et al.*, 1984; Hallam, 1988).

marine faunas in the upper and lower Sundance Formation and argued for an unconformable relationship. West (1984) placed the J-2 and J-3 unconformities (Pipiringos & O'Sullivan, 1978) at the base and the top of the lower Sundance Formation. Stone & Vondra (1972) considered the upper and lower Sundance Formations to be conformable.

The oolite bodies at the top of the lower Sundance Formation have previously been considered to be marine. Stone & Vondra (1972) concluded that the oolite bodies were deposited in a near shore, subtidal environment, representing sand waves formed under the influence of both ebb and flood currents – an environmental interpretation shared by West (1984). DeJarnette & Utgaard (1986) concluded that the upper member of the lower Sundance Formation was deposited as a series of barrier bars prograding over a back-barrier lagoon and tidal flat muds.

The middle member of the lower Sundance Formation, which underlies the rocks described here, is a massive, olive-green mudstone that contains abundant valves of the pelecypod, *Gryphaea nebrascensis*. A thin (5–10 cm) *Gryphaea*-rich lag rests at the top of this mudstone at localities 7 and 9 (Fig. 1). At the three southernmost localities, the middle member contains abundant quartz sand.

Quartzose aeolian dunes were widespread in the western United States during the middle and late Jurassic. Although the base of the lower Sundance Formation in our study area is a marine limestone, in southern Wyoming, the coeval Canyon Springs Member of the Sundance Formation is an aeolian sandstone (Blakey *et al.*, 1988). The Entrada Formation is the most widespread of the preserved late Palaeozoic and Mesozoic aeolian sandstones of the region (Kocurek & Dott, 1983). In south-western Utah, the J-3 unconformity is at the top of the Entrada Formation (Fig. 2, Imlay, 1980), in south-eastern Utah, the upper part of the Entrada underlies the J-5 (Blakey *et al.*, 1988) and is therefore approximately coeval with the aeolian oolite described here.

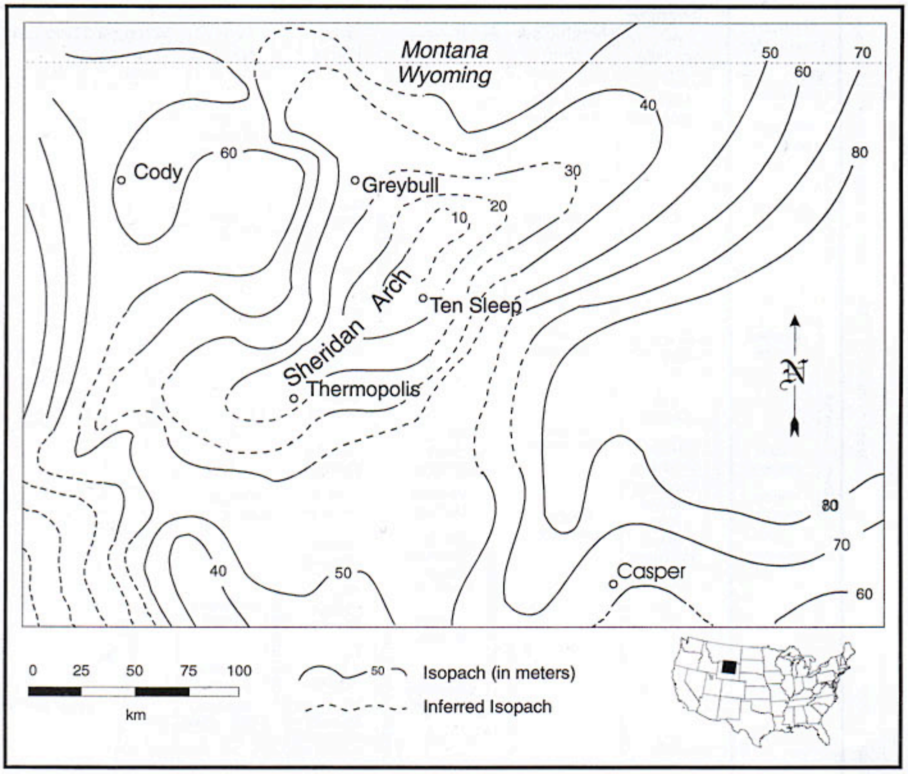

Fig. 3. Isopach map of the lower Sundance Formation, indicating presence of the Sheridan Arch in north-central Wyoming (modified from Peterson, 1954a).

DESCRIPTION AND INTERPRETATION OF FACIES

On the basis of physical sedimentary structures and petrographic features, we recognize three distinct depositional facies within the upper member of the lower Sundance Formation of our study area (Fig. 4).

Facies 1

Description

Facies 1 occurs as 2–12 m thick, discontinuous oolite bodies with flat bases and convex tops. These carbonate sand bodies can rarely be traced for more than one kilometre. Facies 1 is present only in the central part of the study area, from Stucco (Loc.10) to Little Sheep Mountain (Loc. 4, Fig. 1). Rocks of Facies 1 have sharp, erosional basal contacts with rocks of Facies 2 and 3. Where the upper surface can be observed, wave-rippled oolite of Facies 2 overlies a sharp contact. Facies 1 is cross-stratified on a large-scale, containing sets up to 12 m thick (Stone & Vondra, 1972). Some thick sets constitute the entire sand body (Fig. 5). Where sand bodies are composed of more than one set of cross-strata, the facies is trough cross-stratified with sets defined by erosional surfaces that dip about 5–10° down flow (second and/or third order bounding surfaces of Brookfield, 1977). Extensive erosional surfaces produced by scour during the migration and climb of a series of large bedforms (first-order bounding surfaces of Brookfield, 1977) are absent. The dip directions of cross-strata are highly variable and are locally bimodal (Stone & Vondra, 1972). Most of the sets dip NW, with a secondary dip toward the SW, and a few sets dip to the NE (Fig. 6). Generally, northward-dipping sets have steeper dips (20–30°) than southward dipping sets (10–15°) (Stone & Vondra, 1972).

The defining characteristic of this facies is, however, not the large scale of cross-stratification, but the ubiquitous presence of thin, laterally persistent, inverse-graded layers within the cross-strata (Fig. 7) that dip 10–15° and comprise at least 80% of this facies. In some of these layers, low-angle foresets are visible (Fig. 7). Also present within the large-scale cross-strata are thicker, steeper-dipping (25–28°), structureless beds with abrupt basal pinch-outs. Molluscan bioclasts up to 5 mm in diameter – the only particles larger

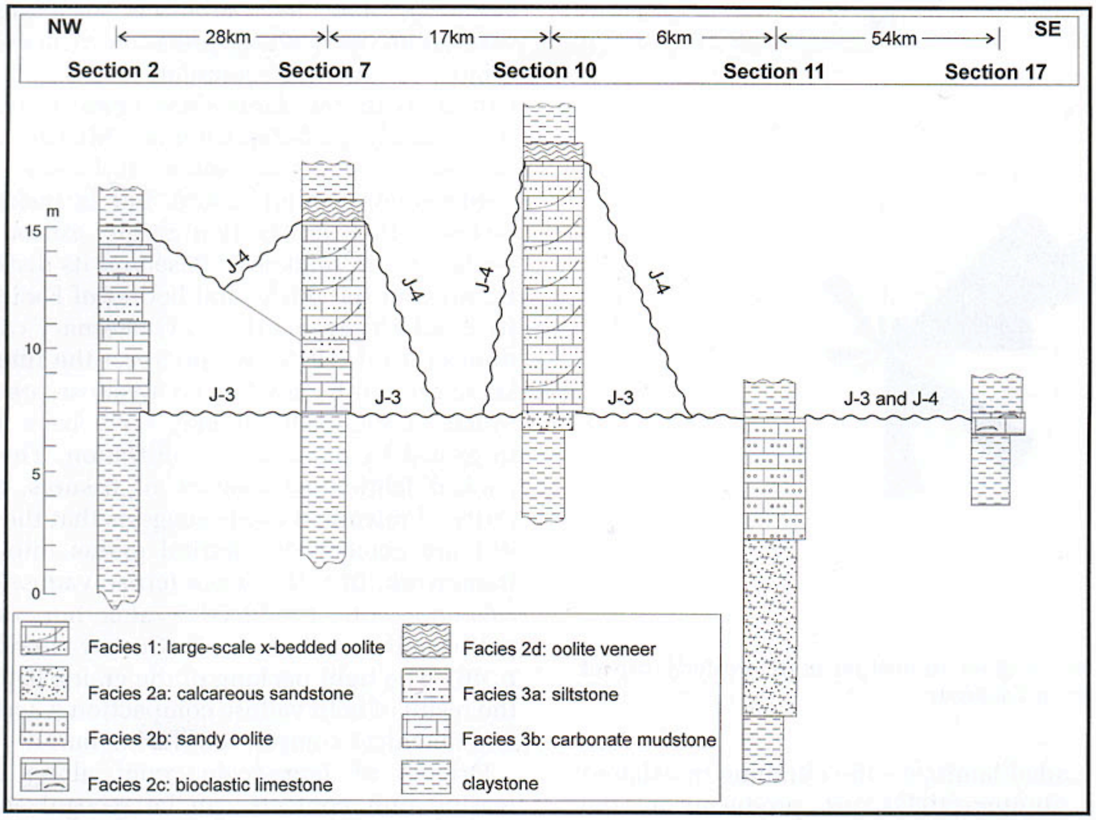

Fig. 4. Stratigraphic relationships among Facies 1–3. Sections were chosen to show the position of Facies 1 (interpreted to be aeolian) between Facies 3 (lagoonal) to the north and Facies 2 (high-energy marine) to the south. The datum (J-3) is interpreted as a deflation surface.

Fig. 5. Large scale cross-strata in Facies 1 at Locality 5 (interpreted as aeolian). Single set, about 6 m thick, is in sharp contact with underlying rocks of Facies 3 (interpreted as lagoonal).

than sand size within this facies – are equally dispersed along bounding surfaces and horizontal strata at the base of this facies at localities 8 and 10 (Fig. 8). Adhesion structures (Fig. 9) are also present at the base of the sand body at locality 8. Facies 1 contains no trace fossils.

Radial-concentric ooids of fine to medium sand size constitute about 42% of grains (Fig. 10), while abraded bioclasts – echinoderms, molluscs, and brachiopods – make up about 15%. Fine to very fine quartz grains make up about 22% of the grains (Fig. 11), and, except for those that are ooid nuclei, are typically segregated into the basal portions of individual inverse-graded laminae.

Intergranular micrite (Fig. 10) is common (16–20%) and is fairly uniformly distributed throughout the thickness of the sand bodies. Due to interpenetration of grains, the rock has a closely packed fabric.

Interpretation

Facies 1 is interpreted as aeolian, based on the following reasoning. Thin, laterally persistent,

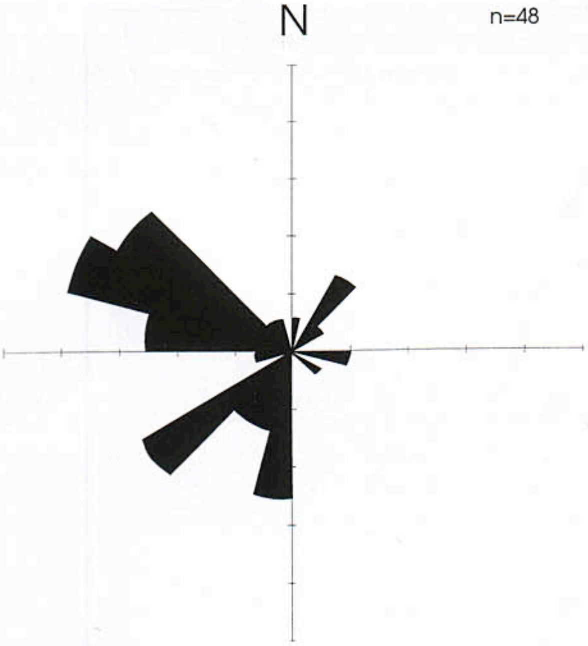

Fig. 6. Rose diagram indicating north-westerly dip of cross-strata in Facies 1.

inverse-graded laminae – the climbing translatent strata of Hunter (1977), are produced by the migration and climb of wind ripples and are the best criterion for the recognition of aeolian strata. Thicker, steeper, structureless layers are grainflow or grainfall strata (Hunter, 1977). The packing, sorting, and rounding of detrital grains of this facies are similar to those described by Dodd *et al.*, (1993) from aeolianites of Mississippian age. The granule lags (interpreted as Bagnold surfaces), and the adhesion structures also support an aeolian interpretation. A depositional origin for the intergranular micrite is incompatible with the large-scale cross-stratification; it is clearly post-depositional. Micrite cements carbonate sand in some Holocene marine hardgrounds (Shinn, 1969), but is restricted to distinct, thin crusts that rarely exceed a few decimetres in thickness. Based on its distribution throughout the thick sand bodies of Facies 1 and its similarity to micrite in Quaternary carbonate dunes (Ward, 1973), we interpret the intergranular micrite of Facies 1 to be a vadose precipitate. Much of the material may have been initially implaced by mechanical infiltration. The tightly packed fabric, the absence of fissures, and the rarity of reworked clasts suggests that the micrite did not cement the detrital grains into a rigid framework. In soil science terms, vadose diagenesis apparently produced a calcic horizon, not a petrocalcic horizon (Soil Survey Staff, 1975; p. 46). The tight packing of the grains is probably the result of both vadose compaction (Clark, 1979) and chemical compaction during burial.

Origins of large-scale relief along aeolian-marine unit contacts can be recognized as inherited, reworked, and/or erosional (Eschner & Kocurek, 1988). The lensoid nature of the sand bodies could be due to preservation of isolated bedforms (inheritance), to erosion of a laterally continuous sand body, or to a combination of these factors (reworked). Stone & Vondra (1972) interpreted the lenses as preserved bedforms. Our new observations support this view. If a laterally

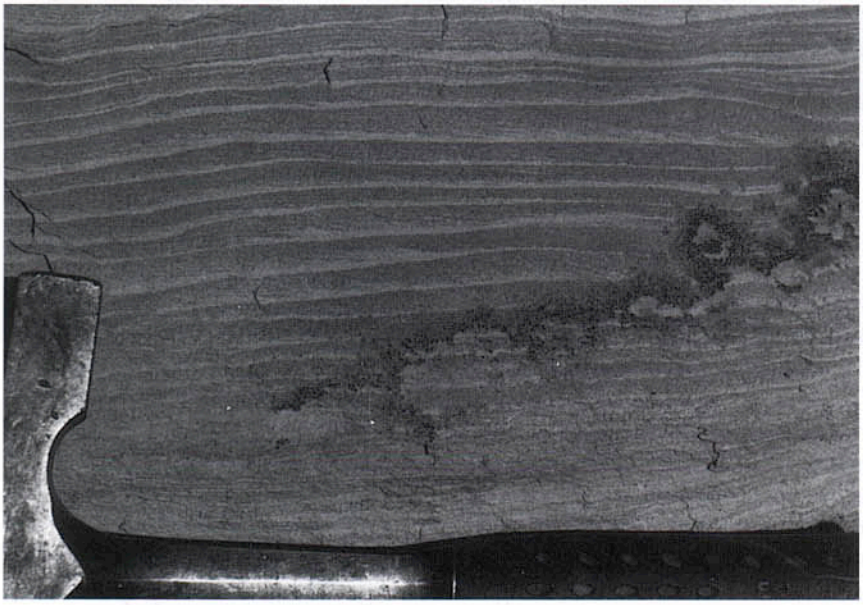

Fig. 7. Inverse-graded strata deposited by migrating wind ripples (Facies 1). Light bands are rich in quartz, and dark bands are rich in ooids and peloids. Note low-angle, faint foresets (see Kocurek & Dott, 1981; Fig. 3).

Fig. 8. Deflation lag (Bagnold surface) at base of Facies 1, Locality 10. White grains are molluscan shell fragments.

continuous body of aeolian sand had been deposited, first-order bounding surfaces – produced by the migration and climb of dunes (Wilson, 1971; Brookfield, 1977; Kocurek & Havholm, 1994) – should be present within any erosional remnants. First-order bounding surfaces appear to be absent from the lenses and all structures that are present could have originated within isolated, individual bedforms that migrated across a sand-poor substrate. Reworking of aeolian material by the Sundance Sea was much less extensive in the study area than it was in north-eastern Utah where Eschner & Kocurek (1986) documented mass flow deposits generated by dune collapse just above the contact between the aeolian Entrada Formation and the overlying marine Curtis Formation. The binding effect of intergranular micrite was probably a minor factor in limiting the amount of reworking in the study area; palaeogeography was probably more important (as discussed below).

Given the abundance of large rhizoliths in Quaternary and late Palaeozoic aeolian limestones (McKee & Ward, 1983; Loope, 1988), the absence of rhizoliths in Facies 1 is surprising. This, together with the absence of animal traces and correlation with the widespread erg of the Entrada Formation (Kocurek & Dott, 1983), suggests a hyperarid palaeoclimate.

The palaeowinds reflected by the dip direction of cross-strata within the rocks we interpret as aeolian do not fit well with the general atmospheric circulation patterns for the Jurassic shown by Peterson (1988). Our data are, however, similar to those reported from the coeval Moab Tongue of the Entrada Formation of eastern Utah by Poole (1962), which Peterson (1988; p. 243) considered anomalous.

Facies 2

Description

Facies 2 is divided into four subfacies (Fig. 4): calcareous sandstone (2a), sandy oolite (2b), bioclastic limestone (2c), and oolite veneer (2d). These rocks dominate the upper member of the lower Sundance Formation in outcrops south of Greybull (Fig. 1).

Calcareous sandstones of subfacies 2a are thin-bedded and well-sorted, with abundant wave ripples. Sandstones of subfacies 2a grade into sandy oolites (subfacies 2b). These two subfacies are the most extensive of Facies 2 and are present at localities 10, 11, 12, 13, 15, 16, and 18 (Figs 1, 4); at many sites between these measured sections, however, these subfacies are absent. Lenticular bodies of these subfacies reach up to 12 m in thickness and up to 1·5 km in length. These lithosomes have flat tops and concave bases (Fig. 12). Sets of cross-laminae (Fig. 13) are typically less than 5 cm thick and were deposited by current and wave ripples.

The texture, grain types, and mineralogy of facies 2b are nearly identical to those of Facies 1. Dominant allochems are radial-concentric ooids, molluscan skeletal fragments, and echinoderm ossicles. Skeletal debris is angular and not strongly abraded. Intergranular micrite similar to that found in Facies 1 constitutes up to 16% of rock volume.

Subfacies 2c is coarse-grained and crudely cross-stratified. It is composed of thin (0·3–1·0 m) beds that persist laterally for only a few metres to tens of metres, and is restricted to the southernmost localities of the study area (Locs. 14, 17, and 19; Figs 1, 4). Lithosomes of this subfacies are in sharp contact with both underlying and overlying strata. The dominant allochems are echinoderm ossicles (40% of rock volume), while syntaxial overgrowths fill most intergranular space.

Subfacies 2d is the most geographically restricted of the subfacies of Facies 2; it occupies the tops of some Facies 1 oolite bodies north of Greybull. Total thickness of this subfacies never exceeds 1 m, and is usually less than 0·2 m.

Fig. 9. Adhesion structures at base of Facies 1 at Locality 5.

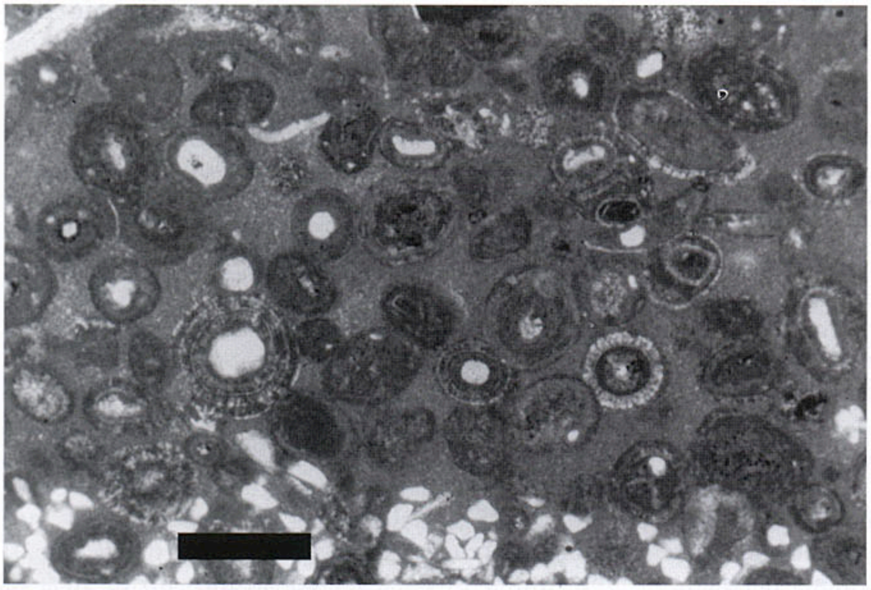

Fig. 10. Photomicrograph of Facies 1 (interpreted as aeolian). Scale bar =0·5 mm. Note segregation of quartz (white) and carbonate grains and abundance of intergranular micrite.

Straight-crested subaqueous ripples (Fig. 14) are the only sedimentary structures we have observed in these oolite veneers. Ooids are radial-concentric and are cemented by calcite spar.

Interpretation

We interpret all the subfacies of Facies 2 as products of subtidal processes operating in well-oxygenated, normal sea water. *Subfacies 2c* represents grainstone shoals developed on the crest of the Sheridan Arch. In this high-energy environment, finer particles were winnowed, leading to accumulation of coarse skeletal grains. *Subfacies 2a and 2b* were probably deposited in scours on the north-western slope of the Sheridan Arch. As in Facies 1, we interpret the intergranular micrite in *subfacies 2b* to be a vadose precipitate. The absence of intergranular micrite from subfacies 2c could be the result of syndepositional cementation, but we have found no evidence (in the form of lithoclasts, borings, or encrusting organisms) to confirm early marine cementation.

Current and wave ripples that are found across the tops of the Facies 1 sand bodies (interpreted above as aeolian) were used as evidence for a subaqueous origin of Facies 1 by Stone & Vondra (1972), West (1984), and DeJarnette & Utgaard

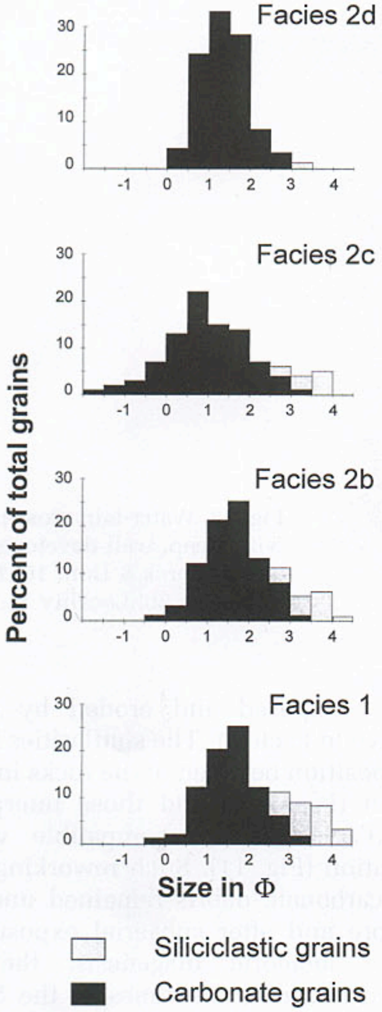

Fig. 11. Comparison showing strong similarity of mineralogy and texture of subfacies 2b, 2c, and 2d (interpreted as marine) to those of Facies 1 (interpreted as aeolian).

(1986). We interpret these thin, rippled veneers that lack intergranular micrite (subfacies 2d) to be products of minor reworking of the aeolian dunes during transgression. On the basis of a very similar rippled veneer, the Permian White Rim Sandstone of south-eastern Utah, now considered aeolian (Huntoon & Chan, 1987) was long misinterpreted as a marine deposit.

Facies 3

Description

Facies 3 is composed of silty mudstone, siltstone, and limestone and is restricted to the northern part of the study area (Fig. 4). Thinly laminated mudstone (the papery limestone of Imlay, 1956), the dominant lithology of this facies, thickens to the north-west from 0·3 m (Loc. 9) to over 4 m (Loc. 2). Facies 1 oolite bodies rest on silty mudstone at several localities (Fig. 4). Lamination is defined by interbedded silt-sized quartz and quartz-poor, pelleted micrite (Fig. 15). DeJarnette & Utgaard (1986) described fenestral fabrics (Tebbut *et al.*, 1965) from this facies and reported insects, ostracods, and abundant fossil fish on a few bedding planes in southern Montana.

Interpretation

We follow DeJarnette & Utgaard (1986) in interpreting the depositional environment of this facies as a restricted lagoon.

MODEL FOR DEPOSITION AND PRESERVATION

We suggest that the discontinuous, scour-filling, high-energy marine deposits of subfacies 2a and 2b are the preserved remnants of a once-continuous sheet of material that accumulated in a shoal near the crest of the Sheridan Arch. The oolitic sand sheets from the trade-wind belt of the south-eastern Bahamas (Wanless & Tedesco, 1993) are a modern analogue. Due to relative sea level fall, this sediment sheet then became

Fig. 12. Outcrop of sand body composed of subfacies 2a and 2b (interpreted as marine) at Loc. 8. Note concave-up basal scour (dashed line). Figure for scale.

Fig. 13. Water-lain cross-laminae with steep, well-developed foresets (see Kocurek & Dott, 1981; Fig. 3). Subfacies 2b, Locality 11.

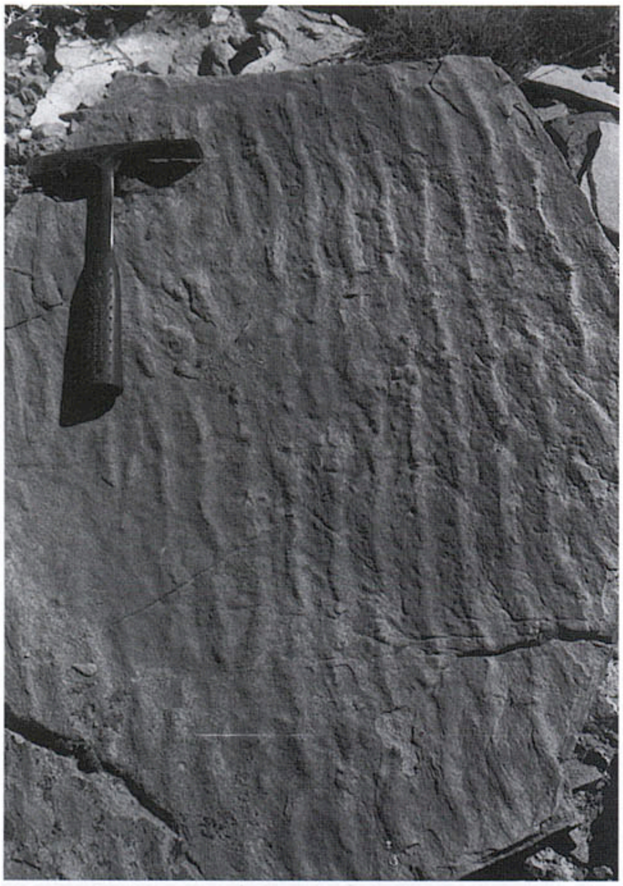

Fig. 14. Wave rippled oolite of subfacies 2d on the top of a Facies 1 sand body (interpreted as aeolian) at Locality 5. Thin veneers of such water-laid strata led previous workers to interpret entire sand bodies to be of marine origin.

subaerially exposed and eroded by southerly winds to yield Facies 1. The similarities in texture and composition between of the rocks interpreted as aeolian (Facies 1) and those interpreted as marine (Facies 2) are compatible with this interpretation (Fig. 11). Such reworking requires that the carbonate debris remained uncemented both before and after subaerial exposure. With regard to meteoric diagenesis, the calcite-dominated marine grainstones of the Sundance Formation were probably unreactive, relative to Holocene analogs. Although there is some disagreement concerning the importance of original mineralogy of carbonate to the rate of meteoric cementation (see Budd, 1994; McClain *et al.*, 1994), aragonite-rich sediments are generally believed to become lithified more rapidly than calcite-dominated sediment.

An arid palaeoclimate (as inferred from the lack of trace fossils and rhizoliths in Facies 1 and as interpreted by previous workers) also would have slowed diagenetic alteration (Ward, 1973; Quinn, 1991). It is possible that the aeolian sediments were derived from contemporaneous shorelines, the foreshore deposits of which were subsequently removed as relative sea level fell. This interpretation minimizes the time of exposure of the marine carbonates to meteoric water. The remnants of subtidal oolite sand bodies (subfacies 2b) with vadose cements, however, indicate a drop in relative sea level after their deposition. This drop could have resulted from differential subsidence of basement blocks as in the basins

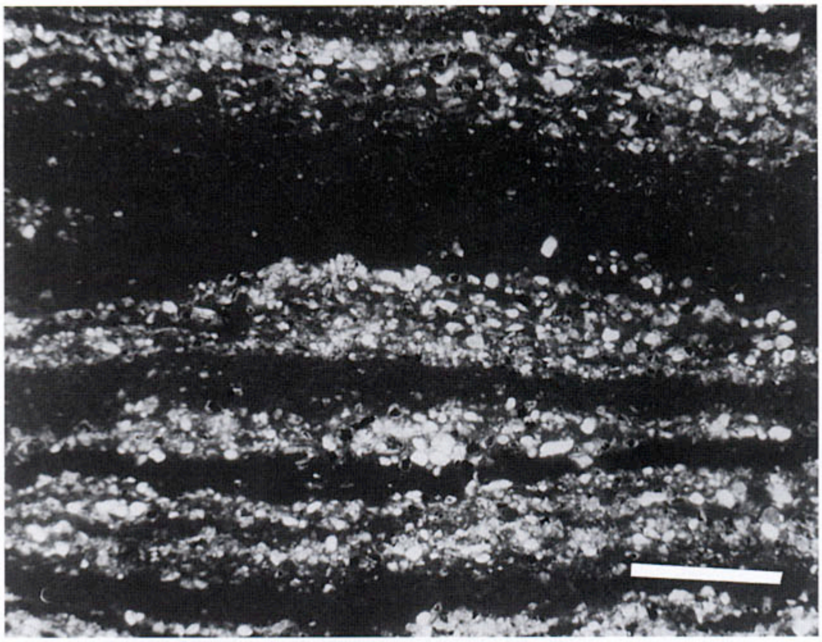

Fig. 15. Silty mudstone of Facies 3 (interpreted as lagoonal). Thin lamination is product of interbedding of quartz silt and carbonate mud. Scale bar =0·5 mm.

and swells of the Jurassic of Great Britain (Sellwood & Jenkyns, 1975) or from a eustatic sea level fall. However, the possible role of eustatic sea level fall in the development of the aeolian oolite bodies is difficult to assess. A regression that corresponds to the development of the J-3 unconformity and the top of the middle member of the lower Sundance Formation appears on Hallam's (1988) global sea level curve (Fig. 4), whereas the curve of Vail *et al.* (1984) shows continued transgression without correlation to these features.

In noting the apparent absence of aeolian limestones from the Mesozoic record, Rice & Loope (1991) speculated that the rate and amplitude of sea level fluctuations of the Mesozoic were not so conducive to deposition and preservation of these strata as were those of the late Palaeozoic and the Quaternary. Although questions concerning Mesozoic ice caps and glacio-eustasy remain open (Eyles, 1993; p. 158), there is no reason to interpret the Middle Jurassic rocks of the Bighorn Basin as a record of glacio-eustastic sea level fluctuations.

Cross-stratified oolite is a common Jurassic lithofacies (Hallam, 1975) and it is possible that other Jurassic aeolian oolites have been misinterpreted as subaqueous in origin. We have searched for wind-rippled strata within large-scale cross-bedded oolite facies in the Jurassic of southern Utah (Blakey *et al.*, 1983) and on the Cotswold Shelf in east-central England without success.

DeJarnette & Utgaard (1986) were the first to recognize a genetic relationship between the laminated mudstones in the north (our Facies 3) and the grain-supported rocks (our Facies 1 and 2) to the south. They attributed the mudstones to deposition in a lagoon that formed in the lee of contemporaneous shoals. Our aeolian interpretation of some of the grain-supported rocks does not necessitate a fundamental change in this interpretation. Rather than a shoal, we envision emergence of a broad island that would have substantially reduced the wave energy on its lee side. Subaerial exposure of carbonate material and the underlying siliciclastic muds of the underlying middle member of the lower Sundance Formation may have provided not only a source for aeolian sand (saltation population), but may also have been a source of silt-sized material (dust) that was deposited further downwind (northward, in the lagoon) to form the quartz laminae in Facies 3.

The preservation potential of uncemented oolitic dunes on a structural high would at first seem to be quite low. Based on the location of the aeolian sand bodies relative to the palaeowind directions and Peterson's (1954a) isopach map, we suggest that the dunes described here occupied the lee side of a low island in the Sundance Sea (Fig. 16). The dunes were buried by low-energy shelf deposits, rather than cut out by ravinement as the high energy shoreface on the windward side of the island migrated northward.

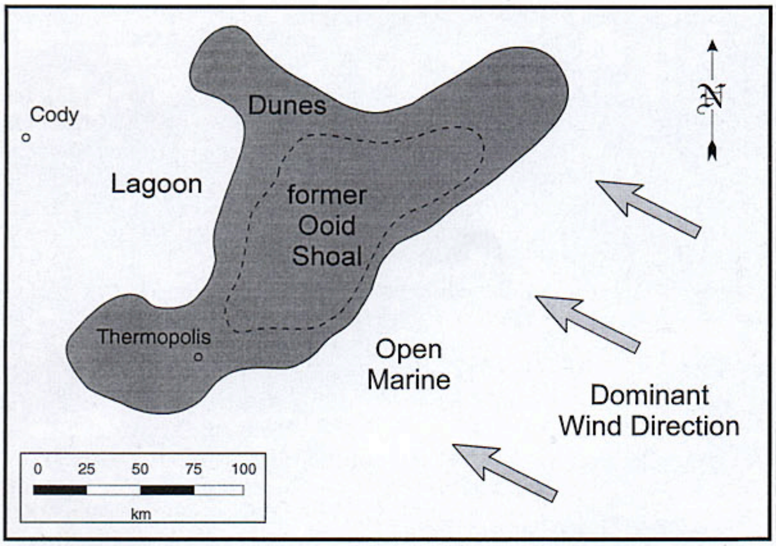

Fig. 16. Palaeogeographic reconstruction based on Peterson's (1954a) structural contour map (see Fig. 3). Ooids that formed in shallow-water shoal at crest of the Sheridan Arch (grey tone) were subaerially exposed and deflated by south-easterly winds during regression and lowstand to form aeolian oolite sand bodies of the study area. Uncemented aeolian strata were preserved beneath low-energy marine deposits during subsequent transgression.

CONCLUSIONS

1 Although previously interpreted as marine, oolitic sand bodies in the lower Sundance Formation of Wyoming's Bighorn Basin are primarily composed of inverse-graded laminae deposited by migrating wind ripples. These are the first aeolian limestones described from Mesozoic rocks. Current ripples – thought by previous workers to indicate a subaqueous origin for the sand bodies – are restricted to the upper surfaces of the sand bodies and developed after marine inundation of the dune field.

2 The isolated sand bodies lack first-order bounding surfaces and probably represent individual bedforms that migrated across a nearly sand-free surface.

3 Marine oolitic grainstones with textures and vadose cements nearly identical to those of the aeolianites are locally preserved upwind (southeastward) from the aeolianites, suggesting that the dunes were generated by deflation of uncemented subtidal deposits during a fall of relative sea level.

4 Thinly laminated rocks of lagoonal origin directly under- and overlie aeolian sand bodies, suggesting that low-energy conditions were dominant on the lee side of a broadly emergent island in the Sundance Sea. This leeward position allowed preservation of uncemented aeolian sands on the flank of a structural high as dunes were flooded during sea level rise.

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