

9

Primary Features of Marine Sedimentary Rocks ■

9-1. Beds and Bedding

Sections 9-1 through 9-6 describe sedimentary structures, many of which may be either marine or nonmarine. The remainder of the chapter presents structures and rock associations typical of certain marine environments, and Chapter 10 describes associations in nonmarine environments. The descriptions are brief and might well be supplemented by other sources, such as the exceptionally clear introductory book by Leeder (1982) or the more specific ones by Reineck and Singh (1980), Harms and others (1982), Scholle and Spearing (1982), and Scholle, Bebout, and Moore (1983).

The basic structure in all environments is the sedimentary bed (*stratum*), which is a distinct layer of sediment or rock that may differ in a variety of ways from overlying and underlying layers. Genetically, the base of a bed represents an abrupt change in depositional conditions or sediment supply; the bed represents more or less uniform conditions; and the top represents another abrupt change. The changes may include a period of erosion or a pause in deposition, and thus some bed surfaces are minor unconformities or omission surfaces (Section 9-6). When erosion surfaces between beds of closely similar materials are so faint that the composite unit looks like a single bed, the beds are said to be amalgamated. For example, a dense turbidity current might sweep away all but the basal sand division of a preceding turbidity-current deposit, so that two sand beds become amalgamated into a single thick unit. Amalgamated deposits should be considered as separate beds, no matter how obscure their internal contacts may be.

Beds are studied and described according to (1) how they differ from adjoining beds (by grain size, fabric, composition, or primary color); (2) their shape (Fig. 9-1); (3) their thickness (actual thickness is most useful); (4) their lateral extent, noting the degree to which it can be determined; (5) their

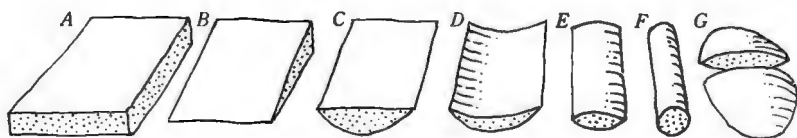


Fig. 9-1. Some bed shapes: A, tablet; B, wedge; C, trough; D, lunate trough; E, lenticular spar; F, cylinder; and G, lens.

internal structures; and (6) the nature of their contacts with adjacent beds. The most common internal structure, lamination, consists of layering within beds. In cross-bedding (cross-stratification), the laminations are oblique to the bed containing them, a common relation in current-deposited sediments. Cross-bedding is described according to the overall geometry of the cross-bedded units, the shape of the inclined surfaces, and the angles they make with the top and bottom of the bed (Fig. 9-2).

Grading in beds may be by grain size or by composition, and often is noticeable due to a color gradation. Some size-graded beds have a matrix of fine sediment throughout and some consist of relatively well-sorted coarse and fine materials. Size grading is normally from coarser up to finer sizes, but may be inverse, complex, or inconsistent.

Similar beds may be grouped in bedsets (Campbell, 1967), and specific kinds of beds or bedsets may be repeated cyclically, as ABCABC***, or rhythmically, as ABCBABC***. Cycles of beds that become broadly coarser grained upward or finer grained upward are of particular value in interpreting cyclic changes in the energy of transporting currents. Beds in coarsening-upward and fining-upward cycles tend also to thicken upward and thin upward, respectively; however, cycles based solely on changes in thickness may be due to other causes, such as variation in sediment supply.

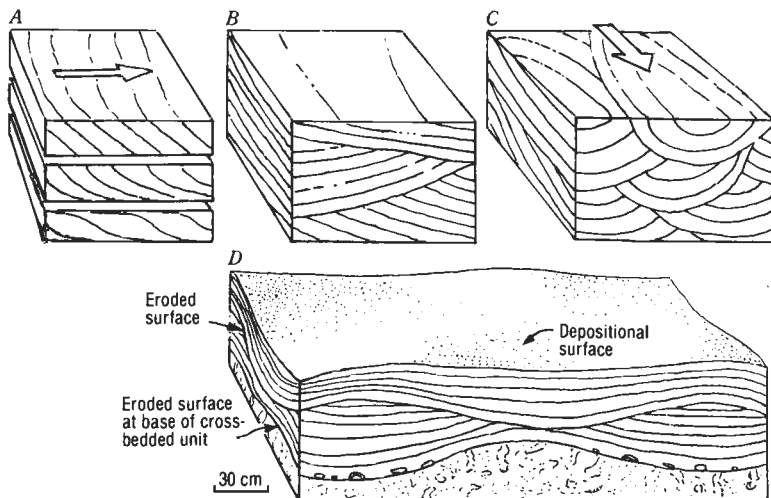


Fig. 9-2. Cross-bedding, with arrows indicating current direction where appropriate. A. Three tabular sets with (from top) angular, parabolic, and sinusoidal cross-lamination. B. Wedge sets indicating variable current direction. C. Trough sets or festoon cross-bedding. D. Hummocky cross-bedding, thought to be formed by storm waves on the lower shoreface (Hunter and Clifton, 1982).

In addition to their genetic value, specific kinds of cycles may be used to identify formations or stratigraphic tops of beds in areas of complex structure. A number of kinds of cycles and rhythms are described in this chapter, and Einsele and Seilacher (1982) have presented additional kinds.

Bedding differs from beds in being the general aspect of bedded rocks, as might be shown by a succession of beds in a large exposure, by lamination in a single bed, or by the grain fabric within a small sample (Fig. 9-3). Cross-bedding has already been described.

9-2. Depositional Bed Forms and Structures

These features vary with the nature of the transporting current and with the concentration and texture of the sediment. Currents that transport sediment can be classified into two categories, one being *fluid gravity currents*, which are generated by gravity acting on a fluid. Rivers and tidal currents are examples. *Sediment gravity currents*, the other category, are generated by gravity acting on a mass of suspended sediment that entrains intergranular fluid. Turbidity currents and debris flows are the best known of this category, which also includes fluidized sediment flows, liquefied sediment flows, and grain flows. The mechanics of sediment gravity flows have been reviewed by Lowe (1982), and deposition from fluid gravity currents has been described by Harms and others (1982).

Fluid gravity currents deposit sediment mainly from the traction load (grains that slide, roll, or skip along the bed). The sediment is cast into bed forms that vary in size and shape with the depth and power of the current and the grain size of the sediment. Where the forms are not preserved on the upper surface of a bed, they can often be identified by the bed's internal lamination and fabric.

At low velocities (as between 20 and 40 cm/sec, averaged through the lower 35 cm of a stream), silt and sand finer than 0.6 mm are deposited as *current ripples*, which migrate slowly downstream as grains are deposited on their steeper downstream slopes, finally constructing thin cross-laminated beds (Fig. 9-4A,B). When the sediment supply is moderate, the

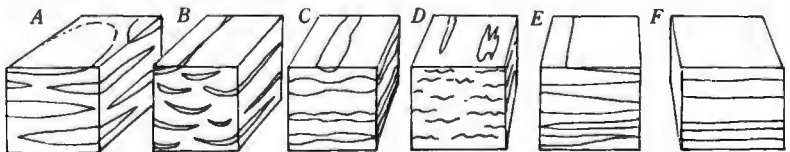


Fig. 9-3. Bedding patterns: A, lenticular; B, trough-flaser; C, linear pinch and swell; D, wavy discontinuous; E, nonparallel planar; and F, parallel planar.

beds dip at low angles upstream, and these angles increase as the sediment supply increases, such that steeply *climbing ripples* are produced when sediment is deposited over the entire ripple bedform (Fig. 9-4D). Oscillating bottom-currents produced by waves commonly cast sediment into *oscillation ripples*, which are symmetrical if waves are acting alone and asymmetrical if a unidirectional current is superimposed. Oscillation ripples can be distinguished from current ripples by straighter crests that branch here and there (Fig. 9-4C).

At moderate current velocities (up to about 90 cm/sec averaged through the lower 35 cm of a stream), current ripples coalesce and grow, and sediment coarser than about 0.2 mm is cast into larger forms called *dunes*, *megaripples*, or *large ripples*. Dunes may initially be ridges transverse to the current but generally change at higher velocities to mounds or cusped forms with the internal structure of festoon cross-bedding (Fig. 9-5A). As velocity increases, the dunes become lower and spaced farther apart, and at high velocities (as at 120 cm/sec averaged through the lower 15-20 cm of a stream) the bed becomes planar. Deposited sand is laminated parallel to the plane bed, and the upper surface is commonly lined with thin stripes of grains aligned parallel to the current. At higher velocities the bed may be cast into a series of low sand waves called *antidunes*, some of which migrate slowly upstream as sand is deposited on their upstream slopes and others remain stationary or migrate downstream. The laminations are occasionally disturbed by the shear of the swift current (Fig. 9-5B).

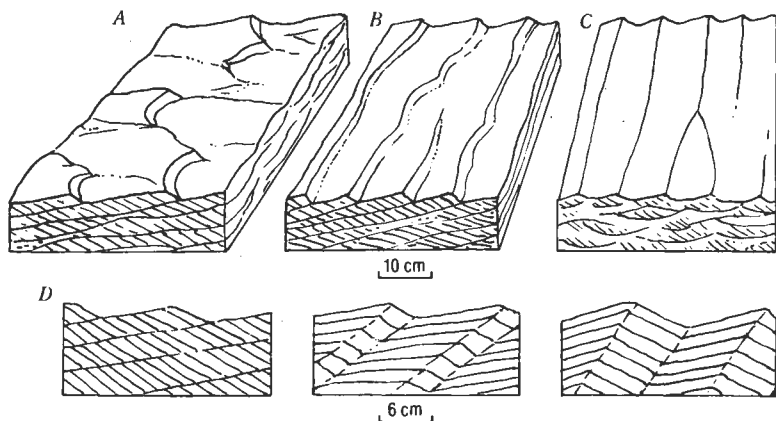


Fig. 9-4. Ripple structures, all from currents flowing toward the right: A, linguoid current ripples; B, transverse current ripples; C, oscillation (wave) ripples affected by a superimposed current; D, sections through ripple-drift beds, with angle of climb increasing to the right.

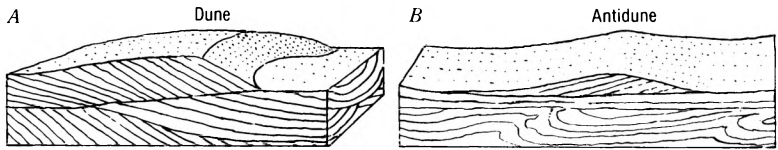


Fig. 9-5. A. Dune formed by flow from left to right. B. Antidune with cross-bedding indicating migration upstream, lying on planar and convoluted laminations.

Bed forms in sediment coarser than about 0.6 mm are exceptions to this progression, in that a planar bed rather than ripples forms at low current velocities, and antidunes may form before a plane bed at high velocities (Harms and others, 1982). Bed forms in associated finer sediments must thus be used to distinguish between low-velocity and high-velocity planar bedding in coarse sandstone.

Turbidity currents keep sediment suspended by turbulence and by additional dispersive mechanisms in their lower, denser parts. Beds are deposited in successive stages, generally giving a broadly graded layer consisting of

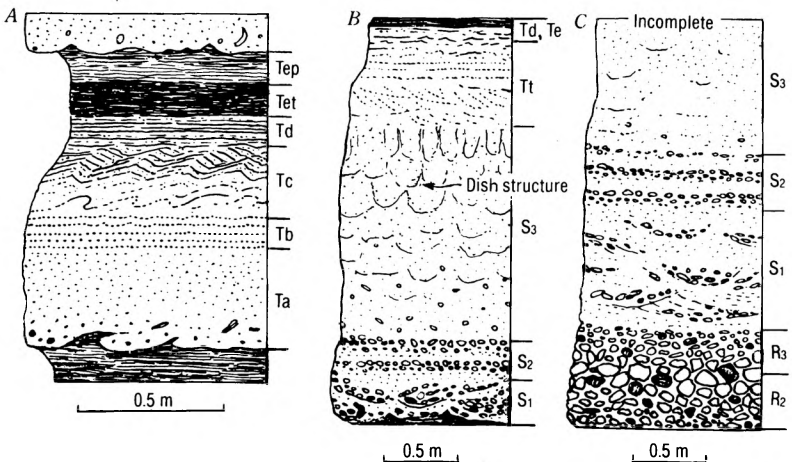


Fig. 9-6. A. Section through an idealized deposit of a sand-rich turbidity current, with divisions lettered as by Bouma (1962). B. Idealized deposit of a high-density turbidity current that carried abundant sand and pebbles. Division S_1 was deposited in traction; S_2 was transported as a coherent traction carpet; and S_3 was deposited from suspension. Tt is a traction-laminated division that commonly includes Tc and Tb of the Bouma sequence as well as a basal division with large-scale cross-bedding. C. Deposit of a high-density turbidity current that carried abundant sand, pebbles, and cobbles. Division R_2 was a traction carpet and R_3 was deposited from suspension. B and C are after Lowe (1982), ©The Society of Economic Paleontologists and Mineralogists, copied with permission.

divisions that may be obvious or may require close examination. The relatively coarse divisions (as *Ta* in Fig. 9-6A) are absent from deposits formed from low-density turbidity currents, and the coarse divisions formed from high-density currents vary with the range of grain sizes being transported. These coarse divisions are not completely understood, but the classification proposed by Lowe (1982) provides a basis for analysis and comparisons. Briefly, and for idealized cases, high-density flows carrying sediment finer than about 0.5 mm deposit the *Ta* division by rapid settling of large amounts of sand. The deposit may be normally size-graded and is unlaminated because it is not reworked in traction. If the sand is fairly well-sized, upward escape of intergranular water may redistribute fine sediment so as to form *elutriation pillars* and *dish structures* (Fig. 9-7).

In contrast, high-density flows carrying abundant coarse sand and fine pebbles may form coarse basal deposits in three stages: (1) settling of sand and pebbles that are reworked in traction, forming cross-bedding and cut-and-fill structures (division S_1 in Fig. 9-6B); (2) rapid settling of a carpet of sand and pebbles, which is swept along bodily beneath the main current and becomes reverse size-sorted due to intergrain collisions and the buoyant effects of fine sediment (division S_2 in Fig. 9-6B); and (3) rapid settling of a thick layer of sand that may develop water-escape structures as already described (division S_3 in Fig. 9-6B). More than one size-graded layer (as in S_2 of Fig. 9-6B) may result if the current surges (undergoes an increase in velocity).

Finally, high-density flows containing abundant cobbles as well as smaller grains generally deposit the cobbles in a basal sandy conglomerate. Deposition of this conglomerate may start with a traction-worked (cross-bedded or imbricated) division, but more commonly the first division is deposited bodily

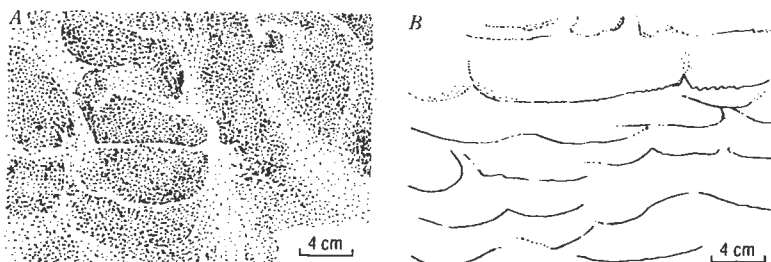


Fig. 9-7. A. Vertical sections through elutriation pillars (light-toned) and adjacent dish structures, in dark sandstone. B. Vertical section through dish structures in light sandstone. From photographs by Wentworth (1966). Dish structures tend to become narrower and taller in the upper parts of thick beds, as indicated diagrammatically in Fig. 9-6B.