Invariable and Variable Bedforms and Cross-Bedding

In contrast to the dispersion in cross-bed dip directions that is caused by bedform three-dimensionality, bedform variability causes dispersion in inclination of bounding surfaces (Fig. 1). Where variable bedforms are two-dimensional, bounding-surface dips are dispersed in inclination but not in direction; where variable bedforms are three-dimensional, bounding-surface dips are dispersed in both inclination and direction.

Variability of bedforms arises from two kinds of processes: flow changes that cause bedforms to change in morphology or behavior, and bedform interactions that cause bedforms to change, even in steady flows. Processes that can cause variability even in steady flows include relatively random processes, such as splitting and merging of individual bedforms (Allen, 1973), and more systematic processes such as superpositioning of one set of bedforms on another (Rubin, 1987). Although distinguishing the deposits of variable and invariable bedforms is relatively simple, distinguishing variability produced by flow fluctuations from variability produced by superimposed bedforms is a difficult problem that has been the subject of many previous studies (McCabe and Jones, 1977; Hunter and Rubin, 1983; Terwindt and Brouwer, 1986; Rubin, 1987).

Fluctuating flow and superimposed bedforms can be expected to produce recognizably different kinds of structures because the effects of flow fluctuations are more widespread than the effects of bedform superpositioning. For example, changes in flow commonly cause entire trains of bedforms simultaneously to change in angle of climb (Figs. 13 and 14), or cause individual bedforms to change in profile for great along-crest distances. The foresets produced by such processes will extend for long distances along strike. In contrast, the effect of superimposed bedforms is more localized. For example, superimposed bedforms might not extend across the entire length of a main bedform or may arrive at different parts of the crestline of the main bedform at different times (Figs. 46, 65-67, and 72-74). These more localized processes deposit foresets with more limited along-crest extent, and the foresets deposited by superimposed bedforms commonly dip in a different direction from the bounding surfaces, as illustrated in many of the computer simulations.

Flow fluctuations can be either random or cyclic. Cyclic flow fluctuations can produce cyclic foresets by causing cyclic fluctuations in bedform size (Figs. 15-17), cyclic fluctuations in bedform asymmetry or migration speed (Figs. 18-24, 29, 58, 67, and 77), or cyclic avalanching processes (Hunter, 1985). Any of these fluctuations in flow can produce annual cycles of eolian foresets (Stokes, 1964; Hunter and Rubin, 1983) and can also produce tidal cross-bedding with a double cyclicity (neap-spring and ebb-flood), as described by Boersma (1969) and Terwindt (1981). Cyclic cross-bedding can be produced even in steady flows by superimposed bedforms that transport sediment in cyclic pulses across the main bedform crest or along the lee slope (McCabe and Jones, 1977; Hunter and Rubin, 1983; Rubin, 1987).

Some of the computer-generated bedforms are perfectly straight-crested and have superimposed bedforms that exactly parallel the main bedforms (Figs. 25 and 27); such bedform assemblages produce structures that are virtually indistinguishable from those produced by fluctuating flow. In the real world—or in more realistic simulations, such as those shown in Figures 65 and 66superimposed bedforms do not exactly parallel the main bedforms for long distances along-crest, and the deposits of superimposed bedforms are more readily recognized. In real deposits, the distinction between fluctuating-flow compound cross-bedding and superimposed-bedform compound cross-bedding can also be based on nongeometric characteristics of the bedding. For example, fluctuating-flow cross-bedding may contain mud drapes, indicating sediment fallout during intervals of low-velocity flow. Similarly, reversals in migration direction of superimposed bedforms are direct indicators of flow reversals.