dard deviation (Fig. 3-7), is poorest at the plunge point and over the offshore bar since at those locations the sediment consists of mixtures of the two modes, medium sand and granules, and this mixing increases the overall range of sizes. Elsewhere the medium-sand mode exists alone, so the sorting is correspondingly better.

Similar distributions of mean grain sizes across beach profiles have been found by other investigations, including studies of gravel and cobble beaches (Krumbein and Griffith, 1938) and of beaches where tides are important (Bascom, 1951; Inman, 1953; Miller and Zeigler, 1958, 1964; Birkemeier et al., 1985). Figure 3-8 shows grain-size distributions of samples collected at intervals across the beach profile at the Field Research Facility, Duck, North Carolina. Wide ranges of sizes are present, with many of the individual samples being multimodal. Otherwise, the pattern of changing sizes across the profile is much like that seen in Figure 3-7 for the Lake Michigan beach. The coarsest grain sizes are found in the swash zone at and above mean sea level, with a tendency for decreasing grain sizes up the beach face in the landward direction and also toward the offshore.

Miller and Zeigler (1964) studied an area of irregular bottom topography with transverse spit-like bars extending out from the shore at the tip of Cape Cod, Massachusetts. In spite of the irregularity in morphology, there was a fairly regular trend of median sediment sizes, with the coarsest material being in the breaker zone and finer sediments both shoreward and in the offshore. There was some rhythmic longshore periodicity in the median grain sizes, but the presence of the shore-attached bars was not reflected in the cross-shore change in grain sizes. On California beaches, Bascom (1951) found the coarsest mean grain size at the plunge point of breaking waves and also found coarse material on the exposed summer berm. He hypothesized that the coarse berm deposit represented material carried up and over the berm crest by maximum wave uprush. Alternatively, in some cases it may represent a lag
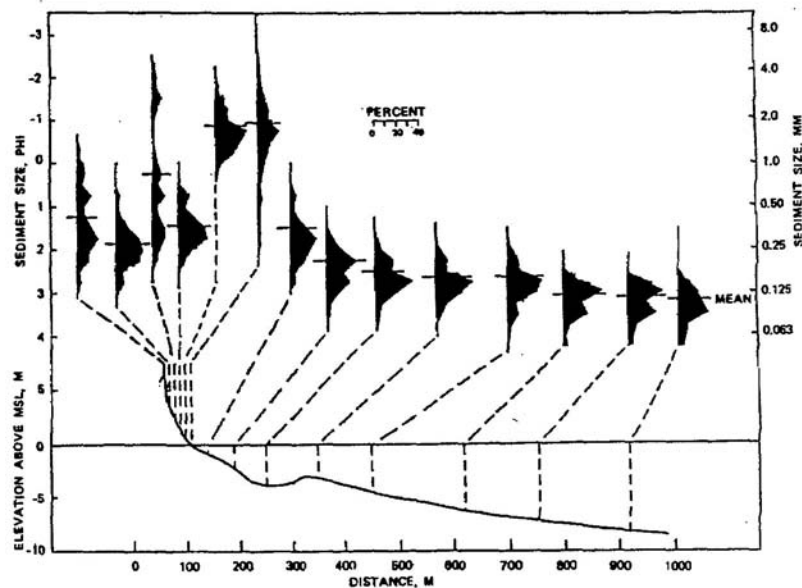

Figure 3-8 Grain-size distribution of samples collected across a beach profile at the Field Research Facility of the U.S. Army Corps of Engineers, Duck, North Carolina. [From W. A. Birkemeier et al., *A User's Guide to the Coastal Engineering Research Center's (CERC's) Field Research Facility*, 1985, U.S. Army Corps of Engineers.]
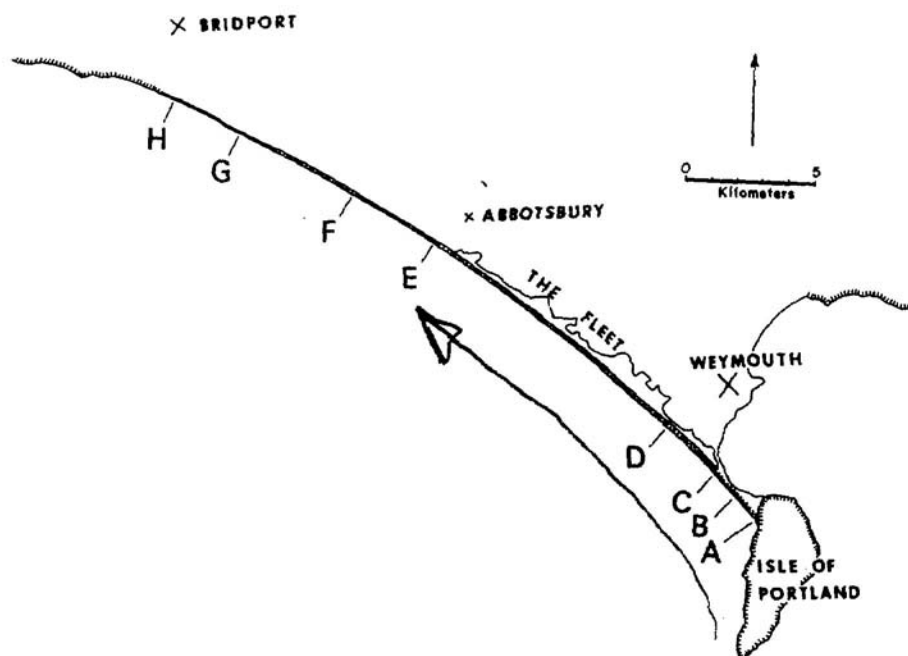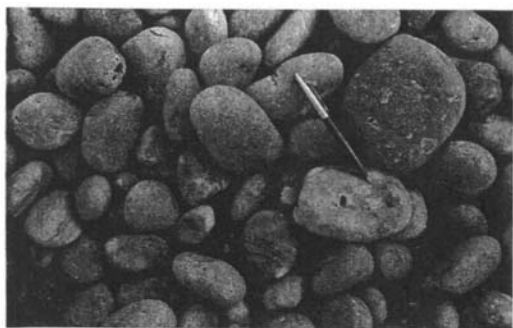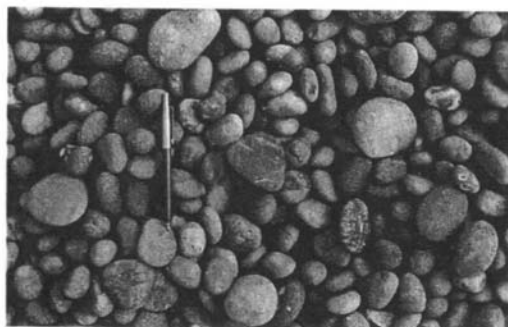
Figure 3-9 Longshore sorting of beach sediments along the length of Chesil Beach, Dorset, England. The map gives locations of the sediments shown in the series of photographs, ranging from cobbles (A) to the east to pea-size gravel mixed with sand (H) in the west.

increases to 0.65 mm at the exposed south end. There is some evidence that variations in wave energies along the length of Chesil Beach might similarly be a factor in producing grain-size changes. King (1972, pp. 308–311) appears to support this hypothesis, based on the fact that the coarsest material is found where the local offshore slope is the steepest. The reasoning is that the steeper offshore slopes allow more of the initial wave energy to be concentrated on the beach. Wave measurements obtained by Hardcastle and King (1972) from the beach opposite Wyke Regis and West Bexington, a span of about three-quarters of the total length of the beach, yielded average wave heights that were a factor 1.1 larger at Wyke Regis at the east end near Portland. On the other hand, Carr (1971) reported that their wave measurements showed no evidence of wave-height variations along the length of the beach. It is questionable, therefore, whether longshore variations in the wave energy along Chesil Beach are sufficient to account for the observed grain-size sorting, even though this does offer a satisfactory explanation at other coastal sites.
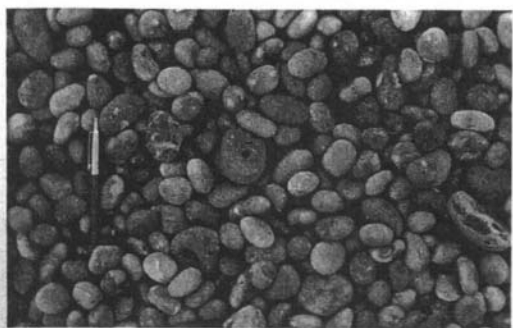
Lewis (1938) explained the sorting along Chesil Beach in terms of different wave energies reaching the beach from various directions. The beach is approximately perpendicular to the approach of the dominant waves of high energy from the southwest. The next largest waves come from the west or southwest and would move pebbles of all sizes to the east toward Portland where they would be blocked. Smaller waves generated in the English Channel arrive from the south to southeast, and according to Lewis would be capable of moving only the smaller shingle westward. A long-term interplay between larger waves from the west and
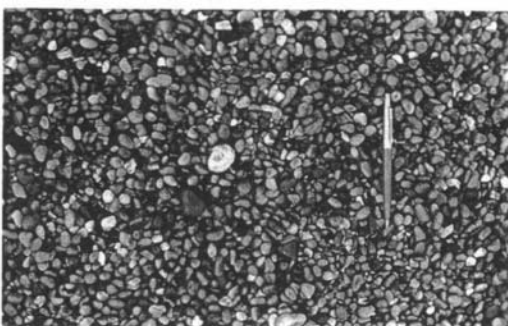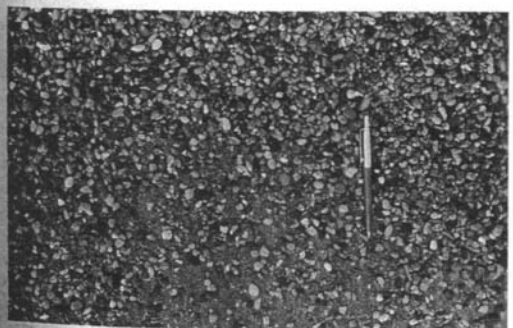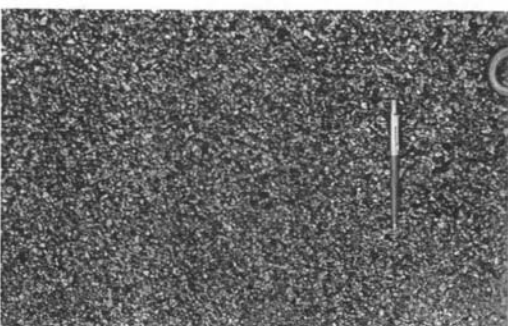
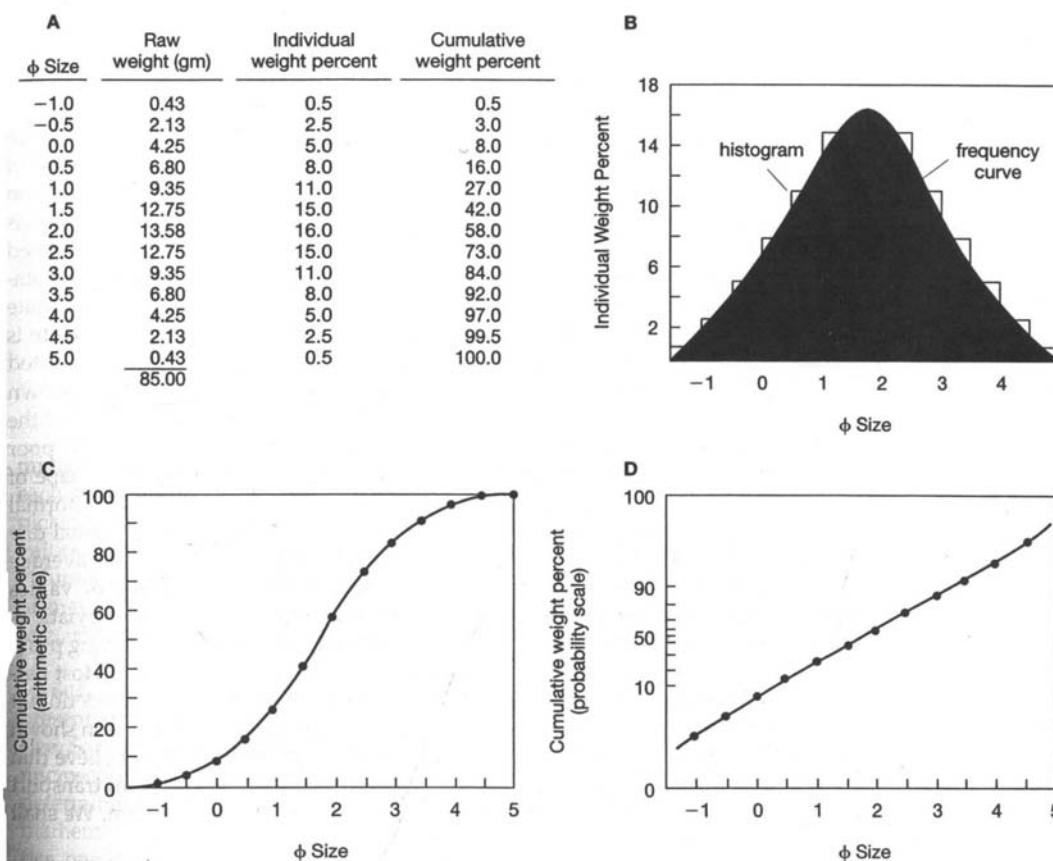**Figure 3-9** (*Continued*)

A

φ Size	Raw weight (gm)	Individual weight percent	Cumulative weight percent
−1.0	0.43	0.5	0.5
−0.5	2.13	2.5	3.0
0.0	4.25	5.0	8.0
0.5	6.80	8.0	16.0
1.0	9.35	11.0	27.0
1.5	12.75	15.0	42.0
2.0	13.58	16.0	58.0
2.5	12.75	15.0	73.0
3.0	9.35	11.0	84.0
3.5	6.80	8.0	92.0
4.0	4.25	5.0	97.0
4.5	2.13	2.5	99.5
5.0	0.43	0.5	100.0
	85.00		

B

C

D

FIGURE 3.3
Common visual methods of displaying grain-size data. A. Grain-size data table.
B. Histogram and frequency curve plotted from data in A. C. Cumulative curve with an arithmetic ordinate scale. D. Cumulative curve with a probability ordinate scale.

Raw sieve weights are first converted to individual weight percents by dividing the weight in each size class by the total weight. Cumulative weight percent may be calculated by adding the weight of each succeeding size class to the total of the preceding classes. Figure 3.3B shows how individual weight percent can be plotted as a function of grain size to yield a grain-size **histogram**—a bar diagram in which grain size is plotted along the abscissa of the graph and individual weight percent along the ordinate. Histograms provide a quick, easy pictorial method for representing grain-size distributions because the approximate average grain size and the sorting—the spread of grain-size values around the average size—can be seen at a glance. Histograms have limited application, however, because the shape of the histogram is affected by the sieve interval used. Also, they cannot be used to obtain mathematical values for statistical calculations.

A **frequency curve** (Figure 3.3B) is essentially a histogram in which a smooth curve takes the place of a discontinuous bar graph. Connecting the midpoints of each size class in a histogram with a smooth curve gives the approximate shape of the frequency curve. A frequency curve constructed in this manner does not, however, accurately fix the position of the highest point on the curve; this point is important for determining the modal size, to be described. A grain-size histogram

Application and Importance of Grain-size Data

Grain size is a fundamental physical property of sedimentary rocks and, as such, is a useful descriptive property. Because grain size affects the related derived properties of porosity and permeability, the grain size of potential reservoir rocks is of considerable interest to petroleum geologists and hydrologists. Grain-size data are used in a variety of other ways (summarized by Syvitski, 1991):

1. To interpret coastal stratigraphy and sea-level fluctuations
2. To trace glacial sediment transport and the cycling of glacial sediments from land to sea
3. By marine geochemists to understand the fluxes, cycles, budgets, sources, and sinks of chemical elements in nature
4. To understand the mass physical (geotechnical) properties of seafloor sediment

Finally, because the size and sorting of sediment grains may reflect sedimentation mechanisms and depositional conditions, grain-size data are assumed to be useful for interpreting the depositional environments of ancient sedimentary rocks.

It is this assumption that grain-size characteristics reflect conditions of the depositional environment that has sparked most of the interest in grain-size analyses. Geologists have studied the grain-size properties of sediments and sedimentary rocks for more than a century; research efforts since the 1950s have focused particularly on statistical treatment of grain-size data. This prolonged period of grain-size research has generated hundreds of learned papers in geological journals and has swelled the bibliographies of numerous sedimentologists. Thus, it would be logical to assume that by now the relationship between grain-size characteristics and depositional environments has been firmly established. Alas, that is not the case!

Many techniques for utilizing grain-size data to interpret depositional environments have been tried; however, little agreement exists regarding the reliability of these methods. For example, Friedman (1967, 1979) used two-component grain-size variation diagrams, in which one statistical parameter is plotted against another (e.g., skewness vs. standard deviation, or mean size vs. standard deviation). This method putatively allows separation of the plots into major environmental fields such as beach environments and river environments (Fig. 3.8).

FIGURE 3.8

Grain-size bivariate plot of moment skewness vs. moment standard deviation showing the fields in which most beach and river sands plot. (Redrawn from Friedman, G. M., 1967, Dynamic processes and statistical parameters for size frequency distributions of beach and river sands: Jour. Sed. Petrology, v. 37, Fig. 5, p. 334, reproduced by permission of SEPM, Tulsa, OK.]
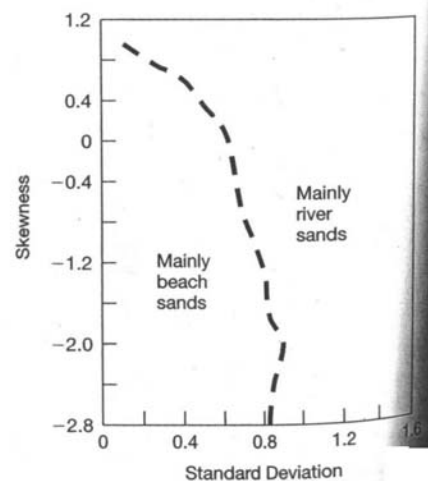
Passega (1964, 1977) developed a graphical approach to interpreting grain-size data that makes use of what he calls *C-M* and *L-M* diagrams, in which grain diameter of the coarsest grains in the deposit (*C*) is plotted against either the median grain diameter (*M*) or the percentile finer than 0.031 mm (*L*). Passega maintains that most samples from a given environment will fall within a specific environmental field in these diagrams. Visher (1969), Sagoe and Visher (1977), and Glaister and Nelson (1974), have all suggested that depositional environments can be interpreted on the basis of the shapes of grain-size cumulative curves plotted on log probability paper. Cumulative curves plotted in this way commonly display two or three straight-line segments rather than a single straight line (Fig. 3.9). Each segment of the curve is interpreted to represent different subpopulations of grains that were transported simultaneously but by different transport modes, that is, by suspension, saltation, and bedload transport. Sediments from different environments (dune, fluvial, beach, tidal, nearshore, turbidite) can putatively be differentiated on the basis of the general shapes of the curves, the slopes of the curve segments, and the positions of the truncation points (breaks in slope) between the straight-line segments (e.g., Visher 1969). Although success using these various techniques has been reported by some investigators, all of the techniques have been criticized for yielding incorrect results in an unacceptably high percentages of cases (e.g., Tucker and Vacher, 1980; Sedimentation Seminar, 1981; Vandenberghe, 1975; Reed, LeFever, and Moir, 1975).

More sophisticated multivariate statistical techniques, such as factor analysis and discriminant function analysis (e.g., Chambers and Upchurch, 1979; Taira and
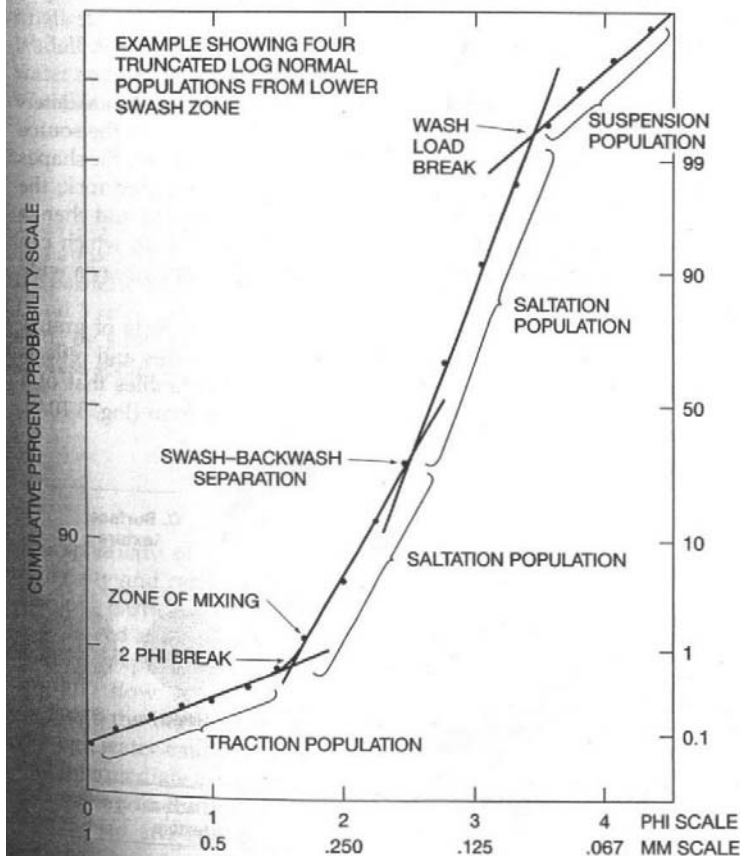

FIGURE 3.9

Relation of sediment transport dynamics to populations and truncation points in a grain-size distribution as revealed by plotting grain-size data as a cumulative curve on log probability paper. [After Visher, G. S., 1969, Grain size distributions and depositional processes: Jour. Sed. Petrology, v. 39, Fig. 4, p. 1079, reprinted by permission of SEPM, Tulsa, OK.]