Sand Dunes on the Central Delmarva Peninsula, Maryland and Delaware

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1067-C

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By CHARLES S. DENNY *and* JAMES P. OWENS

SURFACE AND SHALLOW SUBSURFACE GEOLOGIC STUDIES IN THE EMERGED COASTAL PLAIN OF THE MIDDLE ATLANTIC STATES

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During the maximum advance of the late Wisconsin ice sheets, an environment cooler and drier than the present one permitted dune building on the Delmarva Peninsula

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SAND DUNES ON THE CENTRAL DELMARVA PENINSULA, MARYLAND AND DELAWARE

By CHARLES S. DENNY and JAMES P. OWENS

ABSTRACT

Inconspicuous ancient sand dunes are present in parts of the central Delmarva Peninsula, Maryland and Delaware. Many dunes are roughly U-shaped, built by northwest winds, especially on the east sides of some of the large rivers. On the uplands, the form and spacing of the dunes are variable. A surficial blanket composed mainly of medium- and fine-grained sand—the Parsonsburg Sand—forms both the ancient dunes and the broad plains between the dunes. The sand that forms the dunes is massive and intensely burrowed in the upper part; traces of horizontal or slightly inclined bedding appear near the base. Quartz is the dominant mineral constituent of the sand. Microline is abundant in the very fine to fine sand fraction. The heavy-mineral assemblages (high zircon, tourmaline, rutile) are more mature than in most of the possible source rocks. The most abundant minerals in the clay-sized fraction are dioctahedral vermiculite, kaolinite, illite, montmorillonite, and gibbsite. The first four minerals are common in deposits of late Wisconsin and Holocene age. The gibbsite may be detrital, coming from weathered rocks of Tertiary age. The soil profile in the dune sand is weakly to moderately developed. At or near the base of the Parsonsburg Sand are peaty beds that range in age from about 30,000 to about 13,000 radiocarbon years B.P. Microfloral assemblages in the peaty beds suggest that the dunes on the uplands formed in a spruce parkland during the late Wisconsin glacial maximum. The river dunes may also be of late Wisconsin age, but could be Holocene.

INTRODUCTION

Ancient sand dunes are common morphologic features in parts of the central Delmarva Peninsula, Maryland and Delaware. Many of the dunes are parabolic forms built by northwest winds. U-shaped forms are best developed on the east sides of some of the larger rivers. On the uplands, the dunes assume a variety of forms. Some are U-shaped, others are irregular mounds, still others are long narrow ridges having only a slight curvature in plan to suggest dune-building by northwest winds.

The dunes are inconspicuous. Their relief is low, especially on the uplands. Most parabolic dunes have gentle side slopes; rarely is the slope to windward gentler than that to leeward. The spacing between the dunes is irregular; some are in groups, others are more or less isolated. In short, the dunes on the central Delmarva Peninsula are not well developed either in form or in abundance compared with those in other parts of the Atlantic Coastal Plain (Thom, 1967).

A surficial blanket of sand, the Parsonsburg Sand (Rasmussen and Slaughter, 1955; Denny and others, 1978), covers many areas in the central Delmarva Peninsula (fig. 1) and is the material that forms the dunes. However, in some places, the surface of the Parsonsburg Sand is a gently undulating plain without any dune forms. In the uplands east and south of Salisbury, Md., the Parsonsburg Sand commonly consists of an upper light-colored sand and a lower dark-colored sand or silt-clay rich in organic matter. Peaty sediment is also found in the upper sand in some places. The organic matter ranges in radiocarbon age from about 30,000 to about 13,000 years B.P. and contains microfloral assemblages suggesting that when the sand was deposited the climate was cooler and drier than it is at present. The region may have been a pine-birch barrens in which were shrubs, small ponds, and swamps containing spruce and alder. Presumably, this is the environment in which the dunes on the uplands were formed (Sirkin and others, 1977).

Along the rivers where the best developed parabolic dunes occur, the Parsonsburg Sand mantles terraces east of the rivers. The terraces are underlain either by sandy beds of Tertiary age (Beaverdam Sand and Pensauken Formation) or of Sangamon age (Kent Island Formation; Owens and Denny, 1978). At one locality, the Parsonsburg Sand is underlain by peaty sediment and may be contemporaneous with some of the Parsonsburg Sand on the uplands. Elsewhere along the rivers, the sand might range in age from late Sangamon to early Holocene.

The uplands east and south of Salisbury include a large area of what Rasmussen called the "Maryland basins," groups of more or less circular poorly drained swales bordered by low sandy ridges (Rasmussen, 1953, 1958). Comparison of a map of the "Maryland basins" east of

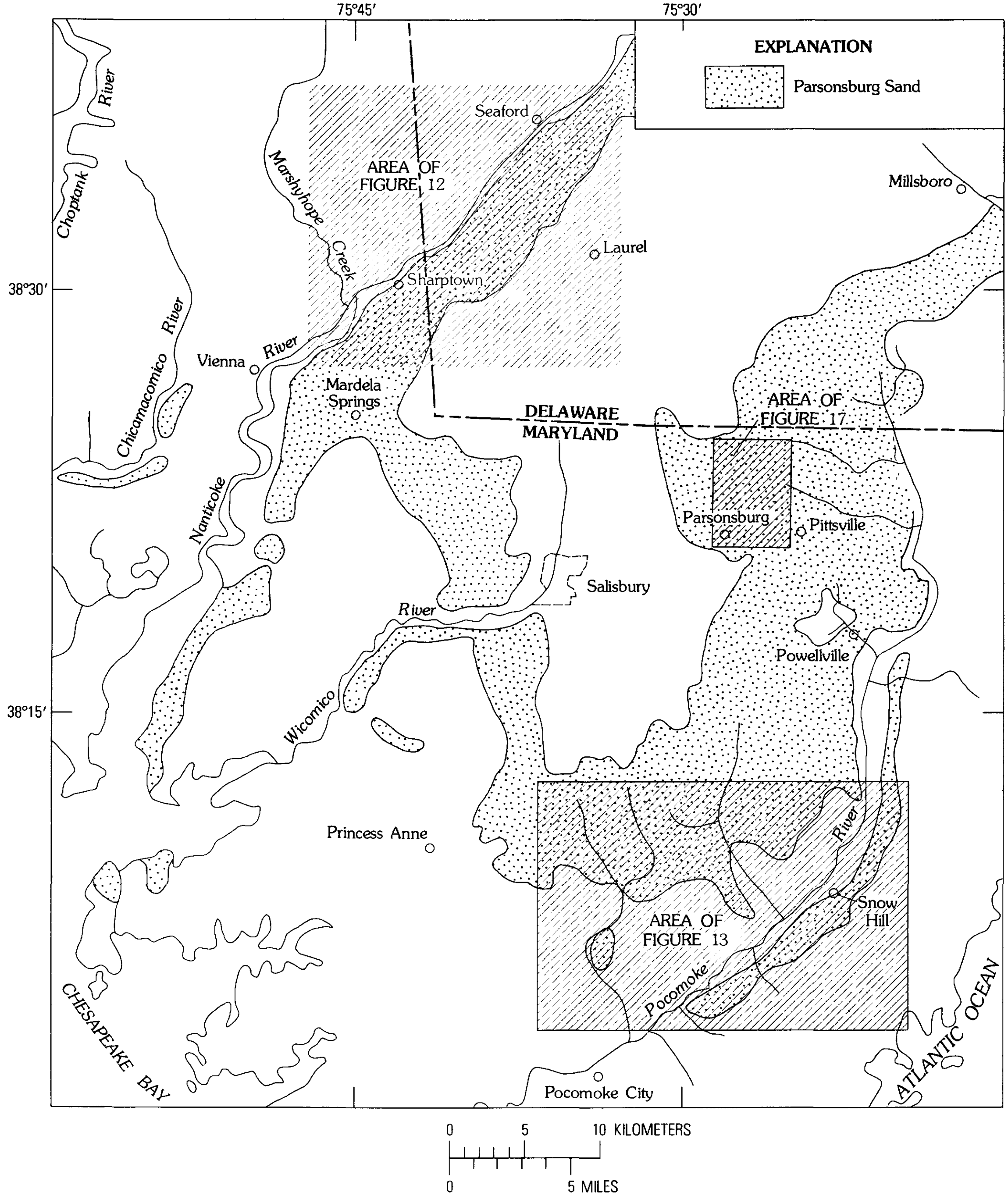

FIGURE 1.—Distribution of the Parsonsburg Sand (Denny and others, 1978) on the central Delmarva Peninsula between the Nanticoke and Pocomoke Rivers. In many areas, the Parsonsburg Sand forms parabolic or irregularly shaped dunes. Areas outlined are locations of detailed maps of the dunes reproduced in this paper.

Salisbury (Rasmussen and Andreasen, 1959, pl. 4) with our map of the sand dunes in the same area shows wide discrepancies between the position and form of the sand dunes and the rims of the "Maryland basins."

The U-shaped or parabolic dunes are a type "*** in which the middle part has moved forward with respect to the sides or arms" (McKee, 1966, p. 9–10; *see also* Hack, 1941, p. 242; Cooke and Warren, 1973, fig. 4.27). When the dunes were active, the "arms [were] *** anchored by vegetation and the entire dune [was] *** relatively stable" (McKee, 1966, p. 10). Figure 2 illustrates the terms used to describe the dunes.

The individual dunes range from small knolls about 1 m (3–4 ft) high and about 30–90 m (100–300 ft) in di-

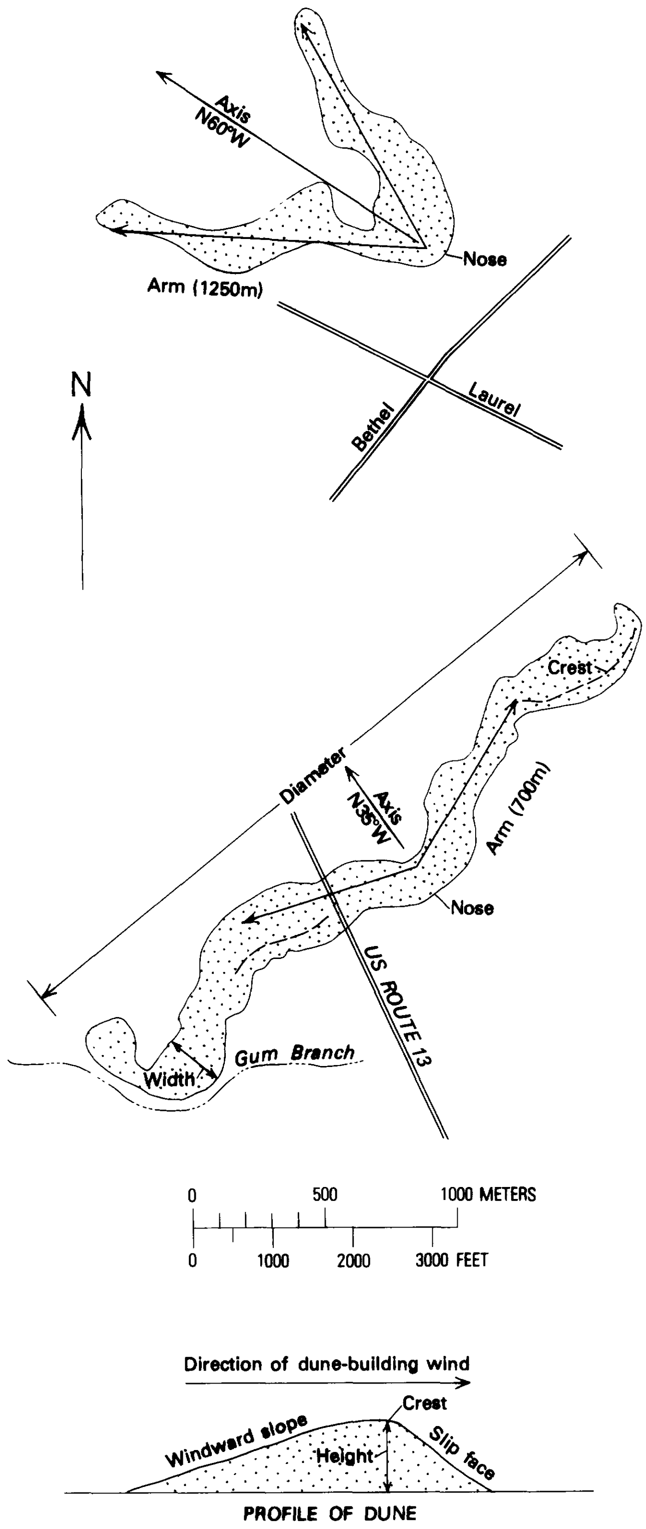

FIGURE 2.—Parabolic dunes in the Laurel quadrangle, Delaware, central Delmarva Peninsula.

ameter, to long narrow ridges as much as 4.6 m (15 ft) high and more than 4 km (2.5 mi) in length. In plan, some ridges are long, gently curving bands; others turn as much as 180°. The long, gently curving ridge in figure 2. is interpreted to be three parabolic dunes whose arms are connected. The dune was built by northwest winds; it has a gentle windward or back slope to the northwest and a steeper slip face to the southeast.

ACKNOWLEDGMENTS

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LITHOLOGY

The Parsonsburg Sand that forms the dunes is composed largely of medium- and fine-grained sand. Roughly 45 percent of the grains range in diameter from 0.25 to 0.50 mm and about 40 percent, from 0.125 to 0.25 mm (fig. 3). Small amounts of coarser and finer grains include small pebbles, granules, very fine sand, and silt. The size distribution is common for dune sand. A binocular examination of several samples of sand reveals large percentages of rounded to well-rounded grains in the medium and coarse sand fractions. In addition, many of the sand grain surfaces are frosted and pitted.

SAND COMPOSITION

The mineral composition of the Parsonsburg Sand and of its possible source rocks is discussed in detail elsewhere (Denny and others, 1978; Owens and Denny, 1978). The dune sands are mostly quartz, although the mineralogy varies from place to place. Microcline, the next most abundant constituent, makes up 10–20 percent of the very fine to fine sand fraction (0.149–0.074 mm) but declines rapidly in the medium to coarse sand fractions, where it is estimated to occur in amounts less than 5 percent. The compositional variation of the light minerals in the dune sand in the size range cited above is shown in figure 4 together with the quartz-feldspar ratios in the various possible source rocks. Except for the sand of the Walston Silt and those from the modern barrier at Assateague Island, the Parsonsburg Sand has a lower feldspar content than do most of the possible source formations. The heavy-mineral assemblages in

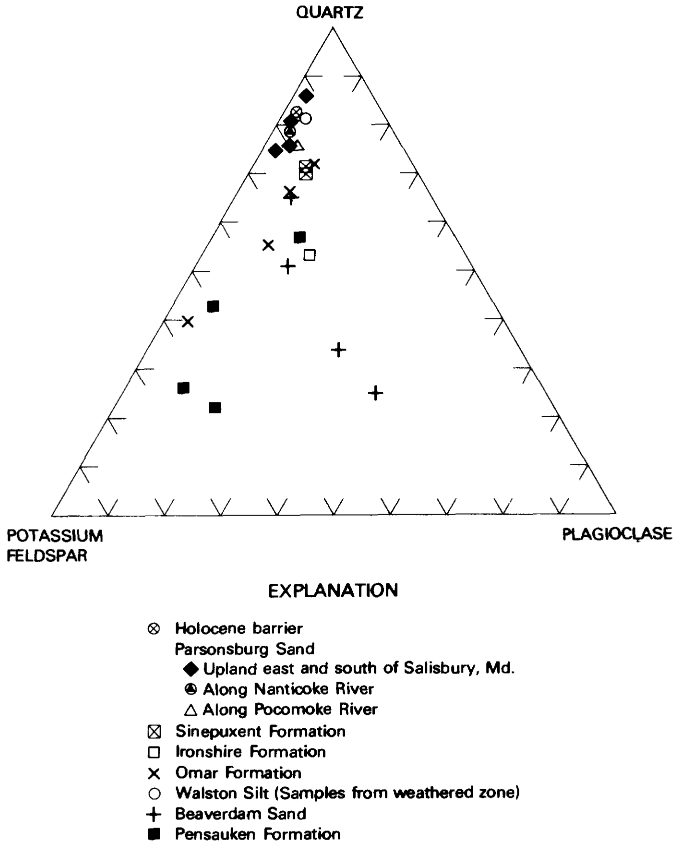

FIGURE 4.—Ternary diagram showing quartz-feldspar ratios for the Parsonsburg Sand and possible source rocks in the very fine to fine sand-size fraction (0.149–0.074 mm).

the Parsonsburg Sand are more mature (higher zircon-tourmaline-rutile concentrations) than they are in most adjacent formations except the Walston (fig. 5).

The more mature composition of the Parsonsburg Sand as compared with that of most of the adjacent source rocks suggests several possible interpretations. The first explanation is that the Parsonsburg Sand is well drained, and the compositional maturity is the result of intrastratal weathering of the more labile minerals such as amphiboles, pyroxenes, and to a lesser degree the feldspars. This explanation does not seem likely because the older Ironshire Formation of Sangamon age composed of relatively well-sorted clean sand is compositionally less

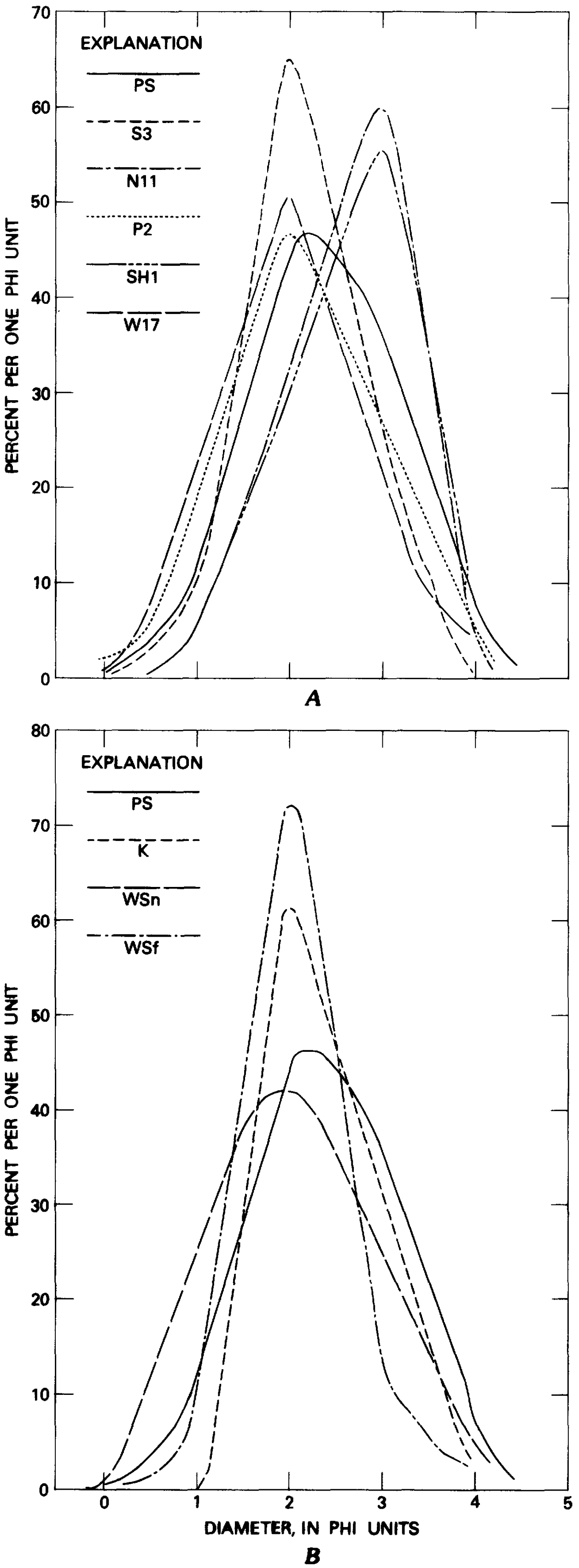

FIGURE 3.—Frequency curves showing grain size of dune sand. *A*, Dunes on the central Delmarva Peninsula. PS is a curve representing an average of 25 samples. Field numbers S3, N11, P2, SH1, and W17 designate curves for individual samples. *B*, Comparison of Delmarva dunes with those of other regions: PS, Delmarva dunes; K, Kelso dunes, Mojave Desert, California (Sharp, 1967, fig. 17, sample 13); WS, dunes at White Sands National Monument, New Mexico (McKee, 1966, table 1, dome-shaped and parabolic dunes): WSn, near source, WSf, 16 km (10 mi) from source.

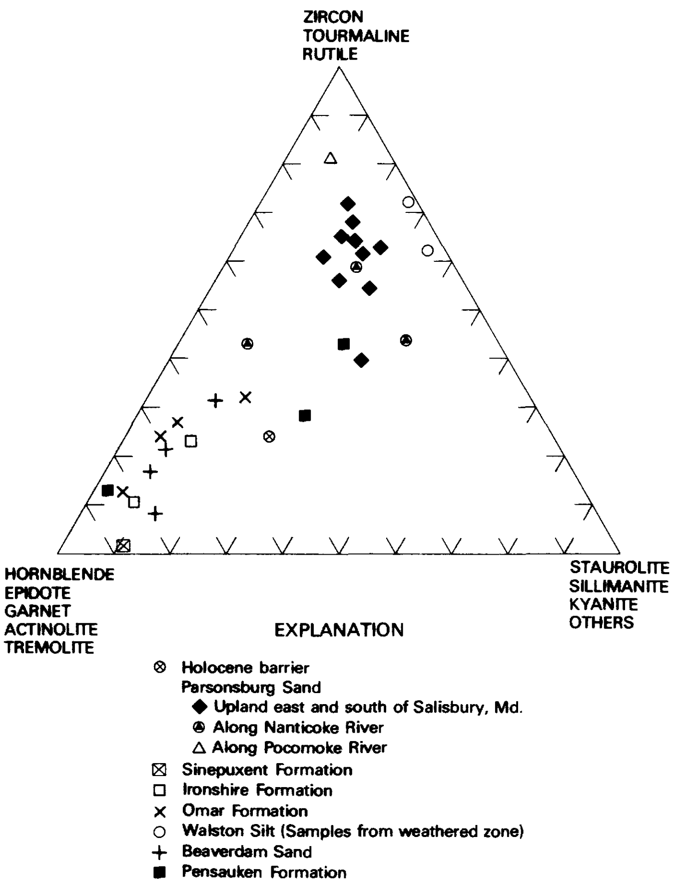

FIGURE 5.—Ternary diagram showing heavy-mineral assemblages (> 2.80 sp gr; 0.149–0.074 mm in diameter) in Parsonsburg Sand and in possible source rocks.

mature than the Parsonsburg Sand (figs. 4 and 5). A second explanation is that the Parsonsburg Sand acquired its maturity through mechanical abrasion. The rounded and pitted nature of many of the quartz sand grains in the Parsonsburg lends support to this explanation. A third explanation is that the Parsonsburg Sand was derived from deeply weathered beds near the surface of adjacent formations. The mineralogy of the Walston Silt (figs. 4 and 5) supports this explanation. On the basis of existing information, the sands of the Parsonsburg were probably derived from adjacent older rocks in two steps. First, the parent rock was deeply oxidized under subaerial conditions, and second, the weathered debris was reworked by wind and water to form the Parsonsburg Sand.

INTERNAL STRUCTURE

The sand that forms the dunes is massive in the upper part; toward the base, however, traces of bedding appear. Many fresh exposures show no bedding; it is only when the outcrop has dried out and has been etched by wind-driven sand that the face may show a faint stratification caused by slight changes in grain size. The beds are 1–2 cm thick. The attitude is horizontal or slightly inclined, rarely more than 10°. High-angle cross-bedding was nowhere observed. The sand below the dunes is commonly well stratified in horizontal layers and is described elsewhere (Denny and others, 1978).

The typical cross section through a dune and into the underlying sand shows a gradual transition from massive sand above to well-bedded sand below, the result of the disturbance or alteration of the sand during and after deposition. Some of the disturbance is due to the growth and decay of roots. Large tubes 0.3–0.6 m (1–2 ft) in diameter at the top and tapering downward to depths of 2 m (6 ft) or more are clearly root casts; in some of them the root is still preserved. Some of the alteration is the result of weathering and will be discussed shortly.

The most distinctive feature of the gradual transition downward from massive to well-bedded sand is what appears to be ancient animal burrows, tube-shaped bodies of sand differing slightly from the enclosing sand in texture or color (fig. 6). In cross section, some of these tubes

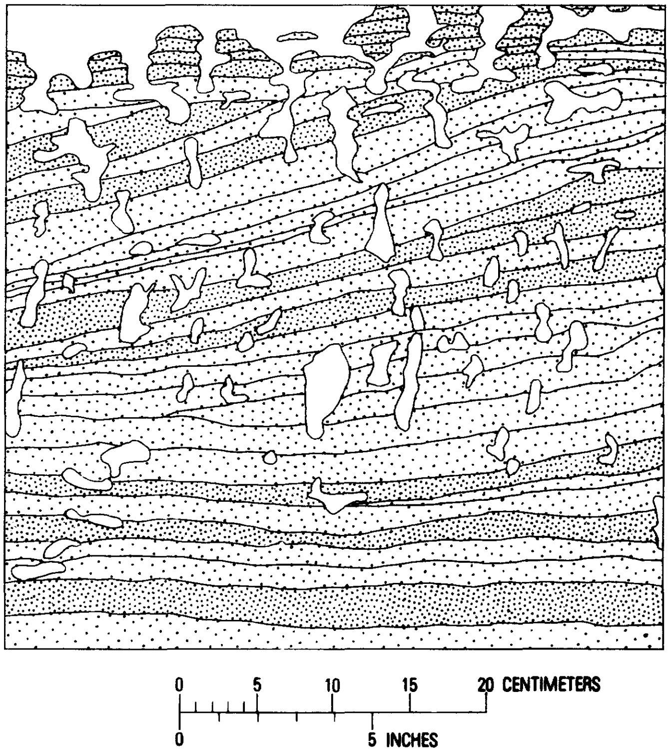

FIGURE 6.—Cross section of bedded sand cut by irregular bodies of massive sand. The massive sand fills tubes and cavities believed to be animal burrows. The larger cavities appear to have formed where many tubes intersect. The animal is unknown. Sketched from a photograph. Exposure in borrow pit north of Parsonsburg, Md. (Pittsville 17, fig. 16).

resemble the outline of fingerprints and thumbprints. Individual tubes are about 1–3 cm (0.4–1.0 in.) in diameter, range from perhaps 5–15 cm (2–6 in.) in length, and have long axes more or less vertical. In places, many such filled burrows intersect to form large bodies of massive sand. The burrows are especially conspicuous where filled with black sand. When the burrows were open to the sky, water or wind moved black sand across the ground surface and into the open end of the tube. The animal that formed the tubes is unknown.

WEATHERING

A dune of Parsonsburg Sand is typically weathered to depths ranging from about 0.3 to 1.2 m (1 to 4 ft). A surface horizon (fig. 7, horizons 1 and 2) of loose, very pale brown loamy sand overlies an intermediate horizon of slightly sticky brown sandy loam (horizon 3). The underlying material (horizon 4) is a loose, very pale brown loamy sand or sand that contains thin discontinuous yellowish-brown wavy bands or lamellae (U.S. Soil Conservation Service, 1975, p. 25) of material similar to that in the intermediate horizon (table 1). The intermediate horizon is discontinuous, and in places the upper horizon overlies the basal horizon, as shown in the right-hand part of figure 7.

In the weathering profiles at only two localities (the uplands east of Pittsville, Md.), the zircon, tourmaline, and rutile percentages decline with depth, suggesting local postdepositional chemical weathering.

The clay-sized fraction (<2 microns) of samples from several weathering profiles in the dune sand were X-rayed; the results are shown in figure 8. In the weathering profile in the dune near Snow Hill (G5, fig. 8), the most common minerals are dioctahedral vermiculite, kaolinite, illite, montmorillonite, and gibbsite. Not shown in this figure but also present in the samples are halloysite and goethite. Vermiculite (containing chloritized layers) is the most common mineral throughout all the weathering horizons in this profile; kaolinite (+halloysite) is the next most common mineral. Illite, montmorillonite, and gibbsite are minor constituents. This particular profile shows little variation in mineral concentrations from top to bottom.

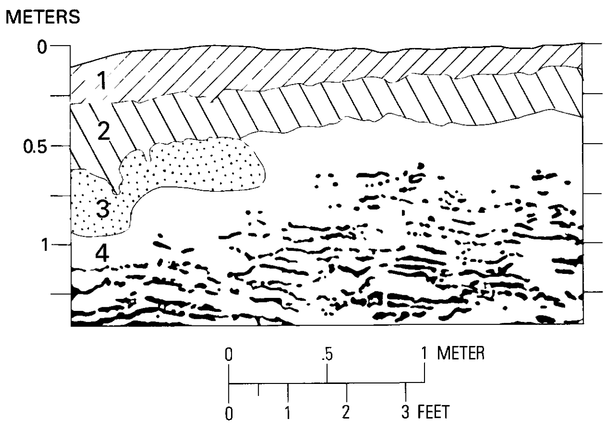

FIGURE 7.—Cross section of weathering profile in Parsonsburg Sand forming a parabolic dune. Numbers designate weathering horizons. 1, gray, loamy sand (plow layer); 2, pale-yellowish-brown loamy sand; 3, brown sandy loam, discontinuous; 4, very pale brown sand and loamy sand containing wavy brown bands (lamellae) of sandy loam. Dune is near Snow Hill, Md., southeast of the Pocomoke River (locality G5, fig. 13). For descriptions of horizons, see table 1. Sketched from a photograph.

TABLE 1.—*Weathering profile in sand dune southeast of Pocomoke River near Snow Hill, Md. (loc. G5, fig. 13)*

[Color designations are based on the "Munsell Soil Color Chart" (Munsell Color Co., 1954). See also table 2]

Horizon	Description	Average depth in m (ft)
1.	Loamy sand, gray (2.5Y 7/2), structureless (Ap horizon)	0.0–0.3 (0.0–0.9)
2.	Loamy sand, pale yellowish brown (10YR 6/4, dry) becomes paler upward; structureless or faint paper-thin wavy bands parallel to ground surface; few fine roots (A(?) horizon); transitional downward into horizon 3	0.3–0.6 (0.9–1.9)
3.	Sandy loam, brown (7.5YR 5/4, moist), slightly sticky; weak fine subangular blocky structure, unstratified; few fine roots; many burrows (B horizon); transitional downward into horizon 4. In places horizon 2 directly over lies horizon 4	0.6–0.9 (1.9–3.0)
4.	Sand and loamy sand, very pale brown (10YR 7/4–8/1, moist) mottled with light yellowish brown (10YR 6/4), single grain, loose, many burrows, unstratified; contains yellowish-brown wavy bands (lamellae) of sandy loam similar to those of horizon 3, bands 0.25–2.5 cm (0.1–1.0 in.) thick, 5.0–60.0 cm (2.0–24.0 in.) long; in a vertical plane the undulations range from 5.0–10.0 cm (2.0–4.0 in.) high; bands become sandier with depth (C horizon)	0.9–1.5 (3–5)

Samples from weathering profiles at three other localities in dune sand (D3d, P12d, SH20) and at one locality in sand of presumed Sangamon age (S5) have in general the same clay mineralogy. There is, however, some variation in the mineral concentration through the weathering profiles. In the D3d profile, kaolinite is the major mineral in the lower part of the profile but declines toward the surface, where it is replaced by vermiculite as the major mineral. Gibbsite also increases toward the surface. The same pattern is followed to varying degrees in the other profiles.

The mineral assemblages in the weathered zone of the

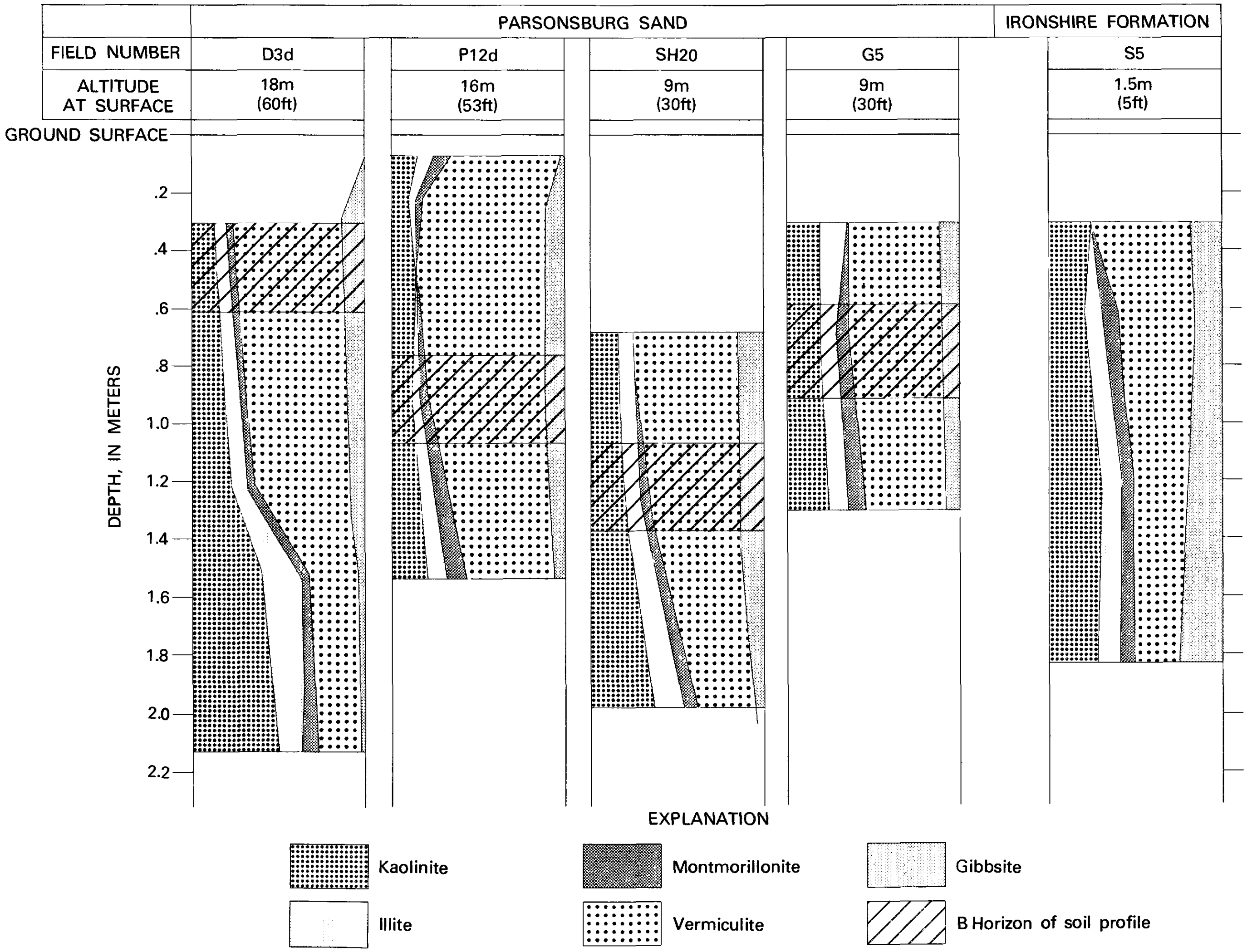

FIGURE 8.—Clay-sized (< 2 microns) mineral assemblages in the weathering profiles of four dunes composed of Parsonsburg Sand and in a weathering profile in the Ironshire Formation.

dune sand in the central Delmarva Peninsula appear anomalous in some respects. Vermiculite (soil chlorite in part), kaolinite, illite, and montmorillonite are common in deposits of Wisconsin and Holocene age (Owens and others, 1974). The presence of gibbsite is particularly interesting. To some, the presence of this mineral in a soil-mineral assemblage suggests intermediate to intense weathering if the deposit is well drained and is Quaternary in age (Jackson, 1965). On the other hand, the upward increase in chloritized vermiculite, particularly into the A soil horizon, suggests mild weathering in well-drained Quaternary deposits (Jackson, 1965). As most dunes are of late Wisconsin age and as the climate was probably cool temperate, the gibbsite in the soil profile is probably detrital. A study of the clay-silt fraction in the possible source rocks (Owens and Denny, 1978; Denny and others, 1978) shows that the Tertiary units, particularly the Beaverdam Sand, have large concentrations of gibbsite locally in the weathered zone. This unit and perhaps also the Walston Silt may have supplied silt-sized aggregates of gibbsite to westerly winds. If so, the gibbsite could have been carried across the peninsula and deposited during deposition of the Parsonsburg Sand. Thereafter, the gibbsite could have been redistributed in the dune sand. Gibbsite was removed from the surface horizon (2) and deposited in the intermediate horizon (3) and along bedding planes in the underlying material (horizon 4) to form the wavy brown bands or lamellae.

Most samples of peaty clay at the base of many of the dunes contain gibbsite. Its presence in these unweathered peaty sediments suggests that in these beds the mineral is indeed detrital rather than a product of post-depositional subaerial oxidation. The presence of gibbsite in the basal clays supports the interpretation that most if not all of the gibbsite in the overlying sands is also detrital.

The soils developed on the parabolic dune near Snow Hill, Md. (G5), are largely Entisols (Regosols) (fig. 9) or soils without pedogenic horizons (Lakeland series, no B horizon. For explanation of soil terminology see Hall, 1973; Birkeland, 1974). Adjacent to the dunes are areas of Ultisols or soils containing a horizon of clay accumulation (Fort Mott and Sassafras series, B horizon). These three series are described in table 2. The dune near Snow Hill is mapped as a complex of the Lakeland and Fort Mott soil series. This relation is shown in figure 7, which has a Fort Mott profile on the left and a Lakeland profile on the right.

The discontinuous yellowish-brown wavy bands (lamellae) in the basal or C horizon appear to be associated in the lower part of the profile with traces of the original bedding of the deposit. This relationship is illustrated in a section through a low parabolic dune at Glass Hill, about 3 km west of Pittsville, Md. (fig. 10). Massive sand about 1.75 m (70 in.) thick containing wavy brown bands (lamellae) in the lower part grades downward into horizontally bedded sand at a depth of about 2.5 m (95 in.). The sand containing wavy brown bands is intensely burrowed. Near the base, discontinuous masses of unburrowed sand show faint horizontal stratification, in part due to dark-mineral laminae. The wavy brown bands (lamellae) may be the result of the deposition of silt- and clay-sized particles by water moving down through the sand, as previously mentioned.

The arrangement of the weathering horizons in some exposures suggests the destruction of weathering products by erosion and deposition. For example, in figure 7, horizon 3 is shown to be discontinuous; it appears to have been partially removed and subsequently buried by younger sand (horizons 1 and 2).

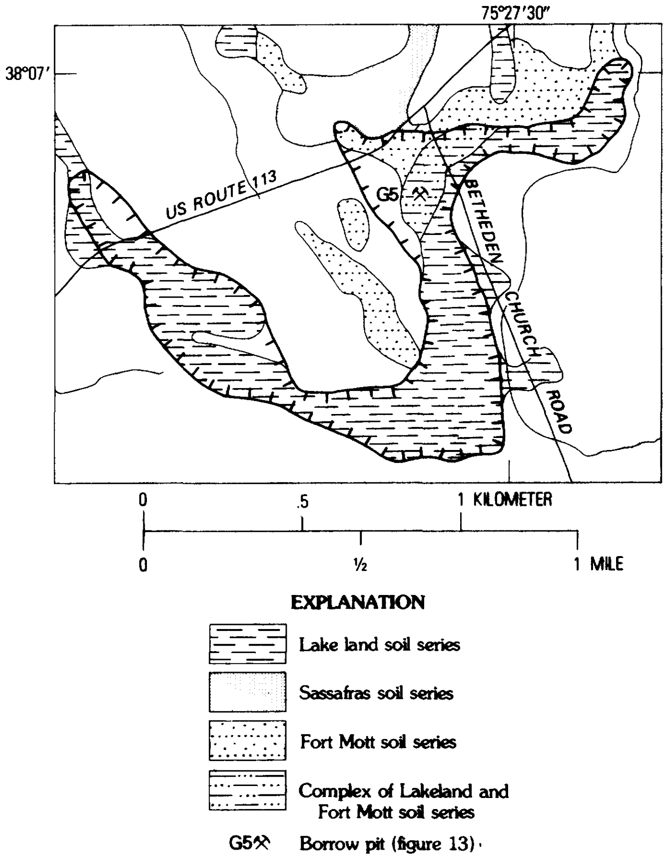

FIGURE 9.—Soils developed on parabolic dune near Snow Hill, Md. Outline of dune shown by hachured line. Dune is composed of Parsonsburg Sand; the adjacent areas are underlain by the Kent Island Formation of late Sangamon age. Lakeland, Sassafras, and Fort Mott are well drained to excessively drained soils. Remainder of area is underlain by moderately well to poorly drained soils. Map generalized from Hall (1973). For description of soil units see table 2.

TABLE 2.—*Soils developed on parabolic dune (G5) near Snow Hill, Md.*

[Modified from Hall, 1973. Horizon thickness in cm (in.)]

	Lakeland loamy sand	Lakeland loamy sand, clayey substratum		Fort Mott loamy sand		Sassafras sandy loam
A_p	0–25 (0–10), grayish-brown (2.5Y 5/2) loamy sand.	Similar to Lakeland loamy sand, except that A horizon is sandier and C horizon contains more clay at depth of about 152–213 (60–84).	A1	0–8 (0–3), grayish-brown (10YR 5/2) loamy sand.	A1	0–3 (0–1), very dark grayish-brown (10YR 3/2) sandy loam.
C	25–100 (10–40), light-yellowish-brown (2.5Y 6/4) and yellowish-brown (10YR 5/6) loamy sand.		A2	8–61 (3–24), light-yellowish-brown (2.5Y 6/4) loamy sand.	A2	3–20 (1–8), olive-brown (2.5Y 4/4) to grayish-brown (10YR 5/2) sandy loam.
	100–183 (40–72), pale-olive (5Y 6/3) to light-gray (5Y 7/1) sand.		B21t	61–76 (24–30), yellowish-brown (10YR 5/6) sandy loam.	B1	20–33 (8–13), light-yellowish-brown (10YR 6/4) heavy sandy loam.
			B22t	76–94 (30–37), strong brown (7.5YR 5/6) heavy sandy loam.	B21t	33–53 (13–21), light-yellowish-brown (10YR 6/4) light sandy clay loam.
			C	94–127 (37–50), light-yellowish-brown (2.5Y 6/4), very light loamy sand; irregular inclusions of material similar to that in B22t horizon in upper part.	B22t	53–84 (21–33), strong-brown (7.5YR 5/6) sandy clay loam.
					C	84–127 (33–50), yellowish-brown (10YR 5/8) loamy sand.

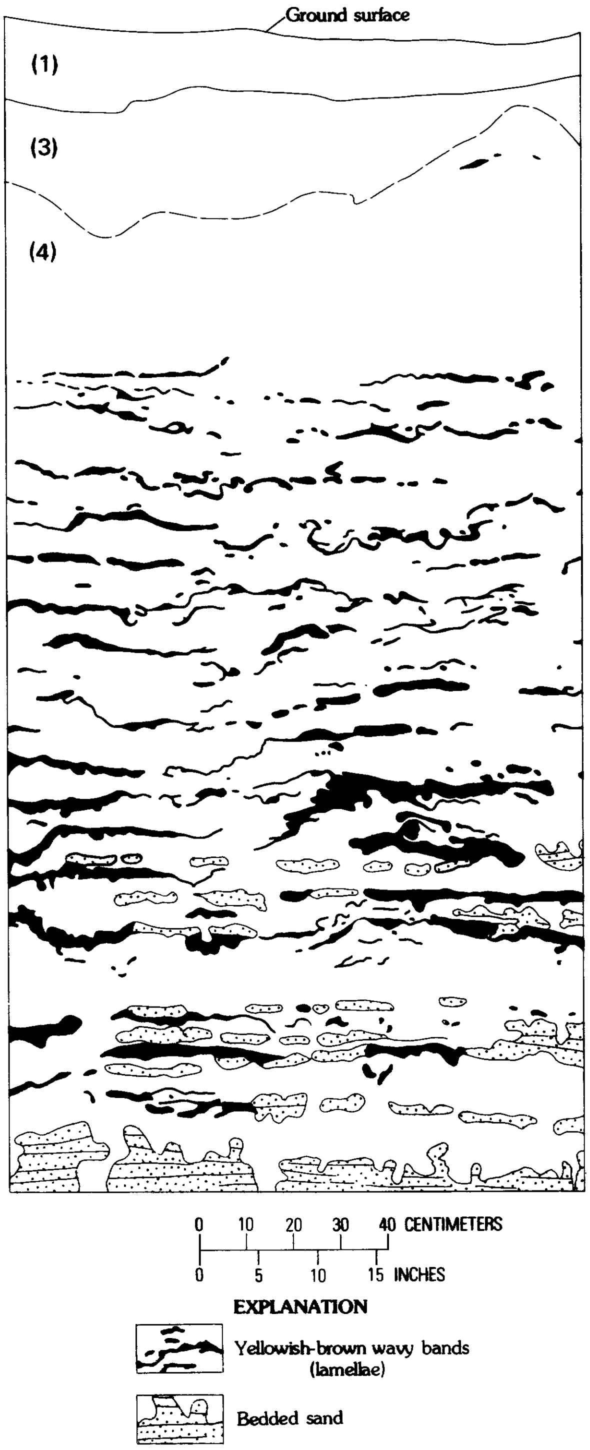

FIGURE 10.—Cross section of weathering profile in parabolic dune near Pittsville, Md. The dune is mapped as Evesboro loamy sand, 5–15 percent slopes (Hall, 1970). Numbers designate weathering horizons. Sketched from photograph.

In some dunes, an older weathering profile appears to be truncated by a younger sand layer (fig. 11). A discontinuous horizon (3) of brown silty sand separates a surface horizon (1 and 2) of a very pale brown sand from a basal horizon (4) of pale-yellow to white sand containing discontinuous wavy bands of brown silty sand, the whole probably constituting a single weathering profile. However, the intermediate and the basal horizons (3, 4) may constitute an ancient weathering profile, truncated at the top and overlain by a younger deposit of sand (1 and 2). This dune near Wango, Md., was perhaps first built, then weathered, eroded, and finally covered by younger sand. If this is a two-cycle dune, when did the episodes of weathering, erosion, and deposition take place? If the older dune (3, 4) is late Wisconsin in age, the early episode of weathering may have been early Holocene, the "comparatively warm Hypsithermal interval" (Flint, 1971, p. 524), the surface sand (1 and 2) being younger. The climate of the Eastern United States during the interval 10,000–6,000 years ago may have been slightly drier than it is at present (Wright, 1971, p. 452). Perhaps the surface sand is no more than a few hundred years old, the result of deforestation and cultivation in colonial times.

RIVER DUNES

Dunes of Parsonsburg Sand are found along the Chicamacomico, Nanticoke, Wicomico, and Pocomoke Rivers (fig. 1). Only those along the Nanticoke and the Pocomoke are described here. The dunes are on the southeast sides of the valleys (figs. 12 and 13) and near the rivers are at altitudes of about 3 m (10 ft); away from the rivers, they are at altitudes of about 12 m (40 ft). Near the rivers, the valley sides are underlain (fig. 14) by sand, gravel, and, locally, clay-silt of the Kent Island Formation (upper Sangamon); farther from the rivers, the valley sides are underlain by either the Omar Formation (lower Sangamon) or the Beaverdam Sand (Pliocene).

The river dunes vary greatly in size. Mean values for the dimensions of the Nanticoke River dunes are: diameter 1,130 m (3,700 ft); length of arm about 760 m (2,500 ft); and height about 3 m (10 ft). For the Pocomoke River dunes, dimensions are: diameter about 1,070 m (3,500 ft); height about 2.2 m (7.3 ft); and length about 580 m (1,900 ft). The data are summarized in table 3. The axial trend of more than 90 percent of the river dunes is northwest (fig. 15).

The largest and most spectacular of the river dunes are long isolated sand ridges such as Easter Hill near Seaford, Del. (fig. 12). Easter Hill stands on an essentially featureless plain about 3.2 km (2 mi) south of the river and is about 5 km (3 mi) long. The plain is underlain largely by the Beaverdam Sand. A second long sand ridge is found about 1 km (0.6 mi) to the south. Bedding was not observed in the few exposures available in the dunes. The form of these long sand ridges in plan and in profile (fig. 16) suggests that each one is made up of several nearly straight parabolic dunes whose arms touch

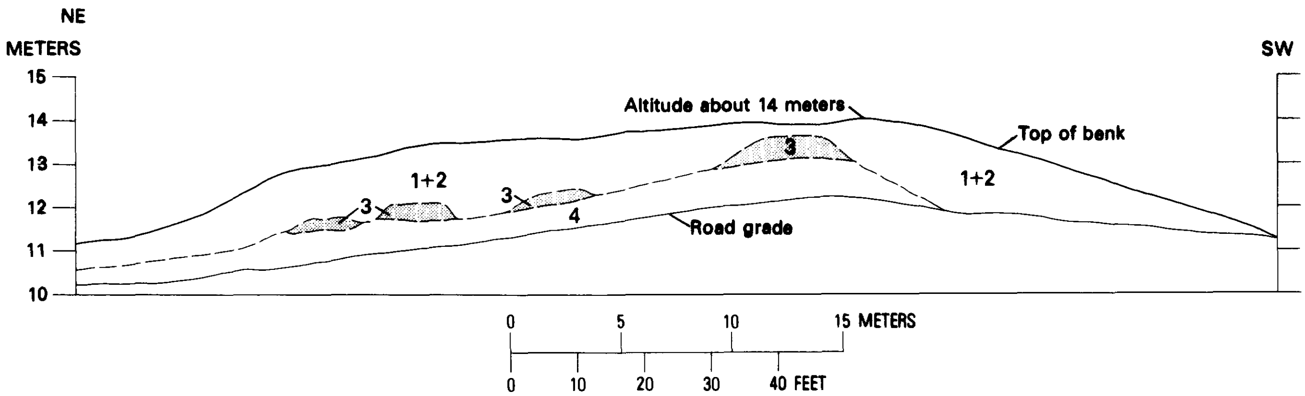

FIGURE 11.—Cross section through sand dune, suggesting two successive episodes of dune building. The dune is on Beech Island near Wango, Md. For approximate description of weathering horizons 1, 2, 3, and 4, see table 1.

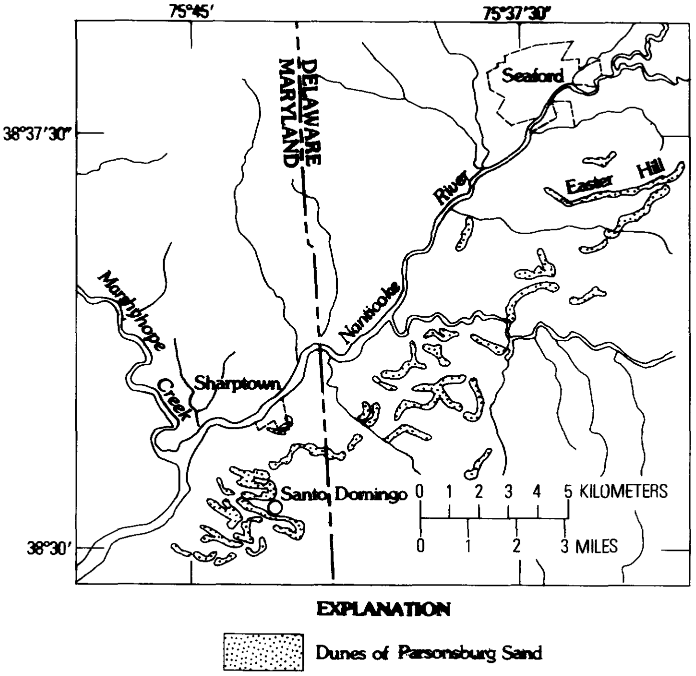

FIGURE 12.—Dunes of Parsonsburg Sand along Nanticoke River near Sharptown, Md., and Seaford, Del. Easter Hill is a dune nearly 5 km in diameter. Several large U-shaped dunes near Santo Domingo are also shown. For location see figure 1.

one another. Deposition was by winds from the northwest. The ridges resemble the "complex transverse dune" of David (1972, chap. 7, fig. 15).

The environment in which such long isolated sand ridges are formed is not known. Jordan (oral commun., 1973) has suggested that Easter Hill might be a "precipitation ridge" or "a ridge due to precipitation of sand at a forest edge," as described by Cooper (1958, p. 55). This suggestion is reasonable. However, the features described by Cooper on the Oregon–Washington coast are much larger than Easter Hill, and between them and the sand source at the beach is a sheet of sand. The precipitation ridges on the northwest coast mark the landward edge of great dune fields.

Isolated ridges like Easter Hill might form where the supply of sand is available only from time to time. Suppose, for example, that sand from a bare Nanticoke flood plain formed a dune ridge on the edge of a terrace southeast of the river. If, in time, the surface of the flood plain became more or less stabilized by vegetation so that the supply of sand to the westerly winds was greatly reduced, it would seem likely that the dune on the terrace edge would move southeastward as sand was eroded from its gentle windward slope and deposited on its steeper slip face. If, after a time, the vegetation on the flood plain were disrupted, sand would again be available for eolian transport, and a second dune ridge would form on the edge of the terrace southeast of the river. Perhaps some such mechanism operated to produce the isolated ridges south of the Nanticoke River near Seaford (fig. 12).

UPLAND DUNES

The dunes on the upland east and south of Salisbury (fig. 1) are long narrow ridges that range in diameter from about 600 to 6,000 m (2,000–19,500 ft; table 4). Many of the dunes are symmetrical in cross profile, and the side slopes are very low, commonly only 2° or 3°. Some of the ridges are asymmetric in cross profile, the steeper slopes being on the southeast sides of the ridges. The steepest slopes are not more than about 10°. The dunes curve and recurve and have no consistent alinement overall, nor are they arranged in as orderly a fashion as are parabolic dunes in other regions (Cooper, 1967, pl. 6; Thom, 1967, figs. 9 and 11).

Upland dunes northwest of the Pocomoke River near Snow Hill (fig. 13) tend to be elongated in an easterly or a northeasterly direction. Between the upper reach of Dividing Creek and Nassawango Creek, the ridge pattern suggests the southeast advance of a tongue-shaped mass of dunes onto the plain northwest of the river un-

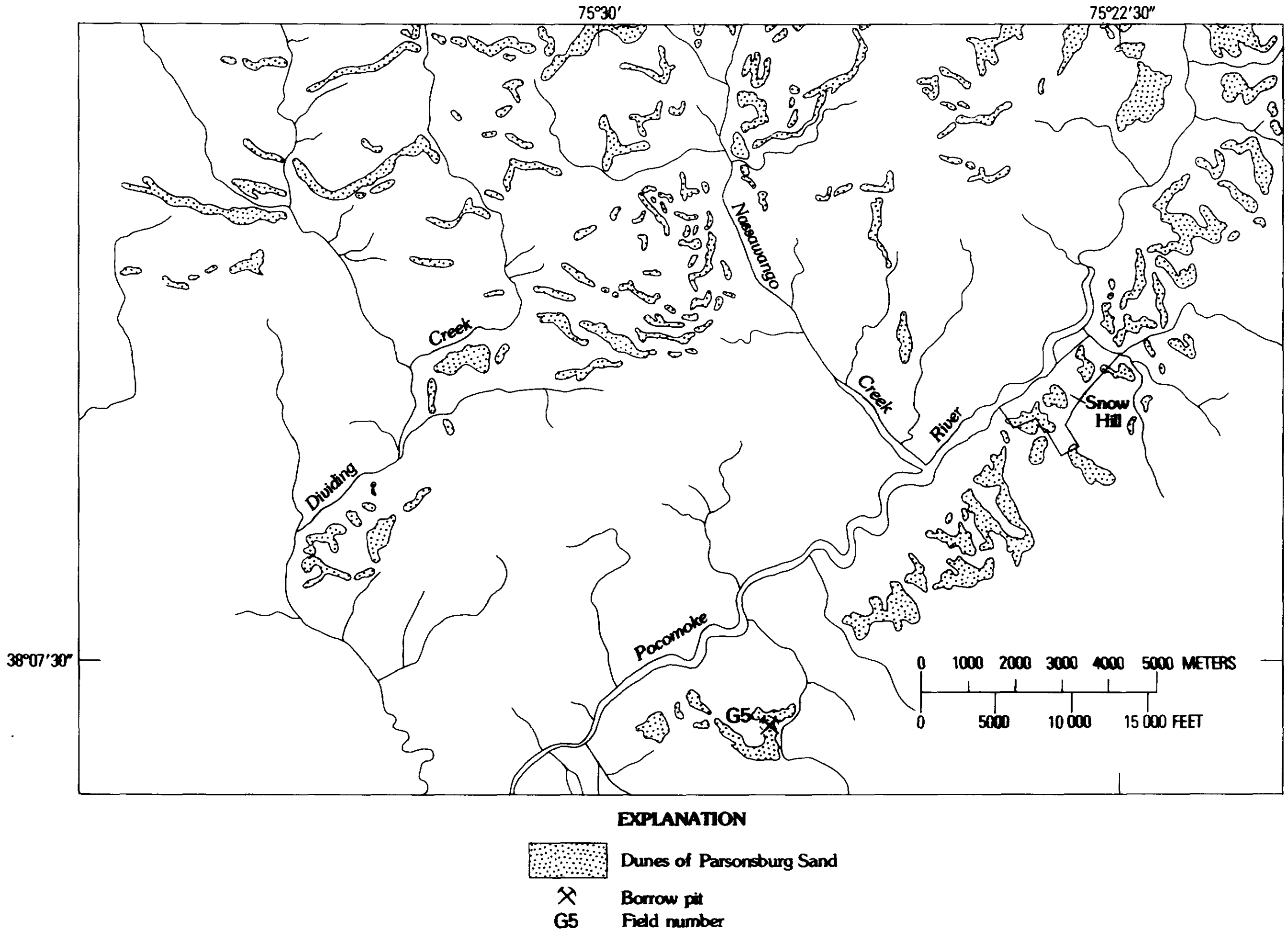

FIGURE 13.—Dunes of Parsonsburg Sand near Snow Hill, Md. Upland dunes northwest of Pocomoke River and river dunes southeast of the river are shown. For location see figure 1.

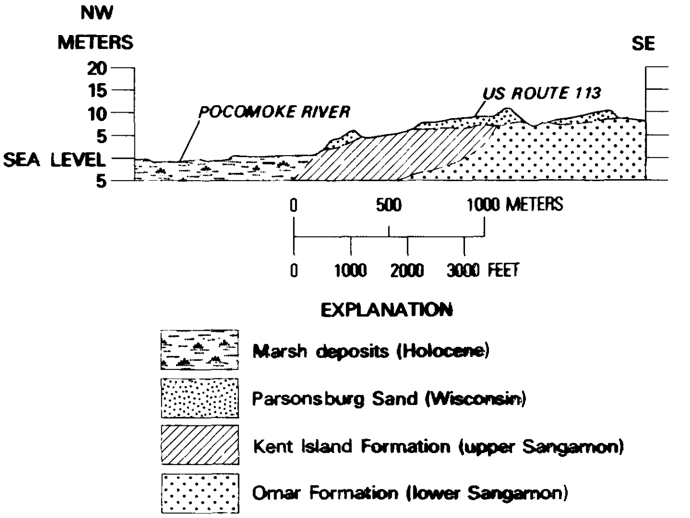

FIGURE 14.—Cross section of isolated parabolic dunes on southeast side of Pocomoke River, near Snow Hill, Md. The slip face on the southeast side of the dunes is steeper than the back slope on the northwest side.

TABLE 3.—*Dimensions of dunes along the Nanticoke and Pocomoke Rivers*

[In meters; feet in parentheses]

	Minimum	Maximum	Mean[1]
Nanticoke River			
Diameter	760 (2,500)	4,720 (15,500)	1,130 (3,700)
Height	1.5 (5)	5 (15)	3 (9.5)
Width	46 (150)	400 (1,300)	200 (660)
Length of arm	150 (500)	2,590 (8,500)	760 (2,500)
Pocomoke River			
Diameter	600 (2,000)	2,200 (7,200)	1,070 (3,500)
Height	1 (3)	5 (15)	2.2 (7.3)
Width	60 (200)	64 (210)	290 (950)
Length of arm	90 (300)	1,580 (5,200)	580 (1,900)

[1] Of maximum width or height or of longer arm.

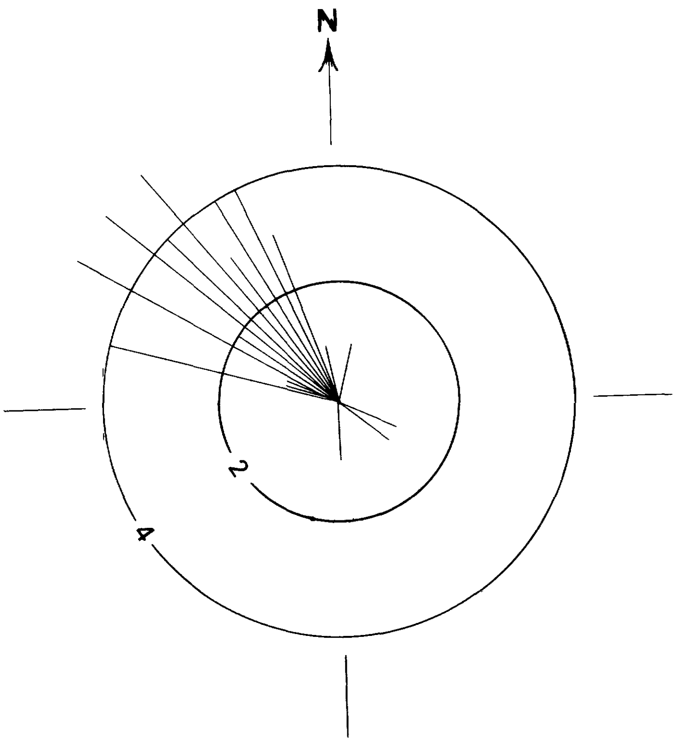

FIGURE 15.—Rose diagram showing that the long axes of most river dunes trend northwest, suggesting formation by northwest winds. Diagram based on 47 measurements of axis of parabolic dunes measured on 1:24,000-scale topographic maps. 4, number of dunes.

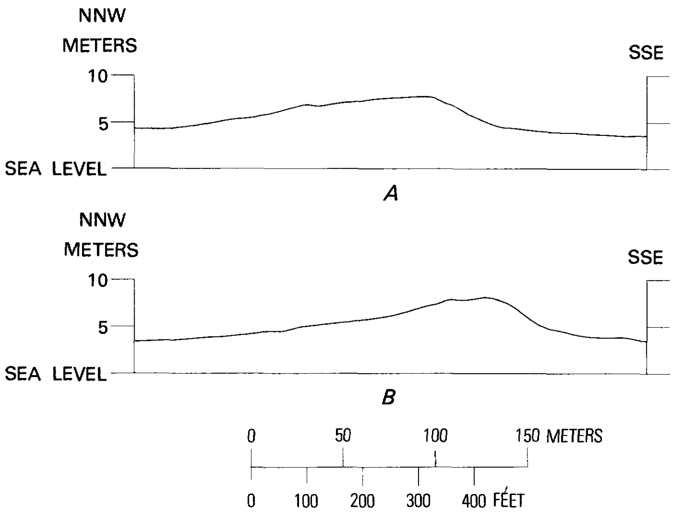

FIGURE 16.—Asymmetric profiles of parabolic dunes formed by winds from the northwest. Easter Hill (A) and adjacent dune (B) near Seaford, Del. (Laurel quadrangle, Delaware). Vertical exaggeration × 5.

TABLE 4.—*Dimensions of dunes on uplands east of Salisbury, Md.*

[In meters; feet in parentheses]

	Minimum	Maximum	Mean[1]
Diameter	600 (2,000)	6,000 (19,500)	1,220 (4,000)
Height	1 (3)	6 (20)	1.8 (5.8)
Width	60 (200)	640 (2,100)	19 (61)
Length of arm	210 (700)	1,980 (6,500)	540 (1,800)

[1] Of maximum width or height or of longer arm.

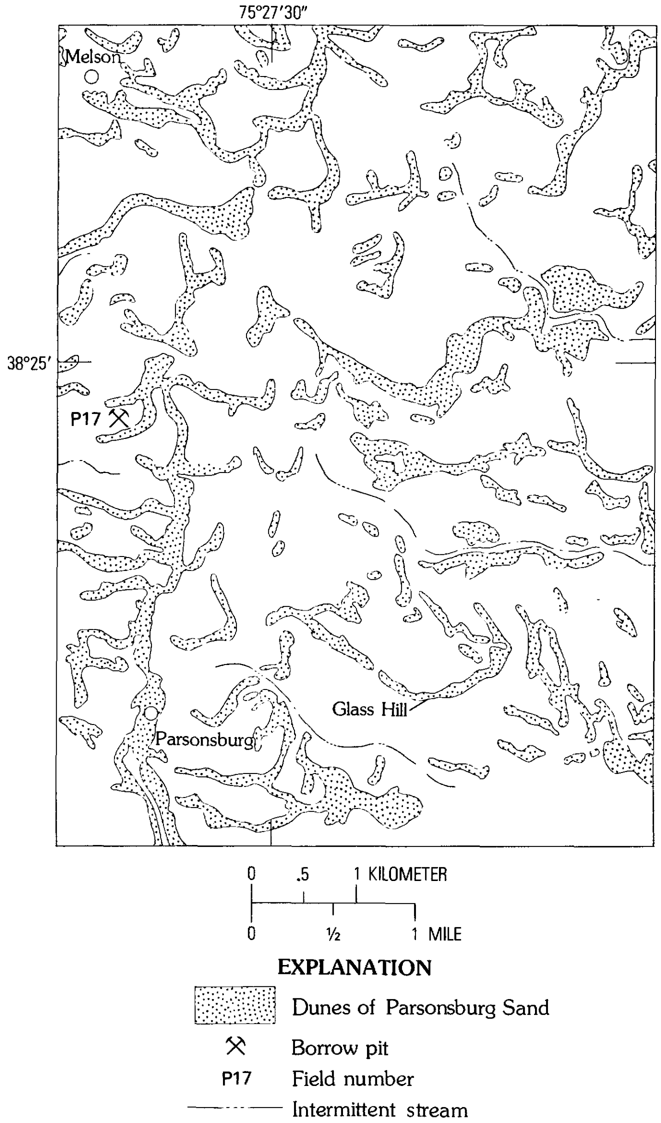

FIGURE 17.—Sand dunes on uplands near Parsonsburg, Md. Most of the basins between the dunes are poorly drained. Based on soil drainage as shown on soil maps of Wicomico County, Md. (Hall, 1970, sheets 11, 12, 19, 20, 27, 28, 36, and 37, scale 1:15,840). For location see figure 1.

derlain by the Omar Formation of early Sangamon age (Owens and Denny, 1978).

Dunes on the Wicomico–Pocomoke River divide north of Parsonsburg, Md. (fig. 17), are long narrow gently curving low ridges that have a tendency to run in an easterly or northerly direction. Many of the narrow bands are connected to form a pattern resembling parabolic dunes formed by northwest winds. The prominent north-trending sandy ridge near Parsonsburg is the crest of the

Wicomico River–Pocomoke River divide at an altitude of about 25 m (80 ft). Attached to the ridge on both sides are many curving arms suggesting that the divide is a line of parabolic dunes. The soil in the basins between the ridges is very poorly drained; the surface layer (0.3 m; 1 ft) is a black muck. The swales commonly have standing water in the spring and dry out in the summer. The modern streams have bisected some of these ancient dunes even in this headwater area.

The spacing of the dunes on the uplands is irregular (fig. 18). Groups of individual knolls or ridges do not closely resemble well-recognized dune patterns, which are commonly characterized by a regularity of the spacing of the individual elements (Cooke and Warren, 1973, p. 280).

The shape of the upland dunes suggests that the dune-building winds were dominantly from the northwest (fig. 19). Nearly 80 percent of the dune axes are in the northwest quadrant (fig. 20).

On the uplands west and south of Salisbury (fig. 1), a belt of Parsonsburg Sand, ranging from about 2–7 km (1.0–4.5 mi) in width, extends from the Nanticoke River south-southeast for about 55 km (44 mi), almost to the Pocomoke River. In this belt, the surface expression of the Parsonsburg Sand is not uniform. In places there are parabolic dunes similar to those elsewhere. Also present are ridges as much as 4.5 km (2.8 mi) long and 0.5 km (0.3 mi) wide and irregularly shaped areas as much as 2 km (1.2 mi) in diameter. The belt of Parsonsburg Sand follows the landward edge of the Kent Island Formation that marks a shoreline of the Sangamon Sea on this part of the peninsula. Some of the topographic features, such as the west-facing scarp southwest of Hebron, which has a toe at about 10.5 m (35 ft), and some of the larger ridges, may be shore features of Sangamon age. Others are probably sand dunes of either Sangamon or Parsonsburg age. Without radiometric dates or knowledge of the microflora, one can only guess.

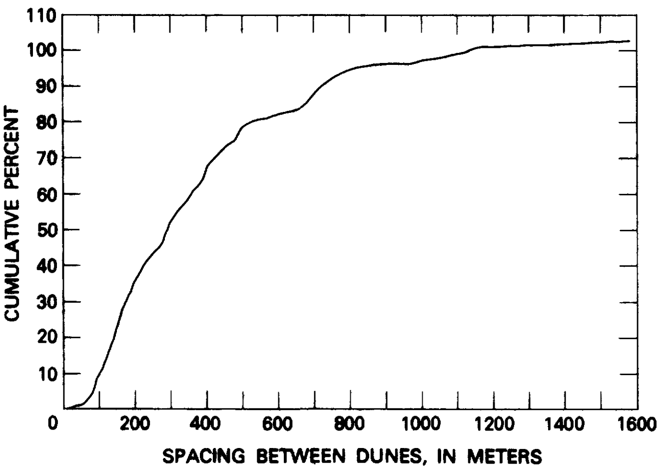

FIGURE 18.—Cumulative curve showing spacing between upland dunes. Distance between the dunes ranges from less than 100 m (328 ft) to more than 1,500 m (4,920 ft). The estimated mean spacing is 317.5 m (1,048 ft). Curve is based on 191 measurements along lines trending N. 45° W. across the uplands east of Salisbury, Md., and spaced 1 km (0.62 mi) apart.

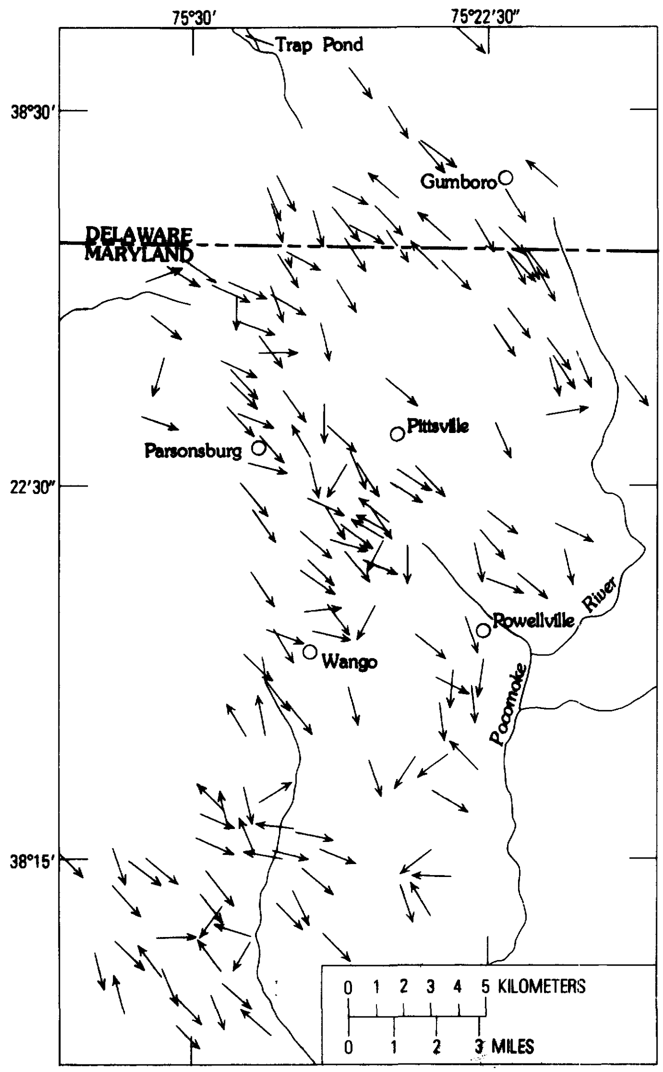

FIGURE 19.—Orientation of parabolic dunes on uplands east and south of Salisbury, Md. Axes of parabolic dunes were measured on 1:24,000-scale topographic maps. Arrows show inferred direction of dune-building wind.

AGE AND ORIGIN

Near the base of the Parsonsburg Sand that forms the dunes of the central Delmarva Peninsula are peaty beds dated by radiocarbon as about 30,000 to about 13,000 years B.P. (Denny and others, 1978). The microflora in the peaty beds (Sirkin and others, 1977) suggests that in early Parsonsburg time the area was a pine-birch barrens and later, a boreal forest. During the Wisconsin glacial maximum, about 18,000 years B.P., the area supported a spruce parkland and local bog tundra. Spruce

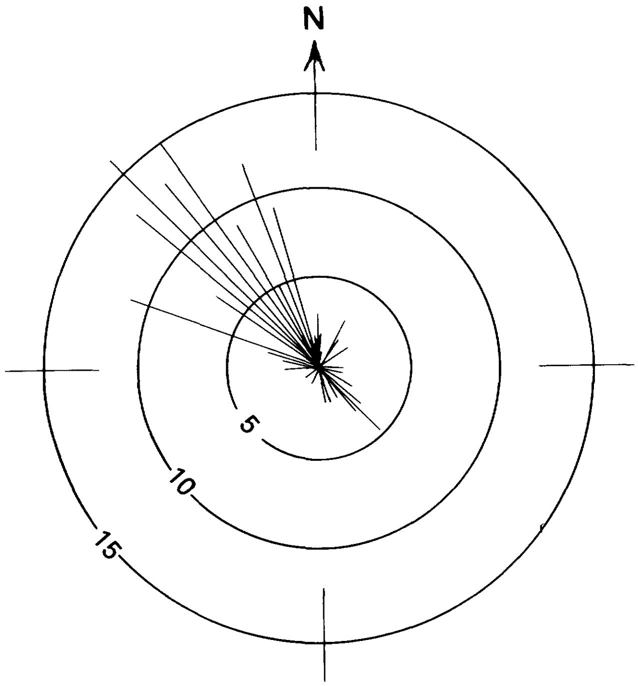

FIGURE 20.—Rose diagram showing the orientation of dunes on uplands east and south of Salisbury, Md. Diagram based on 179 measurements of axes of parabolic dunes measured on 1:24,000-scale topographic maps. 10, number of dunes.

remained an important element in the flora until about 13,000 years B.P.

Areas of bare ground, which are not available at present, are probably the prime requirement for dune formation. We assume that during the glacial maximum, the upland dunes were formed in the spruce parkland where such areas of bare ground existed, perhaps the shores of interdune ponds or the banks of streams.

We postulate that the source of the sand was older sands of early Sangamon (Omar) age (Denny and others, 1978). The sands were beach and nearshore deposits ranging in altitude from about 10 to 14 m (35 to 45 ft) above sea level. To account for Parsonsburg Sand on the high divide near Parsonsburg, we further postulate a Sangamon island capped by sand dunes as the local source of the Parsonsburg Sand at altitudes ranging from about 20 to 24 m (65 to 80 ft) above sea level.

Mineralogically, the dune sand has a lower feldspar and a higher stable heavy-mineral content than do most of the other formations of the central Delmarva Peninsula. The only exception is the deeply weathered Walston Silt which caps the higher parts of the uplands. The dune sand is thought to have been derived from the Walston and the upper weathered horizons in other adjacent formations. The clay-silt fraction in the dune sand and in the unweathered peaty sediment beneath the dunes contains small but consistent concentrations of gibbsite. These facts suggest to us that the sand was indeed derived from weathered beds in the source areas and that the gibbsite is mostly detrital and not an indicator of postdeposition weathering. The data indicate that any evaluation of the clay-mineral assemblages in the soil horizons must take into account the weathering history of the parent rock.

The absence of high-angle crossbedding so characteristic of parabolic dunes elsewhere (McKee, 1966) requires an explanation. Perhaps the parabolic shape of the sand ridges is related more to the presence of adjacent swales than to the forward movement of a slip face on the leeward edge of a blowout. If the dunes formed in a spruce parkland, perhaps the sand was blown out of a swale and accumulated on its rim, where the vegetation, such as grass and small shrubs, held the sand, inhibiting the formation of a slip face and the migration of the dune (Goldsmith, 1973, p. 1128; 1975, p. 17).

The dunes are low and inconspicuous features of the landscape. Their distribution is spotty and irregular. The field relations can be explained if we assume that there were local sources of dune-building sand and a means of stabilizing the windblown sand before it had moved very far. We suggest that on the uplands in late Wisconsin (Parsonsburg) time, the poorly drained basins between the dunes (fig. 17) were small ponds. Perhaps during the winter and early spring the ponds were dry or frozen, leaving areas of bare sandy ground. Westerly winds picked up sand and deposited it on the edge of the basin, where it was held by plants and small shrubs.

The dunes along the rivers differ from those on the uplands; the differences suggest that the age and depositional environment of the river dunes may not be the same as for the upland dunes. The river dunes are largely confined to the southeast or east sides of the river valleys, and parabolic forms are better developed than on the uplands. The Parsonsburg Sand that forms the river dunes does not contain peaty sediment, in marked contrast to the upland dunes that commonly have peaty beds at or near the base of the formation. The only exceptions are a dune along the Nanticoke River (near Mardela Springs, Md.) and one near Federalsburg, Md., on Marshyhope Creek just north of the area shown in figure 1. The river dunes may be of late Wisconsin age. On the other hand, they may be Holocene, formed prior to the development of the adjacent marsh and swamp coincident with the postglacial rise in sea level.

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