Slump Blocks in the Atlantic Highlands of New Jersey

GEOLOGICAL SURVEY PROFESSIONAL PAPER 898

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By JAMES P. MINARD

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A description of slump blocks and slumping in the hills of the northeastern New Jersey Coastal Plain, and a discussion of their potential as geologic hazards

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SLUMP BLOCKS IN THE ATLANTIC HIGHLANDS OF NEW JERSEY

By JAMES P. MINARD

ABSTRACT

Many slump blocks are present in the bluffs of the Atlantic Highlands along the south side of Sandy Hook Bay and the north side of Navesink River, N.J. At present, slumping is taking place in parts of the bluffs that are as much as 60 m (200 ft) high. The formations in the bluffs are largely unconsolidated nearly flat-lying silty and clayey marine sands of Late Cretaceous and early Tertiary age. Blocks range in size from about 30 m (100 ft) to 180 m (590 ft) in width, by about 150 m (490 ft) to 900 m (2,950 ft) in length; vertical displacement is as much as 26 m (85 ft). The larger blocks may contain as much as several million tons of material.

Most former slumps probably occurred when tidal currents and open ocean waves eroded the bluffs, possibly centuries ago to as recently as about 100 years ago. Since 1972, slumping has been reactivated in former slump blocks and initiated in steep slopes adjacent to older blocks. In addition to undercutting the toe of the slope, other factors such as an unusually high water table and, conceivably, earthquake tremors, may have contributed to the slumping. The entire bluff along Sandy Hook Bay appears to have a history of slumping and should thus be considered an area of possible geologic hazards. Slumping is currently causing considerable damage to houses and properties. Careful investigations should be made and precautions exercised before any construction is done at the base, on the slope, or on top of the bluff.

INTRODUCTION

The statutory charter of the United States Geological Survey is to make examinations of and report upon "the geological structure, mineral resources and products of the national domain." USGS neither approves nor disapproves land-use plans for privately owned land or the siting and design of any structure on privately owned land. Accordingly, no attempt has been made in this report to evaluate land-use or construction siting and design and nothing herein should be construed as a conclusion or recommendation concerning these subjects.

Several years ago, slump blocks were mapped and described in the bluffs along the southern shore of Sandy Hook Bay and along Navesink River (Minard, 1969). The slump blocks were observed and identified during routine geologic mapping of the Sandy Hook quadrangle (fig. 1).

Although many slump features were recognized, only three slump blocks were shown. Two of these are the largest and most distinct blocks and clearly show the characteristic features of such slump blocks—concave upper scarp, bulged convex lower profile, and a rotation normal to the scarp face (Minard, 1969, p. 36–41).

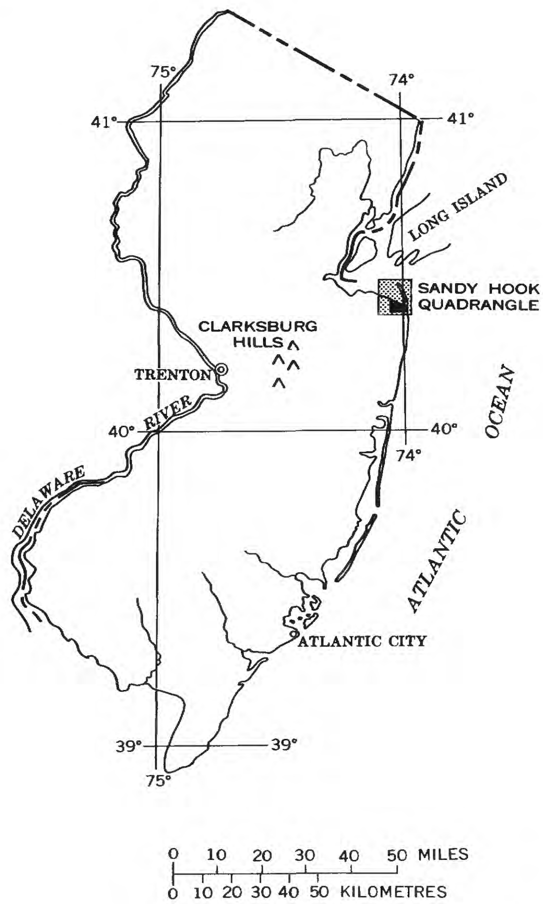
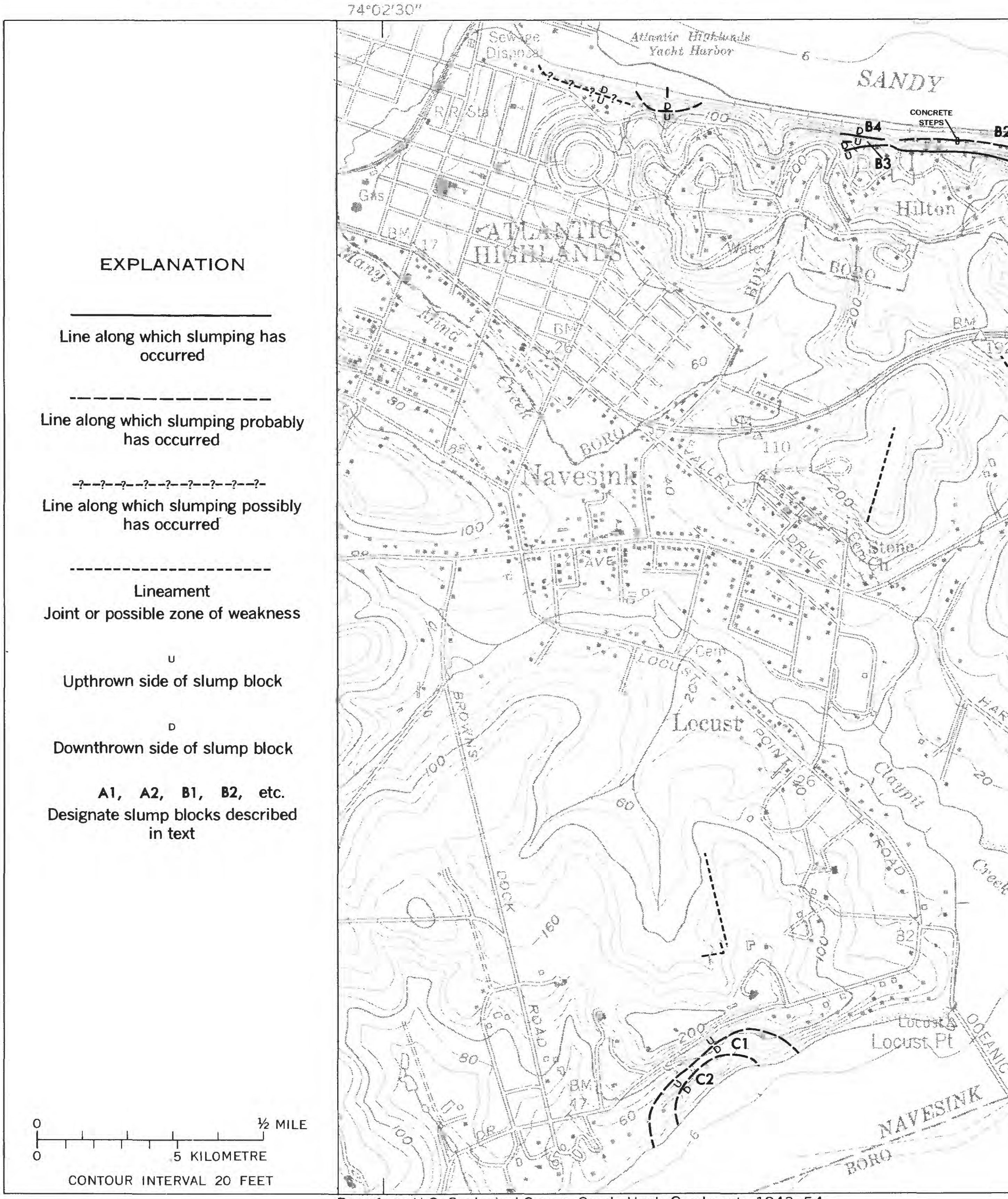


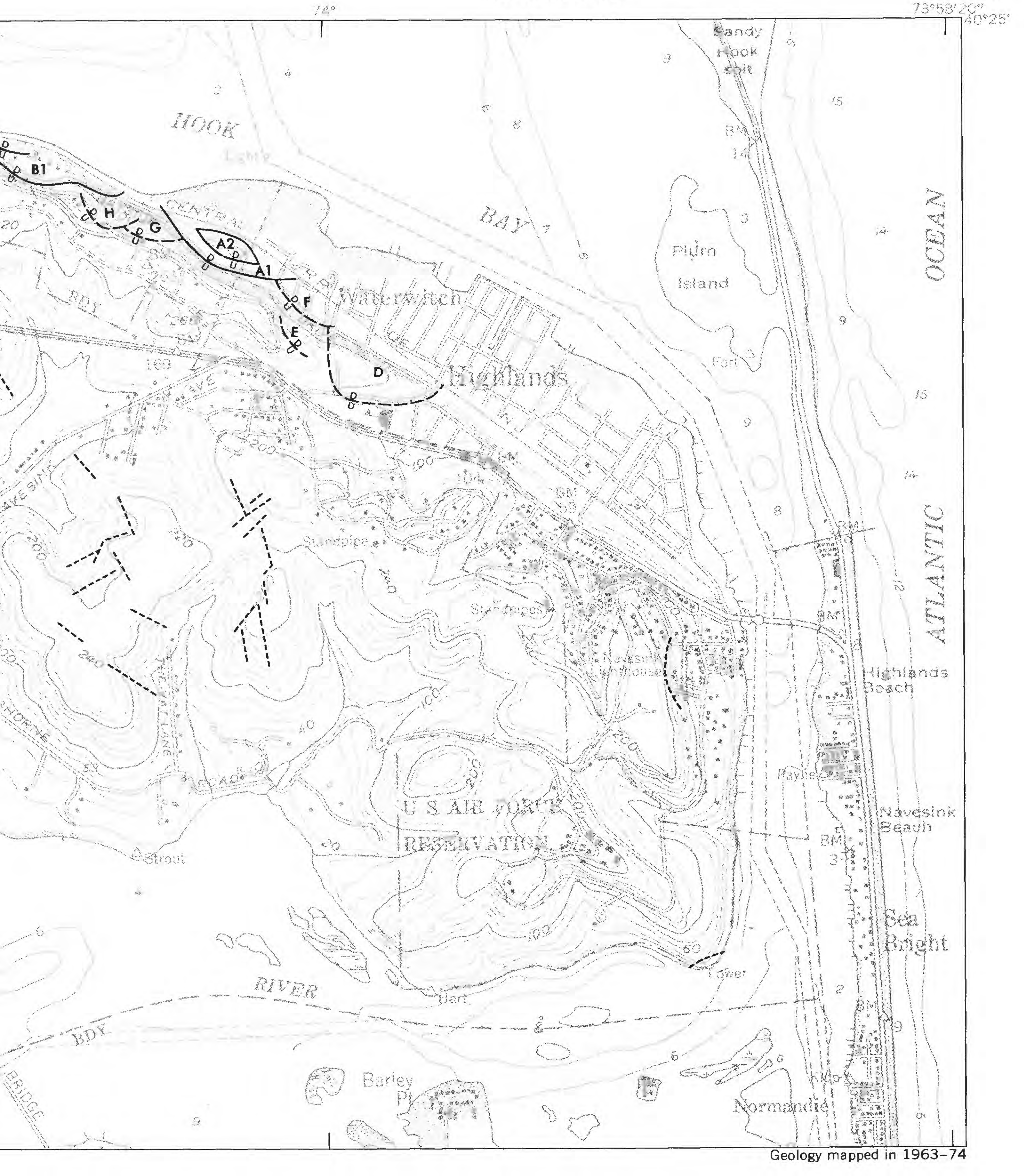
FIGURE 1.—Index map of New Jersey showing location of Sandy Hook quadrangle (stippled) and the area referred to in this report as the Atlantic Highlands (solid black area in the south-central part of quadrangle).

From about the summer of 1972 to the present (summer 1974), slumping has recurred in former slump blocks and has begun in steep slopes adjacent to older blocks. In this report, all slump blocks identified as definite, probable, and possible are outlined on a large-scale map (fig. 2); the physical settings



Base from U.S. Geological Survey, Sandy Hook Quadrangle, 1943–54

FIGURE 2.—Map of the Atlantic Highlands



Geology mapped in 1963–74

showing location of slump blocks and lineaments.

of the blocks and the characteristics of the material in them are described, and their past, present, and potential instability is discussed. A glossary (p. 23) gives the meanings of certain words in this report.

ACKNOWLEDGMENTS

Appreciation is extended to the many people who helped in gathering the material for this report. Property owners generously gave permission to enter and cross their properties and volunteered pertinent information. Included were Mr. and Mrs. Robert T. Abrams, Mr. and Mrs. John R. Sundin, Mr. and Mrs. Martin Finan, Mr. Martin Jensen, Mr. Edward Weiler, and Mr. Clifford Brooks—to name a few. Engineers with Woodward, Moorhouse & Associates generously supplied oral information on their test borings. The assistance of many others not mentioned is equally appreciated. Frank Markewicz, Principal Geologist, New Jersey Bureau of Geology and Topography, supplied valuable information and stimulated further investigation.

PHYSICAL SETTING

The location, form, and nature of the material in the Atlantic Highlands all contribute to the process or combine to increase the probability of slumping. In this report, the name "Atlantic Highlands" does not have a political subdivision connotation (except where the borough of Atlantic Highlands is specifically mentioned) but encompasses the area of hills between Sandy Hook Bay on the north and the Navesink River on the south.

The topography of the Atlantic Highlands and surrounding hills is equaled in relief and dissection in the entire Coastal Plain of New Jersey only by the Clarksburg Hills, 48 km (30 mi) to the southwest (fig. 1). The Atlantic Highlands area is unique in that it is the only area in the entire Coastal Plain of New Jersey (which includes about 10,360 km^2 or 4,000 sq mi) in which hills higher than 60 m (200 ft) and precipitous bluffs practically border the ocean. The mass of hills apparently inspired early settlers to use the name Neversink.[1]

This name was later modified to Navesink. The bluffs are protected from the open ocean only by Sandy Hook and a narrower barrier bar. Similar conditions are present on Long Island, N.Y., to the northeast, where many landslides have occurred in coastal-plain sediments (Fuller, 1914, p. 54–56), and along Chesapeake Bay, Md., to the southwest, where slumping is common. The rugged topography in the Atlantic Highlands is caused by the sandy permeable nature of the sediments and the resistant layers of rock locally present. The permeability of the unconsolidated materials allows water to pass through the sediments instead of eroding the surface, and the layers of rock resist erosion by water and create steep slopes.

CHARACTERISTICS OF THE FORMATIONS

The Atlantic Highlands are underlain by different formations of marine and beach-complex origin (fig. 3). These layers range in thickness from a metre

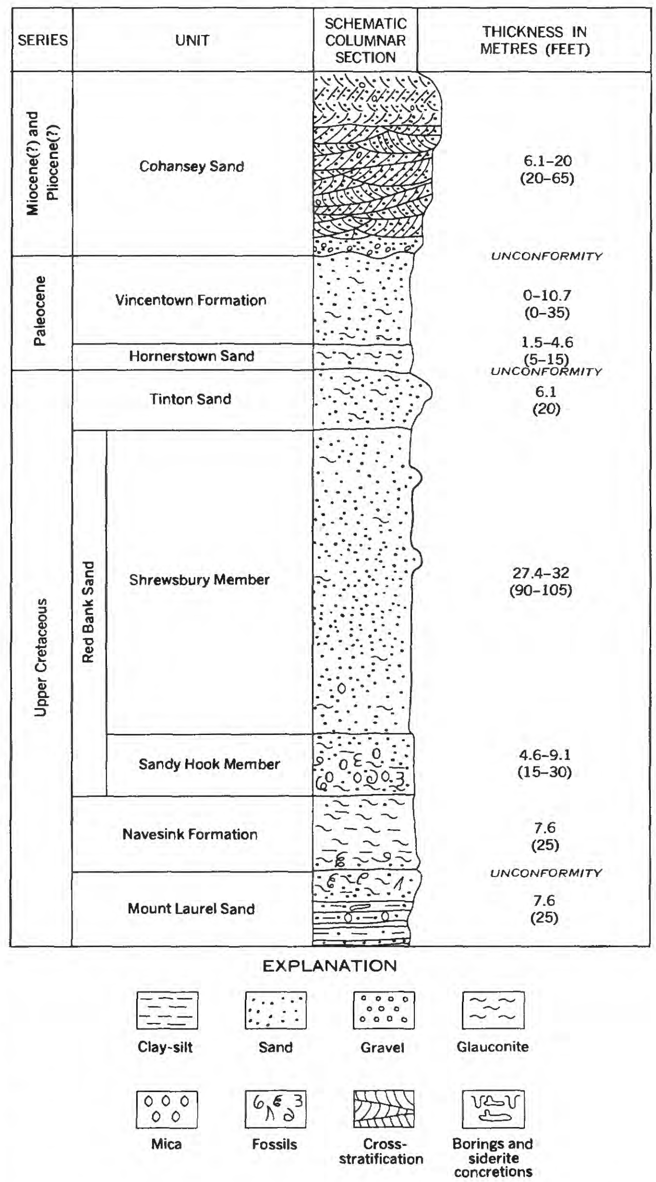


FIGURE 3.—Stratigraphic column showing formations of Late Cretaceous and early Tertiary age underlying the Atlantic Highlands.

[1] So shown on a map entitled "The province of New Jersey, commonly called the Jerseys." This map was published nearly 200 years ago on December 1, 1777, by William Faden, Charing Cross, London, England. It was based on a survey made in 1769.

(several feet) to slightly more than 30 m (100 ft). The formations are largely unconsolidated sands containing varying amounts of silt and clay. A detailed description of the stratigraphy has been given by Minard (1969). The significant characteristics of the formations are discussed below. Grain sizes are given in table 1.

TABLE 1.—*Average grain size of the material constituting each formation (in weight percent of the total sample)*

[Figures represent the average of five sieve analyses of channel samples of each unit]

	Grain size	Mount Laurel Sand		Navesink Formation		Red Bank Sand: Sandy Hook Member		Red Bank Sand: Shrewsbury Member		Tinton Sand	Hornerstown Sand	Vincentown Formation	Cohansey Sand	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper				Lower	Upper
Gravel	Granule to pebble	--	3	--	--	--	--	--	--	--	--	--	14	7
Sand	Coarse to very coarse	2	2	10	35	3	2	10	16	12	5	10	26	48
Sand	Medium	4	32	32	25	9	18	50	52	18	25	53	46	33
Sand	Very fine to fine	54	32	32	10	52	53	30	24	38	27	23	13	11
	Clay to silt	40	31	26	30	36	27	10	18	32	43	14	1	1

MOUNT LAUREL SAND

The oldest unit cropping out in the Atlantic Highlands is the Mount Laurel Sand. It crops out along the base of the bluff west of slump block B (fig. 2), where nearly the entire thickness of 7.6 m (25 ft) is exposed. The lower two-thirds of the formation is mostly thin-bedded very fine to medium-grained glauconitic quartz sand containing thin layers of clay and silt which constitute about 40 percent of this part of the formation (table 1). The formation is greenish gray to dark greenish gray; much lignite and mica are present. The upper third of the formation is thick-bedded coarse grained to pebbly sand containing about 31 percent clay and silt (table 1). Glauconite may constitute nearly half the formation in the upper metre (few feet), and fossils and fossil fragments are common there.

NAVESINK FORMATION

The Navesink Formation overlies the Mount Laurel Sand; it is a massive to thick-bedded clayey glauconite sand about 7.6 m (25 ft) thick. Clay and silt constitute about 26 to 30 percent of the formation (table 1). The rest consists almost entirely of fine- to coarse-grained glauconite sand. The formation is largely dusky green to greenish black and olive black. A small amount of quartz sand is present as a trace of fine grains throughout, but is especially plentiful in the base and near the middle. The formation underlies the lower and middle slopes of hills along Sandy Hook Bay.

RED BANK SAND

Overlying the Navesink Formation is the Red Bank Sand which is divided into two members, the lower Sandy Hook Member and the upper Shrewsbury Member (Minard, 1969, p. 16). The Sandy Hook is a compact dark-gray massive-bedded silty, clayey feldspathic quartz sand about 4.6 m (15 ft) to 9.1 m (30 ft) thick. The sand is fine to very fine and contains abundant mica, carbonaceous matter, and pyrite; glauconite is abundant in the basal metre (few feet). Fossils are abundant, and concretionary masses of siderite are present locally. Clay-silt content ranges from about 27–36 percent. The unit underlies middle slopes along Sandy Hook Bay and lower slopes along Navesink River. The Shrewsbury is a massive-bedded silty and clayey, fine to medium feldspathic quartz sand about 27.4–32 m (90–105 ft) thick. Many coarse grains and some very coarse grains are present, especially in the upper half of the member (table 1). Much of the member consists of fairly loose sand, except locally where crusted or cemented by iron oxide. Clay-silt content ranges from about 10–18 percent. The unit underlies middle to upper slopes along Sandy Hook Bay and along Navesink River.

TINTON SAND

The Tinton Sand overlies the Red Bank Sand and is the uppermost unit of Cretaceous age in the area. It is massive-bedded clayey, medium to very coarse feldspathic quartz-glauconite sand to glauconitic quartz sand. It is stained, crusted, and cemented by iron oxide and is mostly shades of brown. The sand is poorly sorted; grain size ranges from clay and silt to very coarse (table 1). Granules are locally abundant, and some pebbles are present in the upper metre (few feet). Glauconite also is more abundant in the upper part. Clay-silt content is about 32 percent. The unit underlies steep middle to upper slopes of the highest hills.

HORNERSTOWN SAND

Unconformably above the Tinton is the Hornerstown Sand, the lowermost unit of Tertiary age. Typically it is dusky green and grayish olive, massive-bedded, poorly sorted clayey glauconite sand. Locally the upper metre (few feet) is oxidized to dusky red and may contain thin layers of ironstone. Several percent quartz sand is present throughout, and as much as 30 percent occurs in the basal half metre. Grain size ranges from clay to coarse sand; clay constitutes one-third to one-half the formation locally (table 1). The formation underlies middle to upper slopes of the highest hills. It is well exposed at Waterwitch on Sandy Hook Bay, along the north side of Navesink River, and near the top of several other bluffs at various localities.

VINCENTOWN FORMATION

The Vincentown Formation is thick to massive-bedded medium glauconitic quartz sand. Typically it is light greenish to yellowish gray, but locally it is moderate red and brown and is cemented by iron oxide. Glauconite content is nearly half the sand fraction in the basal metre (few feet). Grain size ranges from clay to coarse sand, but generally more than half the unit is medium sand (table 1). Much of the sand is clean and loose, but in some outcrops as much as 25 percent clay and silt are present. The formation does not appear to be fossiliferous in the Atlantic Highlands area, but it is very fossiliferous elsewhere (Minard, 1969, p. 24). It underlies steep middle and upper slopes in the hills.

COHANSEY SAND

The Cohansey Sand is composed chiefly of clean, somewhat pebbly, medium to coarse quartz sand; however, much fine and very coarse sand and granules also are present (table 1). The distinctive characteristic of the sand is the well-formed cross stratification. The sand typically is yellowish gray and grayish to pale yellowish orange, except where stained grayish red to moderate brown by iron oxide.

The basal contact is distinct and unconformable. In most outcrops it overlies the massive glauconitic sand of the Vincentown. Locally, the basal contact is irregular and cuts down through the Hornerstown to the Tinton (Minard, 1969, p. 28). Locally, basal beds are micaceous fine sand and silt and resemble the Kirkwood Formation. The Cohansey underlies the upper slopes and caps the highest hills in the area.

YOUNGER SEDIMENTS

In addition to the previously described units, thin bands of alluvial and tidal-flat material are present along drainage and waterways, and a thick mass of beach sand constitutes Sandy Hook, the barrier bar, and the flat beach area at Waterwitch and Highlands.

INDURATED LAYERS

Some layers of the sediments locally are cemented to varying degrees—from weakly to firmly indurated. The cementing agent is chiefly iron oxide and some iron carbonate. These cemented layers range in thickness from about a centimetre to a metre (½ in. to a few feet) and are locally discontinuous and highly irregular. Typically, the cemented layers are in the coarser material. The layers appear to result from precipitation of excess iron from the ground water where the water becomes sufficiently aerated to oxidize iron, which coats and cements sand grains or pebbles. This process commonly occurs where sand layers intersect a slope and ground water flows outward and down the slope. It also occurs where upward-flowing ground water reaches the surface beneath a stream, and the iron oxide-cemented gravel armors the streambed (Lang, 1961). Although indurated layers are common in sediments of the Atlantic Highlands, they probably constitute only several percent of the total volume of the sediments. The formations containing the most ironstone are the Shrewsbury Member of the Red Bank Sand, the Tinton Sand, and the Cohansey Sand.

STRUCTURE

The layers of sediments in the Atlantic Highlands hill mass resemble those in a layer cake tilted at a low angle towards the southeast, so that the layers dip in that direction from about 1.8 to 7.3 m per kilometre (10 to 40 ft per mile). The top several layers have been dissected by erosion, so that a rugged hilly surface remains.

There are local anomalies to this general picture, especially in the younger (upper) formations. For instance, as described by the author (Minard, 1969, p. 35):

> The base of the Hornerstown Sand is nearly horizontal near Hilton (pl. 1), but the dip increases sharply southeastward, in the hills south of Highlands. The base of the formation near the Hart horizontal control station is 100 feet (30 m)

lower than it is 1 mile (1.6 km) northwest. This relationship may be due to an increase in dip, or it may be the result of displacement along faults or slumps. Several northeast-trending lines in the groups of hills south of Highlands, as seen on aerial photographs, strongly suggest the presence of faults or slumps. Because of the scarcity of outcrops and the highly dissected topography, which prevents augering in critical areas, it was not possible to demonstrate the existence of faults or slumps there.

HISTORICAL NOTES

During geologic mapping of the Sandy Hook quadrangle in 1963 and 1964, the author speculated on the age of the slump blocks (Minard, 1969, p. 40). It was thought that slumping was caused by wave action from the open ocean undercutting the bluffs, as was believed by Fuller (1914, p. 55) for the slump blocks on Long Island. Because Sandy Hook spit protects the bluff between the boroughs of Atlantic Highlands and Highlands (fig. 2) from the open ocean, the author believed that the slumping predated the hook which was thought to be, at least in part, several thousand years old (Minard, 1969, p. 40). A search through the literature, however, reveals some interesting information. There was an early awareness of the changing shape and ephemeral nature of parts of Sandy Hook spit. Although parts of the spit may be several thousand years old, the narrow southern part, south of Plum Island (Island Beach in fig. 4), is younger. Merrill (in Cook, 1885, p. 59, 60, 75–79) discussed the changing shape of Sandy Hook spit. According to Merrill (p. 60), "the Hook has increased in length and breadth so as to include more than four times the area it covered in 1685" (a period of 200 years at Merrill's writing). A map in the front of the Annual Report of the State Geologist for 1885 (Cook, 1885) shows various surveys of the Hook from 1685 through 1853, as well as the 1885 shoreline (fig. 4). It is of interest to note that in Keith's survey of 1685, the Hook did not appear to be connected with the mainland. Merrill (p. 77) stated:

From a point about one and one-third miles [2.1 km] north of Highlands to about one mile [1.6 km] south of it, near Bellevue, on the N. J. S. R. R., the beach has been washed away and remade again and again since the settlement of the country, and doubtless previously by Shrewsbury inlets, once important to navigators. The dates of the inlets, which have been handed down mainly by tradition, are as follows * * * * Previous to 1778 Sandy Hook was connected to The Highlands of Navesink by a narrow isthmus or bar [Lawrence's survey, fig. 4] and the Navesink or North Shrewsbury river was open to the ocean on the east, there being no beach for about three miles [4.8 km] north of the present Seabright [fig. 2]. In 1777–8 a passage was broken through the isthmus, and the tidal currents flowing through this channel allowed the waves to build up gradually a bar or sand reef which

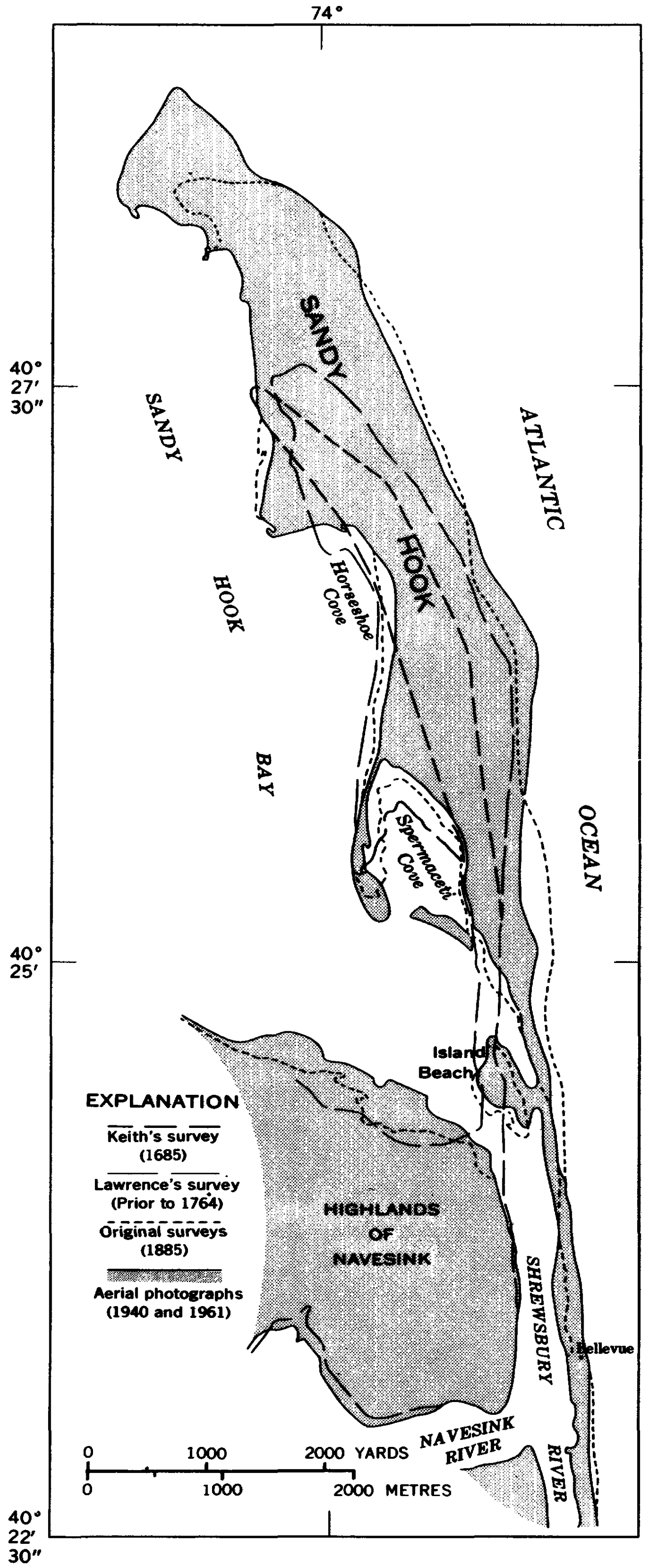


FIGURE 4.—Map of Sandy Hook spit showing progressive changes in shoreline during the period 1685–1961 (modified from Cook, 1885).

closed the eastern passage [through the present bar near Bellevue, fig. 4] or old Shrewsbury inlet in 1810. From this time on the outer beach continued and the Navesink River flowed through its present outlet [north and northwest, fig. 4] until 1830 or 1831, when a breach was made in the sand reef and the second Shrewsbury inlet was formed. Shortly after a bar formed across the present mouth of the river and connected Sandy Hook with the mainland, just north of Highlands, by way of Island Beach [fig. 4]. About 1835 the residents of the vicinity undertook to open a channel through the bar, and after much labor cut a ditch through it, which was gradually widened and deepened by the tides until it became navigable. The second inlet opened in 1830 or 1831, and closed about 1840. The third opened in 1837 or 1838, and for a time there were two navigable inlets—the second or more southerly being most used. The east inlet closed in the latter part of 1848. Within the past 35 years the sea has made occasional breaches in the strip of beach under discussion [the offshore bar that presently (1974) connects Sandy Hook with the mainland in the vicinity of Long Branch adjacent to the south of the map area [fig. 4], but the efforts of property owners, and especially of the railroad company, since the building of the road, have prevented them from attaining any magnitude.

An earlier report by Barber and Howe (1844) gave several dates approximately agreeing with Merrill's observations. They stated (p. 361) that "Sandy Hook * * * changed its character from a promontory to an island in 1778, by an opening forced by the sea, termed the old Shrewsbury Inlet. In 1800 the inlet was closed, and the Hook again became a promontory until 1830, when it was reopened and now is an island."

The point of this discussion of the frequent breaching of the barrier bar connecting Sandy Hook with the mainland is to show that the open ocean apparently did have access to the bluffs of Highlands through breaches in the bar as much as 4.8 km (3 mi) wide. The sandy flats at Waterwitch and Highlands probably were at maximum width when the bar to the east was intact and the Navesink-Shrewsbury River flowed north into Sandy Hook Bay. This is suggested because these sandy flats are similar to a point bar. During this time the bluffs would be protected. However, when the bar was breached, the sand load carried by the rivers would be carried east, and open ocean waves and tidal currents could erode the "point bar," possibly enough to expose the base of the bluffs to active wave and tidal current erosion. If this breaching were typical for hundreds of years before recorded history of the events, slumping may have taken place more recently than originally thought. Some of it may have occurred within the past few centuries.

The different physical characteristics of what appears to be slump block B (fig. 2) was recognized by Merrill (in Cook, 1885, p. 76). In the figure titled "Section across Navesink Highlands and Sandy Hook," slump block B is shown as a terrace at Hilton Park, of different lithology than the bluff behind it (fig. 5). Shown in section with vertical exaggeration, the terrace seems to occupy a precarious position.

Documentation for slumping was sought in the literature, and two references were found. One of these is in Cook (1868, p. 348); he discussed the wear of beaches and shorelines by water and waves, stating that:

At Long Branch, which is hard upland, the wear is very serious. The spot where the first boarding house was located,

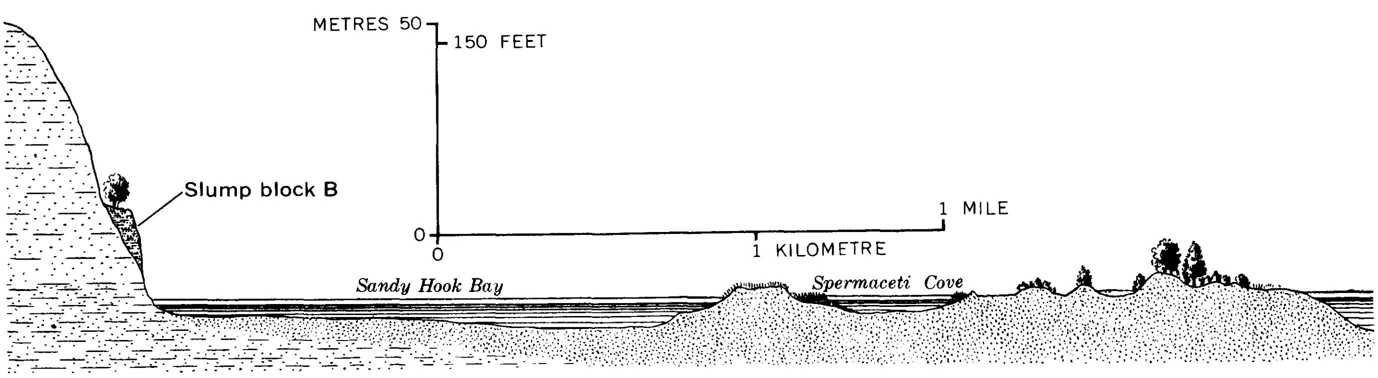


FIGURE 5.—Section showing what probably is slump block B as "a terrace at Hilton Park." From Cook, 1885, page 76.

thirty years since, together with road which ran behind it, is now all worn away, and the shoreline is west of it. The wear is irregular; last year it was from 12 feet [3.7 m] to 20 feet [6.1 m]. Along the shores of Sandy Hook and Raritan Bay the wear is equally rapid. *At the Highlands enormous slides have been the result of this wear* [italics added].

Cook does not say when these slides occurred, but there seems a suggestion of recency. It also seems to indicate agreement with wave cutting or water erosion of shorelines as the mechanism causing the slides. Perhaps there were slides in the bluffs east and southeast from slump block A, including the bluff at the east end of the hills bordering the present north-flowing segment of the Navesink-Shrewsbury River. If so, the slides have been removed by water currents and probably deposited as the sandy flats at Highlands and along the west side of Sandy Hook spit.

The second reference to slumping is more revealing. Barber and Howe (1844, p. 357) reported that:

In the spring of 1782 a slide of earth happened at Greenland bank, the highest point of the highlands, situated two miles north of Beacon hill. The noise was heard for a distance of several miles. The annexed account was published at the time: On the ridge of mountains, commonly called Navisink hills, in Monmouth co., East Jersey, a considerable quantity of land, some say 40 acres, gave way, in April last, and sunk directly down a considerable depth; forming a cavity equal in circumference, at bottom, to the void space above. The tops of the trees, that sunk with the soil, and which were mostly of considerable bulk, are now nearly level with the edges of the remaining ground. Round this again the earth opens, in one continuous fissure, a foot or more in breadth, for a considerable distance; and, as is conjectured, from its present appearance, will shortly go down also—the foundation being perhaps but a loose quicksand. It is supposed, by the country people thereabouts, to have been occasioned by the washing and undermining of the sea, to which it is contiguous.

From the above information it is difficult to pinpoint the location of the slide. Barber and Howe (1844) located it 3.2 km (2 mi) north of Beacon Hill. According to them (p. 356, 357), Beacon Hill is the hill on which Navesink Lighthouse is situated (fig. 2). They referred to the lighthouse as Highlands Lighthouses (p. 356) on Navisink Hills (p. 357). A location 3.2 km (2 mi) north of their Beacon Hill is presently in the east part of Spermaceti Cove, 1.6 km (1 mi) north of Plum Island (figs. 2 and 4); a location 3.2 km (2 mi) northwest is on the wide east end of slump block B (B1, B2). Slump block A is 2.4 km (1.5 mi) northwest of Beacon Hill.

If Greenland bank is at the highest point of the highlands, this suggests that the slide is slump block A or in the near vicinity. Other than the current slumping (1972–74), slump block A is the most youthful-appearing major block. The highest altitude presently shown (81 m (266 ft)) is at the water tower about 183 m (600 ft) directly behind block A. An altitude of 80 m (263 ft) is shown only 91 m (300 ft) from the top of the scarp at the southwest part of block A. If the writers meant at the highest part of the bluff face, it could be any place from Navesink Lighthouse all the way west nearly to Atlantic Highlands. It is interesting to note that the slide of earth "is supposed, by the country people thereabouts, to have been occasioned by the washing and undermining of the sea, to which it was contiguous." If it were contiguous to the sea, then Sandy Hook probably was an island (fig. 4), and open-ocean and tidal currents scoured the bases of the bluffs, as postulated by Minard in 1969 (p. 40). Not being aware, at that writing, of the absence of the bar at different times in the 18th and 19th centuries, a much older date was proposed than is now believed. The slide of April 1782 may be one of those mentioned by Cook, or his slides may have been subsequent ones, possibly associated with lines of weakness developed by the slide of April 1782. If this slide is not the one I map as slump block A (or one of those shown in fig. 2), it may have been completely eroded by waves and currents.

It seems then that an awareness of the instability of parts of the shoreline in question was, in part, recorded at least in geologic literature. However, if there has been no more recent mention (other than that by Minard, 1969) of slump blocks in the area than those by Cook (1868, p. 348 and Barber and Howe, 1844, p. 357), it is easy to understand the apparent lack of public awareness of these few lines of reference in communications not widely read by builders or members of the community and planning committees.

This seems to point out the desirability of better dissemination and use of pertinent geologic information among officials of political subdivisions concerned with zoning and land use. An awareness of the benefits of such information is presently being realized, particularly in certain metropolitan and suburban areas, through the preparation and use of geologic hazard or constraints maps. Maps and studies by knowledgeable engineers and geologists, who probably are more likely to recognize geologic hazards such as landslides, faults, and flood-prone areas, can result in information that can be used by local officials to plan and regulate land use so that natural catastrophies will less likely be initiated or hastened by human activity and so that damage can be averted.

SUMMARY OF CHARACTERISTICS OF SLUMP BLOCKS

The slump blocks described in this report are typical of the landslides of Fuller (1914, p. 55, 56), the Toreva block of Reiche (1937, p. 538), the slump blocks described by Sharpe (1938, p. 68) and Strahler (1940, p. 288, 289), and those mapped by Minard in Arizona (1956 a, b).

Several features and events are characteristic of the slump or Toreva blocks. These features and events are:

1. Downward movement of a mass of rock and (or) earth.
2. A rotational movement of the block normal to the scarp face of detachment.
3. Inward tilting of the upper surface of the block and an upward drag of the beds in contact with the scarp face down along which the block is sliding.
4. An elongate depression on the scarp side of the surface of the block resulting from the tilt and drag.
5. A concave scarp from which the inner convex surface of the block detaches, and a convex bulge at the outer base or toe of the block.

The history of slumping of a block is illustrated diagrammatically in figure 6. Also typical of many slump blocks is the secondary slumping that shears the primary block approximately in two and results in farther downward movement of the resultant outer block and additional rotation and tilting of beds in this block (fig. 7). More shearing and slumping in the secondary block is possible, particularly in unconsolidated sediments (Sharpe, 1938, figs. 8, 11, pls. IV B, VII A). Secondary shearing, however, is not characteristic of Reiche's Toreva block, which is considered a single large mass of unjostled material (Reiche, 1937, p. 538). A block diagram of a typical slump block, with names of the various parts, is shown in figure 8.

The degree of tilt of the upper surface of a slump block towards the scarp of detachment varies considerably. Dips of the upper tilted beds may range from a few degrees to at least as much as 79° (Minard, 1956 a, b; Reiche, 1937, fig. 5). It appears that the farther away from the point of detachment, the steeper the tilt (Minard, 1956, a, b; Reiche, 1937, fig. 2, 6). Also, the upper beds in the outer block or

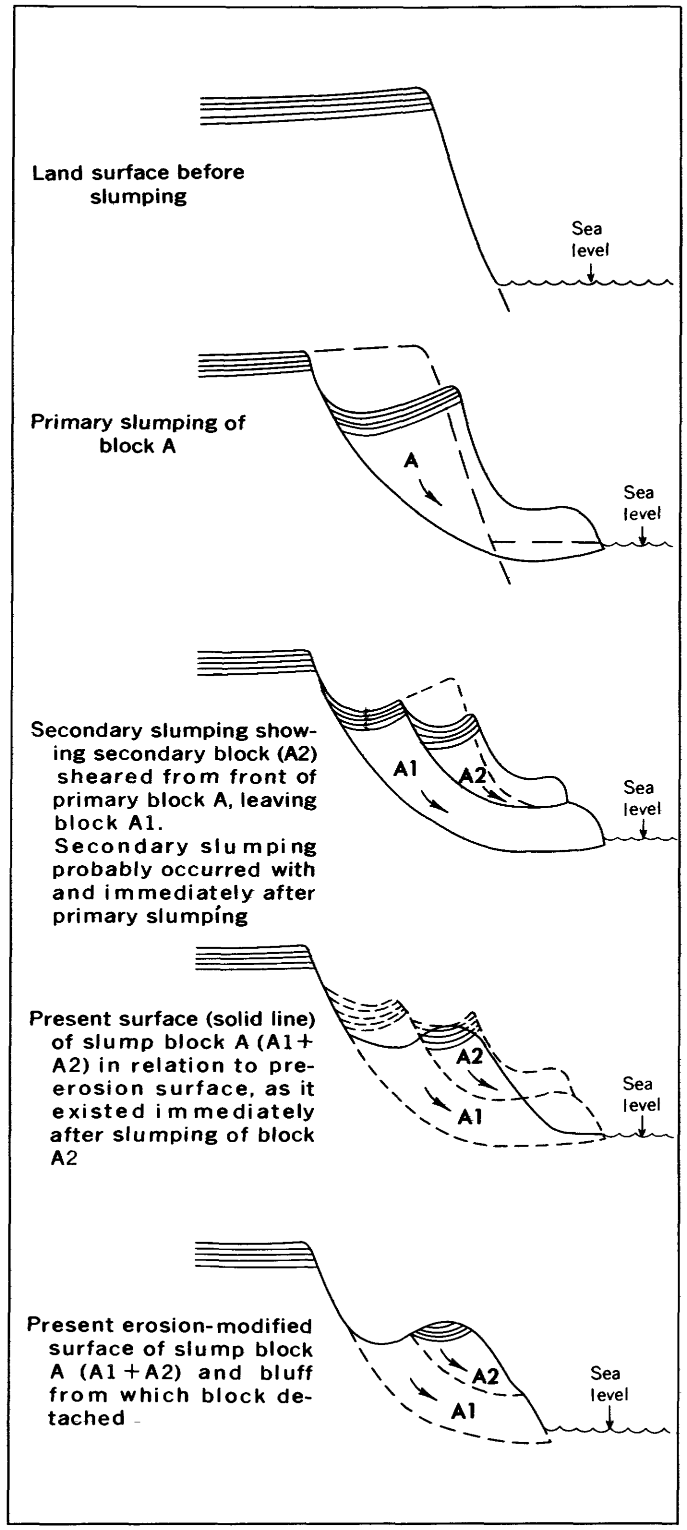


FIGURE 6.—Diagrammatic cross sections through the bluff at the location of slump block A (fig. 2), showing progressive steps in the history of the slumping.

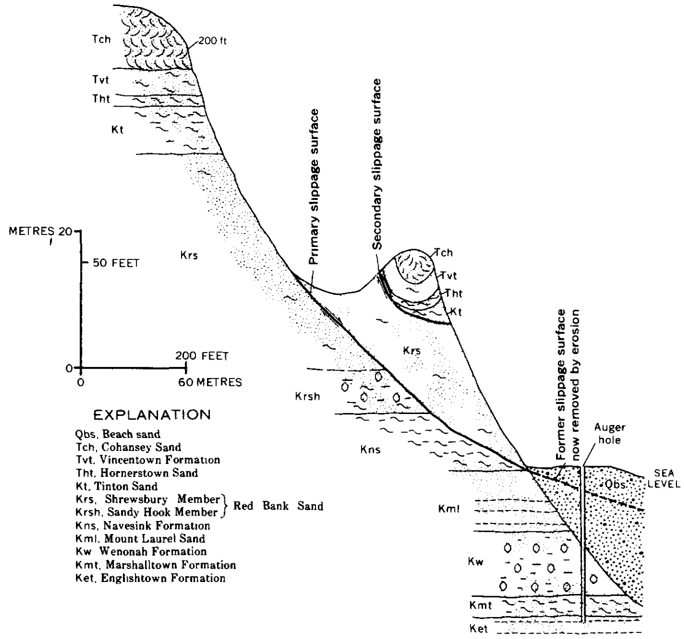


FIGURE 7.—Cross section (looking west) of slump block A in the bluff just west of Waterwitch (fig. 2). Vertical displacement of the small secondary block is about 85 feet. Vertical exaggeration × 4. See figure 3 for explanation of lithologic symbols. Modified from Minard, 1969, figure 13.

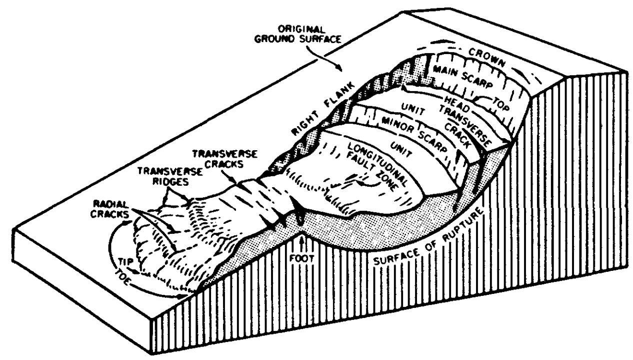
blocks, which are farther from the point of detachment, usually have a steeper dip than similar beds in the inner or primary block (fig. 9).

DESCRIPTIONS OF INDIVIDUAL SLUMP BLOCKS

BLOCK A

Block A is a complete block, about 137 m (450 ft) wide by 425 m (1,400 ft) long—a classic example of a definite rotationally slumped earth mass. It has the convex inner face nestled into the concave scarp along which it slumped downward; the top of the concave scarp is outlined by the road on top. The block has a very prominent bulge at the toe where it has moved a considerable distance away from the bluff. It has a conspicuous sag or depression on the inner upper surface. The sag is about 3 to 3.7 m (10 to 12 ft) deep, 46 to 61 m (150 to 200 ft) long, and 12.2 m (40 ft) wide in the middle, tapering to closure at each end.

The block has a secondary line of failure and slump block (A 2) near the middle of its cross section (fig. 7). The beds in block A 2, which originally were continuous with the beds at the top of the bluff 26 m (85 ft) above, have rotated from a nearly horizontal attitude to about 40° inward and have been dragged on the inner surface to nearly 40° outward



TIP—The point on the toe most distant from the top of the slide

FLANK—The side of the landslide

CROWN—The material that is still in place, practically undisturbed, and adjacent to the highest parts of the main scarp

ORIGINAL GROUND SURFACE—The slope that existed before the movement which is being considered took place. If this is the surface of an older landslide, that fact should be stated

LEFT AND RIGHT—Compass directions are preferable in describing a slide, but if right and left are used they refer to the slide as viewed from the crown

MAIN SCARP—A steep surface on the undisturbed ground around the periphery of the slide, caused by movement of slide material away from the undisturbed ground. The projection of the scarp surface under the disturbed material becomes the surface rupture

MINOR SCARP—A steep surface on the disturbed material produced by differential movements within the sliding mass

HEAD—The upper parts of the slide material along the contact between the disturbed material and the main scarp

TOP—The highest point of contact between the disturbed material and the main scarp

FOOT—The line of intersection (sometimes buried) between the lower part of the surface of rupture and the original ground surface

TOE—The margin of disturbed material most distant from the main scarp

FIGURE 8.—Block diagram showing names for various parts of a landslide or slump block (from Varnes, 1958, pl. 1).

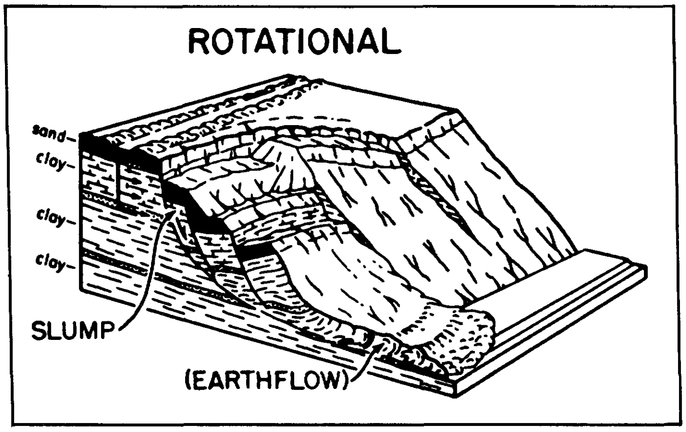


FIGURE 9.—Block diagram showing steeper scarpward tilt of upper beds in outer blocks (from Varnes, 1958, pl. 1).

(fig. 7). The primary (inner) slumping apparently was bottomed in the basal member of the Red Bank Sand and Navesink Formation. Secondary slumping was largely in the upper member of the Red Bank Sand. As can be seen in figure 2, several houses have been constructed on the block. A sand pit is present, from which much material has been removed in the past decade. This probably is beneficial in that it has taken much load off the block. It was in the sand pit that excellent exposures of the different lithic units made it easily possible to correlate these units with those from which they were separated in the bluff 26 m (85 ft) above.

The inward tilt of the upper surface, characteristic of the rotated block, is clearly evident on block A.

BLOCK B

Block B, a definite slump block, is shown in four segments in figure 2. Blocks B 1 and B 2 were mapped by the author (1969) as block B. The wider eastern part of the block is again the classic convex shape fitting into the concave scarp of detachment (outlined by the road). The upper surface is depressed near the inner part, parallel to the long axis, as it is on block A. The overall length of the entire block (B 1–B 4) is nearly 900 m (2,950 ft); the widest part is about 120 m (390 ft). There are no good exposures on the block. Some large (1.2 by 3.6 m (4 by 12 ft)) blocks of ironstone are present and have given confidence to some home owners that their houses are on good solid rock. A detracting aspect, however, is the fact that these blocks are tilted scarpward as a result of rotation during the downward movement of the block.

Block B 2 forms a ramplike feature from west to east; this surface expression reflects the vertical displacement along a secondary line of rupture.

Blocks B 3 and B 4 are new slump blocks that apparently have formed since the summer of 1972. They will be described in more detail in a following section on current slumping.

BLOCK C

Block C is the third and last block shown on plate 1 of Minard (1969). The highest part of this probable slump-block surface is at an altitude of about 30 m (100 ft). The top of the slope above is about 60 m (200 ft) in altitude. The block's maximum dimensions are about 120 m (390 ft) wide and 610 m (2,000 ft) long. From aerial photographs it appears that a secondary outer block may be present. The upper surface of the southern half of this block tilts inward towards the scarp, as would be expected of a rotational block. Except for a narrow strip of beach, the basal part of this block is in direct contact with the water, possibly a serious situation.

BLOCK D

Block D, as outlined in figure 2 is a probable slump block. It is fairly large, about 180 m (590 ft) wide by about 450 m (1,475 ft) long and has several features of a typical slump block. It has a convex inner bulge fitting into a concave scarp which is modified considerably by erosion, except at the west end. The surface of the block noticeably tilts or slants inward. It may be wise to avoid building large structures on this block.

BLOCK E

Block E is a possible small slump block. There has been considerable surface modification by man, but a small concave scarp is characteristic.

BLOCK F

The significant feature here is not a slump block, but the concave scarp that suggests that a slump once occurred, the block having been almost completely eroded, leaving only the typical scarp.

BLOCKS G AND H

Blocks G and H are possible small slumps of minor downward displacement in the bluff between and above blocks A and B. Block H particularly shows a typical convex inner outline, fitted into the concave scarp behind it.

BLOCK I

Block I, near the west end of the bluff not far from Atlantic Highlands Yacht Harbor, has the typical convex-concave profile from above. It is about 45 m (150 ft) wide and 225 m (740 ft) long.

OTHER POSSIBLE SLUMPS OR ZONES OF WEAKNESS

A possible line or zone of weakness may extend westward from block I, but it is not clearly defined.

A line of weakness also may be in the slope just southeast from Navesink (Twin Light) Lighthouse. The slope has a concavity, and material at the base appears jumbled and disturbed. A possible slump block may be at the point of land at triangulation station Lower, southeast from the Air Force Reservation. The bluff east of block C to the bridge is steep and appears to be the product of active erosion and slumping. This also is true for the steep bluff along the north side of Navesink River just northwest from triangulation station Hart.

LINEAMENTS

Short dashed line in figure 2 represents linear features apparent on the aerial photographs. A cluster of such features is evident in the wooded hills southeast from Navesink Avenue. A few other lineaments are northwest of Navesink Avenue and south of Locust. These lineaments may be a reflection of joints or fractures, possibly in the iron-oxide-cemented layers in the upper Red Bank, Tinton, and Cohansey Sands. They may indicate zones of relative weakness.

RECENT EROSION

Surface erosion is active in many places along the bluffs. Many gullies groove the face of the bluff east from near Atlantic Highlands Yacht Harbor to the west ends of blocks B3 and B4. This erosion is largely the result of rainwater runoff, plus groundwater seepage and sapping towards the lower parts of the slopes. Much of the material eroded is loose soil mantle resulting from weathering processes. However, many of the gullies bottom in more compact less weathered in-place material. The combination of surface wasting, solifluction, and sheet and gully erosion constantly removes appreciable volumes of material from the bluff face. This material is carried to the toe of the slope, where it may form temporary small alluvial fans. Much of the material eventually reaches the bay shore and is removed and redistributed by wave and tidal action.

A deep gully cuts into the scarp above the east end of slump block B. Another gully is being extended upward in the headwall above the west end of block A. The vertical headwall is 4.6 m (15 ft) high at present in this gully. A quantity of eroded material forms a heap just above the road near the base of the slope.

Probably the largest area of surface erosion is in the scarp at the east end of block A. A large area of the bluff face is bare, and erosion has migrated headward to the road at the top edge of the bluff.

Erosion is apparent in the scarp of block D, mainly as surface wash. Surface wasting is evident in the upper face of the high bluff on Navesink River, just northwest from triangulation station Hart.

Many small gullies are present elsewhere, such as on the face of block C and nearby. None of the gullying in the bluffs along Navesink River is as severe as that in the bluffs along the south side of Sandy Hook Bay.

On January 23, 1974, a natural vertical drainage hole (fig. 10) was in the floor of the borrow pit on

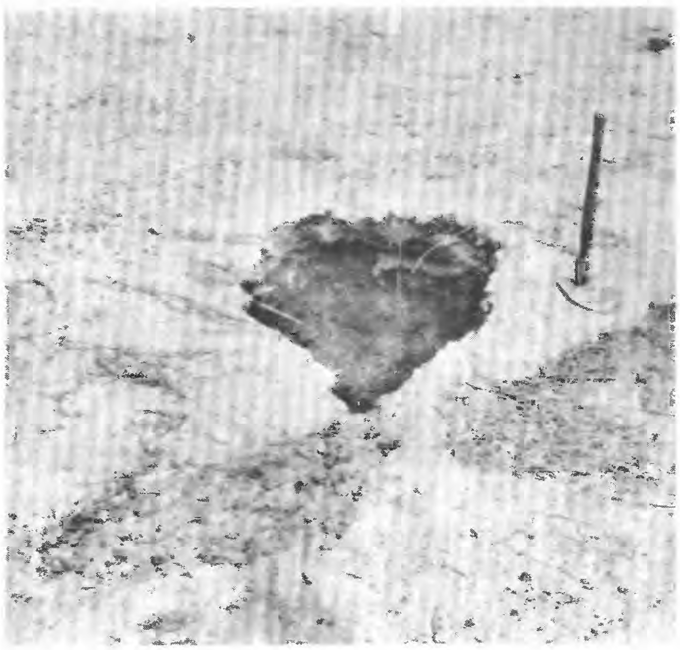


FIGURE 10.—A natural vertical drainage hole in the floor of the borrow pit on slump block A 1. As observed on January 23, 1974, the hole appeared to be the drain for hundreds of square metres of pit floor. This would suggest a permeable zone or "pipe" that might result in piping of underlying sand and caving of the surface. The formation is the upper member (Shrewsbury) of the Red Bank Sand.

block A (A 1 plus A 2). The hole was near the middle of block A 1. Drainage lines from all over the pit indicated that rainwater from hundreds of square metres had drained into the hole. This suggests a permeable zone or "pipe" that might result in piping of underlying sand and caving of the surface.

It is interesting to compare the stages of erosion shown on photographs of different years. Photographs taken after the aerial photographs of 1961 (fig. 11) show that erosion is farther advanced. These differences can be seen on the photograph taken in March 1966 (fig. 12) and that taken in

FIGURE 11.—Stereoscopic pair of vertical aerial photographs showing slump blocks A and B on the bluffs along the south side of Sandy Hook Bay. Scale 1:17,500. Photograph by Aero Service Corp., April 1961.

February 1974 (fig. 13). The gully in the scarp above and near the west end of block A is much deeper and wider at present than it appeared on the stereoscopic pair of aerial photographs taken in 1961 (fig. 11).

CURRENT SLUMPING

Noticeable slumping was reported by local residents to have begun sometime during the summer of 1972. The area affected is slump block B (as mapped by the author in 1969) and the area adjacent to the west of it. These blocks are now labeled B 1, B 2, B 3, and B 4 (fig. 2). At present, B 1 is the least active. No appreciable movement is noticeable on most of it, but cracks in the road pavement and rock wall at the west end of the inner rupture zone of the block indicate some reactivation here or an extension of a line of rupture westward from the previous curved west end of slump block B as shown by Minard (1969, pl. 1).

On January 24, 1974, 22 houses and 8 garages were on, or mostly on, block B 1. Block B 2 has been noticeably reactivated; near the longitudinal middle of this block, several houses and properties are being adversely affected by the slumping. Two houses have been damaged (figs. 14, 15), largely through vertical displacement of as much as 0.3 m (1 ft). An open crack passes in back of two more houses. This crack has been open as much as 20 cm (8 in.) wide and 1 to 1.3 m (3 to 4 ft) deep. At least one stone wall has been cracked completely through. West of here, concrete steps leading down to the shore are conspicuously cracked all the way across; the upper more pronounced crack is shown in figure 16. According to Mr. Edward Weiler (oral commun., January 25, 1974), the steps were not cracked in the fall of 1973.

Blocks B 3 and B 4 appear to be new blocks. No visible evidence of them appears on the aerial photographs of 1961. The movement on block B was first noticed by the local residents in the summer of 1972 (Mr. Martin Jensen, oral commun., June 7, 1973). A new scarp about 4 to 5 m (13 to 16 ft) high is present at the top of the slumping area immediately in back of the line of houses on top of the bank (fig. 17). One house lost its back porch

FIGURE 12.—Oblique aerial (helicopter) photograph (looking west) showing extent of surface erosion on the bluff face (center of photograph) on March 16, 1966. Vertical distance from road on top of bluff to road at base of bluff is about 60 m (200 ft). Slump block A is on right part of photograph. Compare extent of slope erosion with that shown in figure 13. The present front of block A lies about 100 m (several hundred feet) bayward (to the right) from its pre-slump position in the bluff.

(fig. 18), one house has been moved back, another has had its foundation footing exposed, and two more are only a metre or two from the line of failure. This line of failure, at least in the upper exposed part, is in the loose-bedded sand of the upper Red Bank Sand. It may be an extension of the line of failure behind slump block B 1, which was mapped by the author in 1963–64 (Minard, 1969, pl. 1) as crossing Bayside Drive near the curve where the road abruptly turns south and uphill. No cracking was visible in the pavement at the time of that mapping. On June 7, 1973, however, cracking was visible in the edge of the road and through the stone wall. By January 25, 1974, this cracking in the pavement had multiplied and extended across the road and widened considerably in the stone wall (fig. 19); vertical displacement in the road pavement was 6 to 8 cm (3 in.).

The surface of the slope on blocks B 3 and B 4 is irregular and unstable, a truly jumbled mass. Actually, more than two blocks are present; several fissures have opened below the main upper scarp at the rear of the houses, dividing the main blocks into smaller blocks (figs. 20, 21). As a result, trees have been tilted at considerable angles from vertical (fig. 22), vines have been stretched taut between blocks. Most movement is down on lower blocks relative to upper blocks, but in some instances upper blocks have slid down and wedged beneath lower blocks so that the upper edges of the lower blocks actually

FIGURE 13.—Oblique aerial (helicopter) photograph (looking west) showing extent of surface erosion on the bluff face (center of photograph) on February 13, 1974. Vertical distance from road at top of bluff to road at base of bluff is about 60 m (200 ft). Inner part of slump block A is at far right; scarp is above and left of it. Compare extent of slope erosion with that shown on figure 12, nearly 8 years earlier. Erosion has extended upward, nearly undercutting the road, and laterally. Erosion has cut back into the face of the bluff, as is indicated by the steeper banks bordering the edges of the scar.

project about a metre above the lower edge of the upper block, illustrating the relative greater downward movement of the upper blocks.

It appears that initial movement in blocks B 3 and B 4 probably was in the toe of the slope, possibly as a base failure (at least below the base of the old railroad bed). As material at the toe moved towards the bay, support was removed from material above, which followed in possibly several stages of slope failure before the present uppermost block began the slumping that has produced the 4- to 5-m (13- to 16-ft) scarp behind the houses.

The lower slumped material may or may not have included other than surface waste and soil material. The upper block (B 3) has, at least in part, failed in material in place, carrying this and surface waste downward.

CAUSES

Processes leading to slides have been nicely summed up by Jones (1973, p. 10).

An examination of the processes leading to the slides suggests that the physical agents at work to produce slides are principally water, the weight of the slope-forming material, and gravity stresses * * * The events or processes that bring the agents into action are rains and construction operations. The modes of action of the rain are raising the piezometric surface in the slope-forming material, seepage toward the slope, removal of soluble binders in joints, subsurface erosion, rearrangement of grains, chemical weathering, and displacement of air in voids and joints. The modes of action of construction operations are high-frequency vibrations and an acceleration of creep by undermining and locally overloading the slope. The modes of action combine to produce changes in the stress of the slope-forming material, thus causing damage to intergranular bonds, rearrangement of grains, opening of new joints and closing of old ones, an increase in pore water pressure, and elimination of surface tension.

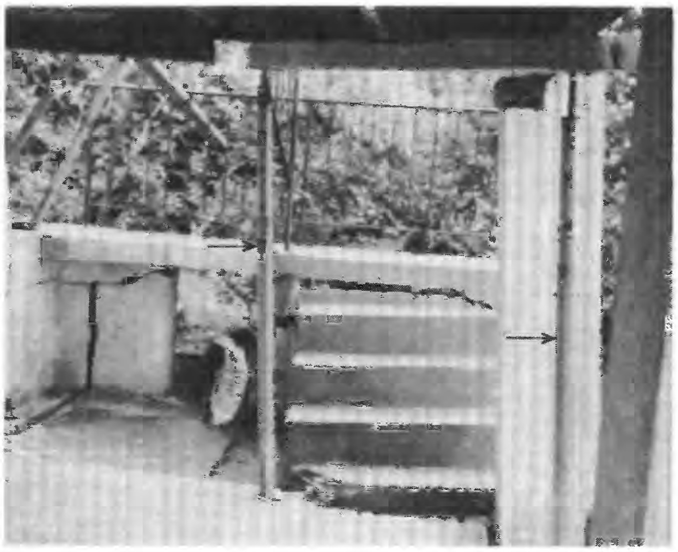


FIGURE 14.—House on wide eastern part of slump block B, straddling line of failure between subsidiary blocks B 1 and B 2, looking west. Settlement since summer 1972 has been more than 25 cm (1 ft). Note two jacks (arrows) holding up rear part of house. Photograph taken June 7, 1973.

FIGURE 15.—Next house west of one shown in figure 14. Major structural damage to house results from its position astride the line of failure between slump blocks B 1 and B 2. Settlement and breakage goes all the way through the house. Photograph taken June 7, 1973.

When some of the various elements of the processes combine to increase shearing stresses and to decrease cohesion and frictional resistance to a sufficient degree, a slide is activated.

Several factors may have been involved in the movement of all the B blocks—weight on top, removal of material at the toe, and excess water, both in the surface waste and material in place. Some residents speculated on a possible weakening effect resulting from the driving of piling for the new concrete bridge nearby. It appears that no additional weight was added to the top. Prolonged heavy rains took place before the first noticeable failures. This would tend to saturate the surface waste and soil, thereby increasing the weight and also increasing pore water pressure which can effectively reduce intergranular contact, hence internal friction.

FIGURE 16.—Breakage in concrete steps (see arrows) on the western part of slump blocks B 1 and B 2 (fig. 2). The steps were reported unbroken in late fall 1973. Photograph taken January 25, 1974. First slumping and ground breakage on the blocks were reported during the summer of 1972. This indicates observable movement continuing over a period of 15 or 16 months.

A higher water table in the material in place beneath surface waste and soil also could cause an increase in pore water pressure and decrease in internal friction in this material. This alone may have been enough to initiate movement. Local residents attribute initiation of movement to the excavation of a sewer trench near the toe of the slope.

An additional danger in the area is that if the outer blocks (B 2 and B 4) move downward and outward the loss of support may be enough to allow the inner or upper blocks (B 1 and B 3) to move more. This in turn could remove support from unslumped areas farther back in the bluff.

FIGURE 17.—Looking east from the west end of slump block B 3. Scarp on right is rupture zone at top and rear of the block. Total vertical displacement is about 4 to 5 m (13 to 16 ft), most of which is reported to have occurred during a 3-month period in the summer and fall of 1972. The flat grassy area at bottom left was level with the lawn at upper right before failure. Photograph taken January 24, 1974. House in background is shown in figure 18.

An interesting facet of the reactivation of old slumping and the initiation of apparently new slumping (other than settling) is the fact that the block seems to have been relatively inactive for a long time before, suddenly, very observable movement became evident. Such areas apparently can become critical by the addition of one or more ordinary factors.

ADDITIONAL CONSIDERATIONS

Because of the lithic nature of some of the formations involved, it is important to consider another set of physical and chemical factors. The lithic nature specifically is the glauconite and calcareous material in certain formations; the physical and chemical factors are the interaction of all the elements, particularly as a result of the role and effect of the glauconite and calcareous material.

During informal discussions with colleagues and other workers in the geologic, hydrologic, and engineering disciplines, it was interesting to learn opinions on the stability of the formations underlying the lower parts of the bluffs. Because in-place material of these formations is compact and firm as compared with surface waste, colluvium, and parts of the overlying formations, many consider these formations stable and not liable to slide.

The formations in question are the upper part of the Mount Laurel, the entire Navesink, and the basal part of the Red Bank (Sandy Hook Member). These formations have several things in common: They underlie the lower parts of the bluffs in the area under discussion; they are largely firm and compact-appearing in place; they are relatively unweathered; and, perhaps most important, in part, they all contain abundant glauconite and calcareous fossil re-

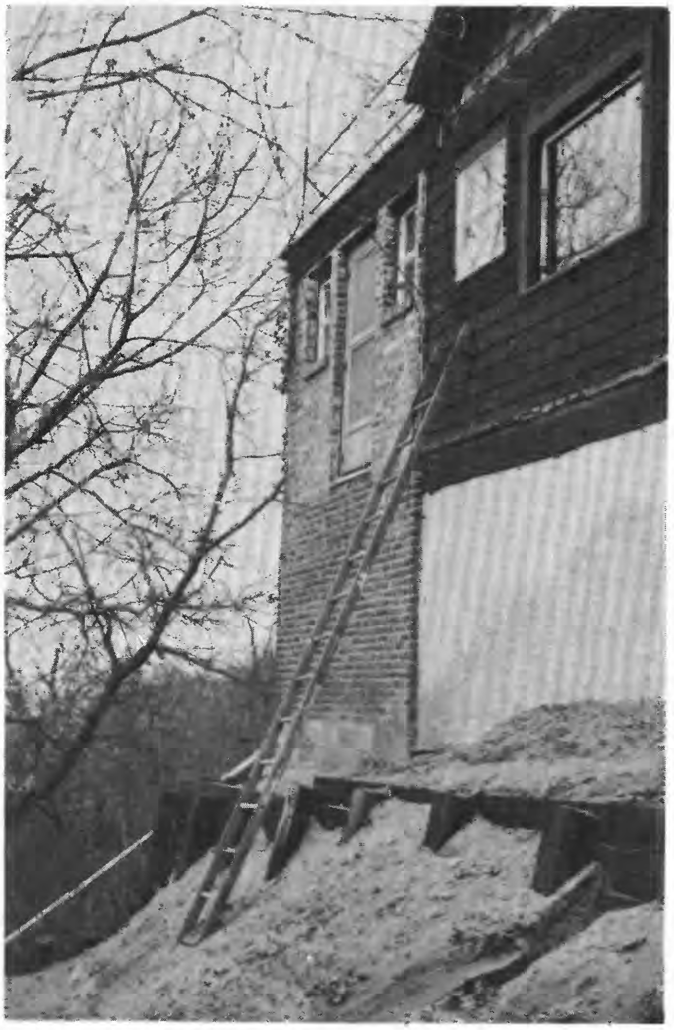


FIGURE 18.—House near east end of bank above block B 3, looking east. This is the house in the background of figure 17. The rear porch, which was attached to the house, collapsed when block B 3 dropped. Note position of door (watch that step!). Photograph taken January 24, 1974.

FIGURE 19.—Cracks in pavement of road and in wall at west end of block B 1 (block B as mapped in 1963–64 (Minard, 1969, pl. 1)). No cracking was visible when field mapped. Cracking was visible June 7, 1973, in parts of the pavement and wall. When this photograph was taken on January 25, 1974, cracking had multiplied and extended across the road, and the cracks were wider in the wall. Vertical displacement was as much as 6 to 8 cm (3 in.) in the pavement near the far side of the road.

mains. The upper part of the Mount Laurel Sand contains as much as 50 percent glauconite, the Navesink Formation contains as much as 70 percent glauconite and many calcareous shells, and the Sandy Hook Member of the Red Bank contains about 15 percent glauconite near the base and calcareous shells in great abundance. It apparently is because these formations appear largely as firm compact masses of material, subject, superficially, only to surface sloughing, that many consider them stable and not likely to slump. A search through the literature, however, reveals some interesting observations and interpretations in several papers.

Benson (1946, p. 328) noted that rocks in an area of landslides in the Dunedin District of New Zealand were divided by bands of incoherent sand or glauconite. He further noted (p. 340) that a railway tunnel passes through a ridge of Caversham Sandstone and that every feature favorable to landsliding

FIGURE 20.—View towards west of a fissure 1 m (several feet) and more deep, separating blocks B 3 and B 4. The fissure is several tens of metres long. Note tilt of tree caused by collapse into fissure.

is present—moderate rainfall, jointed porous sandstone resting on a thin layer of incoherent greensand (glauconite), seaward slope of beds, and frequent vibrations caused by railway traffic and wave

FIGURE 21.—View towards east showing one of the small scarps typical of those on slumps blocks B 3 and B 4. Vertical displacement is about 1 m (several feet).

attack on the closely adjacent shore. He noted that cracking of the tunnel lining with lateral and downward movement of the railroad were a constant source of trouble. He stated (p. 342) that the most rapidly moving point is nearest the north portal and that it probably moved on the greensand below "as if on ball bearings."

In the same year, Proix-Noé (1946) presented a paper with the interesting title "Etude de'un glissemént de terrain dû à la présence de glauconie" (Study of a landslide due to the presence of glauconite), in which she discussed landslides in the cliffs forming the amphitheater of Algiers Bay. She noted that (p. 1) "Since 1896, the amplitude of these accidents keeps increasing due to deforestation of the slopes that result from building development."

Throughout the paper, it appears that the author is emphasizing the importance of the combination of glauconite and calcareous material in the rocks. This is confirmed in the last paragraphs which are quoted here:

The geochemical action of water is determined by the presence of glauconite. Glauconite is essentially a hydrated alumino-silicate with heavy potassium contents, the structure of which is suited to base-exchange.

When crossing the molasse or calcareous formations, the water becomes charged with electrolytes, particularly calcium salts. In contact with the glauconite, the fixation of Ca^{++} ion and the liberation of alkaline ions occur, which fix the water at pH9. The alkalinized water acts as a peptising agent on the collodial micelles and hydrolyses [hydrolyzes]

FIGURE 22.—View toward east showing tilted inner surfaces of block B 4 where slumped down from block B 3. (right of photograph). Notice that trees are tilted scarpward, illustrating rotational nature of the block; some vines appear to be stretched taut.

the alumino-silicates, so that the permeability increases by putting back in suspension particles which are carried along by the water, and by the solubilization of the silicic ion. The marl bed gradually loses its rigidity and then slides. The undercutting at the base of the cliff provokes its periodic collapse.

The same area was discussed 2 years later by Drouhin, Gautier, and Dervieux (1948). These authors reached a conclusion similar to that reached by Proix-Noé, but perhaps stated more clearly and explained in greater detail. They outlined the stratigraphy (p. 104) as an ancient massif of shale and gneiss overlain by sandstone, which in turn is overlain by marl containing glauconite and capped by a calcareous molasse, containing "extensive cracks or pockets due to dissolution, and generally filled with red clay, resulting from decalcification." The history of the landsliding is described (p. 105) as "segregation of huge blocks of mollasse [cap rock] as a consequence of dissolution, perforation of the [underlying] altered marl by these blocks which then drift away very slowly without toppling over."

The authors further noted (p. 105) that "the origin of the phenomena, namely the progressive destruction of the mollasse, had not been explained up to now. Why did the marl not support the mollasse and why did the blocks, once segregated from the cliffs, drive [down] through the marl?" They found (p. 105) near the front of the cliff "a decompression of the marl beneath the mollassic table," and that only 500 to 700 m back from the front of the cliff was the "marl in its normal state of consolidation with a compaction in keeping with the load of the supported soils [molasse cap].

The decrease of the pressure [decompression] is due first to the water supply of the marl resulting from the mollassic infiltration and direct runoff."

Glauconite plays an important part in accelerating the process. Glauconite is found in the upper layers of the marl, underlying the mollasse. This mineral, iron and potash disilicate of variable composition, is an actual permutite which replaces in the ground water the ion Ca [calcium] by the ion K [potassium] through simple contact, and with a strong increase in pH * * *

Water, thus alcalinized results in the defloc[c]ulation of the marl, which is partially put into suspension in the shape of a colloidal gel passing the filters, and which is progressively carried away.

* * * Washed away substances are replaced by water. The water content of the marl increases and its mechanical characteristics decrease steadily and eventually reach those of a highly viscous liquid.

Thus transformed the marl slides * * * *

In conclusion, the authors of these three papers appear to believe that glauconite directly contributes to landsliding. Benson emphasized physical characteristics, the others chemical. Stated concisely, the two papers on Algiers Bay suggest that because of the chemical nature and action of glauconite in the ground water, dissolution and removal of solid material in the marl layer occurs with an increase in water content, hence a marked decrease in ability to support the overlying rock strata.

Abundant glauconite is present in the formations in the bluffs along Sandy Hook Bay, not only in the lower formations cited in the first part of this section, but also in the upper strata, particularly the Hornerstown and Vincentown. Emphasis, however, is on the lower formations because of the greater static load on them. Drouhin, Gautier, and Dervieux (1948, p. 106) noted that where the soil was saturated in the area of their report, the stress limit [of apparently the marl] was exceeded if the height of the cliff [overlying molasse] reached about 20 m.

The bluffs along Sandy Hook Bay near Waterwitch are about 60 m high above the Navesink glauconite. Also, abundant ground water seeps from the bluff at and above this level, after having passed through thick beds of calcareous shell material. If a major rotational slump should occur here, houses on the flat area at the base could be endangered by thousands of tons of material moving a considerable distance out from the base of the bluff, as occurred when block A slumped.

Drouhin, Gautier, and Dervieux (1948, p. 104) suggested that if a large block (4,000 m^3) that broke from the cliff at Algiers Bay had tilted and slid, instead of driving itself down into the underlying material, an entire residential area would have been destroyed.

SUMMARY

Slump blocks were mapped in the bluffs along the south side of Sandy Hook Bay and along the north side of Navesink River by the author in 1963–64.

Since about the summer of 1972, renewed slumping has been observed in former slump blocks and in adjacent areas. In the present study, I have attempted to map not only all definite slump blocks, but also probable and possible slump blocks and to indicate other related features such as possible joints and zones of weakness. As many as 9 to 12 slump blocks may be present, and several of these have 1 to possibly 5 subsidiary blocks.

Slumping in this area is to be expected because hills are high, bluffs are steep and commonly border bodies of water, material is chiefly unconsolidated, the water table is well above adjacent sea level, and lateral seepage and sapping are common along the lower slopes of the bluffs. Slumping here appears similar to that along the north shore of Long Island, except that much of it may be older than that visible on Long Island where scarps are still fresh. This apparently is because the bluffs in the Atlantic Highlands area presently are more protected from erosion by open ocean waves than the bluffs along the north shore of Long Island.

Much slumping on Long Island occurred in or involved clays of Cretaceous age (Fuller, 1914, p. 67, 71), probably equivalent to the Magothy Formation (Minard, 1969, pl. 1) and older. Slumping in the bluffs along Sandy Hook Bay appears to have occurred or originated mostly in the clayey lithologic units such as the Mount Laurel Sand, Navesink Formation, and Sandy Hook Member of the Red Bank Sand (Minard, 1969, p. 36). All these units have 20–40 percent clay (table 2) and 15–70 percent glauconite (Minard, 1969, p. 12, 14, 17).

Ideal conditions are present for slumping in the Mount Laurel, Navesink, and Sandy Hook Member because of the thick Cohansey and Shrewsbury sands above to allow rapid infiltration of water during excess rainfall, the clayey sediments below to impede infiltration and migration at depth and cause the water table to rise above its normal level, a high water table to increase pore water pressure and decrease intergranular friction, and a thick stratigraphic section to provide a heavy static load.

Although probably slump susceptible, the Hornerstown has much less static load than the Mount Laurel, Navesink, or Sandy Hook Member, thus reducing its slide potential in much of its outcrop.

Present slumping is causing considerable damage to private homes and property and, as a result, is of much concern to these people and other residents liable to be effected by any additional slumping.

In addition to slumping, erosion along the faces of the bluffs has removed quantities of material, leaving bare soil material and formations exposed, illustrating the steepness and unstable nature of the slopes. This surface erosion is visible as many gullies and sheet-erosion scars.

The current slumping apparently came as a surprise to many people. Although erosion was known, few realized the slump history of the bluffs, partly because they had not read the limited amount of literature on the subject (Barber and Howe, 1844; Cook, 1868; and Minard, 1969.) and partly because there has not been much recent slumping. Evidence for much of the slumping has to be interpreted from the present form of the land.

The cause for the present slumping has been variously attributed to prolonged heavy rains, driving of pilings, and excavating for a sewerline near the toe of the bluff. Certainly the prolonged heavy rains and resultant rise in the water table and pore pressure are cogent factors to consider. The pile driving apparently predated noticed movement by some time. Studies were and are being made by engineers to determine whether, construction of the sewerline may have had any effect on the slumping.

First cracking of the ground and structures seems to have been noticed during the summer of 1972. The concrete steps (fig. 16) were reported to have cracked sometime between late fall 1973 and January 1974. Woodward, Moorhouse, and Associates, who are monitoring lateral movement of the sewerline, have reported continued movement towards the bay (oral commun., June 7, 1974).

CONCLUSIONS AND RECOMMENDATIONS

It appears that the entire bluff along the south side of Sandy Hook Bay for a distance of about 6.5 km (4 mi), from near Atlantic Highlands Yacht Harbor, and south into the mouth of Navesink River, is an area of possible geologic hazards, principally in the form of slump blocks and landslides. The fact that slumping and large-scale earth movement have begun again, after many years (perhaps centuries) of comparative or seeming inactivity, should be a matter of concern to all in the area affected or liable to be affected.

It seems evident that careful thought, planning, investigations, tests, and analyses should be undertaken before construction is begun in any areas on definite slump blocks, probable or possible slump blocks, along zones of weakness, or near the edges of the tops of any of the high, steep bluffs. Included in such precautionary measures should be avoidance of the removal of material from the toes of possibly critical slopes, prevention of excessive water infiltration in the ground in critical areas, and avoidance of excessive loading on upper surfaces in these areas.

Several slump blocks have depressions on their inner upper surfaces. The absence of standing water or appreciable quantities of aquatic vegetation indicates fairly rapid percolation into the ground. During heavy rains such areas could serve as conduits for excess water entering the ground, thereby raising the water table to possibly critical heights (and pore water pressures) as the lower less permeable strata force some water to migrate laterally and seep from the ground in zones along the lower slopes. The open vertical conduit (fig. 10) observed on block A indicates the high permeability and caving characteristics of the upper loose sandy material.

The possibility of earthquake tremors triggering slumping was considered. If a tremor of sufficient intensity coincided with a condition of high pore water pressure and loss of intergranular contact through liquefaction large masses of sand could "go quick" (lose strength), resulting in rapid downdropping of blocks or masses of earth. No quakes were recorded in the area during 1972. Quakes of noticeable intensity were recorded near Long Branch, N.J., in 1927, about 30 miles northwest of New York City during 1953–66, and near Camden, N.J., in February 1973. The last quake had an intensity of V (MM) at Asbury Park, N.J., about 20 km (12 mi) south of Atlantic Highlands.

Besides the precautions suggested earlier in this report to prevent slumping, additional action may be taken, primarily to remedy an already critical situation that exists on blocks B 1, B 2, B 3, and B 4. If adequate berms or seawalls were constructed at the toes of the slopes, much material eroded from above could be held at the toe to provide additional support. Buttressing the toe with much additional earthfill and riprap would help provide further support, especially if the material were placed in back of the protective wall. Adequate surface and subsurface drainage should be provided to prevent a rise in the water table.

These measures should be considered not only for the areas slumping at present, but also for present and intended sites of heavy construction.

GLOSSARY

Alkaline. Having basic properties, as opposed to acidic.

Barrier bar. Elongate sand ridge rising above high-tide level and generally parallel to the coast, but separated from it by a lagoon or marsh.

Base failure. A landslide or slump in which failure occurs along a surface that passes at some distance below the toe of the slope.

Colloidal. Any substance in a certain state of fine division in which the particles range in diameter from about 0.2 to about 0.0005 micron.

Decalcification. The lack or removal of calcareous material.

Deflocculation. To break up clumps and aggregates into fine particles—synonym of peptize.

Electrolyte. A substance in which the conduction of electricity is accompanied by chemical decomposition.

Feldspathic. Containing feldspar as a principal ingredient; feldspar is a group of rock-forming minerals—basically potassium, calcium, sodium, aluminum silicates.

Glauconite. A generally green mineral—essentially a hydrous potassium iron silicate.

Hydrolysis. Chemical decomposition involving the addition of the elements of water.

Hydrolyze. To subject to, or undergo, hydrolysis.

Intensity of V (MM). Earthquake tremors strong enough to be felt outdoors. Some liquids spilled. Small unstable articles displaced or upset. Doors swing, Sleepers awakened.

Ion. An electrically charged atom or group of atoms. In electrolysis, the negative ions (anions, containing an excess of one or more electrons) move toward the anode, whereas the positive ions (cations, deficient in electrons) move toward the cathode.

Joint. A fracture or parting in a rock or rock mass.

Lineament. A line or linear feature especially visible on aerial photographs, that reveals the hidden architecture of underlying rocks.

Liquefaction. The process of liquefying or reducing to a liquid or near-liquid state.

Marl. Calcareous clay.

Massif. A mountainous mass more or less clearly marked off by valleys and having relatively uniform characteristics.

Micelle. A unit of structure built up from complex molecules in colloids. It may have crystalline properties and can change size without chemical change.

Micron. A unit of length equal to one one-millionth of a metre.

Molasse. Soft green sandstone with marl and conglomerates. Detritus worn from elevated ranges during and immediately after the major diastrophism and deposited in the foredeep.

Peptize. To bring into colloidal solution; to convert to a sol.

Permutite. Capable of being changed.

Piezometric surface. An imaginary surface that everywhere coincides with the static level of the water in the aquifer.

Point bar. A bar formed by sediment dropped on the inside of a growing meander loop or the slip-off slope of a river bend.

Pore water pressure. Pressure exerted by water in the pore spaces of the rock or sediment; the higher the water table, the greater the pore water pressure below.

Quick. Where grains become coated and separated by water and buoyed up by water pressure, hence semiliquid and easily moved.

Sag. Shallow basin; downwarping of beds near a fault caused by frictional drag and rotation.

Sapping. To undermine by removal of material such as sand.

Scarp. A steep surface on the undisturbed ground around the periphery of a landslide, caused by the movement of slide material away from the undisturbed ground.

Shearing. An action resulting from applied force which causes contiguous parts of a body or mass to slide relative to each other parallel to their plane of contact.

Silicate. A compound of any of the silicic acids.

Silicic. Containing silicon dioxide (such as quartz).

Slope failure. A landslide or slump in which failure occurs along a surface that intersects the slope at or above its toe.

Solifluction. Slow downslope flowage of masses of soil and waste saturated with water.

Solubilization. Causing to pass into solution.

Waste. Material derived from rocks or sediments by chemical and mechanical weathering.

Wasting. The process that produces waste.

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