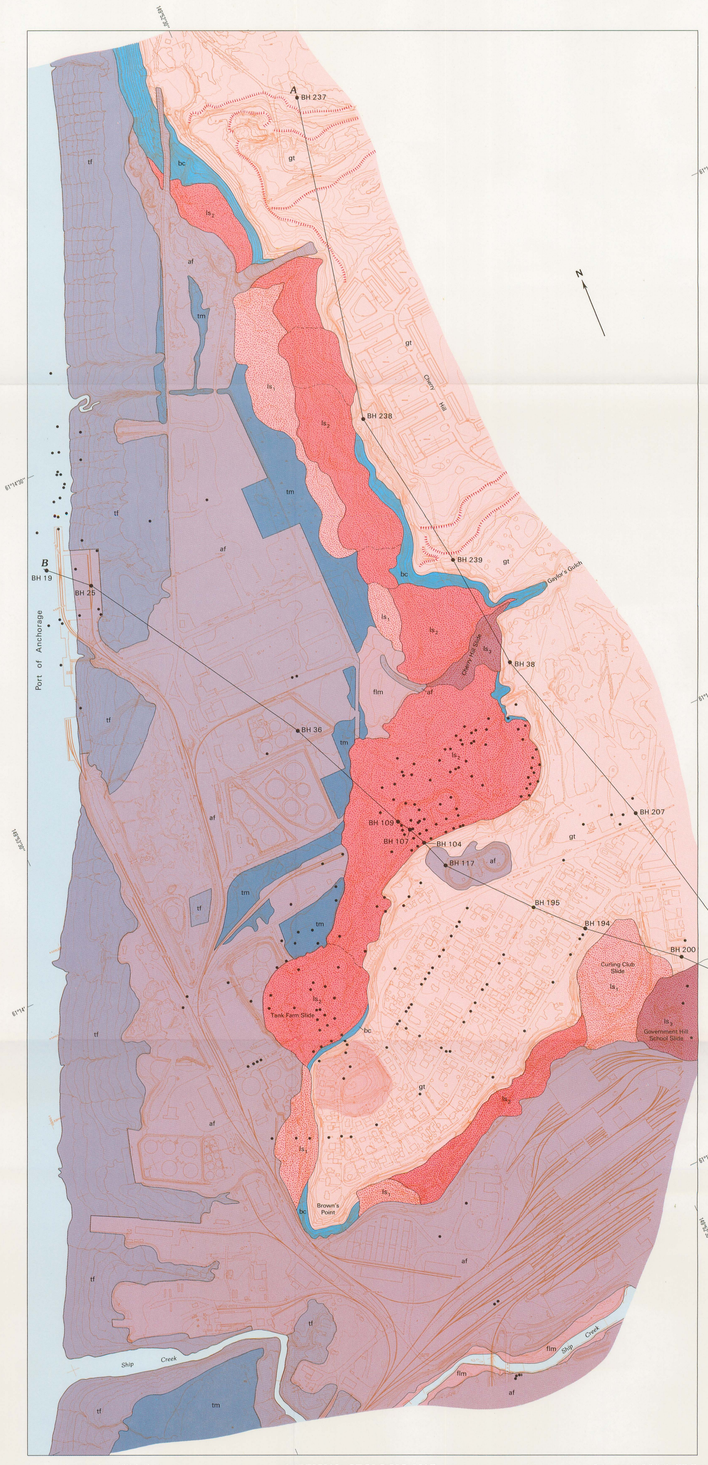
PREPARED IN COOPERATION WITH THE
ALASKA DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

STRUCTURE CONTOUR MAP OF THE TOP OF THE BOOTLEGGER COVE FORMATION

STRUCTURE CONTOUR MAP OF THE BASE OF THE BOOTLEGGER COVE FORMATION

ISOPACH MAP OF THE BOOTLEGGER COVE FORMATION

ISOPACH AND STRUCTURE CONTOUR MAP OF FACIES III OF THE BOOTLEGGER COVE FORMATION



Aerial topographic base map from Jay Whitsford & Associates for U.S. Department of Interior and the Alaska Railroad, 1:1,200

SURFICIAL GEOLOGIC MAP

Geology mapped by R. G. Updike, 1979–80, assisted by B. A. Carpenter

SCALE 1:4800

CONTOUR INTERVAL 2 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

INTRODUCTION

Among the areas that exhibited multiple ground failures during the 1964 Prince William Sound earthquake, the Government Hill area in the northern part of the city of Anchorage attracted particular attention by postearthquake investigators (Shannon and Wilson, 1964; Hansen, 1965; Eckel, 1967; Varnes, 1969; McCullough and Bonilla, 1970). This interest was the result of both the variety of earthquake induced damage and the critical role this area plays in transportation. Subsequent to the initial studies in the years immediately after the earthquake, very few recent studies have been made. The role of the Government Hill area in the economic well-being of south-central Alaska has prompted several site-specific studies by private engineering and geologic consultants and the U.S. Army Corps of Engineers. In addition to the Government Hill School landslide, which was the focus of most of the early studies, another large slide occurred along the bluff line further north and numerous ground cracks were produced in fill and on the tidal flats adjacent to Government Hill. Essentially the entire bluff line in the mapped area is lined with pre-1964 landslides, and much construction has occurred on these older slides or on the upland behind them. Local soil instability beneath or adjacent to structures erected on these soils has been a continuing problem since 1964. Such problems have indicated the need for a better understanding of the local geology and the engineering properties of the soils involved in existing and projected foundation designs.

PURPOSE AND METHOD OF MAPPING

The two foremost publications dealing with the stability of soils at Government Hill are those of Shannon and Wilson (1964) and Varnes (1969). Shannon and Wilson reported studies conducted throughout Anchorage to assess the dynamic and static conditions of the Bootlegger Cove Formation and how these conditions were involved in the massive failures that occurred as the result of the 1964 earthquake. Varnes' work specifically focused on the Government Hill area and was primarily concerned with the potential landslide hazards to the Alaska Railroad facilities in the area. Both studies provided a far-better understanding of the mechanisms of ground failure in Anchorage, but both were site-specific.

The Bootlegger Cove Formation, which is responsible for most Anchorage landslides, was originally named the Bootlegger Cove Clay by Miller and Dobrovolny (1959) for typical sections exposed at Bootlegger Cove, in Anchorage. Because clay (as recognized herein) forms less than 50 percent of the unit's total volume, the unit was redefined as the Bootlegger Cove Formation (Updike and others, 1982; Schmoll and others, 1984) to better reflect its diverse lithologic character. The maps in this report provide an area-wide three-dimensional view of the geology at Government Hill and particularly characterize in detail the areal extent, depth, thickness, and internal variation of properties of the Bootlegger Cove Formation. These maps can be used to evaluate the foundation integrity of existing buildings and to plan for future development. A companion report (Updike and Carpenter, in press) discusses at length the information and ramifications portrayed on these maps.

The surficial geology was mapped on a 1:1200-scale (1 in. = 100 ft) topographic base map (2-foot contour interval) concurrent with several sets of aerial photographs at various scales. The mapping was accomplished using natural exposures, hand-dug trenches, hand-augered drill holes, and morphology (both ground based and from aerial photographs). Observations made at construction and excavation sites from July 1978 to February 1980 were incorporated into the mapping. In addition, the logs for 246 geotechnical and hydrologic bore holes were cataloged and incorporated into the author's interpretation of the geology as expressed at the surface. Nine engineering geologic units have been mapped.

ACKNOWLEDGMENTS

Dave Varnes provided the topographic base map and aerial photographs as well as his own expertise in the area. Henry Schmoll provided substantial technical input into the preparation of the maps. Bruce Carpenter ably assisted the author in the field, and both Varnes and Oscar Ferrians, Jr., consulted with the author in the field. Numerous State, Federal, and municipal agencies, and private firms provided subsurface data as well as histories on the performance of specific structures.

GEOLOGIC SETTING

The Government Hill area is on the eastern margin of the Cook Inlet fore-arc basin, which is bounded on the west by the Bruin Bay–Castle Mountain fault system and on the east by the Border Ranges fault system. Intermediate- to shallow-focus seismicity related to the fault systems, as well as deeper events associated with subduction, are common in the region. Bedrock neither crops out nor has been encountered in bore holes within the mapped area. Quaternary deposits are believed to be several hundred feet thick. The Quaternary history is not thoroughly understood, the best summaries are those of Karlstrom (1964), Miller and Dobrovolny (1959), and Schmoll and Dobrovolny (1972). The upper Pleistocene stratigraphy in the Government Hill area consists of two stratified sand and gravel units separated by a glaciomarine and (or) glaciolacustrine sequence (Bootlegger Cove Formation). These sand and gravel units have been interpreted as fluvial in origin, deposited before and immediately after the last glaciation of the area (Naptowne glaciation). They are separated by clastic sediments that were deposited in a glacially restricted or dammed upper Cook Inlet containing brackish to saline waters. Specific interpretations of age or geologic history are avoided in this report. After the Pleistocene sequence was deposited, successive lowering of sea level coupled with fluvial erosion (for example, by Ship Creek) and mass wasting removed the upper 100 ft (30 m) of the sequence along both Knik Arm and the southern border of the mapped area. Associated with this erosion has been the deposition of Holocene tidal-flat deposits and fluvial deposits in the downcut areas and the accumulation of landslide deposits along the retreating upland scarp faces. Bluff retreat caused by mass wasting, coupled with sediment removal by coastal and fluvial erosion, and subsequent deposition of sediments near sea level may have been influenced by vertical crustal movements associated with seismic events (Plafker, 1969; Brown and others, 1977), which affect the relative positions of high tide lines, bluff morphology, and fluvial base levels.

The depositional regime of upper Cook Inlet during late Pleistocene time varied considerably in response to fluctuations of the glaciomarine system. These fluctuations are recorded within the Bootlegger Cove Formation as distinct geologic facies. These facies show abrupt transition in some places, but in other localities they subtly grade into each other both vertically and laterally. Seven facies of the Bootlegger Cove Formation in the Government Hill area are shown on the cross sections, and although the geologic interpretation and significance of the facies is beyond the scope of this report, their engineering geologic significance is discussed briefly. The facies are: F.I, clay with minor silt and sand; F.II, silty clay and (or) clayey silt; F.III, silty clay and (or) clayey silt, sensitive; F.IV, silty clay and (or) clayey silt containing thin silt and sand lenses; F.V, silty clay and (or) clayey silt with random stones; F.VI, silty fine sand containing silt and clay layers; and F.VII, fine to medium sand containing traces of silt and gravel. Each facies has its own set of physical characteristics, which, together with post-depositional influences (such as overconsolidation, permafrost, and groundwater leaching), account for the behavior of the facies under static and dynamic conditions. In table 1, the physical characteristics for each of these facies have been summarized as computed mean determinations of several hundred values recorded in numerous engineering and geologic reports. In any given stratigraphic section through the Bootlegger Cove Formation the great bulk of the formation is moderately reliable foundation material, but, typically, the existence of limited amounts of certain facies should generate concern for slope and foundation stability. Specifically, facies F.III can be highly sensitive (that is, having low residual shear strength when disturbed), and facies F.VI and F.VII, under appropriate moisture content and depth requirements, can pose a potential liquefaction hazard.

Although there is still considerable debate in the engineering and geologic communities as to which of the three facies is potentially most hazardous, and in fact was responsible for individual 1964 earthquake induced landslides, the realization that the three facies exist in the subsurface should be sufficient for concern in planning and design.

DISCUSSION OF STRUCTURE CONTOUR AND ISOPACH MAPS

Subsurface bore-hole data for 246 sites in the Government Hill area were used to establish the elevation of the top and bottom of the Bootlegger Cove Formation. Elevations of the formation in surface exposures were also determined to augment the bore-hole information. From these sets of information, structure contour maps were made of the upper and lower surfaces of the formation. The structure contour map of the upper surface shows three distinct areas: the "original" surface of the formation in the eastern part of the map, the steep zone associated with erosion and landslides along the bluff line, and the low-elevation erosion surface beneath the tidal flats and Ship Creek flood plain. Elevations are indicated in feet above or below mean sea level and can be compared to the present-day surface elevation on the base map. The original upper surface in the eastern half of the area slopes toward the present-day strandline (even though this Bootlegger Cove surface is at a depth of 20 – 30 ft [6 – 9 m]). The bore-hole data seem to indicate that the upper surface in this western area drops off rapidly, which also reflects the modern topography.

The lower-surface structure contour map is more idealized due to far fewer drill holes that penetrated the base of the Bootlegger Cove Formation. However, the data do show a continuity in slope from the northeast toward the southwest, ranging in elevation from sea level to more than 160 ft (49 m) below sea level. Both structure contour maps suggest deposition from the northeast toward the south to southwest. The similarity between the lower surface contours and the present day topography may reflect a general continuity of land surface relationships throughout much of late Quaternary time, as suggested by Trainer and Waller (1965).

The isopach map presents the interpolated thickness of the formation on the basis of the two structure contour maps and indicates that the thickness varies considerably. This variation in thickness reflects those areas where past sliding and (or) erosion have resulted in relatively thin remnants of the formation (for example, the north-central area, west of the bluffs, where only 60 ft [18 m] of the lower part of the sequence remain). Elsewhere the sequence is quite thick and apparently intact (for example, the southwestern tip of Government Hill where the formation thickness is over 200 ft [61 m]). If the formation is acting as an aquitard and limits vertical migration of water, those areas where the formation is significantly thick or unusually thin may influence the movement of intraformational water or subformation confined water. This may in turn influence the in situ strength characteristics of the cohesive soils.

As indicated in the previous section, facies F.III of the Bootlegger Cove Formation has been identified as sensitive and merits some particular attention due to its potential for failure. On the isopach and structure contour map of F.III, three parameters of this facies are shown. First, the approximate extent to which this facies can be expected to be found in the subsurface is delineated by the bold zero contour line. The red dashed contour lines indicate elevations of the top of the uppermost occurrence of the facies, in feet above mean sea level. The solid, bold contours show the approximate thickness of facies F.III, in feet. Generally, the sensitive facies is found only once in the stratigraphic section at a given locality; however, in some instances the facies is interbedded with F.II or F.IV. In these areas, the total thickness of F.III has been represented by the isopach contours. Comparing the two sets of contours, it can be concluded that (a) the sensitive facies does exist in the subsurface beneath the upland area east and north of the bluff line, (b) the facies is thickest in areas adjacent to the bluff (in areas where shallow ground water and surface water appear to play a role [Updike and Carpenter, in press]), (c) the facies is prominent in those areas adjacent to extensive historic slides, (d) the northwestern part of the mapped area should be expected to be underlain by facies F.III, but this facies is less than 10 ft (3 m) thick, and (e) the facies is still present discontinuously in the subsurface within both the younger and youngest landslide deposit units. For any specific site where F.III is found, the following qualifications should be noted: (1) the map should serve to alert the site developer of potential soils conditions, (2) the map should not be used as a regulatory tool, (3) subsurface geotechnical investigation is strongly recommended to the depths suggested by the map, (4) the hazard potential must be weighed against the design structure to assess what mitigation may be deemed necessary, (5) the isopach and structure contour maps of F.III should be compared with the geologic map to assess what historic ground failure may have occurred in response to the presence of facies F.III at or near the site.

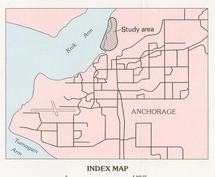
DISCUSSION OF CROSS SECTIONS

Previous investigators have made geologic cross sections through the Bootlegger Cove Formation at various locations in Anchorage (for example, Shannon and Wilson, Inc., 1964; Trainer and Waller, 1965; Varnes, 1969; and Barnwell and others, 1972). However, no clear definition of specific facies has heretofore been attempted and the earlier cross sections could not portray these subdivisions of the formation. On the geologic map, two cross-section lines are drawn, one trending north-south along the upland area behind the bluff, and a second across the bluff and tidal flat to the present-day strandline. These two sections show an interpretation of the seven facies of the Bootlegger Cove Formation on the basis of exposures and subsurface geotechnical bore-hole information. None of the original bore-hole logs delineated facies and thus the interpretation of the logs required a set of criteria established for each facies by the author. These criteria and the mode by which they were applied to the geotechnical logs are described by Updike and Carpenter (in press). Although the reader may be drawn to several observations and conclusions from the sections, three should be pointed out specifically here. First, there is a pronounced trend for the dominant facies to be the coarser, noncohesive units in the north, and the silts and clays to be dominant in the south. This would seem to support the indication of a north to northeast provenance, as suggested by the maps. Secondly, the lower part of the section contains dominantly fine-grained sediments, usually having prominent bedding and lensing. Though silt remains abundant in the upper part of the formation, the texture tends to become more sandy and gravelly. Thirdly, the sensitive facies (F.III) and the noncohesive soils having liquefaction susceptibility (F.VI and F.VII) are found nearly continuously above mean sea level beneath the southern part of the upland, and together are responsible for both the seismic and aseismic ground failure potential for the Government Hill area.

Table 1.—*Mean values for physical parameters of engineering geologic facies, Bootlegger Cove Formation, Government Hill*

[np, nonplastic; nv, nonviscous; ns, nonsensitive; nd, no data available; tsf, tons per square foot]

	FACIES						
	bc_{II}	bc_{III}	bc_{IV}	bc_{V}	bc_{VI}	bc_{VII}	bc_{VIII}
Mean grain size, mm	0.0014	0.004	0.004	0.015	0.006	0.15	0.37
Moisture content, percent	29.8	28.4	29.8	28.0	28.5	25.0	29.1
Plastic limit, percent	23.0	22.1	22.0	20.5	22.2	np	np
Liquid limit, percent	39.0	37.2	28.3	34.8	36.9	nv	nv
Plasticity index	16.0	15.1	7.0	16.0	14.7	np	np
Liquidity index	0.43	0.42	1.10	0.47	0.42	nv	nv
Shear strength, tsf	0.49	0.79	0.52	0.69	1.09	0.61	nd
Compressive strength, tsf	1.69	1.49	0.92	1.16	1.91	1.32	nd
Sensitivity ratio	8.9	2.8	19.7	6.1	4.1	ns	ns



INDEX MAP

0 5 MILES
0 5 KILOMETERS

CORRELATION OF MAP UNITS

LANDSLIDE DEPOSITS: ls_3, ls_2, ls_1
FLUVIAL DEPOSITS: flm; gt
OTHER DEPOSITS: af, tm, tf, bc — Holocene; gt — Pleistocene

DESCRIPTION OF MAP UNITS

af — ARTIFICIAL FILL (HOLOCENE)—Clay, silt, sand, and gravel periodically laid down by man's activities in the area. Sources of sediment generally local, from glaciofluvial sand and gravel, waste material from the 1964 4th Avenue landslide, and from the Ship Creek flood plain. Nonstratified and artificially compacted; occasionally with the addition of chemical- or petroleum-based aggregate binders. Thickness from few in. to less than 5 ft (1.5 m)

flm — FLUVIAL DEPOSITS ASSOCIATED WITH MODERN DRAINAGES (HOLOCENE)—Tan to light-gray silt, sand, and gravel, well-stratified throughout. Generally varies from near surface silt and silty sand containing lenses of sandy gravel to sandy gravel containing sand lenses at depth. Loose to moderately packed fabric; saturated to near ground surface. Often covered by artificial fill. Occurs as floodplain deposits eroded into the Bootlegger Cove Formation and glaciofluvial deposits (Pleistocene) and as alluvial fans. Grades seaward into tidal-flat and tidal-marsh deposits. Average thickness 15–20 ft (5–7 m) but thins toward north and south limits of Ship Creek Valley

LANDSLIDE DEPOSITS (HOLOCENE)—Light-gray, blue-gray, and olive-gray clay, silt, and fine sand intermixed with tan to brown silt, sand, and gravel. Derived originally from the Bootlegger Cove Formation and glaciofluvial deposits. Surface drainage irregular due to hummocky surface topography. Groundwater table variable due to discontinuous strata but normally within 6 ft (2 m) of ground surface; local artesian conditions. Total thickness less than 80 ft (24 m)

ls_3 — Youngest landslide deposits—Related to the 1964 earthquake. Limited erosional modification and pioneer revegetation. Poorly integrated drainage and surface water ponding typical. Slide south of Gaylor's Gulch involved pre-1964 landslides. Vertical and horizontal displacement magnitudes, volume, mechanics of movement and resultant slide topography similar to older slides

ls_2 — Younger landslide deposits—Well-defined linear ridge and trough morphology, impounded water, distinct slide margins and headscarps, only moderate erosional modification (rounding) of surface features. Commonly involved reactivated older landslide deposits. Very late Holocene

ls_1 — Older landslide deposits—Very little slide morphology preserved. Toe and margins of slide units indistinct. Surface undulating with ridges well-rounded and troughs partially filled with retransported sediment and organic materials. Drainage crudely integrated, springs have caused erosion channels, and vegetation is mature. Middle and late Holocene

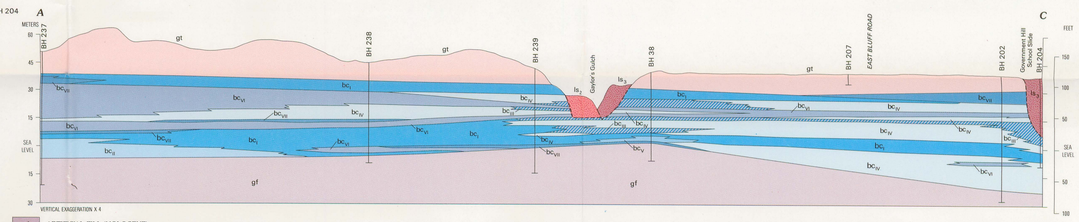
tm — TIDAL-MARSH DEPOSITS (HOLOCENE)—Dark-brown, medium-to dark-gray and tan silt and fine sand containing abundant organic material. Well stratified, usually as thin, even to wavy laminar beds. Found on flat, gently sloping, or depressed areas on the late Holocene tidal flat landward from modern high strand line. Saturated to surface, poorly drained, occasional shallow ponds. Many areas covered by artificial fill. Low permeability; moderate liquefaction susceptibility. Subject to intense seasonal frost heave. Generally less than 6 ft (2 m) thick

tf — TIDAL-FLAT DEPOSITS (HOLOCENE)—Light- to medium-gray clayey silt, silt, silty fine sand, and medium sand, with occasional pebbles and cobbles; boulders rarely found. Stratified throughout, includes laminar beds, cross bedding, cut-and-fill channels, and contorted beds. Typically becomes coarser and more densely packed with increasing depth below modern high-tide elevation. Gentle, seaward-sloping surface having intermittent drainage channels. Saturated to or near ground surface. Clastic wedge increases in thickness from less than 15 ft (5 m) near toe of bluffs to more than 60 ft (18 m) beyond modern shore line

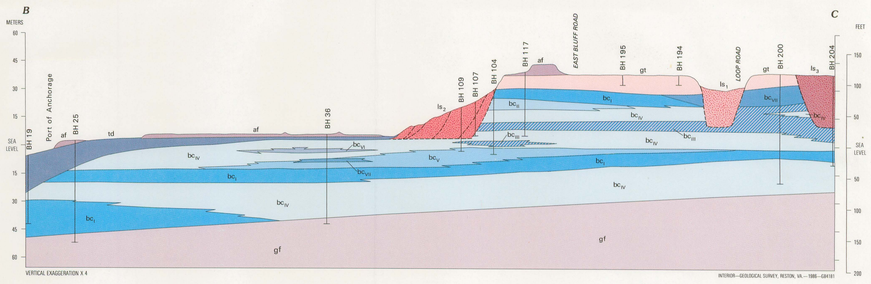
gt — GLACIOFLUVIAL TERRACE DEPOSITS (PLEISTOCENE)—Buff or light-brown to gray or buff-gray silt, sand, and gravel. Stratified and usually dipping south to southwest at less than 5°. Comprised of four fluvial terraces associated with late Pleistocene glacial outwash plains. Overlain by less than 4 ft (1.22 m) of organic silt, discontinuous peat, and Spodosol surface soil. Unconformably overlies Bootlegger Cove Formation. The lowermost terrace surface (presumably youngest) is the "Anchorage Plain" of Schmoll and Dobrovolny (1972). Total thickness ranges from less than 15 ft (5 m) to greater than 65 ft (20 m)

bc — BOOTLEGGER COVE FORMATION (PLEISTOCENE)—Gray, blue-gray, or buff-gray silty clay, clayey silt, silty fine sand, and medium sand with scattered pebbles, cobbles, and boulders. Generally well-stratified, ranging from finely laminated layers less than 0.25 in. (0.6 cm) to massive beds greater than 5 ft (1.5 m) thick, but occasionally nonstratified in diamicton beds from few inches to several tens of feet thick. Discrete engineering geologic facies are defined and shown in the accompanying text and cross sections. Underlies most of map area but exposures are uncommon. Upper surface slopes south, base undulates; Ship Creek and tidal flats eroded into the formation. Underlain by middle and late Pleistocene sand and gravel which does not crop out in the map area. Overlain by late Pleistocene glaciofluvial deposits and late Holocene fluvial and tidal-flat deposits. Thickness ranges from 90 to 195 ft (27 to 59 m)

GLACIOFLUVIAL TERRACE SCARP
ENGINEERING GEOLOGIC UNIT CONTACT
SLIDE BOUNDARIES WITHIN UNIT ls_2
BH 38 BORE-HOLES
AREA LOWERED BY FORMER SLIDES



af — ARTIFICIAL FILL (HOLOCENE)
td — TIDAL-FLAT AND TIDAL-MARSH DEPOSITS, UNDIVIDED (HOLOCENE)
LANDSLIDE DEPOSITS (HOLOCENE)—Divided into:
ls_3 — Youngest landslide deposits—Associated with 1964 earthquake
ls_2 — Younger landslide deposits—Pre-1964 but relatively young
ls_1 — Oldest landslide deposits—Relatively old, considerably modified
gt — GLACIOFLUVIAL TERRACE DEPOSITS (PLEISTOCENE)
BOOTLEGGER COVE FORMATION (PLEISTOCENE)—Divided into facies:
bc_{II} — Clay and minor silt and sand
bc_{III} — Silty clay and (or) clayey silt
bc_{IV} — Sensitive silty clay and (or) clayey silt
bc_{V} — Silty clay and (or) clayey silt with thin silt and sand lenses
bc_{VI} — Silty clay and (or) clayey silt with random stones
bc_{VII} — Silty fine sand having silt and clay layers
bc_{VIII} — Fine to medium sand, traces of silt and gravel
gf — GLACIOFLUVIAL DEPOSITS (PLEISTOCENE)
INFERRED CONTACTS
IDEALIZED SLIP PLANES



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NOTE

Units of measure on the accompanying maps and table are in U.S. customary units because (a) the base map utilized is in U.S. customary units, (b) the raw data from the 246 geotechnical boreholes provided to the author are in U.S. customary units, and (c) the primary users of these maps (that is, engineers, planners, and construction groups) work in the English System. The text provides measurements in both U.S. customary and SI units. The reader may wish to know the following conversion factors: 1 cm = 0.39 inches; 1 m = 3.28 feet; 1 km = 0.62 miles.

ENGINEERING GEOLOGIC MAPS OF THE GOVERNMENT HILL AREA, ANCHORAGE, ALASKA

By
Randall G. Updike

1986

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