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Geologic map of the Anchorage B-8 SW quadrangle, Alaska

By

Lynn A. Yehle,[1] Henry R. Schmoll,[1] and Ernest Dobrovolny[1]

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[1]U.S.Geological Survey
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INTRODUCTION

The area of this map (pl. 1A, in pocket) is located in south-central Alaska mainly within the Matanuska-Susitna Borough. The southeastern part is within the Municipality of Anchorage, downtown lying about 4 km to the south. Knik Arm, one of the two upper extensions of Cook Inlet (fig. 1), bisects the map area north to south. All land east of Knik Arm is included within Elmendorf Air Force Base and is substantially occupied by various facilities connected by a road network. Most of the area west of Knik Arm has undergone relatively little development. Scattered homesteads in this area are isolated from the road network, but some have access from beachheads. Locally, the beach itself provides a route for off-road vehicles, as do winter trails. Only one road connects the area to the rest of the Alaska road network. This map is one of a series of geologic maps of the Anchorage-Knik Arm region for which geologic maps have been published at a scale of 1:25,000 (fig. 2; Daniels, 1981a,b; Reger, 1981a,b,c,d; Updike and Ulery, 1988; Yehle and Schmoll, 1987a,b; 1988; 1989; Yehle and others, 1990).

The geology of the map area east of Knik Arm was mapped at 1:24,000 scale by H.R. Schmoll and Ernest Dobrovolny between 1965 and 1971 by interpretation of 1:20,000-scale air photos taken in 1962 and by field investigations. A generalized version of that mapping was included in Schmoll and Dobrovolny (1972a). It subsequently was photographically reduced to a scale of 1:25,000 by L.A. Yehle and H.R. Schmoll in 1989 and variously modified to accommodate the change in upgraded base maps. Additional interpretations were derived from examination of 1:24,000-scale air photos taken in 1972, and selected data from earlier geologic maps by Dobrovolny and Miller (1950) and Miller and Dobrovolny (1959) also were utilized. Mapping on the west side of Knik Arm was done largely by interpretation of 1:24,000-scale air photos by L.A. Yehle and H.R. Schmoll in 1989 and 1990. Field investigations in this part of the map area were limited to examination of bluff stratigraphy by Ernest Dobrovolny, H.R. Schmoll, and W.W. Barnwell in 1968-1970 and by H.R. Schmoll, R.G. Updike, and C.A. Gardner in 1980, and to a brief ground reconnaissance along the road and air and ground examination of the bluffs by L.A. Yehle and H.R. Schmoll in 1988. Similarity of the geology on the west side to that investigated in more detail on the east side of the arm, however, provides us with a higher degree of confidence in our interpretations than otherwise would be the case.

PHYSIOGRAPHY

The map area lies entirely in the Cook Inlet-Susitna Lowland (Wahrhaftig, 1965). That part of it east of Knik Arm is within an informal subdivision termed the Anchorage lowland (fig. 1; Schmoll and others, 1984). West of Knik Arm most of the area is within a subdivision here informally named the Knik-Matanuska lowland. Together, these two subdivisions have been termed Lower Matanuska Lowland by Karlstrom (1964). The southwestern part of the map area is within another informal subdivision termed the Bootlegger Cove platform (Schmoll and others, 1984) because its surface features and physiographic character are strongly influenced by the Bootlegger Cove Formation that underlies the area at relatively shallow depth. About 15 km east of the map area lies the boundary between the Cook Inlet-Susitna Lowland and the Kenai-Chugach Mountains physiographic provinces; here the rugged Chugach Mountains rise abruptly from the Anchorage lowland along the Chugach Mountain front (Yehle and Schmoll, 1989). The highest point in the map area, about 115 m in altitude, is east of Knik Arm along the Elmendorf Moraine.

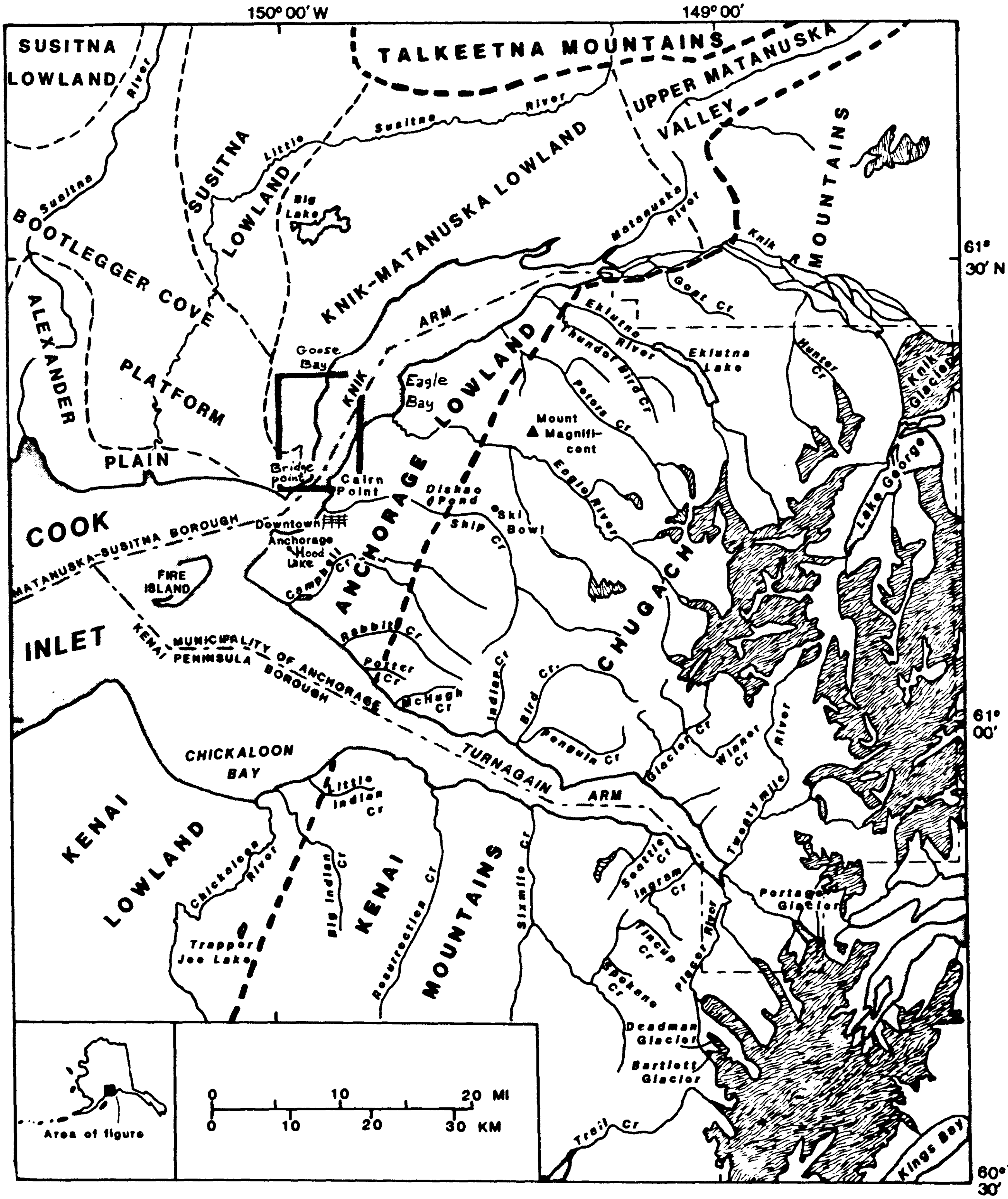


Figure 1.--Location of map area (heavy rectangle) and major geographic features. Thick dashed lines indicate boundaries between major physiographic provinces of Wahrhftig (1965): Kenai-Chugach Mountains, Talkeetna Mountains, and Cook Inlet-Susitna Lowlands; thin dashed lines and water bodies separate physiographic subprovinces of informal usage. Heavy pattern indicates glaciers.

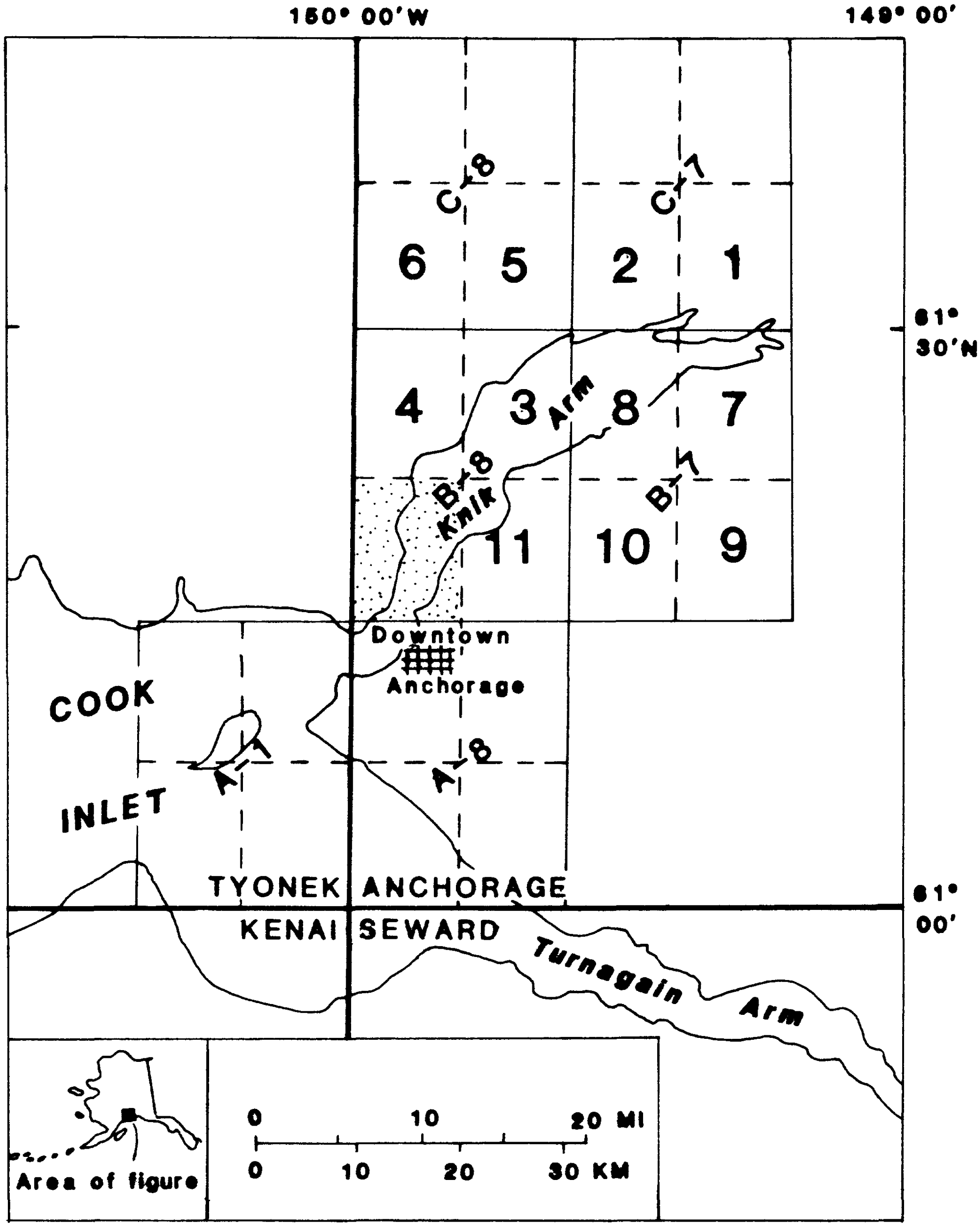


Figure 2.--Index map showing location of geologic maps in the Anchorage-Knik Arm region published at 1:25,000 scale (1, Daniels, 1981a; 2, Daniels, 1981b; 3, Reger, 1981a; 4, Reger, 1981b; 5, Reger, 1981c; 6, Reger, 1981d; 7, Yehle and Schmoll, 1987a, 8, Yehle and Schmoll, 1987b; 9, Updike and Ulery; 1988, and Yehle and Schmoll, 1988; 10, Yehle and Schmoll, 1989; 11, Yehle and others, 1990). Area of this report is indicated by stippled pattern.

The land surface of the map area may be divided into five sectors of which the first is dominant and the last two occur in only small corners of the area:

1. The Elmendorf Moraine and associated landforms produced during its deglaciation extend across both the Knik-Matanuska and Anchorage lowlands in a relatively tight arc from and beyond the west edge of the map area. The moraine reaches its southernmost point near the south edge of the adjacent map area to the east and continues northeastward into the map area (Yehle and others, 1990). The moraine consists of several noncontinuous, massive, steep-sided ridges with relief of as much as 60 m that range from broadly arcuate to more tightly curved and that are accompanied by kames of similar prominence. The moraine crosses Knik Arm in the southernmost part of the map area where the arm is narrowest and the shore is marked by two prominent points, Cairn Point on the east side and an unnamed point on the west side that we informally refer to as Bridge point (in deference to a proposed arm crossing between the two points).
2. In the southwestern part of the map area and distal to the Elmendorf Moraine, the bog- and-pond-covered land surface of the Bootlegger Cove platform sector has an altitude of 30 to 50 m with relief of only a few meters. The nearly flat surface is interrupted locally by a few smooth hills with relief of about 5 m. Locally, small outwash plains slope gently upward to the moraine.
3. Bordering the west shore of Knik Arm from the center of the map area northward and proximal to the Elmendorf end moraine is another sector that is similar in many low-relief characteristics to the Bootlegger Cove platform. Here, however, the low-relief areas of bogs and ponds are less extensive and the intervening hills are larger and more numerous. This sector extends along Mule Creek in the center of the map area, is interrupted by hills of Elmendorf ground moraine, and continues to just beyond the north edge of the map area.
4. West of Knik Arm at the north edge of the map area is a small part of the Goose Bay embayment that is extensively developed northwest of Goose Bay. This sector of emerged tidal flats lies no more than about 5 m above mean sea level and has very low relief except for a few tidal channels incised a few meters below the surface level. This embayment is a companion feature to the Eagle River Flats in the map area to the east, and together the two features comprise the northwest-southeasterly trending Goose-Eagle alignment, a feature considered by Yehle and others (1990) to be of possible structural significance.
5. In the southeastern corner of the map area and distal to the Elmendorf Moraine but sharply separated from it, is the smooth-surfaced, gently west-southwest sloping Mountain View alluvial fan sector that extends broadly into map areas to the east, southeast, and south. Here it has an altitude of about 60 m with very low local relief.

The hydrography of the area is dominated by Knik Arm, which is separated from almost all of the land area by steep bluffs about 5 to 75 m high. Knik Arm is characterized by semidiurnal tides; the mean tidal range at Anchorage (the closest tidal station) is about 7.9 m and the difference between mean higher high water and extreme low tide approximates 10.8 m (U.S. National Ocean Service, 1982). Shores commonly are narrow, sandy to gravelly beaches that are mapped to about the midtide line. Lake Lorraine and Lost Lake are the largest of several lakes and ponds that lie both among the morainal hills and on the more flat-lying surfaces west of Knik Arm. On the east side of the arm, Tuomi and Green Lakes, although smaller than several lakes on the west side, are the most prominent. All of the streams draining the numerous lakes, ponds, and boggy ground of the area are small and drain directly into Knik Arm; the largest of these is Mule Creek in the central part of the map area. A dam built across Sixmile Creek near the east edge of the map area forms Sixmile Lake, nearly all of which lies in the map area to the east.

All of the land area is covered by surficial deposits of Quaternary age that are mapped mainly on the basis of landform boundaries. The Quaternary deposits are well exposed as stratigraphic units only along the sea bluffs where numerous good exposures form a double north-south transect across the map area. Study of these exposures has enhanced interpretation of the geologic chronology beyond what can be gleaned from the surface geologic units. Bedrock is not exposed in the map area; however, sedimentary rocks of Tertiary age underlie the surficial deposits probably at depths greater than about 300 m (Church, 1970; Freethey and Scully, 1980).

SURFICIAL DEPOSITS

Surficial deposits within the map area consist mostly of Pleistocene-age glacial drift that includes extensive areas of moraine deposits as well as related glacioalluvial and glacioestuarine deposits. Non-glacial deposits are more restricted in areal extent, although some are widely distributed; they include Holocene-age alluvium and colluvial, intertidal, bog, and anthropogenic deposits.

Glacial deposits cover large areas as part of the Elmendorf Moraine, a classically arcuate end moraine that includes some prominent kame fields, areas of hummocky to low-relief ground moraine, and a few kame terraces along the proximal part of the end moraine. Other glacioalluvial deposits occur, especially east of Knik Arm in terraces and channels near Sixmile Creek, and dominate the southeastern corner of the map area as part of the broad Mountain View fan. Glacioestuarine deposits include the Bootlegger Cove Formation that crops out mainly in the sea bluffs, and probably include the sand deposits that occupy the extensive flat-lying areas west of Knik Arm.

Non-glacial alluvium is restricted to the narrow floors of the few minor valleys. Intertidal deposits occupy the small area of the Goose Bay embayment at the north edge of the map area and occur as beach deposits bordering the sea bluffs. Colluvial deposits of varying thickness, including a few prominent landslide deposits, occur mainly on the sea bluffs. Pond and bog deposits occur extensively on the flat-lying areas west of Knik Arm and locally within the Elmendorf Moraine. A ubiquitous thin mantle of organic material and windblown silt and fine sand, including minor amounts of tephra, covers all but the most recent deposits. This mantle has not been mapped separately but is included with the underlying deposits. Anthropogenic deposits occur mainly as engineered fill in the southeastern corner of the map area.

GLACIAL DEPOSITS

Glacial deposits in the map area are the products of several glacial advances from and retreats to distant mountains to the north and east (Dobrovolny and Miller, 1950; Miller and Dobrovolny, 1959; Karlstrom, 1964; Cederstrom and others, 1964; Reger and Updike, 1983, 1989; Schmoll and Yehle, 1986). Each of these glaciers successively modified the terrain in the map area, but evidence for only the last major advance and retreat is preserved at the surface. As in most glaciated regions, evidence for older glaciations is based largely on relict landforms, and only those landforms resulting from the last glacier to occupy a given area commonly are preserved. Consequently, of the two glacial advances represented within the map area, the more extensive glacier advance for which there is evidence is the older, and the less extensive advance is the younger. Surface evidence for any intervening advances of lesser extent than the last advance is thus lacking, and stratigraphic evidence for such ice advances of any significance is not compelling, although several probably occurred.

In addition to glaciers from distant sources, glaciers in nearby mountain valleys, notably Eagle River valley (fig. 1) directly east of the map area, contributed deposits to the area. The interplay between glaciers from distant and nearby sources varied depending on a variety of climatic and geographic factors. Three successively less extensive stages of glaciation are outlined as follows:

1. The most widespread glaciers to reach the map area from distant sources overwhelmed nearby valley glaciers in the Chugach Mountains, filling the Cook Inlet-Susitna Lowland and covering parts of the adjacent mountains with ice.
2. When glaciers from the distant sources were less extensive, nearby glaciers such as those in the Eagle River valley were not overwhelmed and extended farther. Eagle River valley glaciers still joined ice from distant sources in the lowland, however, and the resultant combined glacier flowed generally southwestward into the map area.
3. When glacier advances were even less extensive, nearby valley glaciers did not extend far enough down valley to join with distant-source lowland ice which extended only as far southwest as this map area. The lower parts of mountain valleys, such as that of the Eagle River (Yehle and Schmoll, 1989), were free of glacier ice. Drainage in such mountain valleys was commonly blocked by a lowland glacier or its lateral moraines, and lakes at various levels formed between

the lowland glacier and the up valley glacier. Periodically, these lakes drained, perhaps catastrophically, southwestward and westward across the eastern part of the map area, carving channels and (or) leaving deposits at various levels. The drainage was diverted around and through the ice, and some streams may have been graded to estuarine water levels represented by deposits near Mule Creek, west of Knik Arm.

The glacial deposits that are found at the land surface make up landforms of various kinds; the types and spatial relations of landforms serve as guides to mapping the type of deposit and to interpreting the relative ages of the deposits. The three principal types of glacial deposits mapped are (1) morainal deposits, materials deposited directly by glacier ice and that occur in end and ground moraines; (2) glacioalluvial deposits, materials deposited by running water within, around, and draining away from the ice, and that occur in kames, kame terraces, outwash plains, meltwater channels, and alluvial fans; and (3) glacioestuarine deposits, those deposited in estuaries ancestral to Cook Inlet that were bordered in part by glacier ice. Moraine deposits consist of till that is composed mainly of diamicton (a poorly sorted mixture of clay, silt, sand, and gravel) and poorly sorted silty to sandy gravel; some gravel and sand are present locally, as are lesser amounts of silt and clay. Glacioalluvial deposits consist mostly of gravel and sand, although some diamicton and finer-grained material are commonly present in kames. Glacioestuarine deposits, principally the Bootlegger Cove Formation, consist typically of clay and silt, with some interbedded and (or) scattered coarser materials. Other glacioestuarine deposits consist of well bedded medium to coarse sand.

Glacial deposits are further subdivided and relative ages determined with reference to named lateral and end moraines, as discussed by Schmoll and Yehle (1986). Those authors also discuss difficulties in using the chronological terminology developed by Karlstrom (1957; 1964) for classifying glacial deposits in the Anchorage area and used by Miller and Dobrovolny (1959) and most later workers. The localities from which Karlstrom's names are derived are located both in the vicinity of this map area and to the south on the Kenai Lowland (fig. 1). Because most of these typical deposits are not well dated and successive deposits are neither in stratigraphic or geomorphic contiguity, there are many uncertainties in correlation of deposits in the region. Thus, we do not use Karlstrom's terminology, but instead, rely on local terminology and relate our deposits directly to a standard chronology for the Quaternary (Bowen and others, 1986). We apply this chronology without using queries, but recognize that the age of many deposits in the region is uncertain.

All moraine deposits at the surface within the map area are those of the Elmendorf Moraine, and include both end- and ground-moraine deposits. As defined geographically, the Elmendorf Moraine extends north as far as Birchwood (near the mouth of Peters Creek) east of Knik Arm and to Big Lake west of the arm (fig. 1), crossing the Anchorage lowland in a broad arc that culminates just south of Cairn Point on the eastern shore of Knik Arm; the moraine landform includes lateral-moraine and kame deposits as well. The Elmendorf Moraine was named as a geographic feature by R.D. Miller in 1955 (Orth, 1967) and that part in the southeastern corner of this map area was mapped by Miller and Dobrovolny (1959). There, the moraine is a prominent, bipartite ridge the outer segment of which deviates from the trend of the lateral moraines along the Chugach Mountain front east of the map area. The segment of the ridge within the map area is the southwestern end of a 16-km-long, mainly single-crested, morainal ridge that is identified as the typical locality for the complex of moraine deposits of the Elmendorf Moraine (Yehle and others, 1990). In about the center of sec. 33, T. 14 N., R. 3 W., the more northerly ridge crest appears to truncate the more southerly and presumably slightly older ridge crest. The bipartite nature of the end moraine and the truncating relationship suggest that the more northerly ridge marks a minor re-advance of the glacier. West of Knik Arm, the pattern of end-moraine ridges is more complex, and, although we have divided the deposits into older and younger phases there also, a correlation with the deposits of the two distinct ridges east of the arm cannot be made with certainty. We find no evidence, however, for an ice-marginal position shown by Karlstrom (1965, fig. 9-47) as trending about southeasterly across the part of the map area west of Knik Arm at about a position just north of Mule Creek, and extending to the east side of the arm to a position north of Sixmile Creek.

Ground-moraine deposits of the Elmendorf Moraine occur in two forms, (1) hummocky ridges and hills closely associated with the end moraine on its proximal side, and (2) smoother-surfaced hills mainly in the center of the map area and also just east of Knik Arm. A few of these hills exhibit the elongate drumlinoid character more prominently displayed in the map area to the east and northeast (Yehle and others, 1990); as in that area, the hills commonly lack the longitudinal asymmetry (more blunt end facing the direction from which the ice approached) characteristic of many drumlins.

Glacioalluvial deposits that are closely associated with the Elmendorf end moraine are of three principal types, those (1) in kames (hills and ridges) of varying relief, (2) in channels that have either slightly hummocky to irregular floors and might have formed on melting ice, or flat floors and formed mostly somewhat later, and (3) in small glacial outwash plains. The first two of these occur mainly on the proximal side of the moraine; the third type borders the distal side of the moraine in a few places and are eroded remnants of more extensive plains were formed in front of the moraine by meltwater streams that emerged from the glacier. The outwash remnants are subdivided into older and younger phases that probably correlate with the two phases of end-moraine deposits.

East of Knik Arm, glacioalluvium also includes three separately-named deposits that are part of a nine-phase glacioalluvial sequence formed when streams from Eagle River and nearby valleys (fig. 1) flowed through or around the Elmendorf glacier during ice stagnation. The sequence is well developed in the map area to the east (Yehle and others, 1990). Four of the nine phases are represented within this map area by two levels of kame-terrace deposits near Tuomi Lake, the deposits of the broad, low-gradient Mountain View fan (Bartsch-Winkler and Schmoll, 1984, p. 16; Schmoll and Barnwell, 1984), and the channel deposits near Sixmile Lake.

The Tuomi Lake deposits occur in their typical localities near Tuomi Lake, where the two levels of deposits are the highest and lowest of the three levels that are recognized in the map area to the east. The highest-level deposits formed during glacioalluvial phase 1 when some drainage found its way through the glacier, although most drainage was probably still blocked by the glacier and its bordering moraine. The Mountain View deposits formed during phase 2 when Eagle River valley drainage bypassed the glacier and eroded parts of the moraine. These deposits lie at the surface in the most intensively developed parts of Anchorage (Miller and Dobrovolny, 1959, map unit Qo; Schmoll and Dobrovolny, 1972a, map unit an). Although commonly so regarded, most of the Mountain View deposits are not glacial outwash because they did not emanate directly from the glacier. The lower Tuomi Lake deposits formed in phase 4, when all of the drainage went across the area of the deteriorating glacier. The Sixmile Lake deposits are represented in the map area only by deposits of their lowest level; they formed during phase 6 when there probably was little glacier ice left in the area.

Glacioestuarine deposits occur at the surface in two substantially different situations. East of Knik Arm near the south edge of the map area, there is a small area of clay and silt typical of the Bootlegger Cove Formation. West of Knik Arm, two areas, physiographic sector 2, the Bootlegger Cove platform, and sector 3, the low-relief area near Mule Creek, are dominated by sand deposits. The sand deposits may constitute the last phases of the glacioestuarine depositional sequences typified respectively by the underlying, finer-grained deposits of the Bootlegger Cove Formation of sector 2 and the clay and the silt deposits near Mule Creek in sector 3.

The Bootlegger Cove Formation ("blue clay" of Dobrovolny and Miller, 1950; "Bootlegger Cove Clay" of Miller and Dobrovolny, 1959; name revised to its present form in Updike and others, 1982) underlies much of the central part of the Anchorage lowland south of the map area (Miller and Dobrovolny, 1959; Trainer and Waller, 1965). The formation consists of clay and silt with numerous interbeds of sandy silt, silty sand, and fine to medium sand, as well as scattered sand grains, pebbles, and cobbles in widely varying concentrations. A detailed description of the formation from the central Anchorage lowland is given in Updike and others (1988); it is classified further according to a scheme of geotechnical facies based mainly on texture (Updike, 1982; Ulery and Updike, 1983; Updike and Carpenter, 1986; Updike, 1986; Updike and Ulery, 1986). Interest in the formation was originally focused on its origin and age (Miller and Dobrovolny, 1959; Cederstrom and others, 1964; Karlstrom, 1964), but its potential for causing large-scale landslides during major earthquakes was also recognized (Miller and Dobrovolny, 1959). This potential was realized during the great Alaska earthquake of 1964 (Hansen, 1965). Studies following that earthquake yielded two principal hypotheses for the cause of ground failure: liquefaction of sand interbedded in the formation (Shannon and Wilson, Inc., 1964; Seed and Wilson, 1967; Seed, 1968, 1976) and failure of sensitive silty clay (Kerr and Drew, 1965, 1968; Hansen, 1965; Long and George, 1968). More recent studies have indicated that one or more zones of sensitive clay within the formation were responsible for extensive earthquake-induced landsliding (Idriss and Moriwaki, 1982; Updike, 1984; Updike and others, 1988; Olsen, 1989).

The Bootlegger Cove Formation commonly occurs at altitudes below about 35 m, so that the occurrence near the south edge of the map area, at about 60 m, is anomalous. This altitude, however, lies below the 110-m altitude of several deltaic deposits on the margin of the formation in the map area to the south that may grade laterally into it. The formation more commonly crops out in the sea bluffs (Miller and Dobrovolny, 1959).

On the west side of Knik Arm, the stratigraphy and chronology of the surface deposits are better understood on the Bootlegger Cove platform than in the physiographically similar area to the north near Mule Creek, because the platform continues southward across Knik Arm to a similar area in the central Anchorage lowland that has been more intensively studied. There, the sand deposits at the surface have been informally termed "deposits near Hood Lake" (fig. 1), named for the lake near Anchorage International Airport that the deposits entirely surround (Schmoll and Dobrovolny, unpublished mapping). We here apply that name to the sand deposits on the surface of the Bootlegger Cove platform in this map area and divide the deposits into three map units. Each of these units has a similar lithologic content comprising a probably similar stratigraphy, but they differ both in the proportions of their lithologic components and in surface expression.

Two map units occupy the low-lying, nearly flat terrain that dominates the Bootlegger Cove platform. One of these, map unit hs, consists of sand as much as a few meters thick that directly overlies the Bootlegger Cove Formation and is overlain only by the ubiquitous organic-eolian mantle. The second unit, map unit hp, is similar, but the surface material is mappable bog peat.

The third unit, map unit hd, occupies the low hills on the platform, and the stratigraphy is less well known. Three stratigraphies for the hills, not necessarily mutually exclusive, are possible: (1) Some of the hills, as is common to the south of Knik Arm near Hood Lake, may consist of sand several to more than ten meters thick that commonly is interbedded with fine sand, silt, and (or) thin beds of diamicton, all of which overlie the Bootlegger Cove Formation. In this case, the stratigraphy within the hills would be similar to that of the other two map units. (2) Other hills, as seen in transect along bluff exposures on the west side of Knik Arm, exhibit a somewhat different stratigraphy. They consist of sand beds a meter or less in thickness that overlie diamicton; the Bootlegger Cove Formation may be present locally as a thin unit between the sand and the diamicton. This diamicton is informally termed the "Knik diamicton" (Yehle and others, 1990) because it is the type deposit for the Knik glaciation of Karlstrom (1964). The Knik diamicton might represent deposits of the Dishno Pond moraine (Schmoll and Yehle, 1986; Yehle and Schmoll, 1989) and the hills thus would be a surface manifestation of a moraine that subsequently was mantled in most places by glacioestuarine deposits, a concept first promulgated for the Knik diamicton by Karlstrom (1964). (3) With the same stratigraphic relations as in (2), the Knik diamicton alternatively might be a unit within the Bootlegger Cove Formation. The implications of these three postulated stratigraphies are discussed in the sections on stratigraphy and chronology.

Near Mule Creek, the surface geomorphology and the stratigraphy exposed along Knik Arm suggest an origin similar to that of the Bootlegger Cove platform. The deposits in this area are here informally termed "deposits near Mule Creek," and likewise are divided into three map units. The Mule Creek deposits may represent a glacioestuarine inundation of Elmendorf ground moraine younger than the inundation of the Dishno Pond moraines by Bootlegger Cove water. The three map units are: (1) map unit ms, sand deposits overlying clay and silt that, although similar to the Bootlegger Cove Formation, is regarded as a younger unit that is part of Mule Creek deposits; (2) map unit mp, sand beds probably also overlying clay and silt but having a boggy surface with mappable thick peat; and (3) map unit md, thin sand beds and (or) clay and silt beds overlying diamicton that represents till of the Elmendorf Moraine.

INTERTIDAL DEPOSITS

Intertidal deposits include those on the modern beach bordering the sea bluffs and a small area of tidal-flat deposits within the Goose Bay embayment at the north edge of the map area. The beach deposits consist mostly of sand and gravel; boulders are prominent locally. Beaches are widest and deposits somewhat finer-grained along the west side of Knik Arm near the mouth of Mule Creek and for several kilometers to the north. Here, low bluffs mark a minor embayment between two prominent headlands. The tidal-flat deposits are chiefly silt and fine-grained sand; coarser sand may be present near some of the tidal channels and bordering the low bluffs that developed on the glacial deposits but that are no longer actively forming. The modern tidal-flat deposits are divided into upper and lower zones, following the usage of Ovenshine and others (1976) and Bartsch-Winkler (1982). Older intertidal deposits are similar, but their surface now lies above the modern tidal range. The lower intertidal deposits mark a broad area within which the land-water interface shifts continuously. The land-water interface on the topographic orthophoto base map (U.S. Geological Survey, 1979) was prepared using several different series of air photos taken at several different tide-level stages in 1972. These stages were not adjusted altitudinally to a uniform stage level, and other maps and charts (U.S. Geological Survey, 1952; U.S. National Ocean Service, 1982, 1986) were examined for supplemental information. Our water-land contact is an approximation of a mean tide level, and it should be understood that the line does not represent a fixed position but rather one that occurs only at times of mid-tide in a tidal cycle.

COLLUVIAL DEPOSITS

Colluvial deposits (colluvium), as used here, include those deposits on or at the base of slopes that have accumulated primarily by gravity and secondarily with the aid of running water. Colluvium is broadly subdivided into deposits that have accumulated slowly and deposits that have moved quickly en masse, perhaps in a few days or even hours.

Slowly deposited colluvium within the map area includes that on the steep bluffs that border Knik Arm and locally on the walls of a few channels within glacial deposits. Because the sea bluffs and channel walls are incised into surficial deposits, they are particularly subject to instability and renewed erosion. Sea bluffs and channelwalls are veneered by a downslope-thickening wedge of locally derived colluvium. Erosion is likely to occur along the wall when the streams or waves remove at least part of the colluvium and erode the underlying material. Where the bluffs are actively eroding, colluvial deposits are removed as fast as they accumulate at the base of the bluffs, and the stratigraphy of the glacial deposits is well exposed. Waves and tidal currents here may be eroding the bluffs at rates approximating the 0.6 m/yr reported by Miller and Dobrovolny (1959, p. 89) at a similar bluff west of downtown Anchorage. Along most of the sea bluffs, the colluvium is sufficiently discontinuous that it is not mapped separately from map unit s, which is used to indicate the presence of exposed stratigraphy. In other places, colluvium forms long, narrow belts along low terrace and channel escarpments that are too narrow to map separately; these occurrences are represented by a line symbol that marks minor differences in age of alluvial deposits within the same map unit.

The only colluvium within the map area deposited en masse include several landslide deposits that occur along the sea bluffs and that mostly formed during the 1964 Alaska earthquake. Landslide deposits smaller than about 0.3 km^2 in area are not mapped separately. A few landslide deposits are queried because their relation to the 1964 earthquake is unknown or identification on air photos is uncertain. Should such queried areas prove upon further investigation to be, for example, slowly-accumulated colluvium, they would be relegated to the category of "pseudo-landslides" (Shlemon and Davis, 1986). Especially when sea bluffs are eroding most actively, many small earthflows occur, but the deposits are commonly removed by tidal currents and waves shortly after deposition.

Landslides have a high potential for impact on human activity because of their rapid mode of formation and their destruction of previously stable and perhaps inhabited or developed land. Within the map area, landslides are most likely to occur along the sea bluffs where normal erosion caused mainly by action of the tidal currents and waves is most likely to occur. Thus, the bluffs and the areas directly landward behind the tops of these cliffs (especially where they are eroding actively) are the areas of most likely instability; careful attention should be given to such areas prior to undertaking developmental activities. As part of a general slope-stability analysis of the Anchorage area (Dobrovolny and Schmoll, 1974), the bluffs on the east side of Knik Arm have been classified according to degree of stability, including the likelihood of occurrence of major landsliding. Most of the bluffs are in category 5, slopes of lowest stability. Large landslides, similar to those that occurred in and near downtown Anchorage both during the 1964 Alaska earthquake (Hansen, 1965) and earlier (Miller and Dobrovolny, 1959), are considered likely to occur as far north as the bluffs in sec. 32, T. 14 N., R. 3 W. This interpretation was based on the occurrence of a substantial thickness of clay and silt of the Bootlegger Cove Formation in the bluffs. It is likely that similar stability interpretations can be made for the bluffs on the west side of the arm because of the presence of the same formation, and thus the zone of potentially large landslides extends about as far north on that side as well. The largest landslide shown on the map, just south of Bridge point, formed during the 1964 earthquake (Hansen, 1965) and was comparable in size to some of the major landslides in Anchorage.

OTHER DEPOSITS

Other surficial deposits mapped include alluvial, pond, bog, and anthropogenic deposits. Alluvium that is not directly related to glacial activity has been mapped mainly along Mule Creek and its major tributary. Alluvium also occurs within small valleys in areas that are too narrow to map separately. The alluvial deposits are subdivided into stream alluvium and fan alluvium, the latter deposited mainly in a few small gullies on slopes of the Elmendorf Moraine. Alluvial deposits consist mostly of fine sand and silt, but sand and gravel are dominant locally.

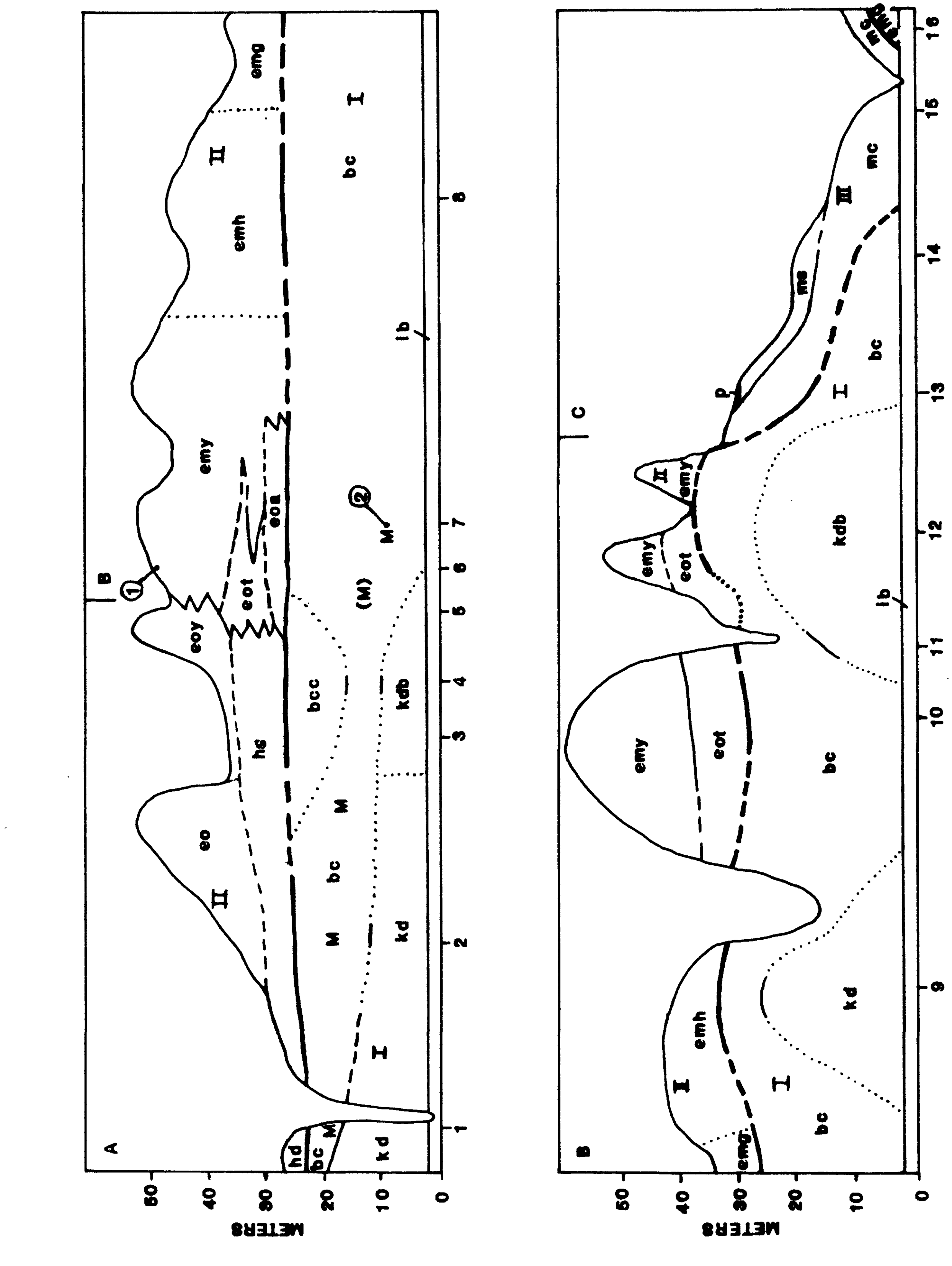
Peat deposits are mapped in the broad areas of boggy ground in association with the deposits near Hood Lake and Mule Creek as discussed above. Smaller areas of peat and pond deposits are scattered locally throughout the irregular terrain of the Elmendorf Moraine. Deposits in both large and small areas consist of peat, varying amounts of silt and sand, and, locally, thin lenses of tephra. The deposits grade laterally into, but are thicker than, the unmapped mantle of organic and eolian deposits.

Anthropogenic deposits are those that have been emplaced or significantly disturbed by the activities of man. Engineered fill has been mapped mainly in the southeastern part of the map area along the main runway and elsewhere on Elmendorf Air Force Base. Areas in which naturally occurring materials have been extensively reworked are shown by an overprint pattern. They include areas of both cut and fill and occur locally in the same area, notably where the Bootlegger Cove Formation has been exposed at the surface; it is likely that much of the surface exposure of that formation has been caused by anthropogenic activity. Minor reworking of deposits within the developed areas is not indicated on the map.

QUATERNARY STRATIGRAPHY

In addition to the deposits mapped at the surface, other Quaternary deposits are exposed only in sea bluffs and are regarded in a stratigraphic, rather than in a geomorphic, context. Such deposits include glacial, glacioalluvial, and glacioestuarine deposits that underlie deposits at the surface and do not have surface expression, as well as deposits that are also mapped at the surface, especially deposits of the Elmendorf Moraine. The stratigraphy is nearly continuously exposed in the bluffs on the west side of Knik Arm. Intermittent exposures occur in the bluffs on the east side of the arm between Sixmile Creek and Cairn Point. Because the detail of these deposits cannot be adequately shown at the scale of the map, they are illustrated separately in figure 3 which occupies two pages.

Figure 3.--Generalized stratigraphy exposed in bluffs along Knik Arm, shown as viewed from the base of the bluffs. Sectors A through D are on the west side, south to north, and sectors E and F are on the east side, north to south. Horizontal scale, 4 cm to 1 km, is the same as that of the geologic map (pl. 1A). Vertical scale corresponds approximately to altitudes represented on the map by contours, but field measurements were made with respect to the upper limit of the modern beach. Colluvial deposits are not shown on the diagram. Location numbers, shown also on the map, indicate sites of measured sections or other detailed observations. Symbols designating stratigraphic units, some of which also appear as map-unit symbols, are explained in description of map units. Heavy contacts indicate boundaries between major stratigraphic groups designated by roman numerals and described in the text. Dashed contacts are inferred; dotted contacts indicate possible interfingering relationships between units. M, location where mollusk shells have been observed in Bootlegger Cove Formation, parenthetical where observed only in landslide deposits formed during the 1964 earthquake. Circled numbers indicate localities of radiocarbon-dated samples listed on table 1.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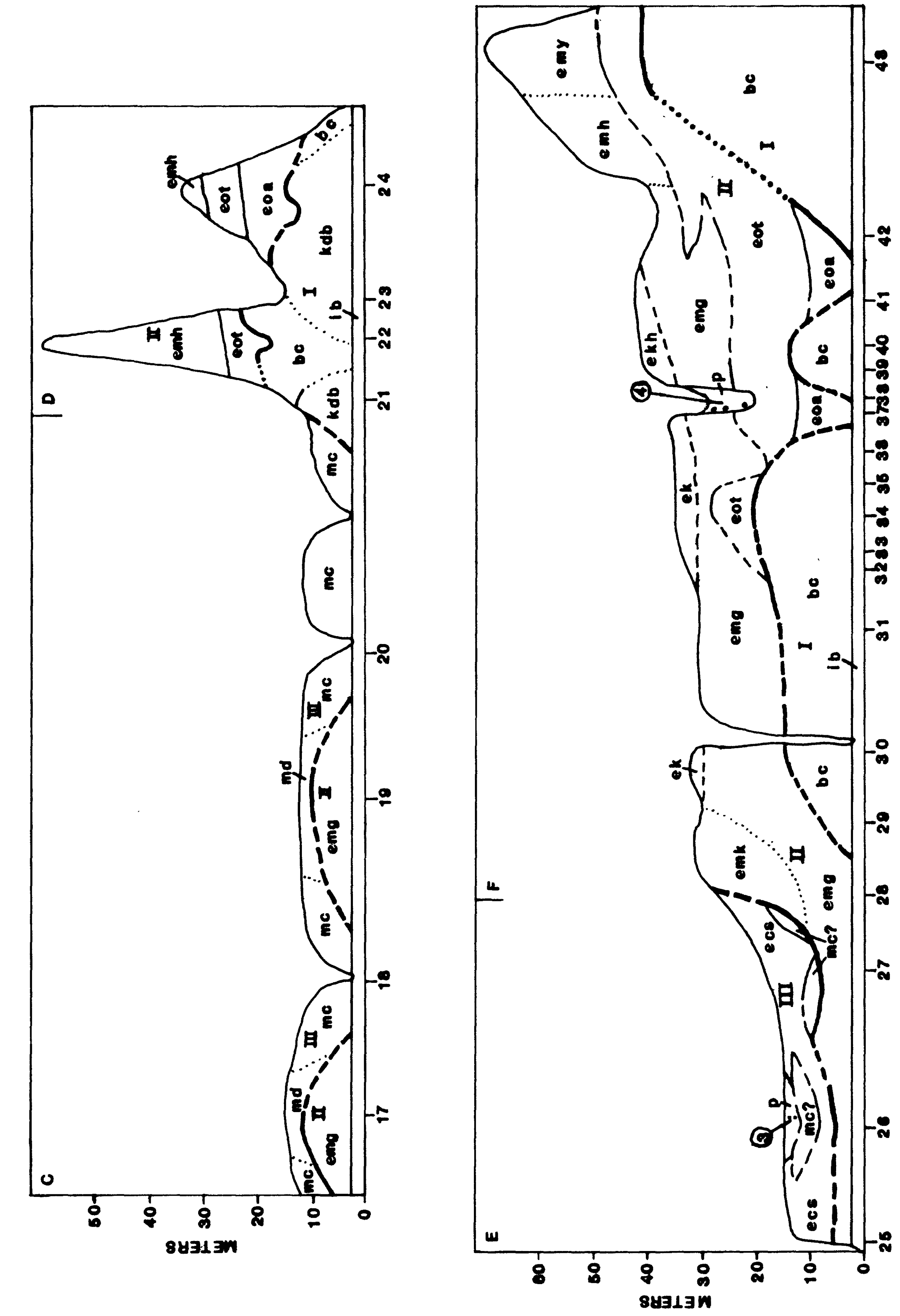
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The stratigraphic diagram is divided into six sectors that correspond to different stratigraphic assemblages, four on the west side of the arm and two on the east side: (A), southwest-trending bluffs in the southern part of the map area beyond the limits of the Elmendorf Moraine; (B), bluffs that cut through the moraine and extend nearly due north from Bridge point; (C), low bluffs marginal to the low-lying area urrounding Mule Creek; (D), the small reach of high bluffs near the north edge of the map area; (E) low bluffs south of the mouth of Sixmile Creek; and (F) bluffs that transect the Elmendorf Moraine from near Green Lake to Cairn Point. Locations of individual measured sections or other detailed observations are numbered 1 through 43 both on figure 3 and on the geologic map (pl. 1A). Locations on the west side of Knik Arm were observed by Dobrovolny, Schmoll, and W.W. Barnwell in 1968 and 1969; additional observations were made by Schmoll mainly in 1979 and 1988. Locations on the east side were observed by Dobrovolny and Schmoll in 1969 and 1970; a measured section at location 43 is given in part by Miller and Dobrovolny (1959, p. 39). The exposures on the west side of the arm are shown at small scale by Karlstrom (1964, pl. 6, section X). Preparation of figure 3 was aided by observations made from low-flying aircraft and oblique air photos taken in 1969 by Dobrovolny and Schmoll and in 1988 by Schmoll and Yehle. The ground surface shown is not derived from field measurements but is generalized from contours on the map.

The deposits shown in figure 3 are divided into three main groups as indicated by roman numerals and separated by heavy contacts on the figure. From oldest to youngest, these are: (I) the Knik diamicton and overlying and (or) laterally interfingering Bootlegger Cove Formation; (II) deposits of the Elmendorf Moraine and related underlying bedded deposits; and (III) younger deposits near Mule Creek and Sixmile Creek. These groups are separated at least locally by minor erosional disconformities, but in some places sedimentation may have been continuous and deposits of two consecutive groups may interfinger. In several places, interfingering relationships between adjacent or sub- and super-adjacent deposits have been observed, but in many other places the nature of such suspected contacts is obscure. Such contacts are indicated on the figure by dotted lines. Dotted lines are also used for arbitrary contacts between units that are differentiated on the map by geomorphological differences that may correspond only to differences in thickness of the units.

The deposits of group I are the oldest exposed in the map area and appear in about the lower two-thirds of the bluffs on the west side of Knik Arm in sectors A, B, and D, and on the east side in sector F. They correspond to the Chickaloon Bay glacioestuarine association of Schmoll and Yehle (1986). The lower of the two units in this group is the Knik diamicton; the occurrences here constitute the typical locality for this informally named deposit (Yehle and others, 1990), so named because it forms the basis for the Knik glaciation of Karlstrom (1964). As seen in the bluffs, the top of the Knik diamicton appears to rise and fall in a gently undulating manner; in places the top apparently lies below the base of the bluff and the diamicton is not present. The Knik diamicton is abruptly overlain in many places, such as locations 1, 2, 4, and 9, by the glacioestuarine Bootlegger Cove Formation (discussed above). The Bootlegger Cove overlies the Knik with only minor disconformity; the irregular top of the Knik was, perhaps, caused by minor erosion prior to deposition of the Bootlegger Cove.

In other places, however, the two units appear adjacent to each other, and numerous observations, especially at locations 11, 13, 22 and 23, suggest an interfingering relationship at least between some upper beds of the Knik and some lower beds of the Bootlegger Cove. This is particularly true where the Knik has a notably bedded character; many interbeds of silt and fine sand are present within the diamicton, and in places the deposit consists mainly of silt and fine sand with thin interbeds of diamicton. Elsewhere, it is difficult to see the stratigraphic relationships in detail, but from a distance, bedding appears to extend from one unit into the other. One interpretation is that all of the Knik diamicton is a facies within the Bootlegger Cove Formation and represents deposition of coarse, poorly sorted material in a glacioestuarine environment.

Of the group I deposits, only the Bootlegger Cove Formation is present in the bluffs on the east side of Knik Arm, sector F. Exposures are poor between locations 29 and 36 and it is not certain that the formation is present as continuously as shown; it is possible that more deposits comparable to those overlying the formation at locations 34, 37, and 41 are present instead. Knik diamicton might also be present. The base of the Bootlegger Cove Formation is probably below sea level throughout sector F, as it is throughout much of the Anchorage area (Trainer and Waller, 1965), where thickness as much as 60 m has been reported from water-well logs (Schmoll and Barnwell, 1984).

As originally interpreted by Karlstrom (1964), the Knik diamicton represents ground-moraine, and perhaps in sector A, end-moraine, deposits of the glacier next older than the Elmendorf glacier, and one that extended a relatively short distance farther south into Cook Inlet basin. The Bootlegger Cove Formation in that interpretation was regarded, in part, as an interglacial interval between the two glacial episodes. In our terminology, the Knik diamicton, if a true till, is the central-basin ground-moraine deposit equivalent to deposits of the Dishno Pond moraines on the flanks of the Chugach Mountains (Yehle and Schmoll, 1989). The view that the Knik diamicton is closely related to the glacioestuarine Bootlegger Cove Formation does not necessarily preclude this relationship, because the Dishno Pond glacier probably terminated in water of an ancestral Cook Inlet (Schmoll and Yehle, 1986); thus the Knik diamicton may represent in part the deposit of a glacier near where its front was fluctuating in estuarine water, whereas the Bootlegger Cove Formation represents glacioestuarine deposition when the glacier terminated farther up inlet.

Mollusk shells are present within the exposed part of the Bootlegger Cove Formation, probably in one poorly-defined horizon, and have been observed at localities 1, 2, 3, 5, and 7. They have not been found farther up Knik Arm, nor on the east side of the arm within the map area, but they had been found in place previously about 8 km southwestward (Karlstrom, 1964; Schmoll and others, 1972). The stratigraphically most critical occurrence is at locality 7 where they are in place in the formation where it clearly underlies the Elmendorf deposits. The shells commonly occur scattered through a thickness of about a meter, but in many places are concentrated in thin beds of fine to medium sand or in stone-rich zones that resemble diamicton. These concentrations probably represent reworking of thicker silt and clay beds in which they were originally deposited.

The shells have been useful not only for establishing the marine affinity of the water in which they were deposited, but have also furnished an age of about 14,000 years for the upper part of the formation and consequently an older limit for the age for the overlying Elmendorf moraine deposits. This age is discussed further in the chronology section of this report. Previously the formation was considered lacustrine in origin because no shells could be determined to be in place (Miller and Dobrovolny, 1959). Both Karlstrom (1964) and Cederstrom and others (1964) reported the shells as in place in the formation, but Karlstrom regarded only the shell horizon as marine (or estuarine in our terminology), the remainder of the formation being considered lacustrine and in part representing deposition in glacial lake Cook. Paleontological investigations by Schmidt (1963) and Smith (1964) undertaken subsequent to completion of Karlstrom's report demonstrated the presence of microfossils of brackish marine affinity throughout much of the formation, and form the basis on which we regard the formation as glacioestuarine. The occurrence of the shell-bearing horizon over a distance of more than 5 km extending from location 7 southwest to beyond the map area demonstrates that the shells were present in more than the very restricted area where they were first found on the south side of Knik Arm about 8 km to the southwest; subsequently they have been reported elsewhere in the upper Cook Inlet region (Schmoll and Yehle, 1986).

The deposits of group II correspond to the Cairn Point glacioestuarine association (Schmoll and Yehle, 1986). Within the map area, they are dominated by till of the Elmendorf Moraine; these are subdivided into end- and ground-moraine deposits of various types depending on geomorphic occurrence, but stratigraphically the deposits are not distinguished and vertical dotted-line boundaries shown on figure 3 are drawn as they correspond to the surface appearance. Locations 6 and 43 correspond to the maximum southward extent of the moraine at Bridge point and Cairn Point, respectively. At location 6, the moraine and outwash deposits have been observed in close proximity, and at several places the interfingering relationships shown could be seen, thanks largely to the occurrence of a large landslide during the 1964 earthquake between locations 5 and 6. Farther southwest, the surface deposits consist only of gravel that constitutes part of the Elmendorf outwash.

In this same area, as well as at other locations in sectors B, D, and F, the till is underlain by a complex of deposits that are here grouped into two units, termed advance-outwash and transitional-outwash deposits. Advance-outwash deposits formed in front of the glacier as its front was advancing and were subsequently overridden by glacier ice; the material is dominantly well-bedded and fairly well sorted gravel. Some of these deposits evidently formed in channels cut into the surface of the underlying Bootlegger Cove

Formation, as at locations 37 and 41; a minor example is seen at location 24. These relationships suggest that an interval of subaerial conditions prevailed at least locally prior to the advance of the Elmendorf Ice. The other unit, the transitional deposits, includes a variety of interbedded, mainly finer-grained materials including medium to coarse sand, sandy gravel, and thin diamicton beds, as well as some finer sand and silt beds. Although the environment of deposition for these beds is uncertain, we believe that they probably represent the advance of glacier ice into estuarine water, and thus are transitional between normal (that is, subaerially deposited) outwash and glacioestuarine deposits. This relationship is best seen at location 6, where both advance and transitional outwash units, as well as adjacent Hood Lake sand deposits and underlying beds of the upper part of the Bootlegger Cove Formation, are complexly interbedded. Such relationships at the corresponding area on the east side of Knik Arm, between locations 37 and 43, cannot be seen as well, mainly because of poorer and less continuous exposures, but we infer that they occur there too. Whether similar relationships exist for the transitional deposits farther up the arm is less certain, but at least between locations 21 and 22 similar interbedding has been observed in places.

The remaining unit within group II, the sand near Hood Lake, is extensively developed south and west of the map area and south of Knik Arm in Anchorage and constitutes a "cover sand" overlying the Bootlegger Cove Formation. Possibly it should be regarded as the uppermost member of that formation if, as we believe, the Hood Lake deposits represent the final episode in the Bootlegger Cove glacioestuarine sequence. Here, however, especially at location 6, Hood Lake deposits are seen grading into the advance and later Elmendorf outwash, although clearly underlying the final outwash deposits, so that at least in a temporal sense it is closely related to the Elmendorf deposits. Because of its widespread occurrence and consistent textural differences, it is also desirable to exclude the Hood Lake deposits from the Bootlegger Cove Formation.

At location 1, the sand near Hood Lake is mapped as unit hd rather than unit hs, although the material present is undoubtedly the same sand unit identified northeastward in the bluff as unit hs. The stratigraphy here illustrates the mapping convention we employ. Surface morphology suggests that the surface sand, and probably the underlying Bootlegger Cove Formation as well, is thinner, and that coarser-grained deposits are interpreted to be present at shallow depth. The bluff exposure shows that this is indeed the case, and we use the hd unit where we infer this type of stratigraphic sequence throughout the similar part of the map area where subsurface information is lacking.

In sectors C and E, the bluffs have a different character in that they are mainly low and their stratigraphy is less complex, at least in gross outline. We interpret that the low-lying areas, especially that on the west side of Knik Arm, was a pre-existing low area, probably an embayment not unlike present-day Knik Arm, at the time of the advance of the Elmendorf glacier (and probably earlier as well), and that deposition of glacial deposits never reached the heights achieved elsewhere in areas of initially higher topography. Upon withdrawal of the Elmendorf glacier, the area remained topographically low, and apparently was again engulfed, if relatively briefly, by estuarine waters that were still relatively high.

The deposits mapped at the surface in the vicinity of Mule Creek have been discussed previously, in their surface manifestation. They are poorly known, but from their surface appearance they are thought to be mainly sand overlain by variably thick peat. The exposures in sector C suggest that the surface deposits, instead, may be silty clay and clayey silt that locally drape diamicton thought to be the upper part of the Elmendorf deposits; the surface sand may be present only locally. It is likely, however, that the sand is more extensive in areas closer to the higher hills of the Elmendorf Moraine, as it is in the bluff exposures at locations 13 and 14. Although generally similar to those of the Bootlegger Cove Formation, the clay and silt deposits near Mule Creek, as seen in badly slumped exposures, are commonly siltier and generally appear softer. Particularly at locations 13 and 14, they were observed to contain very few stones, whereas the underlying Bootlegger Cove deposits in this area are more massive and include interbedded diamicton as well as numerous scattered pebbles and cobbles, all indications of nearby glacier ice. As in the case of the deposits near Hood Lake, we use a mapping convention that is illustrated in the bluff exposures: map unit md is used where surface morphology is interpreted to indicate presence of diamicton at shallow depth, as at locations 17 and 19, whereas map unit ms is used where the sand (or clay and silt) is thicker.

On the east side of Knik Arm in sector E, the low bluffs are dominated by alluvium near Sixmile Lake (Yehle and others, 1990). We inferred in that publication that the Sixmile Lake deposits were graded to a level of inlet water higher than that of the present; we suggest here that such water levels were those represented by the Mule Creek deposits. If so, it is likely that the thin clay and silt lenses associated with the alluvium might be tongues of Mule Creek deposits rather than merely local pond deposits, but this relationship cannot be established without additional study.

CHRONOLOGY

The deposits within this map area are better dated than those of most of the other map areas in our series. Four sites along the bluffs that border Knik Arm (fig. 3) have yielded seven radiocarbon dates that provide good age control for the upper part of the Bootlegger Cove Formation and all of the deposits related to the Elmendorf Moraine; at least by inference a fairly good age bracket is provided for younger deposits as well (table 1). An age of about or perhaps somewhat older than 14,000 yr is regarded as the most reasonable radiocarbon age for a macrofossil-bearing zone within the upper part of the Bootlegger Cove Formation (Schmoll and others, 1972). Radiocarbon locality 2 (fig. 3) is the one site that occurs within this map area of the several sites in the Cook Inlet region from which similar dates have been obtained; it provides the youngest of the several dates. At this site, the dated upper part of the Bootlegger Cove Formation has been observed clearly in place beneath deposits of the Elmendorf Moraine, and it is likely that deposition of the Elmendorf deposits began shortly after the time of the dated horizon.

Two sites yield dates that provide an upper limit for the age of the Elmendorf deposits. The age of a wood horizon in the lowest organic silt (pond deposits) at the base of a bog overlying the Elmendorf Moraine at radiocarbon locality 4 along the east side of Knik Arm is about 12,000 yr. On the west side of the arm at radiocarbon locality 1, wood fragments at the base of colluvial diamicton overlying till of the Elmendorf Moraine have a slightly younger age. These ages probably follow closely the deposition of the moraine because there is only an interval of about 2,000 years within which glacier ice advanced from a point northeast of the map area, deposited the massive, perhaps multi-phased moraine, and then began its retreat.

The massive Elmendorf Moraine was previously regarded (Miller and Dobrovolny, 1959; Karlstrom, 1964; Cederstrom and others, 1964) as representing all of Wisconsin time, or at least the "classical" younger part of the Wisconsin, but extending beyond the range of radiocarbon dating, to about 45,000 yr B.P. in Karstrom's interpretation. The revised dates indicate such a massive moraine can form in a relatively short time, perhaps even a few hundred years. It may be so large in part because it formed on land rather than in contact with estuarine water. Although the Elmendorf glacier initially advanced into such water, as discussed above, the water probably soon receded, permitting the massive moraine to form. Older Wisconsin-age glacial advances within the upper Cook Inlet region, for which lateral moraines have been preserved on the flanks of the Chugach Mountains, but which lack recognizable end moraines, probably terminated in estuarine water of considerable depth (Schmoll and Yehle, 1986). Although there was a longer period of time available within the Wisconsin glaciation during which they could form, these lateral moraines also may have been the product of relatively short-lived advances. We believe that this pattern of short-lived advances and retreats interspersed with relatively longer periods when upper Cook Inlet was dominated by estuarine water may have been dominant during much of the Wisconsin glaciation and perhaps during many of the older glaciations as well. In this concept, the size and morphology of a moraine is related more closely to its environment of deposition than to its age or duration of formation.

The glacioalluvial sequence so well developed in the map area to the east is represented in this map area only by the Sixmile Lake alluvial deposits. These deposits are bracketed by the 12,000-yr-age of the base of the post-moraine bog at radiocarbon locality 4 and an age of about 10,000 yr for peat overlying Sixmile Lake deposits at radiocarbon locality 3. If the inference discussed above, that the Mule Creek deposits are coeval with those of the alluvial sequence, then the Mule Creek deposits also formed within this relatively short period of time.

Table 1.--List of radiocarbon dates in the Anchorage B-8 SW quadrangle, Alaska

Locality number and name	Location[1]	Material	Lab number[2]	Radiocarbon age[3]	Date of collection[4]	Reference
1. Bridge point (informal name)	SW1/4 NW1/4 sec. 36, T. 14 N., R. 4 W.	wood	W-2375	11,690±300	June 14, 1969	Schmoll and others, 1972
2. ditto	NW1/4 NW1/4 sec. 36, T. 14 N., R. 4 W.	shells	W-2389	13,750±500	ditto	ditto
3. Sixmile	SE1/4 NE1/4 sec. 20, T. 14 N., R. 3 W.	peat	W-2937	8,050±350	June 13, 1969	(first publication here)
ditto	ditto	peat	W-2936	9,760±350	ditto	Yehle and others, 1990
4. Cairn Point north	SE1/4 NE1/4 sec. 31, T. 14 N., R. 3 W.	peat	W-2613	5,640±250	August 26, 1970	(first publication here)
ditto	ditto	peat	W-2614	9,905±250	ditto	ditto
ditto	ditto	wood	W-2589	12,350±350	ditto	Yehle and others, 1990

[1]Shown on geologic map, plate 1A, and on figure 3.

[2]Data from Meyer Rubin, U.S. Geological Survey radiocarbon laboratory, Washington, D.C., now Reston, Virginia)

[3]In years before present (1950), not adjusted for ocean reservoir effects.

[4]All samples collected by Ernest Dobrovolny and H.R. Schmoll.

A possibility that the retreat of the Elmendorf glacier might have been even faster, and the alluvial sequence deposited within an even shorter period of time, perhaps only a few hundred years, is suggested by dates at the base of a bog near present-day Matanuska Glacier, about 125 km to the northeast (Williams, 1986). The ages for the base of this bog, as old as 13,100 yr, are seemingly incompatible with the dates given here for deposition of the Elmendorf Moraine, and relationships between the two areas are not fully understood. Assuming, however, that dates from both areas are reasonably correct, stagnation of the glacier and its consequent withdrawal to areas far to the northeast of the map area must have been very rapid. It is also possible that glacier ice in the Matanuska valley at the dated site remained stagnant, or even had withdrawn from the site, while a glacier largely from the Knik River valley advanced to the Elmendorf position. We reject an alternative interpretation suggested by O.J. Ferrians, Jr., (written commun., 1989; oral commun., 1985-1990) that the dated horizon within the Bootlegger Cove Formation at location 7 (fig. 3) is not stratigraphically in place beneath the Elmendorf deposits.

Although the age of the upper part of the Bootlegger Cove Formation is known, there presently are no dates for the lower part of the formation, and thus the length of time it represents is not known. A few thousand years is perhaps a reasonable estimate, but a longer period of time might be more compatible with the concept of short-lived glacier advances espoused above. A major glacier retreat has been postulated for this period of time in Turnagain Arm to the south (fig. 1; Bartsch-Winkler and Schmoll, 1984). A retreat of somewhat lesser magnitude appears to have occurred in Knik Arm, extending perhaps not far northeast of the map area. This may be because of the much greater source area for glaciers in the combined Knik and Matanuska valleys at the head of Knik Arm in contrast to the much more limited source areas at the head of Turnagain Arm.

The Knik diamicton is the least well dated of the major stratigraphic units in the map area. Regardless of whether or not the diamicton interfingers with the Bootlegger Cove Formation, it represents the glacial interval that precedes and (or) partially coincides with deposition of the Bootlegger Cove Formation and is coeval with deposits of the Dishno Pond moraines. Such correlations are tentative, however, and can be made only on the basis of similarity of sequences of preserved deposits. The inability to correlate definitively between stratigraphic units commonly exposed in the center of the Cook Inlet-Susitna Lowland and well defined lateral moraines along the mountain flanks marginal to the lowland is a major limitation to establishing a satisfactory chronology for the region. The lack of finite ages for any of the older stratigraphic units is another limiting factor. These limitations are emphasized by Schmoll and Yehle (1986) and form the basis for offering alternate chronologies for the older deposits. Nevertheless, we believe that the Knik diamicton is at least a part of the major glacial depositional sequence of the late Pleistocene, but whether it forms most of that sequence, or only some later part of it, cannot be determined from present data. The latter interpretation is preferred at present and used in correlations of older morainal deposits in map areas to the east (Yehle and Schmoll, 1989; Yehle and others, 1990).

The chronology described briefly above differs substantially from that proposed by Karlstrom (1957; 1964) whose terminology was also used, albeit with some substantial differences in correlation, by Miller and Dobrovolny (1959) and has generally been used, if with increasing departures from Karlstrom's interpretations, by subsequent workers (for example, Reger and Updike, 1983; 1989; Hamilton, 1986). These changes in correlation have evolved mainly from the determination by both radiocarbon and uranium-series dating methods that the age of a mollusk-bearing horizon in the upper part of the Bootlegger Cove Formation is about 14,000 yr (Schmoll and others, 1972), in contrast to the age of about 45,000 yr interpreted by Karlstrom (1964) from earlier uranium-series dates on mollusk shells from the same horizon.

The changes in correlation between the deposits of the Elmendorf Moraine at Anchorage and those of the moraine complex near Naptowne on the Kenai Lowland (fig. 1), the typical area for Naptowne moraines, are the changes most pertinent to the present map area. The Naptowne moraines include four individually named and geomorphically separate moraine ridges, from oldest to youngest, the Moosehorn, Killey, Skilak, and Tanya moraines. All of these moraines were correlated directly by Karlstrom to the Elmendorf Moraine, all but the outermost Moosehorn moraine corresponding to end positions (Karlstrom, 1965, fig. 9-47) that we do not recognize as such within areas of ground-moraine deposits. The term Naptowne has been widely used in describing the Elmendorf and related deposits in the Anchorage area; in particular the deposits of the Mountain View alluvial fan have been commonly referred to as "Naptowne outwash."

As implied in Schmoll and Yehle (1986), we prefer correlation of the Elmendorf deposits with the deposits of only one of the inner Naptowne moraines, logically the Tanya, rather than with the Naptowne moraines as a whole, as did Karlstrom. Such a correlation has been suggested by Bartsch-Winkler and Schmoll (1984, p. 12) on the basis of radiocarbon-based work by Rymer and Sims (1982) indicating that deposits of the Skilak moraine are older than about 14,500 yr. In that case it is more reasonable to correlate Skilak deposits with those of the Dishno Pond moraines on the lower flanks of the Chugach Mountains in the Anchorage area. The Dishno Pond moraines, however, are equivalent to Karlstrom's Knik moraines, which he correlated with subdued moraines beyond the limits of the typical Naptowne moraines. We prefer to correlate the subdued moraines with lateral moraines higher on the Chugach Mountain front near Anchorage. Because of these uncertainties of correlation, and the lack of radiometric ages to resolve them, we believe that the term Naptowne should be restricted to local use on the Kenai Lowland. Thus, we prefer to use local names In the Anchorage area rather than to continue to use the term Naptowne for deposits there.

Following deposition of the Mule Creek deposits and the later stages of the glacioalluvial sequence, the most prominent geologic processes operating during Holocene time within the map area relate to retreat of the sea bluffs. The bluffs probably retreated by a process of differential erosion from an unknown position seaward of their present position. Especially in the southern part of the map area, the retreat was accelerated locally by massive landsliding caused by great earthquakes, such as occurred in 1964 and at earlier times as well (Miller and Dobrovolny, 1959).

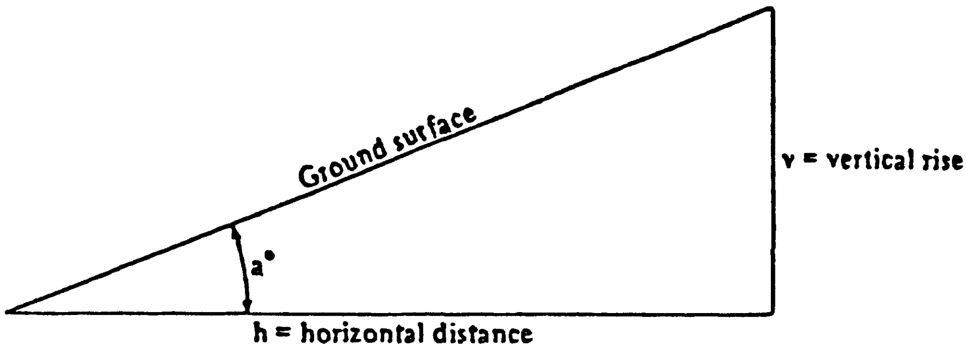
BEDROCK AND STRUCTURAL GEOLOGY

Bedrock does not crop out within the map area but its nature can be inferred mainly from knowledge in nearby areas. Rocks of the Peninsular tectonostratigraphic terrain (Coney and Jones, 1985; Jones and others, 1987) probably underlie the area at great depth; they may include metamorphic rocks similar to those observed along the Chugach Mountain front (Clark and Bartsch, 1971; Clark, 1972) as well as igneous and (or) Triassic to Jurassic sedimentary rocks (Plafker and others, 1982). As interpreted from Church (1970), Calderwood and Fackler (1972), and Magoon and others (1976), these rocks probably are overlain in turn by the Cretaceous Matanuska Formation, the early Tertiary Chickaloon Formation (over most of the area), and soft, continental sandstone, siltstone, claystone, and minor coal of the Tertiary Kenai Group. The uppermost Kenai unit here is probably the Tyonek Formation, which is reported in two drill holes, in one at a depth of about 300 m In the near-shore area west of Knik Arm (sec 1, T. 14 N., R. 4 W.) and in the other at about 435 m near the west edge of the map area (sec. 21, T. 14 N., R. 4 W.) (Church, 1970; Freethey and Scully, 1980). In the southeastern part of the map area, however, the uppermost Kenai unit might be the Sterling Formation because the Sterling is identified as underlying surficial deposits in a drill hole about 5.5 km south of the southeast corner of the map area (Yehle and others, 1986), as determined by examination of plant microfossils (Stricker and others, 1988).

The only geologic structure mapped within the area is an anticline subparallel to the northwest shore of Knik Arm (Magoon and others, 1976; Winkler, 1990), as defined by drill-hole data developed during oil and gas exploration in the map area and nearby (Church, 1970).

DESCRIPTION OF MAP UNITS

Characteristics of the geologic materials delineated by the units of the geologic map (pl. 1A) described here are based primarily on field observations; they are supported in part by laboratory analyses, especially of grain size, the description of which follows the modified Wentworth grade scale (American Geological Institute, 1989). Slope information is based on geomorphic analogy to estimates presented in Schmoll and Dobrovolny (1972b), whose slope categories are used (fig. 4). Standard age designations are omitted from map symbols because all units are of Quaternary age. The correlation of map units is shown on plate 1B (in pocket). Units that appear only in figure 3 are marked by asterisks. The units described here may be overlain by as much as one meter of organic and windblown materials as discussed above.



Diagrammatic representation of slope-measuring terms

Slope in percent = v/h X 100

Slope angle in degrees = a°

Slope ratio = h:v (h to v) where v is equal to 1 unit of measurement

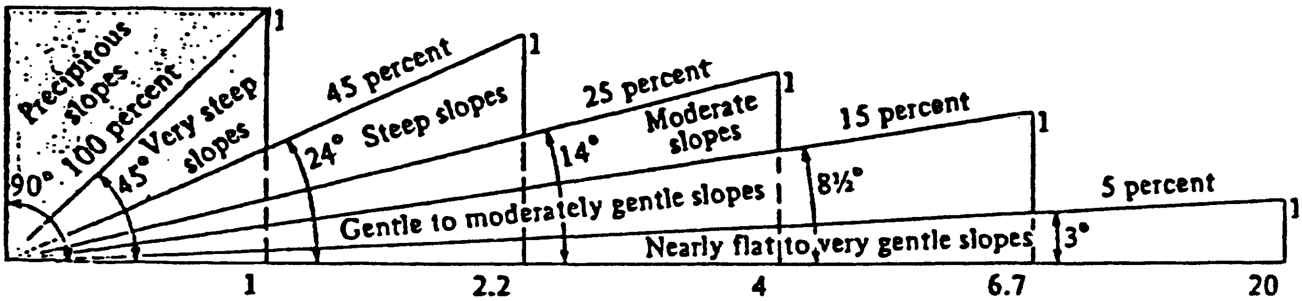


Figure 4.--Diagram illustrating slope categories used on this map (after Schmoll and Dobrovolny, 1972b).

SURFICIAL DEPOSITS

Moraine deposits (late Pleistocene)

Subdivided according to type of moraine (end and several types of ground moraine). The till that composes most moraine deposits is chiefly a diamicton consisting of massive, unsorted to poorly sorted mixtures of gravel, sand, silt, and relatively minor amounts of clay; in places poorly sorted silty sandy gravel; includes scattered large boulders; generally moderately to well compacted.

End-moraine deposits of the Elmendorf Moraine--Thickness probably about 20 m or more. Contacts sharply defined. Topography very irregular; slopes gentle to moderate in small areas on some ridge tops and in bottoms of kettle holes, mainly steep elsewhere

eme — Deposits of the main phase--Occur in a wide arc across the southern part of the map area where they mark limit of glaciers during this advance of ice. Along with adjacent high-relief kame and other high-relief moraine deposits, form part of a massive and topographically bold complex of ice-wastage landforms that constitute the Elmendorf Moraine, a formally-named geographic feature

emy — Deposits of a younger phase--Occur in the southern part of map area on both sides of Knik Arm where they mark a slight re-advance of the glacier beyond the deposits of the main phase; north of Lake Lorraine and in the western part of the map area they mark a glacial advance less extensive than the main phase; deposits in these two areas may not be coeval

Ground-moraine deposits of the Elmendorf Moraine

emg — Ground-moraine deposits, undivided--Thickness several to about 12 meters, overlie Bootlegger Cove Formation, gravel deposited as advance outwash of the Elmendorf glacier, or older glacial deposits. Contacts generally well defined except where gradational with other moraine deposits. Topography smooth to gently hummocky, slopes generally gentle to moderate. Occur east of Knik Arm and scattered throughout the northwestern part of the map area

emh — Deposits with high relief--Similar to other ground-moraine deposits but with more boldly hummocky to hilly topography. Occur in association with end-moraine deposits and in massive hills north of Mule Creek

emd — Deposits in well-developed drumlins--Thickness at least 5 to perhaps 15 m. Occur in elongate hills with moderately steep side slopes that merge laterally into low-relief terrain of other deposits, usually ground moraine. Mapped only at one locality east of Knik Arm and in a few poorly-developed drumlins in northern part of map area

emk — Deposits that include some kame deposits--Similar to ground-moraine deposits, but may include gravel and sand either in large part or locally in areas too small to map separately. Only one occurrence on east side of Knik Arm north of Sixmile Creek

*kd — **Knik diamicton (informal term), undivided**--Diamicton consisting of massive, poorly sorted mixture of gravel, sand, silt, and clay; locally includes interbeds of silt, sand, and gravel that provide a rudely bedded appearance. May represent till equivalent to deposits of Dishno Pond moraines. Shown only on figure 3

*kdb — Knik diamicton that exhibits bedding--In several exposures massive diamicton grades laterally into diamicton that is extensively interbedded with silt, silty fine sand, and sand and gravel; in many such places diamicton occurs as beds as thin as a few centimeters within thicker beds of better-sorted material. May be at least partly glacioestuarine in origin and may grade laterally into Bootlegger Cove Formation. Shown only on figure 3

Glacioalluvial deposits of the Elmendorf Moraine (late Pleistocene)

Subdivided into (1) kame deposits, (2) meltwater-channel and fan deposits, and (3) advance outwash deposits; dominantly of gravel and sand.

Kame deposits--Chiefly pebble and cobble gravel and sand, moderately to well bedded and sorted; some silt, and, especially in the cores of hills, diamicton; locally may include large boulders. Include deposits in small eskers, some of which are shown by symbol. Moderately loose, but compact in cores of hills. Contacts generally well defined; locally merge with moraine deposits. Topography sharply hilly to hummocky with some depressions locally; slopes moderate to steep, except gentle to nearly flat in minor channels, on depression floors, and on some small areas on tops of hills

ek Kame deposits, undivided--In landforms of moderate to low relief, include pitted outwash in some areas. Thickness a few to several tens of meters. Distributed mainly proximal to high-relief kames

ekh Kame deposits that exhibit high relief--In landforms of generally higher relief and locally broader shape than most kames. Thickness probably several tens of meters. Located mainly near end-moraine ridges

ekc Kame-channel deposits--In landforms of generally low relief that commonly lie at levels of the floors of major channels eroded into moraine surface. Thickness poorly known but probably only a few meters. Include pitted outwash-plain and pitted meltwater-channel deposits. Merge with meltwater-channel deposits and undivided kame deposits. Occur in moderately irregular topography having mostly gentle but some moderate slopes. Located mainly near morainal ridges

ektt Kame-terrace deposits near Tuomi Lake--In two levels of terraces that were formed along a glacier. Occur east of Knik Arm proximal to younger end-moraine ridge

Meltwater-channel and meltwater-fan deposits--Chiefly gravel and sand, well bedded and sorted; at the surface may include some finer-grained material with thin organic beds. Thickness poorly known, probably one to several meters. In places channel deposits may be thin or absent and ground-moraine deposits may floor the channel or lie at shallow depth

ec Channel deposits--Occur mainly west of Knik Arm in small, well-developed channels in association with morainal ridges; one additional locality east of Knik Arm near Sixmile Creek

ecs Sixmile Lake alluvial deposits--Occur east of Knik Arm north and south of Sixmile Creek, locally subdivided into different levels separated on the map by scarp symbols

mvf Mountain View glacioalluvial fan deposits--Occur only in southeastern corner of map area as part of broad, low-gradient fan that heads from major meltwater channel east of the map area, extending southwestward past the community of Mountain View (about 2.5 km south of the southeast corner of the map area) to downtown Anchorage

eo Outwash-fan deposits--Occur west of Knik Arm along the distal margin of the main phase of the Elmendorf Moraine in remnants of relatively small fans that have been partly eroded by younger outwash streams. May have formed partly as glacioestuarine deltas

eoy Younger outwash-fan deposits--Occur on both sides of Knik Arm distal to younger phase of the Elmendorf Moraine, commonly in channels cut into older outwash deposits. On figure 3 and in map area to east (Yehle and others, 1990) not mapped separately from outwash-fan deposits of the main phase

*eoa **Advance outwash deposits**--Fairly well bedded and sorted pebble and cobble gravel with minor interbeds of sand. Thickness about 10 m. Exposed in bluffs along both sides of Knik Arm and shown only on figure 3 *eot Advance outwash transitional to glacioestuarine deposits--Mainly interbedded sand, gravel, silt, and diamicton. Thickness about 5 to 15 m. Shown only on figure 3

Estuarine and glacioestuarine deposits

Modern intertidal deposits (latest Holocene)--Chiefly silt and fine sand; somewhat coarser near tidal channels. Well bedded and sorted. Loose, water saturated. Thickness as much as a few meters, probably underlain by several meters or more of older intertidal deposits. Contacts may vary in location with each tide as well as from season to season and year to year. Surface generally smooth, but incised one to a few meters by numerous tidal channels that may have steep margins. Slopes otherwise nearly flat to gentle, commonly less than one percent. Subdivided into lower and upper zones. Mapped only at north edge of map area

il Deposits of the lower intertidal zone--May include driftwood and gravel at shoreward-most part of deposits in discontinuous storm berms. Reworked several times daily by tides; covered by water at high tide; exposed at low tide. Lower boundary of map unit approximates mean tide; upper boundary may be as much as several meters above mean high water

iu Deposits of the upper intertidal zone--Locally more sandy, gravelly, and driftwood-laden than the deposits of the lower zone; covered by tides only when exceptionally high tides are coupled with extreme storms. Contain some organic and windblown material. Surface marked by standing water in some areas. Drainage very poor

io **Older intertidal deposits (Holocene)**--Chiefly silt and fine-grained sand, well bedded and sorted; locally may include thin beds of peat, driftwood, and other organic material and some windblown material. More firm than the modern intertidal deposits. Not flooded by present-day high tides. Thickness several to a few tens of meters. Contacts well defined, except gradational in part to younger intertidal deposits. Located near north edge of map area

ib **Deposits of the modern beach (latest Holocene)**--Chiefly sand with some gravel; locally driftwood laden near base of bluffs. Encompass the upper and lower intertidal zones. Not shown on map where stratigraphic sections (fig. 3) shown

Deposits near Mule Creek (early Holocene and latest Pleistocene)

ms Sand deposits--Mainly fine to medium sand; may include some interbedded coarser sand, silt, and fine gravel; generally well sorted and well bedded. May be underlain in many places by clayey silt of map unit mc; include local areas of clayey silt overlain by surface peat. Probably deposited during the waning phase of a glacioestuarine environment that engulfed low-lying areas of Elmendorf ground moraine during and following downwastage of glacier ice. Thickness one to a few meters. Occur only in low-lying areas around Mule Creek and to the north

mp Sand deposits with peat at surface--Similar to map unit ms, but surface peat is probably more than one meter thick

md Sand deposits that may thinly cover diamicton--Similar to map unit ms, but sand may be relatively thin and (or) include a lag gravel concentrate and overlie diamicton (map unit emg) or gravel and sand (map unit ek)

*mc Clayey silt and silty sand deposits--Includes minor interbedded silt and fine sand. Probably deposited during main phase of glacioestuarine environment following downwastage of Elmendorf glacier. Exposed only in bluffs on west side of Knik Arm near mouth of Mule Creek and shown only on figure 3. May extensively underlie map units ms and mp and occur locally beneath surface peat in place of those units

Deposits near Hood Lake (late Pleistocene)

hs Sand deposits--Mainly medium sand, well bedded and well sorted; includes some interbeds of finer and coarser sand and possibly minor silt and fine gravel beds. Probably deposited during waning phase of glacioestuarine environment in which Bootlegger Cove Formation was deposited, and that formation probably underlies the sand. Thickness as much as 10 m. Occurs only in southwestern part of map area

hp Sand deposits with peat at surface--Similar to map unit hs, but surface peat is probably more than one meter thick

hd Sand deposits that may thinly cover diamicton--Similar to map unit hs, but sand may be relatively thin overlying Knik diamicton instead of Bootlegger Cove Formation; sand may be absent locally. Surface morphology suggests that the hills on which this unit is mapped may reflect Dishno Pond moraine or kame ridges buried by Bootlegger Cove Formation and subsequent deposits. Alternatively, some hills may consist largely of gravel and sand or mainly medium sand, and Bootlegger Cove Formation may be present at greater depth

bc **Bootlegger Cove Formation (late Pleistocene)**--Silty clay and clayey silt with minor interbedded silt, fine sand, fine to medium sand, and thin beds of diamicton, and with scattered pebbles and cobbles in widely varying concentrations. Deposited in a glacioestuarine environment mainly following withdrawal of Dishno Pond ice and prior to and during advance of glacier to position of the Elmendorf Moraine. Thickness ranges from about 1 to 10 m; may be substantially thicker in southwestern part of map area. Mapped at surface only at south edge of map area east of Knik Arm where surface has been anthropogenically altered. Exposed in bluffs along both sides of Knik Arm as shown in figure 3

*bcc Bootlegger Cove Formation that exhibits convoluted bedding--Appears locally in stratigraphic sections and shown only in figure 3

Alluvial deposits (Holocene)

Alluvium deposited by present-day streams. Generally well-bedded and sorted, clasts commonly well rounded. Thickness variable, probably a few meters. Contacts well defined. Topography smooth, slopes nearly flat to very gentle.

al **Alluvial deposits along small streams and in low terraces**--Chiefly sand and gravel. Generally at or no more than a few meters above stream level. Includes narrow active flood plains too small to map separately. Located only along Sixmile and lower Mule Creeks

alf Fine-grained deposits--Chiefly fine-grained sand with some silt; may include peat deposits near surface. Widely scattered, mainly along Mule Creek and other small streams in the northwestern quadrant of map area

aff **Fine-grained alluvial-fan deposits**--Formed where small streams emerge from morainal ridges onto flatter areas distal to moraine. Materials may be less well sorted than most other alluvium. Slopes moderate to moderately gentle, may be steeper near heads of fans. Chiefly fine sand and silt; locally may include coarser sand and some gravel. Occur at scattered localities west of Knik Arm

Peat and pond deposits

p **Postglacial peat and pond deposits (Holocene and late Pleistocene)**--Chiefly mosses, sedges, and other organic material in various stages of decomposition; includes organic-rich silt, minor woody horizons, and a few thin interbeds of mainly ash-sized tephra. At depth may include silt, clay, marl, or fine-grained sand; locally may include sand and some gravel. Form bogs at sites of small former lakes or former stream channels. Soft and moist. Thickness as much as 8 m; adjacent mapped deposits extend beneath these deposits. Contacts well defined. Surface smooth, slopes less than one percent. Poorly drained. Distributed extensively in areas of Elmendorf morainal deposits

Colluvial deposits (Holocene and late Pleistocene)

cw **Colluvial deposits on valley and channel walls and along sea bluffs**--Loose accumulations of debris derived from adjacent, up slope deposits that form a veneer on bluffs. Chiefly diamicton consisting of pebbly silt and sand with some clay, cobbles, boulders, and a variable amount of organic material. Non-bedded to poorly bedded; poorly sorted. Generally a few meters thick, thinner at the up slope part; usually thicker downslope. Contacts generally well defined. Slopes steep to precipitous. Stabilized locally by vegetative cover, but subject to instability because of renewed gully, stream, or coastal erosion and accompanying mass-wasting processes. Mapped along walls of minor channels cut through morainal hills west of Knik Arm and locally along bluffs on east side of Knik Arm; intermittently present elsewhere along bluffs but not shown on figure 3

cl **Landslide deposits, undivided**--Include a wide variety of materials, chiefly diamicton, gravelly silt and sand with relatively minor amounts of clay, and some organic material. Include earthflow deposits too small to map separately. Nonbedded, and nonsorted to poorly sorted. Relatively loose. Thickness poorly known, probably a few to at least ten meters. Contacts well to moderately well defined. Topography irregular to slightly hummocky, slopes moderate to steep. Queried where identity uncertain. Occur at only a few places in association with wall colluvium and on some morainal hills

clq Landslide deposits that formed during the 1964 earthquake--Occur at several localities along bluffs on both sides of Knik Arm

Anthropogenic deposits (latest Holocene)

f **Engineered fill**--Chiefly compacted pebble gravel underlain by a more poorly sorted base course of sandy to silty gravel; in some areas fill may include a more heterogeneous assemblage of material. Mapped mainly along airfield runway in southeastern part of map area and in a few areas elsewhere. Thickness as much as several meters

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