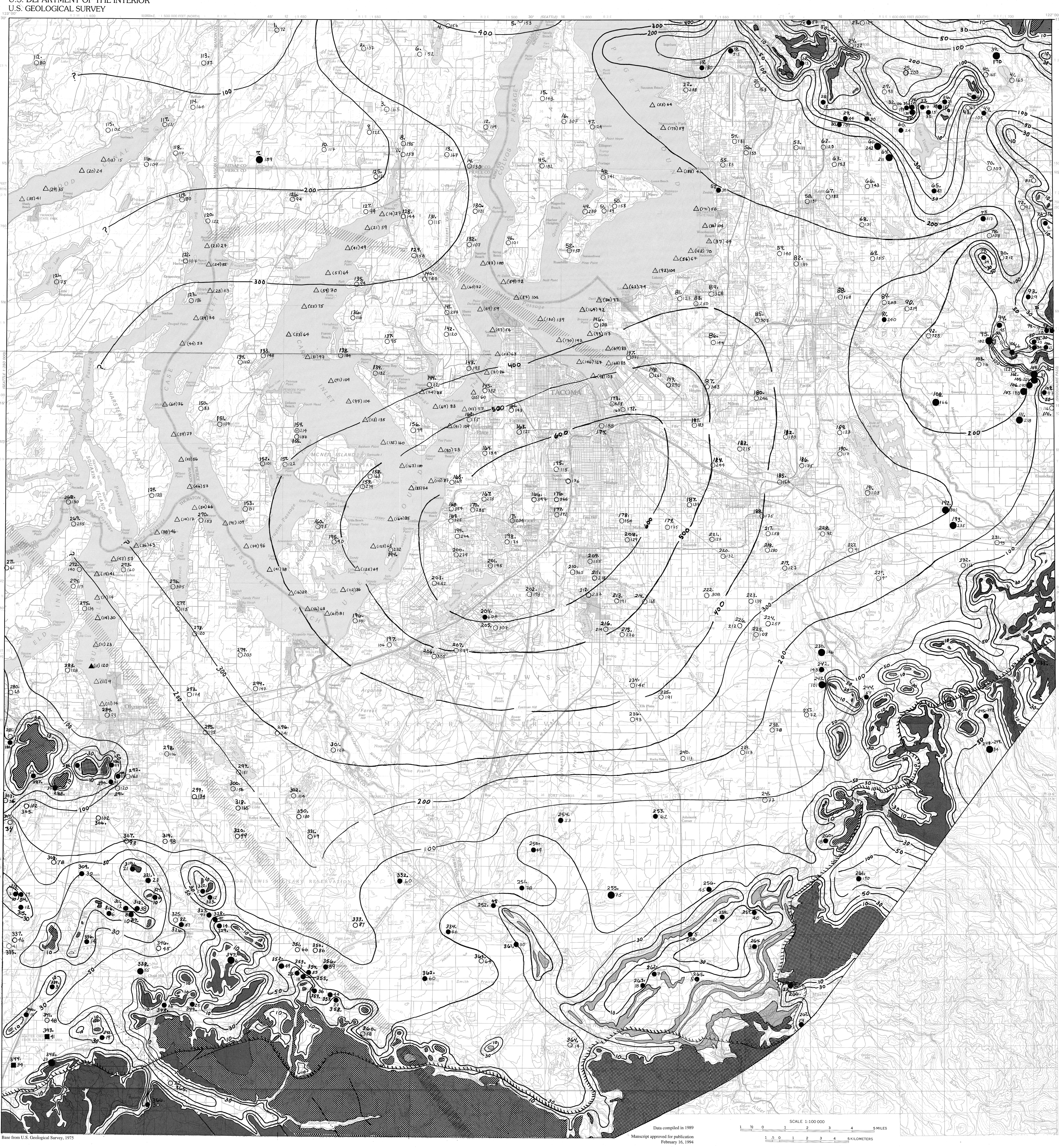
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-2265
SHEET 1 OF 2



Base from U.S. Geological Survey, 1975

Data compiled in 1989
Manscript approved for publication
February 16, 1994

SCALE 1:100 000

EXPLANATION

Area of bedrock outcrop
- **Sedimentary rocks**
- **Volcanic and intrusive rocks**
- **Miocene sedimentary rocks**

—100— **Contour showing depth to bedrock, in meters**

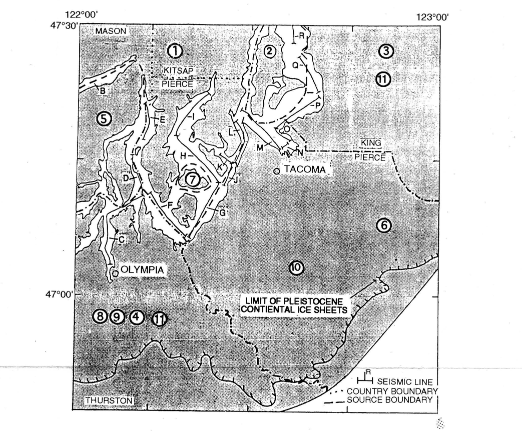
Major structural or geophysical lineament- From Gower and others (1985)

Source of data--Solid symbol, reached bedrock; open symbol, did not reach bedrock. Number with period refers to data entry number in table 1. Number without period is depth of drill hole in meters

- **Water drill holes**
- **Geotechnical drill holes.**
- 19.180 **Oil, gas, or coal drill holes**
- (63)61 **Marine seismic reflection profile**--Depth of water followed by thickness of sediments; all in meters

Southern boundary of continental ice sheets

Fault-- dotted where queried



A

PUBLISHED DATA SOURCES

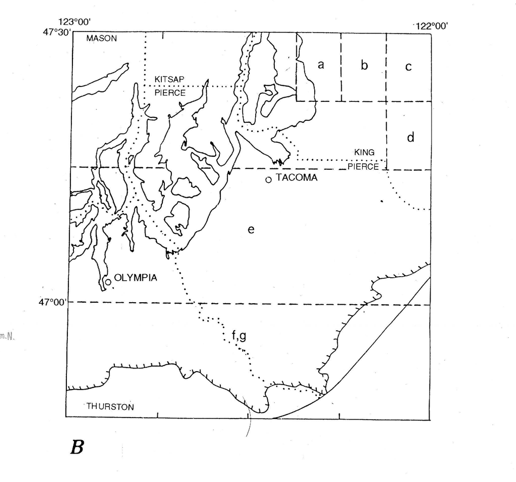
① Kitsap County and adjacent islands, Garling and others (1965).
② Vashan and Maury Islands, King County, Ritzi (1983).
③ Southwestern King County, Luzier (1969).
④ Thurston County, Snavely and others (1958).
⑤ Southeastern Mason County, Molenaar and Noble (1970).
⑦ McNeil Island, Pierce County, A.M. Piper (written commun.., 1930).
⑥ Pierce County, Walters and Kimmel (1968).
⑧ Thurston County, Wallace and Molenaar (1961).
⑨ Thurston County, Noble and Wallace (1966).
⑩ Pierce County, Brown and Caldwell (1985).
⑪ King and Thurston Counties, Hart Crowser & Assoc., Inc. (1986, 1988, 1989 a, b).

UNPUBLISHED DATA SOURCES

In all counties, water-well data are from files of U.S. Geological Survey, Water Resources Division, Tacoma. Also, in Pierce County, data from files of Washington State Department of Ecology, Olympia; McFarland (1983). In Thurston County, geotechnical well data from files of Washington State Department of Ecology, Olympia. In King, Pierce, and Thurston Counties, oil and mineral exploration well data are from files of Washington State Division of Geology and Earth Resources, Olympia, and in southeasternmost Pierce County, written communication is from Carbon River Energy Partnership.

MARINE SEISMIC INVESTIGATIONS

B-Q	USGS high-resolution lines (Snavely and others, 1977)
R	Proprietary data



B

SOURCES OF GEOLOGIC INFORMATION

a. Des Moines quadrangle, Waldron (1962).
b. Renton quadrangle, Mullineaux (1965b).
c. Maple Valley quadrangle, Vine (1969).
d. Black Diamond quadrangle, Mullineaux (1965a).
e. South half of Tacoma quadrangle, Walsh (1987).
f. Centralia quadrangle, Schasse (1987).
g. Centralia-Chehalis district, Snavely and others (1958).

Figure 1.--Sources of depth-to-bedrock and geologic information, Tacoma and part of Centralia 30' by 60' quadrangles, Washington.

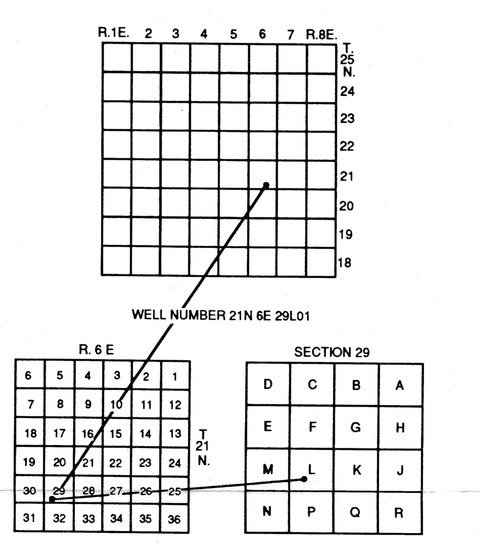


Figure 2.--Sketch showing system used to number wells listed in table 1.

INTRODUCTION

The heavily populated Puget Sound region in the State of Washington has experienced moderate to large earthquakes in the recent past (Nuttli, 1952; Mullineaux and others, 1967). Maps showing thicknesses of unconsolidated sedimentary deposits are useful aids in delineating areas where damage to engineered structures can result from increased shaking resulting from these earthquakes. Basins containing thick deposits of unconsolidated materials can amplify earthquakes waves and cause far more damage to structures than the same waves passing through bedrock (Singh and others, 1988; Algermissen and others, 1985). Configurations of deep sedimentary basins can also cause reflection and magnification of earthquake waves in ways still not fully understood and presently under investigation (Frankel and Vidale, 1992).

This map showing depth to bedrock encompasses the Tacoma and northern part of the Centralia 30' by 60' quadrangles, an area that includes a part of the Puget Sound Lowland and a part of the Puget Sound waterways and islands of the west-central part of Washington. The Puget Sound Lowland is bounded by the volcanic arc of the Cascade Range to the east and by sedimentary and volcanic rocks of the Olympic Mountains and Willapa Hills to the west. Although the Puget Sound Lowland extends southward of the map area, the southern boundary of the map area coincides with the most southern limit of several Pleistocene continental ice sheets (fig. 1, map). Surficial unconsolidated glacial, fluvial, and marine deposits of Quaternary age (surficial deposits) cover most of the Puget Sound Lowland and conceal the underlying structural and bedrock configuration. These Quaternary deposits are more than 600 m thick in the central part of the map area (see also Hall and Othberg, 1974). Tertiary rocks crop out in the eastern, southern, and southwestern parts of the map area and are differentiated as either Miocene sedimentary rocks, Eocene and Oligocene sedimentary rocks, or combined volcanic and intrusive rocks. Two major structural or geophysical lineaments occur in the map area: one is north of Tacoma and the other is southwest of Tacoma and passes under Olympia (Gower and others, 1985).

The purpose of this map is to present data on the thickness of unconsolidated sedimentary deposits; information that will be of use for the analysis of past and future earthquake intensity and ground acceleration in the Puget Sound Lowland as well as for regional land-use planning in an area that could be affected by moderate to large earthquakes. In the Seattle area to the north, seismic activity is high compared to the relatively sparse seismic activity within the map area (Gower and others, 1985). Earthquakes that occur in the Seattle area also may also affect the map area. This map is a contribution to a series of studies of the geology and geologic hazards of the Puget Sound Lowland including Yount and others (1985), Schasse (1987), Walsh (1987), Pessl and others (1989), and Yount and Gower (1991).

DATA SOURCES

The map shows drill-hole data from both published and unpublished sources as well as locations and depths to bedrock calculated from marine seismic reflection data (fig. 1). Locations of drill holes shown on the map are based on data from selected water, oil, gas, coal, and geotechnical drill logs and are listed in table 1. Some of these drill holes penetrate bedrock and, thus, indicate a total thickness of unconsolidated surface sedimentary materials. The majority of the holes were drilled for water and are too shallow to reach bedrock. Nonetheless, these data provide a measure of the minimum thickness of the Quaternary deposits.

Marine seismic reflection studies were conducted along the Puget Sound waterways, located in the northwestern part of the map area, to determine depth-to-bedrock thickness of unconsolidated sedimentary deposits. These thicknesses are calculated from the roundtrip time required for the sound waves to penetrate and return through the materials and from the change in velocity of the sound waves when they enter consolidated materials.

Data are plotted on the map according to the official rectangular public-land survey technique. For example, in table 1 each drill site is designated by township, range, section, and tract which is alphabetically designated. Following the tract designation is the well number. However, for the purposes of this map, if the well is not numbered, then the tract designation is followed by the type of well; for example oil. Figure 2 is a sketch showing the well numbering system.

GENERAL STRATIGRAPHY

Bedrock units shown on the map are not differentiated by formational names, but are separated into sedimentary and igneous rocks. The following is a list by county of the formations and (or) rock types in the map area.

Exposed Tertiary Bedrock

Tertiary units are the oldest rocks exposed in the map area. They consist of both marine and nonmarine siltstone, claystone, and sandstone interbedded with volcanic rocks. The volcanically derived rocks include volcanic sandstone and conglomerate, tuffaceous siltstone, tuff breccia, and lava flows (Sceva, 1957; Snavely and others, 1958; Wallace and Molenaar, 1961; Waldron, 1962; Mullineaux, 1965a, b; Noble and Wallace, 1966; Luzier, 1969; Vine, 1969; Walsh, 1987; Walsh and others, 1987).

Much of the exposed bedrock is Eocene in age and some is Oligocene.[1] The majority of these rocks rim the eastern and southern part of the quadrangle in parts of Thurston, King, and Pierce Counties (Molenaar and Noble, 1970; Walsh and others, 1987). The part of Mason County, shown in the northwest quadrant of the map area, is the only county that lacks bedrock exposures as well as subsurface bedrock penetration data in the study area.

Thurston County

Eocene rocks of the McIntosh, Northcraft, Skookumchuck, and Crescent Formations and volcaniclastic rocks are exposed in Thurston County, located in the south and southeastern part of the map area. The only exposed Oligocene rocks are represented by part of the Lincoln Creek Formation (Snavely and others, 1958; Noble and Wallace, 1966; Beikman and others, 1967), exposed Miocene formations comprise the Astoria(?) and Mashel Formations and unnamed Miocene and Pliocene(?) nonmarine tuffaceous claystone, siltstone, sandstone, conglomerate, tuff (Snavely and others, 1958).

McIntosh Formation (Eocene)

This formation consists mainly of tuffaceous siltstone and claystone that are interbedded with tuff layers and basalt flows (Snavely and others, 1958; Noble and Wallace, 1966). Schasse (1987) reports that outcrops of shale, which is commonly carbonaceous, are also present in this formation. Arkose is also present and is the most common outcrop lithology near the town of Tenino, whereas finer grained sedimentary rocks of this formation are more common south and west of Tenino (Snavely and others, 1958; Noble and Wallace, 1966).

Northcraft Formation (Eocene)

Overlying the McIntosh Formation is a sequence of volcanic and sedimentary rocks that comprise the Northcraft Formation. The volcanic rocks are chiefly ferromagnesian rich lavas, flow breccia, and pyroclastic rocks that overlie basaltic conglomerate and sandstone as well as pyroclastic materials (Snavely and others, 1958; Noble and Wallace, 1966; Schasse, 1987).

Skookumchuck Formation (Eocene)

The Skookumchuck Formation overlies the Northcraft Formation. It consists primarily of arkosic sandstone and siltstone with intercalated carbonaceous shale and coal beds, and with local conglomerate beds and interbedded tuffaceous volcanic rocks (Snavely and others, 1958; Noble and Wallace, 1966; Schasse, 1987).

Crescent Formation (Eocene)

The Crescent Formation consists of tholeiitic basalt flows and flow breccia and is exposed in the southwest corner of the map area (Schasse, 1987; Walsh, 1987). Sedimentary rocks of the Crescent Formation consist of basaltic sandstone and siltstone (Schasse, 1987).

Volcaniclastic rocks (Eocene)

An unnamed sequence of volcanic breccia, sandstone and siltstone, tuff, conglomerate, and beds of coaly material which intertongue with rocks of the Puget Group and of the Northcraft Formation (Schasse, 1987) are present in the southern part of the map area.

Lincoln Creek Formation (Oligocene)

In the map area, this formation, overlying the Skookumchuck Formation, is reported as Oligocene in age and consists of two units: an upper tuffaceous siltstone and a lower tuffaceous, silty sandstone (Snavely and others, 1958; Noble and Wallace, 1966; Beikman and others, 1967).

Astoria(?) Formation (Miocene)

The Astoria(?) Formation contains an upper tuffaceous fossiliferous sandstone unit with a few lenses of siltstone and a lower unit of arkosic sandstone (Snavely and others, 1958; Noble and Wallace, 1966).

Mashel Formation (Miocene)

This formation is best exposed at the mouths of Mashel and Ohop Rivers. It consists of an upper unit of fine-grained fluvial and lake deposits, and a lower unit of gravel (Noble and Wallace, 1966; Walters and Kimmel, 1968). In some areas, the upper unit consists of interstratified clay, lignite, and volcaniclastic sand, and the lower unit consists of a poorly cemented pebble conglomerate (Schasse, 1987).

Intrusive rocks (Miocene)

These rocks are of basaltic, leucoratic, and gabbroic composition that form dikes and sills in the map area (Snavely and others, 1958; Noble and Wallace, 1966; Schasse, 1987).

King County

In the northern part of the map area, units of the Puget Group (Mullineaux, 1965a, b; Vine, 1969) and intrusive rocks of Eocene and Oligocene age (Waldron, 1962; Mullineaux, 1965b; Vine, 1969), and members of the Hammer Bluff Formation of Miocene age crop out (Mullineaux, 1965a; Luzier, 1969; Vine, 1969).

Puget Group

In its overall extent, the Puget Group contains the following three ascending formations: Tiger Mountain, Tukwila, and Renton. Of these the Tukwila and Renton Formations are lithologically the most typical formations of the Puget Group and appear to be the only Puget units found in the map area (Mullineaux, 1965b; Vine, 1969); therefore, the Tiger Mountain is not described below.

Tukwila Formation (Eocene)

The Tukwila Formation is a wedge- or tongue-shaped sequence of epiclastic volcanic sandstone, siltstone, and shale that is found in the coal-bearing sequence of the Puget Group (Vine, 1969). In the Renton 1:24,000-scale quadrangle (fig. 1*B*), Mullineaux (1965b) also describes mudstone, mudflows, tuff beds, and lava flows(?) in this formation. See also Waldron (1962) and Luzier (1969) for a summary of this formation in this area.

Renton Formation (Eocene)

The Renton Formation consists of feldspathic and arkosic sandstone, carbonaceous claystone, and coal (Waldron, 1962; Vine, 1969; Turner and others, 1983). Mullineaux (1965b) also describes conglomerate, mudstone, and shale for this formation in the Renton 1:24,000-scale quadrangle.

Intrusive rocks (Eocene and Oligocene)

Most of these intrusive rock masses in the map area are less than 40 ft thick and form sills and sill-like bodies (Vine, 1969). Other intrusives are irregular bodies and dikes of basalt and porphyritic andesite (Waldron, 1962; Mullineaux, 1965b).

Hammer Bluff Formation (Miocene)

The upper and lower members of the Hammer Bluff Formation crop out in the northeastern part of the map area (Mullineaux, 1965a). The upper member is mostly fluvial sand and gravel, and the lower member is chiefly lacustrine and fluvial quartzose sand and kaolinitic claystone (Mullineaux, 1965a; Luzier, 1969).

Pierce County

The oldest rocks that crop out in Pierce County range in age from Eocene to Miocene. They are present in the southeast part of the map area and consist of (ascending) the Crescent, Carbonado, Northcraft, and Spiketon Formations of Eocene age; intrusive rocks of Eocene(?) age; Ohanapecosh Formation of Oligocene age· undivided volcanic rocks that range from Eocene to Eocene in age; and the Mashel Formation of Miocene age (Walsh, 1987).

Crescent Formation (Eocene)

Rocks of this formation are dominantly tholeiitic basalt flows and flow breccia (Gard, 1968; Walsh, 1987).

Carbonado Formation (Eocene)

This formation consists of arkosic sandstone and siltstone, and shale as well as coal (Gard, 1968; Walsh, 1987).

Northcraft Formation (Eocene)

Andesitic and basaltic pyroclastic breccia, volcanic mudflow breccia, flow(?) breccia, and minor interbeds of volcanic sandstone, conglomerate, and tuff comprise this formation (Gard, 1968; Schasse, 1987; Walsh, 1987).

Spiketon Formation (Eocene)

This formation consists mainly of arkosic sandstone and siltstone, shale, and coal that are exposed in the eastern part of the map area (Gard, 1968; Walsh, 1987).

Intrusive rocks (Eocene?)

These intrusions are sills and dikes of andesite and gabbro that are younger than the Spiketon Formation which they intrude. Also found are dikes and sills of latite that intrude rocks of the Northcraft Formation (Walsh, 1987). Similarly, Schasse (1987) reports diorite, andesite, and andesite porphyry dikes, sills, and plugs in the southeast part of the map area.

Ohanapecosh Formation (Oligocene)

The Ohanapecosh Formation in the map area consists of conglomerate, sandstone, siltstone, and shale which are exposed only along the eastern boundary of the map area (Gard, 1968; Walsh, 1987).

Volcanic rocks (Miocene to Eocene)

These sedimentary rocks are "semiconsolidated lacustrine sand, silt, and clay and alluvial sand and gravel that consist chiefly of detritus of the Ohanapecosh Formation" (Gard, 1968); locally these deposits contain volcanic ash and mudflow deposits (Walsh, 1987). Volcanic rocks, basaltic andesite and andesite flows, and tuffs are also present in the southeastern part of the map area (Schasse, 1987).

Mashel Formation (Miocene)

In the southeast part of the map area, the Mashel Formation comprise unconsolidated fluvial and lacustrine deposits that are divided into two units--an upper unit consisting of interstratified clay, volcaniclastic sand, and lignite and a lower unit consisting of poorly cemented pebble conglomerate with intercalated sand (Schasse, 1987; see also Noble and Wallace, 1966 and Walters and Kimmel, 1968).

Kitsap County

Although Tertiary rocks are exposed elsewhere in Kitsap County, these rocks do not crop out in the map area. However, a sequence of basaltic flows are exposed in a quarry in the southwest part of the county (Sceva, 1957).

Surficial Deposits

Pleistocene and Holocene deposits blanket most of the map area. The Pleistocene deposits include mixtures and (or) beds of cobbles, gravel, sand, silt, and clay. Most of these materials are the products of at least six glacial advances and retreats (T.J. Walsh, written commun., 1993). The maximum glacial advance is represented by the outline of the Puget Sound lobe (Crandell and others, 1958; Thorson, 1989), a part of which is indicated by the hachured line shown in the southern part of the map area (fig. 1). Other Pleistocene deposits resulted from nonglacial alluvial and (or) lacustrine processes. The Holocene deposits were derived from alluvial, lacustrine, swamp, and mass-wasting processes and consist mainly of gravel, sand, silt, clay, and peat or mixtures of these materials (Walsh, 1987; Walsh and others, 1987). The correlation of these units is not possible in this study because of the complex stratigraphy of the deposits, problems with their formational nomenclature (Noble, 1990), and the transitional relationships between some of the unconsolidated deposits of Quaternary age and older unconsolidated to semiconsolidated deposits (Noble and Wallace, 1966; Hall and Othberg, 1974).

Subsurface Bedrock

Of the 366 data entries in table 1,124 represent true bedrock depths with the following distribution by county: Kitsap County, 1; King County, 46; Mason County, 0; Pierce County, 29; and Thurston County, 48. The types of bedrock penetrated by drill holes are presented in table 1 and described below by county. Mason County is not listed because, according to drill records for this study, bedrock was not penetrated in this county. Only four of the 86 seismic reflection shots made in these studies reached bedrock, one in Budd Inlet in the southwest part of the map area (fig. 1*A*; Snavely and others, 1972, line C), and three near the northern boundary of the map area (fig. 1*A*; Western Geophysical, unpub. data, 1971).

The different types of bedrock penetrated are mostly of Tertiary age and most are well consolidated. However, the units described in some drill holes report a gradational change from unconsolidated, Quaternary glacial deposits to unconsolidated sedimentary deposits of Tertiary age (Noble and Wallace, 1966; Hall and Othberg, 1974). Some of these Tertiary deposits are as young as Miocene and include lacustrine sand, silt, and clay, and fluvial sand, kaolinitic clay, conglomerate, mudstone, shale, volcanic ash, and debris from mudflows (Mullineaux, 1965a, b; Walters and Kimmel, 1968). These similarities in composition and degree of consolidation of some Tertiary deposits with the younger unconsolidated Quaternary deposits make them difficult to distinguish by seismic reflection studies without drill-hole data.

Kitsap County

Basalt is the only bedrock penetrated in Kitsap County.

King County

The rock types identified as bedrock in King County consist of andesite, sandstone, brittle clay, and coal. In the original drill logs, a number of the bedrock entries are listed as merely bedrock without a specific rock-type designation (see table 1). A few formations were listed without details of the specific rock types observed. The formations listed as bedrock consist of formations of the Puget Group and the Hammer Bluff Formation.

Pierce County

Sandstone and siltstone are the main types of bedrock reported in Pierce County. The Mashel(?) Formation is the only formation listed, but without details of the specific rock types observed.

Thurston County

In Thurston County, basalt, sandstone, siltstone, and shale are listed for most drill holes; only the McIntosh and Mashel Formations are listed without naming specific rock types.

DISCUSSION

The isopach contour intervals depicting the thicknesses of unconsolidated deposits shown on the map are variable owning to the spacing of drill holes that penetrate bedrock, the sparseness of drill-hole data in some parts of the map area, the variable thickness values of the overlying unconsolidated deposits, the small scale of the map, and the variable relief of the buried bedrock surface. Outlines of bedrock outcrops are used as the zero-depth contour, and the other contours are interpolated and drawn in accordance with the thickness data available. The contour lines are most reliable along the northeast, east, and southern boundaries of the map area, where bedrock outcrops exist and where drill holes penetrate the unconsolidated deposits and consolidated bedrock contact. For these areas, a contour interval of 20 m is used. As deposits of unconsolidated materials thicken and exposures of bedrock and depth-to-bedrock data are rare or absent, a contour interval of 100 m is used. In addition, these contour lines are dashed and (or) queried to indicate the uncertainty of contour positions.

The thickest deposit of unconsolidated materials penetrated is 604 m (table 1, no. 204) near the center of the map area and gives rise to the bulls-eye configuration of the 400- to 600-m contour lines. Due to lack of exposed bedrock control and depth-to-bedrock data in this area, contour lines could have been drawn in a number of ways and, thus, the location of the contours is highly speculative. The true relief of the buried bedrock surface is probably more variable than that depicted.

ACKNOWLEDGMENTS

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MAP SHOWING DEPTH TO BEDROCK OF THE TACOMA AND PART OF THE CENTRALIA 30' X 60' QUADRANGLES, WASHINGTON

By

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