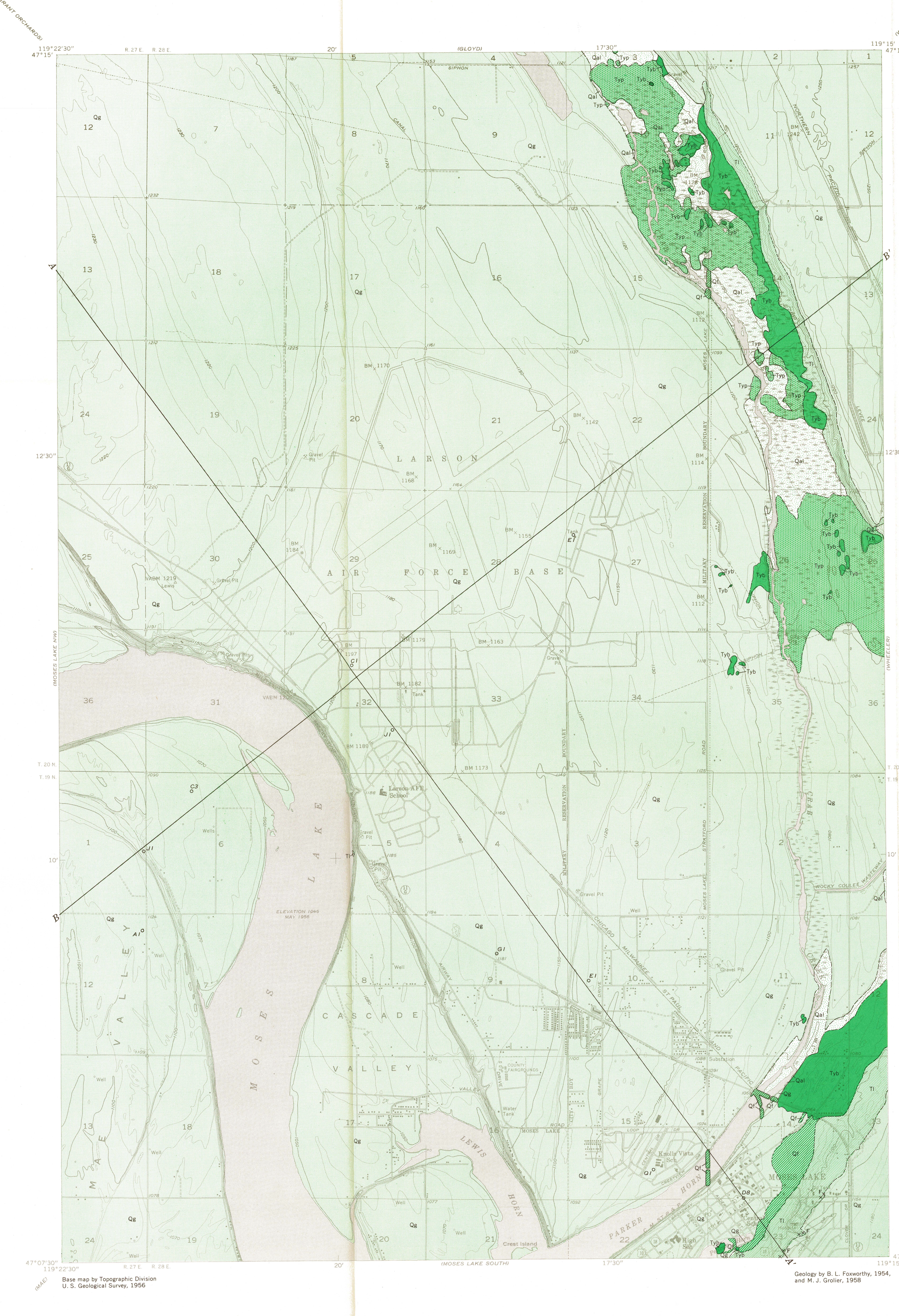
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
WASHINGTON STATE DEPARTMENT OF CONSERVATION

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-330



Base map by Topographic Division
U. S. Geological Survey, 1956

Geology by B. L. Foxworthy, 1954, and M. J. Grolier, 1958

EXPLANATION

QUATERNARY

Recent

🟩 Qf
Artificial fill

▨ Qal
Alluvium
Silt, sand, and gravel

Pleistocene

▨ Qg
Basaltic gravel
Unconsolidated glaciofluvial basaltic gravel and sand

TERTIARY

Pliocene (?)

▨ Tl
Lacustrine sediments
Principally tuffaceous, quartzose silt and sand; contains a few lenses of gravel at places. Abundant fossil ostracods in highest beds assigned a probable Pliocene age

Miocene

🟩 Tyb
▨ Typ
▨ Tyu
Yakima basalt
Sequence of lava flows and a few interbeds of sand, silt, and clay, in which fossils of possible Pliocene age have been found.
Tyb, *upper basalt, is grayish black, relatively coarse-grained, and has a felty texture of plagioclase and pyroxene crystals.*
Typ, *upper porphyritic flow, is dark blue gray, dense to very vesicular and contains abundant phenocrysts of plagioclase.*
Tyu, *subsurface flows, undifferentiated; shown in cross sections*

———— — — – – – –
Contact
Dashed where approximately located, short dash where indefinite

○ C1
Well

× F
Fossil locality

LITHOLOGIC SYMBOLS IN SECTIONS

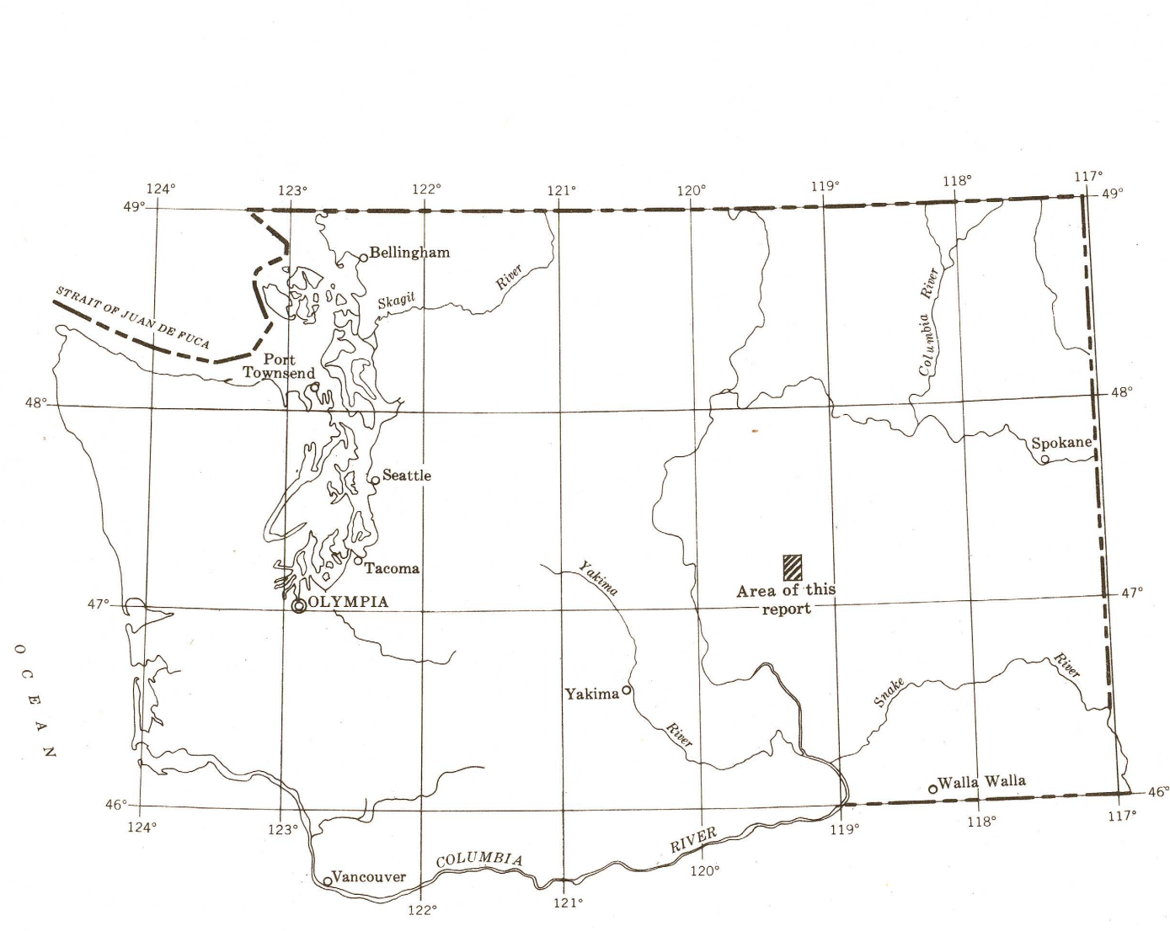
▨ Gravel and sand

▨ Tuffaceous silt and sand

▥ Basalt

▨ Gravel lenses

▨ Clay and silt lenses



INDEX MAP OF WASHINGTON

INTRODUCTION

The geology of the Moses Lake North quadrangle was mapped in 1954 and 1958 by the U. S. Geological Survey. Some of the basic hydrologic data had been collected by the Geological Survey during the early investigations of ground-water conditions in the Quincy Basin (Henshaw, written communication, 1917; Schwennesen and Meinzer, 1918). Most of the data, however, were obtained by the Geological Survey since 1941, in cooperation with the U. S. Bureau of Reclamation and the Washington State Department of Conservation under continuing programs in the area of the Columbia Basin Project of the Bureau of Reclamation. Some preliminary geologic field work in the Moses Lake North quadrangle was done by the Geological Survey in 1954 in cooperation with the Washington State Department of Conservation.

PURPOSE AND SCOPE

The purpose of this investigation is to provide the geologic background necessary for appraisal of the water resources and for the solution of problems of land use and construction in the Moses Lake area, in which, owing to the increase in population and industry, ground-water withdrawal has become heavy.

Furthermore, the study of the basalt which crops out along Crab Creek, north of the city of Moses Lake, fills a gap between areas previously studied by the U. S. Bureau of Reclamation at its O'Sullivan damsite, 9½ miles south of Moses Lake (Jones, written communication, 1945), and its equalizing reservoir, about 25½ miles north of Moses Lake (Walcott and Neff, written communication, 1950). The main water-bearing zones in the area of the Columbia Basin Project of the Bureau of Reclamation, are in basalt and basaltic gravel. Although the scope of this investigation is limited to the geologic setting and to the general hydrology, the knowledge of the stratigraphy of the basalt in the Moses Lake quadrangle will be useful in the eventual correlation of water-bearing zones in the basalt elsewhere in the area.

The map covers an area of about 50 square miles, including Larson Air Force Base and the northern half of the city of Moses Lake (population 11,800 in 1957). The quadrangle is in the area of the Columbia Basin Project of the Bureau of Reclamation, and includes some of the lands irrigated under that project. Field work in the area covered by the present investigation was begun in 1954 by Bruce L. Foxworthy, and was completed by Maurice J. Grolier in October 1958. The geology was mapped largely on topographic maps made by the Bureau of Reclamation, scale, 1:12,000; contour interval, 2 feet. Stratigraphic sections were measured with hand level and steel tape. The wells that appear on the map and the cross sections were inventoried by the Geological Survey prior to this investigation; well numbers are based on the rectangular system for subdivision of public land and refer to township, range, section, and 40-acre tract within the section. The number preceding the slash indicates the township, the number following the slash the range, the number following the hyphen the section, the letter following the section number the 40-acre tract as shown in the diagram below, and the final number is the number of the well in that particular 40-acre tract.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

SQUARE DIAGRAM REPRESENTING A SECTION OF LAND

ACKNOWLEDGMENTS

The writers are indebted to Prof. Norman Anderson and Dr. Philip R. Fehlandt, heads of the departments of geology and chemistry, at the University of Puget Sound, Tacoma, Wash., for making laboratory facilities available.

PREVIOUS INVESTIGATIONS

The area of the Moses Lake North quadrangle is mentioned briefly in records of the early explorers, Arnold (in Stevens, 1855, p. 285) and Symons (1882, p. 110). Russell (1893, p. 96) and Calkins (1905, p. 42, 44) were the first geologists to make a reconnaissance study of eastern Washington. Byers (1902, p. 9-10) collected the first sample of water from Moses Lake for chemical analysis and Henshaw (written communication, 1917) is responsible for collection of the earliest basic hydrologic data available for the area.

In 1916, Schwennesen and Meinzer made a study of the occurrence of ground water in the Quincy Basin, which included the Moses Lake North quadrangle. Their report (1918) includes a geologic section extending across Moses Lake, a generalized stratigraphic column, a water-table contour map, and a discussion of the geologic history.

Between 1919 and 1932, Bretz authored nearly a score of papers dealing with the glaciofluvial history of the region, and his conclusions were summarized recently (Bretz and others, 1956) in a paper which describes deposition of gravel in the Quincy Basin in late Pleistocene time, the glaciofluvial history of the channels now occupied by Crab Creek and Moses Lake, and the origin of the land forms.

Beginning in 1940, the U. S. Geological Survey in cooperation with the U. S. Bureau of Reclamation and the Washington State Department of Conservation conducted several studies concerning the geology and water resources in the area of the Columbia Basin Project of the Bureau of Reclamation. Basic hydrologic data have been collected almost continuously since that time and were released in a series of open-file reports (Taylor, 1944; Taylor, 1948; Mundorff and others, 1952; Walters and Grolier, 1960). The report by Taylor (1948) contains a geologic map of the Columbia Basin Project area, which shows the generalized features of the Moses Lake North quadrangle. In addition, these reports contain water-table and basalt-contour maps and a brief mention of the occurrence of ground water.

Brief mention of the soils of the Moses Lake area was made by Mangum and others (1913, p. 2, 242), and later a soil survey was made by Strahorn and others (1929, p. 34-37). The most recent map of the soils in the Columbia Basin was prepared by Gilkeson (1958).

PHYSIOGRAPHY

The Moses Lake North quadrangle is in the Central Plains section of the Columbia Basin subprovince, of the Columbia Intermontane Province of Freeman and others (1945, p. 53-75). It is in the eastern part of the Quincy Basin, a structural downwarp separated from the Pasco Basin part of the Central Plains section by anticlinal ridges, according to the classification of Freeman and others.

In general, the relief in the area is gentle. The altitudes are highest in the northwest and northeast parts of the quadrangle, 1,230 and 1,260 feet, respectively, above sea level. The lowest altitude is that of Moses Lake, the level of which was 1,046 feet above sea level in May 1956. The greatest local relief, more than 150 feet in places, is along a scarp on the east side of Moses Lake.

The area mapped lies between and across two channelways that carried a large part of the discharge of the Columbia River during late Pleistocene time when it was dammed near the site of the Grand Coulee Dam (about 50 miles north of the map area) by a lobe of the continental glacier (Bretz and others, 1956, p. 967). Tributary streams to the east and northeast also contributed to the flow in these channelways.

Scabland topography developed on the basalt bedrock in the easternmost of these ancient channels, now occupied in part by Crab Creek, through the scour and fill action of flowing water. The scabland topography is characterized by small buttes and mesalike knobs of columnar basalt that rise as much as 35 feet above abandoned anastomosing channels. These basalt buttes and knobs commonly have a vertical upstream face, and a gentle downstream slope. The downstream slope of many of these is strewn with angular blocks of basalt that were removed from the buttes and knobs and deposited in their lee by the river. The overall slope of the scabland area is gently southward. Parts of the scabland, notably in the northeastern part of the quadrangle, have become swampy in recent years as the result of discharge of springs and seeps along the base of the bluff east of Crab Creek, which is due chiefly to irrigation on the highlands farther east.

Perhaps the most striking geomorphic feature in the area is the sinuous pattern of Moses Lake, which occupies the meanders of a former overflow channel of the Columbia River, the westernmost of the channelways described above. The lake was formed by sand dunes that blocked the channel about 3½ miles south of the quadrangle.

Moses Lake collects all surface runoff and large amounts of ground water from the northeastern part of the Quincy Basin. It is fed by two streams, Rocky Ford Creek (beyond the map area) and Crab Creek, and by numerous springs and seeps (principally south of the map area). Rocky Ford Creek, which discharges into the lake about 3½ miles west of the northwest corner of the map area, formerly was the only perennial stream feeding the lake. However, as a result of irrigation, Crab Creek also has become a perennial stream, and the discharge of both creeks has increased materially. The level of Moses Lake is now artificially regulated by a dam near its natural outlet through the sand dunes, about 3 miles south of the quadrangle.

Just east of Crab Creek, a terrace can be traced discontinuously from the northeastern to the southeastern corner of the map. It is clearly delineated by a scarp 50 to 75 feet high, which slopes about 20° toward the scabland.

The interfluve between Crab Creek and Moses Lake now occupied by Larson Air Force Base slopes gently eastward through a succession of terraces that are obscured to some extent by abandoned stream channels choked with long bars of basaltic gravel. These terraces and bars are abruptly terminated by the escarpment on the east side of Moses Lake. The topography of Mae Valley, west of Moses Lake, also consists of terraces, abandoned stream channels, and gravel bars; the surface there is about 50 to 100 feet lower than that of the interfluve between Crab Creek and Moses Lake.

The terraces on both sides of the lake represent successive periods of deposition and erosion of the basaltic gravel, corresponding to periodic fluctuations of great amplitude in the flow of the melt water streams. The highest terraces, east of Crab Creek and west and northwest of Larson Air Force Base, apparently reflect the earliest stages of the streams. The suite of more or less distinct terraces at lower levels on the interfluve and in Mae Valley reflects a history of heavily loaded proglacial streams of periodically dwindling volume and velocity, in which gradients were continuously adjusting toward equilibrium with the abundant gravel load.

Only minor changes in topography have occurred since late Pleistocene time. Small gullies and associated alluvial fans have been formed along the terrace scarps, small cliffs have been produced along the shore of Moses Lake by wave action, and, north and northwest of Larson Air Force Base, a peculiar mounded surface has resulted from the partial removal by erosion of a thin mantle of silt which once covered the underlying gravel.

STRATIGRAPHY

YAKIMA BASALT

The two oldest rock units exposed in the Moses Lake North quadrangle constitute the upper part of the Yakima basalt, of Miocene and possibly Pliocene age. These units were described by Mackin (1955, p. 3-A-9, 3-A-13) in the vicinity of Wanapum and Priest Rapids damsites, 33 and 42 miles, respectively, southwest of Moses Lake. The lower of these units is a porphyritic flow, corresponding to the uppermost of two porphyritic flows recognized by Mackin, which occurs opposite the mouth of Roza Creek, a tributary to the Yakima River (about 60 miles southwest of Moses Lake). The other is a basalt that immediately overlies the porphyritic flow along the Columbia River near the hamlet of Priest Rapids (about 45 miles southwest of Moses Lake). They are referred to on this map as the "upper porphyritic flow" and the "upper basalt," respectively.

The Yakima basalt previously has been assigned an age ranging from early to late Miocene, on the basis of plant and animal remains in underlying and overlying sedimentary formations. In 1936, during construction of the Roza tunnel No. 3 through Yakima Ridge, about 3 miles northeast of Yakima, Washington, R. L. Lupher collected elephant and camelid remains from the lower part of the overlying Ellensburg formation which were identified in 1953 by Jean Hough, of the Geological Survey. She limited the possible range of these fossils to an age not older than middle Miocene and not younger than late Pliocene, and favored an early Pliocene age assignment (Hough, written communication, 1953). Fresh-water mollusks collected by Foxworthy in 1952 on the northwest flank of Sedge Ridge, 22 miles west of Yakima and 85 miles southwest of Moses Lake, occur in a silicified coquina interbedded high in the Yakima basalt sequence. T. C. Yen (written communication, 1952), of the Geological Survey, identified the fossils and listed their age as probably Pliocene.

Upon this evidence, the time of extrusion of the Yakima basalt may be extended and that portion of it which is exposed in the Moses Lake North quadrangle may be tentatively assigned an early Pliocene age.

Drillers' logs of wells in the area report basalt extending below sea level, but the total thickness of the basalt and the nature of the underlying rocks is unknown. Drillers' descriptions of the basalt encountered in wells generally are not sufficiently detailed to establish a stratigraphic sequence for the flows below those exposed within the quadrangle. The descriptions of sedimentary beds encountered locally in the basalt sequence, however, have proved extremely helpful in checking structural relationships between wells in and adjacent to the area mapped. In the cross sections, the subsurface Yakima basalt that cannot be correlated with exposures of the upper porphyritic flow and of the upper basalt has been shown as undifferentiated.

The dip of the basalt is very gentle—probably everywhere less than 100 feet per mile—within the area mapped. The slope of the upper surface of the basalt, which probably approximates the dip, is to the southwest, and along section B-B' is about 100 feet in 3.6 miles between Crab Creek and the intersection of section A-A', an average of about 28 feet per mile.

Upper porphyritic flow.—Only the very top of the upper porphyritic flow is exposed in the Moses Lake North quadrangle. It constitutes the bedrock in the swampy lowland and the scabland along Crab Creek. Most exposures are poor; the best are found along the flood channels of Crab Creek in secs. 10 and 15, T. 20 N., R. 28 E., where the stream has cut 6 or 7 feet into the flow. Here the porphyritic basalt is very vesicular, and has poorly developed columns not more than 2 to 2½ feet in diameter. Elsewhere, the upper porphyritic flow barely rises above the surface in low rugged mounds. It is easily identified, however, by its porphyritic texture and tan to brown color and angular shape of the float.

The fresh rock is dark blue gray, fine grained, crystalline, porphyritic, dense to very vesicular. When weathered it is light tan or bright reddish-brown. The vesicles are elongated and range from 1 mm to as much as 20 mm in diameter. Glassy, shattered phenocrysts of plagioclase, many of which are lath-shaped, may be easily distinguished on fresh surfaces. The phenocrysts usually are clear, light yellow to amber colored, single or composite, and range in length from 1 mm to 10 mm. The mineral constituents of the groundmass cannot be distinguished megascopically.

The total exposed thickness of the upper porphyritic flow probably does not exceed 15 feet. The base of the flow is not exposed. The contact with the overlying upper basalt is covered everywhere with talus.

Upper basalt.—The small mesas and buttes in the valley of Crab Creek are erosional remnants of the upper basalt. More subdued knobs of this unit are found immediately north of the city of Moses Lake, and in the city at the eastern end of Pelican Horn, where it crops out 2 or 3 feet above the lake level. With a few isolated exceptions, all exposures are east of Crab Creek and close to the bluffs that mark the edge of the terrace east of the stream. The accompanying geologic sections, which are based partly on well logs, suggest that the upper basalt has been largely stripped from the underlying upper porphyritic flow for an undetermined distance west of Crab Creek.

The upper basalt is grayish black, crystalline, and dense to finely vesicular. It is coarser grained than the average Yakima basalt, and has a distinct felty texture. Poorly developed crystals of plagioclase are easily recognized with the aid of a hand lens, and minor amounts of yellowish-brown glass give even the freshest samples a slightly altered appearance. The lack of phenocrysts and the relatively coarse-grained felty texture are the most distinctive megascopic features of the upper basalt that distinguish it from the upper porphyritic flow.

The upper basalt is massively jointed and is made up of well-developed prismatic columns, usually 5 to 8 feet in diameter. A horizontal platy joint structure normal to the prism faces is common near the top of the columns. Many of the mesalike remnants of this unit have no soil cover, and the joint pattern on their surface gives the appearance of a roughly hexagonal pavement. Stream-polished surfaces, preserved on the tops of small mesas in sec. 10, T. 20 N., R. 28 E., are commonly pitted where the polished surface has spalled off as a result of heat and frost action. Disjointing of the prismatic columns through mechanical weathering usually is no more than one column wide around the periphery of the mesas. At most places, the upper basalt is relatively unweathered, but well-developed spheroidal weathering can be seen along an abandoned road in the NW¼ sec. 35, T. 20 N., R. 28 E.

Along State Highway 11-G, north of the city of Moses Lake, in the NE¼ sec. 14, T. 19 N., R. 28 E., the lower part of the upper basalt exhibits poorly developed pillows surrounded by palagonite and thin layers of tuffaceous clay. The pillow basalt overlies a layer of pumicite which contains loose, ovoid, porous grains of pumice about 1 mm long. Pillows associated with pockets of opal also may be seen in road cuts in the lowest part of the upper basalt near the common south corner of secs. 10 and 11, T. 20 N., R. 28 E. Nearby, in a drainage ditch, at a point about 1,500 feet north and 75 feet east of the southwest corner sec. 11, buff-colored, baked, diatomite overlies the upper porphyritic flow. It is probably the lateral equivalent of a bed of diatomite known to separate the underlying upper porphyritic flow from the upper basalt in other areas of the Quincy Basin; it has been described in the Quincy-Burke district, 28 miles west and 6 miles south of Moses Lake, by Mackin (written communication, 1946).

Mackin (1955, p. 3-A-9) states that the upper basalt at the locality of Priest Rapids consists of four flows with an overall thickness of about 200 feet. In the Moses Lake North quadrangle, only the lowermost flow definitely is exposed, but the base of a second, higher flow may form the tops of buttes in secs. 25 and 26, T. 20 N., R. 28 E. The basalt of this questionable higher flow does not have the columnar habit typical of the upper basalt seen elsewhere in the area but instead has a more irregular, "brickbat" jointing. It is denser, and, probably because of a higher percentage of magnetite, is darker. The total thickness of the upper basalt exposed in the quadrangle is approximately 35 feet.

LACUSTRINE SEDIMENTS

The Yakima basalt is overlain by predominately lacustrine sediments consisting of tan to yellow-gray, quartzose, tuffaceous sand, silt, and clay, containing scattered lenses of basaltic gravel. On the basis of four genera of ostracods ("*Candona*," *Limnocythere?*, gen. aff. *Lineocypris*, and gen. aff. *Cypridopsis*), identified by I. G. Sohn (written communication, 1959) of the Geological Survey, the lacustrine sediments are tentatively assigned to the Pliocene. The beds are exposed in the bluffs east of Crab Creek and in some of the steeper slopes in the city of Moses Lake, and were encountered beneath a sequence of basaltic gravels during drilling of wells elsewhere in the area.

Exposures near the Samaritan Hospital in the city of Moses Lake provide the best measurable section in the Moses Lake North quadrangle. At the locality, the contact with the underlying Yakima basalt is inferred to be about 30 to 35 feet below the base of the exposure. To provide a basis for comparison with the Ringold formation to the south, and for lateral correlation of surface and subsurface data in and near the quadrangle, the section was measured and is described as follows:

Section of lacustrine sediments in gulch between Samaritan Hospital and Methodist Church, NW¼NE¼ sec. 23, T. 19 N., R. 28 E.

Altitude of top of section: 1,155 feet	Feet
Late Pleistocene:	
Basaltic gravel:	
Gravel (glaciofluvial), light- to dark-gray, subangular to well-rounded; contains basaltic pebbles and lenses of coarse basaltic sand. Underside of pebbles lime-coated, topside weathered to light brown	17
Pliocene ?:	
Lacustrine sediments:	
Silt, yellowish-gray, very fine-grained, quartzose, micaceous, friable, ostracod-bearing; alternates with thin layers (½ to 1 inch thick) of well-indurated, light olive-gray, micaceous, unfossiliferous clay, which splits into small angular chips	8.6
Clay, light olive-gray, slightly indurated, ostracod-bearing; alternates with layers (1 inch thick) of white clay; grades upward into yellowish-gray, very fine-grained, quartzose, friable sand, containing fish scales and vertebrae, and ostracod fragments	1.6
Clay, yellowish-gray, silty, slightly indurated; contains long, transparent, spiculelike needles, and punctate ostracods	2.4
Ash, light yellowish-gray, altered, loosely consolidated; contains transparent, angular quartz, mica, and black opaque minerals	1.4
Sand, yellowish-gray, very fine-grained, friable, clean, ostracod-bearing; contains subangular quartz, biotite, and volcanic glass	1.4
Sand, yellowish-gray, very fine-grained, porous, friable, water-worn, quartzose; contains clear, transparent, bubbly volcanic glass, biotite, transparent spiculelike needles, and scattered ostracods	2.6
Tuff, yellowish-gray, very fine-grained, porous, indurated, poorly stratified, cemented with carbonate and iron oxide; has appearance of a solution breccia and grades upward into a zone of large kidney-shaped concretions	4
Tuff, yellowish-gray, very fine-grained, porous, poorly stratified, moderately cemented with carbonate; contains concretions (2 inches to 6 inches long) of a dusky-brown metallic oxide near the base	6
Sand, dark yellowish-gray, very fine-grained, friable, poorly sorted and stratified, quartzose and tuffaceous, and minor amounts of clay	1
Gravel, dusky-blue to black, medium- to fine-grained, basaltic; particles are subangular, elongated, coated with clay and metallic oxide, and well cemented with clay. Grades upward into mottled, coarse- to fine-grained, friable, crossbedded, basaltic sand, containing grains of quartz and of light yellowish-green subhedral hypersthene. Gravel lenses out into tuff	9
Tuff, yellowish-gray, porous, friable, poorly stratified, partly altered to clay, ramified with tubules coated with white carbonate and (or) black oxide	8
Tuff, pale yellowish-brown to grayish-orange, porous, friable, massive to poorly stratified, vitric (base of sediments not exposed)	12
Altitude of base of section: 1,080 feet	75

The sequence described above, although shown on the map as a single lithologic unit, may be divided into two parts. The lower part, best identified in the field by its massive stratification and the gradational contacts of the beds, is about 40 feet thick and unfossiliferous. The rock is strikingly porous and friable and is ramified by tubules coated with white calcium carbonate. Differences in lithology of the sand and silt in the lower part are slight, and are due almost entirely to the degree of weathering, presence or absence of clay, content of volcanic glass, cementation, and staining. The upper part, approximately 18 feet thick, consists principally of light-colored, very fine-grained quartzose sand and silt, which contains abundant carapaces of fresh-water ostracods. Near the top, quartzose, micaceous silt alternates with thin layers of dark-gray shale and white volcanic ash. Crossbedding is common in the sandy layers.

The mineral constituents of the tuffs cannot be identified megascopically because of the amount of clay or frothy glass that surrounds them. A brief petrographic examination reveals that each of the tuffaceous units consists of clear, transparent, fluted shards of volcanic glass; clear, subhedral to angular quartz; plagioclase; euhedral hypersthene, hornblende, and magnetite. The tuff at the base of the measured section is estimated to consist of 60 percent or more of clear, fluted, volcanic glass.

The lacustrine sediments gradually thin toward the north, from a thickness of perhaps 80 feet at the measured section to only a few feet in road cuts in the NW¼ sec. 11, T. 20 N., R. 28 E. The sedimentary beds and the underlying basalt apparently are accordant, at least along the north-south component of dip. At the extreme southern edge of the quadrangle, the ostracod-bearing beds are overlain by about 15 feet of tan to light-brown, fine-grained, loosely consolidated sand and silt, which contain occasional mollusk shells and root casts.

A massive caliche layer, 1 to 5 feet thick, caps the sedimentary sequence just described and separates it from the overlying basaltic gravel except in the vicinity of the measured section where it has been removed by erosion. The massive caliche is made up of silt, cemented with calcium carbonate. The silt particles are derived from the upper part of the lacustrine sediments, and make up 50 percent or less of the caliche. The caliche is white to light pink, rhythmically banded, and well indurated. It is relatively impervious but dissolves gradually when subjected to continuous saturation. In the hand specimen, it exhibits, on a minute scale, many of the features found in the caves of the limestone regions, such as fissures, stalagmites, and stalactites.

Other zones of caliche have been observed in the mapped area, but none is so extensive, or so useful as a marker horizon, as the layer of massive caliche capping the lacustrine deposits along the top of the Crab Creek bluffs. This extensive layer is believed to represent a period of nondeposition under semiarid climatic conditions.

Drillers' logs of wells in the area indicate that the clay, silt, and sand underlying the basaltic gravel west of Crab Creek locally contain appreciable amounts of gravel, occurring as thin lenses and distinct beds a few feet thick. A single exposure of silt and sand, believed to be part of this subsurface unit, was traced for a distance of 200 feet along the eastern bank of Moses Lake, near the center of sec. 5, T. 19 N., R. 28 E. These materials bear little similarity to any of the beds of the tuffaceous section exposed in the bluffs east of Crab Creek. They are unfossiliferous, coarser grained, and the grains show a higher degree of abrasion. The base is not exposed, but augering revealed that the sedimentary materials extend at least 5 feet below the present surface of the lake.

The section is described as follows:

Section of lacustrine sediments, near center sec. 5, T. 19 N., R. 28 E.

Altitude of top of section: 1,090 feet	Feet
Late Pleistocene:	
Basaltic gravel:	
Gravel (glaciofluvial), dark-gray, well-rounded, very coarse, basaltic	25
Sand and gravel, dark-gray to black, subrounded, loose; contains small angular fragments of caliche and opal, and fills pockets in the underlying sand	4
Pliocene ?:	
Lacustrine sediments:	
Sand, yellowish to rusty-brown, unconsolidated, medium- to fine-grained, laminated and crossbedded, weathered. Contains water-worn fragments of quartz, mica, and dark opaque minerals. Sharp lower contact, grades upward to sand and gravel	8
Silt, yellowish-gray, friable, quartzose, micaceous, weathered (base of sediments not exposed)	7
Altitude of base section: 1,046 feet (lake level)	44

Judging by the differences in the lithology and elevation (cross sections), the fine-grained materials beneath the basaltic gravel may not be wholly contemporaneous with those exposed in the bluffs east of Crab Creek. Because of obvious general similarities, however, such as the common occurrence of the distinctive yellowish clays, silts, and sands, they are given the same designation on the map and cross sections.

These sediments overlying the upper basalt are considered to be lacustrine because they are generally fine grained and well sorted, and at places exhibit good horizontal bedding. The lower part of the measured section in the city of Moses Lake, which is massively bedded, probably was deposited in the quiet, deep water of a lake. The lenses of gravel therein, and those interbedded with finer sediments found during drilling of wells, probably were deposited by streams discharging into the lake. Thin bedding, local crossbedding, and the profusion of fossil fresh-water ostracods in the upper part of the type section are evidence that these sediments were deposited in the shallow, littoral waters of a lake.

In the past, the lacustrine sediments exposed in the Crab Creek bluffs, and those encountered in wells of the Moses Lake area have been assumed to be of Pleistocene age; they are part of the "lake beds" of Schwennesen and Meinzer (1918, p. 143, pl. 14). The age assigned these lake beds, in the Quincy Basin, by Schwennesen and Meinzer is based upon a few mollusks found in black basaltic sand, 2 feet below the surface, 17 miles west and 5½ miles south of Moses Lake, and identified in June 1917 as *Lymnaea palustris* Müller, *Valvata lewisii* Currier, and *Pisidium* probably *variabile* Prime by W. H. Dall, geologist and paleontologist of the U. S. Geological Survey (written communication, 1917). However, the black sand where these fossils were found and the lacustrine sediments of the Crab Creek bluffs are lithologically different; they are not lateral equivalents and were mapped as different units by Taylor (1948, pl. 1). Culver (1937, p. 58) considered the lacustrine sediments as an extension of the Ringold formation, as did Mundorff and others (1952, p. 18).

Stratigraphically, the lacustrine sediments occupy the same position in the Moses Lake North quadrangle as does the lower member of the Ellensburg formation at and near the Priest Rapids damsite (Mackin, 1955, pl. 3-A-2). Earlier it has been stated that the upper basalt is correlative with a basalt that immediately overlies a porphyritic flow along the Columbia River near the hamlet of Priest Rapids. However, the correlation of the Ellensburg formation at Priest Rapids damsite with the lacustrine sediments in the Moses Lake North quadrangle is weakened by the fact that the upper basalt is only 35 feet thick and consists of but one flow whereas the basalt occupying the above-cited position at Priest Rapids damsite is 200 feet thick and consists of four flows. Whether the lacustrine sediments are the lateral equivalent of the Ellensburg formation is a problem, the solution of which must await a detailed study of the regional relationships of the Ringold and Ellensburg formations, and the precise dating of the lower part of the Ringold formation, which is known to have been deformed with the Yakima basalt (Culver, 1937, p. 60).

BASALTIC GRAVEL

Except in the scablands east of Crab Creek, basaltic gravel forms a nearly continuous mantle over the entire area. The gravel consists almost entirely of basaltic fragments. Particles of nonbasaltic rocks, mostly granite, gneiss, cherty quartzite, chloritic rocks, opal, and caliche, constitute less than 1 percent of the total volume of the gravel at most places. Some selective distribution of the exotic rocks is noticeable, especially those of boulder size. Clusters and trains of granitic boulders are scattered on the surface of the interfluve west of Crab Creek and along Moses Lake. The granitic boulders are most abundant near Moses Lake; along the south shore of the lake in sec. 31, T. 20 N., R. 28 E., they constitute as much as 10 to 12 percent of the rocks at the surface. The gravel in Mae Valley also has a distinctively higher proportion of nonbasaltic rocks than most areas. Locally, caliche fragments may constitute a higher percentage of the gravel. At a gravel pit in the SE¼ sec. 3, T. 20 N., R. 28 E., well-rounded cobbles of caliche constitute as much as 5 percent of the gravel exposed.

The basaltic gravel ranges in color from light gray to black, depending upon the degree of weathering and the coating of the particles. It is usually unconsolidated or only weakly cemented, but at places the gravel at shallow depths is firmly cemented by calcareous or ferruginous cement. Calcium carbonate commonly occurs also as a thin coating on the gravel-size particles near land surface. Weathering has produced gray rinds on some basalt fragments—as much as a quarter of an inch thick on pebbles and even more on larger fragments. However, the weathered fragments are mixed indiscriminately with unweathered cobbles and pebbles, and apparently are not a criterion of the relative ages of the gravel bodies. In some gravel pits, the gravel becomes fresher and cleaner with depth, whereas the shallower pebbles and cobbles commonly are weathered to a light-gray color on their top sides, and are coated with calcium carbonate on their under sides.

Much of the gravel is a heterogeneous mixture of sizes that range from sand grains to large boulders, but good bedding and sorting are not uncommon. At places, particularly where foreset or torrential bedding is present, the sorting has been sufficient to produce beds of "openwork" gravel, in which finer particles do not fill the spaces between the cobbles and pebbles; at other places, streaks of sand and fine gravel are found. Although sorting and stratification are highly variable in the gravel as a whole, there is a suggestion at places that layering is more pronounced at depth.

Stratification in the gravel can best be seen in the pit of the Columbia Sand and Gravel Co., in sec. 5, T. 19 N., R. 28 E. There topset and foreset beds indicative of deltaic deposits of a large stream are exposed. The upper 40 feet exhibits topset bedding that is nearly horizontal. The topset beds are underlain by 30 feet of crossbedded basaltic sand containing a relatively large percentage of nonbasaltic fragments, and the lowermost 30 feet consist of foreset beds with regular apparent dips of 25° to 30° to the south. Within individual foresets sorting is good and the effective porosity is high. In the lower part of the pit, nearly 100 feet below the top of the interfluve, the basaltic pebbles and cobbles are coated with a thin layer of clay. In none of the pits along Moses Lake was there any evidence that the foreset beds dip toward the lake; usually they dip south or southeast. Similar relationships can be observed in a gravel pit on Larson Air Force Base (sec. 31, T. 20 N., R. 28 E.) and in the Holmes Brothers pit (sec. 11, T. 19 N., R. 28 E.).

In the scablands along Crab Creek, the gravel overlies the Yakima basalt unconformably; elsewhere it overlies the lacustrine deposits, also unconformably. The known thickness of the gravel ranges from a few feet in the scablands to 132 feet at a well in sec. 9, T. 19 N., R. 28 E., on the interfluve west of Crab Creek.

The gravel represents debris that was periodically scoured from the Yakima basalt and deposited farther downstream by large glaciofluvial streams issuing from the scabland tracts north and northeast of the area, and by the Columbia River when it was diverted through Grand Coulee by a lobe of the continental glacier in late Pleistocene time. The source of the gravel and conditions of its deposition are discussed by Bretz and others (1956, p. 969-974).

Many of the boulders and finer grained materials were rafted into the area by ice. The largest ice-rafted erratic known within the area is an angular granitic boulder, formerly about 10 feet in diameter, but now split lengthwise along quartz veins. This granitic erratic boulder, and a smaller one of mica-rich gneiss, are located about 1,800 feet south, and 100 feet west of the NE corner sec. 14, T. 19 N., R. 28 E.

Ice rafting also seems responsible for a band of large angular basalt boulders that occur at the surface along the crest and on the lower slopes of the terrace scarp east of Crab Creek. These boulders apparently were dumped on bars and on the shore of a former high-level melt water stream.

The age of the gravel cannot be referred more accurately than to a very short period late in Pleistocene time.

RECENT ALLUVIUM

Recent alluvium covers a relatively small part of the quadrangle, primarily in the valley of Crab Creek. The alluvium consists principally of basaltic gravel, fine-grained sand, and silt. The gravel is mostly material reworked from the glaciofluvial basaltic gravel unit, but also includes angular fragments recently plucked from the basalt in the channel of the creek.

SOILS

Most of the area is mantled by a tan silty soil, from 1 to 5 feet thick, which, at least in part, is believed to be of eolian origin. Gilkeson (1958) described it as a sandy or silty loam belonging to the Ephrata (soil) type. Its relation to thick, extensive loessal soils that occur east of the Moses Lake area is unknown. The wind-deposited silt is markedly different from residual soil derived from the underlying basalt. The residual soil, which in this area is restricted to small patches in the scabland, is a reddish-brown, friable, porous, sandy silt. No attempt was made to show the soils on the geologic map.

ECONOMIC RESOURCES

The economic resources of the Moses Lake North quadrangle include the water of Moses Lake and of Crab Creek, the ground-water supply, the basaltic sand and gravel, and possibly the tuffs.

MOSES LAKE AND CRAB CREEK

As early as 1887, cattle ranchers were attracted to the Moses Lake area because of the plentiful supply of water available in the lake for stock watering, and, to some extent, for irrigation. At that time, however, the water was much too saline for intensive irrigation. It was not until after 1904, when Moses Lake broke through the sand dunes into the channel of lower Crab Creek, that the saline water which previously had been impounded was partially flushed out and was gradually replaced with fresh water from Rocky Ford and Crab Creeks. As a result of this freshening, the lake became important as a source of water for irrigation. In the late 1940's as many as 13 pumping plants were withdrawing water from that part of the lake within the Moses Lake North quadrangle. Since 1952, when water was imported to the area through canals of the Columbia Basin Project of the U. S. Bureau of Reclamation, the importance of the lake as a source of irrigation water has declined, but lake water still was being used to some extent for irrigation and industrial purposes as of 1958.

The water imported under the Columbia Basin Project indirectly replenishes the summertime flow of Crab Creek. This stream has become a dependable, perennial source of surface water.

GROUND-WATER SUPPLY

Ground water in economic quantities is obtained from both the basaltic gravel and the underlying Yakima basalt. In the basalt, the water-bearing zones occur at or near the contacts of individual flows. Commonly, the contacts between two flows are sufficiently permeable that water can be obtained from wells tapping one or more of these interflow zones. Because the top of a lava flow is irregular, the failure of the overlying flow to conform exactly to the asperities of the surface beneath results in the formation of many openings, both large and small, through which water can move, at rates depending on the size and degree of interconnection of these openings.

In many cases where pillow-palagonite developed at the base of the overlying flow, the pillows are tangential to each other; the voids so formed, in many instances, add materially to the permeability of the interflow zones. Also, the top of the underlying flow usually is vesicular; where the existence of these vesicles aided weathering of the basalt, the permeability of the basalt itself doubtless was increased to some extent.

The movement of ground water is, in general, from northeast to southwest within the area mapped. In mid-1958, the water table ranged in altitude from about 1,180 feet near the northeast corner of the map to about 1,040 feet in Mae Valley, where it was about 6 feet below the level of Moses Lake (Walters and Grolier, 1960).

Yields of wells tapping basalt aquifers are as much as 1,400 gpm. On the basis of pumping records for a few basalt wells in the area, specific capacities (gpm per foot of drawdown) range from about 15 to 35. Where the basaltic gravel is saturated, yields of wells tapping it range from about 100 to several hundred gallons per minute, and yields of 500 gpm or more are common.

The ground water throughout the Moses Lake North quadrangle is, in general, of good chemical quality. Water from the basalt usually has a smaller amount of dissolved mineral constituents than does water from the overlying basaltic gravel.

SAND AND GRAVEL

The basaltic gravel is well suited for use as road metal and in concrete and macadam aggregates. It is easily excavated with bulldozers and power shovels, and a simple washing process rids the pebbles of their coating of lime or of clay. The volume of rock taken from the pits annually is conservatively estimated at 300,000 cubic yards, and the supply appears to be virtually inexhaustible.

TUFFS

The tuff along the bluffs east of Crab Creek and Pelican Horn may prove upon further testing to have properties suitable for its use as a pozzolan, a material used to impart superior strength and resistance to hydraulic cement. Thus, the tuff may have an economic value should a local market develop for this type of material. However, at places the tuff is saturated through much of its thickness, during at least part of the year. For that reason, mining of this material might involve problems of drainage, thereby adding to the cost of production.

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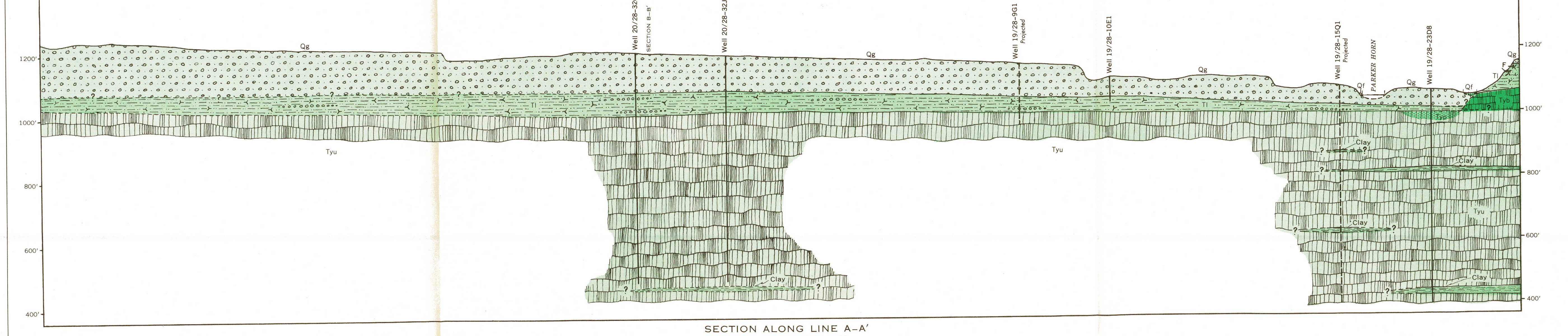
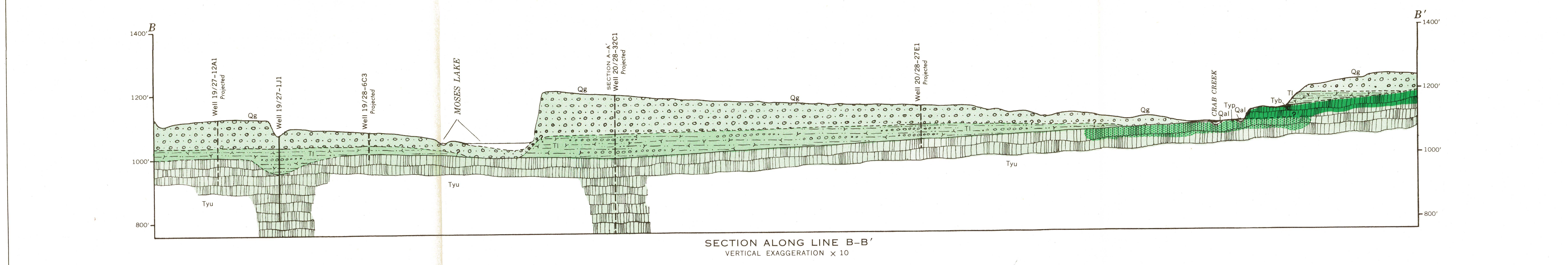


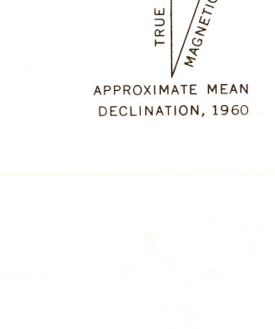
SECTION ALONG LINE A-A'
VERTICAL EXAGGERATION × 10



SECTION ALONG LINE B-B'
VERTICAL EXAGGERATION × 10

GEOLOGY OF THE MOSES LAKE NORTH QUADRANGLE, WASHINGTON

By
Maurice J. Grolier and Bruce L. Foxworthy



APPROXIMATE MEAN DECLINATION, 1961

SCALE 1:24 000
2000 0 2000 4000 6000 8000 10,000 FEET
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

1961

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-330

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