STATE OF WASHINGTON

DEPARTMENT OF NATURAL RESOURCES

BERT L. COLE, Commissioner of Public Lands
DON LEE FRASER, Supervisor

DIVISION OF GEOLOGY AND EARTH RESOURCES

VAUGHN E. LIVINGSTON JR., State Geologist

BULLETIN NO. 68

GEOLOGY OF THE METHOW VALLEY
OKANOGAN COUNTY, WASHINGTON

By

JULIAN D. BARKSDALE

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FRONTISPIECE

Methow Valley looking southeast from lower slopes of Last Chance Point. Goat Wall in the middle distance left is the result of glacial erosion of Midnight Peak Formation andesitic rocks.

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on the

Methow Valley

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FOREWORD

Dr. Julian Barksdale, the author of this report, is the dean of the Methow River Valley geology. Barky, as he is known to his friends and colleagues, began his work in the rugged Methow country in 1939 as a new Ph. D, recently hired by the University of Washington. During a field trip into the upper Methow late in 1938 with Dr. A. C. Waters and Professor and Mrs. Adolph Knopf, Mrs. Knopf advised Marajane, Barky's talented wife, that she should do everything possible to discourage Barky from undertaking such an enormous project. Nevertheless, Barky took on the project and for years, with Marajane's continual support, spent many summers in the Methow working out complex structure and stratigraphy. During those years he had some interesting experiences, not the least of which was working as a cook for a pack-horse outfit to get transportation into the remote back country. He worked out of tent camps for weeks at a time, and sometimes suffered physically to accomplish his work.

Dr. Barksdale has been subjected to occasional criticism for not publishing his work. I was one of the critics until Barky took me through the area on a 2-day field trip in the summer of 1974. After seeing firsthand the size of the project and the remoteness of some of the area, I came away with a different point of view. The logistics problems that he overcame were staggering in their magnitude, and the complexities of the geology would have discouraged most geologists.

Dr. Barksdale has done a remarkable job in deciphering the geologic framework of the Methow area, and we are fortunate to be able to make the information contained herein available to the geologic community. All of the geologists in the future who work in the Methow will be standing on Dr. Barksdale's shoulders.

Vaughn E. Livingston, Jr.
State Geologist

March, 1975

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE METHOW VALLEY OKANOGAN COUNTY, WASHINGTON

By

Julian D. Barksdale

INTRODUCTION

LOCATION AND GEOGRAPHY

The study area comprises almost the entire drainage of the Methow, Twisp, and part of the Chewack Rivers. This, together with the adjacent divide between the Methow drainage and Lake Chelan, amounts to about 1,650 square miles in north-central Washington State from the Cascade crest east to the Okanogan Range and from a line 12 miles south of the Canadian boundary to lat. 48°00 (fig. 1).

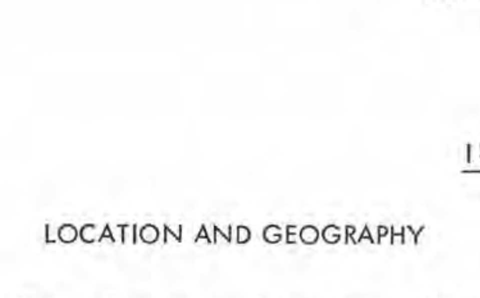

FIGURE 1.—Map showing location of area considered in this report.

The area is one of ridges and canyons, except for the stretch of the Methow River between Mazama on the north (elevation 2,100 feet) and Carlton on the south (1,450 feet). For this distance of 32 miles the valley bottom is more than a mile wide. The broad glaciofluvial terraces, suitable for irrigation, drew homesteaders to the valley in the late 19th century. The relief between the broad valley and the surrounding hills is on the order of 4,200 feet.

Ridges rise to elevations in excess of 7,000 feet, with several jagged peaks reaching almost 9,000 feet above sea level away from the main drainages. The maximum relief of the area mapped is 5,371 feet and is near the center of the map area, where Gardner Mountain (8,897 feet) rises above the Twisp River valley (3,526 feet), 5 miles away.

The major canyons for the most part are U-shaped, the result of extensive glacial erosion. The Methow Valley above Mazama is particularly striking as the walls on both sides of the canyon rise 2,000 feet or more in sheer cliffs above the broad flat floor, where the underfit Methow River has established a well-developed meander pattern in the glaciofluvial fill. The valleys of Twisp River and Eightmile Creek exhibit similar characteristics but to a lesser scale.

The valley floors of the Methow River above Mazama, of the Twisp River above the sharp elbow bend 14 miles west of Twisp, and of the Chewack

River and Eightmile Creek above their confluence are all heavily forested with a mixture of ponderosa pine (Pinus ponderosa), grand fir (Abies grandis), interior Douglas fir (Pseudotsuga menzies), and occasional red cedar (Thuja plicata). Ponderosa pine and cedar are seldom found above 3,200-feet elevation. Grand and Douglas firs overlap with true alpine fir (Abies lasiocarpa), the latter becoming dominant above 4,000 feet.

Forest cover is particularly important in limiting outcrops on the north and east slopes of the tributary canyons entering the Methow and the Chewack Valleys from the west. Outcrops must be sought on the south and west sides of the ridges or above timberline (+7,000 feet).

The lower slopes of the Methow Valley between Mazama and Twisp are largely nonforested, or at best are covered by a sparse ponderosa pine (Pinus ponderosa) steppe mosaic with bitterbrush (Purshia tridentata), and beardless bluebunch wheat grass (Agropyron inermi, a variety of A. spicatum) as the major components. South of Twisp on the better soil sites, the big sagebrush (Artemisia tridentata) mingles with the bitterbrush; but for the most part, on the slopes east of the Methow River, bunchgrass is the predominant vegetation and rock outcrops are plentiful.

The climate of the valley below Winthrop can be classed as semiarid, with precipitation in the Twisp-Winthrop area (mostly in the form of snow) averaging 15 inches per year. Harts Pass, at elevation 6,109 feet on the Cascade crest, has a 27-year recorded yearly average of 60 inches of precipitation. Most years, one cannot plan to travel the crest trails from late October to late May because of the deep snowdrifts. Patches of snow remain on north slopes until late July, some years not melting completely at all. Because of this prolonged melting at the higher elevations, many springs and some streams maintain year-round flow.

Access to the area from the Columbia River (U.S. Highway 97) is northeast from Pateros via State Highway 153 to its intersection with Washington North Cascade State Highway 20 (cross state). This east-west road connects Okanogan with the main Puget Sound artery via the Methow and its tributary, Early Winters Creek, to the Cascade crest at Washington Pass, and down westward-flowing Granite Creek and the Skagit River to the Puget Lowland. The Forest Service maintains excellent secondary roads in all the main drainages in addition to the many main haulage roads constructed and maintained during and after timber sales have ceased.

PREVIOUS WORK

The earliest published record of geological observation of the lower Methow Valley was that of Gibbs (1855). He traversed the range between Fort Okinakane (Okanogan) and the Methow and proceeded down the valley to its mouth. He said (p. 483):

> The Valley of the Methow affords a richer field for the geologist in plutonic and metamorphic rocks than any other portion of the Territory visited by the survey, and would richly reward a careful exploration.

Gibbs was intrigued by the terraces at the mouth of the Methow, reporting that he could count no less than 18 rising one above the other.

The first geological map of the upper part of the area was that of Russell (1900) who, in 1898, ascended the Skagit drainage and examined the gold mining operations on Slate Creek and in the Pasayten Middle and West Forks. He crossed the summit and on his trip down the Methow drainage examined the geology between Crater Pass (Harts Pass) and Winthrop, formally naming the Winthrop Sandstone and the Ventura System of red beds.

Barksdale (1941, 1947, 1948, 1956, 1958, 1960), in a series of papers and abstracts, reported on glaciation, stratigraphy, and structure in the present map area. Mallory and Barksdale (1963) discussed the fossil assemblages found in the rocks of the Methow-Pasayten graben.

Several master's theses at the University of Washington have been written on individual geologic problems. Maurer (1958) reported on the biostratigraphy of rocks in the vicinity of Buck Mountain. Pitard (1958) concentrated on the Mazama area with particular emphasis on the Ventura red beds. Dixon (1959) worked in the Isabella-Sweetgrass area. Ryason (1959) reported on the stratigraphy and structure of the Pipestone Canyon area northeast of Twisp. Adams (1961, 1964) contributed information on the rocks of the upper Twisp River, particularly on the origin of the Black Peak batholith. Libby (1964), in a Ph. D. dissertation, reported on some phases of the crystalline rocks of the Lake Chelan area, with special attention to the Oval Peak pluton.

Royse (1965) published on the flora of the Pipestone Canyon Formation enlarging upon Ryason's plant fossil discovery. Misch (1952, 1966b), in his pioneer work on the general geology and his more recent overview of the tectonic evolution of the Northern Cascades, has contributed a valuable interpretation to the broad geologic problems involved. Menzer (1970) made a study of the geochronology of the granitic rocks of the Okanogan Range, which adjoins the area to the east. Staatz and others (1971) overlapped the northern part of the map area in their study of the mineral resources of the Pasayten Wilderness.

Pierson (1972) made a detailed study of the sedimentary petrology of the arkosic rocks in the vicinity of Harts Pass, and Tennyson (1974) did a collation of other sedimentary petrology studies in the area and added her own interpretation from a restudy of the thin sections. Waitt (1972) restudied the glacial history of the area. Cole (1973) made the most complete study of direction of transport for the sedimentary rocks above the Twisp and below the Midnight Peak Formations.

PRESENT WORK AND ACKNOWLEDGMENTS

Mapping for this project was done on a variety of map bases. Early reconnaissance, using the Forest Service fire control map at 1:125,000 scale for the area north of lat. 48°30'N., accomplished little; so the more detailed mapping was begun on photostatic enlargements of the Methow quadrangle to 1:62,500 scale, with 100-foot contour interval. Air photographs became available in 1948 for the part of the area north of lat. 48°30' N. on a scale of approximately 1:47,500. The Forest Service planimetric maps made from these photos became a plotting base until completion of the U.S. Geological Survey Mazama and Doe Mountain quadrangles (1:62,500 scale). More recently, the area west of the Mazama quadrangle has been covered by a series of U.S. Geological Survey quadrangles on a scale of 1:24,000. Information plotted and replotted on these maps of varying scales has been brought together on the Army Map Service Concrete sheet, at a scale of 1 inch equals 2 miles. The cooperation of the Portland, Oregon, regional headquarters of the U.S. Forest Service is gratefully acknowledged.

The author owes much to Aaron C. Waters for the introduction to the area in 1938. Appreciation also is expressed for the many kindnesses extended by George and Fay Dibble and Jack and Elsie Wilson, and the large number of Forest Service personnel, who over the years supplied maps, trail advice, and hospitality. Numerous graduate students in geology have contributed to the study, and their names will be found in the section on previous work. The exchange of ideas with the students and with field assistants Fred Roberts and Gordon McAllister is gratefully acknowledged.

Many people have contributed paleontological information for which the author is grateful. Their names will be found in the appropriate sections of the text. Special thanks are due Robert Dabritz for his prowess as a collector and finder of new fossil localities.

Appreciation is also expressed to Bates McKee and V. Standish Mallory who have worked in parts of the area and with whom there have been many discussions. Elaine DuRall is the most patient re-typist. The critical help of Vaughn E. Livingston, Washington State Geologist, and his staff, particularly Laura Bray, Doyal Foster, and William H. Reichert, and of Dean Rinehart and Rudolph Kopf of the United States Geological Survey, has been most valuable.

Without the help and forebearance of my wife Marajane and son Tucker this work could not have been done.

GEOLOGY

METAMORPHIC ROCKS

Very little detailed work has been personally done on the metamorphic rocks of the two complexes —Chelan and Okanogan—outside the graben. It will suffice for this report to call attention to their gross aspects. Relatively more attention was paid by the author to the obviously parametamorphic suite, the Leecher Metamorphics, and the intrusive orthogneiss, the Methow Gneiss, which make up an important part of the rocks that crop out in the graben south of Twisp.

Chelan Batholithic Complex

Barksdale (1948, p. 165) referred to the various assemblages of igneous and metamorphic rocks occurring in the southwestern part of the study area as the Chelan batholithic complex. Hopson (1955), Adams (1961, 1964), and Libby (1964) investigated the area in detail and gave local names to the various mappable units that they recognized. Their work and that of the author make it evident that this assemblage comprises a great complexity of paragneisses, schists, and marbles that have been intruded by stocks and batholiths, some of which themselves have been metamorphosed. The general name will be retained, but individual plutons where mapped will be given geographic names and described in the section devoted to igneous rocks.

Adams (1964, p. 292-293) was able to distinguish five major divisions of what he called the Skagit Gneiss (after Misch, 1952), beginning at the Stehekin River at the head of Lake Chelan. He described these units from west to east as:

1. Migmatitic biotite gneiss.
2. Migmatitic to homogeneous hornblende-biotite gneiss.
3. Homogeneous biotite gneiss.
4. Heterogeneous schist unit containing mixed layers of highest medium-grade amphibolitic schist, hornblende biotite schist, biotite quartzite, garnet-biotite-staurolite schist, and muscovite-bearing gneiss, in order of decreasing abundance. These schists grade into gneiss across the strike in a distance of a few feet

to tens of feet and locally grade into gneiss along the strike.

5. Homogeneous biotite gneiss.

Small isolated pods and lenses of quartzite and marble are sparsely scattered throughout all the gneiss. These together with the schist unit, are interpreted by Adams (p. 292) as evidence of the sedimentary nature of the pre-gneiss material.

Libby (1964, p. 9) studied the gneisses occurring in the area between the Oval Peak batholith and Lake Chelan, south of the area mapped by Adams. He described a highly heterogeneous rock assemblage, which in some areas consists of a mass of cross-cutting gneissic dikes enclosing only minor remnants of what could be interpreted as nonmobilized gneiss. In other areas, the gneiss is thinly layered, consisting of alternating layers with different textures, with or without schist intercalations. He found the layers to be both planar and swirled and pinched in a complex manner. Elsewhere the gneiss is essentially homogeneous, the planar structure being marked solely by grain orientation.

The most common gneiss is coarse grained with crystalloblastic texture and largely composed of quartz, oligoclase, and biotite. Green amphibole is present in minor quantity. Schist layers within the gneiss range from migmatitic interlaminations to units hundreds of feet thick and traceable for long distances. The most common of these are biotite schists but there are amphibolites and minor schistose quartzite and calc-silicate schist. Marble layers also occur; one near South Navarre Peak is about 25 feet thick.

Libby (1964, p. 96) was able to trace one schist unit on the southwest border of the Oval Peak batholith for a distance of at least 12 miles. This band, which he informally designated the "Horseheads Pass schist," is only a few hundred feet thick. It separates the Oval Peak batholith from the gneiss. He gave ranges for the minerals present, but, in summary, biotite averages 12 percent, quartz 54 percent, plagioclase of upper oligoclase to lower andesine composition 28 percent, and K-feldspar 8 percent. The accessory minerals are garnet, muscovite, chlorite, colorless amphibole, titanite, apatite, and opaque minerals.

Hopson (1955) mapped the small triangular area in the extreme southwest part of the map as "undifferentiated regional metamorphic rocks (esp. gneiss) containing migmatitic zones." He postulated a pre-Late Jurassic age for the rocks.

Both Adams (1964, p. 292) and Libby (1964, p. 130) considered the metamorphic rocks of the map area to be the southeast continuation of similar rocks, which Misch (1952, p. 7) described as forming the backbone of the Northern Cascades and the product of migmatization and granitization of a sedimentary volcanic sequence, plus small amounts of gneisses of doubtful origin. To this complex he gave the name "Skagit gneisses."

More recently, Misch, (1966b, p. 112-115) proposed the name "Skagit Suite" for two recognizable metamorphic entities: (1) Cascade River Schist, the isochemically metamorphosed eugeosynclinal sequence of varied clastic with subordinate volcanic rocks and minor limestone, and (2) "Skagit Gneiss," a migmatitic complex lying northeast of the Cascade River Schist and forming the backbone of the range.

There is some confusion regarding the nomenclature. Daly (1912, p. 528-536) used the name "Skagit" for the volcanic sequence along the Canadian border just west of the Skagit River. McTaggart and Thompson (1967, p. 1205-1209) preserved the name for these rocks and used "Custer Gneiss" for metamorphic rocks that are the extension of those mapped by Misch, which Daly (1912, p. 523-526) named the "Custer Granite Gneiss." Staatz and others (1972, p. 840) have remapped Misch's area between the Skagit River and the Canadian boundary and follow McTaggart and Thompson's name of "Custer Gneiss."

There seems to be little doubt that most of the rocks of the present map shown as Chelan Complex are, in general, correlative with Misch's (1966b, p. 102) "Skagit Gneiss" and McTaggart and Thompson's (1967) and Staatz and others' (1972) "Custer Gneiss."

It should be pointed out, however, that there is one group of rocks included in the Chelan batholithic complex that is of a different metamorphic family from the others. Adams (1964, p. 293) used the name "Twisp Valley Schist" for rocks exposed between the upper Twisp River valley and his "Black Peak Quartz Diorite" and the long, fingerlike extension of the Oval Peak intrusion. Contact effects from the intrusions have caused minerals, such as biotite, muscovite, hornblende, plagioclase, garnet, and andalusite, to grow statically. In some cases these minerals cut across the foliation of greenschists, quartz-sericite schists, micaceous quartzitic schist, and quartzite, calc-phyllite, and other low-grade metamorphic rocks derived from sedimentary and volcanic rocks. These low-grade metamorphic rocks may be correlative with similar rocks described by Misch (1966b, p. 116) as the "Elijah Ridge Schist."

McTaggart and Thompson (1967, p. 1208) believe that "the Custer Gneiss was probably formed by regional metamorphism and migmatization of Hozameen strata. The gneiss contact is believed to mark a migmatite front, the limit of injection, replacement, and recrystallization of earlier formed metamorphic rocks by trondhjemite and pegmatite." This conclusion is in general agreement with that reached by Misch (1952, 1966b).

The age of metamorphism of Misch's (1966b, p. 113) "Skagit Suite" is not known, beyond its being older than mid-Cretaceous orogeny and, presumably, than latest Triassic-Jurassic-Early Cretaceous deposition. McTaggart and Thompson (1967, p. 1210) say only that the development of the Custer Gneiss is younger than the Hozameen Group and older than Eocene beds, but designate it on their map as pre-Jurassic?.

Okanogan Batholithic Complex

Examination of the granitoid gneisses and associated intrusive rocks northeast of the graben was confined for the most part to a narrow strip immediately northeast of the Chewack-Pasayten Fault. No samples were collected more than 3 miles from the fault and most of them within 1 mile. Barksdale (1948, p. 165) referred to these rocks as the Okanogan batholithic complex and the name is retained. In general, the rocks are largely leucocratic biotite-quartz-feldspar rocks that are for the most part weakly gneissic. Hornblende is present in some thin sections but is not prominent. There is ample evidence of shearing in the development of the gneissic structure. The quartz is granulated, the mica appears in wispy trails that accommodate themselves to the porphyroclasts of elongated, spindle-shaped, and apparently rotated plagioclase. Much of the plagioclase is zoned and some of it twinned. There are sufficient hypidiomorphic crystals that have not recrystallized to give assurance these were igneous rocks of a very light-colored quartz diorite or trondhjemite family that have in part been recrystallized.

The reader is referred to four studies for an understanding of the metamorphic and igneous geology in the Okanogan complex between the Chewack-Pasayten Fault and the Canadian boundary. Goldsmith

(1952) has discussed the petrology of the Tiffany-Conconully area. Menzer (1964, 1970) reported on the geology of the crystalline rocks west of Okanogan. Hawkins (1968) published a comprehensive study on the regional metamorphism of the Lake Creek-Andrews Creek area, and Hibbard (1971) discussed in detail the evolution of a plutonic complex in the Okanogan Range, east of the Hawkins' study area.

Leecher Metamorphics

Barksdale (1948, p. 166) gave the name "Leecher Metamorphics" to a series of distinctly banded hornblende schist, quartzite, quartz-oligoclase-hornblende gneiss, biotite-quartz-oligoclase gneiss, marble, and calc-silicate rocks occurring in a curving belt from 1 to 2 miles wide east of the Methow River in the drainage of Leecher Creek and in the vicinity of the town of Carlton. The best exposed sections lie northeast of Carlton for 6 miles along the prevailing strike, where westward-draining canyons cut across the compositional layering that, in general, parallels the schistosity. The prevailing dips are steeply to the east; the strike, however, swings from a near east-west at the eastern boundary of the area, south of the Texas Creek stock, to north-south in the vicinity of Carlton and then northeast for approximately 6 miles, where the metamorphic terrane ends in a thrust over the non-metamorphic Frazer Creek complex.

The rocks west of the Methow River and east of the Smith Canyon Fault are shown on the map as Leecher Metamorphics, because all of the rock types found in the type area except marble appear to be present. There is, however, a marked difference between the type Leecher and the rocks sporadically cropping out between the Methow River and the Smith Canyon Fault to the west. So numerous are the nearly vertical zones of mylonite striking north-northeast that they almost equal the volume of the less sheared gneiss and schist which appears to have the same general attitude.

The western contact between the Methow Gneiss and the Leecher Metamorphics is a fault. The severely sheared rocks in the fault zone are exposed in the mile-long roadcut along Highway 153, just south of Carlton. The Leecher at the north end of the roadcut are very sheared hornblendic augen gneisses. Examination of thin sections shows the hornblende to be cut by chlorite veinlets and, in some cases, it is largely replaced. The schistose nature of the rock is caused by alignment of the stringers of epidote, chlorite, and hornblende surrounding the mildly drawn out spindle-shaped, dusty feldspars. The feldspar has been sericitized. Quartz is a minor constituent in this particular rock. Dark-green fine-grained rocks that appear to be phyllites are, under the microscope, sheared hornblende epidote schists. Chlorite has in part replaced the hornblende or crystallized in the apexes of small-scale crinkle-folds of the alternating layers of acicular green hornblende and epidote in a matrix of albite and quartz. Shearing in pale-green phyllitic-appearing rocks has apparently reduced the previous generation of metamorphic minerals, suspected to be largely hornblende and plagioclase, to very fine-grain minerals, consisting largely of chlorite and epidote with augen of larger grain size aggregates of epidote. These rocks are diaphthoritic phyllonites (Knopf, 1931, p. 14, 19-20) rather than phyllites, and owe their origin to the process of mylonitization accompanied by retrograde metamorphism.

Quartz-biotite-feldspar-garnet gneisses (SE$\frac{1}{4}$ sec. 19, T. 32 N., R. 22 E.) have also been severely sheared and the biotite almost completely replaced by chlorite. The garnet crystals are 1 mm or more along their longest direction. They contain well-preserved fragments of red-brown biotite and twinned feldspar, one of which could be determined as An_{30}. The garnet is cracked and elongated in the planes of shear. Chlorite has replaced garnet in veinlets along the cracks. Porphyroclasts of quartz and sharply twinned plagioclase in the andesine range, up to 1 mm in size, float in a mylonitized matrix of quartz, feldspar, and chloritized biotite. There is considerable iron oxide distributed in the planes of shearing. These rocks have a complex multistage metamorphic history, and their retrogressive or diaphthoritic phase is especially conspicuous.

Finally there are zones (SE¼ sec. 30, T. 32 N., R. 22 E.) of ultramylonite in which the porphyroclasts are mostly very rounded feldspar crystals in a fine-grained mesostasis of quartz, feldspar, chlorite, and epidote. In several localities, the ultramylonites contain small inclusion-free garnets with the larger ones being cracked and replaced by chlorite only occasionally.

The parametamorphic nature of the Leecher Metamorphics is not unlike that of some of the rocks in the Chelan complex, but the age of neither is known. The Leecher Metamorphics have been intruded by an igneous mass that was penetratively sheared and recrystallized to form the Methow Gneiss. The evidence is not clear just how much metamorphism of the Leecher was accomplished before the making of the Methow Gneiss.

Methow Gneiss

A very distinctive biotite "granite" gneiss crops out, for approximately 50 square miles, in the southeast part of the area. Barksdale (1948, p. 166), named this the "Methow gneiss" for the town of Methow, which lies near the center of the outcrop area. The Methow Gneiss is faulted against the Leecher Metamorphics on the west. It intrudes the gently dipping Leecher on the north almost concordantly and is intruded by the Cooper Mountain batholith on the south. The eastern contact is covered.

Megascopically, the strong gneissic character of the rock is emphasized by the large clots of biotite, in many instances over a cm in diameter. The biotite clots occur as irregularly drawn out ovoids of paper thinness or as ragged books as much as 2 mm in thickness. Blocks of rock quarried out parallel to the gneiss structure have a leopard-spot appearance on the surfaces parallel to the foliation. The biotite ovoids indicate a weak lineation (fig. 2).

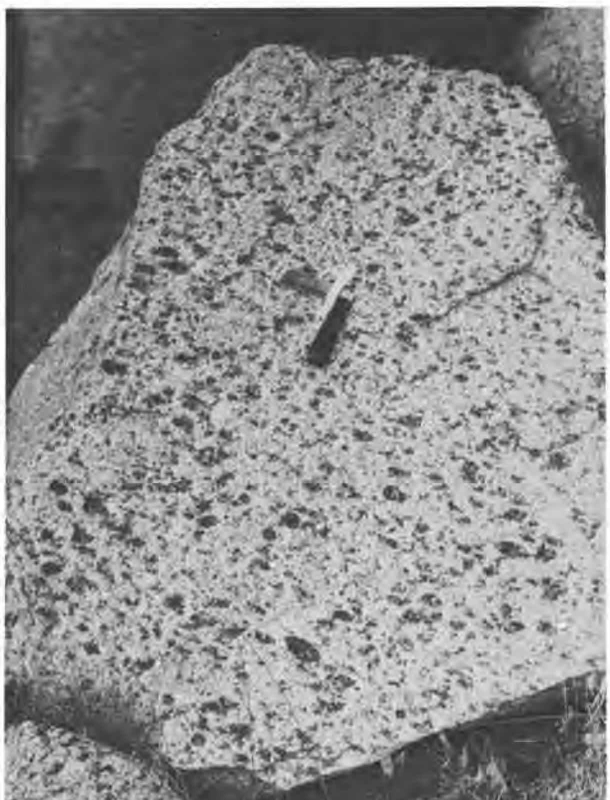

FIGURE 2.—Methow Gneiss. Well-developed foliation on quarry block, north of Methow, State Highway 153. Biotite ovoids illustrate weak lineation.

Many attitudes taken on the well-defined foliation plot out as being nearly horizontal over a large area in the central part of the body mapped. Dips generally are in the 10° to 20° range; seldom do they exceed 30°. The preponderance of gentle dips of the schistosity and its near concordance with the overlying Leecher to the north and east make the Methow Gneiss an attractive candidate for a gneiss dome mode of origin. All that can be said at present (1974) is that the rock has been penetratively sheared and almost completely recrystallized. It is remarkably uniform over a wide area and its parent magmatic composition was that of quartz diorite to granodiorite.

The rock in thin section has a mosaic texture typical of recrystallization and is composed of notably untwinned, clear and fresh plagioclase consistently within the oliogoclase range where determinable. No potash feldspar is present. The quartz occurs in distinctly smaller grains than the feldspar and appears in floods along the planes of schistosity—some of it clear and unstrained but other grains show strain shadows. The strongly aligned biotite is intimately intergrown with epidote. Much of the epidote crystallized in prismatic euhedral form and apparently grew simultaneously with the biotite. Apatite and magnetite are common accessory minerals.

The sheared Methow Gneiss along the fault contact, so well exposed in the south half of the roadcut along Highway 153 south of Carlton, offers a good example of retrogression of a gneiss to a schist. Megascopically, the characteristic leopard-spot appearance of the Methow Gneiss is muted there, because the spots are no longer shiny black but green. The biotite in thin section is completely replaced by chlorite and fine granular epidote. The large epidote clots of the parent rock are drawn into fusiform shapes, enclosed in granulated quartz and sericiticized and granulated feldspar, thus emphasizing the foliation.

All that can be said at this time of the age of the Methow Gneiss is that it is younger than the Leecher Metamorphics and older than the Cooper Mountain batholith.

INTRUSIVE ROCKS

There are numerous magmatic intrusions within the Methow-Pasayten graben and adjacent to it, varying in composition from diorite to granite and in size from thin sills, dikes, and small plugs to those of batholithic dimensions. Some of the major intrusions are syntectonic or have been affected by major tectonic events. Megascopic gneissic structure has been developed in some of the rocks; in others the tectonism is recorded by the development of prehenite, epidote, and chlorite, and by cataclasis of the essential minerals quartz and(or) feldspar, recognizable only in thin sections. The myriad of sills, dikes, and other minor intrusions has not been mapped for the current publication.

Radioactive age determinations for only four of the 15 intrusions described are available; the order of description is, therefore, highly subjective.

Summit Creek Pluton

A light-colored biotite quartz diorite intrudes the Leecher Metamorphics directly east of Carlton in T. 32 N., R. 22 E. This is the western limit of the large body of a faintly gneissic rock that Menzer (1964, p. 22) mapped as trondhjemitic gneiss.

Bates McKee (personal communication) has made a careful study of the contact relations between the Summit Creek body and adjacent Leecher Metamorphics. In general, the contact parallels the marked foliation in the Leecher Metamorphics that dips steeply to the east directly east of Carlton, and swings to an east-west strike, with the north dip south of the intrusion. The quartz diorite has intruded the Leecher rocks lit-par-lit in a broad injection zone, with numerous quartz-diorite sills, tens to hundreds of feet thick, separating the layers of Leecher schist and gneiss. There are numerous rotated xenoliths in the Summit Creek pluton, some of which have reacted with the magma. The contact zone also contains dikes of andesite, basalt, and pegmatite. It is not clear whether the latter are related to the Summit Creek plutonic rocks or to the younger Texas Creek composite stock, which intrudes both Leecher Metamorphics and the Summit Creek pluton.

The weak gneissose structure in the Summit Creek quartz diorite is more pronounced near the contacts than in the main body of the intrusion. The foliation is defined by the more or less parallel arrangement of streaks of wispy biotite flakes. In some hand specimens, elongate streaks of quartz can be seen roughly paralleling the mica. Much of the rock, however, is megascopically directionless.

The predominant feldspar is oligoclase (An_{23-31}), which makes up about 65 percent of the rock. Quartz varies in amount of 10 to 50 percent, probably averaging 30 percent. Potassium feldspar is less than 5 percent. Biotite is nowhere more than 10 percent. The most important accessory mineral is epidote; muscovite, magnetite, titanite, zircon, and apatite are present in small quantities.

The rock has an overall granoblastic texture, the outer growth on the feldspars not following the idiomorphic pattern of the weak normal zoning, and sparse twinning. The quartz is generally recrystallized into elongate mosaics. The wispy biotite is associated with epidote, muscovite, and magnetite.

The age of the Summit Creek intrusion is not known. Menzer (1970, p. 577) reported the results of a rubidium-strontium study of two samples on which both biotite and whole-rock analyses were carried out. He suggested that there was an isotopic homogenization due to penetrative rock deformation of the unit, approximately 104 million years before present.

Pasayten Stock-Dike

Pasayten Peak is a landmark in the most northern part of the map on the ridge separating the Middle and West Forks of the Pasayten River. The peak is underlain by a body of medium- to coarse-grained, light-colored biotite-hornblende quartz diorite, which became of great interest when it was discovered to be the source of the glacial erratics so plentiful in the Harts Pass area. These rocks were the first evidence that Canadian ice had spilled south across the divides from Pasayten to Methow drainages (Barksdale, 1941).

Rocks of similar character crop out on the ridge north of Robinson Pass and in the Lost River Canyon. Recent mapping by Staatz and others (1971, p. 30) has shown that these occurrences, previously mapped as separate small stocks, are in fact parts of a very unusual tabular intrusion that is 12.4 miles long and averages 1.1 miles wide. Staatz' interpretation has been incorporated in plate 1, and the nomenclature adopted.

The rock in Pasayten Peak itself is hypidiomorphic and is composed of 65 to 70 percent strongly zoned plagioclase, with cores as calcic as An_{45}, and showing both normal and oscillatory zonings. Some crystals have albitic myrmekite rims. Much of the feldspar is in the lower andesine range. Potassium feldspar probably constitutes less than 5 percent; quartz is unstressed and makes up 20 to 25 percent of the rock. Green hornblende, showing a strong tendency toward euhedral shape, and deep-brown biotite, in blocky books, together form approximately 5 percent of the rock. Titanite, apatite, and magnetite are the common accessory minerals. Some alteration of biotite to chlorite and hornblende to chlorite and epidote was noted. Some of the feldspar cores have a dusty alteration, but the rock is essentially fresh.

At the southeast end of the stock-dike, the rock has been affected by the younger Monument Peak intrusion. Much of the hornblende has been replaced by aggregates of dark brown biotite, but feldspars are unaltered.

Tabor and others (1968, p. C45-C52) report K-Ar biotite and hornblende ages of 87.7±2.6 m.y. and 86.0±2.6 m.y., respectively, from a sample collected from the center of the dikelike part of the pluton, about 3 miles southeast of Pasayten Peak. These Late Cretaceous ages bear significantly on the local geologic history because they are concordant within the assigned limits of error, and are therefore reliable. This intrusion cuts the Winthrop Sandstone and probably also cuts the Midnight Peak Formation, thereby establishing a minimum age of earliest Coniacian for the Midnight Peak.

Button Creek Stock

A biotite-hornblende quartz diorite stock, approximately 5 miles long by three-quarters of a mile wide, is exposed in the northeast part of the map area. It intrudes the andesitic and volcaniclastic rocks of the Buck Mountain Formation to the northwest and arkosic sandstones and shales of the Panther Creek Formation to the southeast. The intrusion is younger than the Ortell Creek Fault, but its relation to the Chewack-Pasayten Fault in the Eightmile Creek valley is not clear.

The rock of the Okanogan complex exposed on the northeast side of the valley is biotite-hornblende quartz diorite gneiss that has been penetratively sheared. The feldspars show evidence of igneous origin but the overall texture and structure is definitely metamorphic. In contrast, shearing in the Button Creek rocks away from the fault has been minimal. The rock contains hornblende as well as biotite, the former in greater abundance. No intrusions of Button Creek rock were found in gneiss of the Okanogan complex.

The Button Creek rock in thin section is composed of about 50 percent well-twinned, strongly euhedral plagioclase, normally zoned with cores of An_{35-45} grading to rims of An_{15-30}. Most of the feldspar shows sericitic alteration. Orthoclase is sparse or absent. Quartz makes up 20 to 25 percent of the rock, and in some thin sections its extinction is sharp, in others it is mildly undulatory. Biotite with straw yellow to deep-brown pleochroism occurs in ragged, poikilitic crystals up to several mm in diameter. Its shape is controlled by the earlier crystallized plagioclase. In some instances, quartz shows sharp, well-developed crystal faces against the biotite. A characteristic of the biotite is its intergrowth with spindle-shaped grains of prehnite, which have forced apart the biotite cleavages. Magnetite as well as plagioclase and quartz occur as inclusions in biotite, and chlorite is its chief alteration product. Hornblende occurs in well-formed crystals up to 5 mm long and as irregular poikilitic masses enclosing well-formed feldspar, magnetite, and zircon crystals. Its pleochroism is yellow to green to olive. Some crystals are completely altered to chlorite and calcite. Mafic minerals make up about 20 to 25 percent of the rock.

Copper mineralization in the andesitic and the less common felsic volcanic members of the Buck Mountain Formation on Isabella Ridge may be related to the intrusion of the Button Creek stock. Copper staining has stimulated prospecting on the north and west sides of the intrusion and some adjacent rocks. Smaller granitoid intrusions in the andesites of the Buck Mountain Formation near Billy Goat and Eightmile Pass may be continuous at depth with the Button Creek body.

The age of the Button Creek is not definitely known. There is some evidence that it has been involved in the Chewack-Pasayten Fault movement. Roadcuts at the mouth of the Ortell Creek expose highly sheared granitoid rock that may be Button Creek. If so, the stock may be as young as post-Paleocene for the Chewack-Pasayten Fault cuts the Pipestone Canyon Formation of Paleocene age.

Oval Peak Batholith

An irregular-shaped intrusion of quartz diorite, elongated in a northwest-southeast direction, crops out south and west of the prominent bend in the Twisp River (T. 33 N., R. 19 E.), over an area of approximately 50 square miles. The writer mapped the northern and eastern contacts as shown on the map. The southwestern contact was taken from Adams (1961) and Libby (1964).

Adams (1961, p. 163) informally named the intrusion the "Oval Peak pluton," from the prominent peak occurring in the northern part of the main mass that he included in the map area of his Ph. D. thesis. The irregular shape of the body, with its strong projections in a northwest-southeast direction parallel to the regional trend of the rocks of the Chelan batholithic complex-Twisp Valley Schist member, makes for sharp contacts. The contacts are both parallel and discordant with the schistosity of the host rocks surrounding the northern part of the intrusion. Contact effects on the schists are discernible for up to one-half mile from the intrusion.

Libby (1964) completed the mapping of the Oval Peak batholith to the southeast and found a persistent band of schist several hundred feet wide. This can be traced for at least 12 miles as it makes a septum between the southwest boundary of the main body of the Oval Peak intrusion and the Chelan complex "Skagit gneisses" of Misch (1952). The textures of these biotite-quartz-plagioclase schists, and minor hornblende-quartz-plagioclase schists, some of which contain clinopyroxene, do not show the obvious contact effects reported by Adams (1961, p. 163) adjacent to the elongated northern extension of the intrusion. Libby (1964, p. 24 and pl. III) did find, however, that the metamorphic grade of the schist appears to increase southward along the strike but he recognized no such effects along the northeastern border of the main body of the pluton. The sedimentary and volcanic rocks within the graben are intimately mixed with slivers of mylonitized gneiss, schist, and Oval Peak rocks in the major shear zone that is the Twisp River Fault.

The quartz diorite of the Oval Peak batholith in the most northwesterly lobe is of very uniform composition. Adams (1961, p. 163) reports quartz, 23 percent; plagioclase, 62 percent; K-feldspar, 3 percent; biotite, 8 percent; and epidote, 3 percent; with about 1 percent accessory minerals including hornblende, muscovite, chlorite, sphene, apatite, and zircon. The plagioclase in rocks of the northern part of the pluton shows complex oscillatory zoning but with an overall normal trend toward more sodic margins. The average composition is near An_{30} with a range from approximately An_{32} in the cores to An_{10} in the rims. Libby (1964) agrees that the overall composition of the plagioclase for the pluton averages An_{30} but finds that the plagioclase in the southern lobe tends to have more calcic cores.

Biotite is the common dark mineral in the pluton, exhibiting blocky pseudohexagonal shapes. The parallelism of the biotite is pronounced in rocks of the most northwesterly lobe and is present in the southwest margin of the pluton, the dominant trend being northwest-southeast. Epidote occurs in anhedral to euhedral grains associated with biotite and muscovite in the northern part of the pluton. Libby (1964) reports that both epidote and muscovite disappear in the southernmost part of the Oval Peak body, and their place is taken by an amphibole with optical properties similar to those of ferrohastingsite, occurring in amounts from 2 to 4 percent associated with the biotite.

The age of the Oval Peak batholith is not known except that it predates the Foggy Dew Fault.

Carlton Stocks

Two small stocks of coarse-grained quartz diorite with a distinct pinkish color are exposed west of the Methow River, southwest of Carlton. Evidence may be seen in the large roadcuts in Libby Creek that the northern and smaller body near the Smith Canyon Fault has been strongly sheared and converted to schist. At some distance from the fault, hand specimens of relatively structureless rock can be found in the larger joint blocks between the evident shears.

Rocks of the larger southern stock are wholly enclosed in Leecher Metamorphics and show no megascopic evidence of schistose or gneissic structure, although close spaced jointing is developed in the northern part of the intrusion.

All of the rocks in thin section show considerable alteration. The plagioclase is strongly euhedral to subhedral, poorly twinned but markedly zoned. The cores are altered to a mixture of sericite, epidote, and a dusty-gray product that sometimes is nearly opaque. Determination of the feldspar is difficult, but two less altered crystal cores are as calcic as An_{32} and are surrounded by rims of sodic oligoclase. The pink color is evidently due to iron oxide in cracks in the feldspar or along grain boundaries. The iron was probably derived from the almost total decomposition of the mafic minerals. The plagioclase makes up approximately two-thirds of the rock. In some of the specimens, there is no potash feldspar; in others there is a small amount, but not enough to qualify the rock as a granodiorite. The determination was made only after staining with sodium cobaltinitrite. Quartz is present in larger amounts than is normal for most of the quartz diorites in the Methow and makes up 25 percent of some samples. In some specimens it is markedly sheared and shows undulatory extinction; in others, extinction even in the large crystals is surprisingly uniform.

It is difficult to tell what the original mafic minerals were in some thin sections. There has been some microshearing; and reddish alteration products suggest that oxidation was an important alteration reaction. In others, both hornblende and biotite are preserved. Some alteration to chlorite and epidote is recognizable.

The age of these intrusions cannot be determined other than to say they are older than Smith Canyon faulting.

Fawn Peak Stock

A composite diorite to quartz diorite stock makes an irregularly shaped outcrop pattern that is approximately 4 miles wide north-south and $5\frac{1}{2}$ miles long, east-west. Its most southwesterly outcrop is within a mile of the Mazama post office (T. 36 N., R. 20 E.). The lower course of Goat Creek deeply incises the stock.

The southwest one-half of the stock has intruded andesite of the Midnight Peak Formation and the red beds of the underlying Ventura Member. The andesites, red beds, and dioritic rocks are more mineralized there than in the northeast part of the intrusion, where the magma invaded the steeply dipping arkoses of the Winthrop Sandstone.

The intrusion in the south and western part of the stock crystallized as a coarse-grained biotite-hornblende diorite, with minor amounts of primary quartz. The plagioclase, in the calcic andesine range is markedly euhedral, sharply twinned, showing oscillatory zoning, and it makes up 60 to 80 percent of the rock. The feldspar shows some sericitic alteration. Biotite occurs as primary blocky books and as secondary aggregates replacing amphibole. Chlorite and muscovite replace some biotite. Remnants of a green amphibole are encased in secondary tremolite-actinolite, chlorite, and muscovite. A brown staining that may be hematite is associated with this assemblage. Quartz is present as an accessory mineral but seldom makes up as much as 5 percent of the diorite. Apatite and skeletal black opaque minerals, magnetite and(or) ilmenite are important accessory constituents.

There is markedly less alteration in the north and east part of the stock. The rocks there are finer grained than those to the west. Andesine makes up two-thirds of the rock, and green amphibole, much of it euhedral, having a strong brown pleochrism, comprises most of the remaining third. Quartz, biotite, and a black opaque mineral, probably magnetite, are the chief accessory minerals. There has been very little alteration of the mafics. A chilled border facies exists close to the arkose contacts and resembles hornblende andesite porphyry.

The Fawn Peak stock differs from all the others described in this report by being the most quartz-poor. One is hardly justified in naming very much of it quartz diorite. It is the most complexly jointed, and the only one sufficiently mineralized to be seriously prospected for ore deposits.

There are numerous prospect pits in the andesite adjacent to the stock on the south and west sides and in the diorite of the stock there. From the turn of the century to World War II, gold was the mineral being sought. Continued interest in the district over a long period of time has led to the patenting of claims; and as a result, there is a considerable block of patented land within the southwest part of the intrusive. The fact that copper accompanies the gold, as well as silver and zinc, has led to renewed interest in the possibility of developing a large tonnage, low-grade copper mine within the stock. Three major copper companies have recovered thousands of feet of diamond-drill core in their effort to determine the size and grade of the ore bodies. Drilling was in progress as late as 1975.

The Fawn Peak stock was probably emplaced late in the last folding episode. The complex, closely spaced jointing and the existence of minor faulting and shear zones, which are now mineralized, suggest that it was not completely post-tectonic, especially that part exposed west of Goat Creek. The stock cuts the Midnight Peak Formation, thus establishing a maximum age of emplacement as Late Cretaceous. The stock has as yet not been dated radiometrically.

Alder Creek Stock

Immediately southwest of Twisp, a small complex stock of predominantly light-colored quartz diorite makes a rectangular outcrop of about 4 square miles in area. The country rock is largely Newby Group volcanics and for most of the intrusion the contacts are not sharp; many dikes cut the country rock and numerous xenoliths of the volcanic and volcaniclastic rocks occur in the main body of the intrusion. The northern two-thirds of the western border of the intrusion has been affected by movement on the Smith Canyon shear zone; a northeast branch of the fault between Elbow Coulee and the Twisp River separates a wedge of biotite-quartz-oligoclase gneiss of unknown affinity from the stock. Large and small xenoliths of hornblende gneiss are engulfed in the quartz diorite north of Elbow Coulee. The stock's northern and eastern contacts are against Newby Group rocks.

Thin sections of rocks from the main body of the stock are composed of up to 75 percent moderately to strongly aligned subhedral plagioclase with patchy zoning. Locally bent and sometime ruptured twin lamellae give evidence of mild deformation. The composition of the most calcic feldspars determined is An_{32}. The plagioclase is moderately fresh in some slides, in others strongly sericitized. Potassium feldspar is present in very minor amounts. Quartz with marked undulatory extinction occupies interstitial spaces between the feldspar, and occasionally includes small patches of myrmekite or clear orthoclase. The quartz is estimated to make up less than 5 percent of the rock. Biotite and hornblende occur in about equal amounts; the quartz has fair crystal form, but the biotite is very irregular in shape and in some slides is completely altered to chlorite and locally to deep-yellow epidote. In some sections, lozenges of prehnite have grown along the biotite cleavages in amounts equal to the host crystal. The hornblende is relatively unaltered and is strongly pleochroic in the following scheme: X = green, Y = yellow, and Z = olive green. Titanite, zircon, apatite, and magnetite are the accessory minerals.

A small area of moderately dark hornblende diorite occurs in the northeast part of the stock, cutting the older quartz diorite and rocks of the Newby Group. This rock in thin section is composed of almost equal amounts of feldspar and fresh, strongly euhedral crystals of hornblende up to 1 mm in length. Its pleochroic scheme is X = yellow-brown, Y = yellow, to Z = brown. The feldspars are much smaller in size and strongly sericitized. Patches of calcite are present, but quartz is almost totally lacking.

The age of the Alder Creek stock could not be determined. The evidences of deformation of the feldspars and the development of epidote and prehnite suggest that it has been subjected to stresses possibly associated with the thrust faulting that brought the Leecher Metamorphics over the Newby Group rocks immediately to the south, and also to structures associated with movement along the Smith Canyon Fault to the west. The late hornblende diorite and numerous porphyry dikes that can be found in this area may be related genetically to the Midnight Peak Tertiary volcanic episode.

One of the most productive mines in the area has been the Alder, now dormant. This gold-silver-copper-zinc mine is located 5 miles southwest of Twisp, east of the Smith Canyon Fault zone. Between 1939 to 1955, ore was mined from open pits and three adits. The ore came from a 15- to 75-foot-wide silicified, sheared zone in a felsic member of Newby Group volcanic rocks. Ore minerals were deposited possibly during the emplacement of the stock.

Black Peak Batholith

Misch (1952, p. 16) first reported a body of apparently massive granitic rock younger than his "Skagit gneisses" outcropping to the east of Mt. Logan and Mt. Goode on the Cascade crest, and extending east along the crest through Black Peak and Rainy Pass to a point just west of Liberty Bell Mountain (T. 35 N., R. 17, 18 E.). For this he proposed the name

"Black Peak Granodiorite" and suggested that these rocks had been formed from the "Skagit gneiss" (Chelan complex). Later work by Misch (1966b, p. 139) revealed that the Black Peak grades to the west into an orthogneiss younger than his restricted "Skagit Gneiss" and is intruded on the east by the Tertiary Golden Horn batholith.

Adams (1961) mapped the continuation of Black Peak rocks southeast of the type area as a part of his Ph. D. research, and later (1964) discussed the origin of the "Black Peak Quartz Diorite." He found the unit to be an essentially massive rock made up of dominantly quartz diorite, but varying in composition from diorite to granodiorite. To him the evidence was particularly clear that this was an example of an igneous rock derived from a gneiss.

The Black Peak batholith's sharply discordant contacts on the north and east shown on plate I were mapped by the writer. The Black Peak is definitely intrusive on its northeastern margin in the upper Twisp Valley into schists included in the Chelan batholithic complex, which was locally called "Twisp Valley Schist" by Adams (1964, p. 293), and into andesitic volcanics of the undifferentiated Newby Group, called by Misch (1966b, map), the "North Creek Volcanics." The intrusive rock in this area is directionless and exhibits a marked contact aureole approximately one-half mile wide.

The contact on the south and west on plate 1 is taken from Adams (1964, p. 291), who described it as gradational into gneisses of the Chelan complex ("Skagit Gneiss" of Adams and Misch). Rocks of the Black Peak differ from the gneiss megascopically in that they have little or no planar fabric, larger grain size, and more nearly euhedral plagioclase. Adams (1964, p. 293) found that the gradual transition from gneiss to quartz diorite made it impossible to map a sharp boundary in the field. He could, in his laboratory study, recognize a compositional layering in the gneiss that strikes northwest and which, by careful thin-section study, could be traced into the Black Peak body and mapped through the massive rocks. This is part of the evidence for his interpretation that the Black Peak was derived from the gneiss by static recrystallization in the south and west, which was accompanied by partial liquefaction and production of true igneous phenomena to the north and east.

The development of a mafic border, one-quarter to 1 mile wide, is of particular interest in the Black Peak intrusive, south of the pronounced re-entrant in the upper drainage of the Twisp River (T. 34 N., R. 18 E.). The mafic border grades from a biotite-hornblende-quartz diorite to hornblende diorite to hornblendite as one approaches the schists from west to east. Adams (1964, p. 304) considered the mafic rocks to be the result of hydrothermal leaching along the eastern contact, which dissolved and removed silica and alkalies from the reactive gneiss and quartz diorite, leaving a relatively mafic residue. North of the schist reentrant in the upper Twisp Valley, the quartz diorite abruptly cuts across the regional schistosity, and the contact crosses the Twisp River to cut the andesitic volcanics of the Newby Group. The quartz diorite, there, has a markedly igneous texture and is composed of sharply twinned and zoned plagioclase of subhedral to euhedral shapes, averaging An_{25-35} in composition; quartz up to 30 percent; and minor microcline-microperthite filling the interstitial spaces. Biotite and hornblende are the chief mafic minerals, although in a few places pyroxene is present. Adams (1964, p. 294-5) has given a detailed summary of modal analyses of a large number of thin sections from the Black Peak body.

The age of the Black Peak intrusive is uncertain, but Misch (1966b, p. 134) considers it Late Cretaceous in that it post-dates the intra-Cretaceous orogeny and predates the intrusion of the Golden Horn batholith (Eocene-Oligocene). The Black Peak obliterates the Twisp River Fault where it crosses the valley to intrude the Lower Cretaceous(?) Newby Group. The fault is thought to be similar in age to the Chewack-Pasayten Fault, which is post-Paleocene in its latest movement. If this assumption is correct, the intrusion is probably early Tertiary in age.

Noname Stock

A small stock of biotite granodiorite intruding the Methow Gneiss is exposed one-half mile north of the town of Methow. Its outcrop is less than a square mile in area. The highway there cuts through a distinctly pinkish-white leucocratic medium-grained granitic rock in which well-formed crystals of pyrogenic biotite and of titanite can be seen with a hand lens.

The rock, in thin section, is composed of oligoclase that is weakly twinned, and normally zoned in strongly euhedral to subhedral crystals. Quartz occurs in rather large clots made up of several crystals all poikilitically enclosed in still larger areas of unaltered orthoclase. The orthoclase is relatively more abundant than quartz in the few thin sections examined. The rock is compositionally very similar to rocks in the nearby Cooper Mountain batholith, except that titanite and magnetite are more abundant in the stock. In addition, biotite in blocky crystal form is partly altered to chlorite, and occasional grains of strongly yellow, pistacite-epidote are associated with the biotite. The rock shows no evidence of shearing or strong alteration of the feldspars.

Cooper Mountain Batholith

The Cooper Mountain batholith is an elliptical-shaped body of biotite granodiorite that is exposed over an area of at least 120 square miles in the southern part of the map area. On the south and west it intrudes schists, gneisses, and migmatitic rocks of the Chelan batholithic complex; on the northeast it intrudes the Methow Gneiss, Leecher Metamorphics, and volcanic sedimentary rocks of the Newby Group. The contacts between the intrusive and the country rocks are invariably sharp wherever observed, especially where they cut across the structural trend of the Chelan metamorphics on the south and northwest. The northeast contact is not as well exposed.

There is considerable variation in texture within the intrusive body. The rock in the vicinity of Cooper Mountain is very coarse grained and strongly porphyritic. Stained slabs show crystals of potassium feldspar as much as 2 cm long. Some of these have rims of plagioclase. Quartz crystals as much as 1 cm across occur in amounts about equal to the potassium feldspar. The plagioclase crystals are generally not over 0.5 cm long. Biotite in crystals, seldom over 1 mm in diameter, is the only dark mineral in the coarse-grained phase. Polished and stained specimen slabs show plagioclase 59 percent, orthoclase 18 percent, and quartz and biotite 23 percent.

A few miles north and west of Cooper Mountain the porphyritic phase of the granodiorite disappears. Within less than a mile of the southern contact, a more even and apparently finer grain is attained. Megascopically, the bulk of the intrusion appears deceptively fine grained due to the small size of the biotite. Close examination with hand lens, however, reveals that the plagioclase is 1 to 3 mm in longest dimension.

Sodic plagioclase is the predominant constituent as seen in thin section, making up approximately 60 percent of the rock. The crystals are euhedral to subhedral and zoning is oscillatory. The twinning is shadowy and indistinct and commonly absent. Universal stage determinations show cores of An_{20-40} with rims of An_{15-20}. The potash feldspar is orthoclase, some of which has remarkably strong subhedral shapes showing Carlsbad twinning. Much of the orthoclase is anhedral and poikilitically encloses well-formed quartz and plagioclase crystals. Perthite is present, but is not strongly developed. Quartz has a tendency to occur in clots, although occasionally crystal faces are found developed against potassium feldspar crystals. The quartz-orthoclase ratio is about 1:1.

Biotite is the only dark mineral present in most of the rock, and occurs in very small but well-formed blocky crystals with pleochroism from straw yellow to dark brown. It has been replaced in part by chlorite near the borders of the intrusion, but it is quite unaltered in other parts of the intrusion. Amphibole was seen in only two of thirty widely dispersed samples.

Many porphyry dikes issue from the intrusion and cut the granodiorite and adjacent country rock. The best exposed dikes can be seen on the walls of Black Canyon Creek and in the lower Methow River canyon. These gray dikes, mostly vertical, with north to northeast trends, have dark, chilled selvages of a few inches against the country rock. Many of the dikes exceed 40 feet in thickness and show progressive changes from dark, chilled borders through a porphyritic to an almost equigranular texture in their central zones. Euhedral phenocrysts of plagioclase as much as 2 inches long are not unusual. The quartz phenocrysts are in part terminated, although there is considerable rounding and embaying of these crystals. The dikes, 10 feet or less in thickness, are strongly porphyritic to their cores. Closely adjacent to the intrusive in Black Canyon, the dikes make up as much as 25 percent of the outcropping rock. Individual dikes intrusive into the Methow Gneiss can be traced to the northeast in the Methow drainage for several miles.

The age of the intrusion has not been determined, but it belongs chemically and mineralogically to the same family as the Golden Horn and Monument Peak intrusions of early Tertiary age. It is not cut by— hence appears to be later than— the Foggy Dew Fault, separating the Methow graben from the Chelan metamorphic block.

Midnight Stock

A young stock of gray hornblende andesite porphyry intrudes a very thin unit within the Winthrop Sandstone and a thick section of andesite breccia within the Midnight Peak Formation in the upper reaches of Wolf Creek (T. 34 N., R. 19 E.). The stock is less than a mile wide and 2 miles long. No material from this stock was available for examination.

Texas Creek Stock

Immediately southeast of Carlton, a small composite stock is sporadically exposed in the canyon of Texas Creek and on the ridges flanking the canyon. The older rocks are in the southwest part of the stock and consist of medium-grained directionless hornblende diorite that makes a somewhat indefinite contact with strongly hornblendic schists and gneisses of the Leecher Metamorphics. The metamorphic rocks dip into the stock at its west and south boundaries. Between the diorite and the Summit Creek pluton to the east, leucocratic biotite granodiorite makes up the major part of the stock. This potash-rich phase is clearly intrusive into the Summit Creek pluton to the east, the Leecher rocks to the north and south, and the earlier diorite on the west and southwest.

The Texas Creek area was utilized for a University of Washington student field-course study area for several seasons. It is highly recommended as a fascinating place for the study of intrusive relationships and contact metamorphic effects where the stock cuts marble beds of the Leecher Metamorphics. Skarn zones were formed along its south boundary that contain the ore minerals scheelite, chalcopyrite, molybdenite, pyrite, magnetite, and hematite. The gangue is largely calcite, epidote, and garnet. A tungsten prospect in sec. 2, T. 31 N., R. 22 E., known locally as the Dutch John claim, is described by Huntting (1956, p. 345).

The older, darker phase of the intrusion is, in thin section, made up of sharply twinned and zoned andesine crystals, strongly subhedral to euhedral in shape. Cores as calcic as An_{45} have rims of An_{35}. Late overgrowths on some crystals in the low oligoclase range have been accompanied by the development of myrmekite. Hornblende is the most abundant mafic mineral but seldom makes up more than 30 percent of the rock. The crystals are irregularly shaped, having adjusted to space not filled by the earlier formed plagioclase. Pleochroism is in shades of olive, yellow green, to yellow. Biotite is present in wispy crystals but is subordinate to the hornblende. A minor amount of chlorite has been formed by slight alteration of both the hornblende and biotite. Quartz is present in small interstitial patches in most thin sections, but it seldom amounts to as much as 10 percent, and is usually less than 5 percent. Magnetite is the chief accessory mineral but apatite, deep-yellow epidote, and more rarely titanite are present. Although the bulk of the darker phase is a hornblende diorite, local parts of this earlier intrusion can be classified as biotite-hornblende quartz diorite.

The main body of the Texas Creek stock is distinctly more leucocratic than the rocks described above. Petrographic examination shows the plagioclase to be euhedral and complexly twinned and zoned. The most calcic cores are An_{35} and have rims that are An_{28}. The plagioclase in most sections studied is more abundant than the quartz and orthoclase combined, but in the center of the intrusive body the the two feldspars are of about equal amounts. Nonperthitic orthoclase occurs in large patches that encase all other minerals. Alteration of the feldspars has been mild; the orthoclase has altered to a dark, dusty kaolinite, while the plagioclase has altered to sericite and muscovite. The chief dark mineral is a strongly pleochroic dark-brown to yellow, blocky, pyrogenic biotite that has been slightly altered to chlorite. Hornblende is present in most sections, but it is distinctly subordinate to the biotite. The most common accessory mineral is titanite, which occurs in well-formed crystals many of which can be identified megascopically. Apatite and magnetite are common, and deep-yellow epidote locally occurs alone or in association with the fresh biotite.

The major part of the Texas Creek stock is composed of a directionless hornblende-biotite granodiorite and quartz monzonite that are chemically and mineralogically closely similar to the Tertiary Golden Horn and Cooper Mountain intrusives. The equally directionless but earlier calc-alkalic phase may be correlative with the Cretaceous intrusions of the Pasayten Peak stock-dike type of Late Cretaceous age.

Frazer Creek Complex

Scattered exposures of a variety of intrusive rock types in the drainage of Beaver and Frazer Creeks in the eastern part of the area in T. 33, 34 N., R. 22 E. have been designated the Frazer Creek complex. Coarse-grained leucocratic biotite quartz diorite underlies the hills north and west of Beaver Creek. The western contact between the intrusive and fossilferous rocks of the Buck Mountain Formation is easily recognized due to leaching, silicification, and bleaching of andesitic sedimentary rocks. The contact with Pipestone Canyon Formation is inferred to be intrusive rather than faulted but no exposures were found to verify this.

The leucocratic rock in thin section has only a few percent of blocky brown biotite as its mafic constituent, although an occasional crystal of green hornblende is seen. The plagioclase is strongly euhedral, very sparsely twinned, but markedly zoned. The composition ranges from cores of An_{45-32}, to rims of An_{27-13}. Quartz, in coarse unstrained crystals, makes up approximately 20 percent of the rock. Myrmekitic intergrowths occur between the well-formed plagioclase crystals, particularly in the western part of the intrusion. Micropegmatitic intergrowths of quartz and potassium feldspar also fill the angular spaces between the earlier formed plagioclase crystals.

The chief rock type exposed in the southeastern part of the complex is hornblende quartz diorite that is considerably more basic than the leucocratic rock described above. The mafic constituents make up approximately 20 to 25 percent of the volume. Green hornblende in very irregular crystals is molded against the early formed plagioclase and poikilitically includes well-formed feldspar and small magnetite crystals. Biotite is minor in amount and was formed very late. The mafic minerals are fresh looking and show little chloritic alteration. Quartz seldom reaches 15 percent and is usually less than 10 percent of the rock. The plagioclase is very fresh, subhedral, well twinned, but weakly zoned. The most basic cores noted are An_{47}. The composition is in the high andesine range. Rocks near the McClure thrust fault, in thin section, show considerable evidence of cataclasis. Feldspar twinning lamellae are sharply bent, sometimes broken and invaded by thin veins of chlorite and(or) epidote, evidently derived from hornblende.

The hills east of Beaver Creek and north of Frazer Creek, along the eastern border of the area (T. 33 N., R. 22 E.) are underlain by a dark-gray augite-amphibole diorite that, on weathered surface, megascopically, resembles the quartz diorite described above. In thin section, however, it is of a different composition. Pale-green tremolitic amphibole crystals, containing remnants of augite surrounded by rims of green hornblende, comprise 25 percent of the rock. Generous amounts of magnetite are associated with the mafic minerals. The subhedral plagioclase, making up approximately 70 percent of the rock, is unaltered, and its composition is near the andesine-labradorite boundary. Twinning is sharp but zoning is almost absent. Quartz is present only in accessory amounts, if present at all. The rock is a true igneous diorite. There is no evidence of dynamic metamorphism; so the lack of zoning is interpreted as the result of extremely slow cooling of the parent magma.

The age of the complex is indeterminate at this point, except that the most potassic part of it intruded Early Cretaceous Newby Group rocks and possibly those of the Paleocene Pipestone Canyon Formation.

Monument Peak Stock

A roughly circular granite stock, approximately 7 miles in diameter, is exposed on the ridge between Lost River and Eureka Creek in the north part of the map area, and has been given the name "Monument Peak stock" by Staatz and others (1971, p. 35). Erosion in the steep-walled canyon of Lost River is just beginning to expose the eastern part of the intrusion. From Drake Creek to Monument

Creek one can walk for more than 7 miles very near the top of this major intrusion, which has sent numerous sills and dikes from the main magma chamber into the almost vertical beds of hornfelsed black shale, conglomerate, and arkose. There is almost a mile of topographic relief from Lost River to the top of Monument Peak, which means that there was even more relief on the top of the original stock before erosion removed an unknown amount of rock from the top of the western part of the body. The exposed western part of the intrusion is only a cupola on a much larger body.

The granite in Lost River Canyon and on the heights to the west is characteristically yellowish pink in fresh exposures, weathering to a distinctive orange color. It is fine grained and porphyritic near the contacts and medium grained in the interior. The rock is miarolitic with well-developed terminations on both quartz and feldspar crystals exposed in the cavities, which are as much as one-third inch in diameter.

Perthitic microcline is the chief mineral present, averaging about 45 percent; quartz, 35 percent; and plagioclase, largely oligoclase, 20 percent. The plagioclase is weakly twinned and zoned. Pyrogenic biotite in books of blocky outline is the chief accessory mineral, accompanied by minor amounts of titanite, apatite, and zircon.

Spectacular yellowish dikes and sills of rhyolite cut the Monument Peak stock and extend beyond it. They range in width from a few feet to several hundred feet, and are prominent as far west as Slate Peak, 6 miles from the nearest outcrop of the stock. Similar dikes occur in the main valley of the Methow south of the intrusion. One cannot be sure whether they issued from the Monument Peak or Golden Horn intrusions or from an unexposed magma chamber beneath the valley between the two bodies.

Complicating the picture is the presence of many thick quartz-feldspar porphyry dikes, with gray to greenish-gray groundmass associated with the distinctive yellow rhyolites. The complicated multiple intrusions, which make Dead Horse Point on the road to Harts Pass so spectacular, are composed of the porphyry dikes.

Tabor and others (1968, p. C-51) report that biotite collected from the exposures of the main mass 0.4 mile northeast of Monument Peak was dated by J. C. Engels, using the potassium-argon method, as 47.9 ± 1.4 million years. This Tertiary age is in general accord with that reported by Misch (1966, p. 139) for the Golden Horn intrusive as being near the Eocene-Oligocene boundary.

Golden Horn Batholith

A northwest-southeast trending granitic intrusion, 19 miles long by 6 to 7 miles wide, is exposed along the Cascade crest in the most northwesterly part of the map area. It was named the "Golden Horn granodiorite" by Misch (1952, p. 17). The southeastern part of the batholith has been studied in detail by Stull (1969).

The batholithic rocks exposed in the magnificent peaks of Golden Horn, Tower Mountain, and Silver Star are now readily accessible in roadcuts along Washington North Cascade State Highway 20 (cross state), via Granite Creek and Washington Pass. Misch (1966b, p. 139) pointed out that this forceful intrusion cut across or shouldered aside steeply folded Lower Cretaceous sandstones and shales on its northeast side and made spectacular intrusion breccias on its southwest boundary, where it engulfed blocks of Black Peak Quartz Diorite, containing inclusions of hornfelsed volcanics. Rocks of the Golden Horn are fine to coarse grained and are gray to pink in fresh outcrop but weather to a characteristic yellow or yellowish orange. Much of the rock is miarolitic with cavities, a few mm to several cm in diameter. Well-formed crystals of quartz, feldspar, and locally black amphibole protrude into the cavities.

Misch (1966a, p. 216) first mentioned the occurrence of three types of granite within the Golden Horn mass: a two feldspar biotite granite, a one feldspar biotite granite, and an alkaline granite-bearing sodic amphibole. Stull (1969) mapped and described these three rock types in detail in the southeastern parts of the batholith. The two feldspar variety has approximately equal amounts of perthitic orthoclase, zoned plagioclase (oligoclase to albite), and quartz. Biotite is more common than hornblende, the combination of the two seldom amounting to more than 5 percent of the rock. These rocks exhibit striking rapakivi textures vividly brought out by pink perthitic orthoclase cores contrasting with white plagioclase rims. Stull (1969, p. 20) describes the three types of rapakivi.

The one-feldspar granite consists (Stull, 1969, p. 25) largely of perthite 45 to 63 percent; albite, seldom in primary crystals, 3 to 14 percent; and quartz, 28 to 35 percent. Biotite and amphibole are the dark minerals. The alkali granite differs from the rock just described in that the potassium feldspar is predominant (greater than 60 percent); quartz (32 to 34 percent); and albite less than 4 percent. Biotite is absent. The mafic, in thin section, is a dark blue, sodic amphibole. Megascopically, these are the black crystals, locally as much as several inches long, occurring in the miarolitic cavities.

Considerable similarity exists between the highly potassic rocks of the Golden Horn and those of the Monument Peak stocks. Both contain phases that are true granites in a geographic area in which Misch (1966b, p. 139) has pointed out the typical intrusive rocks are calc-alkaline diorites, quartz diorites, and granodiorites.

Potassium-argon age measurements made on biotite by J. L. Kulp and G. H. Curtis date the emplacement of the Golden Horn near the Eocene-Oligocene boundary (Misch 1966b, p. 139).

SURFACE ACCUMULATED ROCKS

Newby Group, Undifferentiated

The name "Newby Formation" was given by Barksdale (1948, p. 167) to strongly folded, faulted, and altered andesitic bedded breccias and flows, black shales, and interbedded volcanic lithic sandstones. The type locality was designated as Lookout Ridge, extending from Lookout Mountain in sec. 35, T. 33 N., R. 21 E. to Black Pine Lake, sec. 36, T. 33 N., R. 20 E., about 6 miles southwest of Twisp. The name of the formation was taken from Newby Ridge, a spur of Lookout Ridge. Subsequent work to the north of the type area has shown that the great thickness of the Newby rocks of eugeosynclinal origin can be subdivided. It is here proposed that the name Newby be raised to Group status because, in parts of the map area, it has been possible to subdivide the group into two formations—Twisp and Buck Mountain. Newby Group, undifferentiated, is used for those areas where Newby Group has not yet been subdivided.

Twisp Formation

The oldest formation recognized in the map area, and the older formation in the Newby Group, is here named the Twisp Formation. It is a complexly folded and faulted accumulation of thin-bedded black argillites and interbedded lithic sandstones named for the town just south of the southernmost exposures of the formation. The type area of the here designated formation is the channel walls of the Methow and lower Chewack Rivers, between Twisp and a point two miles north of Winthrop, where scattered outcrops afford the best exposures. Exposures in roadcuts just south of Winthrop on both sides of the Methow River are particularly instructive in both lithology and fold pattern. The outcrops are so widely spaced and the structures so complex that it is not possible to designate a type locality.

It will be noted on plate 1 that for the area north of the Twisp River the formation is exposed largely west of the Methow and Chewack Rivers; the exception is the topographic high immediately east of Winthrop. The core of this hill is composed of complexly folded Twisp unconformably under andesitic sedimentary breccia of the Buck Mountain Formation. The unconformity is well exposed on the south end of the hill (sec. 12, T. 34 N., R. 21 E.).

The Twisp Formation is composed largely of very hard, argillitic black shales, which characteristically weather into long, sharp, pencil-like fragments. Bedding in the argillite varies from a fraction of an inch to 4 inches in thickness; some beds are laminated. The formation contains occasional interbedded dark volcanic siltstones, in places irregularly concretionary, and varying in thickness from a few inches to 2 feet, and beds of dark volcanic lithic sandstone, locally conglomeratic, up to 10 feet thick. The impression of the overall lithology, however, is essentially one of fine-grained black clastics that are judged to be marine because of the consistently regular bedding and fine texture.

Bedding attitudes characteristically are steep and are widely varied in strike. The formation is structurally weak; its component beds, especially those composed of argillaceous rocks, have responded incompetently to stress and are tightly folded with amplitudes and wavelengths measuring tens to hundreds

FIGURE 3.—Twisp Formation. Folded black shales 1.8 miles south of Winthrop on State Highway 20.

of feet. The folded rocks were subsequently broken into many fault blocks. Only locally, where igneous sills have stiffened the formation, can individual folds be traced for more than a mile.

The total thickness of the Twisp can only be estimated; but approximately 4 miles west of Winthrop (sec. 20, T. 35 N., R. 21 E.), at least 4,000 feet of section can be measured on the west limb of a vertically plunging fold. Neither the base nor the top of the section has been identified.

No diagnostic fossils have been found in the Twisp. Fragments of molds of belemnites occur in two localities: SW$\frac{1}{4}$ sec. 16 and SW$\frac{1}{4}$ sec. 22, T. 35 N., R. 21 E., and cycad fragments have been found in the NE$\frac{1}{4}$ sec. 22. However, these are insufficient for an age determination. The rocks lie unconformably beneath the Buck Mountain Formation (Hauterivian-Barremian) and may possibly be Early to Middle Jurassic in age, perhaps equivalent to some part of the Ladner Group as defined by Coates (1970, p. 150), and later extended by Jeletzky (1972), in the Manning Park area of southern British Columbia. The part of the Ladner to which it is most similar is exposed on the road leading from Manning Park Lodge northeast to the naturalist's hut.

Buck Mountain Formation

The name Buck Mountain Formation is here given to a distinctive assemblage of interlayered volcanic and volcaniclastic rocks, 14,500 feet thick, that extends with local interruptions northwest 50 miles from 3 miles southeast of Twisp to the International boundary. The formation is named for a small mountain about nine miles north of Winthrop. The base of the type section is a mile east of the summit of Buck Mountain, at Buck Lake in sec. 22, T. 36 N., R. 21 E., where it is defined by the Chewack-Pasayten Fault. The type section is steeply homoclinal, faces southwest, and extends through Buck Mountain, terminating on the ridge separating Second and Third Creeks, in sec. 29, T. 36 N., R. 21 E., where it is truncated at an erosional unconformity by arkose of the stratigraphically overlying Goat Creek Formation. The only unfaulted exposure of the basal contact is found immediately east of Winthrop, where the Buck Mountain is seen to overlie the Twisp Formation along an erosional unconformity.

The formation occurs in a series of fault blocks, and throughout most of its length it is bounded on the east by the Chewack-Pasayten Fault. Structural trends are more uniform within the fault blocks than are those within the incompetent, stratigraphically lower Twisp Formation. The prevailing strike in the type section is northward to N. 35° W. and dips are steep, ranging from 70° W. to 70° E., and overturned. Few dips as gentle as 35° were observed. The formation can be described best in terms of three informal and unmapped members.

The lowest member is in fault contact with the Okanogan complex and its exposed thickness is about 2,500 feet.[1/] It consists predominatly of andesitic breccia that contains a few interbedded siltstone-sandstones and a few vesicular to amygdaloidal but more commonly massive flows. The andesitic groundmass is typically recrystallized to a mat of chlorite, epidote, and albite; the feldspar and mafic phenocrysts in most places having been completely saussuritized. However, in some breccias and flows, hornblende and plagioclase crystals are preserved that are only slightly altered. Some of the sedimentary interbeds contain marine fossils.

The andesitic breccias grade upward into a thick middle member that is composed of 6,300 feet of lithic sandstones, siltstones, and black shales in which lenticular beds of conglomerate up to 850 feet thick occur. The clasts in the conglomerate vary in size from granule gravel to boulders of well-rounded dark-colored andesite, chert, dike rocks, and rare limestone; in lenticular beds at higher stratigraphic levels, some granitoid clasts occur as large pebbles, cobbles, and boulders up to ten inches in diameter. The sandstone matrix of the conglomerate is largely andesitic debris.

The sandstone beds characteristically consist of angular clasts of andesite, plagioclase (much of it euhedral), green hornblende, and magnetite. Quartz is distinctly an accessory mineral in these rocks. The sorting is generally good; these sandstones are clean marine graywackes that contain virtually no matrix

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1/ The thickest section (5,000 ft.) of the lower breccia member is preserved in the vicinity of Davis Lake (secs. 17 and 18, T. 34 N., R. 22 E.), southeast of Winthrop.

but owe their lithification in a large measure to the authigenic growth, in intergranular spaces, of minerals of the chlorite and epidote families, together with calcite.

The uppermost unit consists of dark-gray volcanic lithic sandstone, siltstone, and black shale, and differs from the middle unit in that it does not contain conglomerate interbeds. The fragmental material is very low in quartz, and high in lithic fragments and volcanic feldspar. In the type section only 1,400 to 1,640 stratigraphic feet of this unit are preserved unconformably, beneath the arkose of the Goat Creek Formation. A section of 3,200 feet, thought to be the thickest, can be measured in sec. 10, T. 36 N., R. 21 E., west of the Chewack River, 5 miles north of Winthrop. The upper part of this section is fossiliferous.

Age and Correlation

V. Standish Mallory and Robert Dabritz have made extensive collections of fossils from widely distributed localities in rocks of the Newby Group. Mallory has identified a belemnite recovered from the lower volcanic unit of the Buck Mountain Formation, in the vicinity of Davis Lake, SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 16, T. 34 N., R. 22 E. as: Acroteuthis cf. A. impressa Anderson, a form which occurs in strata of Neocomian age in California. Mallory's best localities (UWA 2010, A2012, A2013) sec. 21, T. 36 N., R. 21 E., west of the summit of Buck Mountain, occur in the middle unit of the formation. He has identified the following two ammonites, three pelecypods and two belemnites:

Shasticrioceras hesperum Anderson
Shasticrioceras poniente Anderson
Inoceramus colonicus
Periplomya trinitatensis Stanton
Pleuromya papyracea Gabb
Acroteuthis aboriginalis Anderson
Acroteuthis shastensis Anderson

All of the fossils listed except the Shasticrioceras are found in California and Alaska in beds commonly considered Hauterivian, usually middle or late Hauterivian in age (Imlay, 1960). Moore (1959, p. 208) considers the Shasticrioceras to range into the Barremian.

Mallory also identified two ammonites from the upper unit of the Buck Mountain Formation (UWA 2018) (sec. 20, T. 36 N., R. 21 E.) near Third Creek, west of the summit of Buck Mountain, as:

Hoplocrioceras remondi Gabb
?Ancycloceras ajax Anderson

Both of these fossils are known to occur higher in the section in California than Shasticrioceras. Since they are stratigraphically the highest forms recovered here, it seems probable that the Buck Mountain Formation represents a time from middle or late Hauterivian to well into the Barremian.

Coates (1970, p. 150) in studying the geology of the Manning Park area of southern British Columbia revived the name Jackass Mountain Group of Selwyn (1873, p. 60) for the rocks that Rice (1947, p. 15) called the Dewdney Creek Group. He restricted the Dewdney Creek Group to a moderately thick section of volcanic sandstone, siltstone, and pebble conglomerate occurring unconformably above black argillites of the Ladner Group, as exposed along Skagit Bluffs on the north side of the Hope-Princeton Highway. He found fossils in this abbreviated section that he considered indicative of Upper Jurassic age. The immediately overlying sandstone of the Jackass Mountain Group is shown by Jeletzky (1972, p. 61) to be lithologically indistinguishable from the Dewdney Creek volcanic sandstone. Paleontological and regional structural grounds are cited by Jeletzky as the only

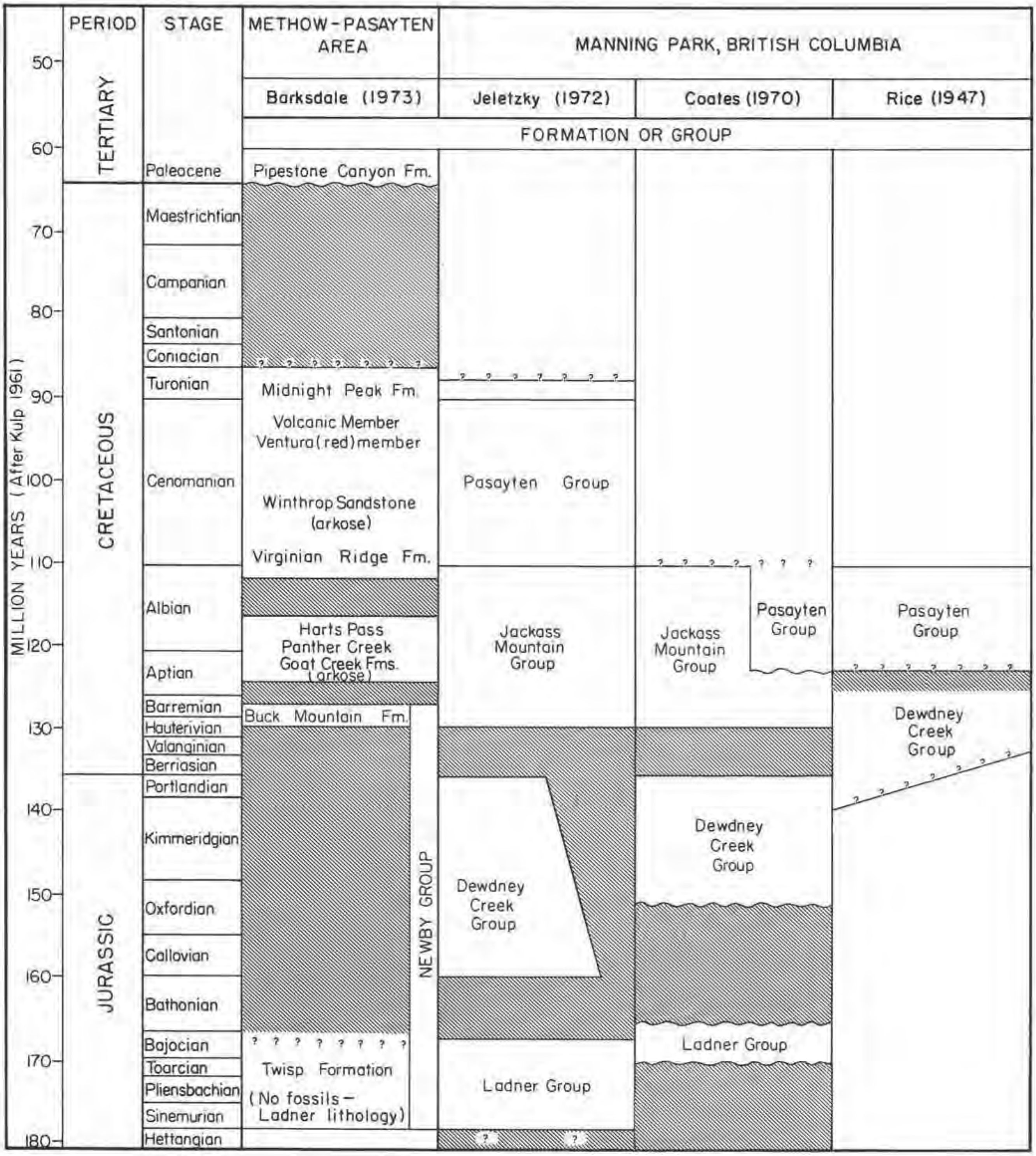

FIGURE 4.—Temporal correlation of units in Methow-Pasayten graben, Washington and British Columbia.

evidences of a prolonged hiatus and unconformity developed during the late Tithonian (Portlandian) and Berriasian to late Hauterivian times of emergence and erosion in this part of British Columbia.

The Buck Mountain Formation appears to have been deposited in the same time interval as the Hauterivian and Barremian part of the Jackass Mountain Group of Coates and Jeletzky.

Goat Creek Formation

The Goat Creek Formation is here named for a section of well-bedded, coarse- to fine-grained arkose and black argillite, 5,120 feet thick, exposed discontinuously northwestward from near Buck Mountain for 21 miles to the northern border of the map (pl.1). It is named for the creek whose headwaters drain the type section exposed in the east end of the drainage divide between Isabella Ridge and Sunrise Peak, in sec. 4, T. 37 N., R. 20 E. At the type section, the Goat Creek Formation conformably underlies black shale and roundstone granitoid conglomerate of the Panther Creek Formation and unconformably overlies volcanic and volcaniclastic rocks of the Buck Mountain Formation.

In the formation exposed from Ortell Creek Fault to the Monument Creek batholith, the beds are vertical near the basal contact, but become steeply overturned to the east as one goes west through the section. Many determinations of facing indicate that the beds are younger to the west. No evidence could be found of repetition of section.

Outcrops of arkose in the block between the Ortell Creek Fault and the Boesel Fault are discontinuous, but part of the Goat Creek Formation is repeated in the anticline west of Sweetgrass Butte.

Arkoses of the Goat Creek Formation crop out south of the Boesel Fault, where they unconformably overlie fossiliferous upper Buck Mountain Formation, and in turn are overlain unconformably by the Virginian Ridge Formation.

The Goat Creek Formation cannot definitely be identified in the Cascade crest area unless it forms part of a complexly faulted core of an unmapped antiform south of Tatie Peak in SW¼ T. 37 N., R. 18 E.,

FIGURE 5.—Looking north-northwest from Sweetgrass Butte showing type sections of Goat Creek and Panther Creek Formations.

the most northwesterly part of the map area.

Lithologically, the Goat Creek sandstones are plagioclase arkoses very similar in average composition to arkoses of the younger Harts Pass Formation. The fabric grains, in thin section, are composed of angular plagioclase, sericitized or slightly kaolinized, and sometimes altered to minerals of the epidote group. Potassium feldspar is of minor importance. The feldspar averages 55 percent; quartz rarely makes up more than 25 percent of the coarse- to medium-grained arkose, but it is more important in the fine-grained varities, averaging about 30 percent. Lithic fragment composition is a low 15 percent, with plutonic fragments being more numerous than volcanic. The accessory minerals are biotite, altered to chlorite or muscovite, detrital epidote, muscovite, apatite, zircon, and magnetite.

The rocks are characteristically well indurated. Adjustment of grains during deformation is demonstrated by the close packing of the quartz and feldspar, with the resulting crinkling of the rather thick books of biotite, partially altered to chlorite. The most common intergranular material is chlorite and minerals of the epidote-clinozoisite group and locally

Goat Creek Formation
Type Section

East end of drainage divide between Isabella Ridge and Sunrise Peak, sec. 33, T. 38 N., R. 20 E., and sec. 4, T. 37 N., R. 20 E.

Panther Creek Formation

Top of section	Thickness (feet)
Arkose, light-gray to off-white, coarse-grained, with minor black shale interbeds. A 3-ft bed of granitoid pebble conglomerate occurs at its base	2,270
Arkose, fine-grained	965
Arkose, coarse-grained, with minor pebble conglomerate lenses; near mid-section, 100 ft of shale and fine sandstone interbedded	585
Shale, black	145
Arkose	485
Shale, black, very indurated; slaty parting parallel to bedding	670
Total thickness	5,120

Unconformity

Buck Mountain Formation—andesitic flows, breccias, and sediments prehnite(?). These minerals are probably not the result of recrystallization of a matrix; rather they are products of mild metamorphism of clean arkose.

Age and Correlation

No fossils have been found in the Goat Creek Formation, but it is probably correlative with a part of Coates' (1970, p. 151) "Jackass Mountain Group," most likely "the Upper Greywacke Member," reported by Jeletzky (1972, p. 59, fig. 10-1) to be of Aptian(?) age.

Panther Creek Formation

The name Panther Creek Formation is here proposed for a section of black shale containing beds of granitoid, roundstone conglomerate and minor arkose, approximately 5,200 feet thick. This distinctive unit of clastic extremes is discontinuously exposed from the Boesel Fault, for 18 miles northwestward, until its outcrop is truncated by the Monument Peak batholith. The name is taken from the creek that drains the south slope of the east-west ridge of the type section, which is located in W½ sec. 9 and E½ sec. 8, T. 37 N., R. 20 E. At the type section, the Panther Creek conformably overlies the Goat Creek Formation and is conformably overlain by massively bedded arkose mapped as Harts Pass Formation.

The Panther Creek Formation in the type area strikes N. 20° to 25° W., with near vertical to sometimes overturned dips. Facings are to the west and overturning is locally 75° to the east. Much of the rock is a very hard, black hornfels, cut by dikes and sills related to the shallow Monument Peak batholith, which is in the early stage of being deroofed.

The formation also crops out in the fault block to the southeast of the type section between the Ortell Creek Fault and the Boesel Fault, where it makes up both the east and west limbs of a syncline east of Goat Creek and the east limb of an anticline adjacent to the west. There is less conglomerate and more arkose interbedded with the black shale in this section than in the type section.

Rocks thought to be correlative with the Panther Creek crop out southwest of Harts Pass, along the Cascade crest, beneath the type Harts Pass Formation. In this area, 2,700 feet of arkose with rare conglomerate beds are overlain by 400 feet of black shale. This section has been faulted and its base cannot be seen.

Lithologically, the shale comprises about 90 percent of the formation in the type section. It is thin-bedded, very black, and where not affected by the many intrusions, is fissile, weathering into small platy fragments. The arkose occurs in beds from a few inches to 15 feet thick, but comprises only 4 percent of the type section. Thin-section study shows that the fabric grains are composed of approximately 35 percent quartz, 40 percent plagioclase, with minor potassium feldspar, and 20 percent lithic fragments, nearly half of which are volcanic. The other lithic fragments are sedimentary, plutonic igneous, and metamorphic in orgin. Accessory minerals are biotite, epidote, and chlorite. The cementing material is largely chloritic with minor calcite. Minerals of the prehnite-pumpellyite assemblage have developed under the stress conditions.

The conglomerate, in six to eight intervals, makes up about 6.0 percent of the formation. It is well distributed in the middle 2,500 feet of the formation's black shale. The conglomerate beds have sharp contacts with the underlying shale showing little

Panther Creek Formation
Type Section

East-west ridge dividing upper Panther Creek drainage from upper Goat Creek headwaters, $E\frac{1}{2}$ sec. 8 and $W\frac{1}{2}$ sec. 9, T. 37 N., R. 20 E.

Harts Pass Formation

	Thickness (feet)
Top of section	
Shale, black, with minor arkose beds 2 to 10 ft thick in upper part of section (quartz porphyry sills comprise approximately one-third upper 350 ft of section)	1,350
Arkose	15
Conglomerate of granitoid, well-rounded clasts up to maximum of 5 in; matrix is fine arkose, grading into bed above.	15
Shale, black	21
Conglomerate	25
Shale, black	220
Arkose	70
Conglomerate	150
Shale, black	24
Conglomerate	10
Shale, black, with lenticular arkose beds 8 to 10 ft thick near top of unit	1,000
Conglomerate	35
Shale, black	75
Conglomerate	60
Shale, black (one-half mile south of type section along strike, two lenticular beds of conglomerate, 50 and 150 thick, can be followed for 1 mile. They are truncated by Ortell Creek Fault)	780
Arkose, thin-bedded, with pebbly granitic lenses containing molds of marine pelecypods	50
Shale, black, poorly exposed in type section but well exposed and conformable over Goat Creek Formation 1 mile north of type along strike	1,300
Total thickness	5,200

Goat Creek Formation

or no cannibalization or incorporation of shaly fines in the usual arkosic sand matrix. The beds are lenticular but some have been traced along the strike for more than a mile. In some instances, the conglomerate grades laterally into arkose but more often the bed simply lenses out.

The first outpouring of coarse debris produced lenticular beds 50 to 150 feet thick of roundstone, pebble to boulder conglomerate of rather poorly sorted but exceptionally well-rounded clasts of several types of rock up to 18 inches in diameter. Coarse- to fine-grained quartz-rich, biotite granitoid rock, hornblende diorite, faintly gneissic hornblende-feldspar rocks, strongly gneissic and sheared aplitic types, dark-gray to greenish aphanites (possibly dike rocks), a few gray

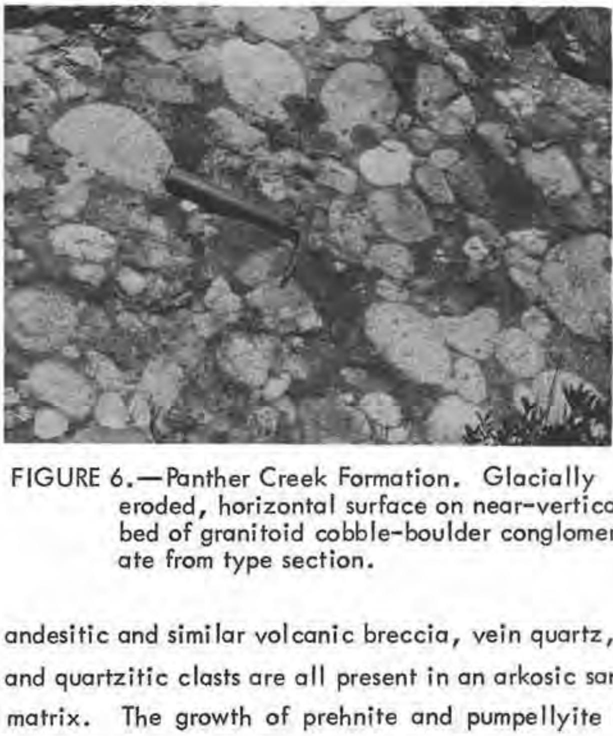

FIGURE 6.—Panther Creek Formation. Glacially eroded, horizontal surface on near-vertical bed of granitoid cobble-boulder conglomerate from type section.

andesitic and similar volcanic breccia, vein quartz, and quartzitic clasts are all present in an arkosic sand matrix. The growth of prehnite and pumpellyite is recognized in the arkose. The granitoid rocks often make up more than 50 percent of the cobble to boulder sized clasts.

Induration of the conglomerate is quite variable. Joints cutting the beds in some places make smooth planes passing through clasts and matrix alike to form pebble to boulder mosaics. Glaciated surfaces on many of these firmly indurated vertical-dipping conglomerates offer detailed information on bed facings and depositional surfaces. The term induration is used instead of cementation because the effects of low-grade metamorphism were probably greater than conventional cementation. The conglomerate fails to crop out on wooded, deeply weathered, or glacial-debris-covered slopes, but deep cuts along logging roads reveal almost unconsolidated gravel instead of conglomerate and enable the unit to be traced.

Age and Correlation

Marine fossils are found as molds in the thin-bedded arkoses associated with minor pebble conglomerate, approximately 1,350 feet above the base of the formation in the type section (UWA 9653, sec. 9, T. 37 N., R. 20 E.).

The following pelecypods have been identified by V. Standish Mallory:

- Megatrigonia cf. M. condoni (Packard)
- Pterotrigonia oregona (Packard)
- Anchura biangulata Anderson
- Ampullina avellana (Gabb)

The Trigonia species are most commonly found in Aptian-Albian stage strata, but the Anchura and Ampullina species occur commonly with faunas indicative of late Hauterivian age, according to Imlay (1960, p. 173). Perhaps in the Methow area, the latter fossils occur in strata younger than the age generally ascribed by Imlay, but older than the upper Aptian of the Hart's Pass Formation, which rests above them. This would make them middle Aptian in age.

Rocks with a lithology similar to that of the Panther Creek Formation were examined by Smith and Calkins (1904, p. 22) between Ruby Creek and the

Hidden Lakes in the area lying between the present map area and the Canadian boundary. They gave the name "Pasayten Formation" to the unit and noted that these shales and sandstones were without contemporaneous volcanic materials and:

> It is along the main divide north of Barron that the most instructive exposures of the Pasayten formation are seen. The lowest part of the section seen along the crest of the Hozomeen Range includes at least 1,000 feet of black shale, above this is a sandy conglomerate with pebbles 1 to 8 inches in diameter. About 500 feet of this conglomerate is exposed at the head of Canyon Creek. Sandstone overlies the conglomerate and is succeeded by more black shale.

The head of Canyon Creek is 10 miles north of Harts Pass along the Cascade crest. The section described by Smith and Calkins is probably equivalent in part to the type Panther Creek Formation. The base of the section is not exposed in the Canyon Creek locality.

Daly (1912, p. 485) mapped a distinctive granite boulder conglomerate approximately 1,400 feet thick along the Canadian boundary strip and called it "member J. of the Pasayten Series." Rice (1947, p. 17) remapped Daly's section as a part of the Hope-Princeton quadrangle project in southern British Columbia and redefined Daly's conglomerate as "Division C of the Dewdney Creek Group." He measured 1,290 feet of massive conglomerate containing many granite cobbles up to 8 inches in diameter, overlying 790 feet of massive conglomerate with interbeds of fine-grained, sandy argillite. At another section, 1,300 feet of conglomerate was found to be overlain by 2,660 feet of thin-bedded, dark, sandy argillite, gray-green graywacke, tuffaceous sandstone, and concretionary sandy shale. He considered the Dewdney Creek group to be Lower Cretaceous in age.

Coates (1970) restudied the section of Daly (1912) and Rice (1947) in his mapping of the geology of Manning Park and included the conglomerates in the middle part of "the Jackass Mountain Group, a Lower Cretaceous marine assemblage."

Jeletzky (1972, p. 62) records the findings of two fossils in thin-bedded to laminated argillaceous rocks about 145 feet stratigraphically below the thick conglomerate north of Manning Park Lodge. The argillaceous rocks are distinctly graded and locally sole-marked. He interprets them as turbidites. The fossils are *Brewericeras* (*Leconteites*) *leconti* and *Aucellina* ex. aff. *A. gryphaeoides* (Sowerby). These he considers Albian and (?)Aptian in age.

Harts Pass Formation

The Harts Pass Formation is here named for a section of predominantly marine arkose with subordinate amounts of fossiliferous black shale, 7,900 feet thick, exposed along the Cascade crest northeast and southwest of Harts Pass (sec. 7, T. 37 N., R. 18 E.) for which the formation is named. The formation extends northwest from its southern termination of a fault 3 miles east-northeast of Silver Star Mountain to the northwestern limit of the area mapped, a distance of about 18 miles.

The type area is designated as the terrane occupied by the formation within three miles northwest and southeast of Harts Pass.

The formation, in the type area, is divisible into three parts: The lower member consists of massively bedded arkose with very minor black shale interbeds, and is best exposed on the Cascade crest (secs. 23 and 24, T. 37 N., R. 17 E.), along the main trail beginning 7,000 feet almost due south of Harts Pass. The middle member of the formation is composed of about equal amounts of arkose and black shale, and is best exposed where the North Fork of Trout Creek cuts the strike ridge, approximately three miles southeast of Harts Pass (sec. 19, T. 37 N., R. 18 E.). The upper member, a massively bedded arkose with minor amounts of black shale can best be seen in the steep valley wall of Slate Creek (secs. 1 and 2, T. 37 N., R. 17 E.), immediately south of Slate Peak and a mile north-northwest of Harts Pass.

Thicknesses of the three members in the type area were measured from cross sections carefully drawn using as a base the topography from U.S.G.S. Slate Peak Quadrangle (1:24,000) and are presented as follows:

Harts Pass Formation
Type Section

Virginian Ridge Formation—black mudstone, chert conglomerate, and chert-grain sandstone

Unconformity

	Thickness (feet)
Upper Member	
Arkose, massive-bedded (up to 50 ft thick), medium- to coarse-grained, marine, with minor crossbedding; interlayered, with fine-grained arkose and, more rarely, black argillite, a few in to 10 ft thick, containing cephalopods and echinoderms	2,200
Middle Member	
Arkose, medium-grained, marine, and black argillite in about equal amounts, varying from 50 ft to 120 ft in thickness. Where the argillite is predominant, it carries beds of fine arkose 6 in to 1 ft thick. Where the arkose is predominant (in beds 2 to 22 ft, individual thickness), there are black argillite interbeds of a few in to a few ft in thickness	2,500
Lower Member	
Arkose, marine, in beds 3 to 6 ft thick, with argillite interbeds 6 to 10 in thick in upper part of section, but arkose beds increase in thickness down section to 10 to 50 ft, separated by black argillite beds of 6 in to 4 ft. There are a few granule quartz and feldspar lenses in these sandstone. Fossiliferous.	3,200
Total thickness	7,900

Panther Creek Formation—black argillite with granitoid pebble to boulder conglomerate and arkose interbeds

The section exposed in the vicinity of Harts Pass can be traced northwestward for about 5 miles along the strike to where it begins to swing to a more northerly direction and thicken. The section farther north has not been studied in detail.

Seven miles southeast of Harts Pass along the strike, the Methow River cuts across the formation exposing only 3,200 feet of arkose stratigraphically above a black argillite mapped as the Panther Creek Formation and stratigraphically below black shales and chert pebble conglomerate of the Virginian Ridge, which overlies the Harts Pass Formation with slight angular discordance. Continuing to the southeast along strike for an additional 3½ miles, the Harts Pass Formation thins to 2,300 feet of massive arkose that lies unconformably beneath the Virginian Ridge. The arkose there rests conformably on black argillite mapped as Panther Creek Formation.

Rocks mapped as Harts Pass Formation occupy a triangular-shaped area of about 4 square miles, 8 miles southeast of Monument Peak. They consist mainly of thick-bedded arkose resting conformably above the type section of the Panther Creek Formation. The arkoses are cut by many sills and dikes. Insufficent work has been done in this area to tell whether there has been structural repetition of section.

FIGURE 7.—Harts Pass Formation. Middle and upper members in type area, overlain unconformably by Virginian Ridge Formation. Photographed from 3 miles southeast of Harts Pass.

A few miles farther to the southeast, in the block between the Boesel and Ortell Creek Faults, Harts Pass Formation appears to occupy the core of the Sweetgrass syncline. The arkose is not as thickly bedded in this section and contains more black shale interbeds than has been noted in other basal sections of the formation.

The arkoses of the Harts Pass Formation in the type area are well sorted, extremely well indurated, and rarely crossbedded or channeled. The contact between overlying light-colored arkose beds, with underlying argillite interbeds, are characteristically sharp. The black carbonaceous argillites are well indurated, fracture with sharp edges, and break across the bedding at unpredictable angles.

Pierson (1972, p. 14), who made a detailed lithologic study of the type Harts Pass Formation, reports that the arkoses have a modal composition of quartz 30 percent, feldspar 55 percent, and lithics 15 percent. Very angular-shaped grains of monocrystalline quartz make up 70 percent of the siliceous framework. The remainder of the siliceous grains are polycrystalline quartz aggregates. The feldspar is largely plagioclase in the oligoclase-andesine range and does not appear to have been albitized. Myrmekitic intergrowths, apatite inclusions, and occasional zoned grains suggest a plutonic origin. The potassium feldspar is minor, varying in the samples examined from 1 to 11 percent. Pierson (1972, p. 22) found evidence that the potassium feldspar content was influenced by grain-size variation within the same bed; the finer the grain the higher the potassium feldspar content. Sampling and study of medium- to coarse- grained types may give a false impression of the total potassium content. The lithic clasts tend to be felsic plutonic and metamorphic fragments with minor volcanic clasts.

The heavy mineral suite includes biotite, epidote, zoisite, muscovite, chlorite, sphene, and opaques.

The extreme induration of the Harts Pass arkoses can be explained by two generations of cementation; an earlier polymineralic matrix, at times approaching a pure chlorite cement, is probably the result of a diagenetic reaction in unstable grains. The remaining pore space was filled by precipitated carbonate and silica. There is a total absence of zeolites, but a few widely scattered samples from the middle and upper members contain well-developed prehnite.

Age and Correlation

Ammonites were first found in 1939 in the upper member of the Harts Pass Formation in roadcut outcrops of black shale, interbedded with white arkose, approximately 0.7 miles southeast of Harts Pass.

This locality lies approximately 870 feet stratigraphically below the eroded top of the formation and approximately 7,000 feet above its base. The most common fossil remains are broken fragments of a straight, transversely ribbed ammonite with the beginning of a bend at the larger end. Part of a cast of a normally coiled ammonite on which the suture pattern could be worked out was also found. The fossil material was sent to Professor Siemon William Muller of Stanford University, who identified the uncoiled form as belonging to the genus Hamites. The coiled form he recognized as Puzosia cf. P. mayoriana (D'Orbigny) or Puzosia cf. P. sharpei Spath. He considered the fossils as probably Albian in age.

The original discovery outcrop was greatly enlarged during a subsequent road-widening project and has since yielded several additional species. David L. Jones (written communication) of the U.S. Geological Survey, Menlo Park, California, examined additional collections and confirmed the Hamites sp. and recognized also Melchiorites cf. M. shastensis Anderson. Both of these forms occur in the Gabbioceras wintunium zone in northern California and are probably late Aptian rather than Albian in age.

V. Standish Mallory collected extensively from the original locality (UWA 6230, sec. 7, T. 37 N., R. 18 E., SW. 48°43', 120°39'). Mallory (personal communication,1973) has determined the following:

Dumblea sp.
Cheloniceras sp.
Hamites cf. H. attenuatus
Hypophylloceras cf. H. onoensis (Anderson)
Melchiorites sp.
Pinna equivellara
Anchura biangulata Anderson

Dumblea is a widely distributed Lower Cretaceous echinoid. Cheloniceras is reported from upper Aptian; Hamites attenuatus is known from the interval upper Aptian-upper Albian; Hypophylloceras onoensis is Aptian; the genus Melchiorites occur from the lower Aptian into possibly the lower Albian.

On the basis of the study to date, Mallory (personal communication, 1973) is of the opinion that the upper part of the Harts Pass Formation is Aptian, and probably upper Aptian in age.

The Harts Pass Formation may be correlative with the upper part of the "Jackass Mountain Group" of Coates (1970), probably in part of the section referred to by Jeletzky (1972, p. 59) as "variegated marine clastics (succession and facies pattern poorly known)." These rocks overlie the conglomerate unit in Manning Park. Thin sections of a sandstone collected along the Hope-Princeton Highway (Canada 1) in this stratigraphic position have been examined by me, and the mineral composition is essentially that of the Harts Pass arkoses.

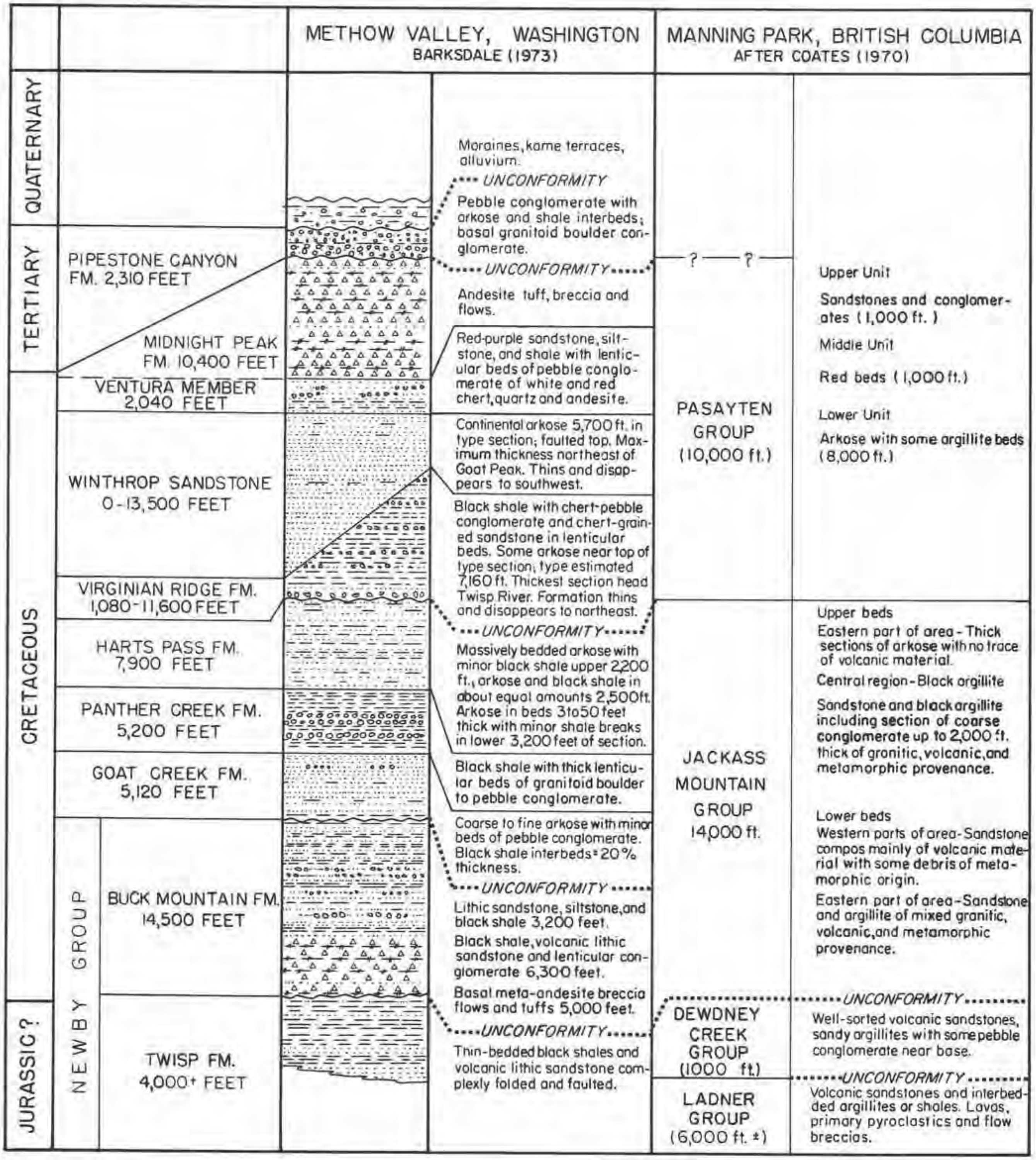

FIGURE 8.—Lithologic comparison of stratigraphic sections Methow–Pasayten graben in Washington and British Columbia.

Virginian Ridge Formation

The name Virginian Ridge Formation was given by Barksdale (1948, p. 169) to a marine section of steeply dipping black mudstone, siltstone, chert-grained sandstone, and chert pebble conglomerate beds found in Wolf Creek and along Virginian Ridge between Wolf Creek and the Methow River (secs. 35 and 36, T. 35 N., R. 20 E.), the locality of the type section, approximately 5 miles west of Winthrop. Field work during the present study shows the formation to be distributed over a wide area from the valley of the Twisp River on the southeast to at least as far as Slate Peak on the northwest and McLeod Mountain on the northeast. Its thickness, conservatively estimated at 7,160 feet at the type locality, ranges from about 1,100 feet in the northeast to about 11,600 feet in the west-central part of the map area.

In the stratigraphic section at the type locality, neither the base nor the top is exposed, but 4,480 feet in the middle part of the section was measured and is detailed on the following page.

The Virginian Ridge Formation rests with marked discordance on rocks of the Newby Group, south of The Boesel Fault; clasts in widespread basal conglomerate were derived from the Newby Group rocks. The best exposed section of this conglomerate, which is 1,250 feet thick, is in a roadcut along the north side of the Twisp River, 4 miles west of Twisp. Here the conglomerate is made up of poorly sorted, well-rounded pebbles to cobbles, not over six inches in diameter. The clasts are black argillite, andesite breccia, lithic sandstone, and chert bound in a matrix of grit and sand of the same derivation. The unit rests on the eroded black shales of the Newby Group at this locality. Cementation is poor, therefore, these conglomerates do not crop out, except in artificial cuts and on severely glaciated surfaces. The basal conglomerate is not exposed in the type section but occurs along the strike 6 miles northwest of Winthrop,

FIGURE 9.—Type section Virginian Ridge Formation. Photo looking southwest from State Highway 20, 5 miles west of Winthrop.

Virginian Ridge Formation

Type Section

Virginian Ridge-Wolf Creek trail section. First outcrop (estimated 1,000 ft above base) on upper trail, first canyon above cabin, sec. 36, T. 35 N., R. 20 E., to deep saddle on Virginian Ridge sec. 35, T. 35 N., R. 20 E.

Winthrop Sandstone

Top not exposed

	Thickness (feet)
Middle section	
Sandstone, light-gray, arkosic	8.5
Siltstone, black; poor outcrop	190
Sandstone, light-gray, arkosic; cross-bedded, soft weathering	17
Siltstone, black, and fine-grained gray sandstone	165
Sandstone, gray, feldspathic	17
Siltstone, black, shaly	66
Sandstone at base, massive, gray; top few feet severely jointed	21
Siltstone, black, with lenticular gray chert sandstone	384
Sandstone, chert, massive, gray	21
Siltstone, black, with lenticular gray chert sandstone	384
Sandstone, chert, massive, gray	21
Siltstone, gray	267
Sandstone, gray, with chert gravel conglomerate base	26
Sandstone, gray, weathering, blocky, grading to siltstone at top	37
Conglomerate, chert, $\frac{1}{2}$-in pebbles at base, grading up to fine pea-gravel size	26
Siltstone, black, nodular weathering, and fine sandstone	78
Sandstone, chert, coarse, with irregular chert gravel lenses	32
Siltstone, black, splintery weathering, with sandy beds	151
Conglomerate, chert pebble	25
Shale, black, nodular weathering, with thin sandstone beds	355
Sandstone, gray, fine	9
Sandstone, chert, gray, lenticular	24

Virginian Ridge Formation Type Section—Continued

Covered	426
Sandstone, arkosic; crops out sporadically	180
Covered	776
Covered	119
Conglomerate, chert; massive-bedded, pebbles greater than 1 in diameter	62
Sandstone, chert, gray	22
Siltstone, black, and shale; sporadic outcrops	137
Sandstone, chert, gray	11
Siltstone, black to olive, nodular weathering	108
Chert grit	3.5
Covered (shale soil)	101
Conglomerate, chert; massive outcrop, pebbles (½ to 3/4 in, and smaller), some white quartz, silica cement	28
Shale, black; with occasional dark, medium-grained sandstone beds up to 4 ft thick	158
Hornblende porphyry sill	9
Covered (shale soil)	317
Sandstone, gray	4.5
Silt-shale, black	20
Sandstone, gray, medium-grained	6
Siltstone, black	3.5
Sandstone, gray	6
Siltstone, black, nodular weathering	15.5
Conglomerate, sedimentary, volcanic black and gray chert pebbles (well-rounded, 3/4 in and smaller); very poorly consolidated	5
Sandstone, gray, coarse	3.5
Siltstone, olive, nodular weathering	10
Sandstone, olive, coarse	4.5
Total thickness	4,480

Covered—base not exposed

Unconformity

and in the fault blocks east of Patterson Lake, 3½ miles southwest of Winthrop. The basal conglomerate is lacking where the Virginian Ridge shales rest, with slight angular discordance, on the arkoses of the Harts Pass Formation, northwest of the Boesel Fault.

A section of the Virginian Ridge Formation estimated to be 11,600 feet thick is exposed in the valley of the North Fork of the Twisp River (sec. 36, T. 35 N., R. 18 E.), where it rests on rocks of the Newby Group. It can be followed east over the divide into the upper reaches of Wolf Creek. Some structural thickening is suspected, but it cannot be demonstrated. Conglomerate beds are distributed throughout the section in upper Wolf Creek, but they are thicker and contain larger sized chert clasts than conglomerate beds to the north and east. The middle 5,000 feet of the section in upper Wolf Creek is largely chert pebble and cobble conglomerate.

The most striking change in thickness and character of the formation is found on the northeast limb of the Goat Peak syncline. A vertically standing section of 1,080 feet of black shale, gray siltstone, chert grain sandstone, and chert grit and granule conglomerate is completely exposed above timberline in sec. 19, T. 37 N., R. 19 E. It is overlain conformably by the Winthrop Sandstone and rests unconformably on the Harts Pass, Panther Creek, and Goat Creek Formations.

The most continuous section of the Virginian Ridge Formation is exposed in the southwest limb of the Goat Peak syncline. There, the formation can be traced along the strike from the Boesel Fault to Slate Peak, a distance of twenty-five miles. In this limb, thickness varies from 7,800 feet in the southeastern part of the outcrop to 4,000 feet on the ridge 2 miles southeast of Harts Pass.

Lithologically, the predominant rock types in the Virginian Ridge are black mudstone and greenish-

FIGURE 10.—Virginian Ridge Formation. Predominantly black shale, with chert pebble conglomerate and chert grain sandstone making hard outcrop. View to the northeast (Robinson Mountain in distance). Road in lower left is 2.5 miles southeast of Harts Pass.

black siltstone. The pelitic rocks have a characteristic nodular weathering, and are poorly exposed, except in major streams or roadcuts, or where they are totally exposed above timberline; as, for example, from Last Chance Point to Slate Peak. There the lenticular nature of the associated dark-gray, chert-grain sandstones and chert pebble conglomerates, which are also characteristic of the formation, can be seen. The conglomerate beds range in thickness from 3 to 62 feet in the type section, and individual beds of sandstone and conglomerate can be traced from tens to thousands of feet along the strike. Occasional beds of arkose occur in the upper part of the section.

The drab gray to black chert clasts of the conglomerate are only moderately rounded, and average less than an inch in diameter in exposures on the south limb of the Goat Peak syncline. Clasts in the upper Twisp River-Wolf Creek exposures reach up to 3 inches in diameter and are more rounded; the beds there are much thicker than those in the Goat Peak syncline. Cement in the conglomerate is largely quartz; jointing in these rocks characteristically cuts across clasts, sand matrix, and cement.

Pierson (1972, p. 14) has studied the sandstones in the upper part of the Virginian Ridge section in the Harts Pass area. His calculations indicate the following averages: chert, polycrystalline quartz and quartzite, 55 percent; lithic fragments of several kinds of volcanic and metamorphic rocks, 30 percent; feldspar, 10 percent; and single quartz grains, 5 percent. The cement there is largely chlorite, carbonate, silica and sericite.

In summary, the Virginian Ridge Formation is made up predominantly of black mudstone and siltstone characteristically containing chert pebble conglomerate and chert grain sandstone interbeds; a few arkosic beds interfinger with the chert sands in the upper part. Beds rich in clastic chert are thicker, are greater in number, and the clasts larger in the south and west part of the map area. In accord with this, the grain size, number of coarse clastic beds, and total thickness of the formation decreases to the north and east. This is strong evidence that the clastic material was derived from the west. The formation south of lat. 48°30' N. rests unconformably on the Newby Group, and north of this line on the arkoses of the Harts Pass, Goat Creek, and Panther Creek Formations. Clearly this is an unconformity of considerable magnitude.

Age and Correlation

Marine fossils were reported by Barksdale (1948, p. 170), from a locality near Patterson Lake, 3 miles southwest of the town of Winthrop, (NW¼ sec. 8, T. 34 N., R. 21 E.). Two collections were made; one in 1941, from which Dr. Ralph Stewart (written communication, 1942) of the U.S. Geological Survey, recognized the following:

Trigonia sp. cf. T. evansana Meek
Trigonia sp. cf. T. leana Gabb
?Etea angulata Packard (as Meretrix)
?Trigonarca sp.
Venerid sp.
Turritella sp.
?Cyclothyris sp.

Another collection from the same locality was made in 1946, from which Dr. W. P. Popenoe (written communication), of the University of California at Los Angeles, was able to recognize the following similarities:

Trigonia sp. cf. T. evansana Meek
Trigonia sp. cf. T. leana Gabb
Trigonia sp. cf. T. maudensis Whiteaves
Trigonia sp. cf. T. diversicostata Whiteaves
Turritella sp.
Cucullaea sp. cf. C. ponderosa Whiteaves

The Virginian Ridge Formation rests with angular unconformity, not only on the Buck Mountain volcanic sediments, but also on Goat Creek Formation arkoses in sec. 7, T. 35 N., R. 20 E., approximately 7 miles northwest of Winthrop. Several pelecypods and one cephalopod were collected from this section and identified by V. Standish Mallory (written communication, 1973) as:

Megatrigonia cf. M. condoni (Packard)
Pteritrigonia oregona (Packard)
Beaudanticeras haydeni (Gabb)

He points out that the genus Beaudanticeras is usually thought of as being an Albian indicator. The Trigonia species are most commonly found in Aptian-Albian age strata, but the M. condoni is known to extend into Cenomanian age strata.

The best known Virginian Ridge Formation fossil locality (UWA 9971, NW¼ sec. 1, T. 37 N., R. 17 E.) occurs along the much traveled road from Harts Pass to the Slate Peak Lookout. Stratigraphically, the most productive fossil bed here lies approximately 600 feet above the base of the Virginian Ridge Formation. The fossils occur as molds in dark chert grain sandstone beds, and have been identified by V. Standish Mallory (written communication, 1973). The more common fossil is a robust gastropod Actaeonella packardi Anderson. Molds of Turritella also occur and one is thought to be Turritella cf. T. hearni Anderson. The Actaeonella packardi Anderson is known from beds near Hornbrook, California, dated as Turonian in age, and in the Santiago district of Orange County, California. The California beds are thought by some to be as young as Santonian-Campanian (Senonian). Turritella hearni is known from Turonian age rocks from near Montagu and Yreka, Siskiyou County, California.

The paleontologic data indicates that the Virginian Ridge Formation is probably in part Albian but mostly Cenomanian in age. It can hardly be as young as Turonian here in light of the radioactive age given as about 86 million years by Tabor (1968, p. C45) for the Pasayten stock-dike, which cuts beds known to overlie the Virginian Ridge and that may in fact intrude the formation itself.

There is no lithologic correlative of the Virginian Ridge Formation in the described Cretaceous section of southern British Columbia. It is thought to be the temporal correlative of some part of the lower arkose member of the "Pasayten Group" of Coates (1970) and Jeletzky (1972). This point will be discussed in more detail in the following section on the Winthrop Sandstone.

Winthrop Sandstone

The name "Winthrop sandstone" was given by Russell (1900, p. 117) to a continental assemblage of nearly white, massive arkosic sandstones and light-gray shales cropping out on the north border of the Methow Valley, 5 miles northwest of Winthrop. He estimated the thickness to be about 2,000 feet.

FIGURE 11.—Winthrop Sandstone. Upper part of type section truncated by Boesel Fault. Outcrop northeast side of State Highway 20, 6 miles northwest of Winthrop

The type locality of the Winthrop Sandstone actually lies in secs. 13 and 14, T. 35 N., R. 20 E. on the northeast side of State Highway 20 between 5 and 6 miles northwest of Winthrop. The beds there strike N. 10° E. and dip steeply northwest. The basal beds of the Winthrop, although interrupted by a minor intrusion of feldspar porphyry, show a gradation into the black shale and chert pebble conglomerate of the underlying Virginian Ridge Formation. The upper part of the section has been cut out by the Boesel Fault. The formation is well exposed in both of the glacially eroded walls of the Methow Valley, although the cover of deep soil and glacial debris prevent satisfactory tracing of beds elsewhere. The estimated thickness of the formation preserved on the northeast side of the Methow River in the type section is 5,700 feet. A thickness of 6,510 feet of section is exposed over the

Virginian Ridge Formation directly across the Methow Valley from the type section.

A much thinner section of Winthrop Sandstone is exposed in the northeast limb of the Midnight Peak syncline in the Twisp River-Little Bridge Creek area, 7 miles southwest of Winthrop. Only 2,080 feet of section can be measured between the underlying typical Virginian Ridge Formation on the northeast limb, and the overlying andesitic breccia of the Midnight Peak Formation on the northeast limb, and 2,700 feet on the southwest limb of the fold. In the vicinity of Gardner Mountain (T. 35 N., R. 14 E.), Winthrop Sandstone is present only as a few tens of feet of feldspathic-lithic sandstone, and is not shown there on plate 1. The Winthrop thins as it is traced northwest from the Boesel Fault along the southwest limb of the Goat Peak syncline. At the mouth of Little Boulder Creek, it is 4,230 feet thick; and 4½ miles northwest, in the cliffs above Early Winters Creek, 3,200 feet of section can be measured. The arkose section thins and disappears approximately 1 mile northwest of Last Chance Point (T. 37 N., R. 18 E.). Well-bedded, apparently conformable, volcanic lithic sandstone and(or) red beds and volcanic breccias of the Midnight Peak Formation overlie the Virginian Ridge shale and chert conglomerate disconformably. The general relationship is very much like that found in the Gardner Mountain area of the Midnight Peak syncline and indicates a regional thinning and disappearance of the Winthrop Sandstone to the west and southwest. The thinning is probably a depositional feature rather than the result of erosion. Many small cross faults, and some low-angle thrusting at Last Chance Point of younger over older beds occur where the more rigid Midnight Peak Formation could not adjust to the folding by bedding plane slippage. The absence of the Winthrop beyond Last Chance is, nevertheless, independent of these structural complications. The Winthrop Sandstone thickens spectacularly across the Goat Peak syncline from southwest to northeast, where 13,500 feet of arkose are exposed in its northeast limb. On the high divide between the Lost River and the Goat Creek drainages, the beds steepen in dip from 75° SW. becoming overturned, dipping 60° NE., as one goes northeast from the top of the section (base of the red Ventura) to the base resting on a very thin Virginian Ridge Formation (1,080 feet). No evidence that the strata are structurally repeated could be found.

The Winthrop Sandstone is highly feldspathic and on freshly broken surfaces is light-gray to greenish gray, often showing distinctive mottling. Some beds weather white, but more commonly weather light buff. The beds vary in thickness from a few inches to 12 feet with thin shale and siltstone partings, which emphasize the cross bedding that is common. Many outcrops are so massive that reliable attitudes are only obtained with difficulty, if at all. The formation is essentially sandstone, the grain size varying from very fine to very coarse, including sparse lenses of small pebble conglomerate. Siltstone and shale are minor constituents of the formation.

In thin section, samples from the lower and middle part of the Winthrop Sandstone consist of more than half feldspar, mostly plagioclase, but up to 10 percent of the feldspar may be of potassium varieties; quartz averages nearly 30 percent; lithic fragments of both volcanic and fine-grained sedimentary rocks usually make up less than 20 percent. Varied amounts of biotite, chlorite, muscovite, and epidote occur as accessories. As one goes up section, the volcanic lithic fraction increases, commonly exceeding 60 percent. The grains are cemented by chlorite and other fine micaceous minerals. Quartz and zeolite(?) are locally present, and in sections rich in lithic fragments, secondary epidote accompanies the chlorite as cement. The formation is interpreted as continental in origin.

Age and Correlation

The Winthrop Sandstone is in gradational contact with the underlying marine Virginian Ridge Formation and is gradationally overlain, over much of its outcrop, by the continental red beds of the largely volcanic-derived Ventura Member of the Midnight Peak Formation. Fossil leaves were collected by Russell (1899) from silt-shale interbeds in the type locality, behind the old school house on the Boesel ranch, approximately 7 miles northwest from Winthrop on the Harts Pass (Methow River) road. Knowlton (Russell, 1900, p. 171) identified them and found them similar to forms described from the Upper Cretaceous of Greenland. Additional collections were made from the Russell locality. Dr. Roland W. Brown (written communication, 1946), of the United States Geological Survey, identified the fossils as:

Anemia cf. A. supercretacea Hollick
Cladophlebis sp.
Gleichenites cf. G. geiseckiana Heer
Pseudocyas steenstrupi Heer
Cyparissidium gracile Heer or Sequoia fastigiata Heer
Menispermites sp. or Nelumbium sp.
?palm fragment and fragments of dicotyledons

Leaves collected from an outcrop of arkose on the ridge 2 miles due north of Bench mark 2806, Twisp River Road, were also identified at the same time by Dr. Brown (written communication, 1946) as:

Cladophlebis cf. septentrionalis Hollick
Sapindopsis sp.
other fragments of dicotyledons

Both collections, in the opinion of Dr. Brown, indicate Upper Cretaceous age, but because the species in most cases are not clearly defined, no more definite identification could be made. Closely comparable, if not identical, species have been described from the Cretaceous of western Greenland and the Upper Cretaceous of Alaska.

The Winthrop Sandstone is probably correlative with the arkose described by Daly (1912, p. 480) as Member B of the "Pasayten Series" exposed in the Canadian boundary section between monuments Nos. 81 and 85. Penhallow (Daly, 1912, p. 487) considered the plant fossils collected by Daly from two localities in Member B to give evidence of both Lower and Upper Cretaceous (Shasta-Chico) ages. Daly thought that this member was at the base of his section, although it has been proven to be at the top.

Rice (1947, p. 19-22) remapped Daly's Pasayten section as the "Pasayten Group," and collected plant fossils along the southeast side of the Similkameen River, 10,000 to 11,000 feet above the base of the "group" and several thousand feet below the red-bed sequence. W. A. Bell, of the Geological Survey of Canada, identified ferns, conifers and angiosperms, most of which are common to those identified from the Winthrop Sandstone. Bell (Rice 1947, p. 23) considered the flora to be very late Lower Cretaceous age, equivalent to the Albian of Europe.

Coates (1967, p. 151) assigned 8,000 feet of arkose, with some argillite overlain successively by 1,000 feet of red beds and about 1,000 feet of sandstone and conglomerate to his "Pasayten Group." The age was reported as Albian for the lowest unit on the basis of marine fossils found in the easternmost outcrops of the arkosic rocks. In a later paper Coates (1970, p. 150) interpreted the lower part of the arkose to be part of his "Jackass Mountain Group." Jeletzky (1972, p. 59) reiterates a late Albian age for the lower arkosic unit of "the Pasayten Group of Coates."

There is little doubt that the Winthrop Sandstone is lithologically correlative with a part of the Canadian boundary section, called by Daly, Rice, and Coates the "Pasayten Series or Group." The Methow section of the Winthrop Sandstone cannot, however, be as old as the Albian age claimed for those rocks. Thousands of feet of black shales of the Virginian Ridge Formation underlie the Winthrop in the area mapped. The fossil evidence from the Virginian Ridge Formation, points to its being as young as Cenomanian.

Perhaps the best explanation for the apparent confusion in dating is that the Cretaceous basin in late Albian time was receiving sediment simultaneously from both west and east. Evidence indicates that the black muds and chert and minor volcanic pebble conglomerates that became the Virginian Ridge Formation were pouring into the sedimentary basin from the west-southwest during an early part of the Late Cretaceous. At the same time or possibly beginning a little earlier, the wedge of feldspathic debris, which became the lower member of formation of the "Pasayten Group" in Canada, was being supplied from the east or northeast. Its deposition in Canada may well have begun in late Albian time and continued there through Cenomanian and possibly into Turonian time. The upper part of the lower member in Canada would, therefore, be temporally and lithologically correlative with the Winthrop Sandstone. The correlations are summarized in figure 4.

Midnight Peak Formation

Midnight Peak Formation is the name given by Barksdale (1948, p. 173-4) to the youngest rocks in two major northwest-trending synclines cut by the Twisp and Methow Rivers. The name was taken from Midnight Peak, 15 miles west-northwest of Twisp, Washington. (On more modern maps, the name has been changed to Midnight Mountain.) The type section of the Midnight Peak Formation, resting on Winthrop Sandstone, is exposed in the southwest limb of the syncline lying between the Twisp River and its tributary Canyon Creek (T. 34 N., R. 20 E.).

The formation is composed predominantly of andesitic volcanic debris. A very distinctive, and readily mappable red-bed unit, made up of dark-red to purple shale-siltstone, pink to dark-red sandstone, and pink to gray conglomerate occurs in places at its base, although it is not present at the type locality. The name Ventura Member is given to this unit, where mappable, following the original designation by Russell (1900, p. 4) for outcrops of distinctive red rocks near the then thriving mining town of Ventura on the Methow River, approximately 20 miles northwest of Winthrop. No traces of the town survive.

Ventura Member

Although considerable variation in lithologic character is typical of the Ventura Member throughout its widespread distribution, the type section is here designated as the section exposed and measured in Lucky Jim Bluff, 9 miles northwest of Winthrop on the southwest side of the Methow Valley, in parts of secs. 8, 9, 16, and 17, T. 35 N., R. 20 E. There, the red-bed sequence underlies a prominent glacially

FIGURE 12.—Type section in Ventura Member. Midnight Peak Formation, Methow Valley, 9 miles northwest of Winthrop (secs. 8, 9, 16, and 17, T. 35 N., R. 20 E.).

rounded remnant of the volcanic member and can be followed downward in section to a well-exposed base that grades into the Winthrop Sandstone.

Fine- to coarse-grained sandstone, varying in color from white to deep red, makes up 70 percent of the Ventura Member in the type section. Next in im-

Midnight Peak Formation
Ventura Member
Type Section

Lucky Jim Bluff, parts of secs. 8, 9, 16, and 17, T. 35 N., R. 20 E., Mazama quadrangle (measured with Alden B. Pitard).

Volcanic (upper) Member—andesitic breccia

	Thickness (feet)
Top of section	
Covered. Soft reddish soil	40
Arkose, white, well-sorted	20
Covered, but includes 30-ft thick diorite sill	95
Covered	265
Sandstone, red, fine-grained	125
Sandstone, red	280
Shale, red	56
Conglomerate, containing abundant red chert clasts, with red sandstone matrix	8
Sandstone, red, medium- to fine-grained, with silt beds up to 18 in thick	20
Siltstone, red, with sandstone and grit lenses up to 6 in thick	50
Sandstone, red, medium-grained, in beds 6 in to 2 ft thick, with interbeds of red siltstone	36
Sandstone, red, conglomeratic, massive	8
Siltstone and shale, red, with distinctive blocky fracture	15
Sandstone, red, coarse at base, grading into fine-grained at top, lenticular	38
Porphyry sill, white	24
Sandstone, red, fine-grained, in beds from 1 in to 2 ft thick	19
Siltstone and mudstone, red, with green splotches, beds 6 in to 1 ft thick, nodular weathering	27

Midnight Peak Formation Ventura Member Type Section—Continued

Sandstone, red, and minor conglomerate lenses with red shale interbeds; cliff former	35
Mudstone, red, silty	10
Sandstone, red, fine-grained	3
Shale, red	5
Sandstone, red	10
Conglomerate, no pebbles over 1 in; white chert, vein quartz, jasper	3
Shale, red	2
Sandstone, red, fine-grained, with siltstone interbeds of lenticular character	27
Sandstone and shale, red	20
Sandstone, dark-gray, with conglomerate lenses several ft thick. Shale at top of bed about 2 ft	20
Sandstone and shale, red	4
Conglomerate, pebble, lenticular; channel filling of gray and green andesite, white and reddish chert clasts	8
Shale, with minor sandstone, red	38
Talus cover with occasional outcrops of gray-green sandstone, containing andesite fragments	252
Andesitic breccia, gray-green, bedded; grades down into gray, fine-grained sandstone	215
Sandstone, dark-red, fine-grained	20
Sandstone, dark-gray; grading into conglomerate at base; vein quartz, chert, and volcanic pebbles	75
Sandstone, red, with pebbles	18
Shale, red	14
Sandstone, gray with reddish cast	27
Sandstone, red, fine-grained	3
Sandstone, gray, massive	20
Shale, red	2
Sandstone, gray, with thin red interbeds	40
Arkose, light-gray; over 6-in bed of red siltstone	30
Sandstone, red, silty	.5
Sandstone, gray, arkosic	6
Sandstone, red, silty (base arbitrarily picked as the lowest red bed in type section)	.5
Total thickness	2,034

Winthrop Sandstone—arkose, light gray

portance (12 percent) is the mudstone-siltstone fraction. The darkest red-maroon color is characteristic of the finer grain sediments. Gray to green andesitic breccia makes up 10 percent of the section. Conglomerate is of minor importance in the type section (8 percent), but is spectacular in appearance. The conglomerates are lenticular, poorly to moderately well sorted, with maximum sized clast usually less than 8 inches in diameter. In most of the conglomerates, chert and andesite clasts are the dominant components. The chert is gray, white, light green, and various shades of red in color. The sand matrix and interbeds are angular chert and lithic clasts. The andesite clasts are sometimes vesicular, are dark-gray, green, maroon to red in color, and better rounded than the cherts. Occasional rounded clasts of buff sandstone, light colored arkose, vein quartz, and gray chert fine-pebble conglomerate clasts are seen; granitoid clasts are rare.

The sandstones near the base of the member have appreciable quantities of quartz and feldspar mixed with andesitic volcanic clasts and chert. The cement is largely red iron oxide but calcite and a mica hash of bleached biotite and chlorite occur.

Ventura Member in the Midnight Peak syncline.—The southeasternmost outcrops of red sandstone are found on the northeast limb of the syncline along Little Bridge Creek. Beginning 1½ miles northwest of the mouth of this tributary of the Twisp River, the poorly exposed red beds can be traced for 3 miles until the northeast limb of the syncline is removed by the Gardner Mountain Fault, northwest of sec. 21, T. 34 N., R. 20 E. These are included in the Midnight Peak Formation on plate 1. Red beds occur well above the base of the formation, with some 2,000 feet of andesite breccia and lithic sandstone intervening between the poorly exposed red beds and the first recognizable arkose of the thin Winthrop Sandstone below.

No red beds are found along the southwestern limb of the syncline from the Twisp River to Midnight stock (T. 34 N., R. 19 E.). The Ventura Member was mapped in the offset northwestern continuation of the west limb of the syncline between Midnight Mountain and north Gardner Mountain. There, the red beds, estimated to be 300 feet thick, were deposited directly on black shale and chert pebble conglomerate of the Virginian Ridge Formation. The Winthrop Sandstone, which typically occupies the interval between the Virginian Ridge and the Ventura (or Midnight Peak), pinches out northwestward from the Twisp River outcrops and is absent in this area.

Ventura Member in the Goat Peak syncline.—Exposures of the complete red-bed Ventura Member can be seen in the southwest limb of the Goat Peak syncline from the Boesel Fault to Lost River, a distance of 12½ miles. Several cross faults, between Lost River and Robinson Creek, interrupt the continuity of outcrop for the next 4 miles at which point the underlying Winthrop Sandstone thins to zero. Beyond this point to the northwest, the gray andesitic breccia, lithic sandstone, and shale, 1,500 feet thick, overlie the Virginian Ridge Formation directly and are overlain by 650 feet of red sandstone and shale. The red sandstone and shale are overlain by andesitic breccia. This type of occurrence is described as also occurring on the northeast limb of the Midnight Peak syncline in Little Bridge Creek.

A good section of the red-bed member can be followed on the southeastern slopes of the canyon of Lost River where the latter has eroded through the base of the axial portion of the syncline, which plunges southeast there. A dense forest cover obscures the bedrock on the northeast limb of the syncline between Lost River and the Fawn Peak stock, but spotty outcrops allow the member to be mapped beyond the intrusion southeast of its truncation by the Boesel Fault.

The writer was unable to complete the mapping of the red-bed member beyond Last Chance Point and the mouth of the Robinson Creek, but Staatz and others (1971, p. 28) were able to map the two members in Robinson Creek and on the southwest shoulder of Robinson Mountain. They report that the member there is composed of 60 percent dark red to purple argillite, consisting of small angular grains of quartz, plagioclase, altered volcanic rock, chert, and epidote. Cement is mostly hematite, but chlorite, calcite, and sericite are also common. They also reported no red beds on the northeast limb of the structure on Robinson Mountain.

Volcanic (Upper) Member

The type section of the Midnight Peak Formation's upper volcanic member is here designated as the andesitic sandstones, tuffs, breccias, and flows exposed in the southwest limb of the syncline, lying between the Twisp River and its tributary Canyon Creek (T. 34 N., R. 20 E.). The estimated thickness of the member taken from a section drawn across the syncline 3 miles southeast of Midnight Mountain is 10,400 feet.

Volcanic (upper) Member in the Midnight Peak syncline.—Light- to dark-gray, greenish-black well-bedded andesitic lithic sandstone, tuff, and fine breccia, approximately 500 feet thick, rest directly upon Winthrop Sandstone in the southwest limb of the syncline from the Twisp River northwest to the Midnight stock. The bulk of the formation, however, is composed of purple, gray, red, and green altered andesitic breccia and occasional identifiable flows. The rocks are well indurated and resistant to erosion, forming the prominent peak, Midnight Mountain.

Northwest of Midnight stock, the volcanic member, which there underlies Gardner Mountain, was deposited upon approximately 300 feet of red beds of the Ventura Member. The rock, which makes up a large part of the summit of Gardner Mountain, is a distinctive green andesite, containing large hornblende phenocrysts. The more common varicolored breccias underlie Storey Peak and Milton Mountain.

The northeast limb of the syncline east of Little Bridge Creek is composed of 2,000 feet of volcanic sandstone, tuff, and fine breccia, grading stratigraphically into coarse andesitic breccia. Along Little Bridge Creek, beginning $1\frac{1}{2}$ miles from the mouth of this tributary of the Twisp River, red sandstone and shale approximately 500 feet thick overlie the breccia and are in turn overlain by breccia. Faulting obscures relations as the beds are followed along strike northwest.

Volcanic (upper) Member in the Goat Peak syncline.—The Midnight Peak Formation is also well exposed in a parallel northwest-trending sister structure, the Goat Peak syncline. The thickness of the volcanic upper member preserved there is estimated from a section drawn across the structure in the vicinity of Mazama to be 5,000 feet. It can be separated from the Ventura Member on both limbs of the Goat Peak syncline from the Boesel Fault to Robinson Creek, a distance of 14 miles. Beyond Robinson Creek it was not possible to separate the formation into members.

The basal beds of the Volcanic (upper) Member of the Midnight Peak Formation are for the most part light- to dark-gray and greenish andesitic fine breccias and tuffs, with some well-bedded lithic sandstones grading into the red-bed sequence below. A particularly good place to study this relationship is on the slopes northeast of the mouth of Lost River.

The well-bedded breccias and tuffs consist of angular clasts of gray, green, red, and purple andesite in a weakly metamorphosed matrix of fine-grained andesitic debris. Some homogeneous dark-colored andesites are judged to be flows, but coarse breccia is the dominant mode of occurrence. Jointing is widely spaced, and the rock makes very massive outcrops, particularly on the glacially steepened cliffs called the Goat Wall along the Methow River, between Mazama and Lost River. Epidote occurs in veinlets and as coatings on slickensided joints where the volcanic pile has adjusted to tight folding. Attitudes are difficult if not impossible to obtain in the volcanic member above its base.

The andesitic rocks in some thin sections are completely saussuritized, but in others, andesine feldspar and green hornblende phenocrysts are preserved. Outlines of pyroxene are recognized in some of the rocks, but more often it is altered to chlorite and(or) epidote.

Staatz and others (1971, p. 29) have studied the volcanic member of the Midnight Peak where it outcrops on Robinson Peak and report the rocks to vary from dacite to pyroxene andesite. The tuffs consist of tiny fragments of devitrified glass, quartz, feldspar, and a little argillite. They recognized alteration minerals of calcite, clinozoisite, and zeolite.

Age and Correlation

No fossils have been found in the Midnight Peak Formation. It can only be said to be stratigraphically younger than the leaf-bearing Winthrop Sandstone, which is Late Cretaceous in age. The Midnight Peak Formation is probably no younger than the youngest Coniacian or uppermost Turonian since it appears to have been intruded by dikes associated with the 86-million-year-old Pasayten Peak stock. Daly (1912, p. 484) described as "Member C of the Pasayten Series" a 600-foot-section of red argillaceous sandstones, grits, gray feldspathic sandstone, and gray, red, and green conglomerates, overlying a thick arkose section (Member B) along the Canadian boundary. He mentions no volcanics in this part of the section.

Rice (1947, p. 20) described as distinctive the rather vivid purple color of some of the members of his Division D of the Pasayten Group. This is apparently Daly's C Member. Rice measured 900 feet of purple rocks along the Hope-Princeton Highway in Manning Park, British Columbia. They are described as well-bedded purple, occasionally green tuff or tuffaceous graywacke, purple argillite, or fine-grained tuff, purple and green andesite porphyry, and coarse and fine conglomerates, with many granite pebbles and a green or purple coarse-grained matrix. Division D is succeeded by up to 2,200 feet of soft, light brown to green arkose or graywacke interbedded with many thin beds of fine conglomerate.

Coates, (1970, p. 151) remapped the area of Daly and Rice and proposed the middle unit of his "Pasayten Group" to be 1,000 feet of red beds. He stressed that the red beds record a gradual change in provenance from an easterly granitic source area for an underlying 8,000 feet of arkoses to a westerly source for the red beds, composed mainly of volcanic and sedimentary rocks. Above these red beds, he recognized up to 1,000 feet of pebbly, coarse- to medium-grained carbonaceous arkose and graywacke below truncation by the Chuckuwanten Fault. He restricted the entire Pasayten Group to an Albian age.

Jeletzky (1972, p. 61) considers the red beds and conglomeratic arenite above them to be post-upper Albian. The Ventura Member is roughly correlative with the red beds of Daly (1912), Rice (1947) and Coates (1970) in the Manning Park area, but apparently the thick andesitic pile, which comprises the Methow's Volcanic Member of the Midnight Peak Formation, did not reach Canada. Its stratigraphic position is occupied by the pebbly arkose-graywacke above the red beds in the southern British Columbia section.

Pipestone Canyon Formation

Barksdale (1948, p. 175) gave the name Pipestone Canyon Formation to a section of granitic, chert, and volcanic-clast conglomerate, coarse to fine arkosic sandstone, and thin interbeds of fine siltstone and shale totalling 2,313 feet in thickness. The type area was designated as the Pipestone Canyon, an abandoned glacial channel, approximately 5 miles northeast of Twisp, in the drainage of Beaver Creek (secs. 15, 22, and 27, T. 34 N., R. 22 E.).

Rocks of the Pipestone Canyon lithology are found in only three small fault blocks within the

FIGURE 13.—Upper part of type section in Pipestone Canyon Formation (secs. 15, 22, T. 34 N, R. 22 E.).

Methow-Pasayten graben. One, the bold cliff seen from the highway 2 miles north of Twisp, along the east side of the Methow River, exposes a gently dipping basal granitoid boulder-cobble conglomerate resting on vertical beds of volcanic rocks of the Buck Mountain Formation.

The Pipestone Canyon Formation is present in a third small fault block between the Methow River exposures and those of the type area. The formation in the third block is deeply weathered and poorly exposed.

The basal conglomerate in the type area has a varied thickness as it overlaps an erosion surface of considerable relief. The deepest exposure in the canyon reveals a bed, 145 feet in thickness, consisting of a poorly sorted cobble to boulder conglomerate. Well-rounded rocks of granitoid and gneissic composition, with a maximum clast size of up to 5 feet, are set in a red to purple matrix of coarse quartz-feldspar sand. Granitoid rock fragments dominate the conglomerates for the lower 300 feet of the section. The clasts diminish in size upward through the unit and become increasingly more abundant in chert, andesite, and light-colored quartz-bearing volcanic rock fragments. The sands are arkosic and poorly cemented. The buff siltstones and shale interbeds are laminated in places and give evidence of long periods of low-energy deposition, suggesting periods of temporary lake development. It is in these fine sediments that fossil leaves, cones, and wood are preserved.

Sporadic outcrops over a wide area show the upper two-thirds of the section to be soft sandstone and shale with only a few conglomerate beds. The section is truncated by the Chewack-Pasayten Fault.

Age and Correlation

Ryason (1959) discovered well-preserved fossil plants and described them as *Parataxodium* sp. and *Nymphaeites* sp.

Royse (1965, p. 19) made more extensive collections and reported the following flora:

Metasequoia occidentalis (Newberry) Chaney
Taxodium dubium (Sternberg) Heer
Nymphaeites angulatus (Newberry) Bell
Cercidiphyllum arcticum (Heer) Brown
Dillenites sp. cf. *D. ellipticus* Hollick
Platanus raynoldsi Newberry

Pterospermites sp. cf. P. spectabilis Heer
Vibernum antiquum (Newberry) Hollick

Using LaMotte's (1952) geologic ranges of species, Royse concluded that although the eight species, which constitute the Pipestone assemblage, range from Late Cretaceous well into the Tertiary, the only epoch common to all is the Paleocene.

The paleontologic and stratigraphic sections of the Methow Valley are summarized in figures 14 and 15.

Pipestone Canyon Formation
Type Section

In Pipestone Canyon, secs. 15, 22, and 27, T. 34 N., R. 22 E., Okanogan County (measured with Dan Ryason).

	Thickness (feet)
Top of section	
Sandstone and shale; soft, makes weak outcrop; thickness estimated	1,430
Conglomerate; pebble clasts (mostly under 2 in but some 6 in diameter); chert, flint, and light-colored quartz-feldspar porphyry	100
Grit, coarse, grading into arkosic sandstone	45
Conglomerate; fine pebbles of chert and volcanics in quartz and feldspar matrix	22
Grit, grading into light-gray sandstone	6
Sandstone; laminated, fine-grained	4
Conglomerate, lenticular beds; well-rounded pebbles of chert, flint, white quartz-feldspar porphyry	6-10
Sandstone, buff to white, arkosic, conspicuous cavernous weathering	30
Conglomerate; pebbles (maximum 3 in diameter mostly less than 2 in) of chert, andesite, light-colored volcanics	26
Sandstone, with lenticular beds of laminated siltstone	18
Conglomerate; fine pebble, largely chert and flint	25
Sandstone, fine-grained	10
Conglomerate; poorly sorted, maximum pebbles 6 to 8 in, grading down to sand; red andesite, gray chert, flint, quartzite, some rotten granitic pebbles	35
Conglomerate; fine pebbles (maximum 3 in diameter, mostly less than 2 in) of chert and flint most commonly but containing light-colored volcanics—andesite and rhyolite	45
Sandstone, arkosic; thin-bedded	20

Pipestone Canyon Formation Type Section—Continued

Sandstone and siltstone; laminated, brown weathering	35
Sandstone, arkosic	8
Conglomerate and sandstone; well-rounded, light-colored granitic clasts (usually under 6 in diameter), some sandstone and a few chert pebbles. Conglomerate channels the siltstone below	40
Siltstone; laminated, lower ft is fissile, gray in color, (laminations from fraction of mm to 1 cm), and grades upward into brown shale that weathers white	8
Sandstone; very poorly sorted, arkosic, coarse-grained, with conglomerate lenses up to 10 ft thick of granitic derivation	140
Conglomerate of granitic boulders less than 1 ft in diameter, which grades into coarse light-colored sandstone	5
Shale, dark-gray, platy; weathers white	9
Basal conglomerate containing granitic boulders (maximum 4 to 5 ft in diameter), well-rounded, light-colored granitic and granitoid gneiss in a matrix of gruss, red to purple in color. Deposited on irregular surface of dioritic gneiss and other granitoid rocks of Okanogan complex	145
Total thickness	2,313

GLACIATION

Barksdale (1941, p. 721) first called attention to the fact that the Methow Valley had been subjected to continental glaciation when ice moved south out of Canada up the valleys of the north-flowing branches of the Pasayten River and across divides into both Methow and Skagit River tributaries in the vicinity of Harts Pass. Excellently preserved striations were found at an elevation of 7,290 feet on the Cascade crest due north of Harts Pass.

Many granitic erratics from the Pasayten Peak stock-dike were found resting on the Cretaceous sedimentary rocks in the meadows south and east of Harts Pass and on the divide between the Middle Fork of the Pasayten River and Robinson Creek. Ice overrode Goat Peak (7,019 feet) just east of Mazama, Lookout Mountain (5,522 feet) five miles southwest of Twisp, and Leecher Mountain (5,012 feet) just off the present map due east of Carlton. Methow Valley-derived erratics are found at elevations of 4,500 to 4,600 feet on Goat Mountain west of the mouth of the Methow where it joins the Columbia River. The above elevations are probably close to the maximum height of Methow ice during a stage of glaciation when the terminus of the coalesced Okanogan and Methow lobes was south of the present junction of the rivers. Ample evidence that the Okanogan lobe lasted longer than the Methow

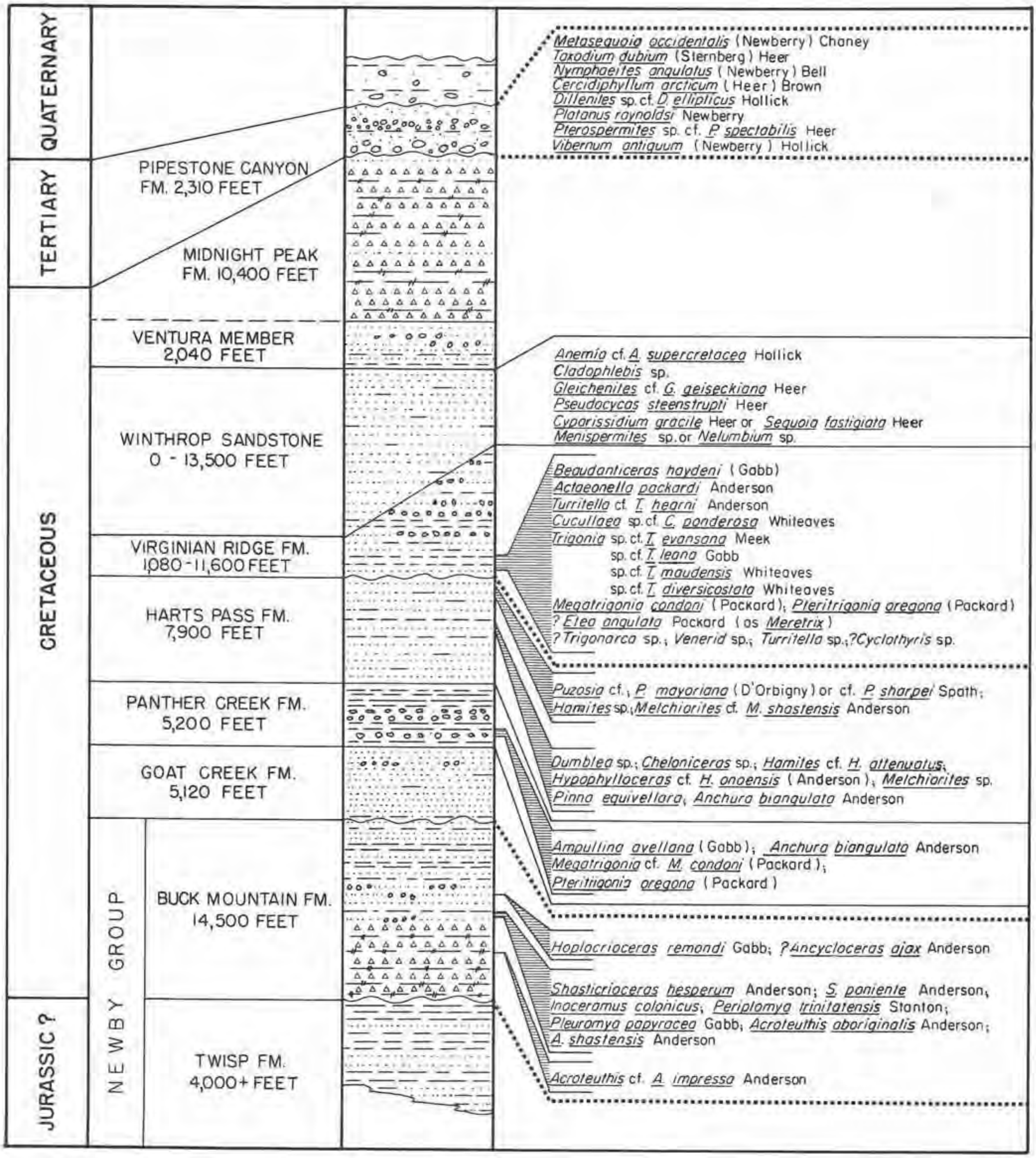

FIGURE 14.—Paleontologic section, Methow Valley.

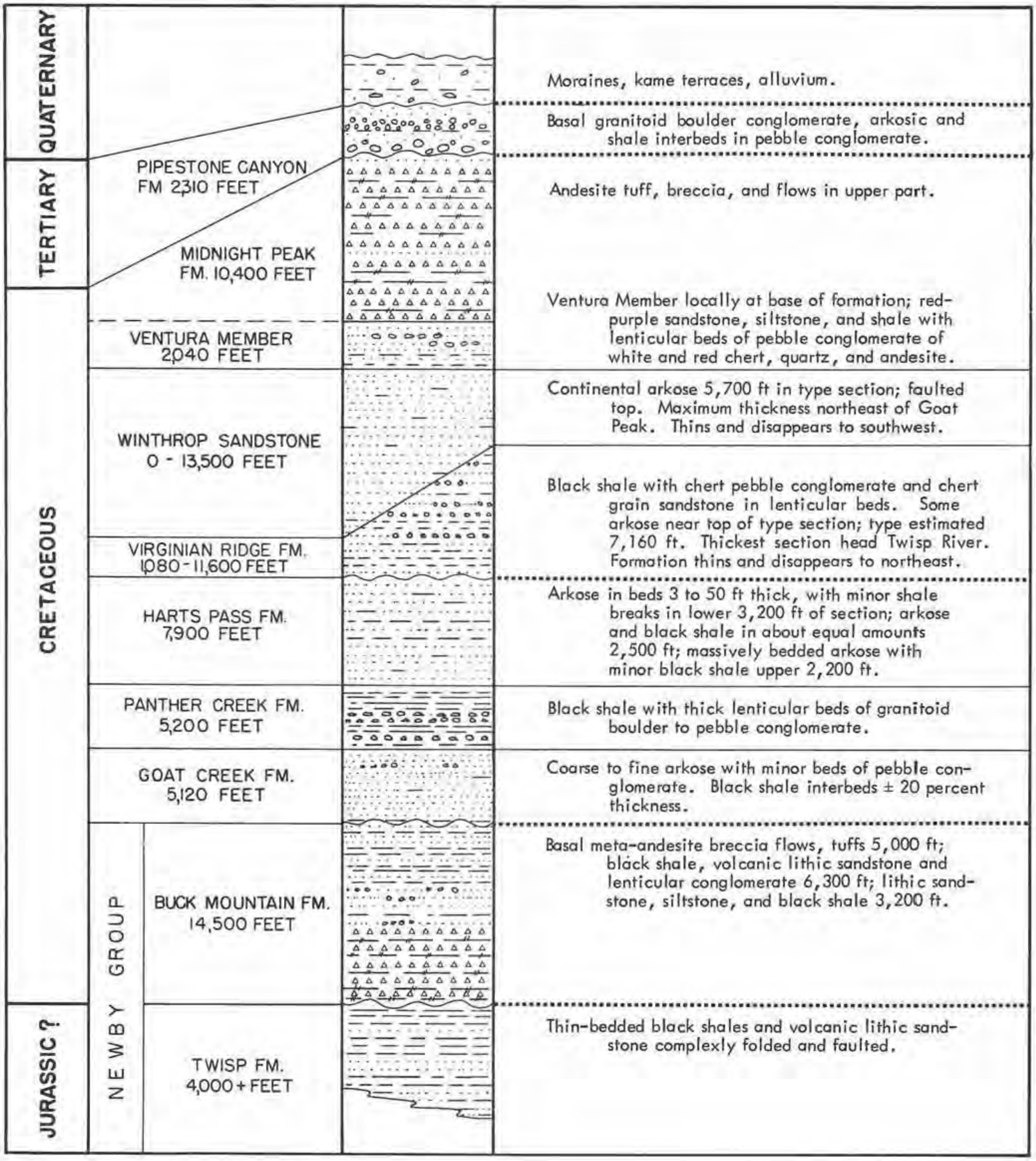

FIGURE 15.—Stratigraphic section, Methow Valley.

lobe is provided by the numerous eastern-derived basaltic "haystack" erratics found on the east side of the Methow River, near its mouth.

Barksdale (1941 p. 732) proposed that a valley glacier stage in the Methow followed the continental ice maximum, and pointed out at several places what were considered at the time to be recessional moraines at the mouth of Libby Creek at Carlton, at the mouth of Benson Creek, and at a large kettle complex in the Twin Lakes area near Winthrop. Ice from the Okanogan lobe spilled into the Methow drainage via Benson Creek at some time after the Methow maximum, building a moraine there and contributing much granitic debris from the east.

Waitt (1972) has restudied the geomorphology and glacial geology of the Methow drainage basin. His conclusions in general are that, although cirques, aretes, and U-shaped hanging troughs dominate the northern Methow landscape, surface drift, characteristically of northern provenance, mantles high ridge crests as well as valley floors suggesting deposition from an ice sheet rather than a valley glacier. Furthermore, ice-sheet glaciation post-dated the most recent alpine advances because alpine drift and depositional landforms characteristic of alpine glaciation are absent in the Methow region, apparently having been eroded by the ice sheet. The deposits identified by Barksdale as moraines are shown to be kame-kettle complexes built by the wastage of dead ice in a very late stage of deglaciation.

The upper limit of evidence for a continental glacial maximum in the northern Methow region is at about 8,000 feet. From that elevation, the ice surface sloped to an elevation of about 3,000 feet in the Columbia River valley. Thus the Cordilleran Ice Sheet covered the northern areas almost totally; its surface broken only by a few scattered peaks (nunataks) rising above the ice.

Waitt was able to show that the continental ice, which spilled south from Canada across the divides separating the Pasayten and Methow drainages, also continued down the Cascade crest and contributed ice into the upper Twisp River drainage and into the headwaters of the Stehekin River-Lake Chelan drainage to augment that basin's locally derived ice. There is no evidence, however, that the Methow Mountains (divide between Lake Chelan and lower Methow River) were crossed by continental ice south of lat. 48°15' N.

There seems to have been no rebirth of alpine glaciers after the Cordilleran Ice Sheet disappeared, largely by downwasting and regional stagnation.

Barksdale (1941, p. 737) came to the conclusion that, based largely on the thinness of the weathering rind of the high elevation erratics, the preservation of striated bedrock surfaces and the general freshness of glacial deposits, the widespread ice sheet at its maximum was late Wisconsin in age.

Waitt (1972, p. 33) concludes that the freshness of the Methow drift indicates that the glaciation correlates broadly with the Fraser Glaciation of the Puget Lowland and British Columbia (late Wisconsin). He also concludes that the ice sheet probably arrived in the Methow region by 16,000 years B.P. and had largely diminished by 13,500 years B.P. There seems to be little or no evidence of pre-late Wisconsin glacial deposits.

STRUCTURE

The Methow-Pasayten Graben

Bounding Structures

The dominant structural feature of the area studied is the Methow-Pasayten graben (Barksdale 1958; Mallory and Barksdale 1963) in which the folded and faulted Jurassic-Cretaceous-Tertiary sedimentary and volcanic rocks are preserved in a structural low between metamorphic and igneous highs to the northeast and southwest. The graben is $15\frac{1}{2}$ miles wide at its narrowest part, near Twisp in Washington. It widens to more than 24 miles in the northern part of the map area, and reconnaissance mapping shows that it narrows again to 16 miles at the Canadian boundary (lat. 49°00' N.). The structure is at least 52 miles long in Washington, and it extends northwestward for an additional 120 miles into British Columbia.

Bowen (1914) was the first to point out the graben nature of the structure that contains folded Cretaceous rocks in the Fraser River canyon of British Columbia. Subsequent workers, Cairnes (1924), Rice (1947), Duffell and McTaggart (1952) mapped the folded and faulted Cretaceous extending northwest from the boundary for 120 miles to approximately lat. 50°32.5' N., where the boundary faults converge in the Fraser River canyon. Thus this narrow structural feature maintains its integrity for over 170 miles. Duffell and McTaggart (1952) point out that northwest from the point of convergence in the Fraser River canyon the graben ceases to exist as both the western and eastern faults bounding the folded Cretaceous rocks are downthrown to the east.

The graben's northeastern boundary in Washington is the Chewack-Pasayten Fault, which was examined by Barksdale (1958, p. 1531), from the point where it crosses the Canadian boundary at the Pasayten River, S. 20° E., for 47 miles where it becomes unrecognizable in the weakly gneissic rocks of the Okanogan complex, east of 120° west longitude, about eight miles southeast of Winthrop. Six miles northwest of the northern boundary of the map, the Chewack-Pasayten Fault trace swings in strike from N. 30° W. to N. 50° W. The fault separates various kinds of granitic gneissic rocks on the northeast from strongly folded and faulted sedimentary and volcanic rocks on the southwest. At no place along its trace can any units be matched across the Chewack-Pasayten Fault.

The glacial and post-glacial alluvium in the valley of Eightmile Creek and the Chewack River hides the fault outcrop, hence no Holocene displacement was recognized. The dip of the fault in the map area cannot be directly determined, but the fault's straight trace suggests that the attitude is near vertical or dips steeply to the southwest.

On the spur between Ramsey Creek and the Chewack River (sec. 11, T. 35 N., R. 21 E.) the fault trace strikes N. 30° W. and shows up clearly as a shear zone approximately 300 feet wide that is mostly in the granitoid gneiss of the eastern block. The zone has weathered to an ocherous brown color and contains rich, red hematite streaks. The schistosity of the granitoid gneiss is near vertical and strikes north-south. The gneiss is shattered into small joint blocks and weathers to a reddish-orange color for considerable distance from the fault. The jointing is so close-spaced that it is difficult to collect a standard-sized hand specimen. The volcanic breccia, sandstone, and shale, adjacent to the fault at that point, strike N. 10° W. and dip to the east 75°. Shearing effects in the sedimentary section there are not uniformly evident, but elsewhere along the contact the volcanic rocks are shattered, and are altered to a rusty brown for several hundred yards away from the fault.

The gneissic banding in the rocks northeast of the fault varies in strike from N. 20° W. to N. 50° W. and the dip of the foliation varies from 30° to 50° NE. The foliation can be mapped for approximately a mile northeast of the fault where the rock becomes almost directionless. Thin sections of the gneiss near the fault reveal its cataclastic origin. The quartz and much of the feldspar were granulated and recrystallized as were the biotite and hornblende. Large feldspar porphyroclasts were rotated and shaped into augen; considerable pressure twinning was developed. Some late movement occurred in which mechanically cracked feldspars were not healed. The cracks have been invaded by iron oxide stain, which possibly accounts for the characteristic orange to light reddish-brown color of the gneissic rocks close to the fault.

FIGURE 16.—Chewack-Pasayten fault scarp of Summit Creek gneissic quartz diorite. Pipestone Canyon Formation weakly cemented sandstone makes gentle topography in foreground (sec. 15, T. 34 N., R. 22 E.).

An imposing fault scarp rises northeast of the fault at the eastern border of the map area (T. 34 N., R. 22 E.). The cataclastic gneiss just described rises above the easily eroded Pipestone Canyon Formation of Paleocene age, which dips gently north into the fault zone. Glacial cover and soil hide the contact but the two rock types crop out within a few hundred feet of each other. These relations are evidence only that there has been a relative down-dropping of the Paleocene block with respect to the Okanogan complex rocks. There is no apparent evidence for strike-slip movement for the latest activity on the fault, which is at least as young as post-Paleocene.

Lawrence (1968) studied the Chewack-Pasayten Fault in the Hidden Lakes area near the Canadian boundary, north of the present map area. He (1971, p. 147) suggested on the basis of field and petrofabric studies that:

> . . . primary right lateral strike-slip motion of Middle and Late Cretaceous age, probably followed by reverse motion.

It is not clear what "reverse" means in this statement because the only reference to attitude is that the fault is vertical.

Coates (1970, p. 153) studied the Pasayten Fault immediately north of the Canadian boundary and pointed out that there must have been a large amount of dip-slip movement in order to accommodate the very large thickness of Lower Cretaceous strata west of the fault. He noted that strike-slip movement is also indicated because of the lack of correspondence between the sedimentary rocks west of the fault area and possible source areas to the east.

In summary, there is great vertical displacement along the Chewack-Pasayten Fault. The block to the southwest has been dropped relative to the northeast block making possible the preservation of more than sixty thousand feet of stratigraphic section of Jurassic(?), Cretaceous, and Tertiary folded and faulted sedimentary rocks. Evidence that some of the movement was strike-slip in nature could not be documented.

The graben boundary on the southwest is formed by two faults: the Foggy Dew Fault and the Twisp River Fault. The older, the Foggy Dew Fault, can be mapped as the graben boundary in the 17-mile interval between the elbow bend on the Twisp River and the point to the south where the fault disappears into the young Cooper Mountain batholith. The fault strikes N. 32° W. and its rather straight overall trace indicates a steep dip. There is evidence in the fault's outcrop pattern in the tributaries of Gold Creek that the dip is steeply northeast. Mylonites derived from hornblendites, granitic gneisses, and Newby Group volcanic rocks can be collected in a zone as much as one-quarter of a mile wide, where the fault traverses the upper reaches of the North Fork of Gold Creek, Foggy Dew Creek, and the South Fork of Libby Creek.

Chief evidence that the major displacement along the Foggy Dew Fault has been dip-slip, down to the northeast, is that along the fault mesozonal metamorphic rocks of the Chelan batholithic complex have been brought into contact with a thick section of relatively unmetamorphosed Jurassic(?) and Cretaceous volcanic and sedimentary rocks. These relations are similar to those described in the Ross Lake Fault zone by Misch (1966b, p. 133), and the Foggy Dew Fault may well be a continuation of this major Cascade structure. No evidence of strike-slip movement has been recognized along the Foggy Dew Fault.

The age of the latest movement on this segment of the southwest boundary fault can only be approximated as Upper Cretaceous or lower Tertiary. The fault cuts Midnight Peak volcanics of probable Turonian age and is intruded by the Eocene-Oligocene(?) Cooper Mountain batholith.

The younger boundary fault, the Twisp River Fault, has developed a shear zone approximately one-half mile wide, striking N. 50° W., beginning at the southeastern border of the Black Peak intrusion and extending southeastward for at least 21 miles. The shear zone has been excavated to form the canyon of the upper Twisp River for 12 miles above the point where that southeast-flowing stream swings to the northeast in a conspicuous elbow bend. The fault zone —with diminishing physical expression—continues on to the southeast for about nine miles southeast of the bend, beyond which it was not recognized.

The shear zone in the upper Twisp Valley is largely covered by glacial terrace material and modern stream alluvium. Occasional outcrops reveal the mylonitized rocks of the Chelan crystalline block to the southwest of the fault and of the andesitic sediments and breccias of the Newby Group and the black shales and chert pebble conglomerates of the Virginian Ridge Formation to the northeast of the shear zone.

Mylonite cutting a biotite-quartz-feldspar crystalline rock, probably belonging to the Chelan batholithic complex, crops out in roadcuts north of War Creek and southeast of the Twisp River (sec. 12, T. 33 N., R. 19 E.). The schistosity of the mylonite strikes approximately N. 45° W. and is vertical. Lineation in the planes of shear indicate the last movement was horizontal.

Across the Twisp River to the northeast, approximately one-half of a mile from the mylonite mentioned above, outcrops of Virginian Ridge chert pebble conglomerate show megascopic results of granulation and pebble elongation. Thin sections show a flaser structure of very fine-grained quartz recrystallized from the tectonically reduced chert of former pebbles. At several other places in the Virginian Ridge, beds of apparently unbrecciated conglomerate can be traced into a rock resembling a schistose quartzite as the fault zone is approached.

Farther northwest, volcanic breccias and lithic sandstones of the Newby Group near the fault zone are sheared to gray and greenish schistose rocks, which under the microscope show all gradations from unstressed volcanic fragments to very fine-grained chlorite, epidote, and plagioclase schist. Considerable recrystallization has taken place in these rocks with the growth of a nearly colorless unidentified micaceous mineral.

Movement along the Twisp River Fault must have been complex. Overall, the graben block is down to the northeast, but there must have been some late left-lateral strike-slip movement. The position of the triangular block of Virginian Ridge Formation, south of the big elbow turn of the Twisp River, and the block of Midnight Peak volcanics and red beds, down dropped south of a cross-fault, indicates the left-lateral nature of part of the movement.

All that can be said as to the age of the latest movement on the Twisp River Fault is that it is younger than the Foggy Dew Fault, which it truncates, and older than the Black Peak batholith, which truncates it.

Structures Within the Graben

Folding.—Folding within the graben probably occurred in four separate episodes. The fourth or most recent episode produced two parallel northwest-trending, asymmetrical major folds: the Goat Peak syncline and the Midnight Peak syncline. These folds involve the conformable Virginian Ridge, Winthrop, and Midnight Peak Formations, which rest unconformably on all the older sedimentary and volcanic rocks within the graben.

The Goat Peak syncline can be mapped for a distance of 25 miles N. 40° W. from its truncation by the Boesel Fault (T. 35 N., R. 20 E.) to the Cascade crest. The northeast limb of the fold is the steeper, and the beds, locally overturned, dip steeply to the northeast. The beds in the southwest limb have dips as low as 10° northeast in the southernmost exposures. They steepen to 75° in the vicinity of Early Winters Creek (T. 35 N., R. 19 E.), and farther northwest along strike, flatten to a gentle 30° northeast near the Cascade crest.

The Midnight Peak syncline lies to the southwest en echelon to the Goat Peak structure. Both limbs are preserved in the south half of the syncline. The structure is truncated on the southeast by a cross fault. There is sufficient convergence of the limbs to indicate a plunge to the northwest. The Midnight Peak syncline is more nearly symmetrical than the Goat Peak; dips on both limbs average 65°. The northeast limb and axial part of the syncline is faulted beneath the southwest limb of the Goat Peak syncline along the Gardner Mountain Fault. A small segment of what may be part of an intervening anticline can be seen immediately northwest of the juncture of the Gardner Mountain and Boesel Faults (T. 34 N., R. 20 E.).

An anticline lies northeast of the southern part of the Midnight Peak syncline, its axial trace in the Virginian Ridge Formation. It plunges west-northwest and can be mapped for 10 miles along its sinuous trend between the Twisp River and the Boesel Fault. The anticline's northeastern limb is overridden by the Moccasin Lake Fault. The core of the anticline is composed of folded Newby Group rocks, showing marked angular discordance with the overlying Virginian Ridge Formation. The dips on both limbs of the anticline vary from 60° to 75°.

There is a marked discontinuity in direction of folding of rocks of the same age on either side of the Boesel Fault. An asymmetrical south-plunging anticline, whose axis trends N. 25° E., is well exposed 4 miles west of Winthrop, south of the Methow River. The anticline involves the type sections of both the Winthrop Sandstone and the underlying Virginian Ridge Formation. The west limb of the fold dips 70° and the east limb 35° to 45°. The east limb cannot be followed north of the Methow River, but the west limb is mappable from its truncation by the Moccasin Fault for 8 miles northeastward to where it curves into the Boesel Fault.

Folded structures formed during the third (next to the most recent) episode of folding, and almost surely involved in the most recent episode (fourth) of folding, can best be seen in the fault block lying west of the Button Creek stock and the Boesel and Ortell Creek Faults, northeast of the Goat Peak syncline. There the Sweetgrass Butte syncline and its companion anticline to the west trend N. 25° W. and are probably representative of third-episode folding. The rocks involved are the middle Cretaceous Goat Creek, Panther Creek, and Harts Pass Formations. The axial trends of these folds make an angle of 20° with the sub-Virginian Ridge Formation unconformity, beneath which they disappear. The dips on the limbs of the Sweetgrass fold range from 50° to 70°, the steeper limbs being to the west. Locally the west limb is overturned.

Folds of this same (third) episode of folding are also evident in the northwestern part of the map area where folded and faulted beds of the Harts Pass and Panther Creek Formations emerge from beneath the sub-Virginian Ridge Formation unconformity, forming a narrow band more than 17 miles long. In these beds an anticline was mapped in the canyons of Early Winters Creek and the West Fork of the Methow River, and in the ridge separating them (T. 36 N., R. 18 E.). The beds trend N. 30° to 40° W.—not markedly different from trends in the Goat Peak syncline—and dip typically in excess of 60°. The core of the fold is mainly incompetent black shale of the Panther Creek Formation; the limbs are composed of thick, competent beds of arkose of the Harts Pass Formation. Locally the competent arkose beds have been isoclinally compressed to such an extent that they rise up and pinch out the shale core of the anticline. This is best shown in Trout Creek, a tributary of the West Fork of the Methow River (SW$\frac{1}{4}$SW$\frac{1}{4}$ T. 37 N., R. 18 E.).

The strongest evidence for more than one period of folding at this locality is the outcrop width of the Harts Pass Formation, which widens fourfold between its faulted terminus, east of Silver Star Mountain, and the northern limit of mapping, northwest of Slate Peak. Erosion evidently removed a part of the folded section there before deposition of the Virginian Ridge Formation. The western limb has been broken by faulting (not shown on geologic map) and also disappears beneath the sub-Virginian unconformity in the eastern limb of the Grasshopper syncline. The unconformity may account for the disparity in apparent thickness of the Harts Pass Formation on opposite sides of the Panther Creek Formation.

Folding during the second episode can best be demonstrated on the ridges leading south and west of Buck Mountain (T. 36 N., R. 21 E.). There a thick overturned homocline of Buck Mountain Formation, striking N. 25° W. and dipping 90° to 75° east, is unconformably overlain by west-dipping Goat Creek Formation of strongly contrasting lithology.

The unconformity can also be seen north of the Ortell Creek Fault where it is vertical, extending northwest and separating Buck Mountain Formation andesitic tuff, breccias, and flows from Goat Creek Formation on the west. Folding in the volcanic rocks cannot be convincingly demonstrated beneath the Goat Creek there, but considerable amounts of Buck Mountain Formation shales, volcanic lithic sandstone, and conglomerates were removed by erosion before the deposition of the Goat Creek.

Second-episode folding involving Buck Mountain Formation, south and east of Winthrop, is difficult to define owing to the erratic distribution of outcrops. The best exposed fold is immediately southeast of Winthrop, where a fairly open syncline (T. 34 N, R. 22 E.) can be traced southeast for four miles, until it is cut off by a cross fault. The steepest opposing dips are 70°. A light-colored, tuffaceous marker bed can be recognized in both limbs. The trend is approximately N. 25° W. in the southern two-thirds of the fold, swinging to nearly west south of Winthrop where the Buck Mountain Formation can be seen to rest with marked angular unconformity on the underlying Twisp Formation.

An anticline involving Buck Mountain Formation bedded andesitic breccia and shale is poorly exposed beneath the folded sub-Virginian Ridge unconformity (T. 34 N., R. 21 E.); the axis trends N. 60° E. and the limbs dip at angles of 60°.

The first or earliest period of folding was of a distinctly different type from the succeeding three. Individual folds in the Twisp Formation can be followed for even less distance than those of the later formations. Part of the difficulty is due to the cover and deeper soil formation, but much of it stems from the incompetent behavior of the weak shales. The fold trends box the compass, steep dips are the rule, and plunges up to 90° have been found. The scale of the individual folds is measured in tens to hundreds of feet rather than in miles. Some of the best examples of the folding in the weak Twisp Formation can be seen in the roadcuts between Winthrop and Twisp, on the glaciated hill tops northwest of Winthrop, on Patterson Mountain west of Winthrop, or on Stud Horse Hill directly east of the town. An exception to the small-scale failure can be seen in T. 35 N., R. 21 E. Several porphyry sills in the weak, black shales of the Twisp have acted as stiffeners, and amplitudes of the plunging folds are greater than amplitudes of most folds in the formation.

The forces which repeatedly folded the thick sedimentary section preserved in the graben can only be generally characterized as compression in a northeast-southwest direction. The origin of the compression is not understood, but is suspected to be related to movement between the continental Okanogan block and the Chelan-"Skagit" block of debatable ancestry.

Faulting.—For descriptive purposes, the faults within the graben are discussed in three groups, based largely on inferred age of major movement, which, in turn, is based on the ages of the units cut by the faults, as well as locally, on the ages of units not cut by the faults. No comprehensive detailed structural analysis is attempted here because the main purpose of this paper is description accompanied by broad interpretation.

The first and probably oldest group of faults involves rocks of the Newby Group and older: the Smith Canyon Fault and related shear zones and the McClure thrust. Numerous other faults cut rocks of the Newby Group and have been recognized and mapped over short distances, but appear to be of less significance and are not discussed in the text.

A fault that affects only rocks of the Buck Mountain Formation and Goat Creek-Panther Creek-Harts Pass Formations is the Ortell Creek Fault.

The third group of faults includes those which involves all of the units of the Cretaceous folded section. These are the Moccasin Lake Fault, the Gardner Mountain Fault, the Boesel Fault, and many northeast-southwest cross faults.

The Smith Canyon Fault is a major north-south, nearly vertical shear zone, which can be traced from a mile north of the Twisp River south for 15 miles, where it is cut off by the Cooper Mountain batholith. The broad flat valley of Smith Canyon formed along the shear zone as did the upper part of Alder Creek (T. 33 N., R. 22 E.). The apparent movement on the fault was both vertical and left lateral; the Carlton block, defined as rocks east of the fault, composed of Leecher Metamorphics and Methow Gneiss farther east, moved up and to the north with respect to the western block composed of rocks of the Newby Group. In the latest movement, the Carlton block was thrust northward over the Buck Mountain Formation and young intrusions along the McClure thrust—movement that was left-lateral strike-slip along the Smith Canyon Fault.

The best exposure of the shear zone of the Smith Canyon Fault is in a roadcut on the south side of Libby Creek (sec. 23, T. 32 N., R. 21 E.), where the latter intersects Smith Canyon. Gray-green, purple ultramylonites and phyllonites lie within the zones of maximum shear and "horses" of recognizable volcanic sedimentary rocks interspersed in the zone, which there is 0.3 miles wide, and is mainly in rocks of the western block. Adjacent on the east are gneisses of the Leecher Metamorphics intruded by the Carlton stocks of quartz diorite. The smaller stock, exposed along the road, is semi-schistose due to shearing for a distance of 0.2 miles east of the easternmost exposure of the sheared volcanics.

Several near vertical, N. 10° to 20° E. shear zones, branching en echelon from the Smith Canyon Fault, cut rocks of the undifferentiated Newby Group, mylonitizing them in zones a few tens of feet to hundreds of feet in width. The rocks of the shear zones have a phyllitic appearance in hand specimen, but under the microscope are seen to be cataclastically reduced rocks, phyllonites. Commonly, neomineralization is shown by crystalloblasts of feldspar, or clots of epidote—group minerals that disturb the planes of shear. Although only three such zones of shear are shown on the map, there are undoubtedly many more that can be mapped at a larger scale.

The McClure thrust (T. 33 N., R. 22 E.) forms the northern boundary of the Leecher Metamorphics, north of which lie rocks of the Buck Mountain Formation, young intrusive rocks of the Frazer Creek complex, and the Alder Creek stock. The fault has an east-west strike west of the Methow River and swings to the northeast where it crosses the river. The paragneisses and schists of the Leecher make an impressive cliff east of the river, at the base of which are scattered outcrops of unmetamorphosed quartz diorite, a phase of the Frazer Creek complex. There is no evidence recognized of an intrusive relationship between them. Limited outcrops of east-west striking, gently southward-dipping shear zones occur both in the gneiss at the base of the cliff and in the unmetamorphosed quartz diorite below and north of the cliff. None of these shears can be traced far, but they lend support to a thrust hypothesis.

Outcrops in the Methow River flood plain are rare, but in sec. 35, T. 33 N., R. 22 E. (where the river channel impinges on State Highway 153) a red-brown massive appearing rock crops out at low water. This rock, in thin section is an almost completely silicified, ghostly textured tuff or volcanic sediment, containing a few embayed quartz crystals or fragments displaced on widely-spaced microshears. This rock definitely does not belong to the Leecher Metamorphics, but could have a Newby Group affinity and be a part of the overridden lower plate of the thrust.

Thick glacial-wastage deposits cover much of the barren south and east slopes of McClure Mountain. However, sufficient outcrops exist to permit sampling the steeply dipping, highly sheared gneiss and phyllonite of the Leecher Metamorphics, south of the McClure Fault. The rocks north of the fault are better exposed volcanic sediments of the Buck Mountain Formation. The decision as to final placement of the fault on the map was made only after careful thin-section study of the microscopically contrasting but megascopically ambiguous rock types of the two groups. This is a most unsatisfactory way to map structure but it was used as a method of last resort here.

The second, and probably next younger, group of faults is represented by a single fault, the Ortell Creek Fault (T. 37 N., R. 20 E.). It is a near vertical, left lateral shear, separating the near vertical Isabella Ridge section of Buck Mountain Formation volcanics and younger arkoses from moderately folded arkoses and black shales in the Sweetgrass syncline and accompanying anticline. A particularly confusing coincidence made the early mapping of this fault relationship understandably difficult. The distinctive granite boulder conglomerates in the black shale section of the Panther Creek Formation were first discovered on the west slopes of Sweetgrass Butte, striking N. 25° W. and dipping 60° E. They were traced north along their strike down into Goat Creek. A conglomerate thought to be the continuation of the Sweetgrass beds was encountered northwest of Goat Creek. It was soon discovered that it was a member of a west-facing section of conglomerate in black shale, and was correlative with conglomerate in the east limb of the Sweetgrass Butte syncline. This suggests a left lateral movement on the Ortell Creek Fault of at least two miles. The fault disappears westward beneath the sub-Virginian Ridge unconformity and on the east is intruded by the Button Creek stock.

The next and probably youngest group of faults include the Moccasin Lake, Gardner Mountain, and Boesel Faults, as well as the many northeast-trending cross faults.

The Moccasin Lake Fault (T. 34 N., R. 21 E.) forms the boundary between complexly folded, northeast-trending rocks and the north and northwest-trending rocks of the Midnight Peak syncline on the south. The fault strikes N. 60° W. at its termination against the Boesel Fault, extends southwestward curving to a trend of N. 25° W., where it evidently merges with the Smith Canyon shear zone in a relationship not understood at this time. The northeastern block appears to be structurally high with respect to the southwestern block because of the older rocks in it. The fault is therefore inferred to be a northeastward-dipping thrust or moderate-angle reverse fault. No outcrops of the fault have been found.

The Gardner Mountain Fault, well exposed just northeast of Gardner Mountain, strikes N. 45° W. and dips 75° NE. For 10 miles it marks the boundary between the Goat Peak syncline and the Midnight Peak syncline. Much of the northeast limb of the Midnight Peak syncline, and the anticline that might well be expected to intervene, are faulted out. The northeast block appears to be structurally high with respect to the southwest block. Compressional shortening could best be explained by a low to moderate angle thrust, but the Gardner Mountain Fault is a nearly vertical fault that hinges out 4 miles southeast of the junction with the Boesel Fault (T. 34 N., R. 20 E.). An attractive hypothesis is that the northeast block moved southwest on a thrust, now buried, that may be the northwestern offset continuation of the Moccasin Lake Fault. The Boesel Fault acted as a tear, perhaps during thrusting, but sustained additional displacement of the same sense subsequent to thrusting, thereby offsetting the thrust. Alternatively, differential movement along the Boesel Fault might have occurred during thrusting. Later dip-slip movement along the Gardner Fault dropped the northeast block to its present position, which concealed the earlier thrust.

The Boesel Fault (T. 20, 21 N., R. 34, 36 E.) strikes N. 20° E. and is near vertical, judging from its rather straight course across rugged topography. The fault can be mapped for 15 miles from its northeast termination at the Chewack-Pasayten border fault to its junction with the Gardner Mountain Fault, although no exposure of the fault plane or zone was found. Rocks east of the fault have moved up with respect to rocks on the west. There was some left-lateral strike-slip motion on the Boesel as the rocks on the west moved farther to the southwest than did rocks on the east.

Cross faults of minor displacement, which are near vertical and strike N. 50° E., are particularly well developed on the southwest limb of the Midnight Peak syncline. The thinned section of Winthrop Sandstone makes an excellent marker in mapping the extent of the cross faults on the steep northeast wall of the upper Twisp Valley. The most northwesterly fault shows the greatest displacement. It brought up a very thick section of Virginian Ridge Formation, which rests unconformably on volcanic and sedimentary rocks of the Newby Group.

Similar steep cross faults of minor vertical displacement cut the Goat Peak syncline, both north and south of Lost River. These faults strike northeast, and in some instances have been filled by dikes emanating from the Tertiary Golden Horn and(or) Monument Peak intrusions. The cross faults here are probably related to forceful intrusion of these late granitic bodies.

It will be noted that many faults shown on the map are not discussed, and there are many more which could be on the map. Most of these are interpretations of the disruption of local stratigraphic patterns and warrant further study, but the reader will be spared (with one exception) the tedious recitation of details about them, which add little to the broader story.

The exception is the thrusting at low angle of younger-over-older rocks in that part of the Goat Peak syncline that lies north of Lost River. Note that Winthrop Sandstone is cut out and Midnight Peak Formation rests directly on the Virginian Ridge Formation. This relationship can be mapped for over 2 miles, although the thrust is broken by later cross faults. It seems likely that the relatively massive volcanics could not

FIGURE 17.—Thrust fault, Midnight Peak Formation, Volcanic (upper) Member over older Ventura Member red beds. Face of spur between Lost River and Robinson Creek, Methow Valley.

adjust to folding by slippage along bedding planes, but did adjust along shears, some of which are restricted to the volcanics themselves and some of which cut down through the section to become low-angle thrusts. A well-exposed example of such faulting can also be seen on the face of Scramble Point, a few hundred feet above the road between Lost River and Robinson Creek.

GEOLOGIC HISTORY

The oldest geologic event recorded in the map area was the deposition of mud, sand, limy sediment, and basic volcanics probably in a marine environment. At some later time they were intruded by quartz dioritic to granodioritic rocks. All were subsequently metamorphosed to form the schists and gneisses and minor marble that constitute the medium-grade Chelan batholithic complex rocks, the Leecher paraschists, gneiss and marble, and the Methow Gneiss. The similarity between rocks of the Chelan complex and those of the "Skagit Metamorphic Suite" of Misch (1966b) has been discussed by Adams (1961) and Libby (1964). Staatz (1972) calls these rocks the "Custer Gneiss." Misch suggested that the parent sedimentary rock of the "Skagit Suite" might be Paleozoic in age. Although the age of the metamorphism is not known, it is presumed to be older than the Triassic-Jurassic-Early Cretaceous deposition and is likely to be Late Permian or early Mesozoic or older.

The oldest nonmetamorphic rocks in the graben are typical eugeosynclinal sediments, of the Newby Group but without chert, and which everywhere are in tectonic contact with the crystalline rocks on each side of the graben. Black shales and andesitic lithic sandstones of the Twisp Formation have yielded no diagnostic fossils, but their sedimentary characteristics indicate a marine origin. Andesitic porphyry dikes and sills were intruded into them prior to their being complexly folded and faulted. Where thus stiffened, the shales were folded into broad folds, some of which plunge 90°. Where not reinforced by either thick sandstone beds or by dikes and sills, the shales fail incompetently, and the amplitudes of the folds typically measure in the tens of feet. These folded beds were eroded prior to the deposition of the Buck Mountain Formation upon them. The best exposure of the unconformity can be seen on the south end of the large hill immediately east of Winthrop. The basal beds of the Buck Mountain are bedded andesitic breccias that are in marked angular discordance with complexly folded Twisp Formation shales and sandstones.

The marine nature of the Buck Mountain volcanic sediments is not in doubt—corals, echinoids, pelecypods, belemnites, and ammonites of Early Cretaceous age have been found at a number of places in the thick section of bedded volcanic breccias, conglomerate, sandstone, and black shale. These fossils indicate a Neocomian (Hauterivian-Barremian) age.

Folding, uplift and some erosion of the Newby Group eugeosynclinal rocks took place within a very short interval in middle-Lower Cretaceous time. This is no doubt part of Misch's (1966b) intra-Cretaceous major orogeny, which he finds clearly postdates rocks of the upper Nooksack Group of upper Valanginian age, on the west side of the Cascade Range.

This orogeny caused major changes in the provenance of later sediments. No longer was the volcanic source available. The folded and eroded Newby Group rocks were submerged, and a quartz-feldspar-biotite source area to the east and north began to supply thick beds of medium- to coarse-grained arkose, which would become the Goat Creek Formation. It was deposited in a shallow marine environment, with marked angular unconformity over the eroded Twisp and Buck Mountain Formations. After some 5,000 feet of arkosic sand of the Goat Creek Formation had accumulated, the transport energy dropped so that black mud was the major sedimentary material being deposited except when sporadic bursts of energy permitted the transport of large boulder roundstone granitic conglomerate to form interbeds.

The black shale and conglomerate sedimentation was followed without break by marine arkose and black shale deposits, which became the Harts Pass Formation. The widely distributed ammonite fauna found in the interbedded shales of the Harts Pass rock is thought to be Aptian in age. Mild folding along northwest-southeast axes followed deposition of this thick pile of material derived from granitic debris to the east.

Erosion, following folding, faulting and uplift, removed a considerable section of the arkosic pile before the area was again submerged and marine sedimentation from a western or southwestern source began to form the Virginian Ridge Formation. Black mud was the chief contribution, but the energy level rose at times to allow a contribution of chert pebble interbeds. Chert grain sandstone was at other times the resistate fraction. The size of chert pebbles and the number and thickness of the beds are greater on the southwest side of the graben than on the east. South of lat. 48°30' W., this accumulation of black shales, chert conglomerate, and sandstone of the Virginian Ridge Formation rests with marked angular unconformity on rocks of Newby Group. North of this parallel, the Virginian Ridge beds are unconformable on various arkosic clastic units of the Goat Creek-Panther Creek-Harts Pass Formations.

Near the close of Virginian Ridge time, the marine basin was filled with sediment and began to receive continental-arkosic sedimentation this time from the east-northeast. Evidence of interfingering of arkose and the black shale-chert pebble beds is particularly well shown in the Virginian Ridge type area 5 miles west of Winthrop. The result of this renewed arkosic sedimentation, this time in a continental environment, is the very thick Winthrop Sandstone.

The Winthrop Sandstone is impressively thick to the north and east, but thins markedly to the southwest where it crops out on the east side of the Twisp Valley. As it is traced westward, it disappears short of the Cascade drainage divide. The thinning appears to be depositional rather than erosional.

Continental deposition continued after Winthrop time; but its character changed with an introduction of andesitic volcanic sandstones, breccias, and tuff in some places, and red sandstone, siltstone, and conglomerate containing pebbles and cobbles of andesite and red, green, and white chert, and quartz in others. The red sediments constitute the Ventura Member of the Midnight Peak Formation, which can be traced in the Methow Valley from its truncation by the Boesel Fault 6½ miles west-northwest of Winthrop, northwestward almost to the Cascade crest. Quartz and feldspar were still prominent in the Ventura sedimentation but they were overwhelmed by copious andesitic tuff, breccia, and flows, which make up the Volcanic (upper) Member of the Midnight Peak Formation, and which is so well preserved in the Goat Peak and Midnight Peak synclines.

Following deposition of the Midnight Peak Formation, folding and faulting began again in Late Cretaceous time. The evidence for the age of folding is as follows: the Pasayten stock-dike, dated by Tabor and others (1968, p. C48) at approximately 86 million years, definitely cuts the Winthrop Sandstone; and dikes, possibly related to the intrusion, cut the Midnight Peak Formation. The igneous rocks are fresh, the jointing is widely spaced and the alteration of biotite and hornblende is minor, suggesting a post-tectonic or at most a very late tectonic age for the intrusion.

Following the tectonism and erosion of Cretaceous sedimentary rocks, continental, leaf-bearing beds of coarse granitic boulder and cobble conglomerate, arkose, and chert and volcanic pebble conglomerate of the Pipestone Canyon Formation were deposited in a local basin(?) in the eastern part of the map area during some part of Paleocene time.

Renewed tectonism brought the graben into being, activating or re-activating the bordering Chewack-Pasayten Fault. The Paleocene Pipestone Formation was broken into several fault blocks and dropped down against the rising Okanogan batholithic complex. During the Eocene intrusion of the potash-rich rocks of the Golden Horn and Monument Peak batholiths, the latter dated as 47.9±1.4 million years (Tabor and others, 1968), was followed by uplift and erosion that developed the major stream pattern essentially as it is today.

Some modification of the topography by alpine glaciation occurred during the Pleistocene and Recent, but the major changes were wrought by the massive Canadian continental ice sheet that spilled across the major divides into the Methow and Stehekin drainages. Waitt (1972) has shown that although there are numerous erratics and ice-abraded surfaces exist, true moraines are rare. The many conspicuous terraces preserved are essentially ice-wastage features developed by ice that became stagnant when the Canadian source was cut off.

Since glacial times, the streams have resumed their work in eroding the highlands and redistributing the thick fluvioglacial deposits on the valley floors.

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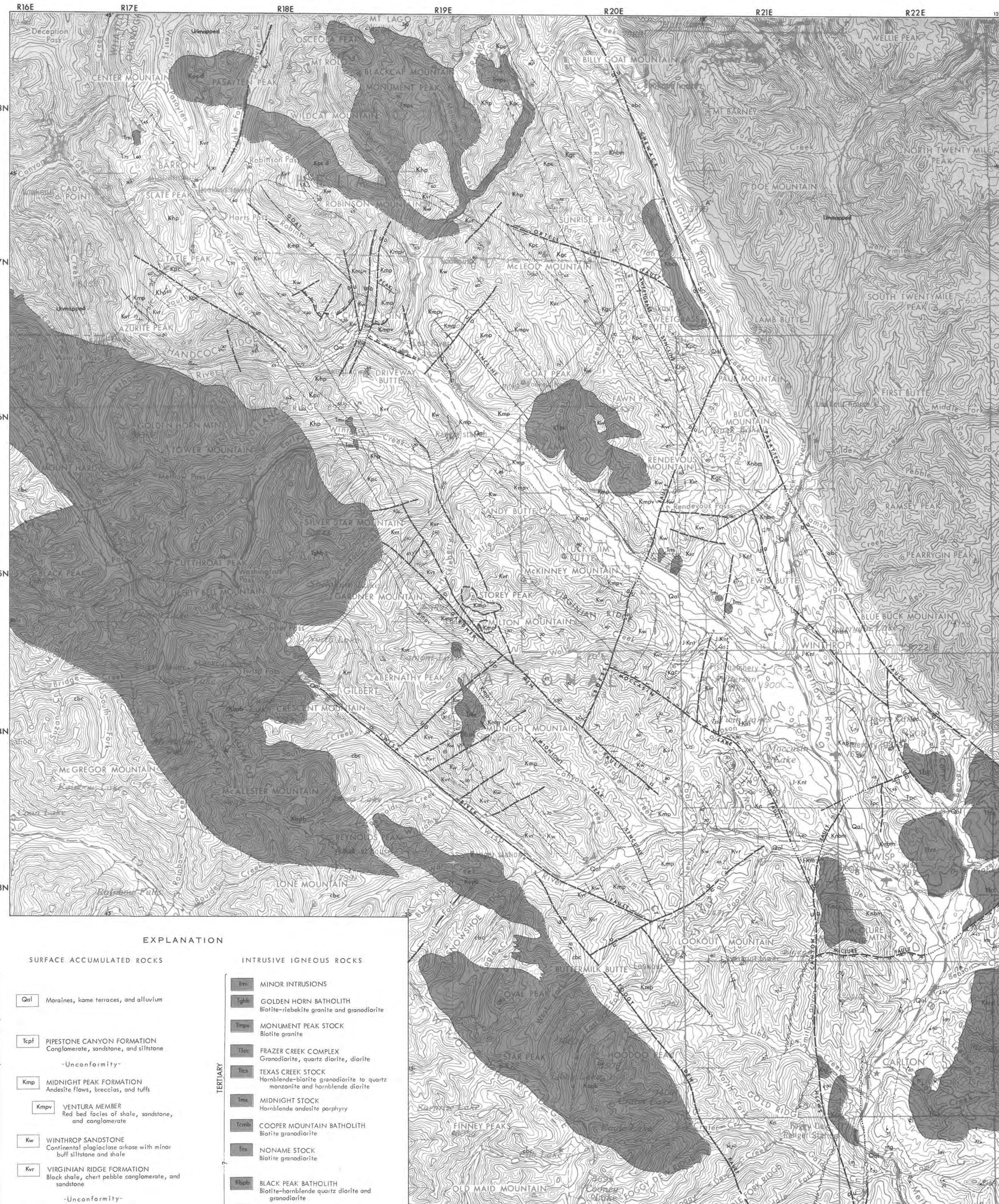
GEOLOGIC MAP OF THE METHOW VALLEY AREA, WASHINGTON

By
Julian D. Barksdale

1975



EXPLANATION

SURFACE ACCUMULATED ROCKS

QUATERNARY

Qal — Moraines, kame terraces, and alluvium

TERTIARY

Tcpf — PIPESTONE CANYON FORMATION
Conglomerate, sandstone, and siltstone

-Unconformity-

CRETACEOUS

Kmp — MIDNIGHT PEAK FORMATION
Andesite flows, breccias, and tuffs

Kmpv — VENTURA MEMBER
Red bed facies of shale, sandstone, and conglomerate

Kw — WINTHROP SANDSTONE
Continental plagioclase arkose with minor buff siltstone and shale

Kvr — VIRGINIAN RIDGE FORMATION
Black shale, chert pebble conglomerate, and sandstone

-Unconformity-

Khp — HARTS PASS FORMATION
Plagioclase arkose, black shale interbeds; marine fossils

Kpc — PANTHER CREEK FORMATION
Black shale, granitoid boulder to pebble conglomerate; marine fossils

Kgc — GOAT CREEK FORMATION
Plagioclase arkose, minor black shale

-Unconformity-

Kn — NEWBY GROUP—Undifferentiated
Andesitic flows, breccias, tuffs, black shales, lithic sandstones, and conglomerates

Knbm — BUCK MOUNTAIN FORMATION
Volcanic flows, breccias, conglomerate, lithic sandstone, minor black shale; marine fossils

- Unconformity -

JURASSIC ?

J-Knt — TWISP FORMATION
Thin-bedded black shales and volcanic lithic sandstone

INTRUSIVE IGNEOUS ROCKS

TERTIARY

Tmi — MINOR INTRUSIONS

Tghb — GOLDEN HORN BATHOLITH
Biotite-riebekite granite and granodiorite

Tmps — MONUMENT PEAK STOCK
Biotite granite

Tfcc — FRAZER CREEK COMPLEX
Granodiorite, quartz diorite, diorite

Ttcs — TEXAS CREEK STOCK
Hornblende-biotite granodiorite to quartz monzonite and hornblende diorite

Tms — MIDNIGHT STOCK
Hornblende andesite porphyry

Tcmb — COOPER MOUNTAIN BATHOLITH
Biotite granodiorite

Tns — NONAME STOCK
Biotite granodiorite

?

CRETACEOUS

Kbpb — BLACK PEAK BATHOLITH
Biotite-hornblende quartz diorite and granodiorite

Kacs — ALDER CREEK STOCK
Biotite-hornblende quartz diorite

Kfps — FAWN PEAK STOCK
Biotite-hornblende quartz diorite and diorite

Kcs — CARLTON STOCKS
Biotite quartz diorite

Kopb — OVAL PEAK BATHOLITH
Biotite quartz diorite

Kbcs — BUTTON CREEK STOCK
Biotite-hornblende quartz diorite

Kps-d — PASAYTEN STOCK-DIKE
Hornblende quartz diorite

Kscp — SUMMIT CREEK PLUTON
Biotite quartz diorite (gneissic)

METAMORPHIC ROCKS

AGE UNDETERMINED

mg — METHOW GNEISS
Biotite-epidote-quartz oligoclase gneiss

lm — LEECHER METAMORPHICS
Biotite and hornblende schists and gneisses with minor amounts of quartzite and marble

obc — OKANOGAN BATHOLITHIC COMPLEX
Granitoid gneisses and associated intrusive rocks

cbc — CHELAN BATHOLITHIC COMPLEX
Biotite and hornblende gneiss, heterogeneous schists, minor marble intruded by quartz, dioritic to granodioritic plutons

Contact
Dashed where approximately located

Fault, showing dip
Dashed where approximately located
U, *upthrown side;* D, *downthrown side*

Concealed fault

Mylonite zone

Fault, showing relative movement

Thrust fault
(T, upper plate)

Axis of anticline

Axis of syncline

Strike and dip of beds

Strike of vertical beds

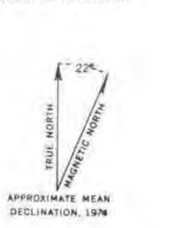
Strike and dip of overturned beds

Horizontal beds

Strike and dip of foliation

Strike of vertical foliation

Horizontal foliation

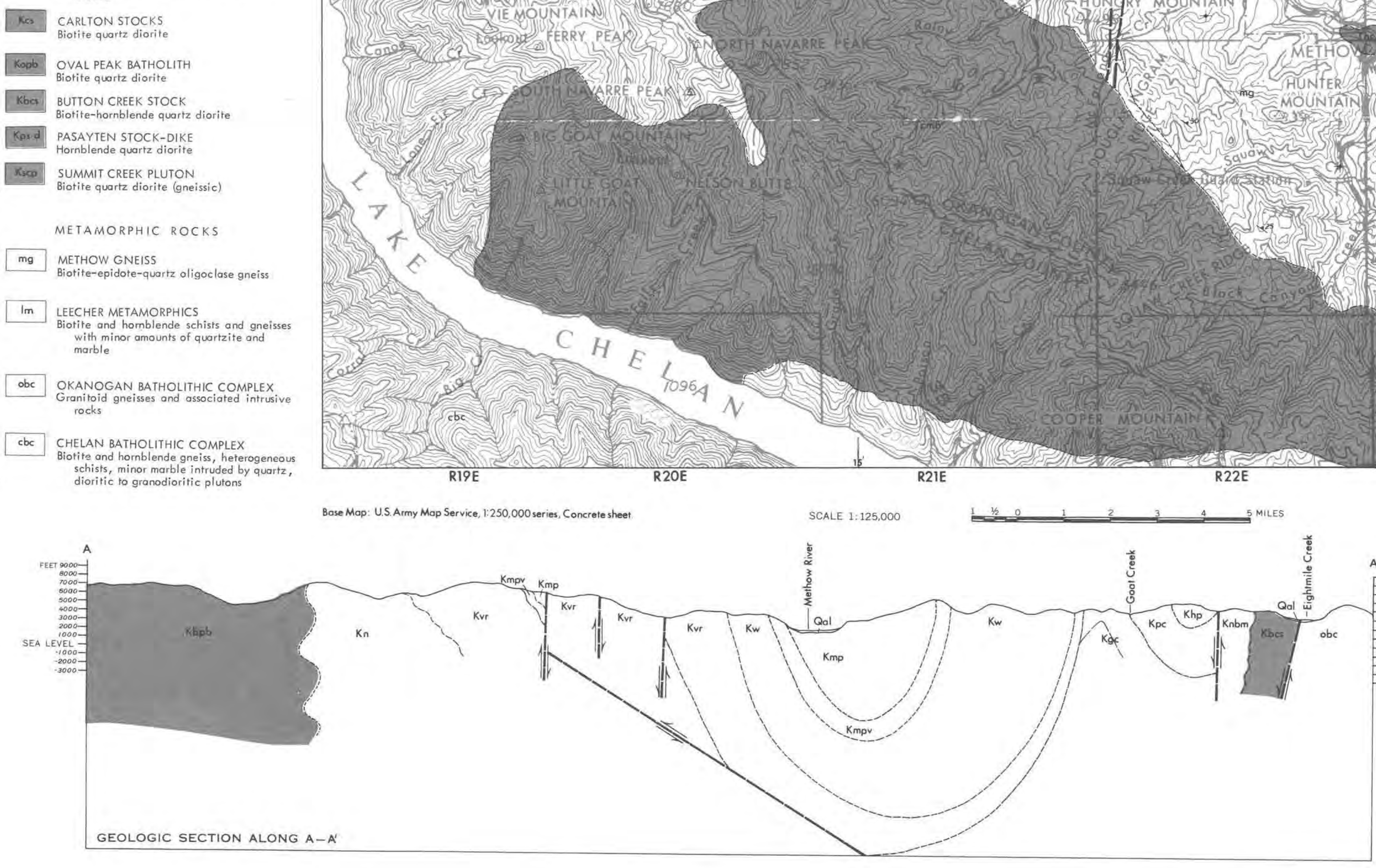


LOCATION MAP

Base Map: U.S. Army Map Service, 1:250,000 series, Concrete sheet

SCALE 1:125,000

1 ½ 0 1 2 3 4 5 MILES



GEOLOGIC SECTION ALONG A—A'

DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND EARTH RESOURCES