STRATIGRAPHIC AND STRUCTURAL GEOLOGY OF THE BLEWETT-SWAUK AREA, WASHINGTON

by

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

STRATIGRAPHIC AND STRUCTURAL GEOLOGY OF THE BLEWETT-SWAUK AREA, WASHINGTON

INTRODUCTION

Location

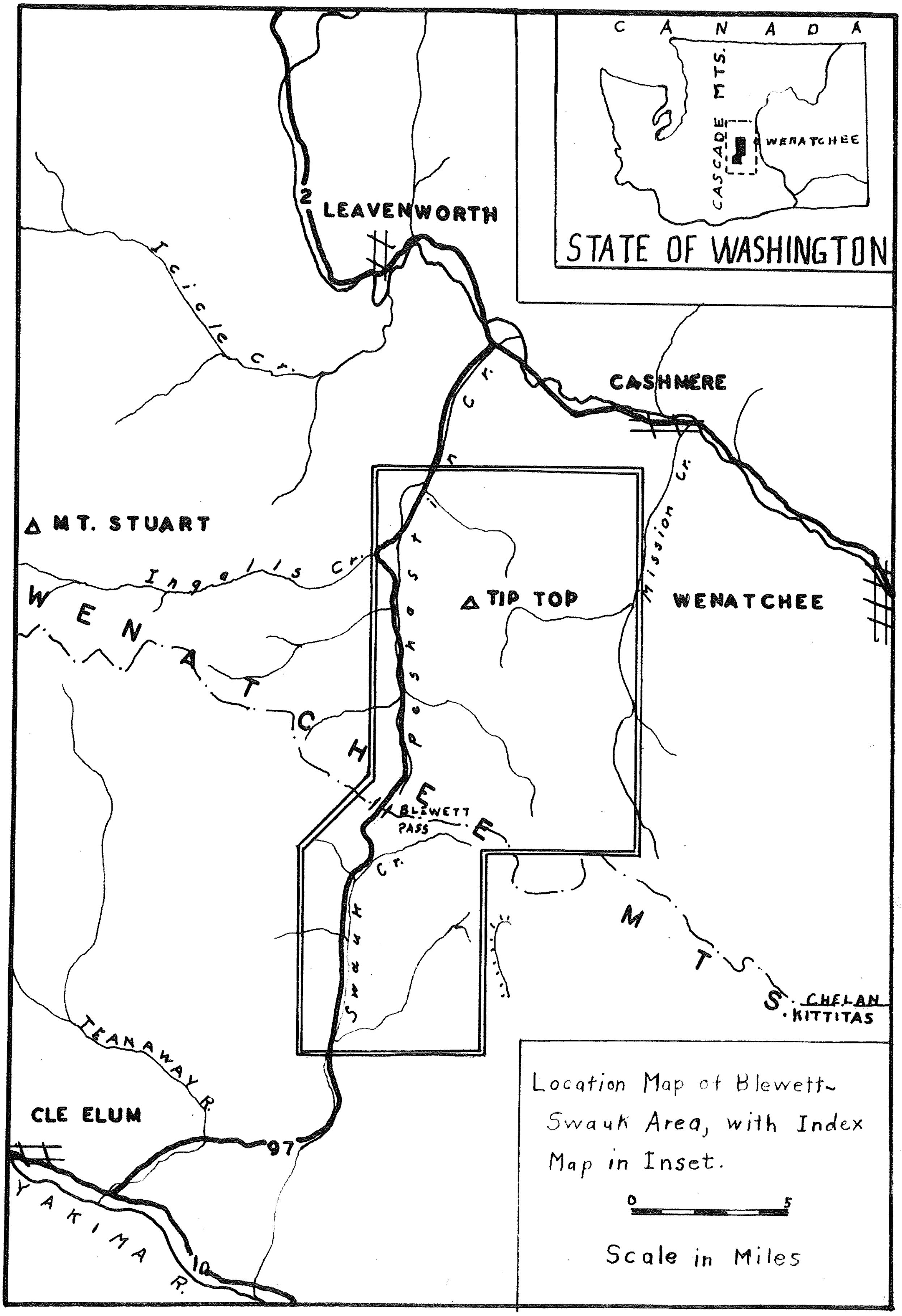
The area of this report is on the eastern flank of the Cascade Mountains approximately in the center of the State of Washington. It is about 12 airline miles due west of the town of Wenatchee. U. S. Highway 97 traverses the west edge of the area crossing the Wenatchee Mountains at Blewett Pass.

Purpose and Methods

This report embodies the results of studies of arkosic sediments in the Mount Stuart quadrangle as well as the discussion of surrounding rocks and their interrelations. Heretofore, this area has been investigated only in a reconnaissance fashion. The purpose of this report is to give a more detailed presentation of local geology which may be of use in helping solve problems of regional significance. The field work was done by Brunton compass traverses in the summer of 1955.

Summary and Conclusions

The continental sediments in the area of this report form two distinct sequences that differ in composition,



Location Map of Blewett-Swauk Area, with Index Map in Inset.

structure, and mode of deposition and may be of two distinct geological ages separated by a hiatus. For many years all these clastics have been called the Swauk formation. These apparently different sequences are separated by the northwest trending Leavenworth fault. Southwest of the fault are, for the most part, well-bedded deposits of alternating light brown arkose, shale, and conglomerate that have been well lithified, complexly sheared, and in part, tightly folded. Northeast of the fault in the vicinity of Camas Land is a sandstone composed almost entirely of white, loosely indurated arkose that was deposited in cross-laminated and massive beds that have been relatively gently folded without apparent faulting.

Russell (1899) interpreted the white massive arkose near Camas Land as being of a different "system" than the clastics of the Swauk mining district and named the former the Camas sandstone. Based principally on the fact that the nearly homogeneous white arkose is different lithologically from the sediments to the southwest and is thus a mappable unit, it is deemed suitable to retain the name Camas sandstone for this sequence. Several lines of evidence indicate that the Camas sandstone is younger than the Swauk and may be unconformable with it.

The major structural feature is a large northwest trending graben that contains the Camas sequence of clastics. The Leavenworth fault, with a minimum displacement of 10,000 feet, forms the contact between the Camas and the adjacent Swauk clastics or relatively upthrown block. Other major faults form the contact between the pre-Tertiary basement complex and the Swauk sediments. These appear to be high angle faults in which the basement rocks were relatively uplifted.

Other large features are northwest trending anticlines and synclines that trend approximately parallel with the major faults. North of the Wenatchee Mountains tight folds with steeply dipping limbs predominate in the Swauk; south of the mountains broad open folds are the most common. The north-northwest trend of the crests of the Wenatchee Mountains coincides approximately with the axial trend of the largest fold in the area of this report. The Camas sandstone has been tilted into a homoclinal sequence that is mostly dipping less than 40° to the southwest.

Acknowledgements

The writer wishes to express his gratitude to the faculty of the University of Washington for their valuable assistance in the preparation of this report. Dr. Howard A. Coombs suggested the thesis area, gave invaluable counsel during all phases of research, and made critical readings of the manuscript. Dr. H. E. Wheeler offered valuable advise on Stratigraphic problems. Assistance in the field was given by Hadley Hackney and Fred Turnlow. Dr. Roland Brown of the National Museum identified the collection of fossil leaves.

The author wishes to express his appreciation to his wife, Alene, who aided in the preparation of this paper.

GEOGRAPHY

Topography

The Wenatchee mountains, trending west-northwest, roughly divide the area into two unequal and topographically unlike portions.

The relief of the northern part is greater and in general more rugged. Steep sloped ridges composed of metamorphic rocks border both sides of Peshastin Creek. The region east of Peshastin Creek to Mission Creek is one of mature topography consisting of deep canyons and sharp ridges. The principal exception is Camas land--a resistant gabbro remnant that rises over a thousand feet above the surrounding valleys.

South of the Wenatchee Mountains the entire area is part of an irregularly floored basin that is drained by Swauk Creek and its tributaries. The salient feature is a series of long angular ridges formed by the basaltic dike swarms.

Drainage

North of the Wenatchee Mountains the area is drained by Peshastin and Mission Creeks and their tributaries. These two creeks flow due north where they empty into the Wenatchee River. To the south the entire area is drained by Swauk Creek and its tributaries. This creek flows southward and eventually joins the Yakima River.

Rock Exposures

Although the area is for the most part well covered with soil and vegetation, numerous creeks and logging roads traverse the entire area showing many exposures. The least exposed portion is between Tip-Top ridge and Camas creek where few outcrops exist.

DESCRIPTIVE GEOLOGY

Basement Complex

Peshastin Formation

The rocks comprising the Peshastin formation are mostly slates but they may grade downward into indurated shales or upward into phyllites.

This formation occurs in the form of a crude equilangular triangle; each side is about 3 miles long. This is the extent of the known Peshastin except for a few nearby isolated small remnants. The type locality of the Peshastin, as well as numerous small eastwest trending elongate patches that extend westward to Mt. Stuart, were mapped and named by George Otis Smith (1904). These elongate outcrops, as described in the folio, are "nickel ledges" that were thought to be a contact phenomena of the limey portions of the Peshastin rocks and intrusive peridotite. Field relations indicate that these ledges are iron-nickel bearing masses of calcite and quartz that always occur in extremely sheared zones and are not necessarily confined to the Peshastin formation.

The occurrence of the Peshastin, in the area of this paper, is limited to the eastern edge of the main outcrop, an area about three miles long and one-half mile wide, and to a small outcrop on Sheep Mountain.

The majority of these low grade metamorphics were originally shales containing irregular lenses and beds of fine to medium grained sandstone. On the divide between

Nigger and Ingalls Creeks are a few irregular lenses of silty limestone. Directly east of this across Peshastin Creek is a bed of pebble conglomerate about 30 feet thick that consists principally of well-rounded clastic quartz, chert fragments, and greenstone pebbles up to one-half inch in diameter. Impregnation of secondary pyrite occurs in various areas, notably on the hill directly west of the mouth of Ruby Creek.

These predominantly black to dark gray rocks ordinarily weather brown; although they often weather to shades of yellows and reds, which shows a high iron content. Both regular and irregular joints filled with calcite and quartz are common. The attitudes of the schistosity, which in many cases approximately parallels the bedding, are varied and generally steep. A fairly consistent northwest strike is evident but the directions of the dips change greatly especially near the peridotite contacts.

A microscopic inspection reveals that the shale is mostly quartz with scattered flakes of clastic biotite. The quartz grains are typically sheared and drawn out in elongate particles. Carbonaceous material is present in irregular bands that locally constitute as much as 20% of the shale. One fine grained lens may be classified as an arkose as it contains over 20% feldspar; the rest being mostly chert fragments and clastic quartz with minor amounts of epidote, clinozoisite, chlorite, and magnetite. This sample was well indurated but was not sheared.

Fig. 1 Sheep Mountain. A salient outcrop of Hawkins volcanics standing above the less resistant serpentine.

Fig. 2. Well jointed Peshastin slate from its type area on Nigger Creek.

Hawkins Formation

This formation is composed of volcanic breccias, tuffs, and interocalated volcanics that vary from slightly altered rocks to greenstones.

These volcanics occur along both sides of Peshastin Creek in the thesis area. They are represented by five outcrops large enough to map and by numerous small blocks that were apparently engulfed by the serpentine.

Some of the most rugged topography in this vicinity is due to the presence of this resistant series of lavas and associated tuffs. Sheep Mountain and the two adjacent outcrops on the north are craglike pinnacles with sheer cliffs that terminate at the contact with the less resistant peridotite and sandstone. These salient features appear black from a distance but are usually some shade of green as seen on closer inspection.

The flows which vary from dark green to a light gray are not traceable for any great distance but appear to be intermingled with breccias and tuffs. The breccias consist of angular fragments of basic fine-grained igneous rocks and varying amounts of lapilli, scoriaceous tuff, and chert fragments. The entire series is irregularly transversed with veins of secondary silica and calcite. Dark green is the prevailing color of these breccias, although yellow, brown, red, and purple are not uncommon.

Chlorite, calcite, epidote and quartz are crystallized minerals found in some of the greenstones. In others only chlorite and veinlets of secondary calcite are present.

For a more complete description of the Hawkins formation, which is of little concern to us here, see Weaver's Blewett publication (1911).

Serpentine

Serpentines constitute the bulk of the pre-Swauk basement complex in this area. The exposures are the eastern end of an almost east-west belt varying from two to eight miles wide and about 20 miles long, Weaver (1911). This eastern end has been differentially sheared and intruded by hydrothermal solutions obscuring clues to its original composition.

The rocks represented on the geological map under the general term serpentine include some blocks of volcanics too small to map. Occassional outcrops of massive, dark greenish rocks representing the least altered ultra basics are almost indistinguishable in the field from certain phases of the Hawkins meta-volcanics. Later shearing and hydrothermal action has obliterated most of the contacts between these various units.

A typical specimen of serpentine is several shades of green, irregularly blended together and mottled with white streaks. It has a waxy luster, contains many slickensides, and breaks with a smooth conchoidal fracture. Individual outcrops reveal varied colors and textures that are probably due both to the variations in composition of the original rocks and to subsequent differential serpentinization. Some contain patches and stringers of black, shiny material. Zones of red and brown impure serpentines that are generally highly silicified are more common near the contacts.

Serpentine disintigrates more readily than most of the surrounding rocks. The slopes are characteristically rounded and covered with sharp angular talus. Some zones within the serpentine apparently contain more iron than elsewhere and weather to a dull reddish brown.

Under the microscope the serpentine is seen to be variable in composition and in the degree of recrystallization. Commonly the entire rock is composed of anhedral grains of of antigorite containing a few acicular forms of magnetite. In many sections antigorite occurs as microlamellar aggregates along with its dimorph chrysotile. Scattered remnants of olivine in all stages of serpentinization are seen. Many skeleton crystals of actinolite have been replaced by bastite.

Secondary carbonates, largely calcite and dolomite, in the form of irregular replacements and veinlets constitute a large percentage of many specimans. Tremolite, clinozoisite, and grossularite are minor constituents.

Several lenticular veins of quartz, calcite, and ankerite were observed in old adits in Culver Gulch. They are in part highly mineralized with pyrite, chalcopyrite, and arsenopyrite. Small flakes of gold were obtained by panning the more oxidized portion of these veins. Thin flakes of gold were observed in soft sheared serpentine about three feet from a metaliferous quartz vein. One small vein of chrysotile asbestos was seen.

Pre-Swauk Intrusives

At least two types of intrusions in addition to the serpentine were injected into the basement rocks before the time of Swauk deposition. One is a granodiorite and possibly related andesite porphyry dikes--the latter are greatly sheared and altered. The other is a metamorphosed basic rock that was formerly largely of gabbroic composition.

The granodiorite is an elongate outcrop and together with some metamorphosed basic rocks apparently forms an inlier of basement rocks in the sheared zone on Tiptop ridge. Only isolated outcrops of massive, leucocratic, medium grained rocks could be seen protruding through the thick soil cover. Plagioclase of the oligoclase variety is the chief mineral, being about twice as abundant as orthoclase. The feldspars are in subhedral grains up to 3 mm. in diameter, some of which show normal zoning. Quartz is another essential mineral; biotite and muscovite are accessories. The grains are interlocked in a granitic texture through which are commonly zones of microbrecciation.

The altered andesite porphyry is in dikes and irregular intrusions with a general west-northwest trend. Megascopically samples vary greatly in appearance but are for the most part leucocratic fine grained rocks with phenocrysts of hornblende and feldspar. Microscopically they show remnants of feldspar hornblende, and biotite in a sheared mestosis of fine-grained quartz and feldspar. Only a few grains of feldspar could be identified as plagioclase and orthoclase; the rest are completely altered to kaolinite, sericite, and carbonate. The anhedral grains of biotite and hornblende are largely replaced by chlorite and released magnetite.

The meta-gabbros are massive, dark green rocks faintly mottled with white lines of calcite and quartz. They are in general non-schistose partially or completely uralitized gabbros containing only skeleton outlines of original plagioclase and pyroxene. Dark green hornblende and/or actinolite are the major constituents with varying amounts of epidote, clinozoisite, quartz, and antigorite. Retrogressive chlorite was seen replacing the hornblende in one directionless amphibolite.

In the adjacent area to the west, Weaver (1911, p. 52) described several small patches of meta-gabbro which also contained outcrops of rather fresh gabbro.

<u>Age and Correlation</u>

No fossils have been reported from any of the basement rocks nor has any definite correlation been established with units of known ages. The andesite porphyry dikes intrude the basement complex but do not extend into the Swauk formation. Therefore, all the rocks can be assigned to pre-Swauk time but any other age determination is purely relative as deciphered from geologic relations.

The Peshastin formation is assumed to be the oldest. In two areas it appears to dip under the Hawkins volcanics.

No evidence was found to determine whether or not these two formations are conformable. The peridotite intruded both of these formations.

The andesite porphyry dikes, which are possibly apophyses of the Mt. Stuart granodiorite, was injected into the ultra basics. The meta-gabbro may well be a differentiate of the peridotite. The metamorphism of this gabbro and its lack of intrusive contact with Swauk or Camas sediments suggests it is older and not related to the fresh gabbro of the Camas Land sill.

Swauk Formation and Camas Sandstone

Stratigraphic Nomenclature and Type Localities

The type locality of the Swauk formation lies in the southern part of the area of this report where it was mapped and named by G. O. Smith (1904).

Russell (1899, p. 118), in an earlier publication, divided the terrestial sediments in this area into two formations.

> "The rocks included in this formation present two quite distinct phases, which led me to divide them into two systems, one termed the Camas sandstone and the other the Wenatche sandstone; subsequently, however, these terranes were studied, in part in considerable detail, by Messrs. Willis and Smith and were found by them to be deposits of a single Tertiary Lake or estuary; therefore, the name Swauk sandstone was given to the entire formation after the Swauk mining district where it occurs."

Although Russell's name had priority, the name Swauk formation has been accepted for both units in all subsequent literature. It is the author's opinion that Russell's division of the two units is justified.

Because of the widespread acceptance of the name Swauk, it is suggested that this name be retained for the sequence named by Smith. This unit of light brown appearing arkose, shale, and conglomerate extends from its type area in Swauk Creek northward to the Leavenworth fault in the area of this thesis.

North of this fault lies the massive white arkose in the vicinity of Camas Land as described by Russell (1899, p. 119) as the type area of the Camas sandstone. For the following reasons this sequence is thought to be considerably younger than the Swauk formation; it apparently rests unconformably upon the Swauk in the Wenatchee quadrangle (see p. 30), it was not intruded by the dike swarms, it is less indurated and nowhere tightly folded and complexly faulted as is much of the Swauk formation. Because of the difference in lithology and the apparent difference in age, it is believed proper that the original name Camas sandstone be revived for the upper sequence of white clastics in this area.

<u>Regional Distribution</u>

The general pattern of the distribution of the Swauk formation including the Camas sandstone is in the rough form of a large horseshoe around the Mt. Stuart batholith with its open end to the northwest. From the northwest end, near the town of Skykomish, this pattern of sediments extends southeastward in a discontinuous irregular band to the town of Liberty. It here widens out in a broad curve that extends past the town of Wenatchee, and hence to the northwest in a broad band just past Lake Wenatchee.

Other occurrences of arkose on both flanks of the Cascade Mountains to the north may be Swauk equivalents.

Description of the Swauk Formation

The continental clastics of the Swauk formation occur in the Peshastin Creek-Swauk Creek area and cover about three-fourths of the mapped area. This sequence appears to be resting unconformably upon basement rock inliers in the vicinity of Tiptop. On the northwest it is in fault contact with the basement rocks, on the northeast in fault contact with the Camas sandstone, and on the south is overlain unconformably by the Teanaway basalt.

This formation contains mostly granitic detritus, ranging in size from silt to boulders, deposited in a succession of massive to thinly bedded layers with a total minimum thickness of 7,000 feet. This sequence was subsequently folded into assymetrical northwest trending folds. The ratio of arkose, shale, and conglomerate varies greatly from place to place. Overall the arkose constitutes about two thirds of the sediments and the shale is slightly more abundant than the conglomerate.

A typical dry hand specimen of arkose reveals a weathered surface that grades inward from dark brown through tan to the pale gray of a fresh portion in the distance of one centimeter. Glassy to milky quartz, white to light gray feldspar, and dark rock fragments each constitute about one quarter of the rock. The only megascopically identifiable accessory minerals are dark brown biotite and dull green chlorite. A few assorted granules up to four millimeters long are scattered throughout this mostly medium-grained arenite creating a mottled or speckled appearance. They appear to be angular, are usually pitted, are often bent or broken by minor shear planes, and are moderately consolidated in a dominantly chloritic cement. A consistent orientation of mica flakes shows the approximate plane of bedding.

The arkose occurs in well-bedded layers 1 to 20 feet thick, in massive deposits, and only occasionally in cross-bedded deposits. Although the rock is a light gray, almost all exposures are characterized by being weathered a light brown. The well-bedded strata are the most abundant north of Swauk Creek and are intercalated with deposits of shale and conglomerate. In the vicinity of Liberty the massive medium-grained arenites constitute well over half the sediments.

A thin section inspection shows the sand size clastics are predominantly equant, angular to subangular grains of quartz and feldspar. The plagioclase varies in composition from An_{12} to An_{37}. Oligoclase is the most common but andesine and/or albite are present in many sections. Stained sections indicate that the orthoclase-plagioclase ratio varies from 1:3 to 1:1. Microcline occurs only in minor amounts. The feldspars, except a small proportion of remarkably clear grains, are generally thoroughly altered to kaolin and sericite.

Rock fragments of granule and sand size compose up to one quarter of the arkosic sandstone. The following are commonly present in varying amounts: chert; quartzite; granodorite; many kinds of gneisses, schists and shales; gabbro--fresh and uralitized; and dike rocks.

The micas are biotite, chlorite, and muscovite. The biotite flakes are typically sheared or drawn out in lenticular fashion that are partially replaced by chlorite and/or epidote. Other accessory minerals are epidote, clinozoisite, garnet, sphene, microperthite, stipnomelane, and rutile. The cement contains considerable chlorite. In other places quartz and argillaceous material make up the cement.

The massive units locally display regular systems of jointing. The other types of beds are less often and more irregularly jointed. Many of the joints as well as many of the fault planes can be easily recognized as they are filled with secondary zeolites and calcite.

The Swauk arkose contains many silicified zones represented by salient outcrops that stand boldly above the surrounding rocks. At a distance zones up to 50 feet wide appear to be veins but upon close inspection they are seen to be either areas impregnated with silica or a network of small quartz veins.

The outcrops are ordinarily tan, dull yellow, or whitish with a smooth to irregular ropy type of surface. In places they are brightly colored by red and yellow crusty layers.

Fig. 3. Photomicrograph of medium-to coarse-grained Swauk arkose containing altered feldspars, quartz, and rock fragments. Characteristic microbrecciation caused by shearing is shown in the central portion.

Quartz veins with comb structures are occasionally present and indicate the silica probably came up as solutions. These silicified zones are numerous near the Swauk-Teanaway contact and appear structurally related with the numerous diabase dikes in that area. Other conspicuous silicified outcrops occur intermittently along major fault zones.

Some are a true type of fissure filling. In the vicinity of Swauk Creek many quartz veins have been mined for their gold content. These veins characteristically contain large amounts of angular fragments of shale and sandstone. These fragments were probably plucked from the fractured area by ascending solutions.

The shale is widely distributed throughout the entire Peshastin-Swauk area. It is a siltstone predominently well indurated, dark gray in color, and weathers to a light gray or brown. Occasional outcrops display lighter shades of gray, brown, and olive green or dull shades of red and yellow.

The siltstone is usually uniform in grain size and composition. The lithology is similar to that of the arkose, the principle difference being a larger amount of carbonaceous material in the shale. A few lenses are composed entirely of silt-sized quartz fragments in a clay and carbonaceous matrix. A white bed of calcareous siltstone about two feet thick outcrops a mile up Tronson Creek. This is in marked contrast to the usual dark shale. Unidentifiable carbonaceous material is present in most of the beds. Fossil leaves and other floral remnants were recognized in a few exposures.

Over half the shale was deposited in thinly bedded layers, the rest in beds up to twenty feet thick. The beds are characteristically in sharp contact with the alternating beds of coarser clastics; nowhere do they appear gradational. A few sandy siltstone beds indicate horizontal gradation.

In folding the shale has followed the pattern of the more competent sandstone. Penecontemporaneous squeezing has caused some of the beds to be lenticular. One outcrop reveals a "shale dike" where the more plastic shale was squeezed into a fault in the sandstone.

The conglomerates are generally poorly sorted and lithologically heterogeneous. They may be composed entirely of granodiorite, serpentine, gneiss, schist, slate or aphanitic igneous rocks; but they usually consist of some combination of these types. Small cobbles and large pebbles constitute the bulk of these clastics. They occur with other clastics, varying in size from sand to boulders, in massive wedge shaped deposits up to 300 feet thick or in thin to thick beds that alternate with those of arkose and shale.

The most abundant conglomerate is a light colored one consisting largely of granitoid cobbles, principally granodiorite, and varying amounts of the other types. The cobbles and pebbles are fairly well rounded and set in a well indurated arkosic matrix. These massive units are similar to what Pettijohn (1949, p. 209) classifies as polymictic conglomerates. He defines them as coarse grained representatives of the greywacke and arkose clans, either basal or intercalated at several horizons. They are generally thick wedge shaped, basin-margin accumulations of gravel that were shed from sharply elevated highlands.

The conglomerates are best displayed on the ridge between Scotty and Tronson Creeks where they constitute over one-third of the sediments. Rounded cliffs with irregular faces parallel the strike and represent differential erosion of these massive units. Many outcrops are dotted with cavities up to two feet across showing where the larger cobbles have been dislodged.

Thick wedges of hetrogeneous conglomerate that thin to the south and east are most prevalent near the contact of the Swauk formation with the basement complex. They are more abundant near the bottom of the sequence but are scattered very irregularly throughout the entire succession of beds. The massive units at Shaser Creek are over 5,000 feet from the bottom of the sequence. A traverse south from this point across northward dipping beds shows many thick deposits for about one and a half miles. South of this area no more massive layers of conglomerate are seen--only a few thin lenses.

Similarly the western slope of Ruby Creek is composed of rugged conglomeratic ledges. Southeast of Ruby Creek between the Leavenworth fault and the north ridge of Tronson Creek the strata are mostly those of arkose and shale.

One kind of unstratified basal conglomerate lies on the serpentine on the north slope of Shaser Creek. Subangular to poorly rounded fragments of serpentine and peridotite

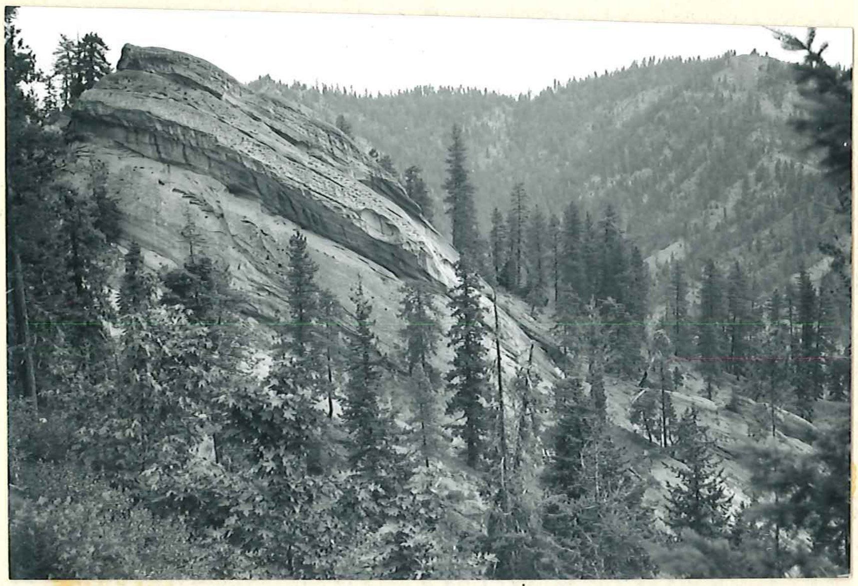


Fig. 4. Outcrop of pitted Swauk conglomerate on ridge between Tronsen Creek and Scotty Creek.

that range in size from clay to large boulders are in a coherent feruginous and serpentinous matrix. Some of the serpentine cobbles are surrounded by a thick shell of weathered material suggesting a possible explanation for their roundness. These clastics are generally brown to dull red mottled with various shades of greens, showing all stages of oxidation of the serpentine. They outcrop in resistant knobs and lenses that appear black from a distance.

A thirty foot thick bed of shale exposed for about 400 feet, indicates this deposit is steeply dipping to the southwest.

The lithology of this shale resembles that of the conglomerate except it contains a higher percentage of hematite and magnetite. The fine-grained iron compounds are strongly oxidized and exhibit brilliant shades of red and yellow amid the more common black and dark green colors. The shale contains iron, nickel, and chromium in the form of hematite, magnetite, limonite, garnierite, and an impure form of chrome-bearing spinel, according to Zoldok (1948).

Lupher (1944, p. 7) concludes that this unit is sharply different lithologically from the Swauk formation and designates it as the Cle Elum formation. He found evidence farther to the west indicating it is probably conformable with the Swauk clastics.

This unit was derived from the nearby peridotite and serpentine or perhaps in part formed in place from the serpentine it rests upon. The iron, nickel, and chromite are the result of lateritic formation from the ultra basics. Lamey (1951) lists this as a Cuban type in which residual material is formed in place from the underlying peridotite and was later moved by landslides or mudflows to lower areas.

This iron-rich deposit is on the north side of a high angle fault that separates it from the north dipping Swauk Arkose. Near the contact the conglomerate contains many slickenside surfaces as a result of shearing which makes it difficult to distinguish from the peridotite in place. Many angular fragments of fault breccia are found in this zone.

One area, containing the lowermost beds of the lower member of the Swauk formation, is unique in character. It is a northwest trending lens-shaped area in the vicinity of Tiptop about six miles long and less than a mile wide. It is bounded by the Leavenworth fault on the northeast and by another high angle fault on the southwest. The whole area is a zone of differential shearing in which movement is expressed as numerous small faults.

The arkose in the lens-shaped area is typically coarse and is so firmly cemented that it resembles granodiorite. On close inspection of a large outcrop usually some pebbles or bedding can be found. It is of the same composition as the granitoid basement on which it rests. The coarse grains in the arkose are angular; many are fresh appearing. This homogeneous little reworked arkose was formerly granitic grus weathered in place or transported but a short distance.

Many types of distinctive conglomerate were observed in this unique area. Boulders of granodiorite over five feet in diameter are firmly cemented with smaller subangular clastics. This constitutes much of the resistant material that forms a bold ridge extending from Tiptop northwest to Peshastin Creek. In two areas there are bold outcrops of large subrounded cobbles of serpentine in a matrix of fragments and clay of the same material. The boulders were weathered before lithification to rusty brown and red shades. The unstratified nature of these fragments together with the great amount of clay points to an ancient mudflow from the near by serpentine. In the southeastern tip of this lens shaped area are massive beds of highly sheared green serpentine conglomerate. Conglomerates consisting wholly or in part of slates and meta-volcanics also outcrop many places in this area.

One dike of granodiorite about two feet wide was found sharply cutting the sediments. Nowhere else was a dike of similar lithology observed intruding the Swauk formation. Lupher (1944) observed acid intrusives cutting Swauk sediments about 20 miles west of here, near the Cle Elum River. He referred to Smith and Calkins (1906), who correlated these intrusions with Snoqualmie granodiorite. It is possible this single dike is a rheomorphic dike formed as a result of

Fig. 5. Swauk conglomerate composed entirely of serpentine and peridotite clastics from cobble size to clay size. Outcrop is on the west side of Peshastin Creek, one mile north of Ingalls Creek.

mobile granitization injected through this highly sheared zone. Coombs (1950) described a locality of granitization in the Swauk formation.

Description of the Camas Sandstone

At least 6,000 feet of sediments in the Camas Land area strike in a homoclinal fashion to the southwest and are truncated by the Leavenworth fault. As these strata are unlike the sequence to the southwest or Swauk formation, they are here called the Camas Sandstone as named by Russell (1899, p. 118). It is not possible to determine if the two formations are conformable or not as they are separated in this area by the Leavenworth fault. However, Chappell (1934, p. 34) described an angular unconformity in the adjoining Wenatchee quadrangle. He found light colored, gently folded sediments overlying darker, highly folded sediments.

Over 95 percent of this sequence is composed of beds of sand-sized sediments. The most of the material fits the description of an arkose as defined by the Committee on Sedimentation, "a sandstone containing 25 or more percent of feldspars derived from the disintegration of acid igneous rock of granitic texture." Some beds are lithologically a feldspathic sandstone; they contain less feldspar and correspondingly more quartz than the others do. Thin lenses of pebble conglomerate appear throughout the sequence. Thin beds of very fine grained arkose and carbonaceous shale are rare.

The arkose as a whole is characterized by its homogeneity. To the unaided eye, rocks from most outcrops appear strikingly similar and seem to vary only in their percent-

Fig. 6. Outcrop of cross-bedded Swauk arkose at Hurley Creek looking northeast. The direction of stream flow was from the northwest.

Fig. 7. Cross-bedded Camas sandstone by Devil's Hole. Its poor induration allows it to be easily eroded.

age of dark rock fragments and biotite. The typical specimen is fine to medium-grained, white to pale gray in color, and is poorly indurated. The feldspar occurs in white grains restricted to sand size and is difficult to distinguish from the white interstitial material. A few exposures are distinctive in containing over ten percent biotite occurring in poorly rounded flakes up to 5 millimeters in diameter. In some the biotite is oriented at random; in others arranged in a parallel fashion that creates a gneissic appearance.

An examination of thin sections shows that most of the samples taken contain the same minerals in varying amounts. Either quartz or feldspar may predominate but on the average they each constitute about a third of the rock. The quartz is in equant, angular to subangular grains that are mostly clear and may or may not have undulose extinction. Some grains of vein quartz were identified by their cloudy, milky appearance.

The range of variation of the orthoclase-plagioclase ratio is about 1:1 to 1:3 or about the same as that of the Swauk formation. However, more samples taken from the latter showed a near equal ratio of the two feldspars. Zoning and carlsbad twinning are both rare features. Albite twinning is commonly found in the plagioclase. The plagioclases are in order of abundance: oligoclase, andesine, albite.

Detrital flakes of mica account for almost a tenth of the volume of the sediments. Reddish brown pleochroic grains of biotite, characteristically bent or folded by compaction, are

Fig. 8. Photomicrograph of usual well washed fine-to medium-grained Camas arkose free from shearing that is generally present in Swauk arkose. (Compare with fig. 5.)

more numerous than all the other kinds. Green flakes of chlorite are a minor constituent. Although muscovite was rarely seen in the specimens taken, it occurs in abundance in a few exposures observed in the field.

Other accessory minerals are microcline, perthite, epidote, clinozoisite, apatite, chlorite, sericite, and kaolin. In addition to the clay minerals sericite and calcite form the interstial material. Quartz, argillaceous material, and calcite cement the clastics together. Rock fragments principally aphanitic igneous pebbles and vein quartz are present in widely varying amounts.

Alteration and microshearing is much less pronounced than in the arkose of the Swauk sequence. In general the plagioclases are not as thoroughly decomposed and there is much less chlorite. There is, however, much unevenly distributed post diagenetic calcite that is not found in the Swauk. Locally the calcite has replaced a large portion of feldspar, quartz, rock fragments, and the accompanying matrix. Also, it fills many irregular veinlets that cut across the grains.

The arkose and feldspathic sandstone was deposited in massive beds up to one hundred feet thick or in cross bedded deposits that show inclined forset beds. As is typical of continental deposition many diastems are represented by cut and fill structure. Elongate lenses of varying textured clastics are formed by the scoring out of river channels and subsequent refilling of gravels.

A characteristic feature of many outcrops is a peculiar weathering effect that resembles exfoliation in granites. The weathering surface develops evenly parallel to the outcrop even though it is at an angle to the bedding. Shear vertical cliffs over 200 feet high are cut in this soft, white arkosic sediment. Such a picturesque escarpment forms the north canyon wall of Little Camas Creek at Devil's Hole. The creek cut away the bottom of the cliff while the top has been shielded from erosion by the nearby gabbro sill on Camas Land. Locally many concretions, averaging about 8 inches in diameter, and holes left by their former presence, give a pitted effect to the light colored cliffs.

The principal types of conglomerate in the Camas sandstone are as follows: granitoid, types containing mostly granodiorite, some quartz diorite, and some granite; milky white quartz; aphanitic and porphyritic igneous rocks, and a few metamorphics including gneisses, schists, and metasediments. Most of the pebbles are light colored, well-rounded, and are under an inch in diameter.

The deposits are not of cobble sized clastics in massive beds and wedges as are the Swauk conglomerates, but are characteristically in the form of thin lenses and beds. They contain pebbles that are rarely over two inches in diameter, haphazardly scattered in medium to coarse grained arkose. The conglomerates commonly grade laterally into the surrounding arkose and at the extremites constitute only rudely linear strings of separated pebbles. The bottom contacts are usually sharp with the underlying beds; the top contacts are most commonly gradation ones with the arkosic sandstone.

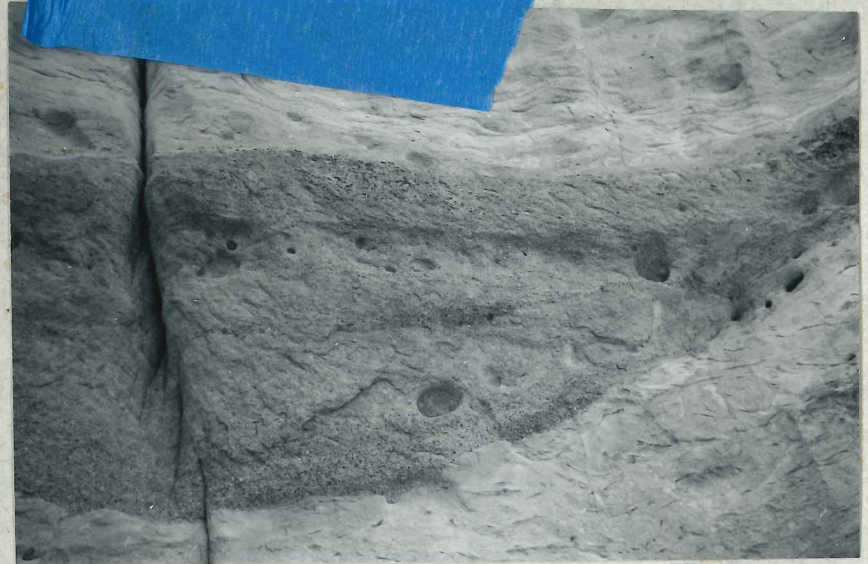


Fig. 9. Cut and fill structure in Camas sandstone from exposure on north bank of Little Camas Creek 2½ miles from its mouth.

Fig. 10. Calcareous concretions and cavities left by their former presence in Camas arkose.

Conditions of Deposition

The environment of the deposition of the Swauk formation has been explained in greatly different ways. G. O. Smith (1904) stated that the larger part of the Swauk formation is fresh arkose, plainly derived from the Mt. Stuart granodiorite, and was deposited in the rising water of an Eocene Lake. W. S. Smith (1916) thought the sand and gravels were deposited by streams, probably in deltas, and the shales were formed in swamps. Waters (1930) concludes that in the Wenatchee valley an in the Chelan quadrangle the Swauk formation is mostly the result of river flood plain and alluvial fan deposits.

Chappell (1936) states the Swauk sediments represent the deposits of a compound alluvial fan spread marginal to the highlands. He infers that the sediments come from both the Mt. Stuart and the Chelan batholiths. Willis (1950) maintains that these sediments were deposited for the most part, by large streams that built coalescent sheets and lenses of alluvial detritus by lateral shifting of their coarses. He postulates the source as being the Okanogan highlands.

The controversy is not so much a matter of correct interpretation as it is the kind of bedding exposed in the particular area where these authors worked. In the area described in this thesis there are two distinct sequences of sediments; each deposited in a different manner. The Camas sandstone contains mostly cross-bedded sediments of fluviatile origin; the Swauk formation contains mostly well-bedded deposits of lucustrine origin, and some of probable stream origin. In analyzing the literature it appears probable that the area worked by Smith is the only one in which the exposures were of predominantly of well-bedded Swauk deposits. The others mapped regions containing mostly massive and cross-bedded deposits.

The environment during the formation of these sediments was non-marine as no marine fossils have been reported. As there is no evidence of rounded sand grains, faceted pebbles, or dune stratification, the deposit~~ion~~ ~~was~~ is probably not of eolian ~~origin~~.

The field evidence strongly indicates that much of the Swauk formation was deposited in a large lake. The well stratified layers of alternating sandstone and shale are typical of those of large lake or marine deposition. The muds, granitic sands, and conglomerates were probably laid down contemporareously in different depths of the lake. Density currents moving down steep slopes may be an important mechanism for deposition of massive poorly sorted conglomerate, Migliorini (1950). Periodic rising and falling of the water would account for the sharp contacts existing between the beds. If the lakes (lucustrine deposition) were (was) a series of ephemeral bodies, there would be alternating dry periods causing the muds to become cracked. Also, there would be almost complete decomposition of the carbonaceous material and oxidation of the iron. A swampy environment would result in the formation of beds of coal and/or much calcareous mudstone and would not be favorable to the formation of a large amount of arkose.

The large lake must have been long-lived to accumulate thousands of feet of eroded detritus. However, it must have receded from time to time as illustrated by fluvial, deltaic, and paludal deposits irregularly present throughout the sequence. This is especially true in many parts of the Swauk Creek basin where much fluvioterrestal deposition occurred.

A nearby source to the northwest is indicated for some of the hetrogeneous conglomerates. Many cobbles and pebbles are characteristic of the rocks existing in the basement complex that extends towards Mt. Stuart. Also, the thick massive conglomerates at the contact of these older rocks wedge out to the south. Conversely a distant source is indicated for most of the finer sediments and much conglomerate. Resistant pebbles in many of the arkosic conglomerate beds are well-rounded and the arkose in general is more acid than the Mt. Stuart granodiorite.

Many lines of evidence were found to illustrate that the Cameas sandstone was deposited by streams and their related agencies. Massive, cross-stratified, and discontinuous lenticular beds are characteristic. Many of these have been eroded in the form of a river channel and refilled. (A large bulk) Much of the arkose is in thick sequences of forset beds that is best interpreted as deltaic deposition. A noteworthy feature is the presence of detached pebbles embedded in the sand and arranged like widely spaced beads on a string.

Gregory (1915, p. 493) reports this feature as characteristic of fluviatile conglomerates.

The clastics in the Camas sandstone were transported from a distant source in a relatively short time. The presence of the large amount of well washed arkose indicates rapid mobilization. The well-rounded larger detritus contains mostly highly resistant material that would come from a far source. The sediments could well have come from the migmatite province to the north which is composed of rocks containing the same minerals. Also, all foreset beds observed dipped in a southerly direction.

The following evidence is cited that there was a moist, warm-temperate climate at the time of accumulation of these continental clastics:

(1) There was abundant vegetation as evidenced from the amount of leaf and other carboniferous remains.

(2) La Motte (1936) states that the leaves of Swauk genera are today found far to the south close or within the tropics where there is abundant rainfall.

(3) There is universal mingling of fresh feldspar with clouded, weathered feldspar. Pettijohn (1949, p. 260) concluded this characteristic of tropical to subtropical accumulation. It is the result of the mixing of the partially decomposed mantle with that of the rapidly eroded rocks.

(4) Barton (1916 p. 435) records the accumulating quartz in arid climates retains red stained surfaces; whereas, the

arkose deposited in a moist climate is a gray color.

Age and Correlation

A great deal has been written concerning the age of the Swauk formation. A detailed review of the literature, including lists of several collections, was well presented by Willis (1950) and will not be repeated here. To sum up, most of the early work tended to show that the age was Eocene principally because of correlation with the Fort Union formation; this formation is now delegated to the Paleocene. A floral collection made by Chappell (1936) was taken from several areas in the Wenatchee quadrangle and was, as a whole, considered by LaMotte to be Paleocene.

From a leaf collection made by the author, Dr. Roland W. Brown identified only two plants to species. There are Lygodium kaulfussi Heer (fern) and Sabalites campbelli (Newberry) Lesquereux. He states that both plants occur all through the Eocene and are not diagnostic of any part of this epoch.

LaMotte (1952) lists these two species as occurring in the Eocene and/or Paleocene. As these collections were taken in strata several thousand feet above the base, the lowermost beds may well be much earlier--possibly upper Cretaceous.

LaMotte (1936) considers the flora of the Swauk and Nooksack--part of the Chuckanut formation--to be similiar. The Chuckanut is considered by Newberry and others to be the continental equivalent of the Upper Cretaceous Nanaimo formation, see McLellan (1927, p. 136).

All evidence is based upon fossiliferous plant remains as no faunal fossils have been cited from the Swauk formation. Paleobotanical age determinations is limited for two principal reasons: the occurrence of a species exists over a long span of geologic time and only limited detailed study has been done on these fossil plants.

The Teanaway basalt lies unconformably upon the Swauk formation. The mid-Eocene Roslyn rests conformably upon the Teanaway. Thus a large segment of geologic time is indicated for the deposition of over 5,000 feet of volcanics and the hiatus of the angular unconformity.

No plant remains were found in the Camas sandstone and it could not be determined from the literature if any previous floral collections were limited to this formation. The Camas sandstone, as previously pointed out, bears little resemblance to the Swauk formation and for several reasons is considered younger. The Camas arkose more closely resembles the Roslyn formation than it does the Swauk. The following information about the Roslyn formation was taken in part from field observation and thin sections studied by the author, and in part from Bressler's doctorate thesis (1951).

Both the Camas formation and the Roslyn formation have overall similar lithology--over 95% arkose and feldspathic sandstone and only a small amount of shale and conglomerate. The composition of the clastics shows no notable difference.

They were both deposited in thick massive or cross-stratified beds that have only been slightly folded. No evidence of faulting, silicification, or intrusion by the diabase dike swarms of presumed mid-Eocene age was found in the Camas or Roslyn.

The chief argument against this possible correlation is the unknown relationship of the Teanaway basalt with the Camas sandstone.

The evidence indicates the deposition of sediments in the Swauk formation probably started in late Cretaceous time, took place mainly in the Paleocene, and extended into lower Eocene. The Camas sandstone is probably younger based on insecure evidence is possibly Roslyn equivalent.

Post Swauk Intrusives

Dike Swarms

One of the outstanding geological features in the Swauk formation is the presence of northwest trending diabasic basalt dikes. There are actually thousands of such intrusions in this area but due to the impracticability of mapping each one, they are arbitrarily placed on the geological map in relative abundance.

Diabase is a term defined and applied in several ways. Its basaltic composition is the only property consistantly agreed upon. Otherwise, it is defined by a combination, or sometimes by only one, of the following properties: texture, genesis, grain size, and alteration. A diabasic texture is usually used synonomously with ophtic--although the latter is

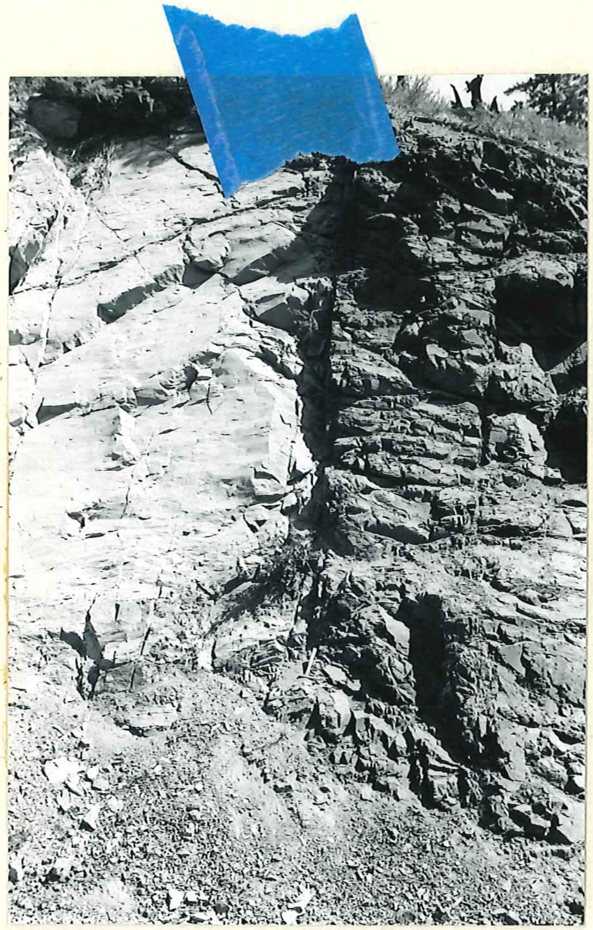


Fig. 11. Sharp contact of nearly vertical diabasic dike. Vertical jointing in arkose to left is parallel with the dike.

sometimes limited to rocks with an excess of augite over plagioclase--or is less often used to convey the lath like texture of plagioclase. This type of texture is almost always present in intrusions and rare in extrusions; so the term is ordinarily confined to the former exclusively. Some authors limit the term to medium grained, calci-alkali basalts. The English usage of dolerite corresponds to the American usage of diabase, and their diabase is reserved for an altered phase of this rock. In this paper the term diabase will refer to fresh, basaltic, intrusive, medium grained rocks; fine and coarse grained equivalents will be called diabasic basalt and diabasic gabbro respectively.

These intrusions are mostly diabasic basalt. The rock is fresh appearing, dark gray in color, and breaks with a hackly conchoidal fracture. Toward the center of the largest dikes the rock is a true diabase in which laths of plagioclase are seen with the unaided eye. Most outcrops are conspicuous from a great distance as they protrude above the sediments and are covered with a thin veneer of red iron oxide.

The basalt dikes have remarkably straight walls where they cut the sediments in a near vertical attitude. Baking effects on the country rock is almost negligible--in many contacts it is less than ½ of an inch. The dikes vary in width from less than a foot to over 300 feet. Although they average about 25 feet in width, these relatively thin dikes commonly persist for over ½ a mile along their strike.

The trend varies from N. 40 E. to N. 20 E. except in the vicinity of Liberty where extremely wide dikes trend almost east-west. Except in the latter area, they are nearly at right angles to the folding as are also one set of joints in the sediments. The dikes for the most part intruded these dialated joints. Most dikes that didn't follow this northeast trend were found to be injected into fault zones. A few irregularly shaped dikes cut the serpentine striking generally northwest but are not confined to that trend.

Several dikes occurring in the Wenatchee uplift are unusual. They are deeply weathered to a light brown color and have spheroidal parting. Many small dark patches gives the rock a porphyritic appearance. These dikes contain sediments that were engulfed and partially recrystallized at the time of intrusion. One injection of magma invaded a bed of conglomerate, dissolved the matrix, and left the pebbles embedded in the resulting dike.

Microscopically all fresh samples are strikingly similar. The small laths of basic labradorite enclosed by pyroxene identifies them as diabasic basalt. The pyroxene varieties augite and pigeonite typically show irregular borders; some are irregular patches but more frequently are equant subhedral grains. Olivine is sparingly present in small anhedral grains of apatite and opaque magnetite are accessory minerals.

Inspection of the deeply weathered dikes gives a clue to their origin. In addition to basalt minerals they contain as much as 20% quartz in grains with crenulated borders. Much of the material was evidently plucked from the arkose and partially dissolved by the magma. The mesostasis near the edge is composed of intermixed calcite, chorite, sideromelane, chlorophaeite, and other altered basalt glass.

These dike swarms are thought to be part of the feeder dikes for the Teanaway basalt for the following reasons. One was seen to broaden out into an apparent flow over the Swauk. It was subsequently eroded, and is now only a small patch of basalt about ½ of a mile away from the present Teanaway contact. The dikes are much wider and generally more numerous to the south where the flows are exposed. The petrology and chemical composition, Smith (1904, p. 6) is similar. Thompson (1932, p. 17) reports the basalt dikes are continuous with the Teanaway flow near Table Mountain.

Camas Land Gabbro

A large assymetrical diabasic gabbro sill-like body was intruded into the Camas formation. It forms a resistant plateau about 3½ miles long and 2 miles wide known as Camas Land. Most of the edges are steep cliffs of igneous rock that invariably dip towards the center in the manner of a lopolith.

The maximum thickness is usually indeterminable as the bottom contact is seldom exposed. On the northwest side the main body is about 400 feet thick below which is a 30 foot bed of arkose that separates it from another 14 foot sill. On the west side it is at least 1,200 feet thick and on the

Fig. 12. Showing contrast of two types of diabasic basalt dikes. On the left is a group of fresh appearing multiple dikes. On the right is a darker dike that contains much partially dissolved arkose and typically weathers in a spheroidal fashion.

south apparently only about 40 feet thick. The inward dips are variable but average about 15°. The immediately adjacent arkose beds depart from their homoclinal dip and are roughly conformable to the inward dips of the intrusion.

The gabbro is grey to greenish grey in color and mostly medium to coarse-grained. Aphanitic black portions are limited to the outer edges and two apophyses located on the northwest side. The rocks weather to a brown color with irregular zones showing dull reddish hues. Most outcrops contain an irregular pattern of joints that are filled with calcite. On the northeast side the exposures are jointed perpendicular to the surface of the deposit into slab like sheets ¼ to ½ inch thick.

This melanocratic phanerite is composed of plagioclase, pyroxene, and small amounts of magnetite. Ophitic texture is characteristic in which the augite enclosed the plagioclase. The plagioclase may constitute 2/3 or more of the rock, occurs in long laths up to 4 mm. in length, and is calcic labradorite in composition. The euhedral grains display albite twinning and a few show normal zoning. Augite and pigeonite occur in subhedral equant grains that are shorter than the elongate labradorite.

Magnetite is in both octahedral grains and in irregular replacement forms. Olivine was seen in one specimen.

Some sericitization and less often kaolinization of the plagioclases has occurred. Irregular veinlets of calcite and altered glass are occasionally present.

Fig. 13. East edge of Camas Land gabbro intrusion. The jointing in the gabbro is about 70° from the horizontal. Assuming this columnar jointing is at right angles to the upper surface, the inward dip would be about 20°.

One sample showed smaller, nearly equant grains of plagioclase that with the pyroxene formed a hypidiomorphic texture of a true gabbro. Chappel (1932) interprets this difference in formation and other features to be the result of magmatic differentiation of which he presents a detailed description.

<u>Teanaway Basalt</u>

This formation is composed of basalt flows, associated pyroclastics, and a small amount of sandstone and conglomerate. Its exposure just south of the Swauk formation forms a prominent ridge that curves northward on both sides of the mapped area forming a large U pattern. In the area covered south of Liberty it is a homoclinal structure dipping about 35° to the south where it rests upon the more horizontal Swauk beds and attains a progressively steeper dip away from the contact.

The basalt is in thick beds that show columnar structure and are well jointed. The rock is black to dark gray, fine grained and breaks into typically cubic blocks. The outcrops show red and reddish brown weathered exposures that contrast with jet black fresh portions.

A petrographical study shows it to be a plateau olivine-poor basalt. Except for lacking a diabasic texture it appears identical with the diabase basalt of the dike swarms.

The volcanic derived clastics are tuffs, lapilli, and breccia that are most commonly light buff and green, but are locally mingled hues of various bright colors. An extremely

Fig. 14. Diabasic dike apparently becoming a flow over the Swauk formation. This is removed ½ mile from known Teanaway and possibly was continuous with it at one time.

irregular band of this material varying from 400 feet to well over a thousand feet thick was laid down on the rough surface of the Swauk formation. Upon these tuffs and breccias are several thousand feet of basalt containing thin layers of intercalated pyroclastics. West of this area in the Teanaway River vicinity, the author observed a great thickness of pyroclastics including some black shale, and relatively few basalt flows.

In one locality at the base of the teanaway are several layers of sandstone consisting mostly of quartz grains and mica. Due south of the town of Liberty and stratigraphically about 200 feet above the base is a bed of conglomerate approximately 75 feet thick. It contains subrounded volcanic and granitoid cobbles up to 6 inches in diameter set in a well indurated matrix of tuff and sandstone.

Based upon the occurrences of vertebrate fossils in the Roslyn arkose, Wheeler (1955) considers this formation to be mid-Eocene. As the Roslyn apparently conformably overlies the Teanaway, these volcanics were presumably deposited only shortly before. Weaver (1937, p. 26) interprets the Teanaway basalt to be a possible equivalent of the lower to middle Eocene Metchosin volcanics.

Superficial Deposits

Only small amounts of gravels have accumulated in the V shaped valleys of the larger streams. Camas land is covered in part by alluvium as the result of deposition of a former stream, see Smith and Curtis (1900).

The only evidence of glaciation is shown by deposits of unsorted glacial debris in the Peshastin valley north of Ingalls Creek. A glacier that came down Ingalls valley widened the Peshastin valley from their junction northward.

For most of their lengths, Swauk Creek and its tributaries do not flow on bedrock but on gravels of probably Pleistocene and Recent age. Most of the stream valleys exhibit at least two alluvial fill terraces. The older one is high on the sides and represented by remnants of a former terrace. The lower is a well defined terrace locally over 70 feet above the creek. The alluvium consists of subrounded cobbles and boulders up to two feet in diameter among finer clastics. The gravels are basalt, diabase, and granitoid clastics and are lightly held together by a ferruginous cement. There is no evidence of glaciation in the drainage area of these streams. The deposits were probably paraglacial and caused, at least in part, by the rapid mechanical weathering that must have taken place in the existing cold climate.

STRUCTURE

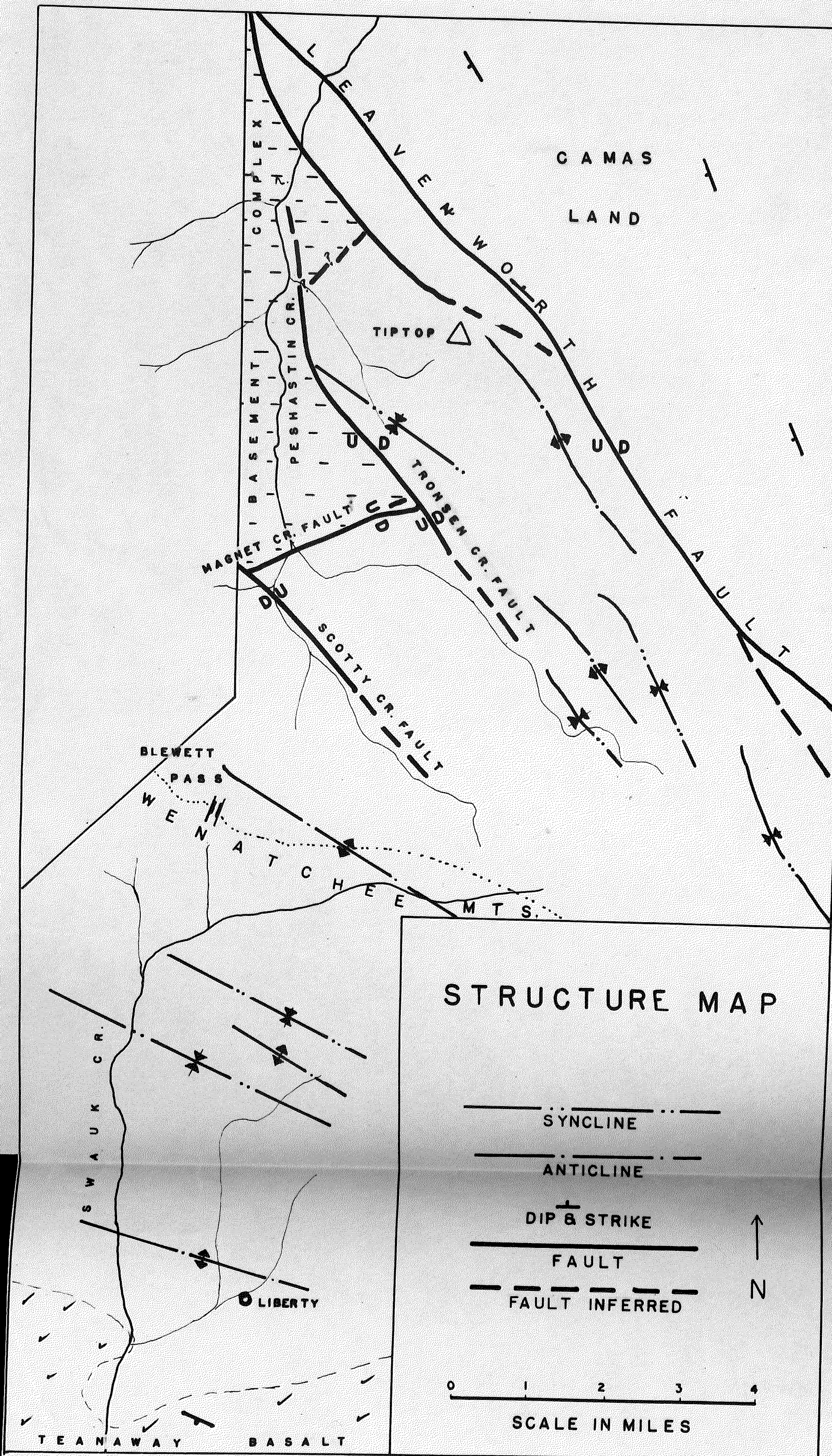
Basement Complex and its Contacts

The general structural trend in the pre-Swauk basement rocks is west-northwest. This is shown by the foliation in the Peshastin slates and large shear zones in the serpentine, some of which can be seen to extend several miles. Other shear zones trending in this direction have been intruded by nickeliferous siliceous carbonate. Several gold-bearing quartz and calcite veins in Culver Springs gulch have a similar strike.

Several pre-Swauk west-northwest trending granodiorite dikes were injected into the basement rocks. This indicates that this structural trend and some deformation was inaugurated before Swauk time. Later faulting is shown by the faulted and sheared diabase dikes of Eocene age that also cut the Swauk.

The contact of the basement rocks and Swauk formation is a series of faults of at least two ages. The massive conglomerate was deposited in wedges throughout the entire formation. The wedges are thick along the fault contact and progressively thin out away from it. It seems likely that faulting at or near this present contact took place during the entire time of Swauk deposition.

Later fault adjustments took place along some of these same zones. This is shown by the extension of the large faults into the Swauk sediments. Blocks of sandstone can be seen sheared within the serpentine several feet from the fault contact.



CAMAS
LAND
LEAVENWORTH FAULT
BASEMENT COMPLEX
PESHASTIN CR.
TIPTOP
UD
UD
DU
TRONSEN CR. FAULT
MAGNET CR. FAULT
SCOTTY CR. FAULT
BLEWETT PASS
WENATCHEE MTS.
SWAUK CR.
LIBERTY
TEANAWAY BASALT
STRUCTURE MAP
SYNCLINE
ANTICLINE
DIP & STRIKE
FAULT
FAULT INFERRED
N
0 1 2 3 4
SCALE IN MILES

Some of the faults can be demonstrated to have a large displacement. Over 5,000 feet of sediments that dip toward the serpentine are truncated by the fault just north of Shaser Creek. The contact fault along Ruby Creek displaces over 3,000 feet of south westerly dipping arkose.

These faults are well demonstrated in the field by the presence of fault breccia, gouge, slickensides, and truncation of bedded sediments. Many are characterized by the filling of secondary silica and/or diabase dikes. The Swauk-clastics near the faults are locally stained for several feet by hydrothermal iron-bearing solutions that later were oxided a bright red.

Leavenworth Fault

The Camas sandstone lies in the northwest trending Chiwaukum graben and in fault contact with the relatively up-thrown block of the Swauk formation. This graben was named by Willis (1953) who describes it as a downthrown block about 12 miles wide bounded on both sides by high angle fault contacts with basement rocks.

The western or Leavenworth fault extends southward into this area leaving the basement rocks and extending into the sediments. The most striking evidence for the fault is the contrast of the white massive arkose in the Camas with the sheared dark bedded shales, arkose, and conglomerates in the Swauk. Drag folding, breccia, microbreccia, gouge, slickensides, and siliceous intrusions were found along the entire fault.

The Camas sandstone is structurally a homocline in which over 6,000 feet of sediments dip southwesterly towards the fault. Willis (1953) estimated the displacement of the Leavenworth fault at about 10,000 feet. As this homoclinal dip extends eastward into the Wenatchee quadrangle, which would make several thousand feet more of homoclinal sediments, (see Chappel's map, 1936), at least this amount if displacement is probable.

Structures of the Peshastin Creek-Swauk Creek Area

Each of four areas in the Swauk sediments in the Peshastin Creek-Swauk Creek area has different but characteristic structures.

The area from the Teanaway-Swauk contact north to Hurley Creek is one of broad open folds whose limbs generally have attitudes of less than 40°. The strata are folded into two major anticlines that trend west-northwest. West of Swauk Creek analagous strikes to this general trend were found—further investigation to the west is required to determine the structural pattern in this adjacent area. Although several silicified zones and other small faults were noted, less faulting was seen than in any other part of the Swauk.

North of Hurley Creek to the fault along Scotty Creek is an area whose principal feature is over 7,000 feet of steeply dipping beds compressed into a large anticline. The limbs contain many irregular flexures whose attitudes vary greatly in a distance of a few feet. The axis of this fold coincides roughly with the crest of the Wenatchee mountains. Along this axis are a great number of faults and shear zones.

The trend of folding is the same as that to the south. Much of the folding is pre-Teanaway as this basaltic formation rests with a marked angular unconformity upon the Swauk. Some deformation took place in a later Tertiary episode as the Teanaway basalt was folded and strikes along the same northwest axial trend. Many of the Teanaway dikes in the major fold forming the Wenatchee Mountains are sheared showing renewed folding along the axis of this anticline during post-Eocene time. These mountains extend southeast where they are capped by the Yakima basalt. Laval (1956) found that the west-northwest folding of the Yakima basalt in that area was accomplished in Pliocene time.

The area between Scotty Creek and Tronson Creek contains strata of different lithology than exists in the thousands of feet of Swauk beds on each side of it. There are more beds of conglomerate, more thin beds of fine-grained sandstone, and all beds are more coherent than the ones in adjacent areas.

The lithology of the strata indicates they are stratigraphically lower than the units on each side. The area is bounded by high angle faults on each side that are extensions of the fault contacts with the basement rocks. Based on this evidence it appears probable that it was elevated along with the basement complex as a small horst. The sediments in this upthrown block were not pushed as high as were the basement rocks--this differential movement resulted in a high-angle fault along Nagnut Creek at the Swauk serpentine contact.

The faults forming the sides of this horst parallel the Chiwaukum graben and it is possibly a minor structure formed at the same time as the major graben. Evidence suggests that the Scotty Creek fault is a high-angle reverse fault, and the Tronsen Creek fault may also be the same. The nature of such faults suggest this block was raised by horizontal compression. Further evidence is the tightly compressed folds that parallel these faults in the area between this small horst and the major graben. Thus, the entire area west of the Leavenworth fault appears as a large horst with a smaller horst formed differentially in it. An interpretation by the author, based largely on the preceding evidence, is that the Chiwaukum graben may have been formed by compression similar to the ~~structural~~ interpretation of the Rhine Graben, Nevin (1949, p. 114). This closely coincides with the views expressed by Willis (1953, p. 794) who states that the faults and folds of the Chiwaukum graben are the results of compressional stress transmitted through the rocks of the basement complex.

The area between Tronsen Creek and the Leavenworth fault is one of complex folding and faulting. Many of the strata are vertical and some are overturned. The folds are typically assymetrical having the steeper attitudes near the axis of the syncline, rather than on the limbs.

Minor flexures and faults are universally present in the area. One thinly bedded section of conglomerate, arkose, and shale about 200 feet thick was compressed into a 90 degree bend in a distance of about 70 feet. The folding was not accomplished by bending but by seven offset shears, that cut entirely across the beds, and by numerous small shears.

Sheared areas are more common adjacent to the Leavenworth fault in sharp contrast to the unsheared Swauk arkose immediately to the northeast across the fault. Two large and particularly complexly sheared areas are along Tiptop ridge and along Mission Creek. The trend of the shearing and folding does not parallel the west-northwest trend that is characteristic of the basement complex and of the Swauk Creek area, but follows the structure of the graben suggesting it was accomplished by the same forces that caused the graben.

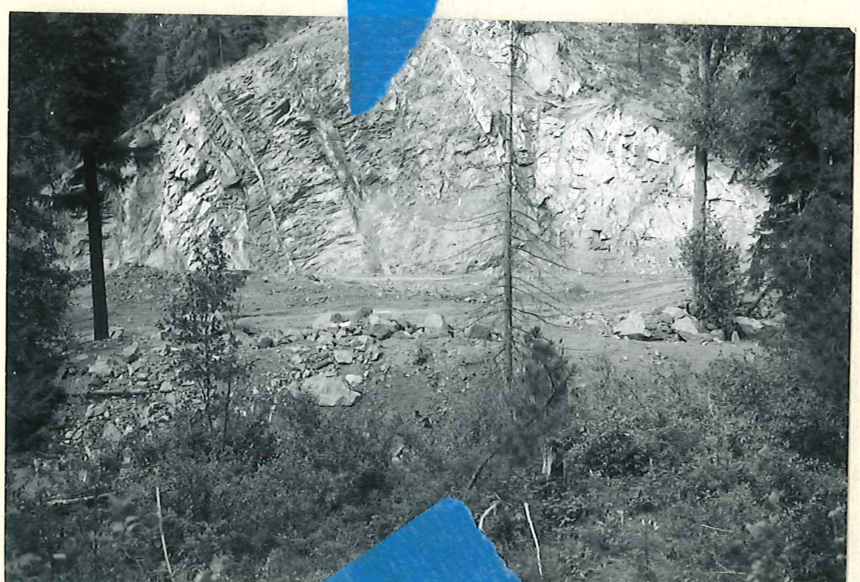


Fig. 15. New road cut showing Magnet Creek fault crossing Tronsen Creek. On the left behind tree is serpentine; on the right Swauk arkose. Multiple dikes in between coming up fault plane shows this is a high angle normal fault.

BIBLIOGRAPHY

Barton, D. C., 1916, Geological significance and genetic classification of arkose: Jour. Geology, vol. 24, pp. 417-449.

Bressler, C. T., 1951, The petrology of the Roslyn arkose central Washington: Pennsylvania State College doctorate thesis.

Chappell, W. M., 1936, Geology of the Wenatchee quadrangle, Washington: University of Washington doctorate thesis.

________________, 1951, Endogenetic alteration of the Camas Land irruptive, Chelan County, Washington: M. S. Thesis, Department of Geology, University of Washington.

Coombs, H. A., 1950, Granitization in the Swauk arkose near Wenatchee, Washington: American Jour. of Science, pp. 369-377.

Gregory, H. E., 1915, Formation and distribution of fluviatile and marine gravels: Am. Jour. Sci., vol. 189, 1915, pp. 487-508.

Knowlton, F. H., 1904, Notes on the fossil plants of the Swauk formation. (In Mount Stuart folio No. 106, U. S. Geol. Surv., by G. O. Smith), p. 5.

Kuenen, P. H. and Migliorini, C. I., 1950, Turbidity currents as a cause of graded bedding: Jour. Geology, vol. 58, pp. 91-126.

Lamey, C. A., 1951, The Blewett iron-nickel deposits, Chelan County, Washington: U. S. Geol. Surv. Bull. 969 d, pp. 97-103.

La Motte, R. S., 1936, Preliminary report on fossil collection from the Swauk formation at the University of California (In Geology of the Wenatchee quadrangle, University of Washington doctorate thesis, by W. M. Chappel, p. 73).

________________, 1952, Catalogue of the Cenozoic plants of North America: Geol. Soc. America Memoir 51.

Lupher, R. L., 1944, Stratigraphic aspects of the Blewett-Cle Elum iron ore zone, Chelan and Kittitas Counties, Washington: Report of Investigations, No. 11, State of Washington, Dept. Cons. & Dev.

McLellan, R. D. 1927, The Geology of the San Juan Islands: University of Washington doctorate thesis.

Nevin, C. M., 1949, Structural Geology, 4th edit., John Wiley & Sons, New York, N. Y.

Page, B. M., 1939, The Geology of the southeastern quarter of Chiwaukum quadrangle: Stanford University Doctorate Thesis.

Pettijohn, F. J., 1949, Sedimentary Rocks, Harper & Bros., N. Y.

Russell, I. C., 1899, A preliminary paper on the geology of the Cascade Mountains in Northern Washington: U. S. Geol. Surv. Twentieth Ann. Rept., pt. 2, pp. 89-210.

Smith, G. O., 1904, U. S. Geol. Surv. Atlas, Mount Stuart folio (No. 106).

_______________, and Curtis, G. C., 1900, Camasland; a valley remnant: Geol. Society of America Bull. vol. 11, pp. 217-222.

Smith, W. S., 1916, Stratigraphy of the Skykomish Basin, Washington: Jour. Geol., vol. 24, pp. 559-582.

Thompson, J. P., 1932, Genesis of the Swauk placer gold, Swauk mining district, Washington: M. S. Thesis, Dept. of Geology, Washington State College.

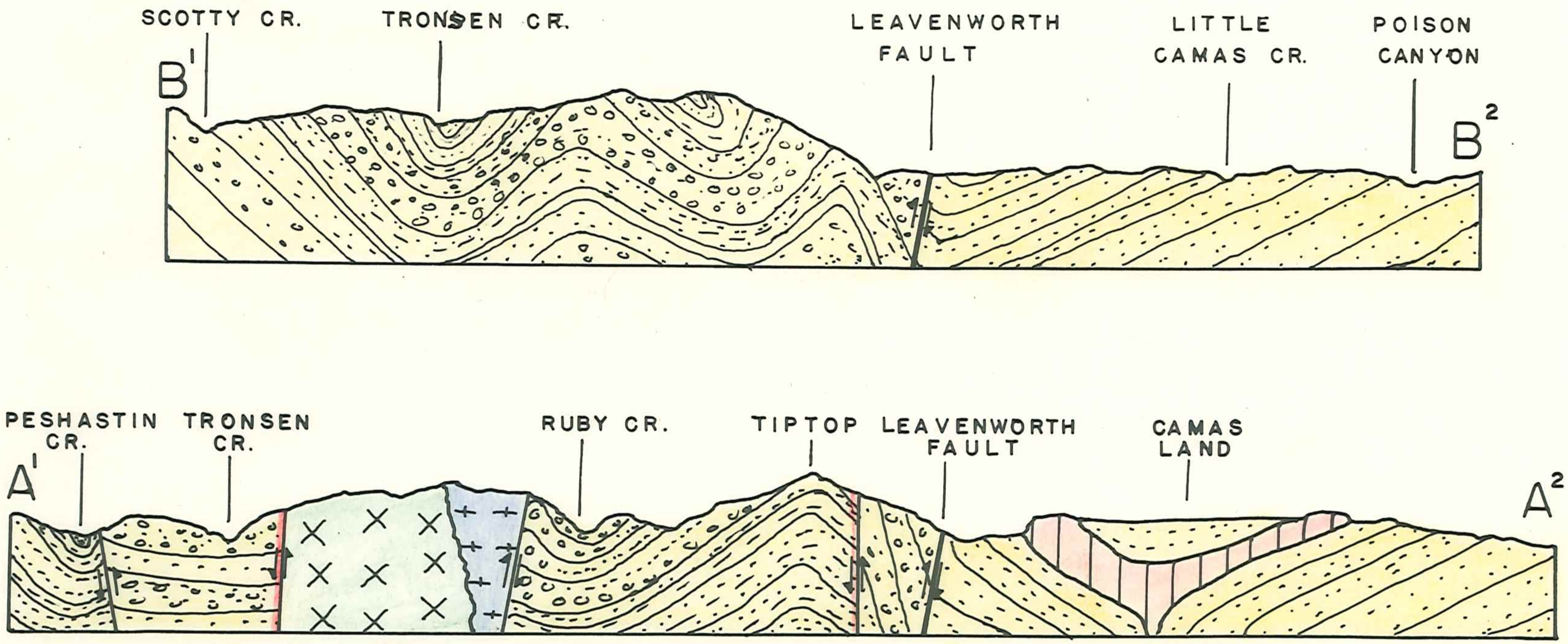
Weaver, C. E., 1911, Geology and ore deposits of the Blewett mining district; Washington: Wash. Geol. Surv. Bull. No. 6.

_______________, 1937, Tertiary stratigraphy of Western Washington and Northwestern Oregon: Univ. of Wash. Publ. in Geol. vol. 4.

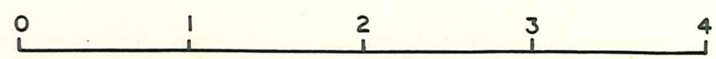
Willis, C. L., 1950, Geology of the northeast quarter of Chiwaukum quadrangle: University of Washington doctorate thesis.

_______________, 1953, The Chiwaukum graben, a major structure of central Washington: Am. Jour. of Science, Vol. 251, pp. 789-797, Nov. 1953.

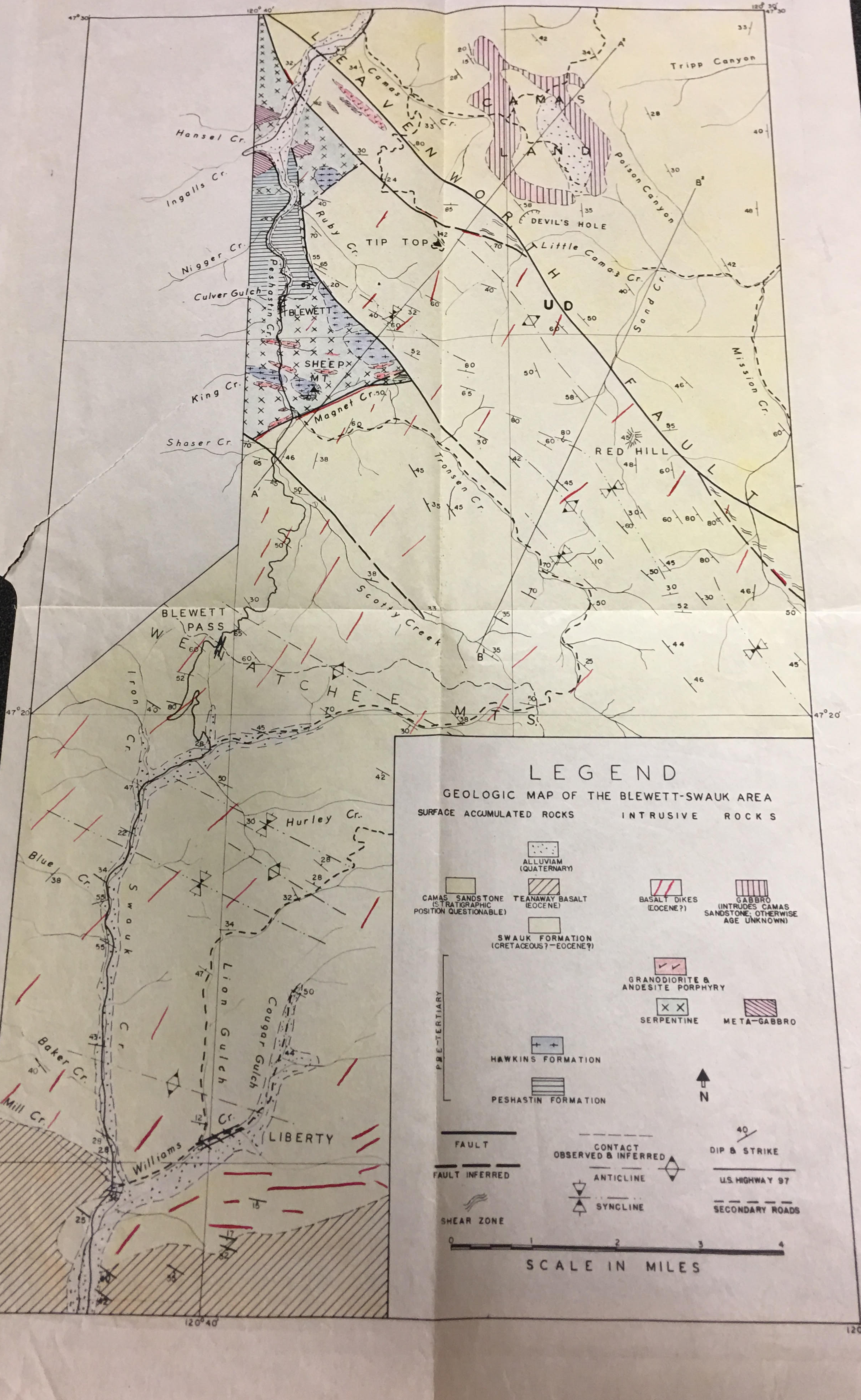
Zoldok, S. W., 1948, Cle Elum iron-nickel deposits, Kittitas County, Washington: U. S. Bureau Mines Report of Investigations, No. 4189.



STRUCTURE SECTIONS



SCALE IN MILES
HORIZONTAL & VERTICAL


LEGEND
GEOLOGIC MAP OF THE BLEWETT-SWAUK AREA
SURFACE ACCUMULATED ROCKS
INTRUSIVE ROCKS
ALLUVIAM (QUATERNARY)
CAMAS SANDSTONE (STRATIGRAPHIC POSITION QUESTIONABLE)
TEANAWAY BASALT (EOCENE)
BASALT DIKES (EOCENE?)
GABBRO (INTRUDES CAMAS SANDSTONE; OTHERWISE AGE UNKNOWN)
SWAUK FORMATION (CRETACEOUS? — EOCENE?)
GRANODIORITE & ANDESITE PORPHYRY
PRE-TERTIARY
SERPENTINE
META-GABBRO
HAWKINS FORMATION
PESHASTIN FORMATION
N
FAULT
FAULT INFERRED
CONTACT OBSERVED & INFERRED
ANTICLINE
SYNCLINE
DIP & STRIKE
U.S. HIGHWAY 97
SECONDARY ROADS
SHEAR ZONE
0 1 2 3 4
SCALE IN MILES
47°30'
120°40'
120°30'
47°20'
LEAVENWORTH FAULT
CAMAS LAND
Camas Cr.
Tripp Canyon
Poison Canyon
DEVIL'S HOLE
TIP TOP
Little Camas Cr.
Sand Cr.
Mission Cr.
Hansel Cr.
Ingalls Cr.
Nigger Cr.
Culver Gulch
Peshastin Cr.
Ruby Cr.
BLEWETT
SHEEP MT.
King Cr.
Magnet Cr.
Shaser Cr.
RED HILL
Tronsen Cr.
Scotty Creek
BLEWETT PASS
WENATCHEE MTS.
Iron Cr.
Hurley Cr.
Blue Cr.
Swauk Cr.
Lion Gulch
Cougar Gulch
Baker Cr.
Mill Cr.
Williams Cr.
LIBERTY
UD
A
A'
B
B'