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A Tectonic Study of a Part of the Northern Eagle Cap Wilderness Area, Northeastern Oregon

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Title: A Tectonic Study of a Part of the northern Eagle Cap Wilderness Area, northeastern Oregon.

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Upper Triassic metavolcanic and metasedimentary strata in the study area are intruded by the Hurricane Divide and Craig Mountain Plutons of the Late Jurassic-Cretaceous Wallowa Batholith. The Clover Creek Greenstone is overlain by the Martin Bridge Limestone, which is in turn overlain by the Hurwal Argillite; although the sequence is in normal stratigraphic order, contacts are generally tectonic. Concurrent with Early-Middle Jurassic regional deformation, during which the strata were folded about northeast trending axes and intruded by intermediate to mafic dikes, emplacement of the plutons of the Wallowa Batholith

began. The plutons intruded vertically through the greenstone and limestone and then horizontally above the greenstone. This resulted in intense penetrative plastic deformation particularly of the Martin Bridge Limestone. Emplacement of the Hurricane Divide Pluton followed a northeast axis, and resulted in isoclinal folding and the formation of northerly trending synformal anticlines in the Martin Bridge atop a zone of uncoupling between the plastic limestone and the more rigid underlying Clover Creek metavolcanic basement. Subsequent final emplacement of the Craig Mountain Pluton caused cross folding of these anticlinal structures.

Granitic plutonism was followed by regional uplift with associated faulting and erosion. Miocene Columbia River Basalt flood lavas were injected along many of the more northerly trending of these faults. This magmatism was concurrent with or followed by block uplift on the order of 1800 m of the Wallowa Mountains along the Wallowa Fault.

A TECTONIC STUDY OF A PART OF THE NORTHERN EAGLE CAP WILDERNESS AREA, NORTHEASTERN OREGON

by

KENNETH GORDON NEAL

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TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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PURPOSE OF STUDY

The area studied was chosen for the following reasons:

(1) previous studies in the area have been contradictory, especially concerning contact relationships between units; this was at least in part due to both the intensity of deformation and the rugged terrain;

(2) no detailed structural analysis had been completed in the area;

(3) the area provided an excellent opportunity to study deformation adjacent to plutonic contacts with good vertical as well as horizontal control.

PREVIOUS WORK

Lindgren (1901) was the first geologist to report extensively on mineralization in northeastern Oregon. He recognized the presence of granitic rock and Triassic limestone in the Wallowas. Swartley (1914) determined the extent of the Wallowa Batholith. Moore (1937) was first to map in the Wallowas, and was followed, in the northern Wallowas, by Smith and Allen (1941), who were the first to recognize the difference in deformation styles above and below the limestone-greenstone contact, and named the rock units in the area. Krauskopf (1943) published a petrographic analysis of the rock units, and Palen (1955) and Laudon (1956) divided the sedimentary units between them and completed detailed stratigraphic sections for Master's degrees which they received from the University of Wisconsin in 1956. Smedes mapped in the northern Wallowas, covering roughly the same area as Smith and Allen,while working on a doctoral dissertation at the University of Washington which he completed in 1959. While his map contains many questionable interpretations, he was the first to recognize the contact between the Martin Bridge Limestone and the adjacent metavolcanic rock as tectonic. Goebel (1963) mapped lithology in a part of the Lostine River Canyon for his Master's degree from the University of Oregon. Bruce Nolf received a Ph. D. from Princeton University in 1966 for his work in the Wallowa Mountains north of Craig Mountain, which includes a detailed biostratigraphic section, in addition to a general study of depositional and tectonic history of the area. W. H. Taubeneck from Oregon

State University has worked in the Wallowas intermittently for the past fifteen years, petrographically analyzing the plutonic rocks of the area.

METHODS OF ANALYSIS

Steps involved in analysis of the area included:

(1) preliminary air photo interpretation;

(2) library study;

(3) reconnaissance of the northern Wallowas;

(4) detailed mapping, and;

(5) laboratory analysis.

A preliminary air photo map (1:12, 000) was prepared prior to field investigation. Because of the high quality of the U. S. Forest Service air photos (also 1:12, 000) and lack of vegetation, a great deal of information including major structural trends and locations of contacts was obtained. The major difficulty encountered in working with these photos was overcoming distortion caused by the great relief.

A reconnaissance of the northern Wallowas was undertaken in late June, 1972, mainly to determine logistical difficulties to be encountered and to compare the general geology of all of the Wallowas to that of the map area. Areas covered included Hurricane Creek, Thorp Creek, West Fork of the Wallowa River to Polaris Pass, Ice Lake, and part of the Lostine River valley accessible by car. A total of 167 km (100 miles) was covered on foot while on reconnaissance.

Detailed mapping of the area was conducted between July 4 and August 22, 1972. Six base camps, two on Thorp Creek, two on Hurricane Creek, one at

B. C. Basin, and one at Ice Lake, were established during this period by backpack and were occupied for as long as thirteen days. A final camp was established at Ice Lake the second week in September, but mapping was curtailed after 5 days because of snow. Points on the map were located by resection using a Brunton compass. The 25 traverses totalled 69 km (41. 5 miles) horizontally one way. A total of 180 km (108 miles) were covered on foot for supply logistics. The total distance, therefore, covered on foot during this project from beginning to end was about 467 km (280 miles).

LOCATION AND ACCESS

The map area, consisting of approximately 36 km^2 (13 sq miles) is located in northeastern Oregon (Fig. 1) some 14 km south of the town of Enterprise. It includes parts or all of Sections 25-28 and 33-36, T. 3 S., R. 45 E., and Sections 1-4 and 9-12, T. 4 S., R. 45 E. The northern Eagle Cap Wilderness Area may be reached by driving east from LaGrande on Oregon Highway 83. The map area is best reached by either driving south from Enterprise up Hurricane Creek to Falls Creek Campground or east from Enterprise on Oregon Highway 83 through Joseph to the Wallowa Lake State Park.

From Falls Creek Camp, the map area may be reached by following the Hurricane Creek Trail (USFS number 1807) south past the two mile marker to a steep break in slope north of Slick Rock Creek. The center of the map area (Thorp Creek) can be reached from this point by crossing a log over Hurricane Creek and either (1) following Hurricane Creek along its east bank downstream for about a kilometer until a large meadow is reached; from this point a vague trail runs east from the meadow and, if it can be followed, leads up a steep knife-edged ridge along the divide between Twin and Thorp Creeks and then turns south along the ridge toward the high glacial valley on Thorp Creek, now known as Harris Basin; or (2) following Thorp Creek east until the canyon becomes too narrow to be passible, and then turning south up the steep ridge that forms the top of the east wall of Sacajawea; the route traverses along the east side of the

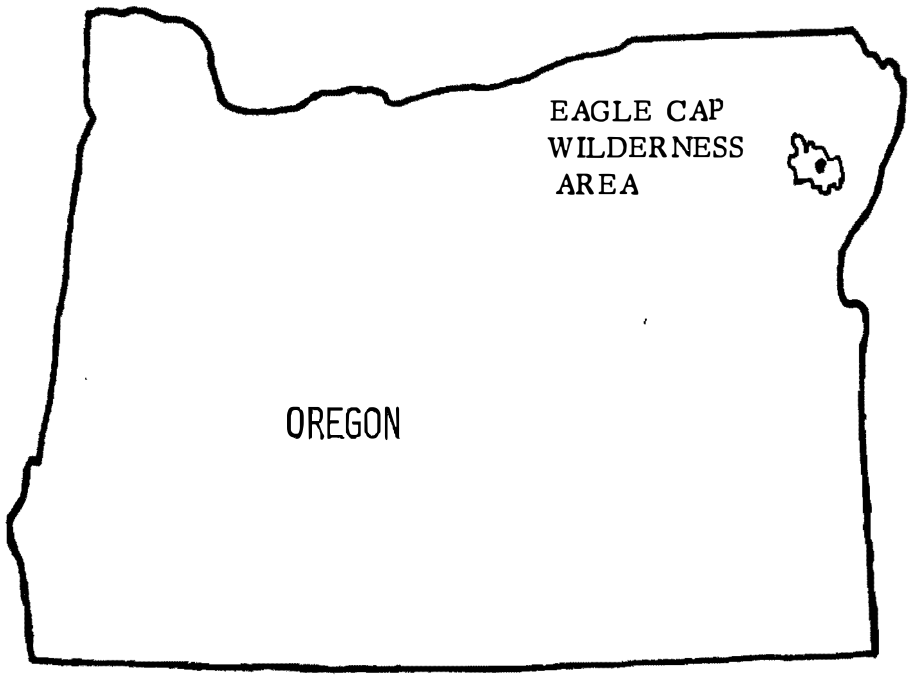


Fig. 1. Location map. Area studied is black region inside Eagle Cap Wilderness Area.

ridge through thick brush and crosses the creek about one kilometer north of the basin, which can be reached easily from this point. The Hurricane Creek Trail itself leads south from Slick Rock Creek into the map area, and numerous routes from this trail lead eastward to points of interest on Sacajawea Peak and the Matterhorn. Most of these routes can be covered without technical climbing techniques, and the only real hazard encountered was rockfall from the vertical face of the Matterhorn.

The eastern end of the study area can be reached by following the West Fork Wallowa River Trail (USFS number 1820) either to the Chief Joseph Mountain Trail, which is followed west to B. C. Creek where an abandoned trail is followed to B. C. Basin, or to the Adam Creek Trail (USFS number 1808), which leads to Ice Lake. Anyone following the B. C. Creek Trail should use caution in marking his route, as a wrong route followed on the way out can lead down blind gulleys to steep cliffs.

Difficult access to the area has been at least partially responsible for previous errors in mapping, and will continue to limit detailed studies of the Wallowas to relatively small areas.

GEOMORPHOLOGY

There is 1224 m (4079 ft) of relief in the map area. Elevations range from a low of 1728 m (5760 ft) where Slick Rock Creek joins Hurricane Creek to 2952 m (9839 ft) at the summits of the Matterhorn and Sacajawea Peak. Slopes range from low angles in glacial valleys to as high as 60 degrees near ridgetops. Although valleys in general are typically U-shaped (Fig. 2), variations in slope due to differential weathering between limestone and argillite, and narrow V-shaped stream valleys caused by rejuvenation in larger valley floors distinguish these from the typical glacial valley. Hanging cirque valleys at elevations of 2160 m (7200 ft) and 2400 m (8000 ft) mark the bases of former tributary ice flows; the 2160 m elevation probably marks the maximum elevations of glaciers that flowed down the Hurricane Creek valley, as large granodiorite boulders which originated at the Craig Mountain Pluton are found along the valley walls at this elevation.

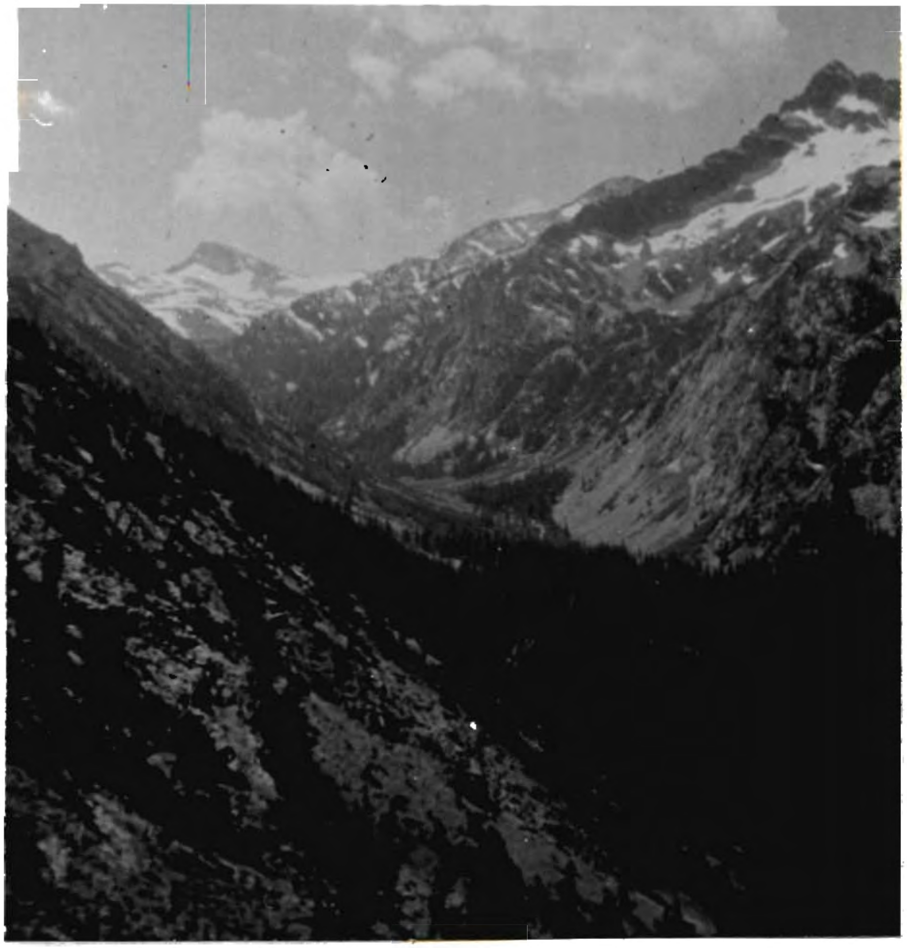


Fig. 2. U-shaped glacial valley, Hurricane Creek. View is southwest from Sacajawea Peak.

CLIMATE AND VEGETATION

The Wallowa Mountains are an area of somewhat higher rainfall than the surrounding plateau country but no reporting stations are located within them except for a snow survey station at Aneroid Lake. In the high country, rainfall is generally limited in the summer to orographically-produced thunderstorms and occasional weak Pacific storms, and in the winter to generally heavy snowfall. The average highest observed snow depth at Aneroid Lake Number 1 gauge is an April 1 reading of 97 inches, to 1960. This data is again undoubtedly outdated because of heavy snowfall in 1968 and 1972. The latter produced snow depths reportedly seven feet deeper than the top of the twenty foot gauge.

Weather during the 1972 field season was quite pleasant. Excepting occasional thunderstorms, only three major storm systems passed through the area during the 2 1/2 months of mapping. The snow-free season lasted exactly two months, as snowfall occurred on July 9 and again on September 9.

Vegetation varies greatly with altitude. Near the level of the plateau it is typical of the temperate forests east of the Cascades, with white and Douglas fir, some lodgepole pine, and hemlock. Forest types vary from this to the alpine, with stands of whitebark pine. Vegetation above 2400 m (8000 ft) in altitude is limited to alpine scrub and few dwarf trees. In the northernmost Wallowas, the timberline tends to coincide with the Clover Creek-Martin Bridge contact with Martin Bridge overlying the greenstone on the uphill side. The timber, in general, tends to be confined to the greenstone side of the contact.

DESCRIPTION OF ROCK UNITS

Rock types in the northern Wallowas (Fig. 3) include:

(1) stratified Mesozoic rock units, the Upper Triassic Clover Creek Greenstone, Martin Bridge Limestone, and Upper Triassic-Lower Jurassic Hurwal Argillite;

(2) Mesozoic intrusive rocks including Early (?) to Late Jurassic intermediate to mafic dikes, and Late Jurassic to Cretaceous granitic rock including and related to the Wallowa Batholith; and

(3) Tertiary Columbia River Basalts, feeder dikes in the study area, and flows in adjacent areas.

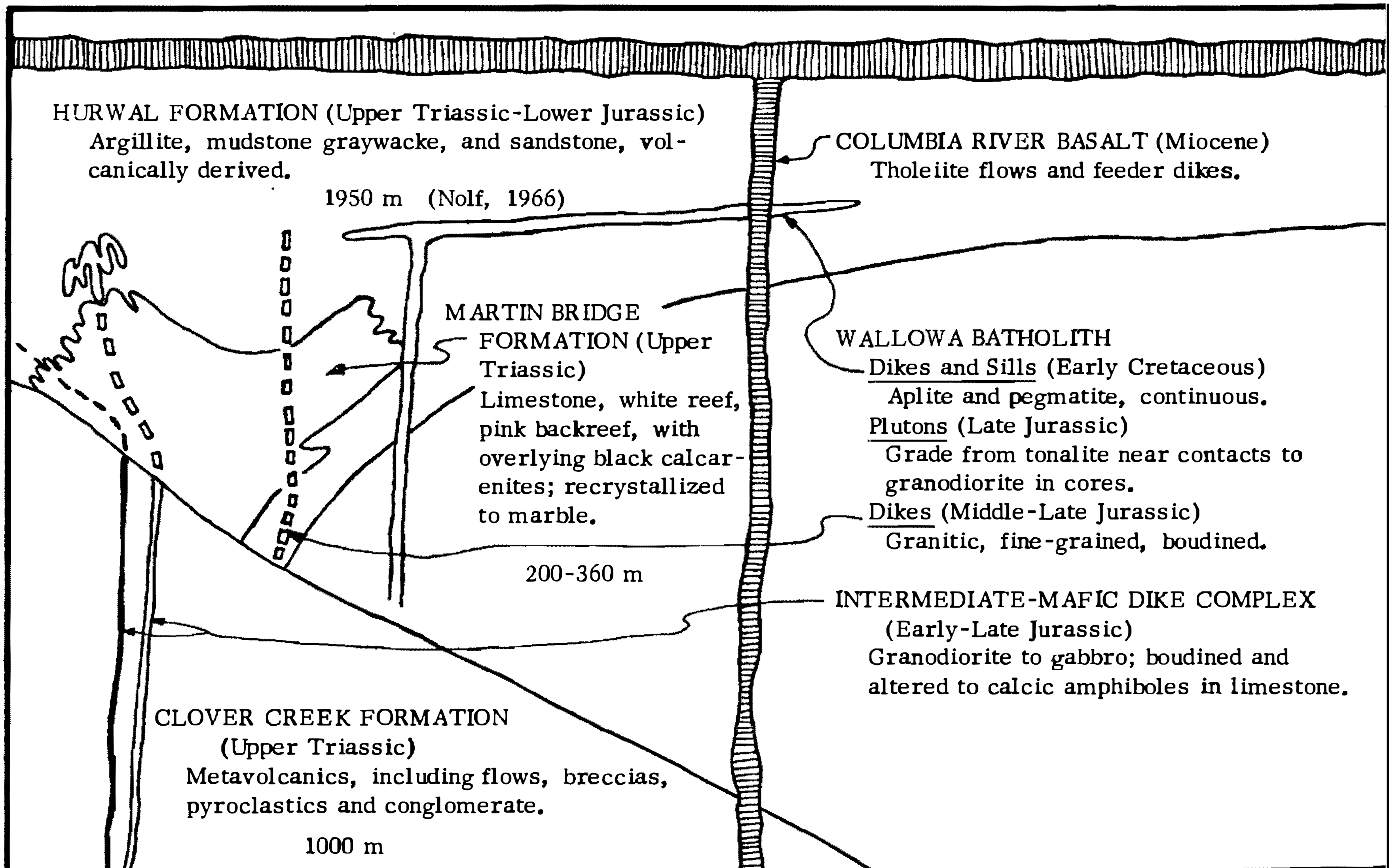


Fig. 3. Stratigraphic sequence, northern Wallowa Mountains, northeastern Oregon.

STRATIFIED MESOZOIC ROCK UNITS

Mesozoic strata in the northern Wallowa Mountains include, from oldest to youngest:

(1) Clover Creek Greenstone, 900 m of metavolcanic and metasedimentary rocks;

(2) Martin Bridge Limestone, 200-360 m of what are probably reef and backreef deposits, overlain by black calcarenites; in the area studied, these have all been recrystallized to marble; and

(3) Hurwal Argillite, 900 m in the area studied, 1950 m at Twin Peaks (Nolf, 1966) of volcanically derived fine grained marine sedimentary strata.

I. CLOVER CREEK FORMATION

General Discussion

The Clover Creek Greenstone was named by Gilluly (1937) for rocks exposed near Clover Creek in the northeast corner of the Baker Quadrangle. Koch and Bowen (1962, in Proska and Bateman, 1962, p. 3) further subdivided the formation into two members, the Harsin Ranch Member, a section of Permian metavolcanic and sedimentary rocks, and the Tucker Creek Member, a section of Upper Triassic metavolcanic flows, breccias, and pyroclastics. Allen (oral communication, 1972) and Nolf and Taubeneck (1963) found Phosphoria (Permian) fauna in graywacke and conglomerate to the south of and in the southern Wallowa Mountains.

Lithology

Nolf (1966) in his doctoral dissertation, described in detail the rock units of the northern Wallowas and the fauna within them. Nolf divided the Clover Creek, which is only Upper Triassic (equivalent to the Tucker Creek Member) in the northern Wallowas, into three members. These include, from oldest to youngest, the Mount Howard Member, composed chiefly of metavolcanic breccia, the Chief Joseph Member, of fine to coarse grained marine sedimentary rocks, and the Dunn Creek Member, composed of massive metavolcaniclastics. Nolf (1966) found only the latter two members of the Clover Creek exposed in the study area. Since the emphasis of this report concerns deformational rather than depositional history, no attempt was made to subdivide these units while mapping them.

Outcrops and Contact Relationships

Only four accessible outcrops of Clover Creek Greenstone occur in the area, so, generally, contacts were located approximately by differentiating between float types. Only two contacts between the greenstone and limestone occur in outcrops within the map area. One of these is a north-south trending vertical fault in B. C. Basin. The other, at the top of an inaccessible talus slope, on the north face of a ridge running east from Hurwal Divide, is a nearly horizontal contact with relatively undeformed greenstone underlying isoclinally folded limestone whose fold axial planes dip slightly to the west, parallel to the contact.

Thickness

The outcrop mentioned in the above paragraph continues eastward to the West Fork of the Wallowa River, where, the estimated thickness of these presumably undeformed beds equals or exceeds 1000 m. Since the base of the unit is not exposed, and thickness of this formation in Hells Canyon are far greater (Vallier, 1972), the 1000 m section is probably a minimum figure.

II. MARTIN BRIDGE FORMATION

General Description

The name Martin Bridge Formation, taken from a bridge over Eagle Creek, was limited to Upper Triassic calcareous sedimentary rocks exposed in the Wallowa Mountains by Ross (1938). This formation crops out in the study area as pink fine-grained to white medium to coarse grained recrystallized limestone, overlain by fossiliferous black calcarenites, all isoclinally folded. The complete common rock section can best be classified as marble in the area of study.

Lithology and Age

Nolf described three members of the Upper Triassic Martin Bridge Formation north of the study area where they are relatively undeformed. These include: the Hurricane Creek Member, which he interprets as a reef, the B. C. Creek Member, thinly bedded calcilutites, pink to duff in color, interpreted as back reef deposits, and the Scotch Creek Member, which overlies the other two and is composed of coarse fossiliferous black calcarenites. Coral, belemnites, brachiopods, and ammonites were found in this member on the west side of Hurwal Divide.

Outcrops and Exposures

Seventy percent of the exposures in the area are of this formation.

Martin Bridge marble crops out along canyon walls and creek bottoms in much of the area. It forms the conspicuous wall east of Hurricane Creek between Sacajawea Peak and the Matterhorn, and the steep wall which towers over Thorp Creek, forming the eastern front of Sacajawea Peak. It is by far the best exposed rock unit in the study area.

Thickness

The intensity of plastic deformation in the area precludes accurate measurement of thickness. The best estimate, determined by comparing cross sectional area of marble perpendicular to fold axial trends with the rough estimate of length of any given "bedding" plane along this same section, gives an approximate original bedding thickness of limestone somewhere between 120 and 270 meters. Nolf (1966) measured an undeformed section on Twin Peaks and determined it to be 1100 to 1200 feet (330 to 360 m). The thickness of black calcarenite increases greatly to the east and south, especially on the flanks of Hurwal Divide near Adam Creek.

Recrystallization and deformation of this formation (Fig. 4) in the map area has produced a section of marble which reaches thicknesses on the order of 3000 m in structural highs.

Contact Relationships

The nature of the depositional contact between the Martin Bridge and the underlying greenstone could not be observed in an undisturbed state in the map area. Nolf (1966) described it as conformable at Chief Joseph Mountain. The

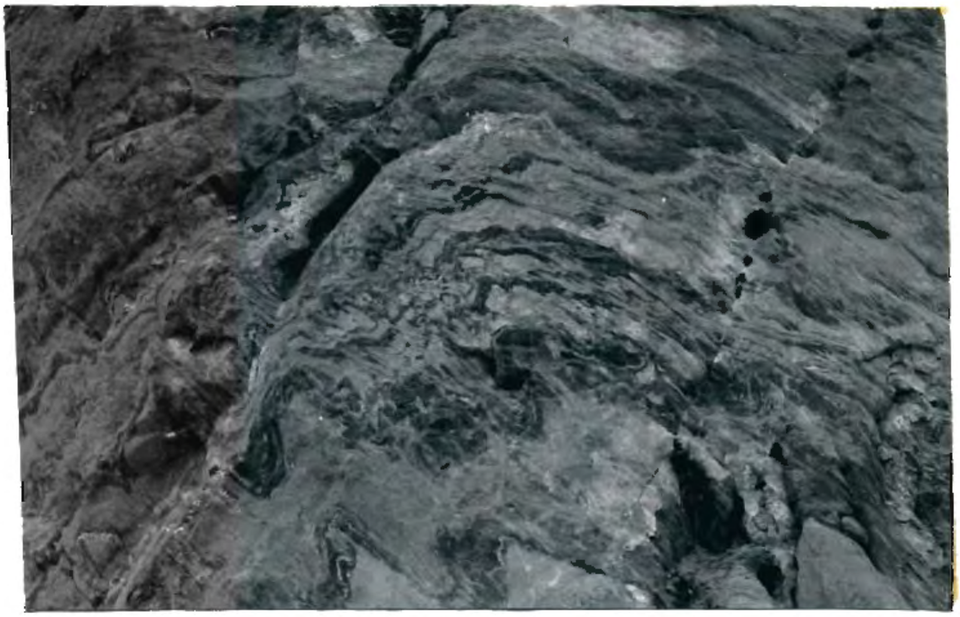


Fig. 4. Photograph of isoclinal folding in metamorphosed Martin Bridge Limestone. The high degree of plastic deformation resulted in recrystallization and plastic flowage. The planar features observed in the formation are generally foliation rather than original bedding. Photograph was taken near Thorp Creek at base of southeast face of Sacajawea Peak.

contact in the area can best be described as tectonic, a zone of uncoupling (a décollement) between the rigid undeformed metavolcanic material and the overlying plastic isoclinally folded marble (Fig. 5).

The Martin Bridge is overlain by the Hurwal Formation along a mixed gradational contact, in some sense tectonic because of plastic flowage in the marble.

Fig. 5. Martin Bridge-Clover Creek contact, ridge south of B. C. Basin. The contact (dashed line) is a zone of uncoupling between the isoclinally folded marble and the relatively undeformed metavolcanic basement.

III. HURWAL FORMATION

General Description

The Hurwal Formation, named by Smith and Allen (1941) for rocks exposed on Hurwal Divide, is a sequence of largely argillaceous sedimentary rocks.

Lithology and Thickness

The formation includes interbedded and/or intercalated mudstone, limy mudstone, argillite, graywacke, and an intercalated sedimentary breccia. All are metamorphosed to hornfelses near intrusive contacts.

The breccia is composed of large angular distorted blocks of mudstone and limestone in a matrix of thinly bedded mudstone. Nolf (1966) named this part of the formation the Deadman Lake Breccia, described it as a "marine megabreccia," and reported (1963) one block to be several hundred feet across at the black marble quarry near Enterprise. The breccia was not sufficiently exposed in the map area to allow accurate measurement of thickness, but it appeared to be on the order of 30 meters.

Nolf (1966) reported an undisturbed formational thickness of 1950 m (6500 ft) at Twin Peaks. However, thicknesses in the study area were somewhat less, the greatest being about 1000 meters where the formation is isoclinally folded in overturned anticlines and synclines along the Craig Mountain plutonic contact on the ridge just south of the Matterhorn. Here, the fold axial planes are near vertical and trend nearly perpendicularly to the trend of the ridge. This particular section of Hurwal and a similar section adjacent to the Hurricane Divide Pluton had been named "Lower Sedimentary Series" by Smith and Allen (1941) because it appears to lithologically underlie the Martin Bridge. The extent of these beds can be followed to the east and north to the Ice Lake Cross Fold, where a stream following the break in trend exposed an outcrop showing the true stratigraphic relationship.

Age

Faunal specimens were quite well preserved, considering the intensity of deformation. Fossil ammonite imprints found near the basal contact of the Hurwal on the west side of Hurwal Divide appear similar to Clionites (Traskites) fairbankski of Karnic Age pictured by Smith and Allen (1941, p. I). Other fauna, generally found in talus, was similar to that in the Martin Bridge. Nolf found early Jurassic (Toarcian) ammonites to the north of the study area in the structural low adjacent to the Sawtooth Stock (Sawtooth Syncline) (Nolf, 1966).

Outcrops and Exposures

The Hurwal Formation crops out in synclinal depressions near the crest of Hurwal Divide, in the cirque north of Sacajawea, along plutonic contacts, and in a few small synclines in outcrops of Martin Bridge. The majority of area mapped as Hurwal, however, encompasses terrain covered by talus, and contact relationships are defined along Martin Bridge outcrops. The outlines of major outcrops of limestone, under close examination, generally have small outcrops of Hurwal along their flanks where Hurwal talus is present.

Contact Relationships

The Hurwal Formation is generally in mixed gradational contact with the underlying Martin Bridge Formation (Fig. 6). While the contact is generally conformable, it is in some sense tectonic, in that the limestone has flowed relative to the argillite.

There is no unit overlying the Hurwal Formation in the map area. Outside the area, however, the Hurwal is overlain unconformably by the Columbia River Basalt.

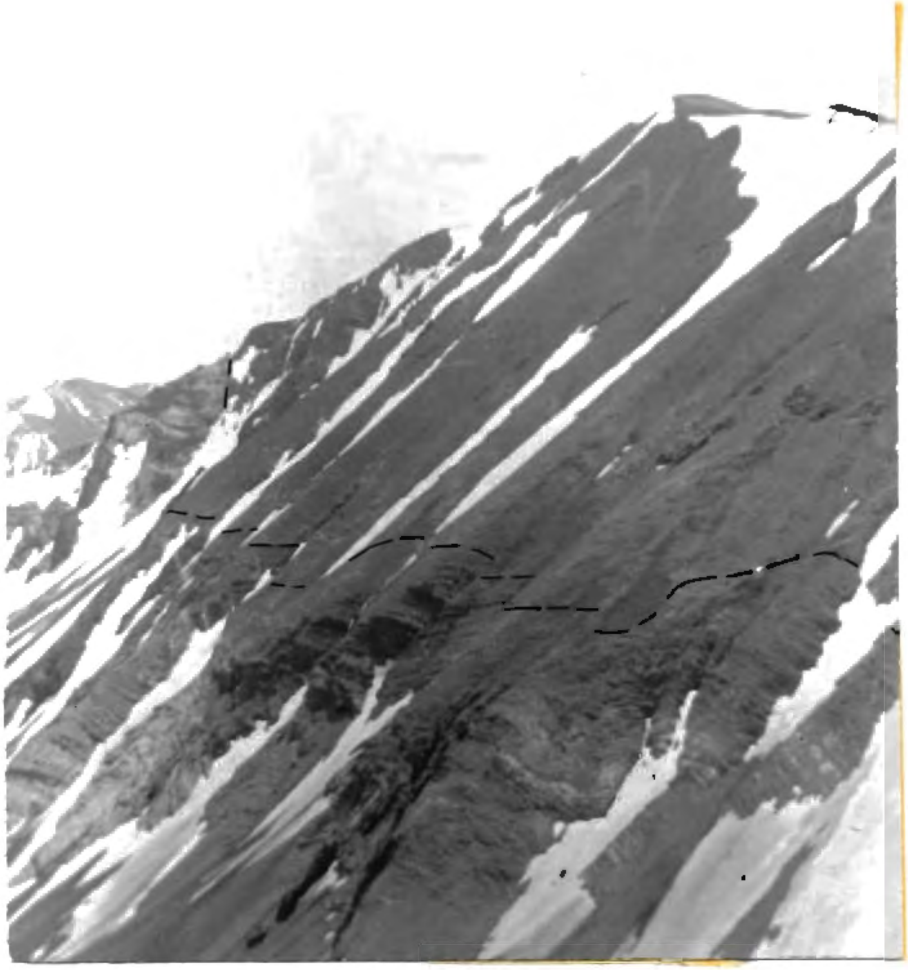


Fig. 6. Martin Bridge-Hurwal contact (dashed line), east flank of Hurwal Divide.

MESOZOIC INTRUSIVE ROCKS

Two distinct episodes of intrusive magmatism occurred during the Jurassic and Cretaceous. The first was an intermediate to mafic dike-sill complex whose emplacement began prior to the beginning of batholith-related deformation, and ended probably before the final emplacement of the Craig Mountain Pluton. The second, granitic emplacement related to and including the Wallowa Batholith, included post Hurricane Divide Pluton-pre Craig Mountain Pluton boudined dikes, the plutons themselves, and relatively undeformed silica-rich dikes which are not boudined and, presumably, post date the batholith.

I. INTERMEDIATE - MAFIC COMPLEX

Emplacement of this complex started with the intrusion of continuous sills which follow bedding planes in Hurwal Argillite west of Ice Lake. These intrusions necessarily predate the intense plastic deformation related to granitic plutonic emplacement since they are deformed with the bedding. Later stages of this magmatic event are recorded as boudined altered intermediate and mafic dikes which were generally, but not always, emplaced along fold axial planes in the limestone as the planes developed. Some of these dikes post-date the major plastic deformation and cut nearly perpendicularly across the fold trends.

The only known post Upper Triassic-pre Tertiary mafic intrusive activity in northeastern Oregon is found in Hells Canyon, where it cuts Upper Triassic and Lower Jurassic rocks and is overlain by Upper Jurassic strata (Vallier, 1972). This plutonic suite consists of metagabbro, diorite, quartz diorite, and, at Mirror Lake, intrusive breccia with clasts of hornblende meta-gabbro, quartz diorite, and albite granite suspended in a matrix of hornblende diabase porphyry. The clasts, from an earlier intrusive episode, possibly correlate with the Permian-Middle Triassic Canyon Mountain Magma Series (Thayer and Brown, 1964). These clasts also indicate that rocks roughly correlative with the Permian Harsin Ranch Member of the Clover Creek Formation underly the Upper Triassic strata exposed.

II. WALLOWA BATHOLITH

General Discussion

The emplacement of plutons and subsidiary intrusions of the Wallowa Batholith was a long, complex process (Fig. 7) involving a time span which included most of both the Jurassic and Cretaceous. In the study area, granitic magmatism can be divided into four distinct stages:

(1) emplacement of the Hurricane Divide Pluton;

(2) emplacement of granitic dikes, since boudined (this episode occurred just prior to final emplacement of the Craig Mountain Pluton;

(3) emplacement of the Craig Mountain Pluton;

(4) emplacement of silica-rich aplite and pegmatite dikes which differ from earlier dikes by, among other things, their continuous nature; this set probably is time-equivalent to the Cordierite Trondjenite dated by Taubeneck (1963) at 95 $\pm$ 3 my. Time of emplacement of the two smaller stocks in the study area can best be described as post Hurricane Divide Pluton.

Plutons in the Study Area

Two large plutons in the map area include the Hurricane Divide Pluton, which is located on the southern end of Hurricane Divide and extends east across Hurricane Creek into the map area at the base of the Matterhorn, and the Craig Mountain Pluton (McCully Prong of Smith and Allen, 1941), whose type locality

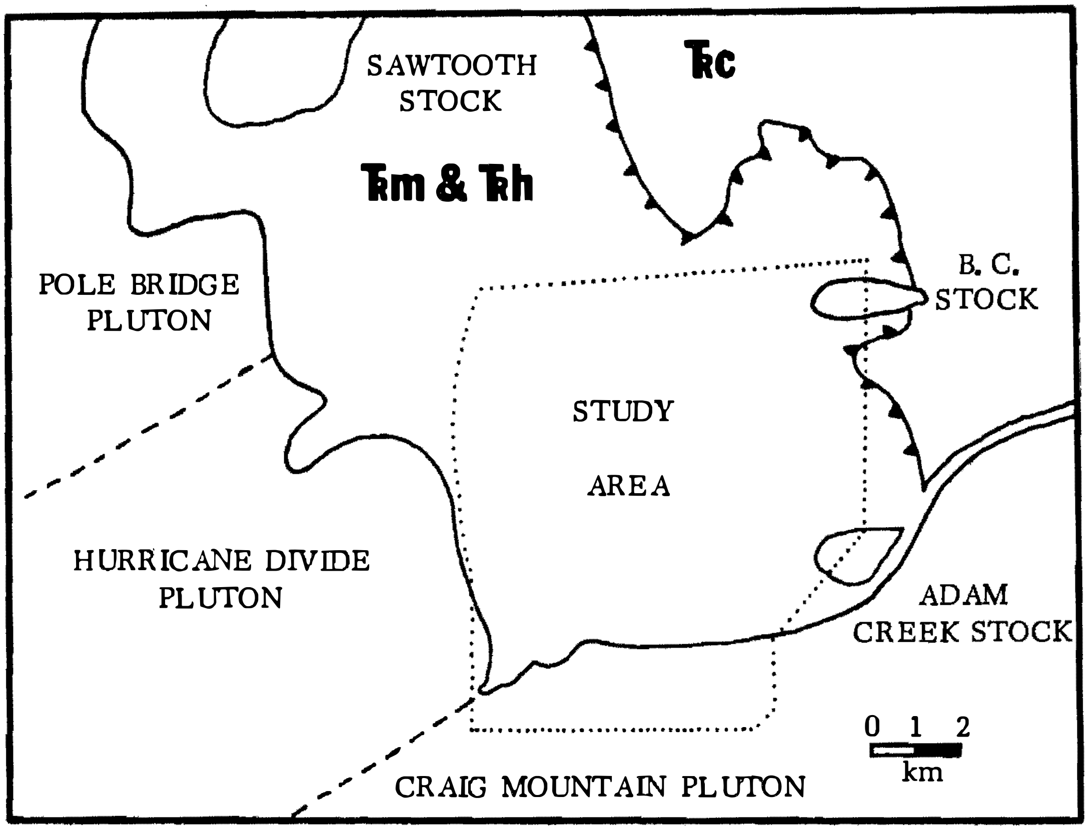


Fig. 7. Sketch map of relative pluton locations, northern Wallowa Mountains, Oregon.

is in the southeast corner of the map area. Two smaller granitic plutons are also located in the area: the Adam Creek Stock is centered on an east-west ridge just north of the meadow on Adam Creek; and the B. C. Stock, which forms a knob in the pass between Hurwal Divide and Chief Joseph Mountain and reaches east into B. C. Basin. Taubeneck (1963) analyzed the general compositions of the plutonic rocks and found tonalite near the contacts grading to granodiorite in the cores. This is a general composition, however, as the mineral assemblages in each pluton have individual characteristics. For example, the Hurricane Divide Pluton appears to contain more biotite and is finer grained than the Craig Mountain Pluton to the south.

Granitic Dikes

Two sets of granitic dikes occur in the study area. They can generally be separated on observation as boudined or continuous.

Boudined granitic dikes cut limestone and argillite deformed by emplacement of the Hurricane Divide Pluton. Along the east wall of Sacajawea, these dikes show internal arching such that their centers have moved northward relative to top and bottom. These quartz-rich dikes occur throughout the map area, although they seem to be concentrated adjacent to the Hurricane Divide Pluton.

The continuous granitic dikes are less numerous than their boudined counterparts, and intrude generally along and adjacent to the overturned Hurwal-Martin Bridge contact where the Hurwal is adjacent to the major plutons. These dikes represent the final granitic dike emplacement in the map area. These dikes are composed largely of orthoclase. Other minerals include quartz, calcite, schorl tourmaline, and tiny, infrequent brown garnets. The textures range from aplitic to pegmatitic, with preferred mineral orientations following the orientation of the plane of the dike. The largest grains and greatest variety of minerals are found in the dike which follows the overturned Martin Bridge-Hurwal contact south of the Ice Lake Cross Fold (Plate 2). Dikes of this set also follow low angle faults which are quite common throughout the area. Dikes following this trend appear as the conspicuous white marker beds near ridgecrests capped by Hurwal Argillite in the northern Wallowas. While these intrusions appear as sills, they crosscut bedding planes in the intensely deformed argillite.

Age of Rocks

Taubeneck (1963) lists two crystallization dates for rocks of the Wallowa Batholith. The earlier, a K-Ar date on biotite in granodiorite, is 149 $\pm$ 5 million years, and the latter, also a K-Ar date on biotite in cordierite trondjenite, is 95 $\pm$ 3 million years. Clearly, the crystallization history of the batholith is far too complex for two dates to be of much help except as an overall range. It is probably safe to assume from these dates only that biotite in the major granitic plutons crystallized during the Late Jurassic, and biotite, where it occurs, in silicic post-batholithic dikes such as the aplite and pegmatite in the study area, probably crystallized during the Cretaceous.

Contact Relationships and Mineralization

Plutons in the study area are concordant, with contacts generally following bedding planes (Fig. 8) except where subsequent faulting has occurred. There has been very little mineralization along the contact. Where the Hurricane Divide and Craig Mountain Plutons converge to the south of the Matterhorn near Hurricane Creek, there is no contact aureole in the limestone whatsoever. This, along with (1) synclinal depressions of Hurwal overlying Hurricane Divide tonalite parallel to the major structural trend in the country rock, and (2) preferred mineral orientations in the granitic rock which were overlooked during this study but observed earlier by both Nolf and Taubeneck (1973, oral communication), imply that emplacement of this intrusion occurred while it was in a highly viscous state, probably well after crystallization had occurred in rock adjacent to the contact. A good cross sectional sampling of absolute ages taken along the long axis of the pluton would aid greatly in determining its cooling history.

Sparse metallic mineralization occurs in dikes and, in a few localities, in country rock immediately adjacent to the plutonic contact. This mineralization includes small uneconomic occurrences of disseminated molybdenite and pyrite, and, in one dike east of Ice Lake, is found what appears to be Powellite, a molybdenum-containing scheelite which fluoresces. Pyrite is widespread in the Hurwal Formation, but its origin may be sedimentary.

Fig. 8. Intrusive contact, Ice Lake. Craig Mountain Pluton (left) is in contact with downfolded Hurwal Argillite. White peak in background is the Matterhorn.

COLUMBIA RIVER BASALT

The outpourings of Columbia River Basalt occurred about 22 million years ago during the Miocene (McBirney, 1973) from fissures now exposed as feeder dikes. These dikes are limited in extent, especially when considering the vast extent of flood basalts in Oregon and Washington.

Remnants of flows of Columbia River Basalt are found capping ridgetops over 2400 m (8000 ft) in the northern Wallowas. A few flows that post-date the start of block faulting can be found at 2100 meters as remnants on ridgetops. One of these is an intercanyon flow in the West Fork Wallowa River Canyon.

Although flows and feeder dikes are both common in the northern Wallowas, only dikes crop out in the map area. Several dikes can be traced for over a kilometer. One, on the west face of the Matterhorn and Sacajawea, can be followed for three kilometers. These dikes vary somewhat in thickness. One, which is exposed near Thorp Creek, is five meters thick (Fig. 9).

The structural control of the emplacement of these dikes will be discussed under POST BATHOLITH REGIONAL UPLIFT.

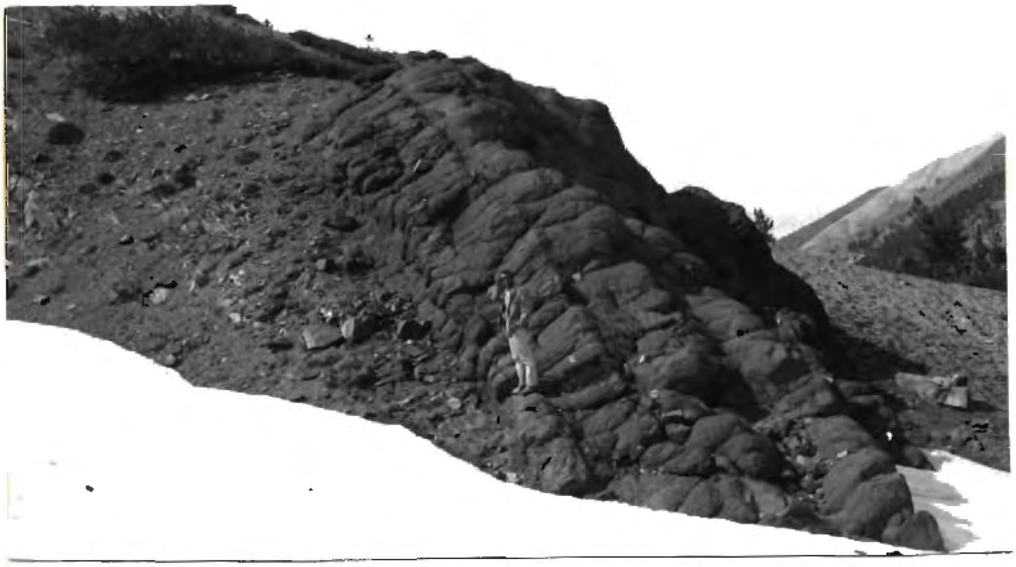


Fig. 9. Five meter thick Columbia River Basalt feeder dike near Thorp Creek. Note man standing on dike for scale.

STRUCTURAL GEOLOGY

Introduction

Three distinct styles of deformation (Fig. 10) occur within the rock units of the northern Wallowas. One, observed in the Clover Creek Greenstone, is a folding along northeast trending axes. The second, observed in the Martin Bridge Limestone and overlying Hurwal Argillite, is an intense penetrative plastic deformation along north-south trending fold axes. The third is a style characterized by vertical and lateral faults that cut all of the pre-Tertiary rock units and, in many places, the Columbia River Basalt.

These styles of deformation are related to three distinct deformational episodes. The first was a Early to Middle Jurassic regional deformation. The second, by far the most intense of the three, was genetically related to the Late Jurassic emplacement of granitic plutons of the Wallowa Batholith. This deformational event probably concluded late in the Jurassic. The third, a Cretaceous-middle Tertiary regional uplift, preceeded in part the outpouring of Columbia River Basalt.

A tectonic map of the study area is shown in Plate 2 (rear pocket).

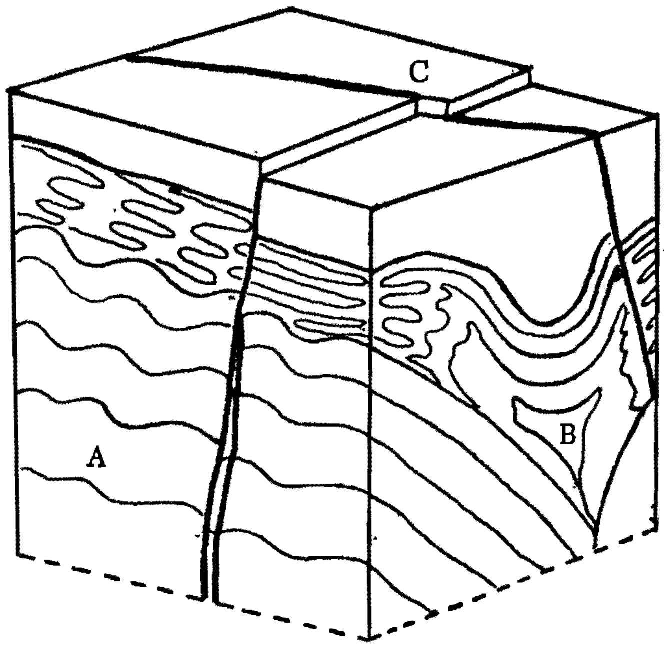


Fig. 10. Schematic block diagram of styles of deformation related to each tectonic event. Styles shown include those of: (A) Early-Middle Jurassic regional deformation; (B) Deformation related to emplacement of plutons of the Wallowa Batholith; and (C) Faulting related to Cretaceous-Middle Tertiary regional uplift.

I. JURASSIC REGIONAL DEFORMATION

Vallier and Fredley (1972) outline two deformational episodes in Hells Canyon (Fig. 11). The older is marked by an angular unconformity separating 2000 meters of Permian metavolcanic and metasedimentary rocks from 4000 m of overlying strata containing Middle-Upper Triassic metavolcanics, including flows, volcaniclastics, graywacke, conglomerate, and argillite. Included in this section, overlying the metavolcanics conformably, are Upper Triassic limestone and shale. The younger deformation, the one observed in the northern Wallowas as well as in Hells Canyon, is marked in Hells Canyon by an angular unconformity separating Triassic strata described in the previous sentence from overlying Upper Jurassic shale and sandstone. These rocks are all folded along northeast to easterly trending axes.

The limited exposure of Clover Creek Greenstone in the study area precludes any detailed analysis. Only two attitudes were noted. These indicate that the bedding strikes northeast and dips vary greatly suggesting folding around northeast-trending axes. The intensity of the next tectonic event in the northern Wallowas apparently obliterated the regional pattern in the overlying sedimentary units.

Emplacement of the intermediate to mafic dike complex described under MESOZOIC INTRUSIVE ROCKS appears to be intimately related to the first de-

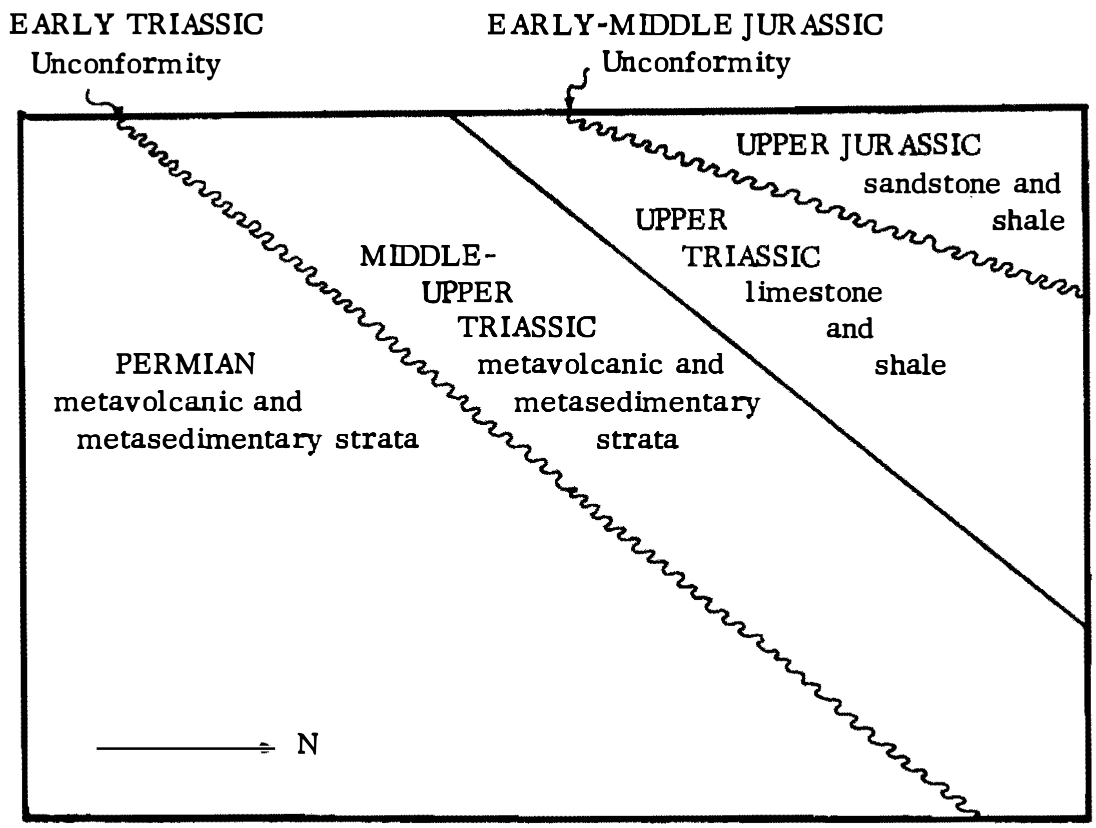


Fig. 11. Schematic diagram of stratigraphic relationships, Hells Canyon, Oregon and Idaho (as described by Vallier and Fredley, 1972).

formation. However, dikes from this complex clearly overlapped tectonic events, and were intruded during late stages of plutonic emplacement.

II. DEFORMATION RELATED TO THE WALLOWA BATHOLITH

The second deformational event is recorded in the isoclinally folded and recrystallized limestone of the Martin Bridge Formation and, to a lesser extent, in the overlying Hurwal Argillite. It can best be described by domains (Fig. 12). Domain 1 follows the north-south extent of Hurwal Divide. Domain 2 follows a general axis through the north cirque of Sacajawea southward through the summit of Sacajawea itself and southward along the summit ridge across and to the south of the Matterhorn. Domain 3 is located in the general area of Ice Lake.

Domain 1 - Hurwal Divide

A. East Flank. The east flank of Hurwal Divide (Fig. 13) is marked by isoclinally folded crystalline limestone and black calcarenite of undeterminable original thickness overlain by about 240 meters of Hurwal Argillite. Fold axial planes strike N. 22^{o} - 35^{o} W. and dip 70^{o} - 85^{o} west near the pass adjacent to B. C. Basin. These fold axial planes are oriented in a nearly horizontal position just to the southeast where they immediately overlie a contact with the underlying greenstone on an east-west ridge. The rocks exposed on this ridge have been offset upward along a north-trending normal fault which has offset rocks in B. C. Basin as well.

The westward dipping fold axial planes observed in B. C. Basin can be traced south along the east side of Hurwal Divide to an east-west ridge over-

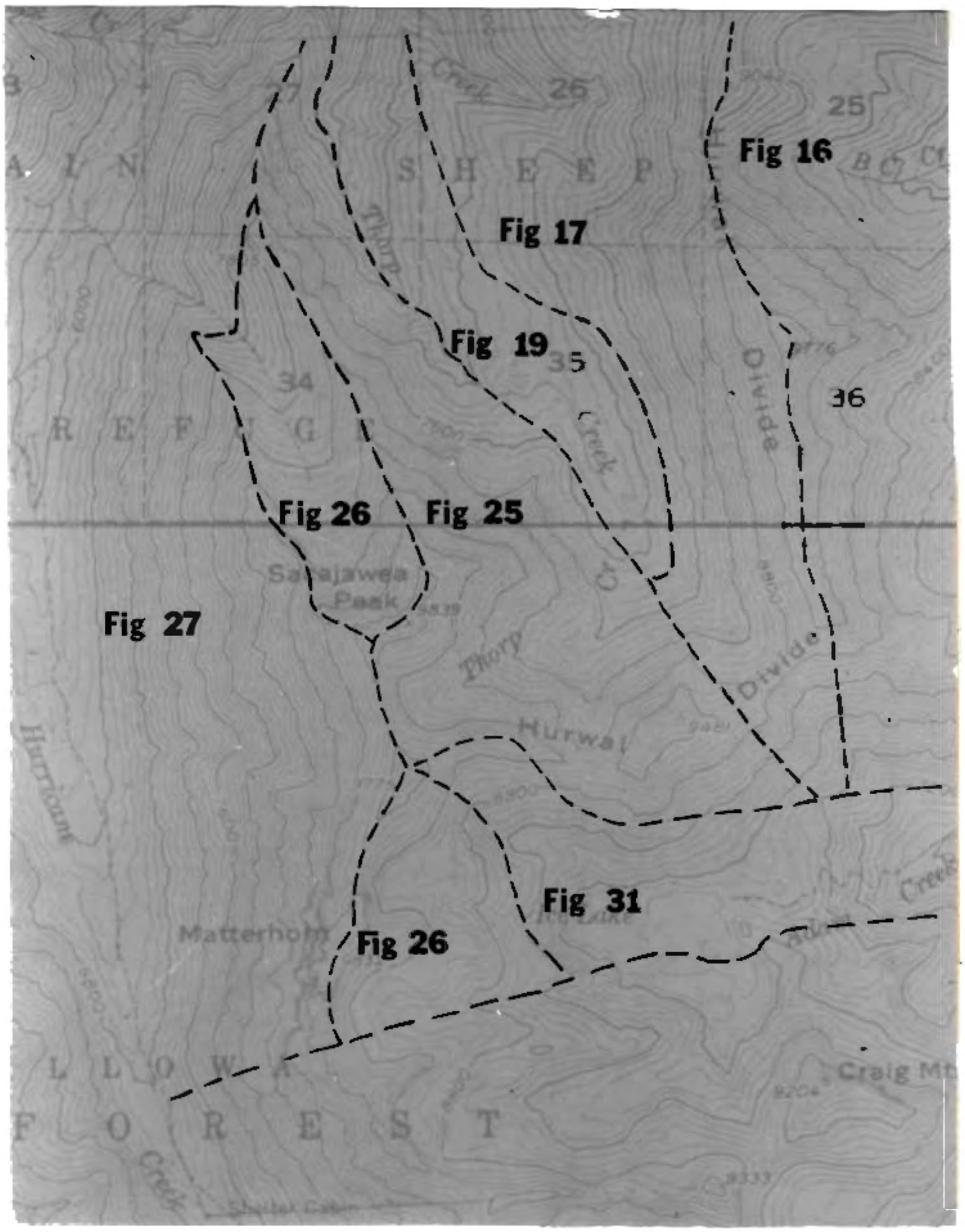


Fig. 12. Map of equal area domains.

Fig. 13. Steep westward dipping fold axial planes in marble (dashed lines), east flanks of Hurwal Divide.

looking Adam Creek, which flows through a meadow to the south. Here, the fold axial trend has been rotated clockwise (to the west) by the Adam Creek Stock (Fig. 14). Along this intrusive contact, the style of folding is characterized by wave lengths of 15 cm and amplitudes of 60 cm.

B. West Flank. Outcrops on the west flank are similar but less numerous (Fig. 15) than those on the east. No structure is discernable in most of the outcrops. One area, overlooking the high meadow on Thorp Creek (Harris Basin), exhibits moderately tight folds characterized by fold axial planes which trend N. 15^{o} to 20^{o} W. and dip 60^{o} to 85^{o} east. Amplitudes are on the order of 15-20 m, with wave lengths commonly 10 m.

Analysis of Domain 1. Comparison of equal area projections of poles of foliation in Martin Bridge Marble and bedding in Hurwal Argillite on the east and west flanks of Hurwal Divide (Figs. 16 and 17, respectively) shows the symmetry of the foliation and axial planes relative to the axis of the ridge. At the southern end of Hurwal Divide north of Adam Creek, the cross sectional relationship between the two sides of the ridge can be observed (Fig. 18). The ridge bisects a major anticlinal structure. The axial planes of the isoclinal folds radiating within it converge downward. Therefore, by definition, this anticlinal structure is synformal.

Poles of foliation and bedding planes measured along Thorp Creek (Fig. 19) show a similar pattern to that of the west flank of Hurwal Divide, although the planar features tend to be steeper. This is because the Thorp Creek valley (Harris Basin) is a zone of transition between Domains 1 and 2.

Fig. 14. Tight isoclinal folding of marble adjacent to the Adam Creek Stock (right). Fold axes have been rotated west (clockwise) by emplacement of the stock.

Fig. 15. Steep eastward dipping fold axial planes (dashed lines) in marble, west flanks of Hurwal Divide. Valley in center of picture (Harris Basin) contains Thorp Creek.

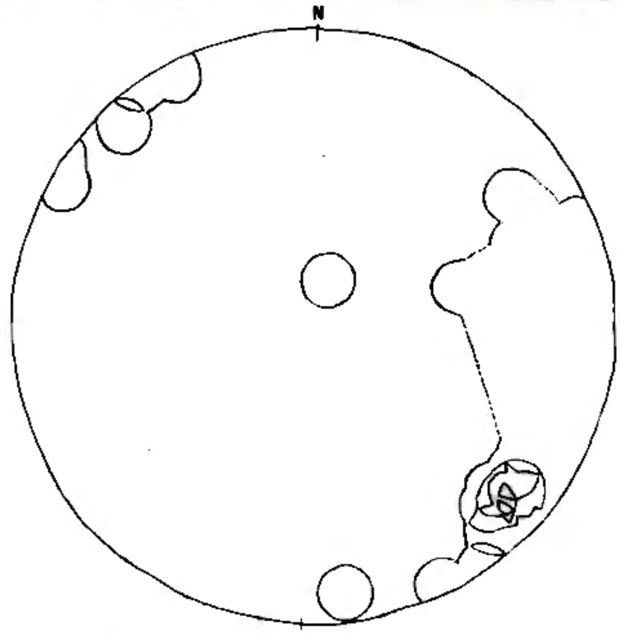


Fig. 16. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, east flank of Hurwal Divide. Contour interval is eight percent of 25 points per one percent area.

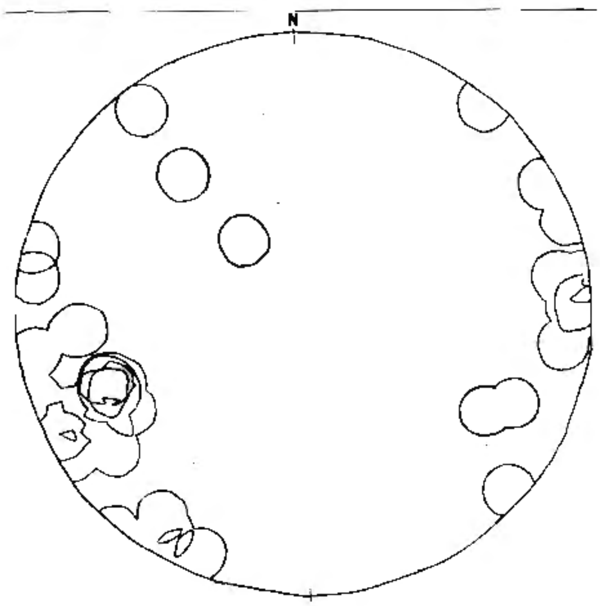


Fig. 17. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, west flank of Hurwal Divide. Contour interval is five percent of 40 points per one percent area.

Fig. 18. Cross sectional relationships as seen on Hurwal Divide looking north from Adam Creek. Note downward convergence of fold axial planes (dashed lines).

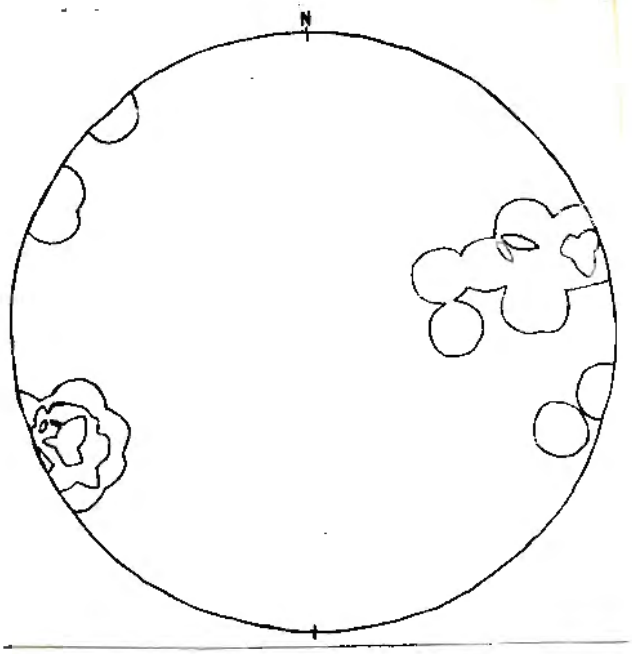


Fig. 19. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, Thorp Creek valley (Harris Basin). Contour interval is 6.7% of 30 points per one percent area.

Domain 2 - Sacajawea Peak and the Matterhorn

A. East Flanks. Although most of the east face of Sacajawea is inaccessible, it is possible to look northward down structure from near the headwaters of the west fork of Thorp Creek (Fig. 20). The fold pattern here shows intense plastic deformation of white marble. Plastic flowage in the marble has produced folds of much greater amplitude and frequency than is found at the contact with the overlying argillite. The deformation in the marble in this section is characterized by wave lengths and amplitudes on the order of 15 meters and 150 meters, respectively.

Fold axes strike approximately N. 30° W. on the southeast face of Sacajawea Peak. This trend is somewhat sinuous, however, and varies with height. This trend changes to N. 7° W. at the west fork of Thorp Creek and then returns to N. 18° W. in the pass at the ridgecrest to the south (Fig. 21).

Fold axial planes dip gently westward at the top of the face (again referring to Fig. 20), steepen abruptly along an easterly dipping plane bisecting the face, and are overturned to a nearly vertical eastward dip at the base of the cliff. The same pattern can be seen looking south from Thorp Creek (Fig. 21). The westward dip of fold axial planes on the east face of the Matterhorn (Fig. 22) are part of this same structure.

B. West Flank of the Matterhorn - Sacajawea Peak Ridge - North Cirque of Sacajawea Peak. As was true on Hurwal Divide, the dip of fold axial planes reverses from west to east across the crest of this ridge. Fold axial planes in the north cirque of Sacajawea show rotation similar to those on the east face of

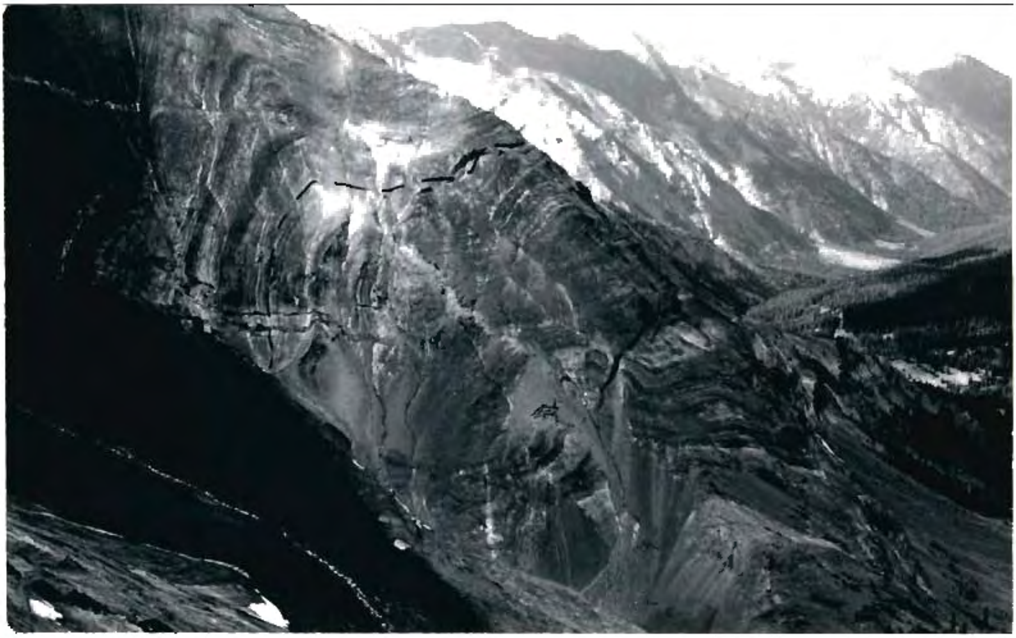


Fig. 20. Face on southeast flank of Sacajawea Peak cutting across structure. Fold axial planes (represented by dashed line) dip gently westward at top of outcrop, steepen abruptly, and overturn at the base of the outcrop.

Fig. 21. Southward continuation of folding to Hurwal Divide from the outcrop pictured in Fig. 20. Note overturned axial planes in background, gouge zone in axial plane in foreground.

Fig. 22. Steep westward dipping fold axial planes, east flanks of the Matterhorn. Note syncline in lower left corner with Hurwal (formerly "Lower Sedimentary Series") overlying Martin Bridge, denoting true stratigraphic relationship.

Sacajawea, except that the sense of rotation has reversed (Fig. 23). The fold axial planes on the cirque headwall strike N. 18° W. and dip from 40° east near the floor of the cirque, to 60° west halfway up the headwall, to east again near the top. A fault has downdropped the west side of the headwall to show fold axial planes dipping slightly eastward.

To the west of the cirque, along the west flanks of the ridge, fold trends vary from N. 40° W. at the northern end of the ridge to N. 45° E. at the contact between the Hurricane Divide and Craig Mountain Plutons near the Hurricane Creek Cabin. A detailed look southward at nearly isoclinal folding near Fullington Creek (Fig. 24) shows steepening of the eastward dip of the fold axial plane with depth.

Equal area plots of poles of foliation and bedding planes on the east flank of Sacajawea, and along the west flank (west face) of the Matterhorn - Sacajawea Ridge (Figs. 25, 26, and 27, respectively) clearly show the symmetry across the axis of the ridge and the cirque. The convergence of fold axial planes is discernable on Sacajawea Peak from Deadman Meadows (Fig. 28) and from Hurwal Divide looking north (Fig. 29). The Matterhorn Synform, named by Nolf (1966), is a true synform (Fig. 30), with younger Hurwal Argillite overlain by older Martin Bridge Marble along an overturned contact. Prior to work by Nolf (1966), this section of Hurwal was believed to be the same as the "Lower Sedimentary Series", a name assigned by Smith and Allen (1941) to the clastic upper member of the Clover Creek Greenstone.

The finer lined of the two sets of fold axes shown on Plate 2 represents

<u>Fig. 23.</u> Headwall,north cirque, Sacajawea Peak, as viewed from the north. Summit of the peak is at left center. Dashed lines represent fold axial planes. Solid line represents a fault.

Fig. 24. Eastward dipping fold axial planes (dashed line), west face of the Matterhorn--Sacajawea ridge near Fullington Creek. Note increase of dip with depth.

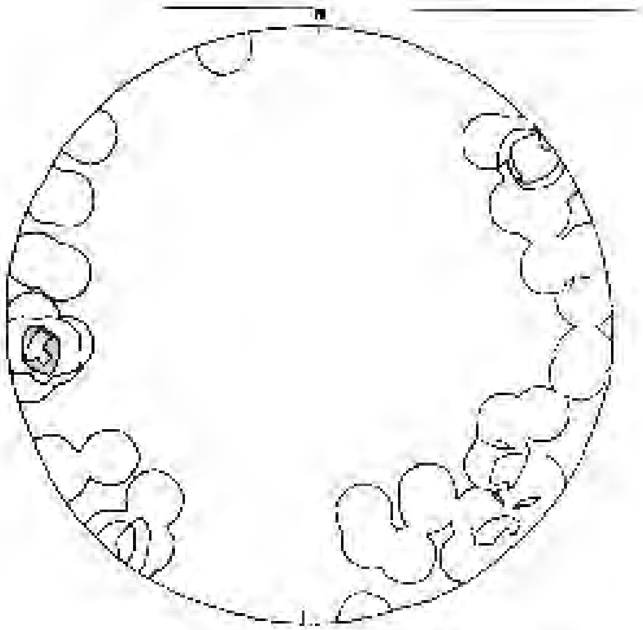


Fig. 25. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, east flanks of Sacajawea Peak and the Matterhorn. Contour interval is 3.2% of 60 points per one percent area.

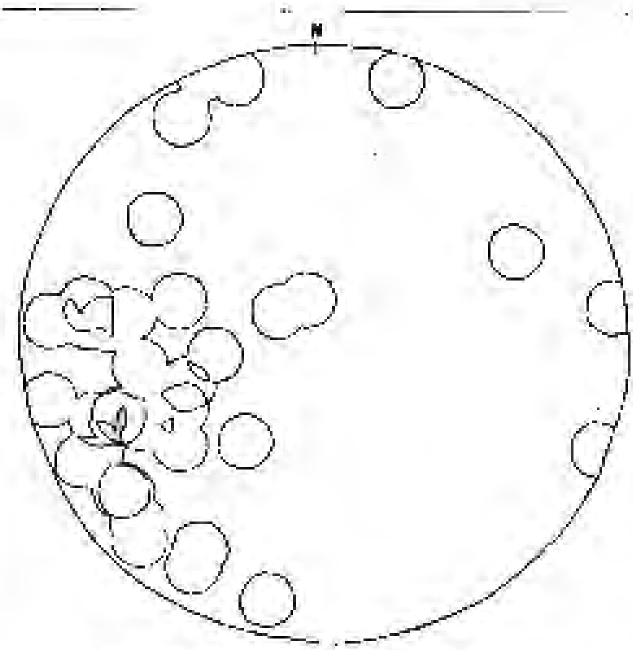


Fig. 26. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, cirque north of Sacajawea Peak. Contour interval is four percent of 50 points per one percent area.

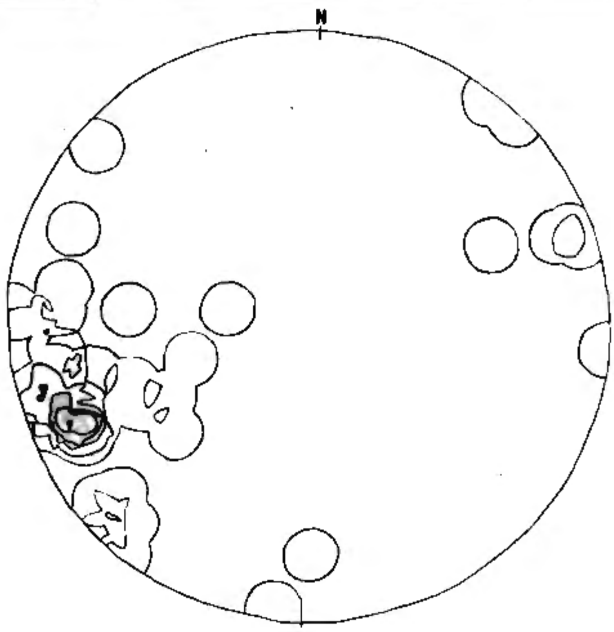


Fig. 27. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, west flank of Sacajawea Peak and the Matterhorn. Contour interval is four percent of 50 points per one percent area.

Fig. 28. View south from Deadman Meadow of Sacajawea Peak. Note downward convergence of fold axial planes towards center of the base of the peak.

Fig. 29. Hurwal Argillite folded synclinally in axis of synformal anticline, Sacajawea Peak (right summit). View is northwest from the south summit of Hurwal Divide.

Fig. 30. Matterhorn Synform, viewed from the south. Older Martin Bridge overlies younger Hurwal along overturned contacts which converge downward.

the intersection of the fold axial planes of overturned anticlines with the surface of the earth, with symbols (ear muffs) pointed in the direction of dip. The seemingly sinuous pattern of these traces is generally due to topography rather than structure. The heavier lined fold axes represent the major structures, the synformal anticlines, that follow the topographic axes of Hurwal Divide, the north cirque of Sacajawea Peak, and the summit ridge of the Matterhorn. Cross sectional relationships (Plate 1) show a relationship between topography and the major structures. From Plate 2, it is apparent that these trends are continuous (ignoring subsequent faulting) except for one striking exception, named the Ice Lake Cross Fold. An equal area plot of poles of foliation along this fold (Fig. 31) clearly shows that the trend is east-west in this structure, roughly perpendicular to other folds in the Martin Bridge. The cross fold is synformal in nature, with marble overlying argillite along an overturned contact (Fig. 32). The sharpness of the break in fold trend is striking (Fig. 33), and is clearly a result of plastic flowage in the marble.

Boudinage

Introduction. As described under Contact Relationships, the concordant relationships between the plutons and country rocks suggest a genetic relationship between their emplacements and this episode of deformation, since fold axes in the metasedimentary rocks trend normal to the axes of elongation of these plutons. However, two additional variables must be analyzed before the full picture may be understood. First, what was the time period involved in plutonic emplacement, and, secondly, what was the sequence of plutonic emplace-

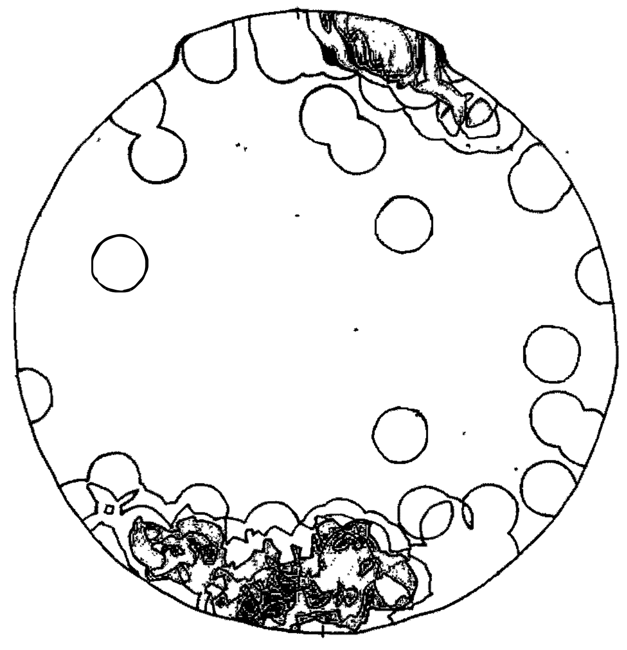


Fig. 31. Equal area plot of poles of planes of bedding and foliation, Martin Bridge and Hurwal Formations, Ice Lake Cross Fold. Contour interval is 1.25% of 160 points per one percent area.

Fig. 32a. Break in trend, Ice Lake Cross Fold, Hurwal Divide, viewed from the south.

Fig. 32b. View west from Ice Lake looking down structure at Ice Lake Cross Fold. Note overturned Martin Bridge-Hurwal contact, and synformal nature of fold.

Fig. 33. Close up showing sharpness of break in trend, Ice Lake Cross Fold.

ment. The most useful indicator of time sequence is boudinage.

The three distinct sets of boudins present in the Martin Bridge Formation (Fig. 34) include:

(1) quartzite boudins, in lenses, originally interbedded with limestone;

(2) the Early(?)-Late Jurassic intermediate to mafic dike complex; and

(3) boudined pre-Craig Mountain Pluton granitic dikes.

Quartzite Boudins. Lenticular quartzite boudins range from one to six centimeters in thickness (perpendicular to bedding), and, in two measured sets along the west flank of Sacajawea Peak, from one to 16 cms in width as exposed parallel to bedding.

Clusters of these boudins are common throughout the white marble. They are indicative of the degree of flowage in the marble, as they probably represent relic bedding. These boudins, however, do not pertain to the questions concerning emplacement sequence, since their deposition was contemperaneous with that of the limestone.

Intermediate to Mafic Dike Complex. Dikes and sills of this complex vary greatly in their size, deformational character, and composition. The earliest is a granitic sill one meter thick (Fig. 35) exposed in a conspicuous knob of overturned Hurwal Argillite west of Ice Lake. One syncline of this sill crops out in such a way that the fold axis, which plunges steeply toward Ice Lake, is exposed. This sill is important because:

(1) the sill is continuous and concordant with an original bedding plane, marking the beginning of the magmatic episode as prior to deformation;

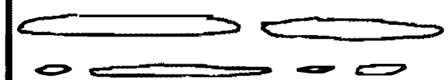
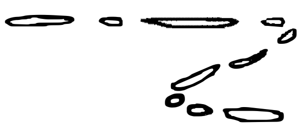
BOUDIN SHAPE	ROCK DESCRIPTION	ELONGATION	HOW ORIENTED
	DIKES, GRANITIC, FINE-GRAINED	LESS THAN 10%	N. 60^{o} - 80^{o} E.
	DIKES, INTERMEDIATE TO MAFIC ALTERED TO CALCIC AMPHI-BOLES	20% - 75%	Parallel to foliation. Parallel to fold axial planes. N. 60^{o} - 80^{o} E.
	QUARTZITE, FINE GRAINED, IN LENSES	20% - 45% (in clusters)	Parallel to bedding.

Fig. 34. Summary of Boudin Types

Fig. 35a. Outcrop containing isoclinally folded granitic sill west of Ice Lake.

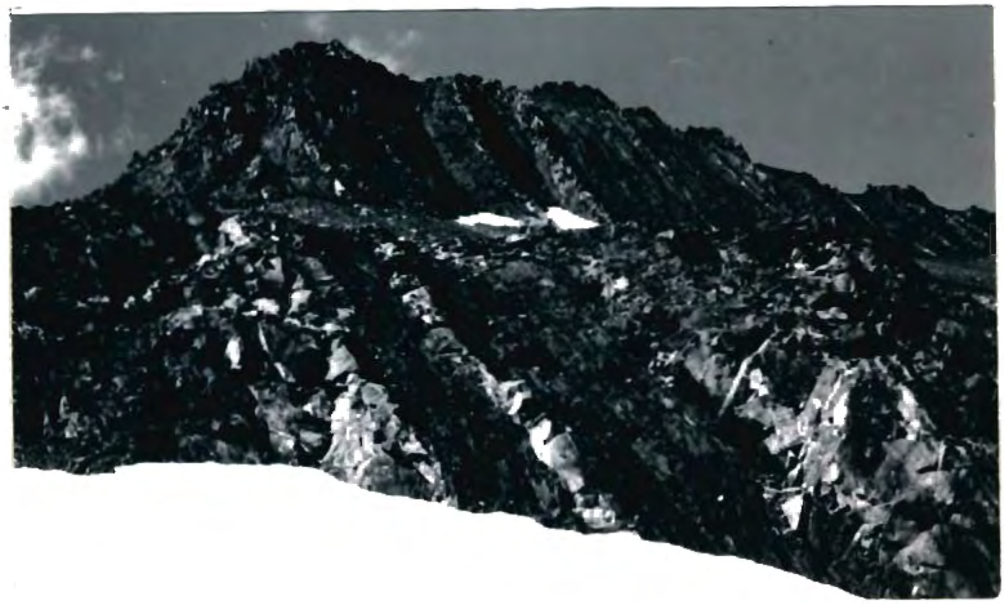


Fig. 35b. Close up of folded granitic sill. Note the steep eastward plunge of axes and the continuous nature of the sill.

(2) where intruded into argillite, it is not boudined, thus showing the contrast in competence between the argillite and limestone; the limestone is far more plastic.

Dikes mafic to intermediate in composition were intruded throughout the process of plutonic emplacement. This is indicated by dikes which were intruded along axial planes of folds genetically related to plutonic emplacement and boudined. Dikes of this type vary greatly in thickness (less than a centimeter to two or three meters). These dikes follow axial planes in northerly trending folds and along the Ice Lake Cross Fold (Fig. 36). Often several of these dikes will follow fold axial cleavage in a single fold (Fig. 37).

A few of these dikes were emplaced after folding along the north-south fold axes had ceased, and cut these folds almost perpendicularly. These late dikes and the granitic dikes that where emplaced shortly thereafter clearly outline the sequence of plutonism.

Boudined Granitic Dikes. These boudined granitic dikes cut the north-south structural grain in a manner similar to the last dikes from the intermediate to mafic complex. These two to three meter thick dikes show a northward arching along the east face of Sacajawea. The boudinage was probably caused by flowage of marble along the axial plane of this arch.

Interpretation of Jurassic Structures

Sequence of Events. Jurassic tectonism in the Wallowa Mountains occurred as a complex sequence of events, many of which overlap one another. They can be best summarized in four steps.

Fig. 36. Altered and boudined mafic dikes following fold axial planes westward, Ice Lake Cross Fold.

Fig. 37. Altered and boudined mafic dikes following different axial cleavage planes of single fold northwest of Ice Lake.

(1) A mild regional folding along northeast trending axes occurred from Middle-Upper Jurassic. Emplacement of the intermediate to mafic dike complex began prior to

(2) the beginning of the emplacement of the Hurricane Divide Pluton, whose principal movement followed a N. 60^{o} E. trend. Although no dates have been published defining a cooling history for the pluton, the emplacement is estimated to have began prior to Middle Jurassic. Emplacement of the intermediate to mafic dikes continued.

(3) The beginning stages of emplacement of the Craig Mountain Pluton were well underway before the cessation of mafic dike emplacement. This is indicated by dikes which:

a. follow the axial planes of second folding in the Ice Lake Cross Fold, and

b. are emplaced perpendicular to the general north-south trend which resulted from movement of the Hurricane Divide Pluton.

(4) The emplacement of the Craig Mountain Pluton deformed the Martin Bridge Marble such that

a. the Matterhorn Synform has been rotated clockwise, implying relative right lateral movement along the intrusive contact; and

b. the predominate north-south synformal anticlines have been shortened along their axes and rotated counterclockwise, implying relative left lateral movement along the contact. This shortening and rotation is exemplified by the Ice Lake Cross Fold; the rotations of the axes near the Craig Mountain Intrusive contact imply that the plutonic material migrated from a center southeast of the Matterhorn.

c. northward plastic flowage has occurred in the marble; this is particularly noticeable on the east wall of Sacajawea, where mafic dikes have been offset as much as 180 m by this movement (Fig. 38). During the time that flowage occurred, granitic dikes were emplaced along a N. 60° E. trend. These dikes are boudined, and show bowing at the centers of their exposed lengths on the east flank of Sacajawea. Displacement of these dikes is considerably less than the mafic dikes which trend parallel to them, thus indicating their younger age of emplacement.

Structures, thus, relate as a sequence of overturned isoclinal folds, with overturning occurring symmetrically about axes of major structural highs (Plate 1). Since these highs are anticlinal structures with limbs which converge downward, along with the isoclinal fold axes, they have been classified as synformal anticlines.

Genetic Relationships - Deformation Caused by Plutonism. The geometry of deformation in the study area suggests that:

(1) plastic flowage occurred mainly within the limestone, with the Martin Bridge - Hurwal contact having the characteristic shapes of synformal anticlinal structures rather than the shapes that would be produced by isoclinal folding across the contact;

(2) movement of the marble occurred mainly in an upward direction and diverged from the core of the major folds; this implies an increase of horizontal compressive stress with depth from top to bottom of each structure;

(3) the underlying greenstone reacted rigidly to the deformation. For the

Fig. 38. Photograph showing relative lateral displacements of boudined mafic (A) and granitic (B) dikes, east face of Sacajawea Peak. Since the granitic dike shows less offset, it is younger. Both dikes were intruded prior to final emplacement of the Craig Mountain Pluton.

most part, it was undeformed by plutonism except along intrusive contacts (Nolf, 1966).

These factors further suggest that strain was greatest in the Martin Bridge, with the overlying Hurwal reacting relatively passively to the deformation. What factors, then, could have controlled such a select deformation? Mudge (1968) lists three prerequisites for control of concordant intrusions. These include:

(1) a well defined parting surface, such as a contact between two dissimilar rock units or an unconformity;

(2) sufficient, but not too much, lithostatic pressure, produced by somewhere between 900-2250 m (3000-7500 ft) of overburden;

(3) a barrier to fluid migration, usually a mudstone layer, which limits the ability of migrating magmatic fluids to permeate and weaken the overlying strata.

How do these prerequisites compare to the apparent control of the Hurricane Divide and Craig Mountain Plutons? The first, a well defined parting surface, certainly characterizes the contact between a rigid volcanic sequence and overlying plastic limestone. The second prerequisite, concerning depth, is somewhat more vague in the northern Wallowas since the top of the Hurwal Argillite is an erosion surface. The present thickness at Twin Peaks, 1950 meters, is certainly within the range given by Mudge. The third prerequisite, a mudstone barrior to fluid migration, characterizes the Hurwal. This barrior, from deformational evidence, must have also been somewhat of a parting surface as well.

The emplacement of each pluton involved two stages. One involved the upward migration of magma through the volcanic rock and limestone until this migration was stopped by the argillite. Since upward migration was no longer feasible, the second stage began, with movement of the pluton along the path of least resistance, through the limestone, pushing it and the passively overlying Hurwal ahead of it as it intruded eastward. The limestone was folded along axes normal to the main emplacement vector, with anticlines forming synformally because of the confining of major compressional stresses to one horizon. The Martin Bridge - Clover Creek contact can, therefore, best be described as a horizon of uncoupling, or décollement, since this deformation for the most part ignored the metavolcanics.

Final Granitic Dike Set

The final granitic dike set intruded during Cretaceous time in a manner restricted closely by structural control. These controls included:

(1) the overturned Martin Bridge - Hurwal Contacts along the Matterhorn Synform;

(2) the N. 60° E. fracture set followed in part by mafic and earlier granitic dikes;

(3) low angle (nearly horizontal) faulting which occurs in the intruded sediments; and

(4) a few of the N. 10° W. lateral faults whose presence marks the beginning of the last tectonic episode.

III. POST - BATHOLITH REGIONAL UPLIFT

Regional uplift probably began during the Cretaceous in northeastern Oregon. This is indicated by (1) the presence of Upper Jurassic marine sandstone and shale in Hells Canyon (Vallier, 1973), strata whose deposition necessarily predates the uplift, and (2) the absence of known fossiliferous Cretaceous formations east of the Bates Quadrangle (Baldwin, 1964). Erosion during this uplift removed virtually all of the cover from the Wallowa Batholith. Present day ridgetops of the Wallowa Mountains are remnants of the surface produced by this erosion. The eroded material is apparently buried beneath a deep cover of Columbia River Basalt.

Faulting accompanied this uplift. Three post-batholith, pre-Columbia River Basalt fault sets are found in the study area. These include:

(1) a left lateral set trending N. 12^{o} W.;

(2) a vertical to high angle reverse set trending north to N. 10^{o} E.; and

(3) a left lateral and vertical set trending east-west.

Movement began along the first set prior to final granitic dike emplacement. This is indicated by a dike which follows one of these faults on the north bank of Ice Lake. This fault is also intruded by a Columbia River Basalt feeder dike, as are most of the northerly trending dikes. Movement on this and other dikes continued through the Tertiary, at least until the time of basaltic magmatism. The relative timing of movement between these fault sets is irratic. No one fault pattern always offsets the other two consistantly. Rather, the movement history must be related to individual faults.

The largest offset occurs along a fault striking N. 10° E. in B. C. Basin, where the Martin Bridge - Clover Creek contact has been displaced at least 450 m (1500 ft) upward to the east. This and other faults parallel to it in the Wallowas seem to conform to a style of faulting, and follow the trends of faults involved in basin and range faulting in eastern Oregon and Nevada. Other faults with noteworthy offsets include vertical and left lateral movement each on the order of 180 m along the Fullington Creek and B. C. Faults (Fig. 39). This movement occurred in a manner resulting in the relative down-dropping of the block between the faults. Similar magnitudes of movement can be found along a major right lateral fault cutting north-northwest through Ice Lake and a broad vertical north-easterly trending shear zone near the mouth of Slick Rock Creek.

A fourth faulting occurred to the north of the study area and resulted in block uplift on the order of 1800 m (6000 ft) of the Wallowa Mountains. This uplift began after initial Columbia River magmatism. The principal offset occurs along the Wallowa Fault, which forms the N. 50° W. trending escarpment near Joseph and Enterprise.

Fig. 39a. Fullington Creek Fault from Hurricane Divide. Fault follows gulley filled with snow (center), where it offsets a syncline of Hurwal (dark horizontal band) left laterally and upward to the south.

Fig. 39b. Photograph looking west from B. C. Basin at B. C. Fault. Fault forms vertical line separating light and dark colored rocks in pass (arrow). Displacement of the fault is left lateral and up north.

SUMMARY - GEOLOGIC HISTORY

Geologic history in the northern Wallowa Mountains of northeastern Oregon can be summarized into four episodes. The first, an Upper Triassic depositional episode, involved volcanism, the development of reefs and subsidence and rapid fine-grained clastic deposition in an environment where slumping could occur. The second, a Jurassic deformational episode, began as regional deformation accompanied by intermediate and mafic magmatism, and concluded with granitic plutonism which caused intense plastic deformation of the sedimentary strata. The third, an episode involving regional uplift and faulting, began with late-stage granitic dike emplacement during the Cretaceous and continued through much of the Tertiary. It overlapped with the fourth episode, that involving Columbia River basaltic magmatism and block faulting, which took place mostly during the Miocene. Block faulting apparently ceased prior to glacial deposition during the Pleistocene.

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