1980

Structural investigation of a section through the Seven Devils Mountains Idaho

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STRUCTURAL INVESTIGATION OF A SECTION

THROUGH THE SEVEN DEVILS MOUNTAINS, IDAHO

by

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B.S., Pennsylvania State University, 1974

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1980

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6-10-80
Date

ABSTRACT

Detra, Earl H., M.S., Spring, 1980 Geology

Structural Investigation of a Section Through the Seven Devils Mountains, Idaho

Director: David M. Fountain

Rocks of the Seven Devils Mountains consist of an entire suite of island-arc-type rocks including subvolcanic, volcanic, pyroclastic, volcaniclastic, and epiclastic rocks, generated during the development of a Permian through Triassic island-arc system. These rocks were subjected to a single major deformational event characterized by east-over-west thrust faulting which was concentrated near the east flanking metamorphic-plutonic terrane. From geometric and kinematic arguments, this deformation is proposed to be synkinematic with motion of previously identified thrust faulting related to emplacement of the Idaho batholith. Various structural elements have been analyzed and systematic variation of deformational style has been defined. A model entailing batholithic uplift is favored as an agent of deformation, but subduction cannot be ruled out, and a combination of models may ultimately explain deformation of Seven Devils terrane.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to all of the individuals whose efforts contributed to the completion of this research. Special thanks are due to my thesis committee, especially Dr. David Fountain for his steady encouragement and Dr. Don Hyndman for his thought-provoking comments. Special recognition is also reserved for Katie Marron, whose prompt and diligent typing was absolutely invaluable. Many others, too numerous to mention here, also rendered valuable assistance for which I am extremely grateful.

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CHAPTER I

INTRODUCTION

The Seven Devils Mountains are situated in west-central Idaho, forming the divide between the Snake and lower Salmon River drainages near Riggins, Idaho (Fig. 1). The most distinctive characteristics of the range is its extreme relief, rising from about 400m above sea level in Hells Canyon to over 2800m elevation at the Devil Peak, less than 10km away.

Rocks underlying much of the Seven Devils Mountains are part of a discontinuous belt of eugeoclinal volcanic and volcaniclastic rocks extending from central Alaska to northern Mexico (Fig. 3). The northern half of this belt of Permo-Triassic volcanic rocks, along with overlying sedimentary rocks of late Triassic age, has been designated Wrangellia (Jones and others, 1977). Immediately east of Wrangellia are located the major Cretaceous batholithic terranes of western North America, which usually include a well developed regional-metamorphic envelope. To the west are the heavily deformed late Mesozoic eugeoclinal sequences, such as the Franciscan terrane of western California (Maxwell, 1974).

Wrangellia and adjacent terranes have been obscured locally by flood basalts of Tertiary age, and fragmented by transcurrent faulting related to North American and Pacific plate interaction. These Tertiary geologic events serve to promote controversy concerning the origins and interrelationships of pre-Tertiary rocks.

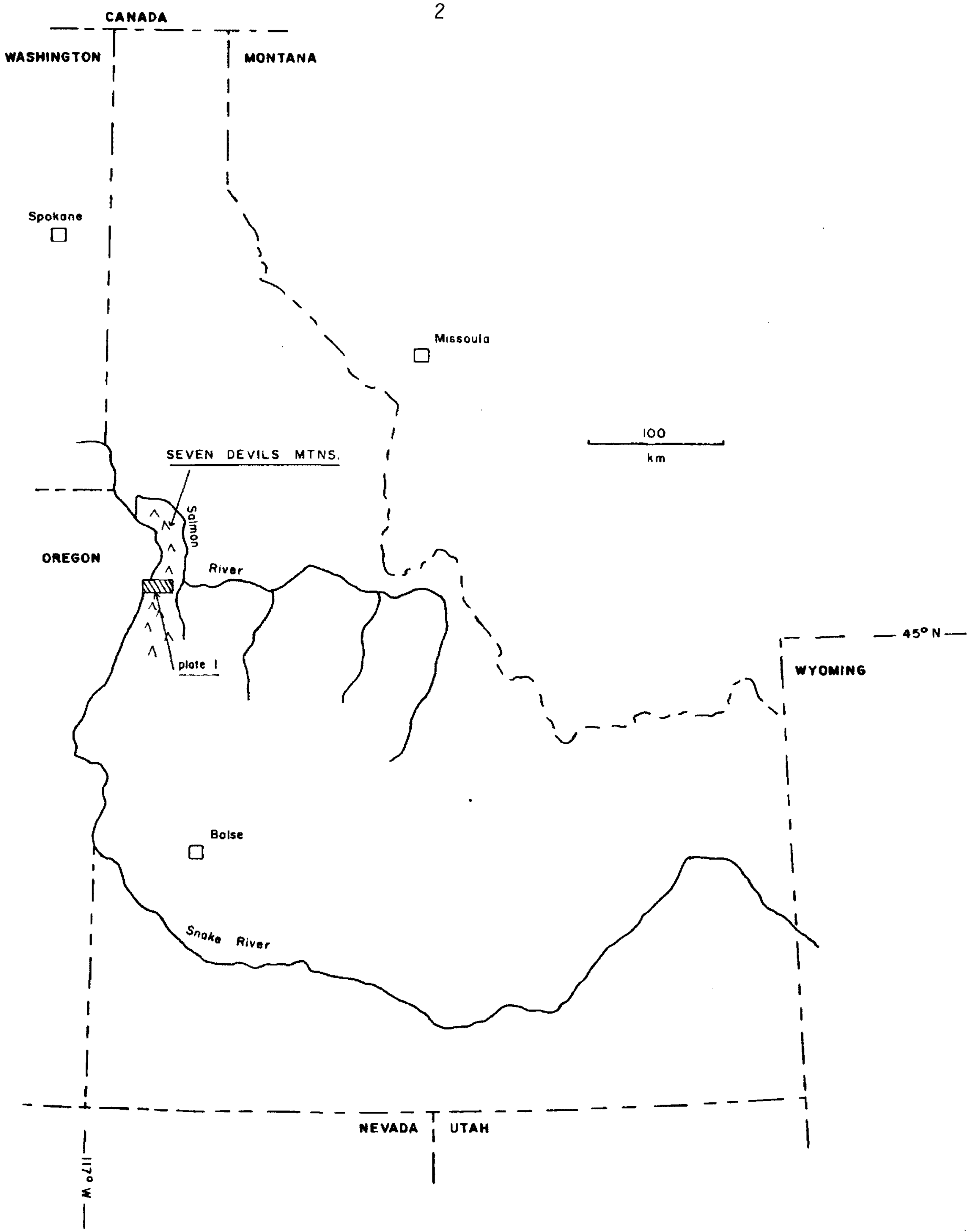


Fig. 1 Location map of Seven Devils Mountains and position of Plate 1.

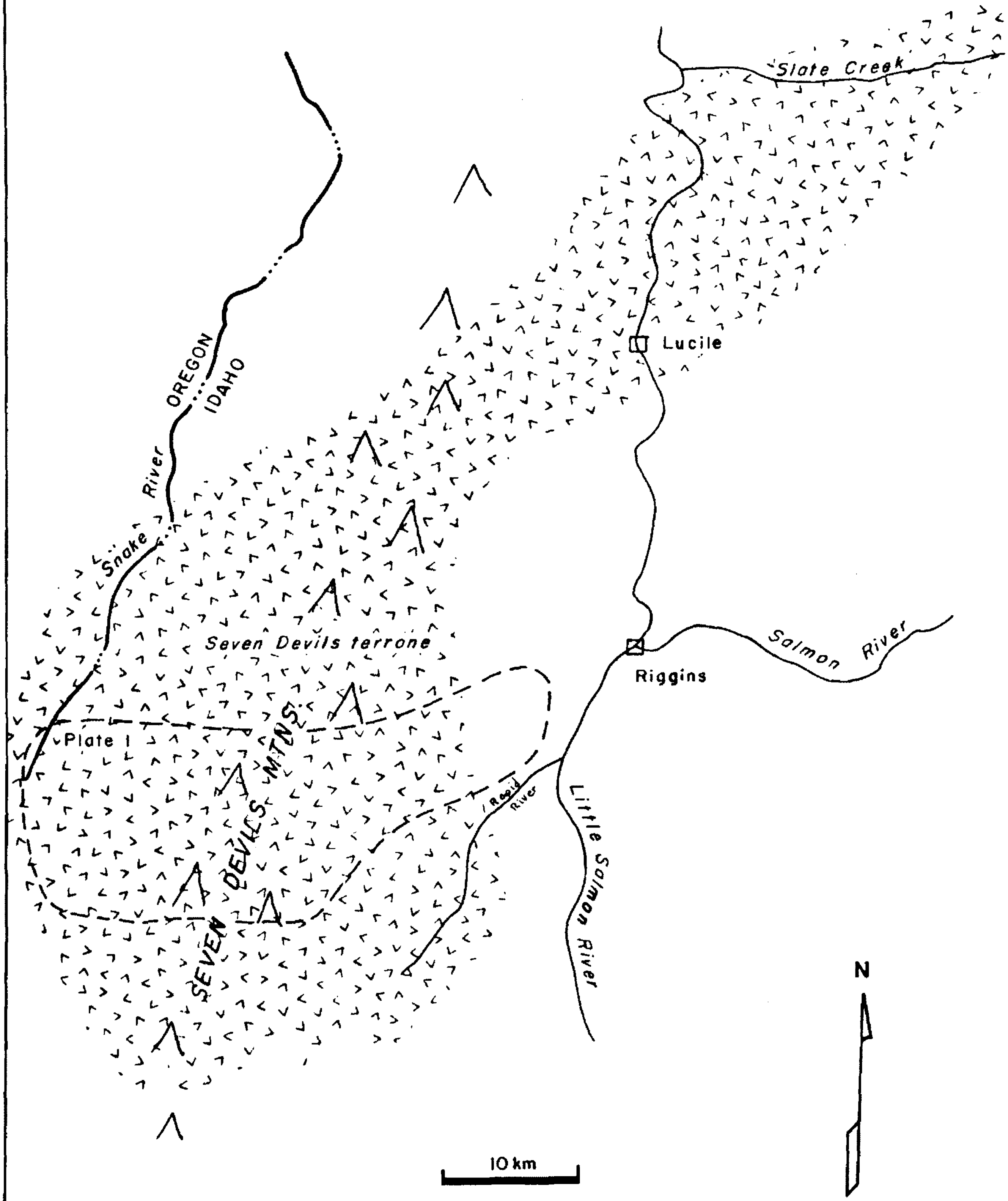


Fig. 2 Detailed location map

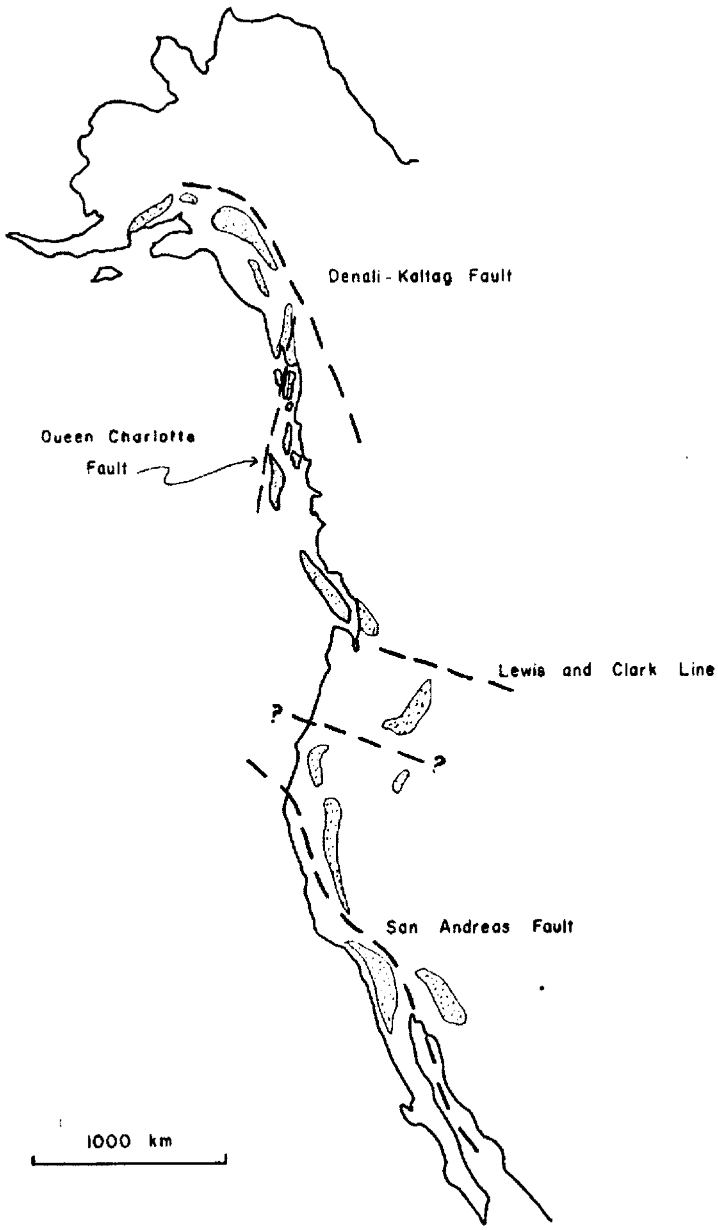


Fig. 3 Distribution of Permo-Triassic volcanic rocks and offsetting structures on the western margin of North America (from King and Beikman, 1974; Jones, et al., 1977).

Similarities between the Wrangellian rocks of eastern Oregon and Idaho and modern island arc rocks have long been recognized. Gilluly (1935) was probably first to propose such an origin for this volcanic belt, and has been supported by Hamilton (1963) in a definitive petrologic and metamorphic study of rocks on the western margin of the Idaho batholith. Since that time, various conflicting hypotheses have been advanced (Hyndman and Talbot, 1975; Hamilton, 1976; Onasch, 1976, 1979; Scholten and Onasch, 1977; Brooks and Vallier, 1978) and the geologic history of the region remains unclear.

Early work in the Seven Devils area was primarily concerned with the economic geology of the various base and precious metal deposits (Livingstone, 1920; Wagner, 1945; Cook, 1954). The volcanic stratigraphy of the Hells Canyon area was extensively studied and described by Vallier (1974, 1977). Onasch (1976, 1979) analyzed the geologic structure of the western margin of the Idaho batholith terrane and adjacent Seven Devils terrane in detail. More recently, Brooks and Vallier (1978) proposed a regional geologic history for the pre-Tertiary of eastern Oregon and western Idaho.

The purpose of this paper is to present a reconnaissance structural investigation of the Seven Devils Mountains in order to aid in reconstructing the geologic history of Seven Devils terrane. A regional synthesis is presented.

In order to accomplish these goals, several sources of information have been utilized. The first of these was an extensive literature survey of the local and regional geologic framework. This phase essentially described the affinities and distribution of the different terranes as they exist today. The next phase involved an in-depth review of rock types and processes occurring at various tectonic boundaries with particular reference to convergent type boundaries. In this way, it was possible to make preliminary comparisons, contrasts and interpretations of the structure, petrology, chemistry and metamorphism of Seven Devils rocks with the processes which may have generated them.

Field activities also entailed two phases. One of these consisted of reconnaissance (1:24,000) geologic mapping of a transect through a relatively unknown portion of the Seven Devils Mountains. This phase provided definition of lithologic types and gross geologic structure for comparison with published descriptions. The second phase involved a detailed description and analysis of ductile-type structural elements in order to define the style of deformation and sense of motion.

CHAPTER II

STRATIGRAPHY AND GENERAL GEOLOGY

The generalized stratigraphic column for this area is shown in Appendix I.

Seven Devils Group

The Seven Devils Mountains are chiefly underlain by an extremely thick sequence of metavolcanic and volcaniclastic rocks of early Permian to late Triassic age. Vallier (1974) designated this package of rocks the Seven Devils Group.

Rock types include pyroclastic breccias, agglomerates, andesite and basalt flows, flow breccias, volcanic conglomerates and other epiclastics, tuffs and minor intercalated limestones. All have been altered to some extent by greenschist facies of regional metamorphism and may be appropriately termed a spilite-keratophyre association. Rocks of former andesitic composition are overwhelmingly dominant.

In the Hells Canyon area Vallier (1974, 1977) recognizes four mappable units in the approximately 6km-thick section. Of the four, only the youngest two were encountered in this study. These two are the Wild Sheep Creek and Doyle Creek formations, both of Triassic age. In the map area (Plate 1), these formations are primarily volcaniclastic in nature, consisting of coarse volcanic breccias and agglomerates. Clasts are almost exclusively keratophyric, sub-rounded to angular and ranging in size from lapilli to 0.3m boulders. They are characteristically supported by a fine-grained tuffaceous matrix of approximately the same composition as the clasts, although in some cases altered to a varying degree. The volcaniclastics are poorly bedded.

Several thin keratophyre porphyry flows are intercalated with the volcaniclastics as are local volcanic graywackes and shales. Limestone units are thin and rare.

The Wild Sheep Creek and Doyle Creek formations are normally difficult to distinguish from each other (see Vallier, 1977) and no attempt was made to do so in this study. However, the Kurry Creek Member which forms the uppermost Doyle Creek Formation is distinctive. It appears to be derived from more mature sediments that the underlying units and includes volcanic conglomerates, graywackes, shales and minor black shales. Sedimentary structures, such as well developed bedding and graded bedding are common in this unit, particularly in the finer-grained portions.

The source area for Kurry Creek rocks was clearly more lithologically diverse than the source areas for other Seven Devils rocks. It must have included diorites, gabbros and limestones in addition to the dominant andesite component. Thin, distal latite ashflow units in the Kurry Creek Member of the Doyle Creek Formation record the final, explosive phases of volcanism in the Seven Devils volcanic pile.

In thin section the mineralogy of Seven Devils Group rocks is typical of the greenschist facies. Albite is commonly present as relict phenocrysts after more-calcic fedlspar, and contains fine-grained inclusions and selvages of sericite, epidote and chlorite. Fine microlites of albite also comprise up to 40% of the groundmass. The remainder of the groundmass is composed of a felty mass of chlorite, epidote, sericite, pyrite, calcite, and leucoxene with local quartz and hematite. No primary mafic minerals were observed in this study, but Vallier (1974) reported relict hornblende and pyroxene in Hells Canyon. Rare amygdules are filled by calcite, epidote, quartz, heulandite and other unidentified zeolites.

Geochemical evidence reported by Hamilton (1963) and Batiza and Vallier (1976) indicates that Seven Devils rocks are principally basalts and andesites of calc-alkalic affinities which have been altered to apilites and keratophyres during a greenschist metamorphism.

Two phases of metamorphism have been recognized in Seven Devils rocks. The first occurred during late (?) Jurassic (Hamilton, 1963) and may have accompanied Jurassic dioritic plutonism. According to Onasch (1979), the second was of early (?) Cretaceous age, possibly related to intrusion and uplift of the Idaho batholith. The first metamorphism was weak and generally contact in nature (Vallier, 1974). The second event boosted Seven Devils rocks to equilibrium greenschist facies in the Salmon River Canyon, but was less evident farther west as indicated by lack of equilibrium and the presence of primary hornblende and pyroxene in Hells Canyon (Vallier, 1974). Locally, higher grades of metamorphism were attained in Seven Devils rocks where they occur in greater proximity to the Idaho batholith (e.g.: at Slate Creek, see Fig. 2).

Basement for the volcanic pile as exposed in Hells Canyon is composed of gabbroic and ultramafic rocks, and may represent oceanic crustal material (Hyndman and Talbot, 1976; Brooks and Vallier, 1978).

Vallier (1977) interpreted the coarse volcaniclastic nature of the Seven Devils Group to indicate rapid deposition marginal to an active volcanic center. These rocks were occasionally emergent, resulting in erosional unconformities, local clastic deposition, and oxidation of clastic and pyroclastic material (see Vallier, 1977). It is suggested here that the widespread breccias of the Seven Devils Group represent the volcano-sedimentary apron deposited proximally to an active calc-alkaline volcanic arc. The uppermost unit, the Kurry Creek Member of the Doyle Creek Formation probably records erosion of the arc during the after the final phases of volcanism.

The best exposures of the Wild Sheep Creek and Doyle Creek formations are in the western portion of Plate 1, along Dry Diggins Ridge and near Dry Diggins Lookout.

Martin Bridge Formation

Thick (∿500m), laterally continuous limestones in the Seven Devils Mountains have been correlated with the late Triassic Martin Bridge Formation of eastern Oregon (Hamilton, 1963). The occurrence of this unit above volcanic units of nearly the same age indicates a rapid transition from intense volcanic and epiclastic deposition to a quiet, shallow, reef environment. Examination of thin sections from limestone outcrops in Hells Canyon suggests that the environment of deposition for at least part of the unit may have been similar to the modern Bahamas Banks (Ray Murray, verbal communication, 1976).

The thick, white, massive central portion of the formation probably comprises a reef core (Vallier, 1974). This reef core lithofacies was observed in the Seven Devils Mountains to grade upward into a graphitic limestone and a breccia unit which may be interpreted as a back-reef breccia (Don Winston, verbal communication, 1976). This breccia consists of strongly weathered and rounded cobbles of limestone in a black, micritic matrix. It is overlain by the Lucile Slate (see below).

Metamorphism of the Martin Bridge Formation occurred under the same conditions as the underlying Seven Devils Group. Although the mineralogy is essentially unaffected, there is a progressive increase of calcite grain size from west to east, toward the Idaho batholith. Fossil evidence is completely destroyed over the same interval.

The Martin Bridge Formation is best exposed in the area of Plate 1 on McClinery Ridge and in the Shingle Creek drainage forming the prominent easterly dip slopes.

Lucile Slate

The Lucile Slate, also presumed to be of Late Triassic age, overlies the Martin Bridge Formation in the Salmon River Canyon. It consists of a fine calcareous phyllite, normally pyritic and very carbonaceous. Locally, it contains scattered clasts of limestone. Chlorite, quartz, sericite and graphite are the principal components with lesser amounts of calcite and pyrite.

The Lucile Slate outcrops poorly and its thickness is unknown, as its top is nowhere exposed. The best exposures are immediately south of the town of Lucile, Idaho, and on the extreme eastern portion of the area on Plate 1, in the Papoose Creek drainage.

Because of their gradational contact and the presence of limestone clasts in the slate, the Martin Bridge reef and Lucile Slate basin may be interpreted to have existed contemporaneously. The slate would represent a restricted black shale basin whereas the limestone represents an offshore carbonate reef or bank, which overlies an older volcanic arc. This setting is almost identical to that proposed by Ripley and Ohmoto (1979) for Triassic rocks in Peru. They speculated that an offshore bench composed of a subsided volcanic arc and overlying sediments formed a barrier for a partially restricted basin in which syngenetic ore bodies were deposited.

Intrusive Rocks

The Seven Devils terrane is intruded by very diverse rock types which are treated in the following discussion as four relatively distinct groups.

The oldest suite of intrusives is composed of gabbroic and ultramafic rocks located in Hells Canyon, and are thought to be of Permian and/or Triassic age (Vallier, 1974). Because they do not occur in the area shown on Plate 1, these rocks were not investigated and are not discussed except to comment that they may be closely related to an oceanic basement complex (Hyndman and Talbot, 1976; Brooks and Vallier, 1978).

The oldest suite of intrusive rocks shown on Plate 1 is a group of keratophyre and spilite porphyries which are exposed as dikes and stacks in the high portions of the Seven Devils Mountains. These rocks intrude most of the Seven Devils Group, but could not be observed cross-cutting the Martin Bridge Formation or the Kurry Creek Member of the Doyle Creek Formation. Their age is, therefore, interpreted to be late Triassic. The keratophyre-spilite porphyries appear to be similar to intrusive rocks in Hells Canyon, described by Vallier (1974), who also speculates a possible late Triassic age for these rocks.

Mineralogically the keratophyre-spilite porphyries are identical to volcanics of the Seven Devils Group except in the abundance and size of albite phenocrysts. The phenocryst abundance is generally higher in the intrusive rocks, varying from negligible in some dikes to approximately 60% of the rock. Phenocrysts may reach 0.75cm in length.

Because of the similarity of the intrusive porphyries to extrusive rocks of the Seven Devils Group they have previously been mapped as volcanic rocks. However, they are homogeneous over large areas, and their contacts with the volcaniclastics are irregular but very sharp in outcrop. At several locations (e.g.: above Shelf and Basin Lakes) large inclusions of sedimentary rocks up to tens of meters long, are completely surrounded by the porphyritic rock.

These relationships dictate that the keratophyre-spilite porphyries be interpreted here as cogenetic with the surrounding volcanic pile. They may represent a shallow subvolcanic intrusive system. They are exposed along the higher parts of the Seven Devils Mountains in the southern portion of Plate 1. The high relief of the central part of the range may be facilitated by the very resistant nature of these rocks.

Jurassic diorite and quartz diorite stocks and dikes comprise the second suite of intrusive rocks encountered by this study. These plutons, best exposed in the Granite Creek drainage in the western portion of Plate 1, are typical, medium-grained, equigranular diorites. They are essentially unmetamorphosed in the Seven Devils Mountains but are more altered and sheared near Lucile, Idaho, probably reflecting the early (?) Cretaceous metamorphism defined by Hamilton (1963).

The earlier, late (?) Jurassic metamorphism (Hamilton, 1963), which weakly affected the older rocks, apparently had no effect on the Jurassic diorite suite. Therefore, the diorites were probably syn- or post-metamorphic with respect to the late (?) Jurassic event. Hamilton (1963) suggests that shearing also appears to pre-date these intrusions.

The youngest set of intrusives consists of rocks directly related to the Idaho batholith. Most of these granitic plutons are exposed outside the Seven Devils Mountains and are not depicted in

Plate 1. They were emplaced during middle to late Cretaceous time (Hyndman and others, 1975) and may have caused the early (?) Cretaceous metamorphic event (Hamilton, 1963).

Plutonic rocks of Idaho and eastern Oregon exhibit a consistent pattern of initial Sr^{87}/Sr^{86} values. Armstrong and others (1977) have found that intrusives of the Cretaceous suite, situated generally east of the Salmon River, have initial ratios of greater than 0.7055. The older suites of rocks, mostly situated west of the Salmon River, exhibit ratios of less than 0.7043. This evidence strongly suggests that the Idaho batholith is of more continental derivation than the more westerly intrusives, and that the western limit of continental crust during Cretaceous time was near the eastern edge of the Seven Devils Mountains (see Armstrong and others, 1977).

Other Rocks of the Seven Devils Mountains

Two other groups of rocks make up small portions of the Seven Devils Mountains but are not considered part of Seven Devils terrane. The Riggins Group is a thick (7km ?) sequence of metavolcanic and metasedimentary schists which was thrust westward over Seven Devils rocks during the Cretaceous (Hamilton, 1963). This thrust, known as the Rapid River thrust, separates middle to upper greenschist facies rocks of the upper plate (Riggins Group) from the lower greenschist facies rocks of the Seven Devils terrane (Hamilton, 1963). Minor lithologies included in the Riggins Group are garnetiferous amphibolite dikes and several serpentinized metaperidotite bodies which were apparently tectonically emplaced. Calc-silicate schists are locally common. Hamilton (1963) presented evidence that the Seven Devils and Riggins Groups exhibit chemical similarities, and suggests that the two groups have similar origins.

Riggins Group rocks do not outcrop in the area of Plate 1, but are covered by Tertiary basalts in the eastern part of the diagram.

The Miocene Columbia River basalts occur sporadically in the higher parts of the Seven Devils Mountains. Small outcrops occur near Dry Diggins Lookout and a larger erosional remnant occurs on the eastern edge of the map area. The occurrence of these basalt outcrops at high elevations (2340m) above the basalts on the Columbia Plateau (1970m) suggests that some uplift of the Seven Devils Mountains may have occurred since Miocene time.

CHAPTER III

DEFORMATION AND STRUCTURE OF THE SEVEN DEVILS TERRANE

Most of the research presented here was devoted to a study of the structural elements of Seven Devils terrane. One phase of the study consisted of reconnaissance geologic mapping of a transect through the Seven Devils Mountains which is depicted on Plate 1. During this phase, the gross geologic features were observed, and an interpretive cross section was produced (Plate 2). A second phase of the study involves a more detailed treatment of mesoscopic structural elements and is discussed below along with results of the first phase.

Faults

The predominant type of deformation in the Seven Devils Mountains is faulting. The rocks appear to have been so brittle as to preclude extensive, penetrative folding, instead resulting in faulting and pervasive fracturing. This brittle response is probably due to the low metamorphic grade of the rocks, and a shallow depth of deformation.

The faults which were most important in the deformation of Seven Devils terrane are a north-northeasterly trending swarm of reverse faults (see Plates 1 and 2). These faults dip moderately to steeply east or are vertical. The relative sense of motion, as determined by drag-fold orientation, fracture patterns and rare slickensides is nearly invariably east side up or west side down. This sense of motion is compatible with that of the Rapid River Thrust noted above. Some of the faults near Seven Devils Lake exhibit conflicting evidence for sense of motion and may have suffered reversal of the primary inferred sense of motion.

A good example of this set of faults is exposed on Dry Diggins Ridge near the junction of the Sheep Creek and Hells Canyon trails. At this location, the fault trends 005° and dips 85° east. It consists of a 5m-thick zone of heavily brecciated and chloritized volcaniclastics. Fault gouge is undeveloped or has been recrystallized. The relative sense of motion, east side over west, is determined by observing the assymetry of drag-folded volcaniclastic beds in the footwall of the fault zone. To the north, this particular fault can be traced for several kilometers but is covered by younger Columbia River Basalts and soil farther south.

A second set of faults occurs in the northwestern portion of the map area (see Plate 1). These faults are inferred from aerial photographs and from inconsistent bedding attitudes in that area. They trend northeasterly and are interpreted to be vertical because of their rectilinearity. Since outcrops of the stratigraphically high Kurry Creek Member of the Doyle Creek Formation occur at much lower elevations on the west side of Hells Canyon, the relative motion at these faults is interpreted to be northwest side down.

The third set of faults depicted on Plate 1 consists of roughly east-west-trending normal faults. They are not considered to be important in the deformation of Seven Devils terrane but do deflect bedding and foliation attitudes in their vicinity. One of these faults controls the Shingle Creek drainage north of Heavens Gate; another is well exposed south of Quad Lakes.

Folds

On the basis of fold analysis, two zones of structural style can be recognized in the Seven Devils Mountains. In the western portion of Plate 1, rocks are intensely fractured and folds are poorly developed. Existing folds tend to be drag folds developed adjacent to reverse faults. For the purpose of this discussion, rocks west of Windy Saddle (center of Plate 1) occupy the "brittle zone".

In contrast, the sedimentary section exposed in the eastern portion of Plate 1 was deformed in a more ductile style. These rocks are not as strongly fractured, generally exhibit a well-developed foliation, and display non-pervasive folding. The ductile nature of deformation in these rocks is probably due to the relative weakness of the sedimentary section, and possibly to higher temperatures of deformation. This style domain is designated the "ductile zone".

Bedding attitudes measured in volcaniclastic rocks of the brittle domain are depicted in Figure 4. Two distinct domains are present. Domain A is defined by poles to bedding which occupy a half girdle representing west-northwest dipping beds. The axis of folding which

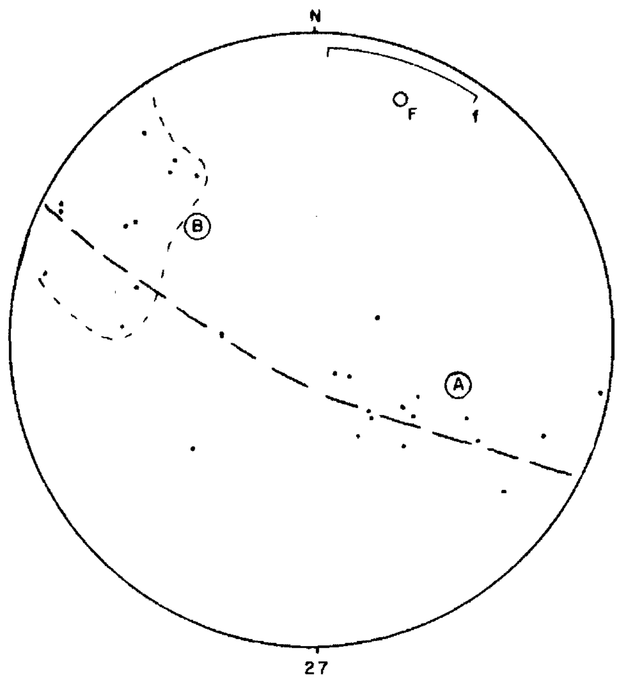


Fig. 4 Orientation diagram of poles to bedding taken from Plate 1. "F" indicates inferred fold axis, "f" indicates the approximate range of trends for reverse faults cutting Seven Devils terrane.

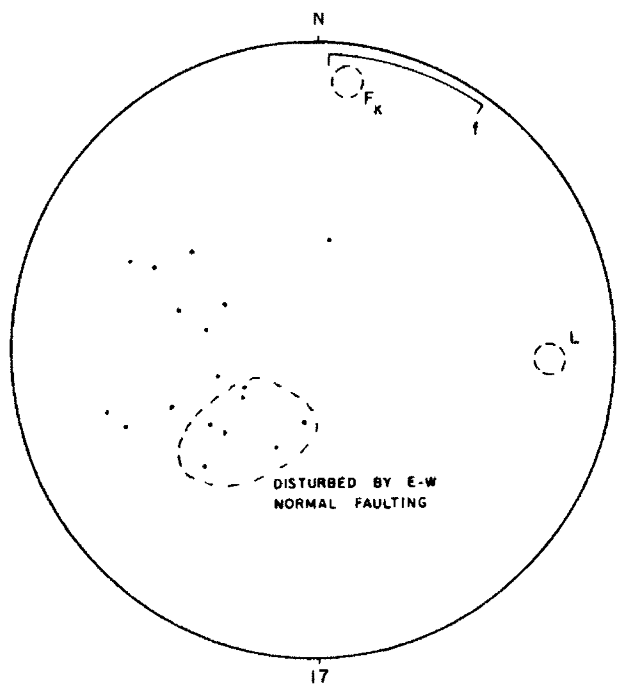


Fig. 5 Orientation diagram of poles to foliation taken from the ductile zone of Plate 1. "F_k" indicates attitude of kink fold axes in foliation (see Fig. 7), "L" denotes the attitude of lineations in the foliation (see Fig. 10),and "f" indicates the approximate range of trends for reverse faults cutting Seven Devils terrane.

is inferred from this half girdle plunges gently north-northeast. Domain B is defined by a cluster of steeply east-southeast-dipping beds which may represent the opposite limb of domain A.

The overall symmetry of Figure 4 is most easily interpreted as monoclinic, which is characteristic of asymmetric folding (see Turner and Weiss, 1963, Ch. II). On the basis of field observations, it is felt that the asymmetry was generated by inhomogeneous deformation in which widely spaced faults cut rocks of otherwise homogeneous structure. Domain A represents those rocks which have been drag-folded along the north-northeast-trending reverse faults, whereas domain B represents the general fabric of the brittle zone.

The most distinctive characteristic of the ductile zone is the development of a strong foliation oriented subparallel to bedding. An orientation diagram of poles to foliation measured on Plate 1 is shown in Figure 5. A diffuse cluster indicated moderately east-southeast-dipping foliations. This·geometry is similar to that of domain B in Figure 4; possibly suggesting a geometric link between foliations in the ductile zone and reverse faulting in the brittle zone.

Analysis of Ductile Zone

Early in the course of this project, the relatively ductile zone of deformation in the sedimentary rocks on the east side of the Seven Devils Mountains was the subject of more detailed study. The results of this study are described below.

Three phases of deformation have been observed in the ductile zone of the Seven Devils Mountains. In the presumed sequence given below, the relative timing of the last two phases is uncertain and may have been simultaneous.

Foliation. The first phase of deformation is defined as the development of a strain-ship foliation with concurrent development of a tectonic "a" lineation in the plane of foliation. The foliation is well developed in tuffaceous units of the Seven Devils Group, in thinly bedded portions of the Martin Bridge Formation and in the Lucile Slate. In outcrop it is visible as a prominent fissility usually subparallel to bedding. All inequidimensional constituent elements such as conglomerate and breccia clasts and individual mineral grains are visibly flattened and/or rotated into the plane of foliation. Most grains show no sign of internal disruption, but some large clasts exhibit fracturing and micro-faulting.

Where foliation is not developed, clasts and mineral grains are roughly equidimensional and angular. Foliation of this type is not observed in volcanic-flow or intrusive rocks.

On a microscopic scale, the foliation results from parallel orientation of chlorite, sericite, and quartz grains in tuffaceous rocks and from calcite, quartz, and clays in limestones. It is further enhanced by comminution of calcite along discrete planes which are very suggestive of microcataclasis.

Poles to foliation measured in the Martin Bridge Formation and Lucile Slate from the Rapid River area to Slate Creek (see Fig. 2) are depicted in Figure 6. The pattern of data points is extremely diffuse, apparently because of post-foliation normal faulting. A strong maximum reflects the dominant east-southeast dips. This maximum is a segment of a great-circle girdle which indicates folding about an axis which plunges gently northeast. The overall symmetry of Figure 6 is roughly orthorhombic and the position of the maximum shows that the foliation has been folded asymmetrically with long east limbs and shorter west limbs.

An orientation diagram of poles to foliation in tuffaceous Seven Devils rocks of the ductile domain is presented in Figure 7. Here, two strong maxima are observed forming a great-circle girdle which suggests folding about a northeast-plunging axis. The south-east-dipping folia are the common type in the Seven Devils Mountains, whereas northwest-dipping folia appêar to be restricted to the Slate Creek area. These data show the existence of a large scale northeast plunging synform with an axis which nearly follows the course of the lower Salmon River.

Lineation. Wherever the strain-slip foliation is developed in Seven Devils terrane, it is accompanied by a mesoscopic lineation. In outcrop the lineation occurs as streaks and smeared grains of calcite in limestones, and chlorite in tuffaceous rocks. In breccias and conglomerates, the lineation is also formed by the dimensional

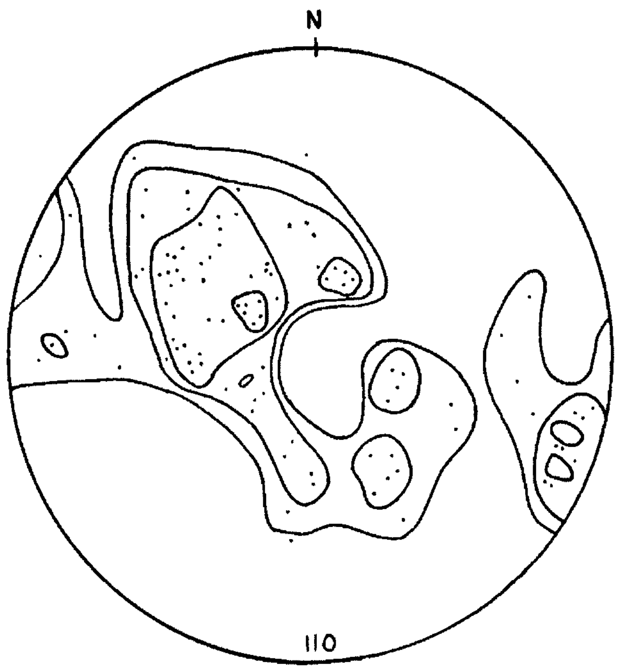


Fig. 6 Orientation diagram of poles to foliation in the Martin Bridge Formation measured in the ductile zone of Seven Devils terrane. Contour intervals at 1, 2, 5, and 10% per 1% area.

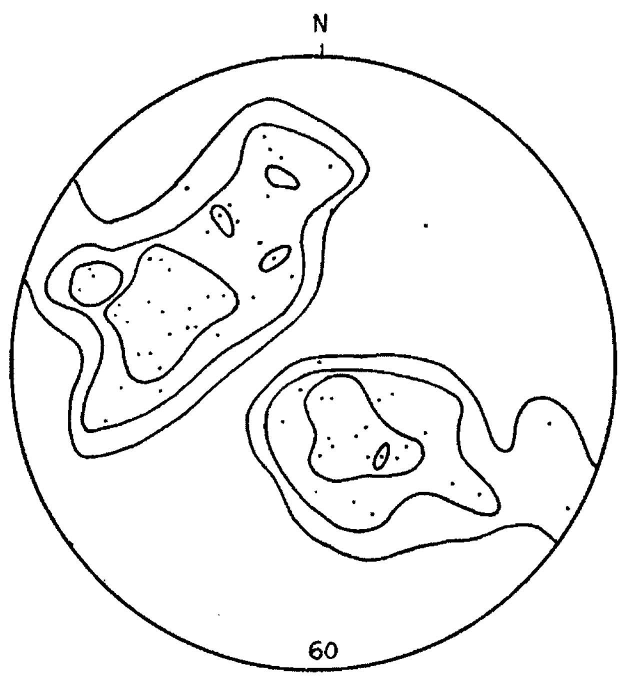


Fig. 7 Orientation diagram of poles to foliation in Seven Devils Group rocks measured in the ductile zone of Seven Devils terrane. Contour intervals at 1, 2, 5, and 10% per 1% area.

preferred orientation of triaxial clasts which appear to have been flattened in the plane of foliation and elongated in the direction of lineation. On Heavens Gate Ridge, average dimensional ratios for conglomerate clasts is 4.3:2.1:1.

In thin section, the lineation is caused by the dimensional preferred orientation of fine calcite and chlorite grains which are not internally disrupted. Due to difficulty in thin-section preparation slates could not be examined microscopically, but lineation appears to be formed by orientation of sericite and quartz grains.

The geometry of lineations in the ductile style domain is summarized stereographically in Figure 10. Attitudes are remarkably consistent, having one well defined maximum and an attenuated great circle girdle generated by folding about a north-northeast-plunging axis. The average lineation plunges 25°/099°, which is very nearly parallel to the average dip of the foliation (compare Figs. 6 and 10).

<u>Origin of foliation and lineation</u>. The type of foliation described above is similar to strain-slip cleavage described by Turner and Weiss (1963, p. 98), in which each cleavage plane represents a discrete zone that has localized slippage. This cleavage plane separates two laminae in which shear strain was relatively homogeneous and grains were not disrupted (Fig. 8). In this way, foliation was promoted by flattening and/or rotation of grains within the laminae, and by cataclasis along the cleavage plane. Lineation, meanwhile, formed in response to ductile elongation of grains and drag across the cleavage plane.

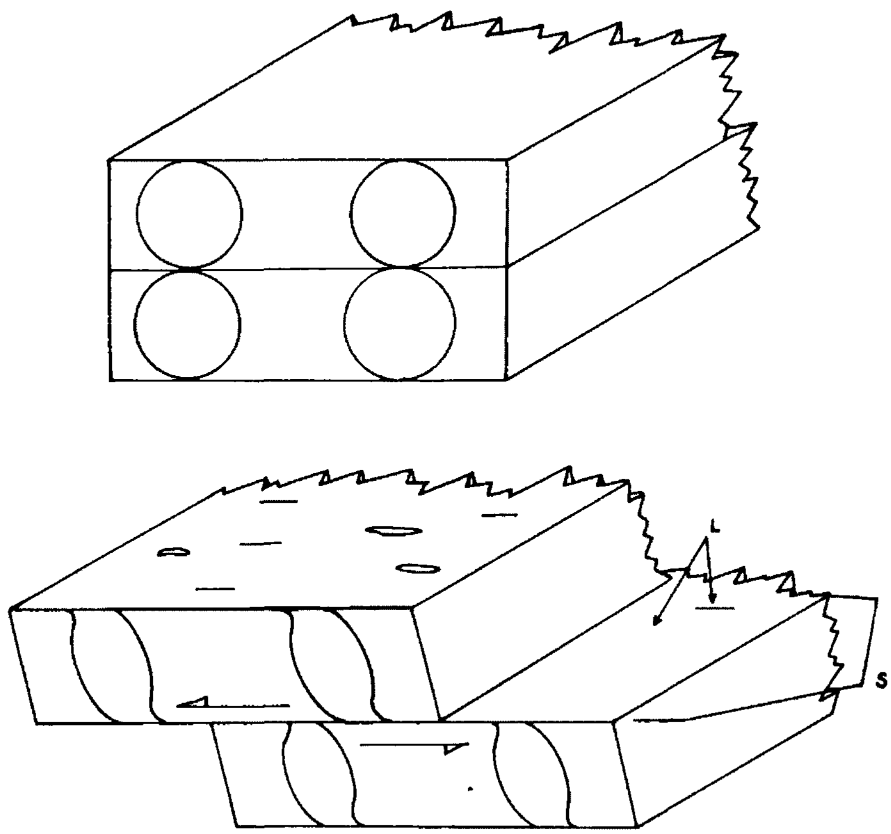
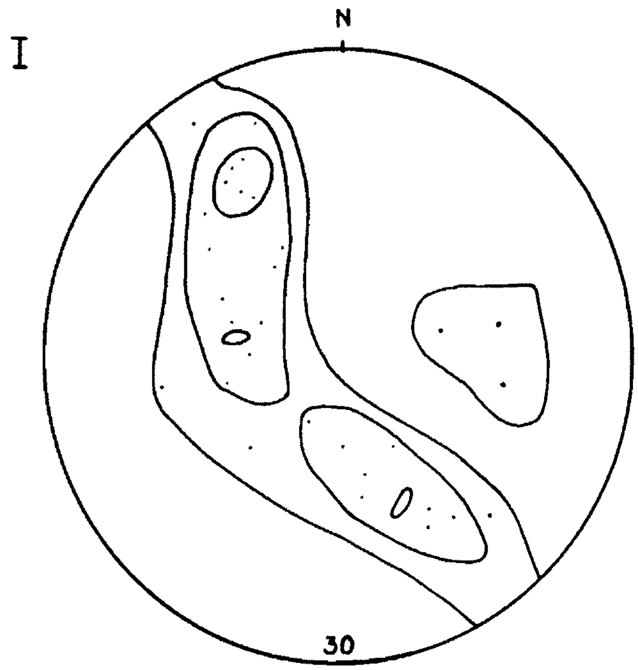


Fig. 8 Schematic diagram showing development of strain slip foliation "s" and shear lineation "l".

Since there is no evidence for the folding necessary to form an axial-plane foliation, especially in the map area (Plate 1); both foliation and lineation are believed to have arisen from intense shearing. Therefore, the lineation is considered to be a tectonic "a" lineation, indicating the direction of tectonic transport. This direction as shown by Figure 10 is in the 099° - 279° line; and observations of shape and symmetry of deformed grains (see Fig. 8) show that the overlying rocks were transported westward or the underlying rocks eastward. This relative sense of motion is similar to that of the superjacent Rapid River Thrust (Hamilton, 1963).

Onasch (1979), investigating a portion of Seven Devils terrane near Slate Creek, defined an isoclinal folding event as the first of three deformations. Though such folds are known to exist elsewhere (e.g.: near Lucile, Idaho), there is no evidence for isoclinal folds in the area of Plate 1. Whether foliation was formed by isoclinal folding or by over-(under?) thrusting, the geometry would be very similar.

Second Deformation. The second (?) phase of deformation of Seven Devils rocks involved the development of large-scale warps in bedding. Figures 9a and 9b exhibit the results of a domainal analysis of bedding measurements from the Seven Devils Group and Martin Bridge Formation. Domain I consists of the area north of Lucile, Idaho, whereas domain II occurs south of Lucile. The inferred fold axis for domain I plunges gently to the northeast and agrees closely with



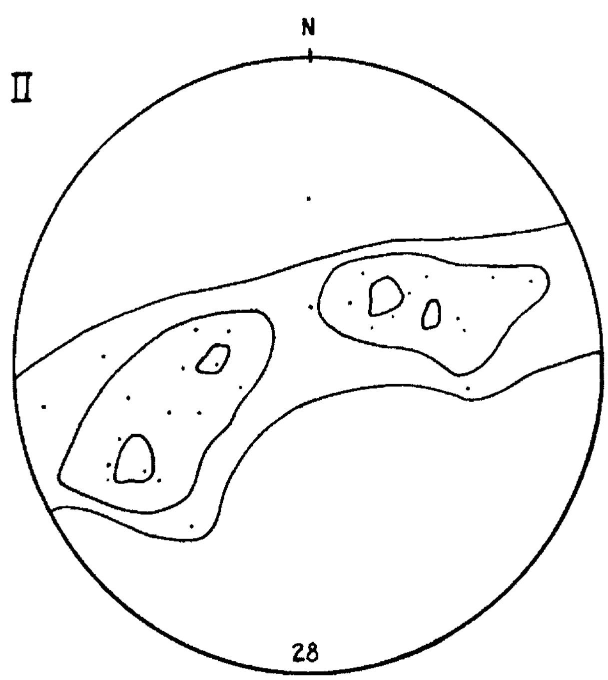


Fig. 9 Domainal analysis of bedding attitudes in the Martin Bridge Formation and Seven Devils Group rocks. Contour intervals at 2, 4, and 8% per 1% area.

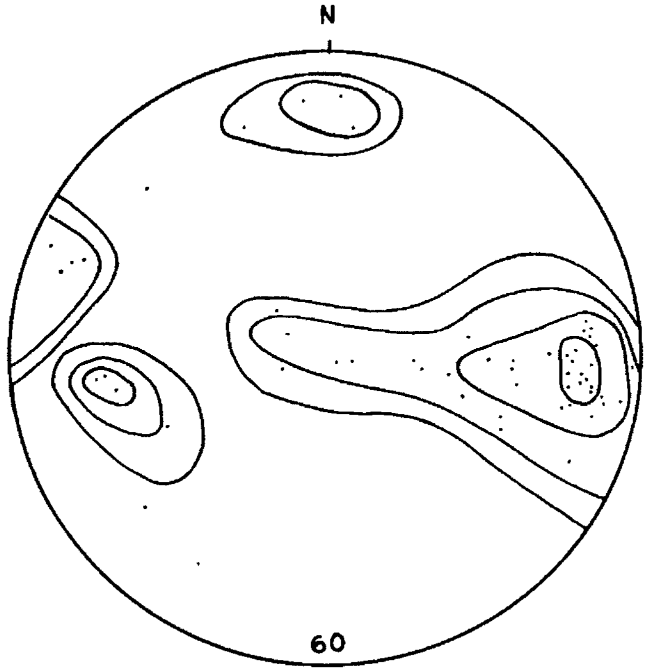


Fig. 10 Orientation diagram of lineations measured in the ductile zone of deformation of Seven Devils terrane. Contour intervals at 1, 2, 5, and 10% per 1% area.

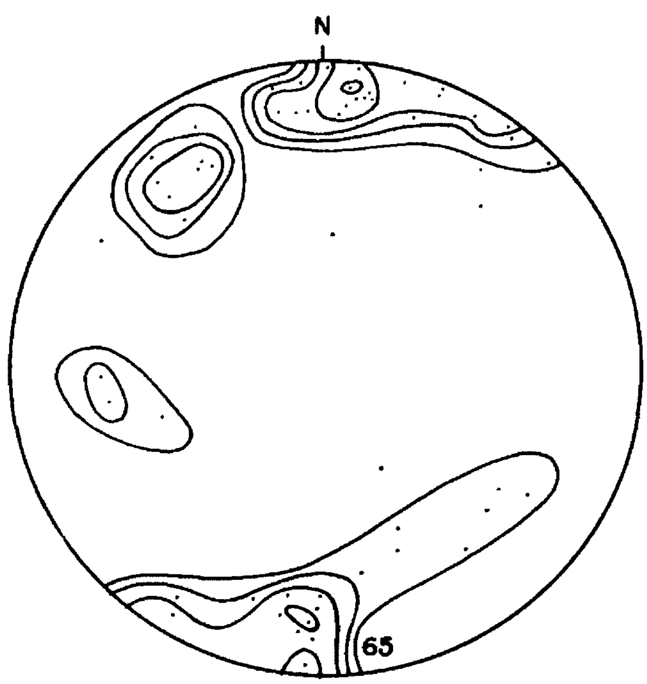


Fig. 11 Orientation diagram of kink fold axes measured in Seven Devils terrane. Contour intervals at 1, 2, 5, 10, and 15% per 1% area.

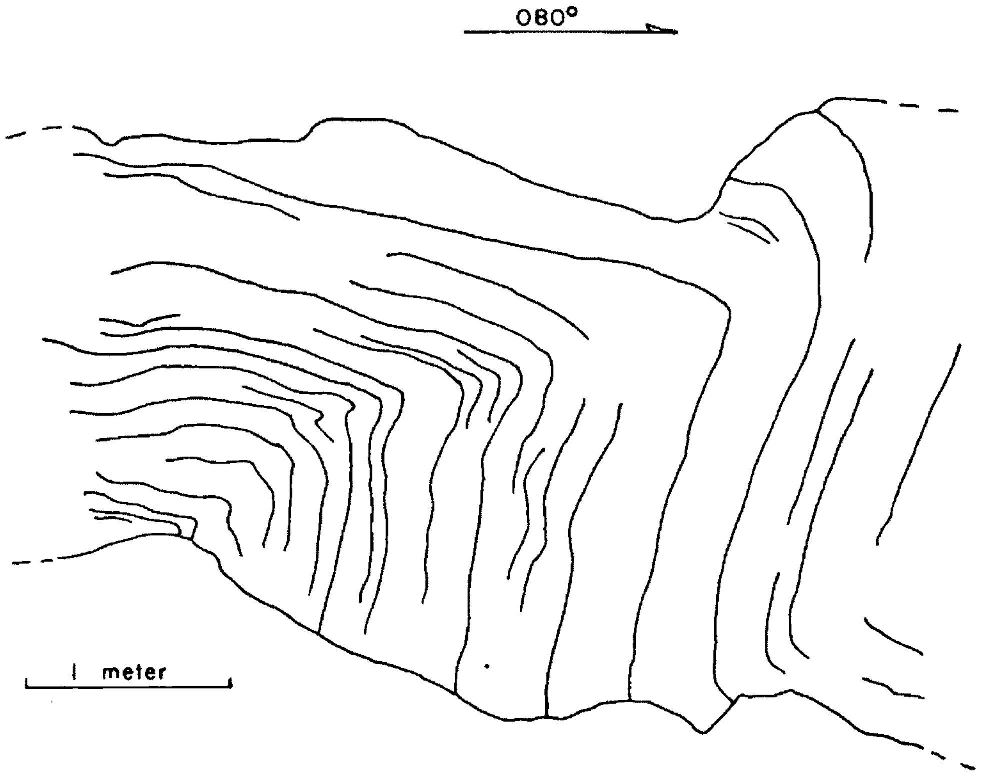


Fig. 12. Sketch of kink fold in foliated Martin Bridge Formation, from road cut in the Shingle Creek drainage.

Onasch's (1979) data. Bedding in domain II (Fig. 9b) has been folded about a south-southeast-plunging axis, which is not apparent in any other data presented here.

Third Deformation. The third (?) phase of deformation consists of non-pervasive kink folds or chevron folds developed at the outcrop scale and larger, in foliated rocks. Direct observation verifies that these folds are responsible for the first-order variation (i.e.: great-circle girdles) in graphic data for foliation and lineation (see Figs. 6 and 10).

Attitudes of kink-fold axes are shown in Figure 11. Though there is some variation, the maxima indicate axes that gently plunge to the north-northeast and south-southwest. The former attitude is compatible with folding inferred from Figures 6 and 10. A sketch of a typical kink-fold is shown in Figure 12.

Timing of Deformation. The relative timing of the three phases described above is uncertain. The only observable temporal relationship is that foliation and lineation precede kink folding. In addition, there are no cross-cutting relationships of these phases with either reverse faulting in the brittle domain or motion along the Rapid River Thrust. The proximity of all these tectonic elements, along with their similar sense of motion, suggests that they may be genetically related to the same dynamic system. They may, in fact, be essentially simultaneous, though there is no direct evidence for this.

The absolute age(s) of deformation in Seven Devils terrane may be constrained by several datable geologic events. Except for minor tectonic adjustments, deformation is certainly limited to pre-Miocene time by the essentially undeformed nature of overlying Columbia River Basalts. The Rapid River Thrust is considered by Hamilton (1963) to be post-early(?) Cretaceous because it cross-cuts metamorphism presumed to be of that age.

Onasch (1979) reports that deformation of the Riggins terrane, above the Rapid River Thrust, is spatially, and therefore genetically, related to metamorphism and intrusion of the Idaho batholith, which occurred during the mid- to late-Cretaceous (Hyndman and others, 1975). This inference is considered to be tenuous, particularly since the Rapid River Thrust is either obscured by metamorphism or cross-cut by the batholith north of the Riggins area (Hamilton, 1963, plate 1). Hyndman (verbal communication, 1980) argues that the regional metamorphism post-dates the late Triassic Martin Bridge and Lucile formations and pre-dates the Late Cretaceous Idaho batholith, but the available data do not permit further constraint of the timing. Onasch (1979) also states that the Rapid River Thrust occurred after metamorphism and is therefore, "no older than late Cretaceous", and is possibly concurrent with other late Cretaceous overthrust structures of western North America.

CHAPTER IV

DISCUSSION

Similarities between greenstones of eastern Oregon and modern island-arc systems were first recognized by Gilluly (1935). Utilizing geochemical and petrologic evidence, Hamilton (1963) rekindled the notion that Riggins Group and Seven Devils Group rocks were deposited in an environment very similar to the modern Aleutian Islands. More recent geochemical results (Batiza and Vallier, 1976) support Hamilton showing that the spilite-keratophyre association of Seven Devils terrane was originally calc-alkaline in nature, typical of modern volcanic arc systems. Metallogenic evidence further supports the island-arc hypothesis, in that ore deposits such as the Red Lodge and Iron Dyke in the Seven Devils District (Frederickson and others, 1976) closely resemble the Kuroko deposits of Honshu Island, Japan (Lambert and Sato, 1974).

The island-arc association appears to be well established, though the detailed structural history is still unclear.

Controversy concerning the origin of the Seven Devils terrane was initiated by Hyndman and Talbot (1975) who argued that the rocks represent an accreted terrane. They cited the presence of sheared serpentinites, metagabbros and westward-directed thrusting (or eastward under-thrusting) as evidence. Hamilton (1976), using geochemical data, advanced the hypothesis that Seven Devils rocks represent a partially subducted island-arc. Brooks and Vallier (1978) also proposed an allochthonous origin for the Seven Devils arc system and suggested that portions of the Riggins Group represent oceanic crust.

Onasch (1976, 1979) and Scholten and Onasch (1977), utilizing extensive mapping and structural interpretation, contended, however, that deformation in the region is directly related to intrusion and uplift of the Idaho batholith.

It is clear from the conflicting proposals summarized above that the juxtaposition of Seven Devils terrane and batholithic - metamorphic terrane is not understood. Two basic themes are evident: 1) partial subduction and accretion to the continent of an island-arc during eastward underthrusting; and 2) overthrusting of an on-shore volcanic arc by a rising and laterally spreading batholith. The relative sense of motion would be the same in either case. Furthermore, the two cases may not be incompatible.

The key evidence for discriminating between the two alternatives is the timing of thrust faulting relative to that of intrusion. In the case of accretion, underthrusting is expected to precede intrusion at any given location within the volcanic arc (Karig and Sharman, 1975). On the other hand, overthrusting should occur simultaneously with, or after, intrusion.

Unfortunately, no direct line of evidence for the relative timing of intrusion and thrusting has been discovered in the Seven Devils Mountains. If, as Onasch (1979) contends, metamorphism preceded thrusting along the Rapid River Thrust, and if the metamorphism was caused by batholithic intrusion, then at least some thrusting is certainly related to batholithic upwelling. These observations do not, however, necessarily preclude underthrusting (subduction) at an earlier time; particularly since the sense of motion would be the same.

It is the feeling of the author that the simplest interpretation requires only a single deformational sequence of events. The increasing intensity of deformation from Hells Canyon to the Salmon River Canyon observed in this study, along with that observed by Onasch (1979) from west to east in the Riggins terrane, also suggests the same conclusion. Moreover, it suggests that the impetus for deformation was generated to the east and was directed toward the west.

Speculative Geologic History

Speculations concerning the geologic history of the Seven Devils Mountains are summarized in Figures 13a through 13d. The interpretations presented are drawn from literature already referenced, and by the present field work in the Seven Devils Mountains and other areas presumed to be parts of Wrangellia. The diagrams are self-explanatory, though several points should be stressed.

From mid-Permian to late Triassic time, a volcanic arc resided somewhere off the coast of western North America. This is an

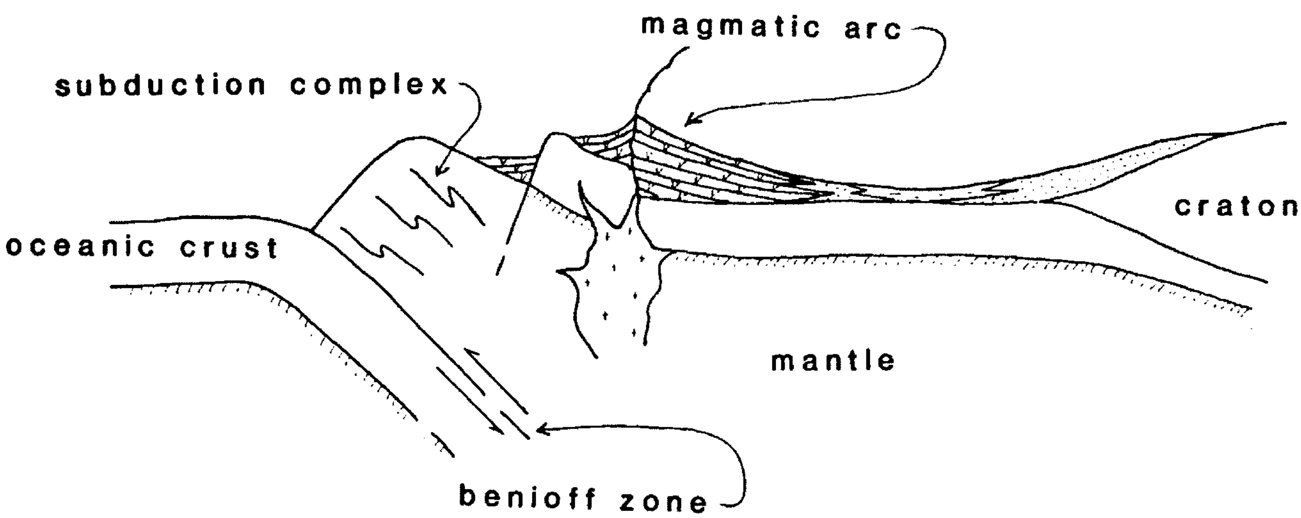


Fig. 13a Reconstruction of Seven Devils tectonic setting during mid-Triassic time. Extensive calc-alkaline volcanism and the development of andesitic stratovolcanoes in the Seven Devils arc are shown.

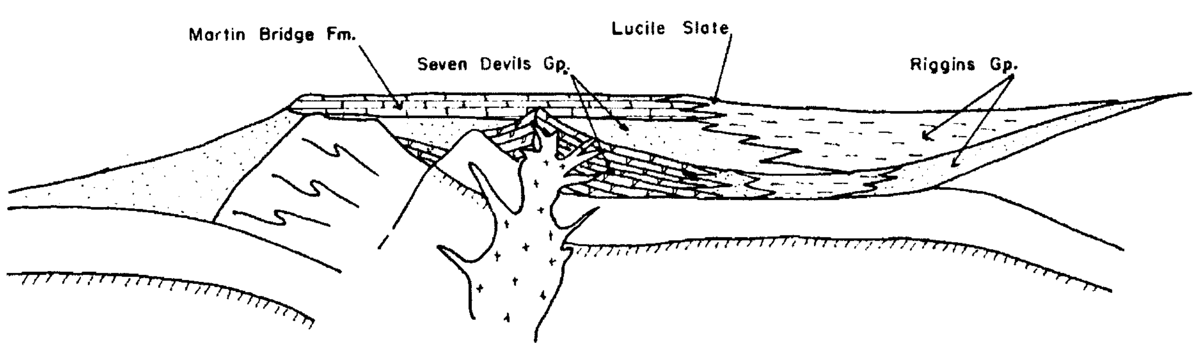


Fig. 13b Latest Triassic reconstruction, showing erosion of the volcanic arc with subsequent clastic and reef deposition. Spilite-keratophyre porphyrys have intruded the volcanic pile.

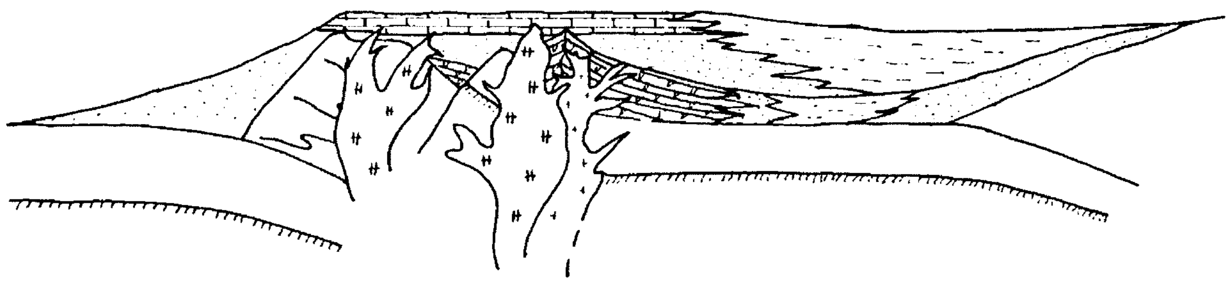


Fig. 13c Late Jurassic reconstruction, showing intrusion of Jurassic diorite and quartz diorite stocks into the Triassic arc. This may have occurred in response to westerly situated subduction.

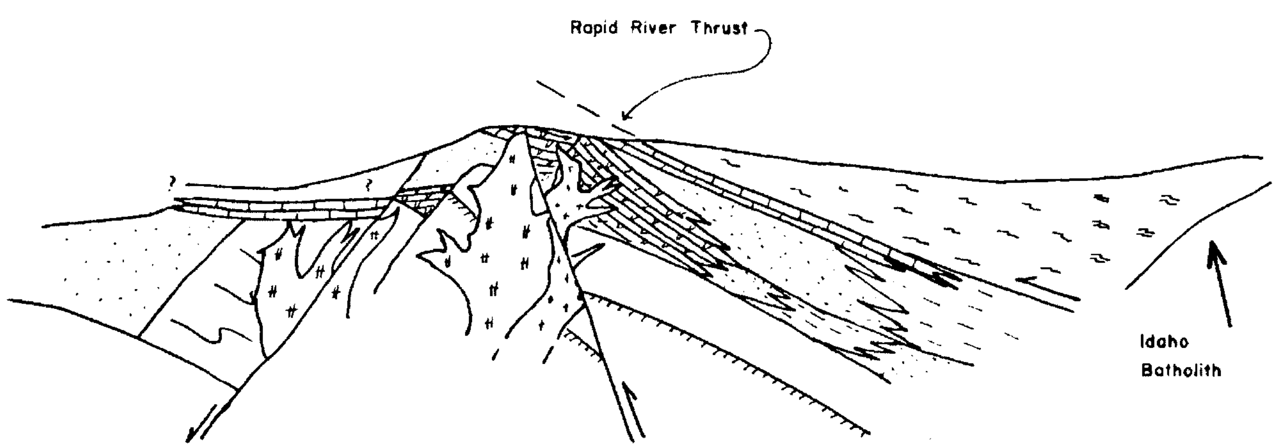


Fig. 13d Late Cretaceous-early Tertiary reconstruction, showing emplacement of the Idaho batholith and related rocks. Thrust faults, generated by lateral spreading of the batholithic terrane, have fragmented the old volcanic arc and back-arc basin.

unusually long-lived volcanic island arc by modern standards, and it is suggested that there may have been more than one phase of arc development during that period (see Brooks and Vallier, 1978). During this time, rocks of the Seven Devils Group were deposited as abundant andesitic pyroclastics, basaltic and andesitic flows, numerous epiclastic beds, with many unconformities. Riggins Group rocks probably were simultaneously deposited as distal equivalents of the Seven Devils Group in a basin behind the arc.

During late Triassic time, volcanism in the Seven Devils arc ceased and the arc rapidly subsided, resulting in development of extensive coral reefs and carbonate banks. At this time, the back-arc basin became stagnant and black euxinic shales were deposited.

The next recorded event is the intrusion of the Seven Devils rocks by the Jurassic dioritic suite. These plutons possibly resulted from more westerly-sited subduction.

Sometime after the early Cretaceous, possibly during late Cretaceous time, the old Seven Devils arc was subjected to a pronounced shearing event which was more intense in the eastern part of the terrane. At this time, basinal Riggins Group rocks already deformed and metamorphosed were thrust into structural superposition of the Seven Devils Group arc rocks. This thrusting is largely attributed to doming and lateral spreading of the Idaho batholith, although the alternative hypothesis of underthrusting cannot be precluded.

Summary

This deformational event is expressed as two distinct structural style domains in the Seven Devils Mountains. The east side of the range, composed mostly of sedimentary rocks, deformed in a more ductile manner. This ductile zone is characterized by prominent foliation and contained lineation, by rotated, elongated and flattened component grains, and by non-pervasive folding. Ductility was probably due to the relative weakness of the sedimentary section, possibly enhanced by latent heat from the cooling Idaho batholith.

Farther west, deformation of the underlying volcanic pile is characterized by more brittle structural elements including pervasive fractures and widely spaced reverse faults.

Despite the variability of style, the sense of motion for both zones is indicated as east-over-west thrusting or underthrusting. This is also compatible with motion along the Rapid River thrust which superposes rocks of the plutonic/metamorphic complex above Seven Devils terrane.

A correlation between structural elements of the brittle zone, ductile zone and the metamorphic complex and their relative timing is proposed in Table 1. A relative time frame for movement on the Rapid River Thrust is also depicted. It should be noted that corresponding structural elements have essentially the same sense of motion.

As stated above, absolute timing of deformation cannot be narrowly constrained. However, at least some deformation occurred after intrusion of the Jurassic dioritic suite, as evidenced by

Table 1. Comparison of structural elements from brittle and ductile zones (this study) and those from the Riggins Group (Onasch, 1979), and suggested relative timing of their formation.

Phase	Brittle Zone	Ductile Zone	Metamorphic Complex (Riggins Group)
I			1) Diverse isoclinal folds
II			2) Easterly plunging asymmetric folds
III			3) East plunging upright asymmetric folds
IV	1) East over west reverse faulting and fractures	1) East over west shearing	4) North-south trending upright, symmetric folds
V		2) Northerly trending kinks and northeast and southeast plunging warps	5) Northeast-southwest trending kink folds and warps

locally sheared rocks of this group. It is proposed that the shearing of Jurassic rocks occurred during phases IV and V (from Table 1), which, it can be argued from similar kinematic interpretations, were essentially contemporaneous late phases of deformation. Earlier deformation of Seven Devils rocks referred to by Hamilton (1963, p. 16) may be related to phases I, II or III. No evidence necessitating an earlier deformation was detected in this study.

Table 2 summarizes the timing of major geologic events recorded in Seven Devils rocks as constrained by the available data. The critical relationships are between events 6 through 10. As is shown, there is considerable potential overlap in the ages of these events. This overlap has resulted in the controversy over deformation on the west margin of the Idaho batholith, and no resolution appears to be forthcoming.

Table 2. Postulated timing of geologic events.

Event	Triassic	Jurassic	Cretaceous	Reference
1. Development of Seven Devils arc	———			Vallier, 1977
2. Deposition of Martin Bridge, Lucile Fms.	——			Hamilton, 1963
3. Deposition of Riggins Group	- - - - - - (not definitely known)	- - - -		Hamilton, 1963
4. Intrusion of Diorite Suite		———		Hamilton, 1963
5. Metamorphism		———		Hamilton, 1963
6. Deformation (Phases I, II, III, Table 1)		- - - - - - - -	- - - — — - - -	Onasch, 1979
7. Deformation (Phases IV, V, Table 1)		- - — —	— — - - -	This study, Onasch, 1979
8. Movement on Rapid River Thrust		——	——— - - - -	This study, Hamilton, 1963
9. Intrusion of Idaho batholith and associated metamorphism			———	Hyndman and others, 1975

CHAPTER V

CONCLUSIONS

Seven Devils-Wrangellian terrane represents a Permian through Triassic island arc system which resided an unspecified distance offshore of western North America. It is suggested here that the distance was relatively limited so as to allow the development of a restricted, black shale basin in the black arc area. The presence of common, subvolcanic intrusive rocks, consanguineous with the volcanic pile, suggest that a volcanic center was located in the area of the Seven Devils Mountains.

All phases of deformation present in Seven Devils rocks near Riggins, Idaho, are dynamically congruent with each other, arising from east-west oriented forces, with the primary sense of motion being east block over west. This motion is compatible with that interpreted for the overriding Rapid River thrust, and with that for late phases of deformation in the tectonically superposed Riggins terrane.

Interpretation of structural elements is in agreement with both genetic intrepretations: 1) partial subduction or underthrusting; and 2) upwelling of the plutonic/metamorphic terrane in the east.

The author suggests that resolution of this problem may be aided by detailed investigation of the various contacts between geologic terranes. This could reveal previously unrecognized cross-cutting relationships and better relative age determination of structural elements. Synorogenic sedimentary deposits, if discovered, could also assist in the dating of motion along thrust faults of the region. However, it is possible that there is no definitive evidence which verifies either deformational model.

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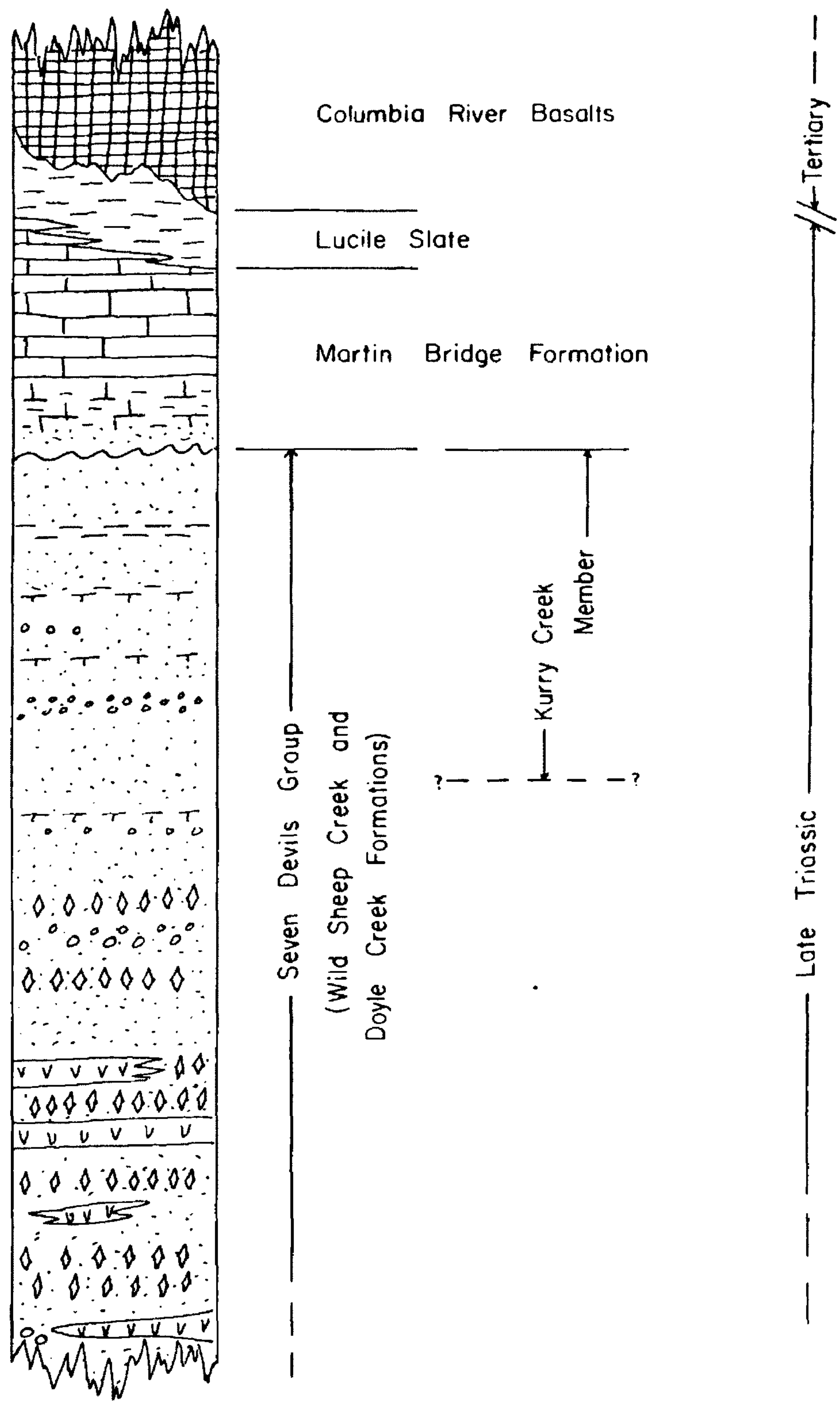

Appendix 1. Generalized stratigraphic section of Seven Devils terrane in the area of Plate 1.