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The carbonate petrology and paleoecology of Upper Triassic limestones of the Wallowa terrane Oregon and Idaho

Michael T. Whalen

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The Carbonate Petrology and Paleoecology of Upper Triassic Limestones of the Wallowa Terrane, Oregon and Idaho

by

Michael T. Whalen

B.A., Rutgers University, 1982

Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science University of Montana

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The Upper Triassic Martin Bridge Formation is exposed as a thick sequence of limestone in Hells Canyon along the Idaho-Oregon border. The allochthonous structural setting and low latitude origin of the Martin Bridge Fm. and underlying Seven Devils Group, which comprise the Wallowa terrane, are fairly well established. A slightly younger unit, the Mission Creek limestone, is exposed about 25 km southeast of Lewiston, Idaho along Mission Creek. This unit is stratigraphically and structurally isolated, and its exact relationship with the Martin Bridge Formation is unclear.

Through stratigraphic and petrographic analysis of these limestones I have ascertained that the Martin Bridge Fm. was deposited first under supratidal conditions and then as intertidal and shallow subtidal platform deposits. Isolation of these carbonates from a cratonic sediment source is indicated by the absence of terrigenous sediments. The Martin Bridge Fm. in Hells Canyon has been subjected to at least eight diagenetic processes that obscured many of the original depositional textures. Well preserved fossils occur in coarse grainstone tempestites in the Martin Bridge Fm. in Hells Canyon. The fossils were preferentially silicified and their external morphology is well preserved. Epifaunal, suspension feeding bivalves and spongiomorphs dominate the assemblage and indicate a relatively shallow, warm water depositional setting.

The Mission Creek limestone was also deposited in warm, shallow water as evidenced by the silicified fossil assemblage dominated by red algae, spongiomorphs, and corals that formed small framework buildups. The lithology and the fauna of the Mission Creek limestone differ from those of the Martin Bridge Fm., and the Mission Creek appears to be younger in age.

Post-Triassic plate tectonic movement transported, rotated, and accreted the allochthonous Wallowa terrane to the continental margin of North America. This terrane may be correlative with the coeval Wrangellia Terrane of southeastern Alaska and Vancouver Island but the existing evidence does not establish that they once formed a contiguous fragment of the earth's crust.
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INTRODUCTION

Tectonics and Displaced Terranes

The widely held view that North America is somehow depauperate in marine rocks of the Triassic System is a misconception. Although the east coast of the continent is devoid of marine Triassic rocks, the west coast and the northwest Cordillera, in particular, disprove the misconception. From northern California and Nevada to southeastern Alaska, Triassic marine limestones are prominent ridge- and cliff-forming units. Many of these limestones are allochthonous with respect to the stable craton of North America and for this reason have recently attracted a great deal of attention.

The accumulated evidence for accreted, suspect, or displaced terranes has led to their widespread acceptance over the past decade. It is now commonly believed that the western margin of North America is a collage of as many as 100 terranes (Jones and others, 1982). "A tectonic (or tectonostratigraphic) terrane is defined as a fault-bounded geologic entity characterized by a distinctive stratigraphic sequence and/or a structural history differing markedly from those of adjoining neighbors." (Beck and others, 1982 p.454). After a terrane has been identified and its boundaries been defined, a number of other matters, such as its position of origin and time of docking must be addressed. Along with the structural and stratigraphic evidence, other features such as a distinctive paleontologic assemblage or the paleomagnetic signature can be instrumental in identifying terranes. Some of the terminology used in terrane analysis is confusing or ambiguous.
Terranes are often called microplates but the two are not necessarily one and the same. Microplates and terranes are both fault-bounded, but microplates differ in that their fault boundaries penetrate the lithosphere, whereas faults bounding terranes die out within the lithosphere.

Four different types of terranes were defined by Jones and others (1983) and they are briefly summarized below:

1) Stratigraphic terranes have distinct stratigraphic sequences and depositional contacts between major lithologic units.

2) Disrupted terranes are composed of large lithologically heterogeneous blocks in a shale, flysch, or serpentinite matrix.

3) Composite terranes are composed of two or more distinct terranes which become joined and share a common geologic history before accretion.

4) Metamorphic terranes are distinguished by a terrane encompassing penetrative regional metamorphic fabric which obscures original stratigraphic relations.

Wrangellia

One of the first terranes to be identified contains a thick package of Triassic rocks. In fact, it was the very distinctive Triassic stratigraphy that allowed Jones and others (1977) to recognize that this now fragmented terrane was once a coherent tectonic entity. They named this terrane Wrangellia, after the type locality in the Wrangell Mountains of southeastern Alaska. Wrangellia now exists as several fragments stretching over more than 10 degrees of latitude from southeastern Alaska to southwestern British Columbia and possibly as far south as northeastern Oregon and Idaho (Jones and others, 1977; 1982;
Figure 1. The western margin of North America showing the distribution of Wrangellia and the Wallowa terrane today and the eastern edge of accreted terranes (Modified from Jones and others, 1982).
1983). The possible southeastern extension of Wrangellia in Oregon and Idaho, where Permo-Triassic rocks (herein called the Wallowa terrane) outcrop, is the focus of this study.

Stratigraphic Relations

Wrangellia is a stratigraphic terrane (Jones and others, 1983) because it is fault-bounded and has a distinct stratigraphic sequence that sets it apart from neighboring terranes. Its stratigraphic sequence consists of Upper Triassic tholeiitic basalts overlain by a thick sequence of carbonates, which grade upward into deep-water basinal sediments. According to Jones and others (1977, 1982, 1983) the two largest fragments of Wrangellia are in the Wrangell Mountains of southeastern Alaska and Vancouver Island, British Columbia; smaller fragments are located on the Queen Charolette, Baranof, and Chichagof Islands, and possibly in the Hells Canyon area of Oregon and Idaho (Jones and others, 1977). Figure 1 illustrates the distribution of Wrangellia and the location of the Wallowa terrane. Figure 2 shows the stratigraphic relations of various fragments of the Wallowa terrane and the Wrangellia Terrane of Jones and others (1977).

The stratigraphic section in the Wrangell Mountains is dominated by the Middle-Late Triassic Nikolai Greenstone, consisting of over 3500 m of mainly subaerial, quartz-normative, tholeiitic basalts with local pillow lavas (Jones and others, 1977). Lying unconformably above this is about 1400 m of Upper Karnian platform carbonates of the Chitistone Limestone, which grade up into the Lower-Middle Norian, open platform, or basinal Nizina Limestone (Armstrong and others, 1969). Conformably
Figure 2. Generalized Triassic stratigraphy of the Wrangellia and Wallowa terranes (Modified from Jones and others, 1977 and Newton, 1983).
above the Nizina are calcareous, cherty basinal deposits of the McCarthy Formation (MacKevett, 1976).

On Vancouver and Queen Charlotte Islands the sequence is dominated by the basic volcanics of the Karnian-Norian Karmutsen Formation. The lower part of this formation consists mainly of pillow lavas (about 2500 m) overlain by pillow breccias and tuff (about 1000 m) and topped by about 3000 m of basalt flows with minor amounts of pillow lavas and sedimentary rocks (Muller and others, 1974). At both locations the Karmutsen Formation is overlain by Upper Triassic limestones but they are not correlative in age (Jones and others, 1977).

The stratigraphic sequence of the Chichagof and Baranof Islands consists of the Goon Dip Greenstone and an overlying marble unit. The greenstone, the base of which is truncated by a fault, consists of metamorphosed basalt flows, sills, and tuff (Jones and others, 1977).

The major components of the Wallowa terrane are Permo-Triassic flow basalts, pillow basalts, andesites, volcaniclastics, and volcanic breccias. Most of these are metamorphosed to the greenschist facies. This assemblage, called the Seven Devils Group in Hells Canyon and the Lower Sedimentary series and Clover Creek Formation in the Wallowa Mountains, is overlain by Upper Triassic marine limestone of the Martin Bridge Formation in the Wallowa Mountains, the Hells Canyon area, and near Riggins, Idaho (Vallier, 1967; 1974; 1977; Brooks and Vallier, 1978). At all localities except Hells Canyon, the Martin Bridge Formation grades into a series of basinal black shales, mudstones, sandstones, and limestones (Vallier, 1977). In the Wallowa Mountains the basinal sediments are called the Hurwal Formation (Smith and Allen,
1941), and near Riggins a similar, but highly metamorphosed, unit named the Lucille Slate overlies the Martin Bridge Formation (Vallier 1967; 1974; 1977). The Wild Sheep Creek and Doyle Creek Formations, in the Seven Devils Group of the Wallowa terrane, were correlated with the volcanic and volcanioclastic rocks of other Wrangellia localities (Jones and others, 1977; Muller, 1977). This correlation is based on similarity of lithology and the presence of daonellid bivalves in the lower part of the Wild Sheep Creek Formation and in beds underlying the Nikolai Greenstone (Jones and others, 1977).

The stratigraphic sequence of Wrangellia indicates subaqueous and some subareal volcanism which produced an oceanic plateau. This was followed by carbonate deposition upon the plateau as it subsided (Jones and others, 1977; Nur and Ben-Avraham, 1982).

**Paleomagnetic Evidence**

Although the Wallowa terrane and fragments of Wrangellia are now separated by more than 10 degrees of latitude, paleomagnetic evidence indicates that they were within 4 degrees of one another during the Triassic. A number of paleomagnetic studies of Wrangellia basalts (Irving and Yole, 1972; Symons, 1971; Hillhouse, 1977) have indicated that these volcanics formed approximately 15 degrees north or south of the Triassic equator. Hillhouse and others (1982) found a Triassic paleolatitude of 18 degrees north or south of the equator for the Wild Sheep Creek Formation in the Wallowa terrane. This correlates well with data from other Wrangellia localities. Hamilton, 1978; Wilson and Cox, 1980; Hillhouse and others, 1982 also showed that the Wallowa terrane
has undergone about 65 degrees of clockwise rotation since the Early Cretaceous. Correction for this rotation shows that the declination of the Wallowa terrane matches with that of Vancouver Island (Hillhouse and others, 1982). Because of the ambiguity of the paleomagnetic studies with respect to polarity, there is still some debate as to whether Wrangellia originated north or south of the Triassic equator. Hillhouse (1977), Panuska and Stone (1981), and Stone and others (1982) have purported that their paleomagnetic evidence indicates a northern hemisphere origin for Wrangellia, while Yole and Irving (1980) claim a southern hemisphere origin. Hillhouse and others (1982) report that paleomagnetic evidence from the Wallowa terrane also indicates a southern hemisphere origin.

Faunal Evidence

Further evidence for a tropical to subtropical origin of the terranes comes from the Upper Triassic silicified mollusc and coral fauna of the Wrangell Mountains, Vancouver Island, and Hells Canyon (Jones and others, 1977; Newton, 1983a; 1983b; and in press). The presence of algae, spinose gastropods and bivalves and the large number of cementing oysters and oyster-like bivalves indicates a warm, shallow water setting for the deposition of the carbonates (Newton, 1983; in press). The variety of scleractinian corals also indicates a warm, shallow water environment.
Geochemical Evidence

Sarewitz (1983) analyzed the geochemistry of the Wild Sheep Creek Formation in the Wallowa terrane. Based on the dominance of volcaniclastics, the wide range of rock types, and enrichment in light rare earth elements, he determined that this unit "generally suggests calc-alkaline arc magmatism." (Sarewitz, 1983 p.635). However he indicated some ambiguities. The major point that Sarewitz established was that the Seven Devils Group is a calc-alkaline volcanic arc assemblage, while the rest of Wrangellia is characterized by tholeiitic basalts formed on an oceanic plateau. Admittedly these two petrogenic environments are different; however, they are not necessarily mutually exclusive. In some tectonically active areas in the world today, such as the Indo-Pacific region, mid-ocean ridge basalts are juxtaposed with island arc type extrusives.

Tectonic History

Most of the evidence from both the fauna (discussed below) and paleomagnetism indicates that the Triassic rocks in Hells Canyon and the Wrangellia localities formed at low latitudes in a volcanically active environment. These rocks were subsequently transported on a moving oceanic plate, the spreading center for which probably existed somewhere in the ancestral Pacific (Tozer, 1982). As the terranes approached the western margin of of North America, they moved north along a major strike-slip boundary. During the Jurassic or Early Cretaceous the Wallowa terrane reached what is now the Columbia embayment, where it rotated in a clockwise direction toward the craton along a strike-slip
fault [possibly the Trans-Idaho discontinuity of Yates cited in Hillhouse and others(1982)]. The Wrangellia Terrane continued its northward strike-slip movement and fragmented into two large blocks and a number of smaller ones that subsequently accreted to the craton from Vancouver Island to southeastern Alaska.

**Purpose and Scope of Study**

The researchers who developed the displaced terrane theory have taken quite a few liberties when correlating units or stratigraphic sequences said to belong to a single terrane. In the case of the Wrangellia Terrane, units were correlated (but formation names not extended) over as much as 1500 km based on little more than a similarity in gross stratigraphy and the occurrence of a few "diagnostic" fossil specimens (Jones and others, 1977).

Superficially the Wallowa terrane, which includes Permian and Triassic rocks in the Wallowa Mountains, Seven Devils Mountains, and Hells Canyon in northeastern Oregon and Idaho (Figure 3), does resemble the main mass of the Wrangellia Terrane. However, this resemblance must be much more than superficial if these rocks are to be considered part of Wrangellia-proper.

If the Triassic rocks of southeastern Alaska, northeastern Oregon, and northwestern Idaho do represent a single piece of the earth's crust then certain paleontological, stratigraphic, and compositional similarities should be common to each of them. I believe that detailed stratigraphic and faunal analysis is necessary before such large scale correlations can be assured. The carbonate rocks that are so prevalent
Figure 3. The distribution of Permian, Triassic, and Jurassic rocks that make up the Wallowa terrane (Modified from Brooks and Vallier, 1978).
throughout the Wrangellia Terrane can, through microfacies analysis, yield tremendous insight into the Triassic sea where the sediments were originally deposited. The fossils in this terrane, many of which have been exquisitely preserved through silicification, can also add a wealth of information about the paleoecology and environments of deposition of the carbonates.

The Wallowa terrane does not crop out as a single, contiguous allochthonous block. Rocks of the terrane are exposed only in those areas where uplift and/or erosion have removed the extensive blanket of Tertiary Columbia River Basalts. Upper Triassic carbonates of the terrane outcrop at several localities in northeastern Oregon and northwestern Idaho. A thick sequence in the Wallowa Mountains has been severely metamorphosed by the intrusion of the Wallowa batholith. Another thick sequence immediately north of Riggins, Idaho, is also severely metamorphosed. Because metamorphism has destroyed the original composition I reconnoitered these areas but omitted them from my detailed study.

I chose two field localities within the Wallowa terrane for studying these Upper Triassic limestones. One is along the Hells Canyon reservoir on the border of Oregon and Idaho. This locality was chosen for its excellent exposure of a thick stratigraphic sequence of Upper Triassic carbonates (Martin Bridge Fm.) and for the abundant silicified fossils found near Spring Creek (Vallier, 1967), which drains from the west into the Hells Canyon reservoir. The other locality is about 25 km southeast of Lewiston, Idaho in a limestone quarry along the east side of Mission Creek on the Nez Perce Indian Reservation, Nez Perce County,
Idaho. This unit of Upper Triassic limestone is important because it is one of only two localities, included in the Wrangellia Terrane (Jones and others, 1977), that have framework buildups of corals and spongiomorphs. This limestone is stratigraphically isolated by the Tertiary Columbia River Basalts, and its relationship to the Martin Bridge Formation is not firmly established. The purpose of this thesis is to evaluate how these two limestone units relate to the Wrangellia Terrane.

Through the study of the carbonate rocks in these two units I analyze:

1) The microfacies and the environments in which the carbonates formed.
2) The fossils present and their paleoecology.
3) A comparison of these rocks and their fauna to other sequences and faunal assemblages attributed to Wrangellia of Jones and others (1977).

Comparison of depositional environments, resulting rock types, and the biota from the Wallowa terrane and other Wrangellia sequences reveals insight into the relationship between these rocks.

Previous Work

Triassic limestones in northeastern Oregon and Idaho were first reported near the beginning of this century. Lindgren (1901), in the results of an extensive economic mineral survey of the Wallowa (or Blue) Mountains, first mentioned the Triassic limestones in the southern Wallowa Mountains and in Hells Canyon. Smith (1912; 1927) reporting on Triassic faunas of North America, mentioned the limestone locality in
the southern Wallowa Mountains. Chaney (1932) and Guilluly and others (1933) both suggested the name Martin Bridge Formation for the series of calcareous shales and massive limestones exposed near Martin Bridge on Eagle Creek in the southern Wallowa Mountains, but it was not until 1938 that Ross formally proposed this name. Smith and Allen (1941) were the first to extend the name Martin Bridge Formation to the dominantly massive Triassic limestones in the northern Wallowa Mountains. Other studies dealing with the stratigraphy of the Martin Bridge Formation in the northern Wallowa Mountains include: Laudon (1956), Cannon (in Hamilton, 1963), and Nolf (1966). Stanley (1979) reported on the paleontology of the northern and southern Wallowa Mountains. The structural relationships of the northern and southern Wallowa Mountains is disputed (Nolf, 1966). The three members of the Martin Bridge Formation defined by Nolf (1966) in the northern Wallowa Mountains do not correlate lithologically with units in the south, and therefore must represent either different facies or different stratigraphic levels. Their differing stratigraphic level is indicated by Halobid bivalves (Grant-Mackie written comm., 1985), which show that the Martin Bridge Formation in the southern Wallowas spans the Karnian/Norian boundary, while in the northern Wallowas it is entirely Norian in age (Nolf, 1966).

The name Martin Bridge Formation was extended by Vallier (1967, 1974) to include the Triassic limestones in Hells Canyon. Vallier based his correlation on lithologic similarity of the limestones in the northern Wallowa Mountains and Hells Canyon and kerri zone ammonites of Lower Norian age found at both localities. Vallier also made the first
collection of silicified fossils (USGS collection M2672) from the Hells Canyon locality in 1964. In a study of the Upper Triassic coelenterates of North America, Montanaro-Galletelli and others (1979) described the coelenterates in the USGS collection from Hells Canyon. Newton (1983a; 1983b, and in press) studied the paleoecology and taxonomy of the bivalve molluscs. These studies were either paleontological or, as in the case of Vallier (1967, 1974), part of a regional geologic study, and little effort was made to interpret the depositional environment using carbonate petrography.

The fossiliferous limestone at Mission Creek near Lewiston, Idaho was first sampled paleontologically in 1936 by Williams and Reed of the USGS. Cooper (1942) reported on the brachiopods, Squires (1956) was the first to study the silicified coral fauna, and Stanley (1979; 1980) examined the fauna at this locality, especially the coral beds in the quarry. To date all other work on this quarry has been paleontological and, as with the Hells Canyon locality, petrology of the limestones has not been studied in detail.

Methods

To gain a better understanding of the deposition and history of these limestones I have approached this study from three perspectives including stratigraphic, petrographic, and paleoecologic analyses.

1) Stratigraphic analysis - I measured five stratigraphic sections, four in Hells Canyon and one at the Mission Creek locality, using a Jacobs staff and pocket transit. While doing so I noted sedimentary and
diagenetic structures and collected oriented samples every three to five meters.

2) Petrographic analysis - I examined 90 thin sections of oriented samples collected in the field. The thin sections were stained with Alizarin Red-S to help differentiate between calcite and dolomite. Semi-quantitative grain frequency comparison charts were used to estimate the percentages of carbonate grains in thin section. Carbonate rock types were classified using the scheme of Dunham (1962) modified by Embry and Klovan (1972). The energy or turbulence of the environment of deposition was classified using the energy index of Plumley and others (1962). The use of semi-quantitative grain frequency counts along with the visual comparison of rock types enabled me to classify the rocks into 12 separate microfacies. Finally, SEM photographs were taken to examine more closely microcrystalline dolomite in some of the microfacies.

3) Paleoecologic analysis - This entailed a number of different methods and procedures. First it was necessary to remove the silicified megafossils from their carbonate matrix by immersing large blocks of limestone into a 7-10% hydrochloric acid bath. Some samples were etched in less destructive acids, such as acetic or formic, in attempts to retrieve microfossils. After the fossils were removed from the matrix I sprayed many of them with a clear Krylon varnish to harden them. Fossil collections and representative thin sections are housed in the the University of Montana Paleontology Museum.
The next step in this analysis was to determine the taxonomic composition of the assemblage and identify each specimen as accurately as possible. Trophic analysis was carried out and each taxa was assigned to a trophic group. I computed rarefaction curves (Hurlbert, 1971) for the assemblages to check for sufficient sample size and calculated taxonomic diversity using the Shannon-Weiner Diversity index (MacArthur and MacArthur, 1961). Faunal similarities between the Seven Devils Terrane and other parts of Wrangellia were measured using the Sorenson (1948) Similarity Index.

GEOLOGY OF THE HELLS CANYON AREA

Figure 4 is a geologic map of the part of Hells Canyon in which I carried out my field work and Figures 5 and 6 are photographs of the Martin Bridge Formation at this locality. The rocks here dominantly belong to the Permo-Triassic Seven Devils Group, which consists mainly of the Permian Hunsaker Creek Formation which is unconformably overlain by the Upper Triassic Wild Sheep Creek Formation. The uppermost unit in the Seven Devils Group is the Karnian Doyle Creek Formation which consists of volcanic breccia, metabasalt, volcaniclastics, tuff, conglomerate, and thin limestone beds. This unit is unconformably overlain by the Martin Bridge Formation (see Figure 2), the top of which has been eroded in Hells Canyon (Vallier, 1967; 1974; 1977; Brooks and Vallier, 1978).

The Martin Bridge Formation in Hells Canyon sits in a down dropped fault block and, within the block, is faulted against the Karnian Doyle Creek, Wild Sheep Creek, and the Late Permian Hunsaker Creek Formations.
Figure 4. Geologic map of part of the Hells Canyon area showing the Martin Bridge Formation and surrounding units. Also shown are the locations of measured sections and the Spring Creek fossil locality. (Modified from Vallier, 1974).
Figure 5. Photograph of the cliff-forming Martin Bridge Formation in Hells Canyon, Idaho.

Figure 6. Photograph of a broad syncline in the Martin Bridge Formation along the Allison Creek drainage.
The Martin Bridge is unconformably overlain by Miocene Columbia River Basalts in the southwestern portion of my field area. The Hurwal Formation, which overlies the Martin Bridge in the Wallowa Mountains, is absent by erosion in Hells Canyon, confirming Vallier's (1967) observations. Within the down dropped fault block the limestone was deformed in a ductile manner into a series of tight, northeast-southwest trending, anticlines and synclines which coalesce into a single broad open syncline (See Figures 4 and 6) to the east (Vallier, 1967). The age of this unit is early Norian (Vallier, 1967; 1974; 1977).

**GEOLOGY OF THE MISSION CREEK LOCALITY**

The Triassic limestone along Mission Creek is about 42 km north of the nearest Martin Bridge Formation outcrop. I informally propose that this unit, which differs lithologically and in age form other occurrences of the Martin Bridge Formation, be called the Mission Creek limestone. Despite the presence of rich, silicified fossils, no ammonoids or monotid bivalves, necessary for precise biostratigraphic control, were found. However, Spondylospirid brachiopods reported from this locality by Cooper (1942), indicate a Norian age. Squires (1956) concurred with Cooper's age determination while Stanley (1979) believed that the coral fauna indicated a late Norian age. The age difference and the occurrence of fossilized framework buildups of corals and spongiomorphs sets this unit apart from the Martin Bridge Formation.

The Mission Creek limestone is completely surrounded by Tertiary basalt (Figure 7) and inference about its stratigraphic position relative to other Triassic units is pure speculation. Figure 8 is a
Figure 7. Geologic map of the Mission Creek locality.
Figure 8. Photograph of the top two thirds of the Mission Creek Quarry.
photograph of the upper Triassic limestone exposed in the Mission Creek quarry.

This outcrop of limestone is possibly fault bounded. The western contact is buried beneath Quaternary conglomerate. The limestone is unconformably overlain on the north and east by Tertiary Columbia River Basalt. The limestone may also be a roof pendant of the Idaho Batholith (Newell cited in Squires, 1956) which outcrops less than a mile south of the quarry.

CARBONATE PETROLOGY

This section, on the carbonate petrology of the upper Triassic limestones at my two field localities, is divided into three subheadings. First, I introduce the history of and reasons for microfacies studies. Then, I outline a system of microfacies classification for the limestones under study. Finally, I briefly mention the distribution of microfacies between the two localities.

Carbonate Microfacies

Brown (1943) was the first to use the term microfacies, but it was not widely accepted until Cuvillier (1952; 1958; 1961) applied the term to petrographic and paleontologic characteristics in thin section. A number of Standard Microfacies (SMF) were outlined by Fluegel (1972) for Upper Triassic reef carbonates in the Alpine-Mediterranean region. Wilson (1975) expanded on Fluegel's work by including Paleozoic and other Mesozoic limestones with those used to define the SMF. Wilson (1975) also related the seemingly random carbonate microfacies to a
depositional scheme of Standard Facies Belts paralleling a continental margin. For the most up-to-date review of carbonate microfacies see Fluegel (1982).

Since the SMF system was originally developed through the study of carbonate sediments deposited on a continental margin, the Standard Microfacies could differ markedly from facies of carbonate sediments deposited on isolated oceanic plateaus. Because I found it difficult to classify some of the carbonates which I examined into the SMF, I decided to define my own categories of microfacies based on the grain composition, matrix, sedimentary fabrics, and diagenetic features analyzed in thin section.

A facies, as defined by the American Institute of Geology's Glossary of Geology, is "The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin; especially as differentiating the unit from adjacent or associated units." A microfacies as defined by Fluegel (1982 p.1) is "the total of all the paleontological and sedimentological criteria which can be classified in thin-sections, peels, and polished slabs." The characteristics which I have used to differentiate microfacies are textures and grain composition including skeletal and other carbonate grains, carbonate matrix, diagenetic, authigenic, and terrigenous minerals, and sedimentary and diagenetic textures and fabrics. I have delineated a total of 12 microfacies (F-1 through F-12) based on these criteria. These microfacies characterize the carbonate rocks at both field localities; however, the rocks from the Mission Creek quarry are more fossiliferous than those from Hells Canyon. The major component
Table 1. Illustrates the relative percentages of carbonate grains, dolomite, skeletal grains, matrix, and terrigenous clastics, plus the average grain size and the presence (X) or absence (blank) of various fabrics in each of the 12 microfacies. Grain size: vf=very fine-grained, f=fine-grained, m=medium-grained, c=coarse-grained, vc=very coarse-grained.
<table>
<thead>
<tr>
<th>MICROFACIES</th>
<th>CARBONATE GRAINS</th>
<th>% DOLOMITE</th>
<th>% MATRIX</th>
<th>SKELETAL GRAINS</th>
<th>% FABRICS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Peloids</td>
<td>Calcarea</td>
<td>Micrite</td>
<td>Unger 1-300μm</td>
<td>1-30μm</td>
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<tr>
<td>F-1</td>
<td>2</td>
<td>10</td>
<td>15</td>
<td>51</td>
<td>2</td>
</tr>
<tr>
<td>F-2</td>
<td>10</td>
<td>8</td>
<td>28</td>
<td>35</td>
<td>7</td>
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<tr>
<td>F-3</td>
<td>12</td>
<td>2</td>
<td>13</td>
<td>49</td>
<td>2</td>
</tr>
<tr>
<td>F-4</td>
<td>21</td>
<td>1</td>
<td>10</td>
<td>45</td>
<td>2</td>
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<tr>
<td>F-5</td>
<td>18</td>
<td>10</td>
<td>12</td>
<td>37</td>
<td>8</td>
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<tr>
<td>F-6</td>
<td>25</td>
<td>1</td>
<td>12</td>
<td>21</td>
<td>11</td>
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<td>F-7</td>
<td>12</td>
<td>9</td>
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<td>F-8</td>
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<td>3</td>
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<tr>
<td>F-9</td>
<td>38</td>
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<td>F-10</td>
<td>26</td>
<td>2</td>
<td>15</td>
<td>23</td>
<td>4</td>
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<tr>
<td>F-11</td>
<td>15</td>
<td>2</td>
<td>25</td>
<td>13</td>
<td>10</td>
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<tr>
<td>F-12</td>
<td>72</td>
<td>1</td>
<td>72</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>
grains and fabrics for each microfacies are outlined in Table 1. Grain and fabric nomenclature is that of Fluegel (1982), to which I have added the pressure solution fabric of stylolites because they are such an important component in the Martin Bridge Formation. In the following microfacies descriptions and interpretations I use the energy index of Plumley and others (1962), which ranks the "energy of the environment of deposition" from quiet, to intermittently agitated, to slightly agitated, to moderately agitated, to strongly agitated water. Also I refer to sedimentary grains as being either carbonate or skeletal grains. This distinction is made with the realization that most skeletal grains are also composed of calcium carbonate but are different in that they are produced by organisms for protection or structural support. I use a simple shorthand system consisting of the letter "F" (for facies) followed by a number to represent each microfacies.

Microfacies Descriptions and Interpretations

Each microfacies is first described briefly in hand specimen and then in thin section. I will only discuss the major thin section components since Table 1 gives compositional percentages for each microfacies.

F-1 Neomorphosed lime mudstone - Figure 9.

Hand specimen - light to dark gray, finely crystalline, massive limestone with small (<0.5 mm thick) calcite veins and some stylolites. Rocks weather brown or gray.
Thin section - the major original component of this microfacies was lime mud, which has since been neomorphosed to 5-25 micron microspar. Greunulose structures and intervening blebs of micrite were observed. It also contains up to 30% dolomite crystals, 10% of which are microcrystalline, and smaller percentages of peloids, skeletal grains, and terrigenous clastics. Stylolites occur locally.

Figure 9. F-1 Neomorphosed lime mudstone. The light colored "blotches" are either the problematical organism Baccanella or a diagenetic feature.

Interpretation - The dominance of lime mud suggests that these sediments were deposited in, quiet water, where the fine-grained mud was not washed away. Environments that meet this requirement are varied. Mud accumulates in near shore areas such as lagoons or tidal ponds. The intercalation of F-1 with F-4 (described below), which forms on beach ridges or terraces and levee crests, implies that deposition occurred in
a tidal flat environment. Lime mud also accumulates on shelves between shoals or organic build-ups (reef, bioherm, etc.) that restrict water circulation. F-1 is also commonly interbedded with grainstone (F-9, F-10) which probably formed shoals. Thus F-1 was deposited in both shallow tidal pools and in restricted areas between shoals or organic buildups.

F-2 Peloid Wackestone - Figure 10.

Hand specimen - Finely crystalline, dark to medium gray limestone with some large (up to 0.5 mm) skeletal grains or intraclasts. Rocks weather tan or light gray. Calcite veining is prominent with some 1-2 mm thick veins of spar. Stylolites may also be visible in hand specimen.

Thin section - Contains 10% peloids (100-600 microns), up to 35% micr spar after micrite, euhedral to subhedral dolomite rhombs in a wide range of sizes, and a several types of skeletal grains. This facies is bioturbated and locally has cryptalgal structures, open space structures, and geopetal structures.
Figure 10. F-2 Peloid wackestone. Peloids are suspended in lime mud. Note the stylolite cutting the bottom of the photo. 10X

Interpretation - The small number of carbonate and fragmented skeletal grains and the large portion of original lime mud indicates that there was little wave or current action and at most intermittently agitated water. The term peloids includes fecal pellets and micritized grains produced by endolithic boring algae and bacteria. The texture of these rocks indicates that they were deposited below fairweather wave base on open shallow shelves or in protected or wave and current restricted areas such as lagoons.
F-3 Bioclastic peloid wackestone - Figure 11.

Hand specimen - Fine to medium-grained, medium gray limestone with some large (up to 2 mm) bioclasts that are usually recrystallized. Weathers brown or mottled gray.

Thin section - Microspar makes up about 50% of this microfacies. Peloids (200-400 microns), fragments of bivalve shells, and coarse dolomite crystals are common. Crinoid and gastropod shell fragments are also present. Sediments of this microfacies were bioturbated by burrowing organisms.

Figure 11. F-3 Peloid-bioclast wackestone. Mollusc shells and peloids in lime mud. 10X

Interpretation - As in F-2, this microfacies contained predominantly lime mud and small percentage of clasts which indicates a relatively
quiet water setting. A shallow water protected area with restricted water circulation or an open shelf below fairweather wave base was probably the site of deposition.

F-4 Laminated Peloid Dolowackestone - Figure 12.

Hand specimen - Alternating light and dark, 0.5-1.0 mm thick, smooth, flat to gently undulating, parallel to subparallel, laminations in a dolomitic limestone. Some of the light laminations are reddish-brown dolomitic layers and others are bounded by stylolites. Rip up clasts, some soft sediment folds, and convolute laminations and gypsum casts occur in outcrop.

Thin section - The major components of this rock type are 5-20 micron dolomite crystals, small peloids (<200 microns), and microspar. Small amounts of void filling sparry calcite, intraclasts, silt, clay, and authigenic iron oxide minerals are also present. Some of the laminations contain cryptalgal filaments but they are not well preserved. Also present are open space structures (birdseyes) now filled with spar. The light laminations are composed of microcrystalline dolomite or sparry void filling cement. The dark layers are composed of lime mudstone, well sorted fine-grained peloids, and microcrystalline dolomite. Boundaries between the laminae are sharp. Figures 25 and 26 illustrate some of the microcrystalline dolomite magnified by SEM 800 and 1600 times respectively.
Figure 12. Laminate peloid dolo-wackestone. Dark laminae are dominantly madeup of peloids, while lime mud makes up the light colored laminae. Microcrystalline dolomite is found throughout this facies. Notice the stylolite that cuts across the bottom of the photo and the fluid escape structure on the right side of the photo. 10X
Interpretation - Microcrystalline dolomite is known to form penecontemporaneously as an early stage replacement mineral in the supratidal and shallow subtidal environments (Deffeyes and others, 1964; Shinn and others, 1965). The light colored layers in this microfacies were probably original lime mud that was replaced by microcrystalline dolomite. Hardie and Ginsburg (1977) describe sediments from the supratidal zone on Andros Island, Bahamas that strongly resemble this microfacies in that they are alternating light peloid laminae and dark lime mud laminae. In the Martin Bridge the light laminae were probably original lime mud while the dark laminae are composed of peloids. The light colored laminations in the Martin Bridge Formation are dolomitized and this process probably entailed a color change. On Andros Island laminated mud and peloids containing microcrystalline dolomite are deposited as overbank sediments on exposed tidal channel bars, levees, and beach ridges. Rip-up clasts also commonly form in this setting when storm waves batter the shore line (Reinick and Singh, 1980). F-4 formed in a similar environment. Support for this interpretation also comes from the, previously mentioned, intercalation of F-4 with F-1 which sometimes forms in tidal ponds.
F-5 Peloid Intraclast Packstone - Figure 13.

Hand Specimen - Fine to medium-grained, light gray limestone with tan blebs of dolomite and calcite veins. Weathers tan or light gray.

Figure 13. F-5 Intraclast-peloid packstone. Intraclasts and peloid are in grain-to-grain contact and lime mud or sparry cement fills interstices. 10X

Thin section - 15-20% peloids (100-600 microns in diameter) in grain support with 10% intraclasts and 2% bioclasts. The matrix is dominantly composed of microspar after micrite but there is some void and burrow filling spar. Bioturbation and stylolites are common and cryptalgal structures in the form of small straight filaments are rare.

Interpretation - The large quantities of peloids, which were produced by endolithic boring algae, burrowing worms, and other organisms, and intraclasts in grain support indicate an environment of slight to
moderate water agitation where waves and currents winnowed and transported sediment. The common intercalation of this microfacies with grainstone (F-9,-10) shows that this microfacies was deposited laterally adjacent to areas of strongly agitated water. The evidence suggests that this microfacies formed on a shallow submerged shelf near or below fairweather wave base or in a relatively open lagoon with some circulation.

F-6 Peloid-Intraclast-Oolite-Packstone - Figure 14.

Hand specimen - Medium gray, fine to medium-grained limestone with some large clasts (0.5-1.0mm) visible in hand specimen. Graded bedding is also apparent in outcrop. Weathers tan or dull gray.

Thin section - Peloids ranging in size from 40 to 800 microns are the most abundant component of this facies. Some of the peloids have neomorphosed, superficial ooid coats, and range in size from 100 microns to 1.0 mm. These superficial ooids are the feature that distinguishes this facies from F-5. Intraclasts, cortoids, and a wide variety of skeletal grains usually comprise 10% of the rock. This microfacies is, in places, burrowed cryptalgal borings are manifested in cortoids. Some of the cortoids have small ?Codiacean algal tubes in their coats. Microspar after micrite and sparry calcite cement fill the interstices between grains. Secondary dolomite crystals are also present.
Figure 14. Intraclast-ooid-peloid packstone. Superficial ooids, intraclasts, and peloids are in grain-to-grain contact and lime mud or sparry cement fills interstices. 10X

Interpretation - The size of some of the grains, especially the large oolites which must have moved repeatedly to have formed, indicates moderately to strongly agitated water. The normally graded beds indicate deposition of a wide range of material from traction transport and suspension as water movement waned after storm surges. These sediments probably formed within fairweather wave base in freely circulating sea water probably on the middle shelf or in an open lagoon.

F-7 Bioclastic Grainstone - Figure 15.

Hand specimen - The most noticeable characteristics of this facies in hand specimen and outcrop are the diverse, coarse grained, well
preserved, silicified shelly fossils (up to 5 cm across) in a fine to medium-grained carbonate matrix. Newton (in press) noted that this facies is characterized by thin, normally graded, lensoidal beds (0.3-0.5 m thick) that rest on a basal scoured surface. Many of the fossils are oriented parallel to bedding. The lenses are capped by ripple cross-laminated limestone composed of sand-size carbonate grains.

Thin section - The large fossils, which are replaced by mega-quartz crystals, are surrounded by a matrix of peloids (200 microns to 1 mm) and intraclasts (0.5 - 3.0 mm) Coarse dolomite rhombs and stylolites also occur.

Figure 15. F-7 Bioclastic grainstone. Mollusc, echinoderm, and brachiopod fragments in grain-to-grain contact. 10X

Interpretation - These shell lenses were deposited in strongly agitated water and waning currents produced by storms. As Newton (1984)
noted the beds are morphologically similar to calcareous storm deposits or tempestites described by Aigner (1982) and Brenner and Davies (1973). Kuss (1983) also describes similar storm deposits from the Upper Triassic Koessen Beds in the northern Alps. The lack of breakage of corals, spinose gastropods, and bivalves indicates that they were not repeatedly transported before deposition. The ripple cross-laminated beds that cap the shell lags are similar to F-6, 9, and 10 and suggest that waves reworked the storm deposits relatively shallow, moderately agitated water above fairweather wave base.

F-8 Oolitic Grainstone - Figure 16.

Hand specimen - Finely crystalline, medium to dark gray limestone with some fine calcite veins. Rocks weather tan.

Thin section - Ooids ranging in size from 200-750 microns are the greatest component of this microfacies (38%). They are neomorphosed so the fabric of their coats cannot be determined. Also they are flattened into ellipsoids parallel to bedding. Significant amounts of peloids (7%), cortoids (10%), and intraclasts (3%) in a similar range of sizes are also present. Some microspar which is probably finely crystalline cement and small patches of sparry cement fill the interstices between the grains.
Interpretation - The high percentage of ooids indicates strong, constant agitation, probably in a shallow-water setting. This microfacies most likely represents open shelf shoals, where sediments were continually worked by wave and/or current action.

F-9 and 10 Intraclast-Peloid Grainstone I and II - Figures 17 and 18.

Hand specimen - These two microfacies contain very similar components and differ mainly in grain size. F-9 is a fine-grained, light gray limestone composed of fine peloids with stylolites and fine calcite veins. It weathers gray or tan. F-10 differs only in that it contains some intraclasts up to 4.0 mm in diameter.
Figure 17. F-9 Intraclast-peloid grainstone I. Constituents are in grain-to-grain contact. Sparry cement fills the interstices. Note the large spar filled burrows on the left side of photo. 10X

Figure 18. F-10 Intraclast-peloid grainstone II. Coarser grained but similar to F-9. Note the recrystallized gastropod shell at the bottom of the photo. 10X
Thin section - The grains composing these microfacies are mainly peloids (up to 500 microns in F-9 and 1.0 mm in F-10) and intraclasts (up to 1.5 mm in F-9 and 4.0 mm in F-10). F-9 contains a larger percentage of peloids than intraclasts and F-10 contains more intraclasts than peloids. Micросpar, spar, and coarse dolomite rhombs are common. F-10 has a few bioclasts and cortoids. Both microfacies are bioturbated but geopetal structures and open space structures occur only in F-9.

Interpretation - The high percentage of transported clasts indicates moderate to strongly agitated water. F-10 probably was produced by more strongly agitated water than F-9 since it has a larger average grain size. These two microfacies are usually interbedded with F-1 and F-5, both of which formed in more protected environments. F-9 and 10 were probably deposited as grainstone shoals which subdued wave or current action and allowed more restricted facies to form between them. The intercalation of these microfacies implies that the shoals shifted frequently.

F-11 Bafflestone - Figure 19.

Hand specimen - Fine to medium-grained, light gray limestone which weathers tan or gray. It is sometimes cut by sparry calcite veins. None of the fossils in this microfacies were silicified and they were not readily apparent in hand specimen or in the field.

Thin section - This facies is composed of framework-building or
encrusting organisms, such as sponges, spongiomorphs, or red algae, and the carbonate sediment which they baffled. The sediment surrounding the framework is composed of peloids (up to 300 microns in diameter), cortoids (up to 2 mm in diameter), and a small percentage of bioclasts. Smaller percentages of microspar, spar, and large dolomite rhombs occur.

Figure 19. F-11 Bafflestone. Cayeuxia (alga) bafflestone with lime mud and peloids. 10X

Interpretation - As the framework organisms grew, sediment filtered in between them and was bound by the organisms or otherwise cemented. The dimension of the framework in the Martin Bridge Formation was difficult to determine but in the Mission Creek limestone the framework thickets ranged from one to five meters in diameter and no more than two meters thick. At least moderately agitated water was necessary to transport the grains trapped within the organic framework. Deposition probably occurred above fairweather wave base in relatively open, circulating
water, which is also necessary for large colonies of suspension feeders.

F-12 Crystalline Dolomite - Figure 20.

Hand specimen - Dark gray, finely crystalline dolomite mottled with white blebs. The rock reacts only slightly to HCl.

Thin section - A mosaic of coarse interlocking euhedral and/or subhedral crystal surround ghost of unidentifiable skeletal or carbonate grains. All original depositional textures are obscured.

![Image of F-12 Crystalline Dolomite](image)

Figure 20. F-12 Crystalline dolomite. Coarse grained dolomite rhombs in crystal mosaic. 40X

Interpretation - This is not a depositional microfacies, but is instead a diagenetic in origin. It was produced by secondary dolomitization of the original limestone of varied composition.
Dolomitization will be discussed in the section on diagenesis.

Microfacies Distribution

All of the microfacies outlined above occur within the stratigraphic section of the Martin Bridge Formation at Hells Canyon, which includes several depositional sub-environments (see Figure 22). F-1 (neomorphosed lime mudstone) is interstratified with either F-4 (Laminated peloid dolowackestone) or F-9 and 10 (grainstone), which are also intercalated with F-5 (Intraclast peloid packstone), and 6 (Intraclast ooid peloid packstone). F-2, 3, 7, and 8 are not common in the Martin Bridge Formation. F-11 (Bafflestone) occurs at three levels in the Martin Bridge section and lies above grainstone. F-12 (Crystalline dolomite) is not associated with any particular microfacies.

Six (F-1, 2, 3, 5, 7, 12) of the twelve microfacies occur in the Mission Creek stratigraphic section. The small number of microfacies observed is not a true representation of the environments of deposition at this locality but is, rather, a product of pervasive diagenesis and metamorphism.

Stratigraphy

Carbonate Stratigraphy—Hells Canyon

In Hells Canyon the Martin Bridge Formation outcrops as 560 m of limestone and dolomite unconformably overlying the Doyle Creek Formation (Vallier, 1967, 1974). The top of the carbonate unit is in some places
cut by a modern erosion surface and in others is unconformably overlain by Tertiary basalt. In the field the most striking feature of the Martin Bridge Formation is its apparently monotonous homogeneity. The limestones weather light gray or tan, and this tends to obscure many of the original sedimentary textures. The only major characteristics readily apparent in the field are bedding thicknesses, pervasive recrystallization, and the large amount of dissolution that has occurred. Dissolution is manifested in modern karst features and nonsutured clay seams. The seams are thin (1 mm to 2 cm) layers of clay minerals, quartz, feldspar, and iron oxide minerals that occur repeatedly throughout the stratigraphic section. They are Similar to clay seams described in many other deformed limestones and are interpreted to be residual concentrations left after limestone dissolution (Barrett, 1964; Wanless, 1979).

I measured a total of four partial stratigraphic sections of the Martin Bridge Formation in Hells Canyon. (See Appendix I for detailed measured sections.) The lowermost section was started at the contact of the Martin Bridge and underlying Doyle Creek Formation. All four sections are located (see Fig. 3) on the east side of the Snake River in Idaho, since the rocks are much less deformed there. I measured a total of 376 m of limestone and dolomite; 250 m of which occurs in the Allison Creek and Dry Gulch measured sections. Vallier (1967, 1974) reported a total thickness of 560 m for the Martin Bridge Formation in Hells Canyon. I did not measure the entire thickness of the unit in detail because of inaccessible cliffs and talus slopes which were not suitable for detailed stratigraphic work.
Since most of the textures and grain constituents are obscured by weathering, petrography proved to be the most useful tool in describing the carbonate rock. Figure 21 is a composite stratigraphic section of part of the Martin Bridge Formation in Hells Canyon.

The lowermost 50 m in the Martin Bridge section is composed of a series of two to five cm thick, gray to tan beds of laminated peloid wackestone (F-4) with millimeter scale wavy laminae, centimeter scale flat laminae, convolute bedding, and rip up clasts. These rocks are interbedded with massive un laminated peloid wackestone (F-2) and massive lime mudstone (F-1). Also found in this part of the section are a few thin beds of calcareous volcaniclastic siltstone. These sediments are interpreted as supratidal-intertidal deposits based on the presence of microcrystalline dolomite in F-1 and F-4 and birdseye structures, desiccation features, and gypsum casts in F-4. Dolomite in the 5-10 micron range is considered to penecontemporaneously replace calcium carbonate in supratidal sediments as has been documented in the modern environment on Bonaire Island, Netherlands Antilles (Deffeyes and others, 1964), in the Persian Gulf (Illing and others, 1965), and on Andros Island, Bahamas (Shinn and others, 1965). A modern analog for the Martin Bridge supratidal deposits are the tidal flats of Andros Island, Bahamas. Andros Island and the Wallowa terrane both formed in a warm, low latitude setting. Hardie and Ginsburg (1977) describe sediments from the tidal flats of Andros Island that closely resemble F-2 and F-4. Laminated mud, silt, and sand-size carbonate sediment on Andros Island is laid down as overbank deposits on exposed tidal channel bars, levees, and beach ridges. Un laminated mud is deposited in lagoons
Figure 21. Composite stratigraphic section of the Martin Bridge Formation in Hells Canyon showing: thickness in meters, the distribution of microfacies, Dunham (1962), modified by Embry and Klovan (1972), rock types, and the relative water depth in relation to normal (fairweather) and storm wave base.
or tidal ponds. Also, the presence of convolute bedding in F-4 is suggestive of steep-sided bars in tidal environments (Reineck and Singh, 1980). In this part of the stratigraphic section F-1 represents restricted environments such as shallow lagoons or tidal ponds, which often form on tidal flats.

At about the 80 m level, overlying the supratidal deposits and a covered interval, are about 30 m of thin to moderately thick bedded packstone and grainstone which includes F-5, 9, and 10. This represents a relative rise in sea level accompanied by a change from supratidal sedimentation to deposition in a moderately agitated intertidal or subtidal environment. Above the grainstone lies massive crystalline dolomite (F-12), intraclast peloid packstone (F-5), dolomitized mudstone, and a thin bafflestone unit (F-11 at 112 m). The crystalline dolomite does not yield any information about the depositional setting. The mudstone is dolomitized and also tells little about the environment. These rocks probably represent wave and current restricted, shallow water conditions. The packstone indicates moderately agitated water with open circulation. The bafflestone is composed of branching spongiomorphs with various bioclasts and non-skeletal carbonate grains filling the interstices. Such bafflestones do not represent true ecologic reefs in the terms of Heckel (1974) but are more likely small colonies (less than 1 m in diameter) of sediment-baffling organisms.

Wackestone, packstone, and grainstone make up the next 46 meters of section. The peloid wackestone (F-2 at 124 m and from 140-160 m), containing up to 30% neomorphosed lime mud, indicates relatively quiet to slightly agitated water. Deposition probably occurred below
fairweather wave base but within the photic zone since cryptalgal structures are present. The intraclast peloid grainstone (F-9 at 132 m) and intraclast peloid packstone (F-5 at 120 m and between 156 and 164 m) indicate intermittent turbulence, possibly caused by storms that winnowed away the lime mud and left grain supported sediments. The grainstone probably formed tide and wave worked shoals inbetween which were more protected conditions where wackestone and mudstone was deposited. The intercalation of these microfacies explains this relationship.

At the 160 m level on Figure 21 is an approximately 10-20 m talus covered interval from the Dry Gulch measured section the exact stratigraphic distance of this interval is unknown.

From 180 to 220 m are grainstone (F-8), packstone (F-6), dolomite (F-12), and bafflestone (F-11). The dolomite is almost completely crystalline and forms eight meters of massive beds. The eight meter thick grainstone unit (F-8) above the dolomite is thin to medium bedded and composed dominantly of ooids. These ooids formed in shallow, strongly agitated water and make up a wave and current worked shoal. The shoal was used as a marker bed to correlate the Allison Creek and Dry Gulch measured sections which are spatially separated by about 2 kilometers. These ooids are not well preserved; neomorphism has destroyed the structure in the ooid coats so that it is impossible to tell whether they were composed of radial or tangentially arranged crystals.
The bafflestone unit (F-11 at 200 m) above the oolite shoal is formed by the red alga, Solenopora, and contains peloids and intraclasts. Overlying the bafflestone and separating it from a second bafflestone is four meters of intraclast ooid peloid packstone (F-6). The second bafflestone lies above this, and appears to be composed of sponges based on textural evidence. All of these facies formed in moderately to strongly agitated water with open circulation. Again, the bafflestone units are small colonies of sediment baffling organisms. Reef-like structures and reef debris were described in the Martin Bridge in the Wallowa Mountains by Nolf (1966) and in Hells Canyon by Vallier (1967); however, truly any reef-like structures were found in the Hells Canyon area during this study.

Lying above the uppermost bafflestone (at 212 m) is a thick sequence of alternating grainstone (F-9, 10), packstone (F-6), mudstone (F-1), and dolomite (F-12). This alternating sequence is interpreted to represent deposition on a shallow shelf. The packstone and grainstone require at least moderately agitated water to winnow away lime mud and transport the larger grains. The grainstone probably formed shoals, while the packstone was deposited on a relatively level bottom. Ephemeral shoals absorbed or focused wave force around them protecting intershoal areas where mudstone and wackestone were deposited. The abrupt interfingering of microfacies indicates actively shifting environments under stable sea level conditions. Tidal action, currents, and storms built up the shoals (F-9, 10) which migrated and interfingered with the mudstone and wackestone. The dolomite is not a depositional facies but a diagenetic one.
**Tempestites**

A final microfacies type not present in any of my measured sections but nonetheless important in the carbonate sequence is the bioclastic grainstone (F-7) found in a series of shell beds near Spring Creek (see fossil locality on Figure 3). These beds are small lensoidal deposits (0.3-0.5 m thick) composed of diverse and poorly sorted fossils, including bivalves, spongiomorphs, corals, echinoids, and brachiopods which are layered parallel to bedding. They are in a peloidal intraclastic matrix and are interbedded with sand size carbonate grains that is only sparsely fossiliferous. Newton (in press) has interpreted these as storm lags or calcareous tempestites.

Similar storm lags were described from the Muschelkalk shell beds of southwestern Germany (Aigner, 1977), Upper Jurassic marine sediments from Wyoming (Brenner and Davies, 1973), and Upper Triassic shelf deposits from the Alps (Kuss, 1983). Newton (in press) lists five major similarities between the Spring Creek beds and Aigner's tempestites:

1) presence of a basal scour.
2) disarticulated bioclasts oriented parallel to bedding.
3) relative thickness of bioclastic beds.
4) normal graded bedding.
5) ripple cross lamination in the upper part of the lenses.

The whole, unbroken corals, spinose gastropods, and bivalves indicates that the fossils were not transported very far before accumulating as storm lags. The beds intercalated with the shell lags are much like F-6, 9, and 10, and are indicative sedimentation above fairweather wave base in a shallow, moderately agitated, subtidal environment (Newton, in
While these shell beds include a relatively large number of reeflike organisms they do not represent reef debris. Some of the organisms, such as the spongiomorphs and corals, are potential framework-builders; however neither are volumetrically important and most corals have a platy or encrusting growth morphology. These organisms may have formed small patches of bafflestone similar to those in F-11. Newton (in press) accurately characterized the biota as occupying "level-bottom communities."

Environment of Deposition and Paleogeography

The Martin Bridge Formation in Hells Canyon represents deposition in shallow marine conditions. The base of the section begins in supratidal deposits. The remainder of the rocks were deposited in relatively shallow water with only mild fluctuation in sea level. The total deposit probably resulted from subsidence of the oceanic platform. The stratigraphic sequence studied was basically a single composite section but lateral relationships can be inferred by invoking Walther's Law. Since the top of the Martin Bridge Formation in Hells Canyon has been eroded it is impossible to determine whether the platform on which these carbonates were deposited continued to subside after deposition of the Martin Bridge. However, the stratigraphic record of upper Triassic limestones of the Wallowa Mountains and the Wrangellia sequence indicates a deepening upward carbonate sequence overlain by basinal sediments. This sequence is similar to those found on oceanic plateaus or sea mounts formed near mid-ocean ridges which subside as they spread.
farther from the ridge (Grigg, 1982). The Wrangellia Terrane probably formed in such a setting and the Wallowa terrane may have formed nearby. Figure 22 is a schematic representation of the depositional setting and microfacies relationships of the Martin Bridge Formation in Hells Canyon.

Most of the classic studies of modern carbonate sediments are centered on the extensive carbonate platforms of the Bahamas or the Persian Gulf. A large percentage of the carbonate rocks preserved in the geologic record were deposited in shallow epicontinental seas. If a carbonate unit is deposited atop a plateau in the middle of an ocean basin the likelihood that it will be preserved decreases as time and seafloor spreading progress.

The tectonic environment proposed for the Seven Devils Group, the Martin Bridge Formation, and the other Wrangellian sequences (Sarewitz, 1983; Nur and Ben-Avraham, 1982; Jones and others, 1977) differs sharply from the types of extensive carbonate platform or shelf deposits that dominate the literature. If these allochthonous carbonate rocks were deposited in an island arc setting or on a volcanic ocean plateau, then an inviting modern analog exists at relatively low latitudes in the Pacific Ocean. Sea mounts and volcanic guyots are prominent features of the Pacific seafloor and carbonate is deposited wherever conditions permit. Extensive ecologic reefs commonly form on shallow seamounts or plateaus. Many reefs may form atolls around submerged volcanic platforms such as Bikini Atoll. They also form fringing or barrier reefs around exposed sea mounts (Hamilton, 1979).
Figure 22. Schematic depositional model for the Martin Bridge Formation. The Hell's Canyon sequence contains only those sediments deposited east of the shelf edge. The deeper water basinal sediments represent facies which probably exist in the Wallow Mountains.
Many guyots, such as those in the Tasman Sea, off the east coast of Australia, are topped by small, relatively level platforms, usually less than 400 square km. These guyots and plateaus rise, from an abyssal plain about 4500 m deep, sometimes to less than 20 m below sealevel (Slater and Goodwin, 1973). Carbonate deposition may be restricted to the platform since the abyssal plain below may be beneath the carbonate compensation depth. Other oceanic platforms, like the Fiji Plateau, the Ontong Java Plateau, or Caroline and Mariana Ridges, are larger and may be closer analogs to the Wrangellia Terrane. In fact the Caroline and Mariana Ridges form a complex tectonic setting, north of New Guinea in the western Pacific Ocean, where spreading centers and subduction zones are in close proximity. In this setting it would be possible to have tholeiitic and calc-alkaline basalts produced and even accreted to one another. The Caroline Ridge is similar to Wrangellia in that it is a volcanic platform; however, it is too deep for shallow water carbonate sediments and is covered by pelagic chalk and ooze (Fischer and others, 1971).

Tozer (1982) interpreted the paleogeography of the proto-Pacific as an ocean basin dotted with islands and shallowly submerged platforms that now make-up the collage of accreted terranes on the western margin of North America. This type of paleogeographic setting could facilitate the migration of invertebrate organisms. The scattered islands or platforms would act as "staging posts" (Rosen, 1983) by breaking up the large distances organisms would have to migrate across the proto-Pacific. This may explain some of the Tethyan faunal associations of the Wallowa and Wrangellia Terranes.
If a setting such as that described above existed during the deposition of the Martin Bridge Formation, then the carbonate facies could be much different from those of "classic" carbonate shelves or platforms. This explains why the microfacies patterns of the Martin Bridge carbonate rocks differ so much from standard microfacies models developed from "classic" carbonate depositional environments.

The carbonate sediments of the Martin Bridge Formation are dominated by lime mud, peloid, and intraclasts (which are also composed of lime mud). The existence of so much lime mud in this setting poses the question of the ultimate source for the mud. There are a number of ways in which lime mud can be produced. Some calcareous green algae, such as Penicillus, precipitate mud size aragonite needles, which add to the sediment as the algae die. Other skeletal grains contribute to lime mud through physical and biogenic abrasion of large particles into smaller ones. Lime mud may also be produced by endolithic boring algae or other boring organisms which often form micritic envelopes on skeletal or other carbonate grains, producing coated grains or cortoids (Bathurst, 1975; Fluegel, 1982).

The large amount of lime mud and grains composed of lime mud in the Martin Bridge imply that algae must have been very prevalent in the environment. However, only limited direct evidence was found for algae. The Martin Bridge Formation at Hells Canyon also conspicuously lacks invertebrate macrofossils. The only major fossil locality is the series of storm lags described from Spring Creek. This assemblage is very diverse but fossils are sparsely distributed throughout the rest of the unit. I believe that the lack of skeletal grains and the preponderance
of lime mud and peloids is a product of restricted water circulation. These areas commonly have low faunal diversity and thus only a small percentage of macrofossils would be preserved in the sediments. Two other mechanisms that played a role in decreasing the number of macrofossils were physical abrasion and biogenic boring. Many of the calcareous macrofossils were probably physically abraded by waves and currents or bored by endolithic algae and bacteria. Abrasion produced fine carbonate sediment while boring formed structureless peloids. Both of these processes would form micrite from skeletal grains. Much of the micrite on modern carbonate shelves is passed through the guts of various detritus feeding marine organisms and deposited as fecal pellets. There is no reason to believe that this process did not also occur during the Triassic. Thus the bioclasts are not truly lacking in the Martin Bridge Formation; they have probably been converted into lime mud and peloids.

The Martin Bridge Formation at Hells Canyon was deposited in relatively shallow water that sometimes deepened to below fairweather wave base, but never below storm wave base. Terrigenous material is sparse. The supratidally deposited sediments contain about four percent volcanoclastic sand grains, which were probably derived from the volcanic platform or island upon which the carbonate was deposited. The general lack of terrigenous sediments implies that the environment of deposition was far removed from a large terrestrial sediment source.
Carbonate Stratigraphy—Mission Creek Locality

As explained in the introduction, the Upper Triassic limestones along Mission Creek are stratigraphically and structurally isolated. Stanley (1979) reported a number of lensoidal beds of branching corals within the Mission Creek quarry. These lenses range from one and five meters in diameter and are one to two meters thick. Although small, their topographic relief is reflected in the surrounding beds that dip away gently. They occur mainly in the southern half of the quarry and can be described as thickets using the terminology of Squires (1964). Coral thickets of this type are unknown from the Martin Bridge Formation in Hells Canyon.

The entire quarry exposes nearly 150 m of limestone, much of which is inaccessible because of unstable talus and the vertical quarry walls. I measured four short stratigraphic sections in the quarry totaling about 70 m, and by tracing key beds from one part of the section to another, compiled a complete composite sequence. Figure 23 is a composite stratigraphic section from the Mission Creek quarry. The rock types compare closely to some of the microfacies delineated for the Martin Bridge Formation in Hells Canyon, but the Mission Creek rocks are more fossiliferous.

The intraclast peloid packstone (F-5) at the base of the section is rich in bivalves and echinoderms. Between the fossils is a matrix of broken skeletal grains, peloids, intraclasts, and mud. This rock type formed in a relatively quiet-water environment but received larger clasts from more agitated water nearby.
Figure 23. Stratigraphic section of the Mission Creek limestone. Format is the same as Figure 21.
DUNHAM (1962) ROCK TYPES

BELOW STORM WAVE BASE
ABOVE STORM WAVE BASE
ABOVE NORMAL WAVE BASE
SUPRATIDAL

KEY
M = mudstone
W = wackestone
P = packstone
G = grainstone
D = dolostone

MICROFACIES

METERS

0 10 20 30 40 50 60 70
The intraclast peloid grainstone (F-9) at the 4 m level is grain supported and indicates strongly agitated water. This is overlain by a bioturbated peloid-bioclast-wackestone (F-3) with bivalves, crinoid fragments, and gastropods. This facies indicates quiet water and lime mud deposition.

The grainstone and packstone which lies above the wackestones is compositionally similar to F-7. It formed in a moderately to strongly agitated environment and is made up of large fossils in a sandy intraclast-peloid matrix deposited during storms, but it lacks the basal scour, normal grading, and cross-ripple laminations characteristic of F-7 (bioclastic grainstone). A thick sequence of peloid bioclastic wackestone (F-3) and peloid wackestone (F-2) (from 22 to 34 m) occurs next. F-3 is comparable to SMF-9 (Fluegel, 1980; Wilson, 1975), in that it contains a large percentage of fossils in lime mud, which formed in shallow, openly circulating water just below fairweather wave base.

The sequence from 34 to 72 m has been intensely metamorphosed and dolomitized. Textures in the dolomite suggest that a few bafflestone mounds surrounded by mudstone and packstone (F-1 and F-5 respectively) occur.

Environment of Deposition--Mission Creek Locality

These environments seem to have been much more hospitable to the development of organic buildups than those represented by the rocks in Hells Canyon. The thickets here are from one to five meters in diameter and one to two meters thick and usually form small lensoid patches which had less than two meters of topographic relief. They consist mainly of
Figure 24. Schematic depositional model for the Mission Creek limestone.
the coral Retiophyllia, spongiomorphs, and encrusting sclerosponges. These thickets acted as sediment bafflers and probably restricted circulation around them by subduing wave action. The thickets are distributed widely throughout the quarry wall and most of them were not traversed by the measured section.

Deposition occurred on a shallow carbonate shelf with gently, intermittent to strong, constant water agitation. Squires (1956) reported coral colonies that had fallen over, possibly broken by storms, and then resumed growth at a different angle. This evidence along with the occurrence of F-7 (bioclastic packstone) indicates that highly turbulent water circulation did occur from time to time. However, the majority of the microfacies here are mudstone and wackestone and indicate relatively quite water. Figure 24 is a schematic representation of the depositional setting for these limestones. Again, as in Hells Canyon, very little terrigenous material is found in the carbonates, which suggests that these limestones were deposited far from any terrestrial sedimentary source.

CARBONATE DIAGENESIS

Martin Bridge Formation--Hells Canyon

Diagenesis has severely affected the limestones of the Martin Bridge Formation in Hells Canyon. In this section I will outline the diagenetic features observed and the processes and sequence of their formation.
Diagenetic Features

Dolomite

Two size populations of dolomite occur in the Martin Bridge Formation: a) microcrystalline dolomite rhombs ranging in size from 5 to 25 microns (see Figures 25 and 26), b) anhedral to euhedral dolomite crystals larger than 50 microns. The microcrystalline dolomite occurs only in F-1, F-2, and F-4. The larger dolomite population occurs in most of the microfacies (see Table 1) and replaces sparry calcite, skeletal fragments, and microspar. Dolomite in this size range also constituted F-12 (crystalline dolomite microfacies) where the entire rock had been dolomitized. Some coarse dolomite rhombs, observed in thin section, were silicified.

Stylolites and Clay Seams

Stylolites were usually seen as solitary surfaces rather than as sets. Stylolite morphology varies and encompasses smooth, hummocky, irregular, low and high peaked, and columnar stylolites (Fluegel, 1982). Stylolites that cut sparry cement were not observed in thin section. Grains cut by stylolites were only present on one side of the stylolite surface. Stylolites have one of two orientations, either sub-parallel or an oblique angle to bedding. Clay seams occur throughout the stratigraphic section as layers of clay minerals, quartz, feldspars, and iron oxide minerals up to two centimeters thick. The seams are laterally continuous and parallel to bedding surfaces.
Figure 25 and 26. SEM photograph of microcrystalline penecontemporaneous dolomite from F-4.
Microspar and Neomorphic spar

The fine-grained matrix in the Martin Bridge limestone is microspar (from 10 to 50 microns) rather than micrite. Microspar is commonly the product of neomorphism. Neomorphic spar is also prevalent, and grumeleuse structures with residual clots of micrite and microspar occur. Most of the carbonate grains and unsilicified macrofossils were also neomorphosed.

Sparry Calcite

Spar is not common in the Martin Bridge Formation. It constitutes less than 10% of any thin section. Some of the spar is neomorphic in origin and void-filling cement is rare and occurs mainly in the various grainstone and packstone microfacies. Some spar also occurs in veins that have no consistent orientation.

Silicification

Chert and other forms of microcrystalline silica were not observed in the Martin Bridge Formation in Hells Canyon. Silicification formed mega-quartz that replaced both fossils in the storm lag deposits and dolomite rhombs.

Diagenetic Processes

As the supratidal and intertidal sediments at the bottom of the Martin Bridge section were being deposited, very finely crystalline dolomite penecontemporaneously replaced calcium carbonate. A likely process to form this dolomite is evaporative reflux (Adams and Rhodes, 1960). In this model the evaporation of surficial sea water produces a
concentrated or hypersaline brine that is pumped through nearshore sediments as evaporation continues. The precipitation of calcium carbonate minerals and evaporites, such as gypsum (See Figure 27), from the saturated brines increases the Mg/Ca ratio while depleting the waters of sulfide ions. The increased Mg/Ca allows for the replacement of calcium carbonate by micro-crystalline dolomite. In modern environments, such as the tidal flats on Andros Island or the Persian Gulf, supratidal dolomite is 2-4 microns in size and is composed of poorly ordered crystals (Shinn and others, 1965; Illing and others, 1965). In ancient supratidal deposits the dolomite is a little larger and has a more ordered crystal structure (Gaines, 1977). Figures 25 and 26 are SEM photos of the micro-crystalline dolomite found in the Martin Bridge Formation. Figure 27 shows gypsum casts from the finely laminated peloid dolowackestone (F-4).

The next major diagenetic process, compaction, occurred relatively early during the history of the Martin Bridge limestone. Carbonate sediments are often deposited with an initial porosity of 40-70% (Bathurst, 1966; Pray and Choquette, 1966). Most of the sediment in the Martin Bridge was initially soft. Peloids, intraclasts, and carbonate and were the most dominant sedimentary components throughout deposition. Even the packstones and grainstones are formed by large percentages of these soft particles. Compaction in this type of sediment was very extensive, often forming grainstone and packstone with tangential and concavo-convex grain contacts (see Figures 14, 16, 18). Dewatering is directly related to compaction. Figure 12 shows a fluid escape structure in F-4 that formed during dewatering. Figure 17 shows
Figure 27. Photograph of gypsum casts found on a bedding plane in F-4.
a spar-filled burrow in a peloid grainstone. The radial compaction of the peloids which form the walls of the burrow indicate that the sediment had a low water content at the time of burrowing (Ziegler and others, 1974), which must have occurred after the initial stages of compaction and dewatering.

As compaction proceeded a more and more carbonate grains came in contact with one another. Localized strain along grain contacts leads to localized dissolution of carbonate material termed pressure solution (Oldershaw and Scuffin, 1967). The development of compaction and pressure solution was documented to occur relatively early in the formation of a carbonate unit, sometimes prior to lithification of the sediments (Shinn and others, 1977).

Pressure solution stylolites and clay seams up to 2 cm thick are common both in thin section and in outcrop. As overburden in the Martin Bridge limestone increased, localized solution along grain boundaries probably led to the development of continuous stylolites or clay seams. The origin of clay seams in limestones is rather controversial. Some form as original depositional layers while others form by the concentration of insoluble material through pressure solution. Barrett (1964) found that pure limestones, with high initial porosity and permeability, had many clay seams. Porosity and permeability allow fluid transfer of calcium and carbonate ions in solution. The limestone of the Martin Bridge Formation in Hells Canyon has a very low concentration of terrigenous material and was thus a likely candidate for developing pressure solution clay seams in response to overburden. I attempted to determine the amount of dissolution by examining grains
in thin section which had been partially dissolved by pressure solution. However, this approach did not yield any useful quantitative data because none of the grains observed continued across seams or stylolites, indicating that dissolution was extensive. A comparison of clay seam material with insoluble residue would also have given an estimation of the amount of carbonate material dissolved, but the clay seam samples which I collected did not survive transportation from the field.

Sparry cementation of these limestones probably occurred penecontemporaneously or subsequent to pressure solution since stylolites do not commonly cut spar. The calcium carbonate dissolved during pressure solution probably precipitated in original voids and burrows on either side of stylolites or clay seams.

The next diagenetic process in the sequence is late dolomitization that produced the coarsely crystalline dolomite. Dolomite precipitation contemporaneous with pressure solution was documented in Paleozoic limestones by Wanless (1979). In the Martin Bridge Formation some dolomite may have formed contemporaneously with pressure solution; however, since dolomite rhombs are found replacing sparry calcite cement crystals much of it must have formed subsequently. These dolomites probably formed as fluids with a high Mg/Ca ratio migrated basinward from the supratidal zone or as similar fluids were mobilized by subsequent volcanic activity.

The shell beds near Spring Creek have been silicified and many of the invertebrate fossils were replaced with mega-quartz, which accounts for the exceptional preservation of some specimens. A few thin sections
contained dolomite rhombs which had subsequently been silicified, so silicification must have occurred after dolomitization. Silicification is restricted to these storm deposited shell lags which lie in the axis of a syncline. This implies, but does not prove, that the transport of silica-rich fluids was somehow structurally controlled. A source for these fluids was not readily apparent.

Aggrading neomorphism is pervasive throughout the Martin Bridge Formation in Hells Canyon. Neomorphism of carbonate sediments can begin in partly consolidated sediments (Bathurst, 1975). I cannot establish the temporal boundaries for the neomorphic process in the Martin Bridge Formation. Neomorphism began as the original aragonite and high Mg calcite sediments were converted to low Mg calcite. This process continued until nearly all original micrite was converted to microspar.

An anomalous diagenetic feature which occurs at four levels in the stratigraphic section in Hells Canyon is what appears to be void filling and interstitial calcite vadose silt. The calcite silt is larger than the microspar which surrounds some of the voids. Calcite silt of this type was first described by Dunham (1969) from the Townsend Mound in New Mexico. The silt Dunham found was composed of calcite precipitated in the vadose zone which then settled into voids and interstices in the rock. Where the silt did not entirely fill the void sparry calcite cement was precipitated on top of it forming geopetal structures. Vadose silt is not common in the Martin Bridge Formation and occurrence of the silt indicates that subaerial exposure either was intermittent or only affected restricted portions of the carbonate platform. Since these rocks were forming on a shallow shelf it is reasonable to
postulate that areas of higher topographic relief were sometimes exposed to vadose processes.

The final major phase of diagenesis formed in response to deformation of these limestones as they were accreted onto the continental margin of North America. The Wallowa Terrane accreted between Late Jurassic and Late Cretaceous time (Hillhouse and others, 1982). During deformation the limestones now in Hells Canyon were folded and fractured and a great deal of pressure solution occurred, forming stylolites oblique to bedding. Calcium carbonate fluids derived during pressure solution precipitated sparry calcite in fractures. Further aggrading neomorphism may also have occurred.

**Metamorphism**

During the Tertiary the Martin Bridge Formation was covered by flows of the Columbia River Basalts and intruded by associated dikes. Metasomatism and some recrystallization of the limestones was undoubtedly associated with this, and metamorphic minerals such as pectolite were observed in limestones adjacent to cross-cutting dikes. As the Snake River cut through the Columbia River Basalts it finally exposed the Martin Bridge Formation to subaerial erosion. Soon afterward large scale surface dissolution began to occur. True karst topography has not formed here, but a number of small caves were encountered in the field and surficial solution of exposed limestones was pervasive.
The diagenetic sequence can be summarized as follows:
1) Deposition of carbonate sediments.
2) Replacement of calcium carbonate minerals by penecontemporaneous microcrystalline dolomite in supratidal and intertidal sediments.
4) Compaction.
5) Pressure solution I.
6) Cementation with sparry calcite.
7) Aggrading neomorphism.
8) Coarsely crystalline dolomitization.
9) Deformation:
   a) Folding and fracturing.
   b) Pressure solution II.
   c) Aggrading neomorphism.
   d) Vein filling sparry calcite.
   e) Silicification.
10) Metamorphism and recrystallization associated with intrusion of batholiths and eruption of flow basalts.
11) Erosion and dissolution by the Snake River and related tributaries, rain water, and ground water.
Mission Creek Limestone

The diagenetic products observed in the Mission Creek limestone were: microspar, replacement and void filling dolomite, silicified fossils, and recrystallized limestone.

The limestone along Mission Creek has undergone a much different diagenetic sequence than that in Hells Canyon. The major feature here has been extensive recrystallization of the limestones produced by contact metamorphism associated with intrusion of the Idaho Batholith, which may directly underlie the limestone outcrop. Recrystallization is pervasive in the northern half of the quarry, where white marble and small recrystallized coral thickets occur. In the southern half of the quarry recrystallization is less pervasive and more patchy. In thin section these recrystallized rocks are composed of mosaics of coarse grained spar and dolomite.

Those rocks that have not been totally recrystallized are extensively neomorphosed. A great deal of lime mud originally formed the wackestones and packstones that dominate the rock types found here. Most original lime mud is now microspar measuring 10-20 microns.

Another prevalent diagenetic process affecting the make-up of these limestones is secondary dolomitization. Dolomite here is medium to coarse grained (50-600 microns) and is preferentially distributed in fractures, voids, and burrows. It is also fills the molds of dissolved mollusc shells. This dolomite formed subsequent to lithification of the sediments and replaced other carbonate minerals or was precipitated in
open spaces.

I have previously discussed the presence of silicified fossils in the Mission Creek quarry. Complete silification of fossils is restricted to a very small zone near the top of the quarry. The timing of silification is difficult to determine since it is restricted to fossils that were originally calcite and does not seem to affect any other clasts.

PALEOECOLOGY

Martin Bridge Formation—Hells Canyon

Much of the limestone in Hells Canyon is completely devoid of fossils. The fossils described here come from a single fossil locality, located in the axis of an open syncline atop the plateau immediately north of the Spring Creek drainage, see Figure 4 (Vallier, 1967; Newton, 1983). The biota of the Martin Bridge Formation is numerically dominated by molluscs but also includes spongiomorphs, corals, brachiopods, crinoids, echinoids, and sponges. The fossils occur in a few graded, lensoidal, storm lag deposits, which were discussed previously. The most important aspect of these fossil deposits is that they are silicified. The external morphology of the fossils is extremely well preserved, but internal structures were completely destroyed by silicification. There are a few other fossil beds located near Kinney Creek, Leep Creek, and Eckels Creek (Vallier, 1967) but they were not silicified.
Table 2. Taxonomic composition of the Hells Canyon fauna. Table lists the number of specimens of each taxa and their trophic types.

ES = epifaunal sessile, EB = epifaunal byssate, EC = epifaunal cementing, EP = epifaunal pedicle attached. DF = detritus feeder, SF = suspension feeder, MP = micropredator, SC = scavenger or rasper.
### Spring Creek Locality

#### BIVALVES

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Trophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lochia sp.</td>
<td>EC SF</td>
<td>54</td>
</tr>
<tr>
<td>Pteriomontaculina sp.</td>
<td>EC SF</td>
<td>44</td>
</tr>
<tr>
<td>&quot;Septiscia&quot;</td>
<td>IM SF</td>
<td>32</td>
</tr>
<tr>
<td>Cassianella cf. C. andrewsiana</td>
<td>IM SF</td>
<td>27</td>
</tr>
<tr>
<td>Cassianella sp.</td>
<td>IM SF</td>
<td>14</td>
</tr>
<tr>
<td>Cristidens sp. M. williamsii</td>
<td>IM SF</td>
<td>13</td>
</tr>
<tr>
<td>Priscilla sp. M. australiana</td>
<td>IM SF</td>
<td>9</td>
</tr>
<tr>
<td>Parallelodiscus cf. P. concinna</td>
<td>IM SF</td>
<td>6</td>
</tr>
<tr>
<td>Cardinidae spec.</td>
<td>IM SF</td>
<td>6</td>
</tr>
<tr>
<td>Talocereus sp.</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Pl.Cart. cf. E. hemispa</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Lucinidae indet.</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Bivalve R</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Trigonid A</td>
<td>IM SF</td>
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</tr>
<tr>
<td>Pterociella sp.</td>
<td>IM SF</td>
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</tr>
<tr>
<td>Chlamys sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Entellina sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Antisquilla sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Trigonid B</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Tangrediidae indet.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Pericardiidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Trigoniidae C</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Articidiidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Gryphaeidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Bivalve U</td>
<td>IM SF</td>
<td>1</td>
</tr>
</tbody>
</table>

#### BRACHIOPODS

<table>
<thead>
<tr>
<th>Species</th>
<th>Type</th>
<th>Trophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echinocrinus sp.</td>
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<tr>
<td>Echinoceratidae sp.</td>
<td>EC SF</td>
<td>44</td>
</tr>
<tr>
<td>&quot;Septiscia&quot;</td>
<td>IM SF</td>
<td>32</td>
</tr>
<tr>
<td>Cassianella cf. C. andrewsiana</td>
<td>IM SF</td>
<td>27</td>
</tr>
<tr>
<td>Cassianella sp.</td>
<td>IM SF</td>
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</tr>
<tr>
<td>Cristidens sp. M. williamsii</td>
<td>IM SF</td>
<td>13</td>
</tr>
<tr>
<td>Priscilla sp. M. australiana</td>
<td>IM SF</td>
<td>9</td>
</tr>
<tr>
<td>Parallelodiscus cf. P. concinna</td>
<td>IM SF</td>
<td>6</td>
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<tr>
<td>Cardinidae spec.</td>
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<td>6</td>
</tr>
<tr>
<td>Talocereus sp.</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Pl.Cart. cf. E. hemispa</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Lucinidae indet.</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Bivalve R</td>
<td>IM SF</td>
<td>4</td>
</tr>
<tr>
<td>Trigonid A</td>
<td>IM SF</td>
<td>3</td>
</tr>
<tr>
<td>Pterociella sp.</td>
<td>IM SF</td>
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</tr>
<tr>
<td>Chlamys sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Entellina sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Antisquilla sp.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Trigonid B</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Tangrediidae indet.</td>
<td>IM SF</td>
<td>2</td>
</tr>
<tr>
<td>Pericardiidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Trigoniidae C</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Articidiidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Gryphaeidae indet.</td>
<td>IM SF</td>
<td>1</td>
</tr>
<tr>
<td>Bivalve U</td>
<td>IM SF</td>
<td>1</td>
</tr>
</tbody>
</table>
I collected about 15 blocks of fossiliferous limestone from the storm beds. Five of these weighed between 10 and 20 Kg. and the others weighed from 2 to 5 Kg. Most of these blocks were processed in dilute hydrochloric acid. I retrieved 717 specimens and classified them into 95 different taxa.

**Taxonomic Composition**

Table 2 is a faunal list of all identifiable taxa found in Hells Canyon. 554 of the 717 specimens are either bivalves or gastropods. I have identified 28 taxa of bivalves, while Newton (1983) reported 38 taxa from a sample of over 2000 specimens. Little taxonomic work has been done on molluscs of the Triassic. The systematics of the Cordilleran bivalves of Upper Triassic age are currently being worked out by Newton (in press). Gastropods of the Triassic are in desperate need of systematic revision. There is also a great deal of controversy about the classification of Triassic corals and spongiomorphs. For these reasons it was often difficult to ascertain the trophic and systematic affinities of some of the fossils.

**Rarefaction**

To determine what constituted a statistically representative sample of the specimens I collected, I performed a rarefaction analysis. Sanders (1969) was the first to employ this statistical method in an ecologic analysis. Hurlbert (1971) modified Sanders work and produced the following formula:
Figure 28. Rarefaction curve for the Hells Canyon (HC) and Mission Creek (MC) faunas.
\[ E(S_n) = \sum_{i=1}^{s} 1 - \left( \frac{N - N_i}{n} \right) \]

Where \( E(S_n) \) = the expected number of species in a sample of \( n \) individuals selected at random from a collection containing \( N \) individuals, \( S \) species, and \( N_i \) individuals of the \( i \)th species. The results of this analysis are shown in Figure 28. As the rarefaction curve begins to plane off it becomes less likely that many new taxa will be found, even with increased sample size. Therefore, the sample I collected is statistically representative of the fauna in the shell lags.

**Diversity**

To measure the diversity of the specimens which I collected at Hells Canyon I have employed the Shannon-Weiner Diversity Index (\( H \)). This formula:

\[ H = \sum_{i=1}^{n} P_i \ln P_i \]

Where \( P_i \) = the proportion of the \( i \)th species and \( n \) = the number of species in the sample, was first used by MacArthur and MacArthur (1961) because it can measure the uncertainty of predicting the identity of an individual randomly drawn from a sample. The "\( H \)" value is often called the entropy of the system and can range from zero to infinity. The
diversity value increases with an increase in either the number of species or the evenness of their abundances. Therefore, it is a measure of both species diversity and dominance diversity. For this assemblage $H = 3.085$.

Trophic Analysis

Based on comparisons with living marine organisms the fossils from the Hells Canyon storm deposits belong to a number of different trophic groups and have various relationships to the substrate. Table 2 lists this information for each taxon. In Figure 29 I have tallied this information to show the relative percentages of the major paleoecologic groups. This fossil assemblage is dominated by bivalve molluscs. Most modern bivalves have paired siphons and are suspension feeders. Most of the bivalves from the Hells Canyon assemblage are epifaunal suspension feeders that were attached to the substrate, either by cement or byssal threads. A few bivalves, in the assemblage, are sessile and unattached while mobile infaunal suspension feeders or mobile detritus feeders are rare.

Gastropods are a quantitatively important component of the Hells Canyon fauna; however, it is difficult to determine the trophic type of individual gastropod species. Very little functional or paleoecologic information is available from gastropods in general, so comparison of the species found with related types of known trophic affiliations was not possible. Modern gastropods encompass a wide range of trophic types including: mobile grazers, filter feeders, carnivores, or detritus feeders, and all of these trophic types were most likely represented in
Figure 29. Concentric pie diagram illustrating the paleoecologic relations of the Hells Canyon fauna. Percentages were calculated using the numbers of individuals of each taxa. The outermost circle gives the relationship to substrate, the next shows the trophic types, the third indicates the mode of attachment, mobility, or sessility, and the innermost circle gives the taxa represented by these categories. Note that gastropods are dealt with separately in this diagram since their relationship to substrate and trophic type are difficult to determine.
the Hells Canyon fauna.

Spongiomorphs make up a relatively large portion of this assemblage. These organisms are now extinct so determining their trophic affinity is difficult. These fossils sometimes form dendritic or platy encrusting colonies. Their internal morphology is similar to that of hydrozoans and stromatoporoids or sclerosponges. The classification of spongiomorphs and stromatoporoids became more complicated with the discovery of modern stromatoporoid-like organisms in caves and crevices within reefs off the north coast of Jamaica (Hartman and Goreau, 1970). These organisms were placed in the new class Sclerospongia within the phylum Porifera. Some paleontologists would like to classify all spongiomorphs, stromatoporoids, and modern sclerosponges in the class Sclerospongia (Stearn, 1983). Fluegel (1981) admits that there are problems with the classification but still refers to spongiomorphs as "hydrozoans." Spongiomorphs may have been micropredators like corals and hydrozoans or suspension feeders like the sclerosponges and stromatoporoids. In this report I am referring spongiomorphs to the class Sclerospongia and assuming that they were suspension feeding organisms.

Brachiopods are lophophorate organisms that spread their lophophore into the water column to filter out suspended micro-organisms. All of the brachiopods from Hells Canyon, were attached to the substrate by a pedicle.

Modern day corals are said to be micropredators since each coral polyp gathers plankton that passes within its grasp. Hermatypic corals have a symbiotic relationship with algae and can also be classified as
autotrophs. For simplicity I will refer to the corals from Hells Canyon as micropredators. Most of these coral species had a platy, encrusting growth morphology and formed small ceroid or meandroid colonies.

Regular echinoids make up a small portion of this assemblage. They are represented by 5 different types of spines and a few small fragments of echinoid test. These organism were mobile and most likely filled a scavenger or rasper trophic niche.

Crinoids also make up a small part of the Hells Canyon fauna. They are represented by a few short segments of crinoid columnals. Modern crinoids are free-living suspension feeder. Most fossil examples are stalked and attached by a root-like holdfast that may be secondarily cemented to the substrate (Moore and Teichert, 1978). The crinoids from Hells Canyon were stalked and therefore were probably attached suspension feeders.

Taphonomy of the Shell Lags

Many of the fossils found in the storm deposits (F-7) were well preserved, partly due to the fact that they were silicified. However, quick burial during storms probably played a more important role in the preservation of fine external morphologic features (see plates 1,2,3). All but one the bivalve shells retrieved were single valves. Approximately 30% of the brachiopods had articulated valves but the rest were single valves.

Although these lags are obviously composed of transported shells their delicate preservation indicates they were not transported far. They probably represent several life assemblages that existed near the
site of deposition.

Paleoenvironment

The faunal assemblage from the storm deposits represents level bottom marine communities in shallow warm water (Newton, 1983a; 1983b; in press). This interpretation is supported by the composition of the bivalve fauna and presence of spinose gastropods, such as Delphiulopsis, and cementing bivalves, such as Plicatula and Lopha (Newton, 1983a; 1983b; in press) These bivalves were often found cemented to other bivalve shells. Corals, which also cement themselves to the substrate, are most often associated with warm, shallow water. The abundance of hard substrates may have been a limiting factor in the distribution of cementing bivalves, coelenterates, and crinoids.

Paleozoogeography

Newton (1983; in press) detected a number of paleozoogeographic affinities for different bivalves from Hells Canyon. Cassianella cf. angusta and Cultriopsis are commonly found in Triassic rocks of the Alps. "Septocardia," Mysidiptera cf. williamsi, and Mysidiella cf. america are restricted to cratonic North and/or South America. Plicatula cf. hekiensis, Parallelodon cf. monobiensis, and Chlamys have Japanese affinities.

Seven of the coelenterate species reported from Hells Canyon (from this study and Montanaro Galletelli and others, 1979), including Disticophyllia norica, Pamirosersis meriani,
*Thecosmilia dawsoni*, and *Andrazella sp.* among others, are of Tethyan affinities. The sclerosponge *Spongiomorpha ramosa* also has Tethyan affinities. Nine of the coelenterate species and one of the sclerosponges are endemic to North America.

As previously discussed, the paleogeographic model proposed by Tozer (1982) may help to explain the diverse range of faunal provinces which seem to have contributed to the Hells Canyon fauna. A proto-Pacific ocean strewn with islands and oceanic plateaus would have facilitated faunal migration across the proto-Pacific, producing a much more cosmopolitan fauna.

**PALEOECOLOGY**

**Mission Creek limestone**

The taxonomic composition of the biota at Mission Creek differs from that at Hells Canyon, with less than 10 taxa in common. The quarry along Mission Creek exposes a number of fossiliferous zones but most of these are recrystallized. Silicified fossils are present at the top of the quarry but silicification is often patchy and this contributed to the small size of the sample that I retrieved from this locality. Squires (1956) reported another collection site at the base of the quarry; however it is now covered by rubble. I collected about twenty large blocks of limestone from the quarry but only a few of these contained silicified fossils. After processing them in dilute hydrochloric acid I recovered a collection of 168 specimens which I then classified into 29 different taxa.
**Taxonomic Composition**

Table 3 is a list of the biota found mainly in silicified zones at the Mission Creek locality. The most abundant fossils in these rocks are branching corals of the genus Retiophyllia and spongiomorphs. The data in Table 3 do not bear out the actual abundance of branching corals and spongiomorphs since most of them were either recrystallized or were not collectible.

At least six small recrystallized, branching coral or spongiomorph thicketst, measuring from one to five meters thick, outcrop in the quarry. Another important component of the biota, which probably acted to reinforce the coral thicket framework, was calcareous algae. The only remnants of this algae are small digitate clusters found in the silicified zone. The rest of the fauna here is rounded out by a few other corals, gastropods, bivalves, sclerosponges, crinoids, echinoids, and sponges. There is a relative paucity of molluscs compared to the Hells Canyon fauna. This may be caused by the small sample size.

**Rarefaction and Diversity**

The rarefaction curve for the Mission Creek samples (Figure 28) indicates that the specimens examined were not necessarily representative of the diversity of the biota preserved in the quarry. The diversity measure for this biota is significantly less than for the Hells Canyon samples ($H=1.05$). This may be due to the high dominance of branching spongiomorphs and corals at Mission Creek.
Table 3. Taxonomic composition of the Mission Creek fauna. Taxa are listed on the left, the next column gives the number of specimens, the third column shows the weight in grams of all specimens of each taxon, and the last column lists the trophic type. EC=epifaunal cementer, ES=epifaunal sessile, EB=epifaunal byssate, IM=infaunal mobile. SF=suspension feeder, MP=micropredator, SR=scavenger/rasper, PP=primary producer.
<table>
<thead>
<tr>
<th>Mission Creek Locality</th>
<th>wt.</th>
<th>TROPHIC TYPE</th>
</tr>
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</table>

**BIVALVES**

<table>
<thead>
<tr>
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</thead>
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<td>IM SF</td>
</tr>
<tr>
<td>?Myophoriopsis</td>
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<td>EC SF</td>
</tr>
<tr>
<td>?Plicanopsis</td>
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<td>EC SF</td>
</tr>
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<td>SF</td>
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**GASTROPODS**

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<tr>
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</tr>
<tr>
<td>Neritopsis sp. 2</td>
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</tr>
<tr>
<td>Delphinuopsis sp. 1</td>
<td>1</td>
</tr>
<tr>
<td>Med. spired gastropod A</td>
<td></td>
</tr>
<tr>
<td>Med. spired gastropod B</td>
<td></td>
</tr>
</tbody>
</table>

**COELENTERATES**

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<tr>
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</tr>
</thead>
<tbody>
<tr>
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<td>17</td>
</tr>
<tr>
<td>?Retiophyllia</td>
<td>12</td>
</tr>
<tr>
<td>Cyathocoenia profunda</td>
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</tr>
<tr>
<td>Cyathocoenia majori</td>
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</tr>
<tr>
<td>Cyathocoenia sp.</td>
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<tr>
<td>Coral B</td>
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</table>

**SCLEROSPONGES**

| Sclerospongia indet.     | 132.88 |

**TABULOZOANS**

| Tabulozoa indet.         | 4     |

**PORIFERA**

<table>
<thead>
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<th>wt.</th>
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</thead>
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<tr>
<td>Dictocoelia sp.</td>
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</tr>
<tr>
<td>Amblysiphonella sp.</td>
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</tr>
<tr>
<td>Calcispongea indet</td>
<td>3</td>
</tr>
</tbody>
</table>

**ALGAE**

| Algae indet.             | 50    |

**ECHINODERMS**

| Echinoidea indet.        | 1     |
| Crinidea indet.          |       |
Trophic Analysis

Algae made up a rather large part of the biota at the Mission Creek locality. The number of individual silicified algal specimens made up almost 50% of the entire sample I collected. These algae were primary producers.

The corals found here, like their modern day counterparts, were micropredators. One species was solitary but the rest are colonial. All of them cemented themselves to the substrate. Spongiomorphs and other sclerosponges are, again, a bone of contention. I have opted to classify them as suspension feeders. Both dendritic and platy growth morphologies are found here.

Most of the bivalves in this assemblage are cementing, epifaunal, suspension feeders. ?Myophoriopsis, however, was a mobile, infaunal detritus feeder. The gastropods, once again, a problem to classify because of the lack of functional and systematic work done on Triassic gastropods. They were probably either predators, grazers, filter feeders, or detritus feeders.

The echinoids found were either scavengers or raspers and the crinoids were suspension feeders. The echinoderms represented only a small (2%) portion of the entire biota. Table 3 lists the trophic groups and relationship to substrate for each taxa. Figure 30 illustrates the paleoecologic relationships of the fauna.
Figure 30. Concentric pie diagram illustrating the paleoecologic relations of the Mission Creek fauna. Format is the same as Figure 29.
Paleoenvironment

The Mission Creek fauna, especially the corals and calcareous algae indicate that the limestones were deposited in warm shallow water. The coral/spongiomorph thickets in the quarry are not extensive and are not ecologic reefs. They are best described as thickets or small patch reefs. The sediment which filtered in between the corals and spongiomorphs formed a mudstone and wackestone matrix indicative of relatively quiet water. Squires (1956) found evidence of coral colonies that had fallen over or been sedimented over and resumed growth. He inferred that this indicated strongly agitated water and a high sedimentation rate. There are a few occurrences of packstone and grainstone in the stratigraphic section, so a turbulent environment of deposition probably did exist at some intervals.

COMPARISON: The Martin Bridge Formation and Mission Creek limestone

The carbonate microfacies of the Martin Bridge Formation in Hells Canyon and the Mission Creek limestone indicate similar environments of deposition. Both units were deposited in shallow, warm water with a preponderance of lime mud and peloids in the original sediments. The Mission Creek limestone is limited in thickness and extent of outcrop compared with the Martin Bridge Formation. The Mission Creek limestone is also the more severely metamorphosed of the two. For these reasons the Martin Bridge Formation in Hells Canyon represents a wider array of depositional sub-environments than are found in the Mission Creek limestone.
The major difference between the Mission Creek limestone and the Martin Bridge Formation in Hells Canyon is in their faunal assemblages. The two localities have only ten fossil taxa in common, thus faunal similarity measures are understandably low, Sorenson similarity coefficient=.16, Simpson similarity index=34.5 (see section on faunal similarity below for more detailed explanations of these similarity measures). The diversity measures (see above sections on paleoecology of the localities) show that the Hells Canyon fauna, dominated by bivalves and gastropods, is much more diverse than the Mission Creek fauna, which is dominated by corals and spongiomorphs. Although these two faunal assemblages differ in composition their trophic structure was probably similar since both are dominated by suspension feeders (bivalves and spongiomorphs at Hells Canyon and spongiomorphs at Mission Creek). The most striking faunal difference between the two localities are the organic buildups which are so common at Mission Creek but nonexistent in Hells Canyon.

COMPARISON: Wrangellia and the Wallowa terrane

Stratigraphic and Time Correlations

The stratigraphic relations of upper Triassic limestones in the northwest Cordillera are illustrated in Figure 31. As already stated, the limestones in Hells Canyon are early Norian in age. This was based on the occurrence of the ammonite Tropiceltites columbianum which occurs in the kerri zone (Vallier, 1967; 1974). The type locality of the Martin Bridge in the southern Wallowa Mountains spans the Karnian/Norian
Figure 31. Chart showing the time- and biostratigraphic relations of upper Triassic limestones in the northwest Cordillera. The circle with a cross indicates the stratigraphic level of fossil localities from which the data in Table 4 were collected.
## Upper Triassic

<table>
<thead>
<tr>
<th>KARNIAN</th>
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<th>NORIAN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOWER</td>
<td>UPPER</td>
<td>LOWER</td>
<td>MIDDLE</td>
</tr>
<tr>
<td>UPPER</td>
<td></td>
<td>UPPER</td>
<td></td>
</tr>
</tbody>
</table>

- Nikolai Greenstone
- Chitistone L.S.
- Nizina L.S.
- McCarthy FM.

<table>
<thead>
<tr>
<th>Wrangel Mountains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver Island</td>
</tr>
<tr>
<td>Hells Canyon</td>
</tr>
<tr>
<td>N. Wallowa Mountains</td>
</tr>
<tr>
<td>S. Wallowa Mountains</td>
</tr>
<tr>
<td>Mission Creek</td>
</tr>
</tbody>
</table>

### Seven Devils Group

- Martin Bridge FM.

### Clover Creek FM.

- Martin Bridge FM.
- Hurwal FM.

### Martin Bridge FM.

- Molsonitic
- N of the gullies
- N of the gullies

### Mission Creek L.S.

- Scouchtopping
boundary (Grant-Mackie, written comm. 1985). In the northern Wallowa Mountains the sequence of Martin Bridge limestone was dated as Lower Norian (kerri zone) but may also span the Karnian/Norian boundary (Nolf, 1966). The Martin Bridge is overlain by the Hurwal formation, which was deposited during early Norian through the rest of the Late Triassic time, into the Jurassic (Nolf, 1966). The Wrangell Mountains have a very thick sequence of carbonates that are dated from late Karnian to late Norian (Jones and others, 1977). The carbonate units on Vancouver Island were interpreted to be different in age by different researchers. The Quatsino limestone, which directly overlies the volcanic Karmutsen Formation, was dated as late Karnian (Carlisle and Suzuki, 1974) or as latest Karnian to early or middle Norian (Jeletzky, 1970; 1976; Muller and others, 1974). The Parsons Bay Formation is, according to Carlisle and Suzuki (1974), dated as late Karnian through late Norian or as early or middle Norian through late Norian (Jeletzky, 1970; Muller and others, 1974). The Sutton Formation was correlated with the Parsons Bay and dated as late Norian, based on the presence of ammonites from the suessi zone (Silberling and Tozer, 1968). The Mission Creek limestone is also difficult to date. The only age diagnostic fossils from the locality are spondylospirid brachiopods reported by Cooper (1942). These fossils suggest an age of Norian to Rhaetian. This would make the Mission Creek limestone contemporaneous with the middle Hurwal Formation in the Wallowa Mountains.

The Chitistone and Nizina limestones in the Wrangell Mountains are the thickest carbonate sequence in the Wrangellia Terrane. All of the other upper Triassic carbonates attributed to this terrane (including
the carbonates in the Wallowa Terrane) were deposited during the span of
time in which the Chitistone and Nizina were laid down. These two units
make up more than 1000 m of dominantly shallow water limestone. The
carbonate rocks in Hells Canyon are similar to these units in the
occurrence of certain rock types and the conspicuous lack of fossils
except in specific beds.

I examined a number of carbonate thin sections from the Wrangell
Mountains (courtesy of Cathy Newton) and most fit into one of the 12
microfacies I delineated for the carbonates in Idaho and Oregon. One
major difference was that the Wrangell carbonates are much less
neomorphosed than those in Hells Canyon.

The lower part of the Chitistone Limestone indicates deposition in
intertidal and supratidal conditions. The supratidal deposits were then
inundated and are overlain by "low-energy restricted shallow-water shelf
deposition interspersed with intermittent high energy shoaling-water
deposition" (Armstrong and others, 1969). This brief description of the
Chitistone Limestone is very similar to the depositional environment
that I propose for the Martin Bridge Formation in Hells Canyon. The
Nizina Limestone, overlying the Chitistone, represents a drowning of the
shallow carbonate platform on which the Chitistone was deposited. Finally the carbonate platform was completely drowned and carbonate
deposition came to a halt and the dark fissile shales and bedded cherts
of the McCarthy Formation were deposited (Armstrong and others, 1969).
The Nizina Limestone and McCarthy Formation have no equivalents in Hells
Canyon. The Hurwal Formation in the Wallowa Mountains is time
correlative with the Upper Nizina limestone and the McCarthy Formation
Carbonate microfacies can represent conditions of deposition over a very limited area. For this reason correlation with microfacies over a great distance is not feasible. The similarity of facies types of the Chitistone Limestone and the Martin Bridge Formation are striking. Both units are known to have formed close to the Triassic paleoequator (Symons, 1971; Irving and Yole, 1972, Hillhouse, 1977; Hillhouse and others, 1982). Both were deposited atop Upper Triassic volcanic and volcanioclastic rocks although the volcanics are different in composition and original tectonic setting (Sarewitz, 1983). And finally both units contain similar carbonate rock types although correlation of specific sequences is not possible without a much more detailed petrographic study. The similarities suggest that deposition of the Chitistone Limestone and the Martin Bridge Formation occurred in very similar environments which may have been proximal to one another. Whether or not these carbonates existed on a contiguous carbonate shelf or platform is impossible to determine at this time.

Faunal Similarities

The similarity of two faunal assemblages can be measured using several methods. One of the more common indices is the Sorenson (1948) similarity coefficient:

\[
\frac{2C}{A + B}
\]

Where \(C\)=number of taxa the two assemblages share in common and \(A\) and \(B\)=
the total number of taxa in each of the two assemblages. Another index which is useful for evaluating the similarity of two assemblages with disparate sample sizes is the Simpson (1949) similarity index:

\[
\frac{100C}{N1}
\]

Where \(C\) = number of taxa in common and \(N1\) = the number of taxa in the more depauperate assemblage. Newton (1983) presented Simpson and Sorenson similarity values for the bivalve faunas from Hells Canyon, the Wrangell Mountains, and a number of other Upper Triassic localities from other displaced terranes in the northwest cordillera. She found that the highest bivalve similarity at the generic level occurred between Hells Canyon and the Wrangell Mountains (Sorenson similarity coefficient=0.65, Simpson coefficient=77). I also calculated combined bivalve, coelenterate, sclerosponge similarity values between Hells Canyon and the Wrangell Mountains: Sorenson=0.53, Simpson=57. These figures show a relatively high similarity but are not high enough to prove that the Wrangellia and Wallowa Terranes were once contiguous.

Stanley (in press) compiled similarity data on Upper Triassic coelenterates from the Wallowa Mountains, Hells Canyon, Mission Creek, Vancouver Island, and the Wrangell Mountains. He found very little similarity between the coelenterates from Hells Canyon and the Wrangell Mountains. His data for the occurrence of coelenterates in Hells Canyon was based on the report of Montanaro Gallitelli and others (1979). It appears that the USGS collection M2672, which was used in that study, was missing all of the spongiomorphs from the assemblage. After I
compiled my faunal list for Hells Canyon I was able to rework Stanley's similarity matrix using my coelenterate data along with that of Montanaro Gallitelli and others (1979). My faunal list indicated the presence of three species of coelenterates and two species of spongimorphs which were not reported in Montanaro Gallitelli and others (1979). The reworked Sorenson similarity matrix of Stanley (in press) is presented in Table 4. The highest coelenterate similarity occurs between the Mission Creek locality and the Sutton Formation on Vancouver Island. Both of these collection localities are dated as late Norian and these two sites each host small lensoidal coral thickets (Stanley, 1979) which are not present at any other Wrangellia locality. These two sites may have been more closely associated than any of the others in the Wrangellia Terrane. The coelenterate similarity is moderately high between Hells Canyon and the Wrangell Mountains implying that the two localities were at least close enough to facilitate the migration of pelagic coelenterate larvae.
Table 4
Combined coelenterate-sclerosponge similarity for various North American upper Triassic localities. Values were calculated using the Sorenson Similarity Coefficient which ranges from 0 to 1.00.

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<td>0.21</td>
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<td>Wrangell Mts.</td>
<td>--</td>
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<td>1.00</td>
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(Modified from Stanley, in press)

The Wallowa Mountains and Mission Creek have relatively low coelenterate similarity with Hells Canyon. The Mission Creek fauna, as discussed above, is very different from the Hells Canyon fauna. In the case of the Wallowa Mountains the difference in coral fauna may be due to a different environment of deposition. The Martin Bridge Formation in the southern Wallowa Mountains contains both deep and shallow water carbonate rocks. A deeper water coral fauna would differ radically from a shallow water assemblage. Also there may be a sampling bias when dealing with the Wallowa Mountains since very little silicified fossil material is found there.

The appearance of coral framework structures, in rocks that are apparently younger than the Martin Bridge Formation or the Chitistone and Nizina limestones, may be related to the acquisition of algal symbionts (zooxanthellae) by scleractinian corals. Extensive ecologic coral reefs are not found until the Rhaetian (=late Norian of North America) stage of the uppermost Triassic in Europe (Wilson, 1975). Stanley (1981) postulated that the advent of coral framework structures...
depended on the development of a symbiotic relationship between corals and zooxanthellae sometime during the Upper Triassic. Most modern shallow water corals possess zooxanthellae which speed up the precipitation of calcium carbonate by the corals and thus facilitate the production of framework structures and the ability to keep pace with sea level changes. This development had apparently not occurred before upper Karnian through middle Norian times when the limestones in Hells Canyon, the Wallow Mountains, and the Wrangell Mountains were being deposited. Fluegel and Stanley (1984) propose that there was a major changeover in reef faunas between Karnian and Norian times. The number of corals increases from the Karnian on. The Vancouver Island and Mission Creek faunas may show the beginning of a trend toward the growth of large framework corals, aided by algal symbionts.

CONCLUSIONS

Table 5 summarizes the major stratigraphic, faunal, and paleomagnetic evidence from the Wallowa and Wrangellia Terranes. Previous to this study other workers had concluded that the Seven Devils Group represented a volcanic arc which formed at low latitudes (Brooks and Vallier, 1978; Sarewitz, 1983; Hillhouse and others, 1982), while the volcanics of the Wrangellia Terrane formed at a spreading center at a similar low latitude (Jones and others, 1977, Hillhouse, 1977).

The mainly suspension feeding bivalve fauna from Hells Canyon was interpreted to indicate a warm, shallow water paleoenvironment (Newton, 1983; in press). The rest of the fauna is also dominated by suspension
Table 5. Chart comparing the stratigraphic, faunal, and paleomagnetic data from localities in the Wrangellia and Wallowa terranes.
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<td>Largely Subaqueous Tholeiitic Basalts</td>
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<td><strong>Dominant Trophic Groups and Taxa</strong></td>
<td>Detritus Feeding Vagrant-epifaunal Gastropods, Bivalves</td>
<td>Micropredator, Suspension Feeding Epifaunal Bivalves, Corals</td>
<td>Suspension Feeding Attached Epifaunal Bivalves, Spongiomorphs</td>
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<td>Suspension Feeding, Micropredator Attached Epifaunal Spongiomorphs, Corals</td>
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<td><strong>Triassic Paleomagnetic Evidence</strong></td>
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<td>Karmutsen Fm. 18° + 6° N or S of Equator (Yale and Irving, 1980)</td>
<td>Wild Sheep Creek Fm. 18° + 4° N or S of Equator (Hillhouse and others, 1982)</td>
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feeders such as spongiomorphs, brachiopods, sponges, and crinoids. The corals formed small, encrusting, cerioid or meandroid colonies. They did not form reefs or any appreciable framework structures. The bivalves, coelenterates, and spongiomorphs of the Wrangellia and Wallowa Terranes are similar but not sufficiently so to require that the terranes were once continuous.

The existence of a thick carbonate unit, such as the Martin Bridge Formation in Hells Canyon, implies a warm water setting for their deposition. The carbonate rock types indicate that deposition at the base of the stratigraphic section occurred supratidally. These supratidal rocks are overlain by shallow water "platform"-type carbonates which were probably deposited within fairweather wave base and were never below storm wave base. The presence of supratidal deposits and intercalated volcanoclastics (Vallier, 1967; 1976) at the base of the section indicates that the underlying Doyle Creek Formation was subaerially exposed at that time. The relative lack of terrigenous material in the carbonates, however, suggests that there was no terrigenous source rocks during the deposition of most of the carbonate unit. The entire sequence of carbonates in Hells Canyon indicates that deposition continually kept up with the rate of subsidence but the top of this unit is an erosional unconformity. At other localities the Martin Bridge Formation is overlain by basinal and turbiditic sediments indicating that carbonate deposition was curtailed and eventually ceased. The carbonate sequence in the Wrangell Mountains is similar to the Martin Bridge Formation; however, it is much thicker and contains deepwater carbonates (Nizina Ls.) that have no time-stratigraphic
equivalent in the Wallowa Terrane. Correlation of these sequences is questionable.

The Martin Bridge Formation in Hells Canyon has undergone a great deal of diagenesis, including: compaction and dewatering, aggrading neomorphism, pressure solution, cementation with sparry calcite, dolomitization, silicification, folding and fracturing, and further pressure solution and cementation.

The Mission Creek limestone near Lewiston, Idaho remains enigmatic. It is younger than the Martin Bridge Formation and is more similar in age and coral fauna to the Sutton Formation of Vancouver Island (Figure 31). A thin limestone unit of a similar age is located in the middle Hurwal Formation in the northern Wallowa Mountains and it may be a lateral equivalent of the Mission Creek limestone. The metamorphism which this unit has undergone supports the idea that it is a roof pendant of the Idaho Batholith. The rock types and the biota at Mission Creek also indicates deposition in relatively shallow, warm water. As with the limestones in Hells Canyon no true ecologic reefs are present at the Mission Creek locality. However, a number of small thickets made up primarily of corals and/or spongiomorphs are present at this locality. These are some of the earliest organic framework buildups in Mesozoic rocks of North America.

The data gathered during this study do not unequivocally establish that the Wallowa Terrane and Wrangellia were or were not physically joined at any time in their history. The striking similarities in rock types, fauna, paleomagnetic signatures, and tectonic histories implies that they were coeval and proximal to one another if they were not at
any time actually contiguous. Since it cannot be proven that the Wrangellia and Wallowa Terranes were once contiguous then the correlation of these two terranes must be questioned.
REFERENCES CITED


Brown, J.S. (1943) Suggested use of the word microfacies. Econ. Geol., 38: 325.


Fluegel, E. (1972) Mikrofazielle Untersuchungen in der Alpinen Triassik-

Fluegel, E. (1981) Paleoecology and facies of upper Triassic reefs in


Fluegel, E. and Stanley Jr., G.D. (1984) Reorganization, development,
and evolution of post-Permian reefs and reef organisms: 175-186.
In Oliver, W.A. and others (eds.) Fourth International Symposium
on Fossil Cnidaria, Palaeontographica Americana No. 54.


Coral Reefs, 1: 29-34.

Guilluly, J., Reed, J.C., and Park, C.F. (1933) Some mining districts of


33-70. In Howell, D.G. and Mcdougall, K.A. (eds.) "Mesozoic Pale-
eogeography of the Western United States." SEPM, Los Angeles, CA.

1078: 345p.

Hardie, L.A. and Ginsburg, R.N. (1977) Layering: The origin and envi-
ronmental significance of lamination in thin bedding: 50-123.
In Hardie, L.A. (ed.) "Sedimentation on Modern Carbonate Tidal Flats
of Northwest Andros Island, Bahamas." Johns Hopkins University


Newton, C.R. (1983b) Paleozoogeographic affinities of Norian bivalves

Newton, C.R. (in press) Late Triassic bivalves of the Martin Bridge Formation, Hells Canyon, Oregon: Taphonomy, Paleontology, Paleoecology, Paleozoogeography. USGS Prof. Paper


Sorensen, T. (1948) A method of establishing groups of equal amplitude
in plant society based on similarity of species content.


J. of Paleo., 38: 904-915.

Stanley, Jr., G.D. (1979) Paleoecology, structure, and distribution of
Triassic coral buildups in western North America. U. of Kansas


Stanley Jr., G.D. (1982) Triassic carbonate development and reef-
building in western North America. Geol. Rdsch., 71:

Stanley Jr., G.D. (in press) Upper Triassic coelenterate faunas of
western Idaho and northeastern Oregon: Implications for biostra­
tigraphy and Paleogeography. USGS Prof. Paper

Studies in Geology 7.


Symons, D.T.A. (1971) Paleomagnetic notes on the Karmutsen basalts,


Wilson, J.L. (1975) "Carbonate Facies in Geologic History." Springer-Verlag, NY.


APPENDIX I

MEASURED SECTIONS
MEASURED SECTION HC

Hells Canyon Road
THICKNESS IN METERS
SAMPLE AND THIN SECTION #

ROCK COLUMN SHOWING THICKNESS OF BEDS

GRAIN CONSTITUENTS AND FABRICS
MEASURED SECTION DG

Dry Gulch
Exact stratigraphic distance unknown

Exact stratigraphic distance unknown

Exact stratigraphic distance unknown
MEASURED SECTION AC

Allison Creek
MEASURED SECTION TS

Top Section
APPENDIX II

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APPENDIX III

Paleontologic Plates
PLATE I
Hells Canyon Fauna

A. *Palaeastrea incrassata*. Scale in cm.
B. *Cyathoeoenia aff. carinata*. Scale in cm.
C. *Spongiomorpha ramosa*. Scale in cm.
D. *Margarastrea cf. pulchra*. Scale in cm.
E. *Thaumastoceolia cf. cassiana*. Scale in cm.
F. *Spondylosprira sp*. Small divisions on scale are mm.
G. *Terebraduloid A*. Small divisions on scale are mm.
PLATE II
Hells Canyon Fauna

A. Permorphidae indet. 1.5X
B. Lopha sp. 1.5X
C. "Septocardia" 2.5X
D. Trigonid B. 2.0X
E. Bivalve U. 1.75X
F. Antiquilima sp. 1. 1.75X
G. Pectinid A. 1.5X
H. Tutcheria sp. 2.5X
I. Gervillaria sp. 2.0X
PLATE III
Mission Creek Fauna

A. Field photograph of recrystallized coral or spongiomorph thicket. Scale is in decimeters.

B. Zygopleridae A. Scale in mm.

C. Disticophyllia cf. norica. Scale in mm.

D. Tabulzoan. Scale in mm.