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Title: GEOLOGY OF THE FACEY ROCK AREA, ETNA QUADRANGLE, CALIFORNIA

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The Facey Rock area includes approximately 4 square miles in the Eastern Paleozoic Subprovince of the Klamath Mountains north of Callahan, California. The structurally complex terrain is composed of sparcely fossiliferous Silurian graywacke, sparsely fossiliferous Ordovician limestone, Devonian to Cretaceous chloritic quartzite and minor gabbroic and dioritic intrusive rocks.

The two limestone lithologies recognized in the area are the Late Ordovician Platy Limestone Member and the Middle Ordovician Massive Limestone Member of the Facey Rock Limestone. These are interpreted as shallow water carbonate bank and deeper water carbonate deposits respectively. Both contain minor amounts of primary bedded chert. The graywacke is interpreted as a proximal turbidite. The chloritic quartzite is believed to be an upper plate remnant of the Devonian to Cretaceous, regional Mallethead Thrust.

Several large, recent landslides are located in the vicinity of Facey Rock. Portions of the landslide debris along with talus deposits have been cemented into a loose breccia by groundwater supersaturated with calcium carbonate.

Thrust faults separate the two limestone members from each other and from the underlying graywacke. They are responsible for the successively older, upward sequence of units observed at Facey Rock. These thrusts are considered subsidiary to the regional Mallethead Thrust. There are numerous high angle faults in the area postdating the thrusts.

Geology of the Facey Rock Area
Etna Quadrangle, California

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GEOLOGY OF THE FACEY ROCK AREA, ETNA QUADRANGLE, CALIFORNIA

INTRODUCTION

Location and Accessibility

The Facey Rock area is situated in the Klamath Mountains of Northern California. The map area is centrally located along the eastern margin of the Etna Quadrangle in Siskiyou County (see Figures 1 and 2). The area is a segment of a large ridge that begins about 6 miles to the north-northeast, near the upper reaches of McConaughy Gulch, and is terminated about 5 miles to the south near Callahan. This ridge, known as Hayden Ridge to the south of Facey Rock, is incised by a number of gulches including Facey Gulch, Trail Gulch, Horseshoe Gulch, and Lodgepole Gulch. The area, which encompasses approximately 4 square miles, includes all of sections 20 and 21 along with portions of sections 16, 17, 28, and 29, Township 41 North, Range 8 West. Portions of the area are federally owned and administrated by the Bureau of Land Management. The remainder of the area is privately owned.

The southern portion of the area is readily accessible by 4-wheel vehicle using either of two jeep trails that ascend the ridge from ranches in Noyes Valley and Facey Gulch, on the east and west sides respectively. Good gravel and paved county roads (unmarked) connect

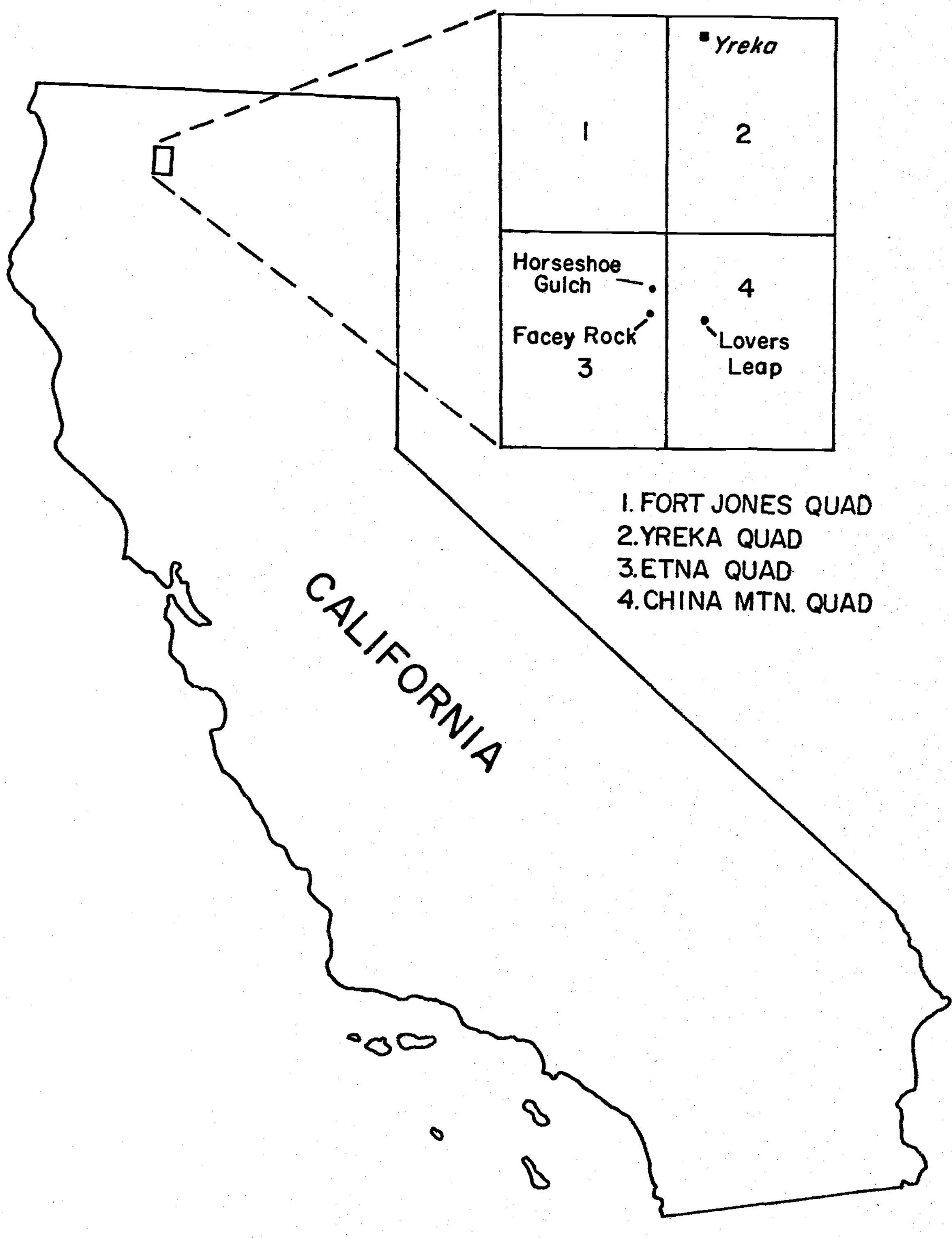

Figure 1. Index map of California showing location of Facey Rock and vicinity

Figure 2. The west side of Facey Rock as viewed from across the Scott Valley. The cliffs are composed of the Massive Limestone Member of the Facey Rock Limestone

these ranches with Callahan on California Route 3 south of Yreka. The rest of the area is accessible only on foot.

Purpose and Methods of Investigation

The purpose of this investigation was to ascertain the structure and stratigraphic relationships of the rocks in the area and determine their depositional environments. In addition, samples were to be taken of the Facey Rock Limestone to establish the age of this previously undated unit.

Field work began in late June 1972 and continued until mid-September. There was an additional week of field work in the fall of 1972 and another in the spring of 1973. Geologic mapping was done on several copies of the U. S. Geological Survey Etna Quadrangle topographic map enlarged by hand to scales ranging from 10 to 24 inches per mile. Aerial photographs were used to a limited extent. Data were consolidated on a photographically enlarged tracing of the Etna Quadrangle map.

The high altitude and age of the aerial photographs made them very difficult to use for determining locations. The steep slopes, dense vegetation, and small number of useable landmarks made location on topographic sheets by conventional triangulation difficult. A sensitive altimeter was used extensively, along with a Brunton Compass to establish locations on topographic maps. Check points were established throughout the area to reduce the error produced by drift in barometric pressure. By adjusting the altimeter several times each day and compensating for drift, as observed during stationary periods, error could usually be held to within 25 feet of altitude. In addition, a hand lens and dilute hydrochloric acid were used for examination of rocks in the field.

Approximately 1200 pounds of rock samples, mostly limestone, were collected for laboratory studies. Forty thin sections were made from among these samples for petrographic examination. After the carbonate fraction was dissolved in concentrated hydrochloric acid, the weight percent and general character of the insoluble residue were determined for 6 samples of 50 to 100 grams each. Approximately 500 pounds of limestone samples were broken up and sent to Dr. Carl Rexroad of the Indiana Geological Survey, who dissolved them in concentrated acetic acid and assigned dates on the basis of conodonts found in the insoluble residues. Finally, a number of samples were slabbed and stained for calcite, dolomite, and feldspar as seemed advantageous.

Topography, Vegetation and Drainage

The north end of Facey Rock has an elevation of 5476 feet (1669 m) which is the highest point in the map area. The lowest point in the area mapped is in the northwest corner where the elevation is slightly below 3200 feet (975 m). This gives the area approximately 2300 feet (701 m) of relief.

The climate of the area is not severe. Temperatures below 0 deg. F. and above 100 deg. F. are uncommon. The average annual precipitation is about 22 inches (56 cm) in the form of rain and snow. The seasons are well defined and approximately 80 percent of the precipitation occurs in the fall and winter months (Mack, 1955, p. 9-12).

The vegetation is characteristic of a semi-arid climate including sage, manzanita, scrub oak and western juniper. Southerly slopes are generally sparsely vegetated by grass and low brush. Northerly slopes are usually covered by either scrub trees and dense brush or are heavily timbered with coniferous trees including Ponderosa Pine.

Most of the streams draining Facey Rock are dry during the summer months. The "Hazel Baker Spring" on the west slope of Facey Rock is the only reliable source of a cool drink on a hot day.

Exposures

In general the exposures are good. The best ones are found along ridge crests, in steep gullies and on southerly slopes. Dense brush and landslides conceal outcrops locally. Some of the contacts in the area are obscured by talus from the massive limestone cliffs.

Previous Work

Mack (1955) published a geologic map of the Scott Valley and adjacent mountains at a scale of 1:62, 500. The Facey Rock area was mapped as a single formation, the Silurian Chanchelulla(?). In 1959 Wells and Walker published a map of the geology between the Scott and Shasta Valleys, south of Yreka, in Siskiyou County at a scale of 1:312, 000. The Facey Rock area was shown to contain one formation, the Ordovician Duzel, although a minor marble member was outlined. In 1962 Romey (in Davis and others) published a map of most of the Etna Quadrangle, including the Facey Rock area at a scale of 1:50, 000. It showed the Facey Rock Limestone as a separate unit of unknown age thrust over the underlying Ordovician Duzel Formation.

STRATIGRAPHY

Regional Stratigraphy

Facey Rock is located within Irwin's (1960) Eastern Paleozoic Subprovince of the Klamath Mountains Province (Figure 3). This is a region dominated by Paleozoic geosynclinal rocks including graywackes, mudstones, cherts, greenstones, limestones and low rank meta-sediments. The rocks of the Eastern Paleozoic Subprovince are separated from those of the Central Metamorphic Subprovince, to the west, by a thin band of ultramafic units. Tertiary and younger volcanic rocks overlie the Eastern Paleozoic Subprovince lithologies to the east.

Local Stratigraphy

Four major stratigraphic units are described in this study (Figure 4). The oldest two are the Massive and Platy Limestone Members of the Facey Rock Limestone of Middle and Late Ordovician age respectively. Next oldest is Unit A, a Silurian calcareous wacke. The youngest of the four is a chloritic quartzite of Devonian to Cretaceous age, possibly belonging to the Stuart Fork Formation. None of these units are in depositional contact with each other. Presumably, the regional Mallethead Thrust (Devonian to Cretaceous) separates the Stuart Fork(?) rocks, structurally on top, from the

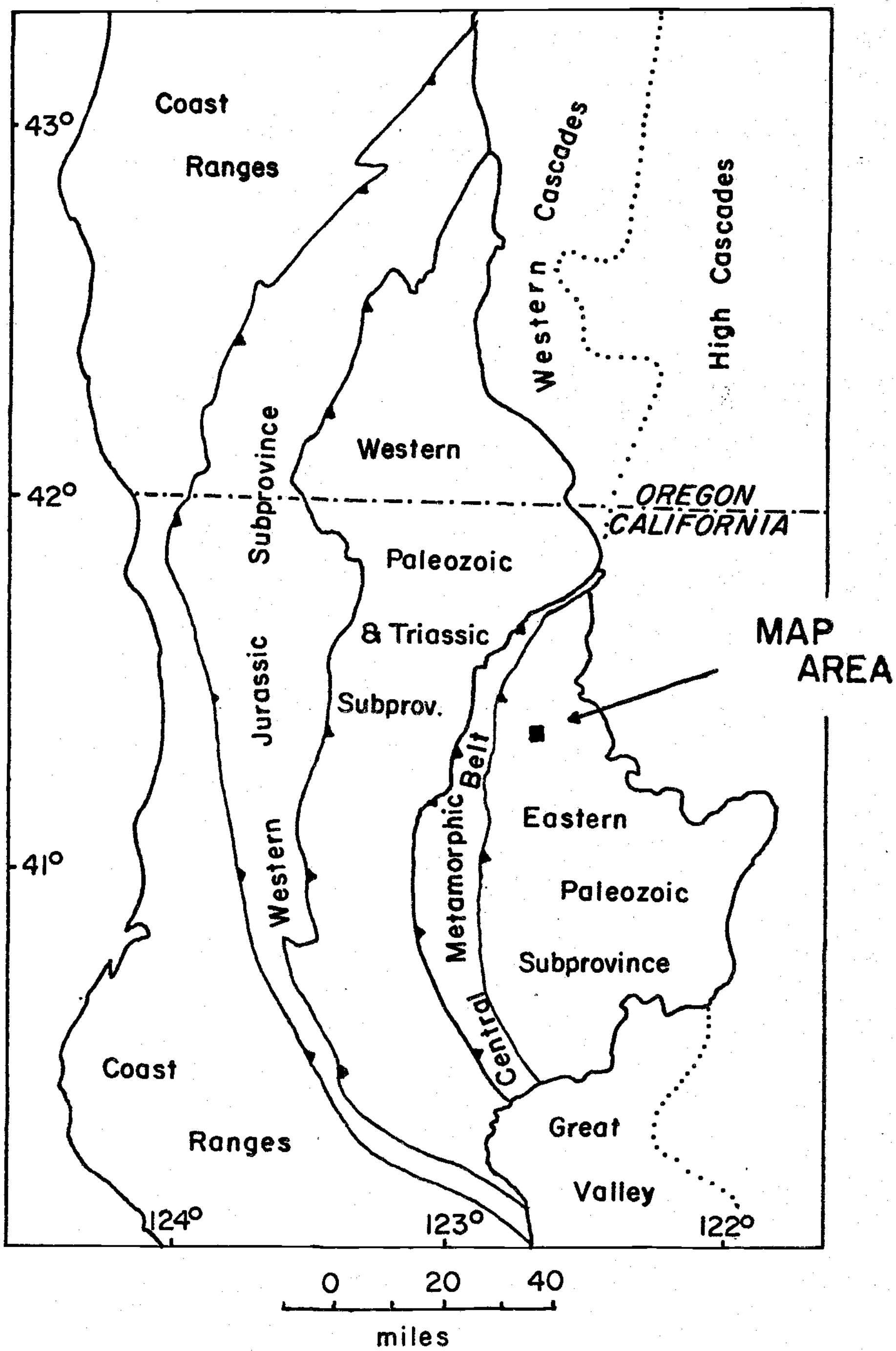

Figure 3. Index map showing study area, subprovinces of Klamath Mountains and, adjoining provinces (after Irwin, 1966)

Stuart Fork Formation(?) (Devonian to Cretaceous)	
-----?-----?-----?-----?---	Inferred position of the Regional Mallethead Thrust
Massive Limestone Member	
....	Present Erosional Surface
Facey Rock Limestone (Middle Ordovician)	
----------------------------	Subsidiary Thrust
Platy Limestone Member Facey Rock Limestone (Late Ordovician)	
----------------------------	Subsidiary Thrust
Unit A (Silurian)	

Figure 4. Structural relationship of the major stratigraphic units described in this study

underlying massive limestone, although the contact has been eroded away in the map area. Thrusts between the two limestone members and Unit A are responsible for the successively older, upward sequence of these 3 units in the map area. These thrusts are believed subsidiary to the Mallethead Thrust.

Unit A (Calcareous Wacke)

Distribution

Unit A surrounds the Facey Rock Limestone on all but the southern end of its exposure (see Plate I). In the eastern halves of sections 21 and 28 it is bounded by quartzites of the Stuart Fork Formation(?). To the south, in the west-central portion of section 29, it is bounded by the Callahan Chert. The wacke extends beyond the map area to the west and north.

Lithology

A weathered surface of Unit A, a calcareous wacke, is usually iron stained to a moderate orange-brown (10YR 6/4) color. There is commonly a pinkish hue visible along weathered projections of the rock. Fresh surfaces have a light gray (N7) color.

This wacke ranges from a siltstone to a granule conglomerate in which most of the clasts appear to be chert grains. It is an extremely hard rock which may or may not effervesce with the application of dilute hydrochloric acid, depending on the locality sampled. In places this rock has been badly sheared and then re-cemented by calcite.

Graded beds 1 to 3 cm (.4-1.2 inches) in thickness are common in this unit, particularly in coarser grained samples. Large blocks of massive sandstone with the same composition are occasionally seen suspended in contorted, thin bedded zones of this unit. These are presumed to be blocks of sandstone which have tumbled down steep submarine slopes. Similar occurrences have been reported in the Ouachita Mountains of Oklahoma and Arkansas (Morris, 1971). Possible flute casts and well defined load casts were found in the unit. Current crossbeds up to about 8 cm (3 inches) in thickness were found at one locality to the west of Facey Rock.

Thin sections reveal that this rock has no porosity. Calcite cement, generally less than 1 percent of the rock, is confined to a few healed fractures. The rock is bound together by matrix which in most samples constitutes about 50 percent of the lithology. The framework of this wacke is disrupted in most cases. A few of the coarse grained versions of this rock do, however, show grain support.

The major constituents of the framework are (see Table 1) chert and quartz grains. Some of the chert grains show circular

Table 1. Modal analysis (500 points) of Unit A (calcareous wacke)

Constituent	Percent of each thin section RWP209	RWP301
Chert	32.4	9.0
Quartz	15.4	23.0
Lithics	3.0	3.2
Opaques	1.6	1.4
Microcline	1.0	Tr.
Plagioclase	Tr.	---
Muscovite	Tr.	Tr.
Detrital Calcite	0.4	0.4
Calcite Cement	---	0.6
Matrix	46.2	62.4
Totals	100.0	100.0

Locality RWP209: SW 1/4 NE 1/4 NW 1/4 sec. 29

Locality RWP301: SE 1/4 SE 1/4 SW 1/4 sec. 16

ghosts with rims, about .2 mm (.008 inches) in diameter, which are suspected to be poorly preserved radiolaria. Minor constituents include opaque minerals, lithics, detrital calcite, and potassium feldspar. The opaques include magnetite and hematite. Some of the lithics appear to be fine grained volcanics. Many of the calcite grains are clearly biogenic. Traces of plagioclase (of unknown composition) and detrital muscovite were also observed.

The matrix is made up primarily of smaller fragments of quartz and chert suspended in unknown clay(s). A small amount of secondary chlorite is visible under high magnification.

Texturally, this rock is very immature. Mineralogically, it is submature to mature, probably reflecting the source(s) more than the amount of transport. The sorting of this rock is very poor and there is a variation in the degree of rounding. Individual grains range from angular to well rounded, but the average and mode are subangular, as determined from Pettijohn's (1957) scale. The author refers to this rock as a calcareous wacke to summarize the most common characteristics of the lithology. At a number of locations the matrix exceeds 50 percent making it a sandy siltstone or a sandy mudstone. By the classification of Williams, Turner, and Gilbert (1954) this rock would be termed a quartz wacke. Pettijohn (in Huang, 1962, p. 250) would classify this rock as a subgraywacke and Krynine's (1948) term for it would be a low rank graywacke.

There are indications of multiple sources for the clastics in this rock. Some of the quartz grains have high sphericity and are well rounded making it very probable that they have been recycled one or more times. This is substantiated by the quartz overgrowths observed on a few of these grains. On the other hand, many of the quartz and chert grains are very angular and irregular in shape indicating that they have not undergone much transport and were probably not derived from sediments. A random sample of 50 quartz grains reveals that nearly all contain irregular (dust) inclusions, about 80 percent contain acicular inclusions (needles), only about 20 percent contain regular inclusions (relatively large, equant crystals) and almost none contain globular inclusions (vacuoles of gas or liquid). According to Keller and Littlefield (1950), a dominance of irregular and acicular inclusions in quartz grains is indicative of a plutonic source. Thus, the majority of the quartz grains in this rock were probably derived from such a source, although many have undergone at least one sedimentary cycle prior to being incorporated in this rock. A few of the quartz grains are clearly metamorphic. These are polycrystalline grains with crenulate borders between individual crystals and in many cases a fabric of flattened mineral grains.

The cherts in this unit may have been derived from those cherts observed in the Facey Rock Limestone (described later). The seemingly diverse origin of the clasts and the fact that very little is known of the igneous and metamorphic history in the early Paleozoic of this region make it unrealistic to speculate further as to the source of this sediment.

Age and Structural Relationships

The lower contact of Unit A occurs below an elevation of 3200 feet and consequently has no surface expression within the map area. The contact between Unit A and the Facey Rock Limestone is buried in talus from the massive limestone cliffs and from the less resistant platy limestone. There is no exposure of this contact, which had to be mapped from the highest occurrence in the float of calcareous wacke.

Potter (pers. comm.) has dated Unit A as Silurian (Late Llandovery or younger) in age on the basis of stratigraphic relationships in the Payton Ranch area, about 15 miles northeast. Elsewhere, Unit A is overlain by fossiliferous units of late Silurian (Ludlow) age. The Facey Rock Limestone has been established to be of Middle and Late Ordovician age (Appendix III). This inverted stratigraphic sequence is believed to be the result of a thrust fault between Unit A and the overlying limestone.

In the eastern portion of the map area Unit A is in fault contact with a chloritic quartzite that may be part of the Stuart Fork Formation. These faults dip to the east at about 45 degrees judging from the trace of the contact on the topography. Romey (1962) mentions the presence of a fault breccia at the base of the Facey Rock Limestone. There is a very prominent breccia at several locations near the base of the limestone, on the west side of Facey Rock. This breccia is believed to be the one which Romey used as evidence for the thrust fault which he first hypothesized. Careful study reveals that this breccia has a non-tectonic origin. Evidence for this will be cited in a later section. Therefore the author agrees with Romey's interpretation of a fault between these two units, but not with the evidence cited for such a fault.

Thickness

There is no reliable stratigraphic section of Unit A within the boundaries of this study area. It is believed that only a portion of the total stratigraphic thickness is exposed in the area mapped. Observations within the map area suggest a minimum thickness of 1000 feet (305 m). In actuality the total thickness may be much greater.

Environmental Interpretation

The Unit A is known to be marine from fossil evidence and seems to have some of the attributes of a proximal, deep water turbidite. Kuenen (1964) inventoried features one could expect to find in ancient turbidite formations. Among these are graded bedding, convolute laminations, current ripple laminations, and sole markings. All of these features can be found in the unnamed calcareous wacke. Kuenen comments that a size distribution ranging from fine silt to medium pebbles and a scarcity of fossil material are common although not diagnostic features of turbidites. This calcareous wacke ranges from fine silt to granule size and contains only occasional small fragments of benthonic organisms.

Kuenen states that the absence of shallow water features such as oscillation ripple marks, winnowed sands, channels, mudcracks, etc., are important requirements for the interpretation of a deep water turbidite. No evidence of shallow water deposition is found in Unit A.

In referring to Unit A as a proximal turbidite, no implication of continental origin is intended. A few recycled grains suggest a continental source, but most of these clastics could have originated in an island environment. Regardless of the paleogeography the author visualizes deposition on a steep submarine slope, below wave base. Turbidity currents, slumps, and rock falls may all have contributed to the depositional process.

Facey Rock Limestone

Romey (in Davis and others, 1962, p. 949) gave the name Facey Rock Limestone to a series of cliff-forming limestone bodies capping high points north of Facey Gulch (locally known as Facey Rock), Limekiln Gulch and Messner Gulch. This study examines the largest mass of this limestone, located in the northwest corner of section 28, the northeast corner of section 29, the southeast corner of section 20 and the western 1/3 of section 21. Also examined were two outliers of this limestone, one in SE 1/4 SW 1/4 sec. 17 and the other in SE 1/4 SW 1/4 sec. 21.

Platy Limestone Member

Distribution and Type Locality

The exposure of the Platy Limestone Member of the Facey Rock Limestone is nearly continuous on the north and west sides of Facey Rock, rimming the Massive Limestone Member (see Plate I). This exposure is covered by landslides in a few places and pinches out on the very southern end of the west side. There is no exposure of the platy limestone on the south end of Facey Rock except for one, too small to be shown on the map, near the bottom of Facey Gulch in the SE 1/4 SE 1/4 NW 1/4 sec. 29. On the east side of Facey Rock there is a small sliver of this unit along the base of the limestone exposure in SW 1/4 SW 1/4 sec. 21 and in the NW 1/4 NW 1/4 sec. 28 The limestone outlier in the SE 1/4 SW 1/4 sec. 21 is also an exposure of this unit. The type locality of the Platy Limestone Member of the

Facey Rock Limestone is designated as the most southerly exposure of this unit on the west side of Facey Rock, located in the SW 1/4 NW 1/4 NE 1/4 sec. 29.

Lithology

The Platy Limestone Member of the Facey Rock Limestone has a light gray (N7), light olive gray (5Y 6/1), yellowish gray (5Y 7/2) or even light brownish gray (5YR 6/1) color on a weathered surface. A fresh surface is usually medium dark gray (N4), medium olive gray (5Y 5/1) or brownish gray (5YR 4/1) color. This unit has low resistance to weathering, making it a good slope former. Outcrops are generally small and low-lying. This limestone has a platy or flaggy fracture, splitting along thin argillaceous layers. Individual plates do not usually exceed 5 cm (2 inches) in thickness. These plates are very resonant when struck with a hammer.

The surfaces of these plates are criss-crossed with fractures. Most of them are very fine, but a few are 1 cm (.4 inches) or more in thickness. These fractures have been filled with sparry calcite. Generally, this calcite filling has a dark gray or black color, although white calcite is a common filling as well.

This limestone is thinly bedded or laminated, depending upon the locality sampled. Thin lamina of argillaceous material ranging from a fraction of a millimeter (a small fraction of an inch) to 4 or

5 mm (.16 to .20 inches) in thickness separate thicker limestone strata up to 5 cm (2 inches) in thickness. On a fresh surface these laminations may not be apparent. Differential weathering on surfaces that cut the bedding reveal millimeter laminations, which are the most common variety.

Most of this limestone member is very fine grained. There are one or two anomalous beds, 15 to 25 cm (6 to 10 inches) in thickness, of a dark, highly oolitic limestone contained within it. Intraclasts and coated grains up to 1.5 mm (.06 inches) in diameter dominate. These grains are frequently deformed against each other in a tightly packed configuration. There is an abundance of yellowish clay material, containing blebs of hematite, in the interstices. Most of the allochems are composed of sparite and there is some micrite with the clay in the interstices.

Commonly, the rocks of the Platy Limestone Member are very disturbed. Significant differences in the attitudes of outcrops over short distances and highly contorted layers within individual outcrops are the rule. The deformation is believed to be the result of faulting, although examination of the rock fabric is inconclusive as to the type of deformation.

Interbedded with the limestone in this unit are two or three layers or lenses of well bedded chert. These cherts are believed to average 5 to 15 feet (1.5 to 4.5 m) in thickness. Individual beds

2 to 15 cm (1 to 6 inches) thick weather out as coherent units. On a smaller scale, sharp, continuous microlaminations are visible at some localities. Outcrops of these cherts are common, but less abundant than those of the associated limestone. These outcrops are generally badly fractured and low-lying, sticking up through the platy limestone talus at a number of locations. The cherts are often badly deformed, similar to nearby limestone strata. This chert occurs in various shades of green, gray and brown on a fresh surface. It is difficult to obtain a fresh surface except by sawing, because of the extensive fracturing and subsequent leaching along these fractures. Weathered surfaces are commonly iron stained.

Four features of the platy limestone that are visible in thin section are clay laminations, occasional lamina containing ghosts of allochems, microstylolites and a few small grains of plagioclase feldspar. The clay laminations are a common occurrence. Individual lamina are usually .2 mm (.008 inches) or less in thickness. Thin section examination of thicker laminations observed in outcrop, usually reveals that these are closely spaced multiple laminations. The lamina containing ghosts of allochems are widely spaced, and are composed mostly of coated grains with a maximum diameter of about 1.5 mm (.06 inches). The microstylolites are common. There is frequently a film of clay concentrated along these solution surfaces, highlighting them. Where microstylolites intersect fractures the fractures are, in most cases, terminated indicating that solution post-dates fracturing. The few grains of plagioclase present are badly corroded. From the absence of other minerals, it is suspected that these are authigenic grains reverting to calcite.

The significant amount of clay in this limestone, along with small grain size, suggests that this rock was originally a micrite which has undergone considerable recrystallization. The platy limestone ranges in grain size from micrite to pseudospar. The average grain size is 0.015 to 0.020 mm (.0006 to .0007 inches), a medium microspar. These grains are fairly equant. There is a variation in grain size which sometimes, but not always, appears to be related to the bedding. This may be related to the argillaceous content as described by Bausch (1968).

Insoluble residues of the average platy limestone lithology (Appendix I) are a medium gray (N5) color. These residues are a fine powder. There is a trace of iron stained material scattered through them. Thin plates of silica, believed to be fracture fillings are a common occurrence. The organic content (Appendix II) is generally only a fraction of one percent. This is lower than might reasonably be expected from the dark color, which is apparently due to the clay content.

Portions of the platy limestone adjacent to the cherts have been partially replaced by silica creating a transition series. The best example of this is at locality 116, just below the contact with the Massive Limestone Member in NW 1/4 SW 1/4 NW 1/4 sec. 21. This silica is finely disseminated and does not appear to be filling porosity. Some layers are more silica rich than others perhaps owing to a variation in permeability or primary silica content.

Age and Structural Relationships

Ordovician conodonts were extracted from one of the well preserved, highly oolitic layers mentioned earlier. These came from locality 066 on the east side of Facey Rock in SE 1/4 SW 1/4 SW 1/4 of sec. 21. Dr. Carl Rexroad, who made the identifications, stated that in his opinion this sample is of late Ordovician age.

Age relationships, extreme deformation and a structural discontinuity (Figure 11) with the older Massive Limestone Member above suggest thrust contacts both above and below this member. As a result of the thrust between the limestone members the platy limestone has been pinched out along much of the east side of Facey Rock.

Thickness

An accurate determination of the thickness of this unit is not possible because of its poor exposure and extremely contorted condition. The exposure on the west side of Facey Rock indicates that the thickness of this unit almost certainly does not exceed 500 feet (150 m) and may be considerably less.

Environmental Interpretation

In the opinion of the author this limestone represents a deeper-water facies. The overwhelming abundance of micrite or micrite recrystallized to microspar and significant clay content in this rock point to low energy conditions. Such conditions are not restricted to deep water, but they are a common occurrence in it. The millimeter laminations observed in this unit are suggestive of a very slow sedimentation rate, crowding together the argillaceous layers which record such extraordinary sedimentary events as flooding on a distant landmass or violent storms.

Concerted efforts to discover fossil remains or evidence of bioturbation were fruitless. Cherts, alone are not positive proof of a deeper water environment as demonstrated in the following section on the Massive Limestone Member. Nevertheless, in the absence of conflicting evidence, cherts are most commonly associated with deeper water conditions. This may be the case with the Platy Limestone Member. If this unit were a deeper-water limestone, episodic changes in circulation, climate, sea level or other conditions might have caused the carbonate compensation level to fluctuate across this depositional environment. The result would be a sequence of cherts and lime muds as observed in this unit.

Parts of this limestone are very dark and fetid, containing pyrite. This suggests a poorly oxygenated depositional environment. Such a condition is more common to deep water in a marine environment.

The occasional layers of poorly to well preserved allochems in this unit are exotic to this environment and require explanation. These beds and lamina may be deposits of infrequent sand flows or turbidity currents which carried material downslope from a distant shallow-water carbonate environment.

Wilson (1969) studied three, modern, deeper-water carbonate environments in an attempt to summarize features commonly found in these environments. Dominance of lime mud and millimeter laminations were two of the features which he considered most common. Wilson also mentioned dark color, sparse fauna, and little or no evidence of bioturbation as frequent features of deeper-water lime mudstones. Tyrrell (1969) also mentions dark color and sparse fauna along with the presence of iron sulfides as products of a stagnant, reducing carbonate environment. Both authors mention the occurrence of cherts in deeper-water limestones.

Massive Limestone Member

Distribution and Type Locality

The Massive Limestone Member constitutes about 90 percent of the Facey Rock Limestone, in terms of the map area. This unit forms the large cliffs that are so prominent when the ridge is viewed from a distance as in Figure 2. On the eastern and southern slopes of Facey Rock this member extends to the base of the limestone exposure or within 50 feet (15 m) of it. On the northern and western slopes the limit of the exposure of the Massive Limestone Member is between 50 and 400 feet (15 to 122 m) above the base of the formation. The type locality of the Massive Limestone Member of the Facey Rock Limestone is designated as the exposure on the highest part of Facey Rock located in the NW 1/4 SE 1/4 NW 1/4 sec. 21.

Lithology

The color of the Facey Rock Limestone is variable. A fresh surface is usually light gray (N7) in color, but may locally assume a medium gray (N5), light bluish gray (5B 7/1), grayish yellow (5Y 8/4) or even pale red (5R 6/2) color. Weathered surfaces are generally medium to very light gray (N6-N8) in color, but are frequently iron-stained giving them a yellowish-gray (5Y 8/1) to grayish-orange (10YR 7/4) hue.

The surface of the limestone is generally covered with solution pits. Microscopic solution pits and an abundance of almost microscopic black lichens combine to give the surface of this rock a soft velvety appearance. This is in marked contrast to the rough, sandpaper texture that is apparent to the touch. Finely disseminated bits of silica protruding from the surface are mainly responsible for this.

Solution on a larger scale has produced dozens of caves in the cliffs of Facey Rock (see Figure 5). Most of these were formed by solution and collapse along joints and fractures. A thin layer of sandstone and chert pebble conglomerate was plastered along the wall of one of these caves. There was definite bedding with alternate layers of conglomerate and sandstone recording high and low energy flow regimes respectively. The author visited a number of these caves during the spring runoff period and found them to be dry. This suggests that much wetter conditions prevailed in the past. Fragments of stalagtites or stalagmites and other pieces of dripstone are frequent occurrences in the limestone talus, indicating the collapse of larger passages.

A nearly universal feature of the Massive Limestone Member is the abundance of small healed fractures. They are usually thin, less than 1 cm (.4 inches), randomly oriented, and not very persistent in any one direction. The filling consists of white sparry calcite.

One of the most obvious diagnostic features of this limestone

Figure 5. The entrance to one of several dozen caves in the cliffs of the Massive Limestone Member of the Facey Rock Limestone

member are the large, prominent chert nodules that stand out from the surface of the rock (see Figure 6). These nodules are usually brown, gray, or black in color and up to 12 inches in diameter. Rohr (1972) noted the occurrence of nodules like these in Ordovician limestones of the Lovers Leap Formation a few miles to the east. Slabs of nodules from Facey Rock, stained for calcite, show that these nodules are relatively solid unlike the limestone centered nodules noted by Rohr at Lovers Leap. The Facey Rock nodules are laced with a minor amount of calcite, which suggests an incomplete replacement process. They have very irregular boundaries and are cut by numerous fractures that have been filled by secondary calcite. In places these nodules are planar or elongate and show crude alignment (see Figure 7). Banks (1970, p. 3041-3047) noted the occurrence of similar nodules in the Mississippian Leadville Limestone of Colorado. He attributed them to silica enriched solutions moving through joints and fractures and replacing some of the adjacent limestone relatively late in the history of the rock. Dr. W. R. Danner of the University of British Columbia (pers. comm.) examined these nodules during a visit to Facey Rock and stated that the alignment of these nodules could reflect either bedding planes or patterns of fractures and joints. This alignment of nodules was a major source of the relatively few attitudes obtained in this unit. At a few locations these elongate nodules are observed to be parallel to laminations in the massive limestone, but whether they are generally good indications of bedding is questionable.

Figure 6. Dark chert nodules in the Massive Limestone Member of the Facey Rock Limestone

Figure 7. Chert nodules in the Massive Limestone Member of the Facey Rock Limestone showing crude alignment

The same silica enriched fluids that were responsible for the formation of the chert nodules in this limestone may also be responsible for the complete or nearly complete silicification of several patches in the Massive Limestone Member. Bold outcrops of a white or nearly white "quartzite" are found in two outliers to the main limestone mass located in the NE 1/4 NW 1/4 sec. 20 and in the SE 1/4 SW 1/4 NW 1/4 sec. 20. In addition to these, there are three other, smaller zones of chertification at the base of the massive limestone exposure along the southern half of Facey Rock's west side.

In outcrop, some of these rocks are very reminiscent of igneous or metamorphic quartz. This resemblance prompted one or more individuals to bulldoze some of these outcrops, presumably in search of a mineralized zone. The author found no evidence of any mineralization and evidently the prospectors did not either, because they did not pursue the possibility further.

On a sawed surface, this rock has a brecciated appearance. Thin section examination reveals ghosts of allochemical grains similar to those found typically in samples of the Massive Limestone Member. These allochems, including coated grains, are composed of coarser quartz grains than is the surrounding matrix. Some of the grains show pore-filling textures.

There is no evidence, in thin sections, of mineralization of this rock to suggest an igneous or metamorphic source for the silica in them. All but one of these silicified zones grade into the normal massive limestone lithology over a distance of 200 feet (60 m) or less. In addition, the localized nature of this lithology makes the contribution of silica from some distant igneous source unlikely.

Presumably small zones in the Massive Limestone Member brecciated by faulting, were permeated by low temperature, silica enriched solutions. The same replacement process which created the chert nodules may have gone to completion in these zones because brecciation made them more accessible to these solutions.

The bulk of the Massive Limestone Member shows no bedding whatsoever. However, there are several localized occurrences of an anomalous, pink limestone with millimeter laminations. These occur at one location on the crest of Facey Rock (locality 162) and two others 50 to 100 feet (15 to 30 m) above the contact between the two limestone members on the western slopes (localities 090 and 141). The best exposure is at locality 141 (see Figure 8) in the NW 1/4 NW 1/4 NE 1/4 sec. 29.

The laminations in these limestones are displayed by thin layers of clay which are more resistant to weathering and stand out from the surface of the rock. Relatively minor occurrences of current cross-laminations and graded beds (approximately 1 cm or .4 inches thick) were noted in some of these zones. Thin sections of these

Figure 8. Small laminated zone in the Massive Limestone Member of the Facey Rock Limestone

rocks show (Figure 9) abundant, coarse grained, idiomorphic rhombs of dolomite suspended in a matrix of coarse microspar and pseudospar calcite. Many of these dolomite grains display evidence of interrupted growth and abrasion. Some of the rhombs displace clay layers indicating early diagenetic growth. The pink color of the rock is derived from finely disseminated, secondary hematite.

These laminated zones yielded a modest collection of conodonts. Most of the microfossils found in the Massive Limestone Member came from these zones, which provided the most definitive data on the age of this unit.

It is unlikely that these pockets of laminated limestone are blocks of the Platy Limestone Member faulted into the massive limestone for several reasons. There is no zone of brecciation or any other evidence for faulting along their boundaries. In places, along the margins of these zones, the laminations become quite feathery and swirl into the massive limestone without any sharp contact. The attitude of the laminations closely approximates the attitudes of nearby chert nodules. Finally, the pink color of this rock is unknown in the Platy Limestone Member and none of the bedded cherts associated with the platy limestone are evident in these zones.

The crest of Facey Rock is crossed by bands of chert in 4 places (see Plate I). These cherts are bedded, but do not have the fine microlaminations occasionally found in the cherts of the Platy

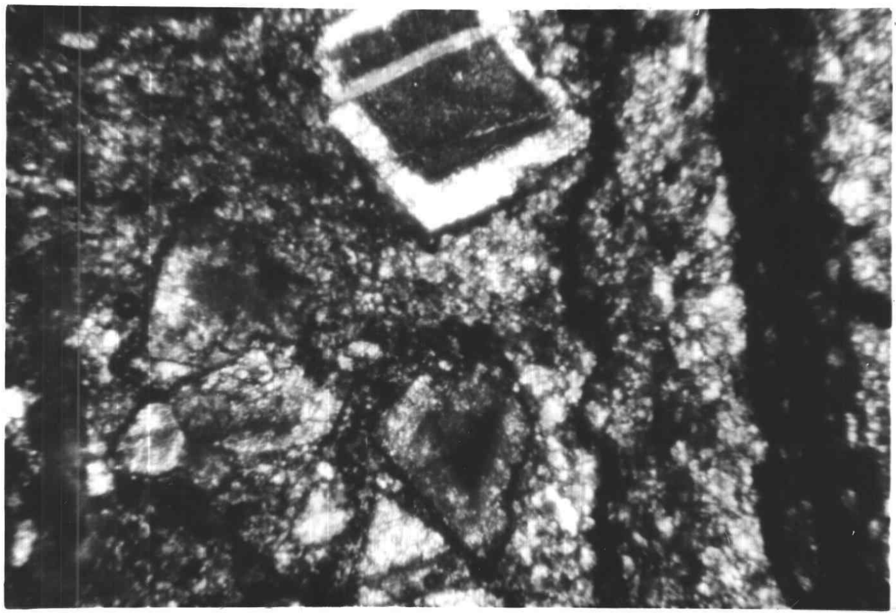

Figure 9. Photomicrograph of the laminated zone in the Massive Limestone Member of the Facey Rock Limestone at locality 141. Note the idiomorphic dolomite rhombs and clay laminations. (3 × 5 mm.; calcite is stained red)

Limestone Member. They are usually a shade of gray, yellow-red or brown and are frequently coated by a yellow-orange iron stain. Spherical ghosts suspected to be poorly preserved radiolaria and concentrations of carbonaceous material are visible in thin sections. These cherts are badly fractured and strongly pitted by chemical weathering. They are less resistant to weathering than the surrounding limestone. There are no outcrops of this chert, the presence of which is indicated solely by its dominance of float rock. The ends of the chert bands trailing down the slopes of the ridge are not well defined. Certainly the bands do trail away from the ridge crest for some distance, but as the slopes get steeper float mapping becomes less reliable. Therefore, the extensions of these chert bodies represent only a reasonable estimate based on the density of chert float.

The presence of these cherts may be accounted for in several ways, but a primary origin seems most probable. It is possible that there is no chert body present and that the chert float was transported to these locations from somewhere else. This is improbable because of the manner in which it straddles the ridge. The few adjacent topographic highs are well exposed and show no possible source for the type and amount of material observed. These cherts might also have been part of the Platy Limestone member or the Callahan Chert faulted into the massive limestone. If the former were true, the platy limestone would crop out adjacent to these cherts high on Facey Rock.

This does not occur. These cherts have a distinctly different appearance than those of the Platy Limestone Member, and are less resistant. They are not a recemented chert breccia as the Callahan Chert is just south of Facey Rock. Selective replacement might also account for the occurrence of this chert. The laminations in the chert have a different appearance from the few laminated zones in the Massive Limestone Member. No laminated zones in the massive limestone abut the contact with the cherts and there is no evidence of a gradational contact, lending support to a replacement origin. Lack of evidence for silica replacement, or tectonic emplacement along with indications of a significant primary silica input in the massive limestone suggest that these chert lenses might be primary.

Although there are no modern examples of cherts being formed in a shallow marine environment, there have been numerous reports (Danner, 1970 and Tromp, 1947) of ancient cherts that appear to have this association. High productivity by silica fixing organisms in a shallow water carbonate environment could create local conditions corrosive to carbonates while at the same time boosting the input of siliceous sediment. Dr. G. R. Heath (pers. comm.) cited the La Luna Formation of Colombia and Venezuela as an example of this phenomenon.

At several locations along the crest of Facey Rock the massive limestone assumes a grayish-orange color that permeates the rock.

This tinted limestone grades into the normal gray, massive limestone and looks suspiciously dolomitic in outcrop. Thin section examination reveals an extremely porous, brecciated texture. Limestone breccia has been recemented by a mixture of ferruginous and carbonate cements. There is no evidence of dolomitization. These zones may have originated from minor faulting or perhaps the collapse of solution channels.

The massive limestone contains a high percentage of allochemical constituents in a matrix ranging in size from micrite to pseudospar that averages medium grained microspar. Visual estimates, utilizing Dunham's (1962) standards, show that some samples of the rock are in grain support while others are not. There has been a variable amount of recrystallization resulting in a full range of allochem preservation. In some thin sections the allochems are well preserved. In others there is only the faintest suggestion of them by micrite rims, alignment of crystals in concentric patterns, and masses of coarse grained quartz and calcite. In still others this texture existed at one time, but presumably has since been completely obliterated. The types of allochems present are (in the order of their relative abundance) intraclasts, lumps, coated grains, and bioclastics. Table 2 lists the percentage of the total allochem content represented by each class as observed in thin sections where the allochems are well preserved.

Table 2. Modal analysis (500 points) of the Massive Limestone Member of the Facey Rock Limestone

Constituent	Percent of each thin section		
	RWP157	RWP162	RWP164
Intraclasts	26.2	32.4	36.0
Coated Grains	12.0	10.2	18.8
Lumps	8.2	20.4	22.4
Skeletal Fragments ?	1.0	0.8	1.4
Matrix	52.6	36.2	21.4
Totals	100.0	100.0	100.0

Locality RWP157: NW 1/4 SE 1/4 NW 1/4 sec. 21

Locality RWP162: SE 1/4 NW 1/4 SW 1/4 sec. 21

Locality RWP164: SW 1/4 NW 1/4 NW 1/4 sec. 28

The allochems range in size from about 0.25 mm (.001 inches) or smaller to nearly 3.0 mm (.1 inches) for coated grains and about 8.0 mm (.3 inches) for intraclasts. The average grain has a diameter of about 0.75 mm (.03 inches).

The sorting of the allochemical grains is difficult to quantify because these grains cannot be removed from the rock and the grain diameters observed in thin section do not directly reflect the sorting. Nevertheless, a rough estimate of the sorting is possible by visual comparison with clastic sediments whose sorting has been determined by other means and whose grain shapes approximate those of the carbonate grains they are being compared with. Using this technique, the sorting of the allochems in the Massive Limestone Member appears to be good.

There is a variable amount of silica present in the Massive Limestone Member. Visual estimates of the silica content in thin sections range from 0 to 35 percent. Insoluble residue data agree with these estimates. Two varieties of quartz are apparent. Cryptocrystalline and microcrystalline quartz grains are disseminated throughout the micrite and microspar matrix. These are probably primary in origin. Medium to coarse grained quartz is concentrated in portions of allochems or in rounded masses that resemble allochemical grains. Some of these polycrystalline masses show good pore filling textures. In a few instances (Figure 10) coated grains

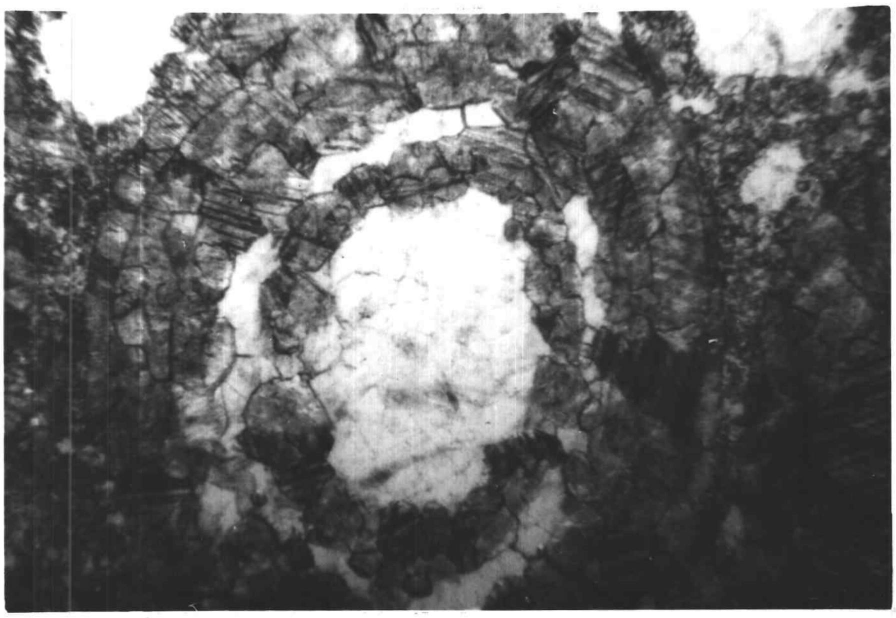

Figure 10. Photomicrograph of an oolite in the Massive Limestone Member of the Facey Rock Limestone showing selective replacement of certain layers by quartz. (3 × 5 mm. ; the lighter colored layers are quartz)

show alternate concentric quartz and calcite layers. An oscillation of the chemical conditions in the environment of deposition favoring the precipitation of silica part of the time and calcite on other occasions might be responsible. The selective solution of certain allochems and of specific layers in coated grains followed by the precipitation of silica in the pore spaces is a more plausible explanation. Friedman (1964) described the creation of this type of "moldic porosity." He cited examples in Florida and the Bahamas where this type of porosity had developed and later been destroyed by pore-fillings of drusy calcite. In this case the post-depositional environment favored the precipitation of silica over calcite in the pore spaces.

In some thin sections of the Massive Limestone Member individual crystals of microspar calcite from the surrounding matrix can be seen invading the boundaries of large quartz crystals in some of the silicified allochems. This probably resulted from the recrystallization of a micrite matrix sometime following the destruction of the moldic porosity by secondary silica. Folk (1965) discusses this type of recrystallization in carbonates and terms it "aggrading, coalesive neomorphism." Portions of the matrix grade between the micrite and microspar size class further suggesting that the original matrix was entirely micrite. Micrite rims found around many of the allochems may have resulted from some localized factor inhibiting recrystallization or they might be due to the action of algae as hypothesized by Friedman (1964). Their origin is poorly understood.

There is a small amount of organic matter in this member visible as a yellow or brown residue finely scattered in the matrix and concentrated along microstylolites. This organic content was apparent as a black, oily film which formed on the surface of the dissolving solution when samples were being prepared for insoluble residue study. Appendix II lists the organic content for three samples of this member determined through a titration technique explained by Royse (1970, p. 127-129). An interesting problem is how solution could take place along these zones, with the necessary movement of fluids, and yet leave the hydrocarbons trapped. Solution occurred, although generally only a millimeter or less of rock was actually removed. Where microstylolites pass through the centers of some of the larger oolites, a small fraction of the oolite is left on each side of the solution surface, but the bulk of the oolite is clearly missing. In most instances the solution zones were probably no more than microscopic films. Perhaps greater viscosity prevented organic residues from moving out of the solution zones.

The Massive Limestone Member of the Facey Rock Limestone is laced with microfractures which are filled by sparry calcite. Presumably these are related to the larger calcite filled fractures seen in outcrops. There is generally little or no displacement of allochems cut by these fractures. Fractures intersecting the more pronounced solution surfaces, mentioned above, are either terminated or displaced (if the intersection was oblique) indicating that many of the fractures pre-date the solution surfaces. In some cases the two coincide.

Idiomorphic rhombs of dolomite or fragments of them are a minor occurrence in the Massive Limestone Member apart from the laminated zones mentioned earlier. Romey (1965, p. 949) referred to "oolites in all stages of replacement by idiomorphic rhombs of dolomite." The author has observed such rhombs only in limestone where oolites and other allochems have been nearly or completely erased by diagenesis and many of these rhombs show abrasion. No instances of dolomite replacing coated grains were noted. Romey also mentions the presence of elongate oolites which he attributes to possible deformation. The writer did not observe any clearly deformed oolites. A few of the coated grains resemble deformed oolites, but their ovoid shape is derived from the elongate forms of the intraclasts in their centers. There did not appear to be any alignment of axes which might be expected if deformation were responsible.

The paragenetic sequence in this limestone appears to be as follows: 1) Induration of a lime mud containing intraclasts, coated grains, lumps and strongly abraded biogenic debris. 2) Inversion of aragonite in the oolites to coarse grained calcite. 3) Selective solution of allochems or portions of allochems creating a "moldic porosity." 4) Precipitation of quartz as pore fillings. 5) Coalescive neomorphism of the matrix to microspar and pseudospar.

In Dunham's (1962) textural classification of carbonate rocks this limestone, where the primary texture is preserved, would be borderline between a packstone and a wackestone. Using Folk's (1961) classification of carbonate rocks this limestone could be termed a moderately well sorted, coarse calcarenite: partially recrystallized, fossiliferous, oolitic intrasparite.

The insoluble residue of the Massive Limestone Member has a white, sugary appearance to the unaided eye. Examination under the binocular microscope reveals that it is composed of almost pure silica in the form of angular quartz grains averaging 0.1 to 0.2 mm (.004 to .008 inches) in diameter. Most of these grains are anhedral or subhedral, but tiny, perfect, singly and doubly terminated quartz crystals up to 1.5 mm (.06 inches) in diameter are common. Molds and casts of oolites, up to 3 mm (.12 inches) in diameter, formed from aggregates of tiny quartz grains are a common occurrence. Other small, rounded, irregular aggretates may be silicified intraclasts. Thin plates of fine grained quartz are probably fillings of feeder fractures. A few tiny lumps of a greasy, brownish-black substance considered to be an organic residue were the only observed contaminants.

The main distinction between the residue of this limestone and that of the Platy Limestone Member are color, grain size and the presence of euhedral quartz grains. Well preserved oolites are also more common in the massive limestone. The weight percent of the insoluble residue in both members is variable and is not a diagnostic feature.

Age and Structural Relationships

Three of 25 samples of the Massive Limestone Member contained conodont assemblages useful in dating the rock. Dr. Carl Rexroad of the Indiana Geological Survey (per. comm.), who examined them, concluded that they are Ordovician in age. As a further check, he showed these specimens to two of his colleagues, Ethington and Clark at a G. S. A. meeting in the Spring of 1973. Rexroad reported:

> I had Ray Ethington look at several slides while I was there and he said 141, from an earlier batch, definitely is Middle Ordovician and has an early Middle look to it. Dave Clark agreed with this. . . . He said that 066 is younger, but that he didn't know how much younger.

Sample 141 was taken from the Massive Limestone Member and sample 066 was taken from the Platy Limestone Member. Noting that the Massive Limestone Member overlies the Platy Limestone Member it appears that these two units have been inverted tectonically.

The contact between the Platy and Massive Limestone Members of the Facey Rock Limestone, exposed in only a few places, shows a structural discontinuity between the two members. The best exposure of this contact is in NW 1/4 SW 1/4 NW 1/4 of sec. 21. Steep slopes and dense brush make photography difficult. Figure 11 is a sketch of the exposure with trees and brush stripped away. Nearly vertical beds of the Platy Limestone Member are truncated beneath the Massive Limestone Member.

The contact between the two members is irregular, but smooth. There is no apparent zone of brecciation as might be expected along a fault plane. No layer of intraformational conglomerate or weathered zone are present to suggest that this was an erosional surface. The conclusion is drawn that this contact is the site of a low angle thrust fault along which the two limestone members behaved primarily in a non-brittle manner at the time of deformation.

Thickness

A determination of the thickness of the Massive Limestone Member of the Facey Rock Limestone is hampered by the vague internal structure of this unit at Facey Rock. A reasonable figure for the minimum thickness would be 500 feet (150 m). A maximum thickness of 1000 feet (300 m) or more is possible.

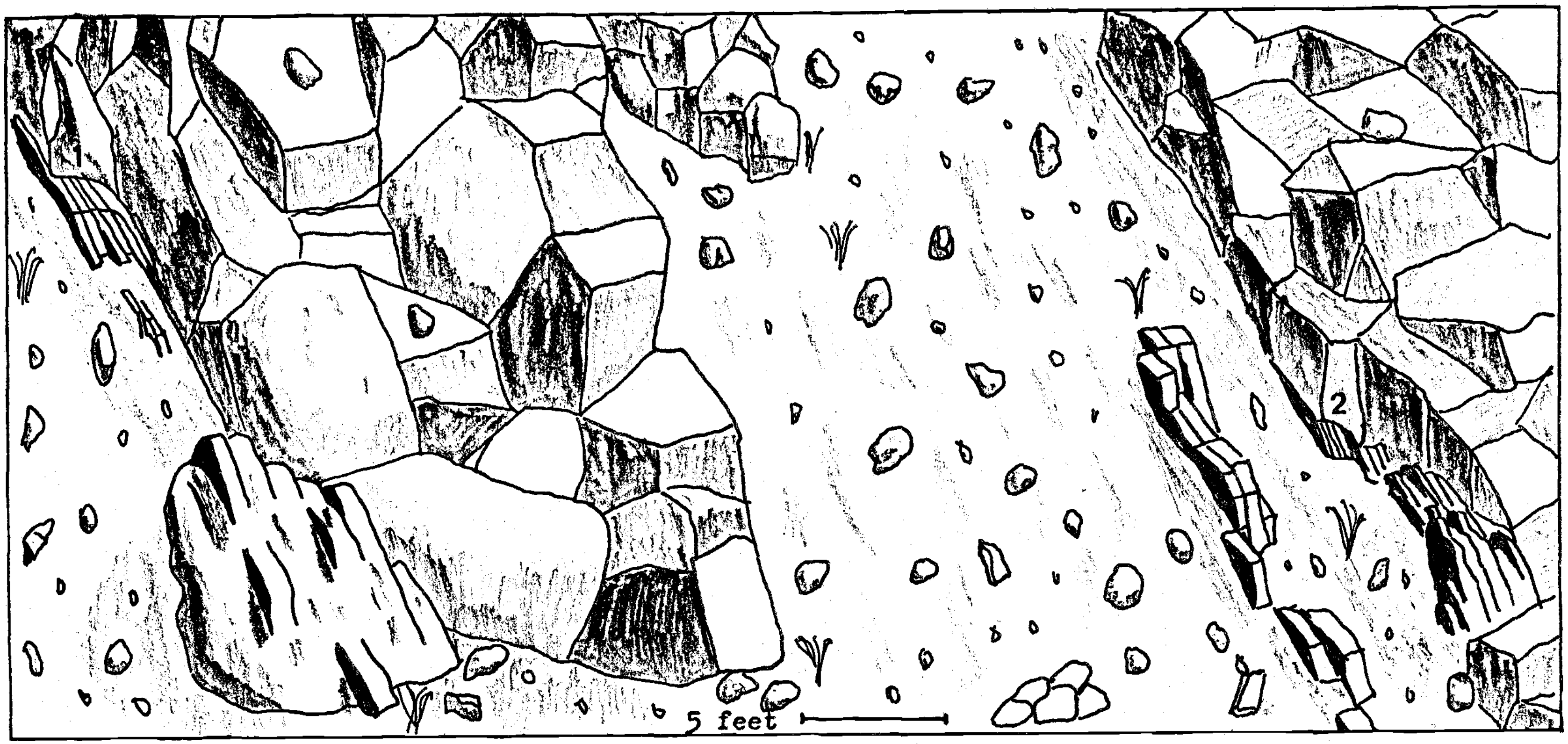

Figure 11. Bird's-eye view of the contact between the Massive and Platy Limestone Members of the Facey Rock Limestone (trees removed). Steeply dipping beds of platy limestone and chert can be seen truncated beneath the Massive Limestone Member below Points 1 and 2 (Locality #116)

Environmental Interpretation

Coated grains, intraclasts, lumps and abraded biogenic grains, of coarse sand size or larger, in a micrite matrix constitute a textural inversion. Folk (1962, p. 82-83) states that this type of textural inversion represents a mixing of sediments from different depositional environments. This may be accomplished in several ways, but it is always characteristic of a transition zone between high and low energy conditions. A fluctuation between high and low energy conditions due to tides, shifting bars, or other phenomenon may have laid down strata containing alternately high and low energy sediments. Subsequent bioturbation may have blended these strata creating a textural inversion. Fecal pellets, burrow structures and fossil fragments often provide clues to such a history.

Winnowed, high energy sediments may be in-filled by silt and clay from a later, low energy regime resulting in a similar textural inversion. Grain support and sheltered porosity are frequently observed under these conditions.

The same type of textural inversion could result if high energy sediments were transported into a low energy environment under extraordinary circumstances, such as during a violent storm. Folk (1962) gives the example of sand from an off-shore shoal or bar being washed into a sheltered lagoon.

No clear evidence of bioturbation is found in the Massive Limestone Member. There is no sheltered porosity and the rock is only partially grain supported. Thus mixing of well sorted layers and in-filling seem less probable.

Silt and clay are conspicuously absent from the Massive Limestone Member. Either there was no landmass nearby to contribute terrigenous material or such a landmass was composed solely of carbonate rocks. Alternatively, prevailing currents might have prevented input from a nearby landmass.

The author visualizes the depositional environment as some type of sheltered zone on a shallow carbonate bank. A protective barrier, such as a series of fringing bars, maintained a low energy environment where lime mud and silica from pelagic organisms were the only significant sedimentary input. Storms or other exceptional conditions then transported sediment into the area from a shallow, agitated environment outside the protective barrier. Circulation may have been restricted locally creating hypersaline and/or silica enriched zones. Such zones might account for some of the early dolomitization and chert lenses contained in this unit.

Barrier bars of the type hypothesized above are known to exist in the Bahamas today (Newell and others, 1960). Hypersaline conditions caused by restricted circulation and high evaporation rates are also known on the Bahama Bank (Cloud, 1970, p. 104).

Penecontemporaneous dolomitization has been reported in some of the tidal flat areas west of Andros Island in the Bahamas (Shinn and others, 1964).

Friedman (1964, p. 777) mentions the association of penecontemporaneous dolomite and algal mats in the Bahamas. The laminated zones in the Massive Limestone Member of the Facey Rock Limestone and the associated dolomitization could indicate the presence of such algal mats although there is no preserved microstructure to support this interpretation.

Friedman (1964) states that the emergence and exposure to fresh waters (meteoric or groundwater) is an essential element in the lithification of and creation of moldic porosity in carbonate sediments of this type. This is easily integrated with the shallow water interpretation given above.

Stuart Fork Formation(?)

Name and Distribution

Romey (in Davis and others, 1962, p. 936) referred to the Stuart Fork Formation as "a distinctive assemblage of interlayered micaceous quartzites and phyllites of metasedimentary parentage with associated greenstones" claiming that they comprised the lowest unit in the Central Metamorphic Belt. Romey noted their occurrence in the Minersville, Coffee Creek and Cecilville quadrangeles. An occurrence just west of the Scott Valley was also noted in the Etna Quadrangle. Zdanowicz (1971) correlated these rocks with phyllites found in Horseshoe and McConaughy Gulches north and west of Facey Rock. A lithology similar to the quartzites of the Stuart Fork Formation was mapped east of Facey Rock in the eastern half of sec. 21 and the NE 1/4 of sec. 28.

Lithology

The Stuart Fork(?) rocks west of Facey Rock are not well exposed. Outcrops are very similar to those of Unit A. The color of most of these rocks is an orange-brown (10YR 6/4), identical to that of the calcareous wacke. A few subtle differences are apparent in the field. Occasional veins of white crystalline quartz are found in this lithology. Similar calcite filled fractures are found in Unit A. Scattered through this unit are occasional pockets of silt-sized material weathering into thin plates (1 or 2 cm thick) with strong undulatory foliation and a dark greenish sheen. Those portions of the unit which most closely resemble the calcareous wacke can often be distinguished with a hand lens by the stretched appearance of the larger quartz grains.

The major constituents of this rock are quartz, chlorite, muscovite, carbonate, garnet(?), sodic plagioclase, graphite(?)

and potassium feldspar. In the foliated varieties the fabric shows obvious deformation effects. Long trains of chlorite and muscovite wrap around quartz grains. Romey (in Davis and others, 1962, p. 937-939) states that the quartzites of the Stuart Fork Formation are dominately composed of quartz, muscovite and chlorite with some occurrence of garnet and detrital albite.

Age and Structural Relationships

There is no fossil evidence for the age of the Stuart Fork Formation. The Stuart Fork rocks are believed to be part of the upper plate of a folded regional thrust designated the Mallethead Thrust by Churkin and Langenheim (1960). This thrust has been traced for several miles along lines to the north and west of Facey Rock by Romey, Zdanowicz, Rohr, Potter and others. The thrust overlies late Silurian (Ludlow) rocks two miles north in Horseshoe Gulch and early Devonian rocks about 15 miles northeast in the Payton Ranch area. Farther north, near Yreka, unmetamorphosed Cretaceous sediments have been reported overlying metamorphic rocks of the Mallethead Thrust. Therefore the Mallethead Thrust is of Early Devonian to Cretaceous age.

The Stuart Fork(?) rocks are in fault contact with the Silurian calcareous wacke (Unit A) in the eastern portion of the map area. This fault could be part of the folded Mallethead Thrust. It seems

Table 3. Modal Analysis (500 points) of the Stuart Fork(?) Quartzite

Constituent	Percent of each thin section RWP001	RWP085
Quartz	80.6	82.2
Chlorite	11.0	12.2
Muscovite	3.4	2.6
Carbonate	2.4	1.8
Garnet(?)	0.6	0.2
Plagioclase	1.2	0.8
Graphite(?)	0.2	0.0
K-Spar	0.6	0.2
Totals	100.0	100.0

Locality RWP001: the NE 1/4 NE 1/4 NE 1/4 sec. 28

Locality RWP085: the SE 1/4 SW 1/4 NE 1/4 sec. 21

more probable that this is a normal fault, downthrown on the east side, bringing rocks from the overlying Mallethead Thrust in contact with the Silurian rocks of Unit A.

Thickness

Romey (in Davis and others, 1962, p. 937) stated that all previously reported thicknesses for the rocks included in the Stuart Fork Formation were structural and not stratigraphic. The Stuart Fork(?) rocks in the thesis area are only a small sliver of the total stratigraphic section and because their internal structure is poorly known an estimate of the thickness within the map area or in total is not possible.

INTRUSIVE ROCKS

Distribution

Most of the intrusive rocks in the area are found on the east flank of Facey Rock. There are a few very small exposures on the west side. These were either too small to map or were seen in float, but not in outcrop. The two largest intrusives, a diorite porphyry and a basalt, occur mainly around the limestone outlier in the SE 1/4 SW 1/4 sec. 21 (see Plate I).

Lithology

All of the intrusions in the area were originally of dioritic or gabbroic composition, but most have been so badly altered that their original mineralogy can only be guessed. The dike curving around the east side of the limestone outlier in the SE 1/4 SW 1/4 sec. 21 is yellowish-gray (5Y 7/2) on a fresh surface, but is frequently iron stained to a dark yellowish-orange (10YR 6/6) hue. This rock is porphyritic with euhedral to subhedral phenocrysts of andesine and biotite, along with embayed quartz grains contained in a light gray groundmass. The phenocrysts and quartz grains have a maximum diameter of about 5 mm (.2 inches). The groundmass, including fine grained plagioclase, has been almost completely altered to cryptocrystalline quartz.

The intrusion bordering this same outlier to the south is a fresh looking, highly vesicular basalt with a medium dark gray (N4) color on a fresh surface. Most of the vesicles, some of which attain a diameter of 15 to 20 cm (6 to 8 inches) are filled with optically continuous, white, sparry calcite. In thin section chloritic-appearing masses, probably altered mafic minerals, are seen suspended in a matrix of fine grained plagioclase.

Contacts

The contacts of these intrusives are puzzling. Although they are not clearly exposed they can be located within a few feet in most cases. There is no evidence of alteration in the limestone adjacent to these intrusions. It is possible these rocks were faulted into position, although there is no supporting evidence. The very recent appearance of the basalt and the separation of the northern tip of the outlier by the porphyritic dike rock lead the author to the tenuous conclusion that these rocks were intruded against the limestone, but for some reason the alteration was minimal.

Age

Variations in the texture and composition of these rocks over short distances suggest that there may be more than one generation of intrusive rocks. All of them cut the Silurian calcareous wacke

(Unit A) and therefore are Silurian (Llandovery) or younger. If these rocks were intruded into the limestone, which appears to be true, then they are younger than the Mallethead Thrust.

QUATERNARY LANDSLIDES AND BRECCIA

Distribution

Two major landslide zones exist on the west flank of Facey Rock and one minor slide occurred on the north end. The composition of the slide debris indicates that the zone of failure was primarily within the Massive Limestone Member of the Facey Rock Limestone. The slide debris extends from slightly above or below the base of the massive limestone to the lower slopes of Unit A. Striking outcrops of a coarse limestone breccia protrude from these landslides and from talus slopes elsewhere around Facey Rock.

Lithology and Morphology

Most of the landslide zones appear as complexes of low-lying, seemingly incoherent limestone outcrops. Fragments of the massive limestone lithology make up more than 99% of the debris. The debris ranges in size from pieces a few inches in diameter to house-sized blocks. In areas where they are largest these blocks are stacked in a loose, random pile creating small caves in the interstices.

Near the tops of the two northern slide zones the contact between the two limestone units is buried beneath landslide debris. In the upper portion of the central, and largest, slide zone are two peculiar features which are believed to be caused by this slide. An area of hummocky topography contains at least one large closed depression. The second feature, clearly visible on aerial photographs, is a strip of land 50 to 100 yards (45 to 90 m) in width along which practically all of the trees and brush have died. This strip encloses an area of several acres filled with large trees and dense brush. The author postulates that minor movement in recent years has altered the ground water circulation in a way that deprives this peripheral zone of needed moisture. Lifetime residents of the area have no recollection of a fire or other phenomenon which might have caused this feature, nor do they recall witnessing or hearing accounts of a landslide of this proportion.

The breccia associated with these slides (see Figure 12) is composed primarily of clasts of the massive limestone lithology along with infrequent pieces of chert and sandstone. These clasts range from coarse sand size to pieces 6 feet in diameter. They have been firmly cemented into a rather porous aggregate by a light brown carbonate cement, presumably aragonite. This breccia is pitted on a scale with the clasts that it contains at any one outcrop. Breccia is found at a variety of levels on Facey Rock (see Plate I) and is not limited to the vicinity of the thrust contact between the limestone and the calcareous wacke as hypothesized by Romey (1962). The breccia is normally found on slopes composed of medium to small landslide debris or talus suspended in a thin soil. It forms bold outcrops, some

Figure 12. Coarse breccia composed of loosely cemented talus and landslide debris

of which have a reef-like appearance, emerging from the soil with a dip equal to or slightly less than that of the slope. Some display roughly planar surfaces mentioned by Romey (1962). These planar surfaces are defined by variations in the degree of cementation.

Contrary to Romey's (1962) interpretation of a thrust breccia the author believes this lithology resulted from cementation of Quaternary landslide and talus deposits by groundwater supersaturated with calcium carbonate. These deposits were later excavated by erosion. Several modern examples of this process are known. Dr. C. I. Smith of the University of Michigan (written comm., 1972) noted that he had observed this process at several locations in the southwestern United States. Dr. A. J. Boucot (pers. comm.) observed cementation of this type in connection with limestones in the Permo-Carboniferous Cache Creek Group at a location on the shore of Lake Stuart, 2 miles north of Fort St. James, British Columbia.

Objections to Romey's interpretation are as follows: (1) The framework of the breccia is far too loose for this to have been a thrust breccia. (2) The distribution of this lithology has no apparent relation to the thrust surface. (3) The clasts do not contain regular fractures or tension gashes and none show slickensides. (4) The outcrops have a distinctly surficial appearance, conforming to the slopes in most cases.

Mack (1958), in a study of the groundwater chemistry of the

Scott Valley, noted that water draining from the area of Facey Rock was quite hard, with an anomalously high calcium content. Lifetime residents of the area reported the occurrence of lime precipitating springs on the slopes of Facey Rock in recent years. The author observed this process on a very limted scale, but suspects that it has been more important in past years than it is presently. A gastropod shell found in Facey Gulch is part of an early paleontologic collection from the area belonging to the University of California, Berkeley. Facey Gulch is the principal drainage south of Facey Rock, and it contains several small springs. This shell was one of a modern land snail common in the area. A thin coating of limey cement, probably acquired from spring waters in the gulch, gave it the superficial appearance of antiquity.

The ages of the landslides in the area are uncertain. Based on the degree of preservation, they are probably Quaternary in age. Several trees growing from the debris of the largest slide appear to be two to three hundred years old. The other two slides seem to be of approximately the same age. These landslides probably predate settlement of the Scott Valley in the mid-1800's since there is no historical account of their occurrence.

STRUCTURE

Introduction

Two thrust faults dominate the structure of the Facey Rock area. These thrusts are considered subsidiary to the regional Mallethead Thrust of Churkin and Langenheim (1960). In addition, a number of high angle faults with relatively minor displacement occur in the area. The internal structure of most of the sedimentary units is vague and possibly quite complex.

Faults

General

Figure 13 shows the pattern of faulting in and around Facey Rock with individual faults labeled for the purpose of discussion. These are only the most significant faults in the area. Certainly there are others of lesser importance which are not shown. Most of the rock in the area has been severely fractured and this along with frequently poor exposures makes it impractical to trace out the smaller faults in the area.

The elevation and thickness of the lower thrust plate (the Platy Limestone Member of the Facey Rock Limestone) change rapidly over short distances (see Figure 14). Faulting may be invoked to explain

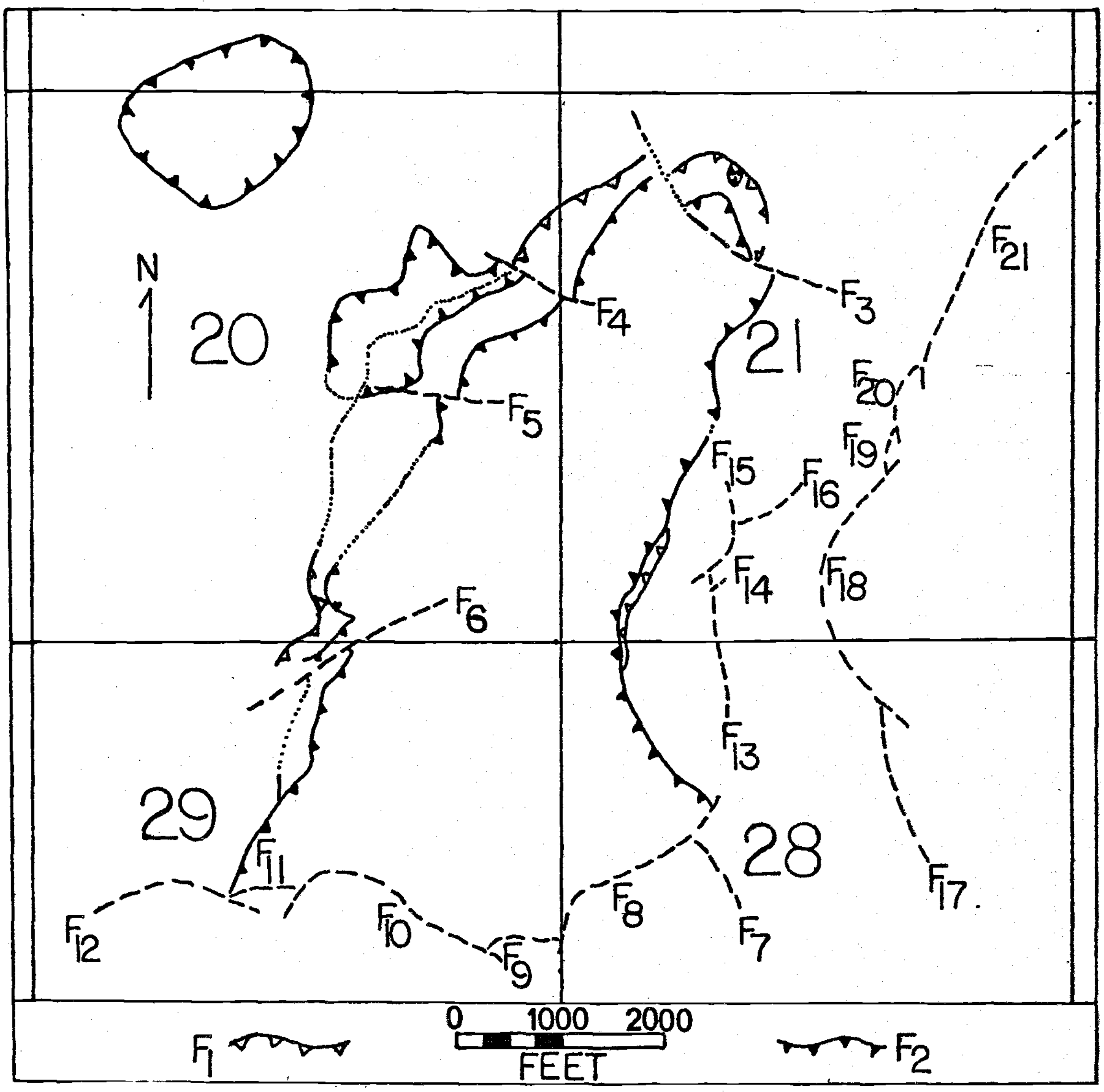

Figure 13. Major Faults in the Facey Rock Area

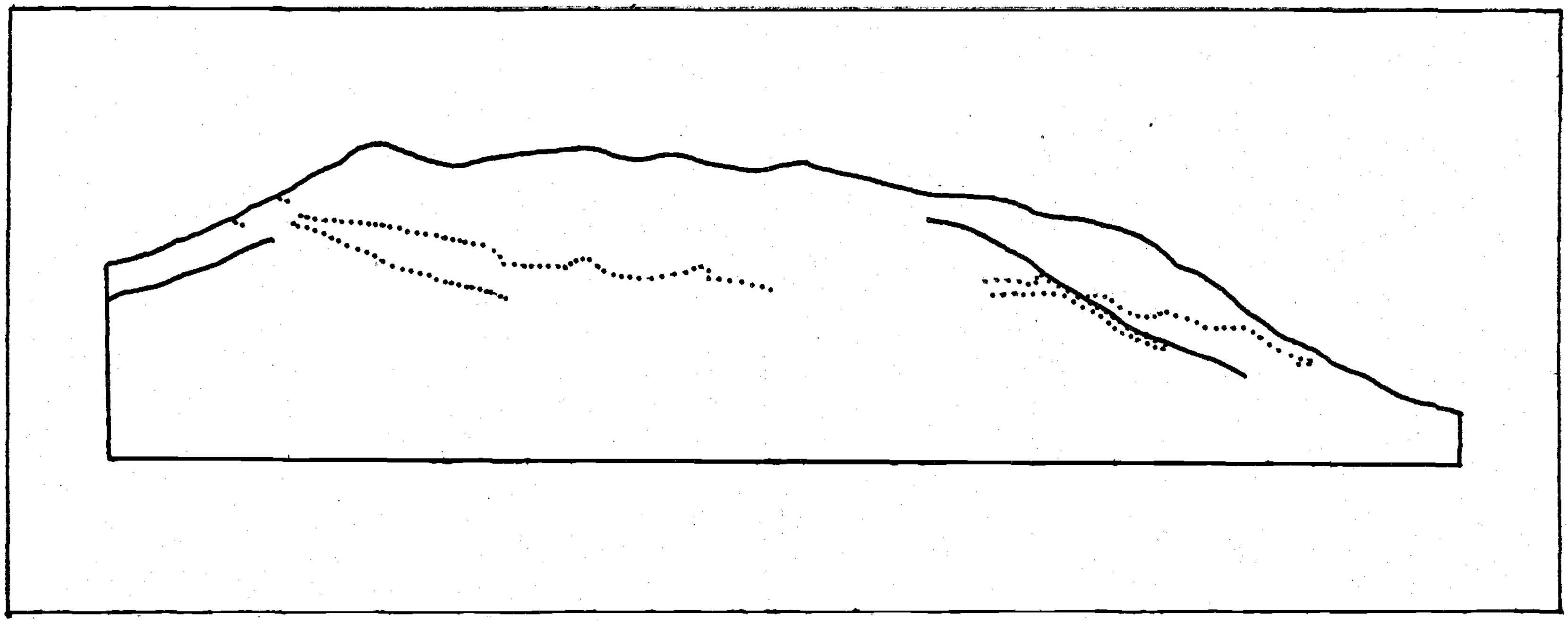

Figure 14. Tectonic profile of Facey Rock (Direction of view is S 60° E): Dotted lines are projections of the surface trace of the upper and lower contacts (where not covered by another unit) of the Platy Limestone Member of the Facey Rock Limestone. Note the irregularity of these contacts.

some of these irregularities. The author has inferred 4 such faults and almost certainly there are others. It should be noted that the second thrust, F2, overriding the lower thrust plate is also responsible for many of these irregularities. The drag created by this second thrust severely deformed the platy limestone below in a non-brittle manner. At several locations the lower thrust plate is truncated or pinched out by the overriding thrust plate. This is the case along much of the east side of Facey Rock.

Types of Faults and Evidence

The faults in the area may be divided into several groups. Faults F1 and F2 are thrusts, probably subsidiary to the regional Mallethead Thrust, caused by drag from the major overriding plate. The contact between Silurian sandstone (Unit A) and late Ordovician platy limestone along F1 is not exposed because the platy limestone is a strong slope former. The contact along F2 between late Ordovician platy limestone below and middle Ordovician massive limestone above is exposed in a few places. The contact is sharp, but it wavers up and down over short distances. There is no apparent zone of brecciation. Disturbed beds of the platy limestone member are seen truncated beneath the overlying massive limestone (see Figure 11). Consequently the inverted stratigraphic sequence must be the result of a thrust rather than an overturned fold.

Faults F3, F4, and F5 are nearly vertical normal faults. None of them have a vertical displacement exceeding 200 feet. Their presence is inferred from irregularities in the contacts they cross and in the case of F4 from the large gully it ascends.

Fault F6 is a reverse fault dipping to the southeast at approximately 45 degrees. The net slip of this fault is estimated to be about 500 feet (150 m). Again, irregularity of the contacts is a reason for the inferrence of this fault. The gully this fault is shown ascending appears to be structurally controlled.

Faults F7 through F12 are inferred because of the sharp transition between the Ordovician Facey Rock Limestone to the north and the Late Silurian Callahan Chert to the south. These faults are nearly vertical and have displacements of at least 500 feet and possibly more.

Faults F13 through F16 were inferred to explain the presence of the limestone outlier on the east side of Facey Rock. The elevation of this block of platy limestone is 400 feet (120 m) below that projected from the cross section of the main limestone mass. These are normal faults with a dip slip movement of 400 feet (120 m) or less. They are probably related to the final group of faults discussed next.

Faults F17 through F21 were inferred because of the sharp transition between the unmetamorphosed sandstone to the west and quartzite to the east. The contact itself is not exposed. These faults dip to the east at approximately 45 degrees as determined by their trace on the topography. Projections of contacts from an east-west cross section suggest that the dip slip movement along these faults is in excess of 1000 feet (300 m).

Age of Faults

Relative ages can be established for most of the faults shown in the map area on the basis of cross cutting relationships. Thrust faults F1 and F2 are probably contemporaneous with the Mallethead Thrust which is of Early Devonian to Late Cretaceous age. These are probably the oldest faults shown. Faults F3, F4, and F5 all post-date the thrust faults because of the offset they produce in the limestone contact. It seems probable that these 3 faults are in response to the same stress and so are of approximately the same age. Fault F6 is younger than the thrust faults which it offsets, but is apparently unrelated to the previous 3. The system, including F7 through F12, is probably younger than the thrusting because it appears to truncate the Facey Rock Limestone to the south of Facey Gulch. There is room for doubt on this point because the two limestone thrust sheets have not been traced south of Facey Gulch at this time. Faults F13 through F16 which down-dropped a portion of the platy limestone, forming the eastern limestone outlier, are obviously younger than the thrust faults and probably contemporaneous with the normal faults F17 through F21.

Folding

Romey shows a synclinal axis with an approximately north-south trend passing through the area of Facey Rock in his 1962 map. Steep slopes and relatively sparse vegetation enabled the author to find and measure a number of bedding attitudes in Unit A east of Facey Rock. There is a fairly consistent westward dip in the bedding of these slopes in agreement with Romey's hypothesis. Supporting data to the north and west of Facey Rock were not available because dense vegetation and moderate slopes which inhibited adequate exposure of the bedding. Romey's interpretation may be correct, but the author found the evidence insufficient to locate a synclinal axis.

The Platy Limestone Member of the Facey Rock Limestone has been so severely contorted by the associated thrusting that an interpretation of its internal structure is impractical. The internal structure of the Massive Limestone is vague because of the scarcity and questionable reliability of bedding attitudes. There is some possibility that the 4 chert bodies straddling the crest of Facey Rock are portions of a single chert lens repeated by a series of faults or folds.

GEOLOGIC HISTORY

The depositional environments of Unit A and the two members of the Facey Rock Limestone were discussed in the sections describing each of these units respectively. Summarizing, the Silurian calcareous wacke (Unit A) is interpreted as a proximal turbidite, the massive Ordovician massive limestone as a shallow, protected bank deposit, and the Ordovician platy limestone as a deeper water carbonate. The two limestone members are allochthonous, but it is likely that they were not transported far. The directions of the thrusts in the map area have not been established. This, along with the variable ages of the units involved, makes reconstruction of the paleogeography difficult. Collectively, these three lithologies could be indicative of an island environment in a geosynclinal setting. There is some possibility that the different facies represented by these three units show a transition in the depositional environment of a single locality through time. If true, a case might be made for the gradual drowning or tectonic lowering of an island platform. Conditions favorable to the types of carbonate deposition represented by the two members of the Ordovician Facey Rock Limestone could exist simultaneously at two locations in close proximity to each other. The difference in depth would not necessarily have to be extreme. The Platy Limestone Member could be derived from a slope marginal to the shallow water bank which formed the massive limestone or from sediments accumulating in a small basin with the bank itself. Dr. G. R. Heath of the School of Oceanography at Oregon State University (pers. comm.) noted that relationships of this kind exist today in the Bahamas, Micronesia, and in some of the coastal waters of Australia. Therefore, the depositional environment(s) could just as easily have remained stable with the different lithologies resulting from the geographic dispersal of these units at the time of deposition alone.

Most of the sediments which were lithified to form the two limestone members were internally derived. The clastics of Unit A, largely chert and quartz grains, appear to have multiple sources. The chert may have been locally derived. The quartz grains are of uncertain origin, but there is evidence (Rohr, 1972, p. 62) that a plutonic terrain existed nearby during the early Paleozoic which might have served as a source for them.

The structural history was detailed in the previous section. Briefly a series of imbricate thrusts created an inverted stratigraphic sequence with Silurian wacke overlain by Late Ordovician platy limestone and capped by Middle Ordovician massive limestone. These thrusts occurred sometime between the Early Devonian and the Late Cretaceous periods. Subsequently the rocks in the area were cut by a number of high angle faults. There were several small gabbroic and dioritic intrusions following the thrusting. The relation of these intrusions to the normal faulting is not evident.

The area has been strongly eroded since the thrusting took place leaving Facey Rock as a klippe. Additional work may demonstrate that these subsidiary thrusts are fairly extensive. A casual visit to Duzel Rock, a limestone capped peak about 9 miles north-northeast of Facey Rock revealed a similar limestone association. A platy limestone lithology there with an outcrop appearance identical to that of the Platy Limestone Member of the Facey Rock Limestone overlies a graywacke and is in turn overlain by a massive limestone lithology. A comparative study of these two areas in the future might make a significant contribution to the understanding of the region's structural history.

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APPENDICES

APPENDIX I

Insoluble Residue Results

Appendix Table 1. Insoluble-Residue Percentages from Limestones in the Facey Rock Area

Collected from	Locality	Insoluble-residue percentage
	116	32.8
Platy Limestone Member of the Facey Rock Limestone	066	5.8
	PS-4	14.4
	092	9.2
Massive Limestone Member of the Facey Rock Limestone	047	36.8
	045	31.0

Limestones were dissolved in concentrated hydrochloric acid.

APPENDIX II

Organic Content Results

Appendix Table 2. Organic Content Percentages from Limestones in the Facey Rock Area

Collected from	Locality	Organic content percentage
	066	0.28
Platy Limestone Member of the Facey Rock Limestone	PS-4	1.37
	106	0.14
	092	0.48
Massive Limestone of the Facey Rock Limestone	157	1.15
	162	0.41

Technique of analysis is described in Royse (1970).

APPENDIX III

Fossil Localities and Reports

Fossil Locality 066, Platy Limestone Member of the Facey Rock Limestone (Collected by Porter, 1972)

Location: Near the base of the massive limestone exposure on the west side of Facey Rock, SE 1/4 SW 1/4 SW 1/4 sec. 21

Report: Conodonts were the only fauna found at this locality. In reference to these Rexroad (1973, written communication) stated,

> Sample 066 has a small Ordovician faunule, ten specimens, mostly long ranging, but a couple are restricted to the Ordovician. In total I suspect it is indicative of upper Ordovician.

Fossil Locality 107, Platy Limestone Member of the Facey Rock Limestone (Collected by Porter, 1972)

Location: On the west side of the north end of Facey Rock, NW 1/4 SW 1/4 NW 1/4 sec. 21

Report: Only conodonts were recovered at this locality. Rexroad (1973, written communication) reported,

> 107 had three cone fragments including a recognizable *Distacodus procerus* Branson and Mehl. This form illustrates one of the real puzzles in conodont biostratigraphy as it is one of several things that appear to have a peek-a-boo range. According to some synomizers it is present in a limited part of the Ordovician. It is also present in part of Silurian Zone III and part of the *siluricus* Zone. So far it has not been reported in intervening rocks.

Fossil Locality 126, Platy Limestone Member of the Facey Rock Limestone (Collected by Porter, 1972)

Location: On the western slope of Facey Rock, SW 1/4 SW 1/4 SE 1/4 sec. 20

Report: Conodonts were the only fauna found at this locality. Rexroad (1973, written communication) commented,

> The things in 126 are very fragmentary, but one specimen probably is Belodella or Belodina. Depending on which, it could be Ordovician or Silurian-Devonian.

Fossil Locality 045, Massive Limestone Member of the Facey Rock Limestone (Collected by Porter, 1972)

Location: On the crest of Facey Rock near the south end, SW 1/4 SW 1/4 SW 1/4 sec. 21

Report: Only conodonts were recovered at this locality. In reference to these Rexroad (1973, written communication) reported,

> 045 has two long ranging cones and a more restricted form duplicated in 066. The later form is Upper Ordovician and Low Silurian.

Note - The author has reason to believe that this sample might be mis-labeled and Rexroad implied that this was not a firm date in later correspondence. Thus the findings at this locality are suspect.

Fossil Locality 141, Massive Limestone Member of the Facey Rock Limestone (Collected by Porter, 1973)

Location: Near the base of the Massive Limestone Member in the central part of the west side of Facey Rock, NW 1/4 NW 1/4 NE 1/4 sec. 29

Report: Only conodonts were found at this locality. After an initial examination of the specimens recovered Rexroad (1973, written communication) commented, "Number 141 had many specimens, but badly broken ones, that are without question Ordovician in age." After showing these specimens to a couple of his colleagues at a GSA meeting in the Spring of 1973 Rexroad (1973, written communication) stated,

> I had Ray Ethington look at several slides while I was there and he said that 141 from an earlier batch definitely is Middle Orodvician and has an early Middle look to it. Dave Clark agreed with this. . . . He said that 066 is younger, but he didn't know how much younger.

Fossil Locality 090, Massive Limestone Member of the Facey Rock Limestone (Collected by Porter, 1972)

Location: Near the base of the massive limestone on the west side of Facey Rock, SW 1/4 NE 1/4 SE 1/4 sec. 20

Report: Only conodonts were recovered from this locality. Rexroad (1973, written communication) stated, "Sample 090 has a diminutive, but abundant and reasonably well preserved faunule that is generally similar to the Middle Ordovician of 141."

Fossil Locality 124, Massive Limestone Member of the Facey Rock Limestone (Collected by Porter, 1973)

Locality: Near the top of Facey Rock on the southern end, NW 1/4 SE 1/4 SE 1/4 sec. 20

Report: Rexroad gave an ostracod valve he recovered from this sample to Dr. R. H. Shaver who concluded that it was a new and undescribed genus in the family Bairdiidae.