AN ABSTRACT OF THE THESIS OF

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in Geology presented on May 6, 1985

Title: GEOLOGY OF THE WILLOW CREEK AREA, ELKO COUNTY, NEVADA

Abstract approved: Redacted for Privacy

Dr. J. G. Johnson

The purpose of this study was to test two hypotheses. The first hypothesis interprets allochthonous rocks in the Willow Creek area of the Pinyon Range as lying on flat, superficial thrusts that truncate the underlying folded Mississippian rocks of the Antler flysch sequence. The second hypothesis interprets the allochthonous rocks as being folded within the Mississippian sequence as if they had arrived as part of the Antler allochthon after flysch sedimentation had begun and were overlapped as sedimentation continued. Evidence presented here supports the second hypothesis.

During Early and Middle Devonian time, deposition in the central Pinyon Range occurred in a miogeoclinal shallow-shelf environment characterized by carbonates of the Nevada Group.

Onset of the Antler orogeny in Late Devonian time was marked by uplift and erosion or nondeposition in the study area. A west-dipping subduction zone formed to the west in oceanic crust, developing an accretionary wedge which became the Roberts Mountains allochthon. The allochthon was obducted onto the continent as incipient subduction of continental crust occurred.

Downbending of the edge of the continent led to the formation of a foreland trough at the leading edge of the allochthon. Telescoping

within the allochthon caused it to rise and shed siliciclastic sediments into the trough forming the submarine fan deposits of the Dale Canyon Formation. The allochthon was then emplaced over the Dale Canyon Formation and was subsequently overlapped by deltaic sediments of the Diamond Peak Formation.

The Roberts Mountains allochthon in the Willow Creek area consists of the Devonian Woodruff Formation forming its base, the Ordovician Vinini Formation at the top, with a small slice of the Siluro-Devonian Roberts Mountains Formation lying in between. Emplacement of the allochthon is dated as during or before *typicus* Zone time of the early Osagean on the basis of conodont collections from the overlapping Diamond Peak Formation.

Geology of the Willow Creek Area, Elko County, Nevada

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed May 6, 1985

Commencement June 1985

APPROVED:

Redacted for Privacy

Professor of Geology in charge of major

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Date thesis is presented May 6, 1985

Typed by Rebecca Simpkins for John H. Whitaker

ACKNOWLEDGMENTS

Thanks go to many people who aided me on the way to completion of this task. Thanks first to Dr. J. G. Johnson who provided me with this challenging and important project and who was helpful and encouraging throughout. Thanks also to Claudia Regier who picked many of my conodont samples and to Gilbert Klapper of the University of Iowa for identification and dating of the conodonts. Also thanks to William B. N. Berry of the University of California at Berkeley who identified my graptolite samples. Thanks to Dr. Robert Yeats and Dr. Cyrus Field for residing on my committee and providing excellent critical comments and questions. Robert Visconti provided many interesting discussions in the field and split rides into town with me.

Funding was provided in part by a National Science Foundation research grant. Funding was also provided by Superior Oil, Minerals Division of Reno, Nevada. Thanks to Don Cohen of Superior Oil for spending time in the field with me at the study area.

Thanks also go to my parents, without whom this would never have been possible, and to my many roommates and friends who put up with me during the long haul. Special thanks go to Ian Walsh, and Philip and Emily Verplanck who helped me prepare my talk. Special thanks also go to Becky Simpkins for her fast, on-call typing services.

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INTRODUCTION

Purpose

This study involved detailed mapping and structural interpretation of early and middle Paleozoic sedimentary rock formations at the toe of the Roberts Mountains thrust fault in the Willow Creek area of the Pinyon Range, north-central Nevada.

Smith and Ketner (1977, 1978), in their study of the Pinyon Range, interpreted allochthonous rocks of the Vinini and Woodruff Formations at Willow Creek as lying on flat, superficial thrusts that truncate the underlying folded Mississippian rocks of the Antler flysch sequence. However, Johnson and Pendergast (1981) interpret the Vinini and Woodruff as being folded within the Mississippian sequence as if they had arrived as part of the Antler allochthon after flysch sedimentation had begun and were overlapped as sedimentation continued. The main objective of this study was to test these two hypotheses. This was done by studying contacts between the allochthon and the surrounding Mississippian clastics and by comparing the internal structure of the allochthon to that of the autochthonous rocks.

In conjunction with this objective, the sedimentary units were subdivided where lithologies suggested distinct depositional facies. Also, some of the units were renamed where appropriate in light of more recent data.

Location and Accessibility

The Willow Creek area of the Pinyon Range is located in the eastern part of the Pine Valley quadrangle about 22 miles south of the town of Carlin, in Elko County. The area mapped encompasses about 25 square miles along the upper reaches of Willow Creek. Access is provided by an unimproved dirt road which extends about 3 miles up Willow Creek, eastward from Nevada Route 278.

Previous Work

The earliest work on the geology of the Pinyon Range was done by Hague (1877) during the 40th Parallel survey. Emmons (1910, p. 88-95) reported on the geology of the Pinyon Range as part of a survey of the mining districts of northeastern Nevada. Carlisle *et al.* (1957) documented the Devonian stratigraphy of the region and Granger *et al.* (1957) provided the first geologic map of the area as part of a reconnaissance survey of Elko County. More recent work has been done by Smith and Ketner (1975, 1976, 1977, 1978), of the U. S. Geological Survey, who published a detailed description of the stratigraphy of the Carlin-Pinyon Range area as well as a discussion of the tectonic history and a geologic map (1:62,500) of the region.

When the Roberts Mountains thrust was first proposed (Kirk, 1933) and mapped (Merriam and Anderson, 1942) a Mesozoic age was suggested. Later, evidence was presented by Kay (1952) and Dott (1955) which suggested that the thrust was mid-Paleozoic in age, and with the work of Roberts *et al.* (1958) came acceptance that the thrust was a direct result of the mid-Paleozoic Antler orogeny.

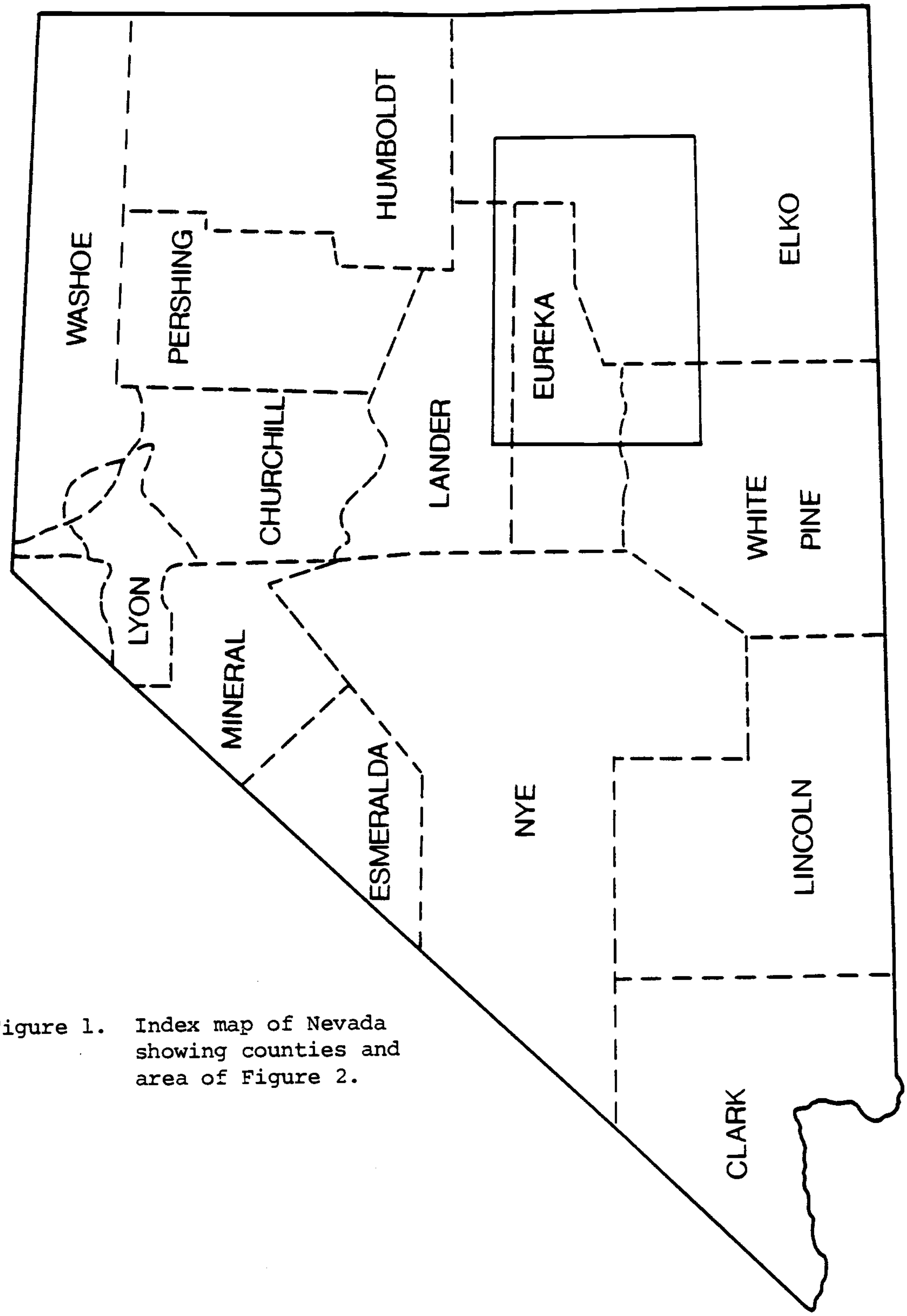


Figure 1. Index map of Nevada showing counties and area of Figure 2.

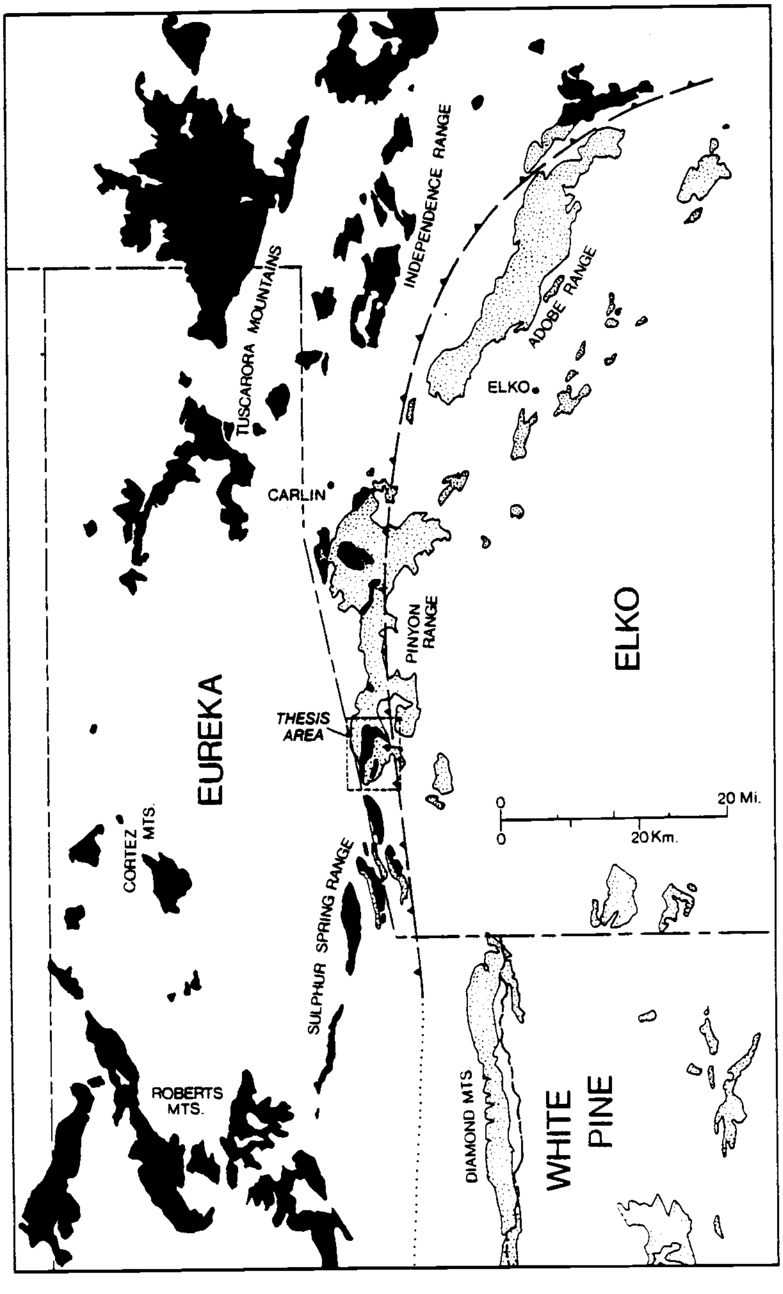


Figure 2. Index map of northeast Nevada. Solid black areas are Ordovician to Devonian rocks of the Roberts Mountains allochthon and stippled areas are Mississippian rocks of the flysch-molasse complex. Sawtooth line marks toe of allochthon. After Johnson and Pendergast (1981).

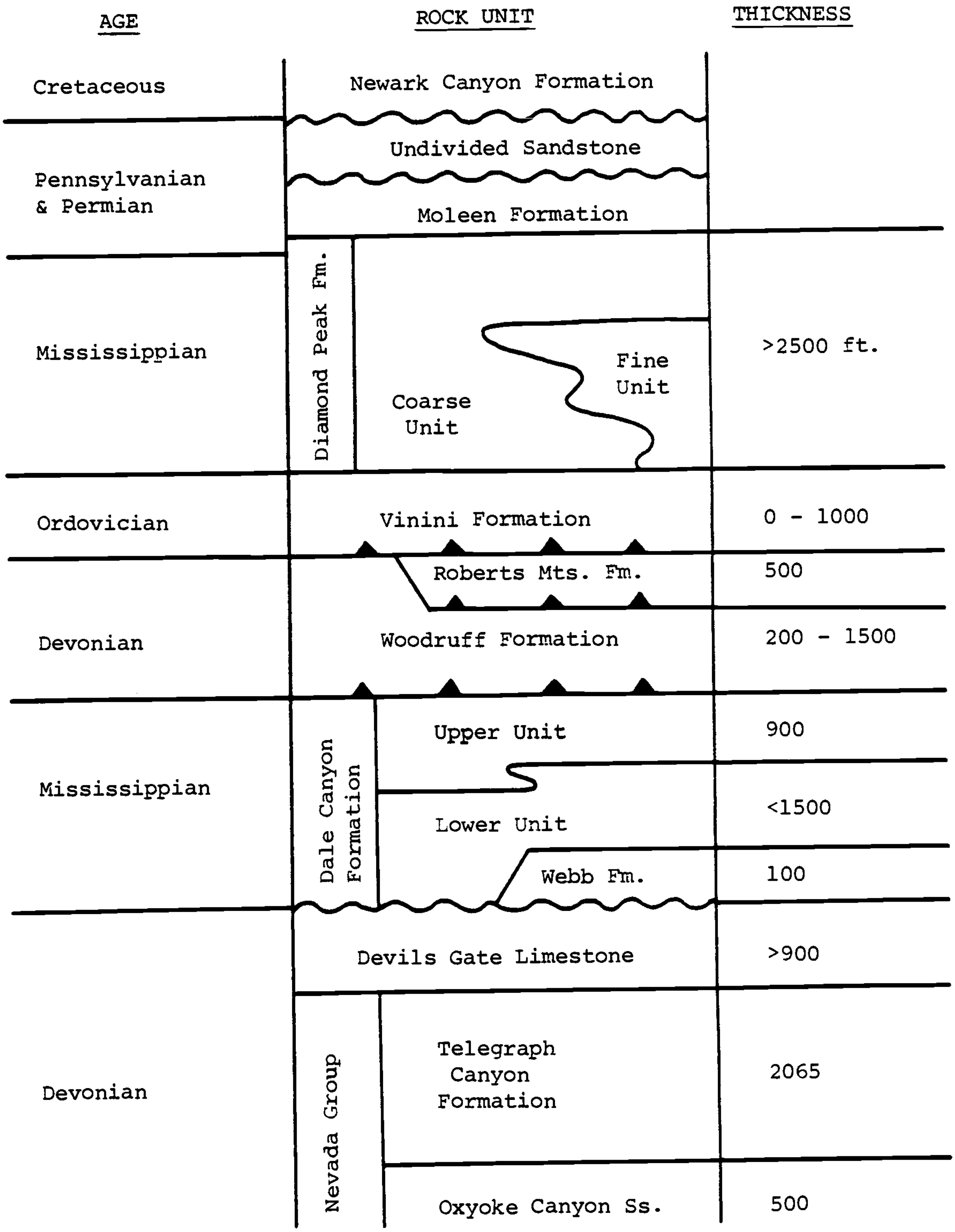


Figure 3. Summary stratigraphic section for the study area.

In an important paper, Smith and Ketner (1968) used stratigraphic relationships in the northern Pinyon Range to suggest an Early Mississippian age for the emplacement of the Roberts Mountains allochthon. This was the first solid evidence of an overlapping relationship. Recently, however, Ketner and Smith (1982) reinterpreted these relationships and suggested that allochthonous rocks in the Pinyon Range may not have been emplaced until sometime in the Mesozoic.

Johnson and Pendergast (1981) identified a number of areas where reinterpretation of the structure shows evidence of a Paleozoic emplacement. One of these is in the area mapped in this study. Smith and Ketner (1977, 1978) described the allochthonous rocks at Willow Creek as a flat sheet (klippe) lying on top of, and truncating, large-scale Mesozoic or Pennsylvanian folds in the Mississippian clastics of the Chainman Shale and Diamond Peak Formation. Johnson and Pendergast's (1981) reinterpretation suggests that the allochthon structurally overlies the clastic rocks mapped as Chainman Formation by Smith and Ketner (1978) and is depositionally overlain by clastics of the Diamond Peak Formation. Thus, the allochthon was interpreted to extend westward beneath the Diamond Peak rocks and to be folded in the same way. As it is generally accepted that rocks of the Diamond Peak Formation are in place here, this interpretation provides an overlapping relationship which dates emplacement as Early Mississippian (Osagean).

Methods and Terminology

Field work was carried out during the summer of 1981 with follow-up work during the springs of 1982 and 1983. Mapping was done at a scale of 1:15,840 using enlarged 15 minute quadrangles. Aerial photographs were used as an aid in determining structures. Samples were collected for lithologic and paleontological analysis. Fifty-seven thin sections were analyzed, and point counts were carried out on twenty-nine slides from the Mississippian clastic sequence. Thirteen samples were processed in formic acid for conodonts. Claudia Regier picked the conodonts from many of the residues. Dr. Gilbert Klapper of the University of Iowa identified and assigned ages to the conodont collections. Graptolite specimens were identified and dated by William B. N. Berry of the University of California at Berkeley.

The classification of Folk (1980) was used for siliciclastic rocks. Classification of carbonate rocks follows that of Folk (1962). Stratification and splitting properties are described using the terminology of McKee and Weir (1953).

GEOLOGIC SETTING

During the early to middle Paleozoic, the western margin of North America was dominated by the Cordilleran geosyncline. The geosyncline may have had its genesis during late Precambrian time, when, as Stewart (1972) and Stewart and Suczek (1977) have noted, there was a distinct change in the tectonic setting and sedimentation patterns along the continental margin. These authors suggest that this change was caused by the rifting away of a piece of continental crust. Sears and Price (1978) suggest that the rifted crust may be the Siberian platform in northeast Asia.

Two models have been presented for the depo-tectonic setting of the Cordilleran geosyncline. In the first model, the continent was bordered on the west by a marginal basin and island arc system (Churkin, 1974; Burchfiel and Davis, 1972, 1975; Dickinson, 1977; Speed and Sleep, 1982). Although this model provides a conventional explanation for sedimentary and tectonic events during the Paleozoic there is little evidence in Nevada of arc-derived volcanics or sediments. In the second model, deposition occurred along a tectonically stable margin (Stewart and Poole, 1974). This model is based on the similarity between western Paleozoic deposits and Mesozoic and Cenozoic deposits of the Atlantic margin of North America. Both have wide lateral extent and great lithologic uniformity. This model does allow for the development of a subduction zone and marginal sea during Devonian time prior to the Antler orogeny.

The sediments of the Cordilleran geosyncline have been characterized as having been deposited in three distinct lithofacies belts: (1) The eastern shallow-shelf assemblage, consisting of limestone, dolomite, and quartz arenite (miogeosynclinal deposits); (2) the transitional assemblage, including limestone, clastics, and chert; and (3) the western deep-basinal assemblage composed mainly of shale, chert, and siliceous mudstone (eugeosynclinal deposits) (Roberts et al., 1958; Smith and Ketner, 1968; Stewart and Poole, 1974). This scheme has proved convenient over the years, but now that more is known of Paleozoic paleogeography these three categories become too simplistic. Therefore, in this report, an attempt will be made to assign formations to specific depositional settings such as continental shelf, slope, or outer-shelf basin.

Deposition in the Cordilleran geosyncline continued until Late Devonian time when tectonic forces of the Antler orogeny compressed and uplifted the eugeosynclinal rocks (Roberts, 1951, 1964; Johnson and Pendergast, 1981). Siliceous rocks of the ocean basin and outer shelf were thrust relatively eastward over carbonate rocks of the continental shelf along the Roberts Mountains thrust, forming the Antler highland (Merriam and Anderson, 1942; Roberts et al., 1958; Smith and Ketner, 1968). A downwarping of the shelf occurred during late stages of emplacement and progressed eastward as the allochthon rode over the edge of the continent (Poole, 1974; Speed and Sleep, 1982). Early detritus from the Antler highland was shed into this flysch trough and accumulated as submarine fans. Some of these deposits were overridden by the allochthon during final stages of emplacement (Johnson and Pendergast, 1981; this report). The toe of the allochthon was buried by additional flysch deposits when movement on the thrust ended in mid-Early Mississippian (Osagean) time, as shown herein. Accumulation of clastic sediments eroded from the Antler post-orogenic highland continued into the early Pennsylvanian (Poole, 1974; Smith and Ketner, 1975; Johnson and Pendergast, 1981).

These events were followed by uplift and folding in the late Paleozoic and in the Mesozoic (Smith and Ketner, 1977). Large-scale folds in the Mississippian rocks at Willow Creek are attributed to tectonic activity of middle Mesozoic age by Smith and Ketner (1977). Basin and Range style block faulting affected the area during the Tertiary Period. Intrusive and volcanic activity accompanied Tertiary faulting and caused silicification and other alteration effects in the Paleozoic rocks of the area.

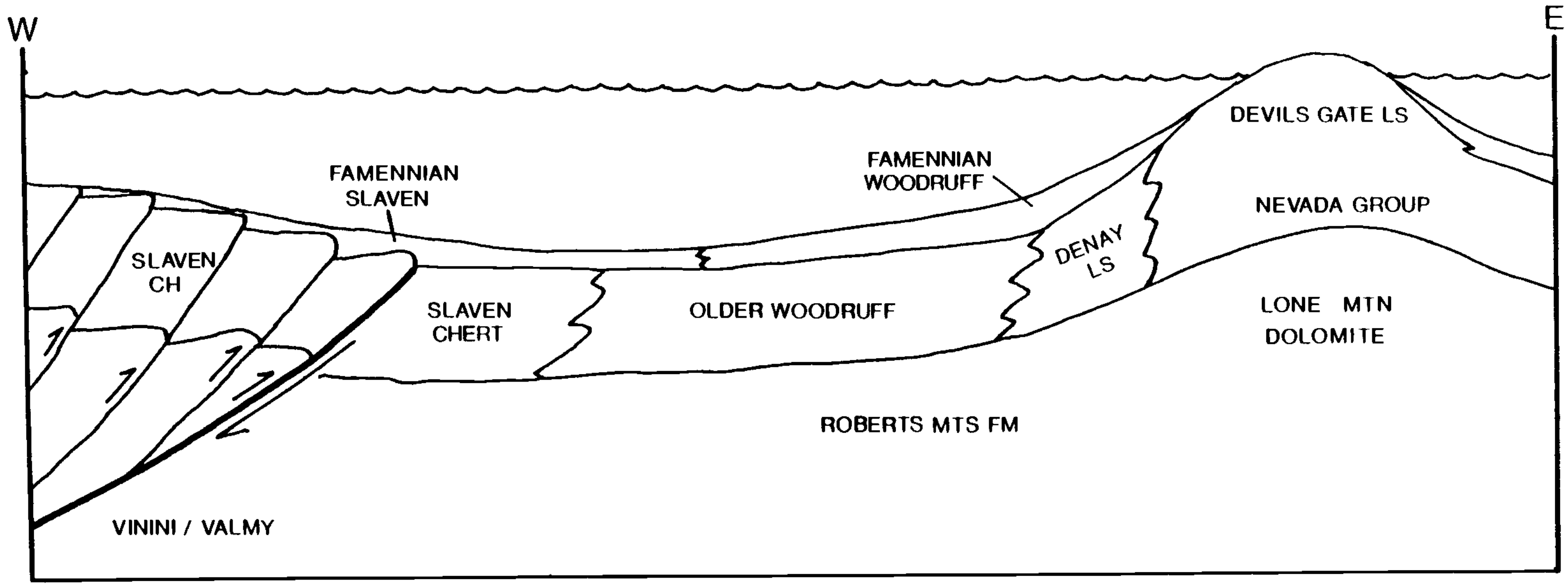


Figure 4. Hypothetical depiction of facies and structural relations during early or middle Famennian time, the time of deposition of the true Woodruff Formation and time of probable initial development of the Roberts Mountains allochthon.

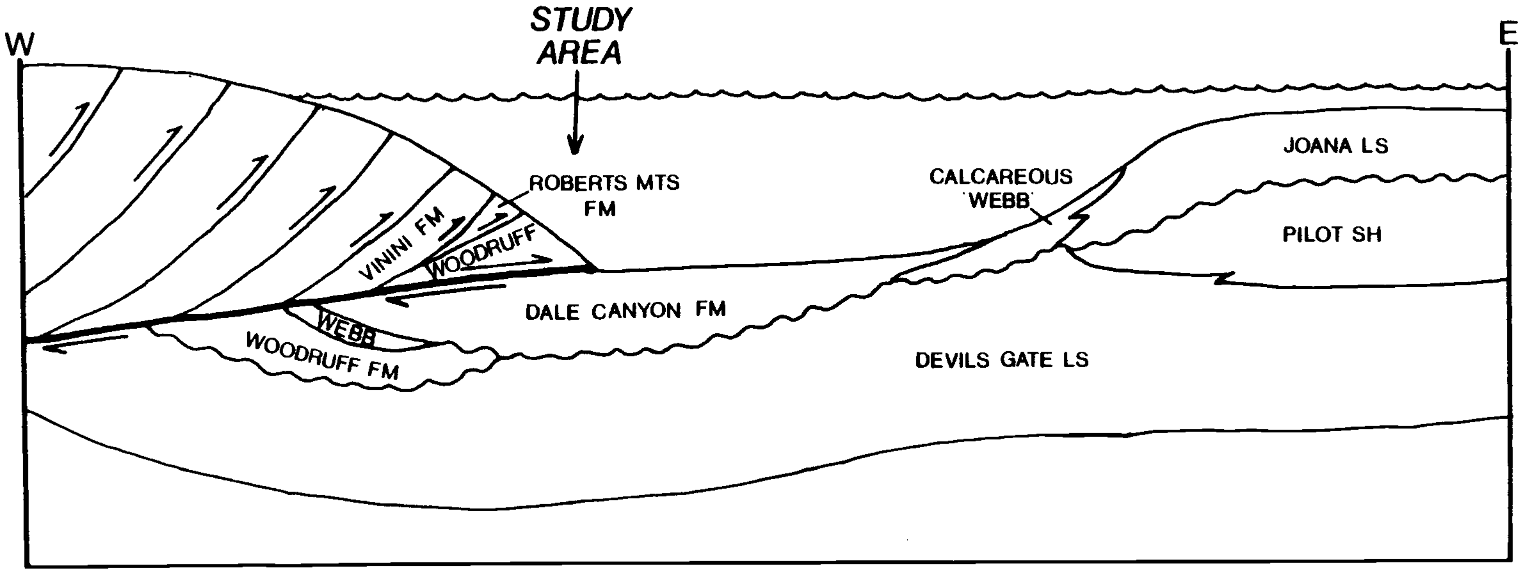


Figure 5. Hypothetical depiction of facies and structural relations during late Kinderhookian or early Osagean time, immediately after emplacement of the Roberts Mountains allochthon and before overlap deposition of the Mississippian Diamond Peak Formation.

VININI FORMATION

General Statement

The Vinini Formation was named by Merriam and Anderson (1942) for exposures along the Vinini Creek in the Roberts Mountains. It is considered to have been deposited in a basinal oceanic environment and has been assigned to the western assemblage of Roberts *et al.* (1958). In the study area it is part of the Roberts Mountains allochthon along with the Devonian Woodruff Formation and the Siluro-Devonian Roberts Mountains Formation. It lies in thrust contact over the Woodruff Formation and the Roberts Mountains Formation and is unconformably overlain by clastic rocks of the Mississippian Diamond Peak Formation.

Age

In the type area, the Vinini Formation is dated as Early to Middle Ordovician on the basis of graptolites (Merriam and Anderson, 1942). Graptolite collections taken by Smith and Ketner (1975) show the Vinini in the Willow Creek area to range in age from Lower to Upper Ordovician although some zones have not been recognized.

Lithology

Merriam and Anderson (1942) described two units in the Vinini Formation at the type area. Their lower unit consists of dark gray bedded quartzites, arenaceous limestones or calcareous sandstones, and finely laminated siltstones with volcanic flows and tuffs present locally in upper sections. The upper unit is made up of bedded cherts and black organic shales.

In the Willow Creek area, the Vinini most closely resembles Merriam and Anderson's upper unit. It consists of beds of chert and siliceous mudstone 2 to 10 cm thick, separated by thin layers of organic shale. The chert is generally black and weathers gray or tan, but in some places it exhibits brown banding and is somewhat translucent. Fine laminations are present in some beds and thin sections show abundant radiolarian molds filled with microcrystalline quartz (Figure 6). In some places the chert is impure and is best described as siliceous mudstone. The shale is black and flakey and, in some places, very carbonaceous. Shale makes up a minor portion of the formation, but weathers out easily and its chips make up much of the soil surrounding exposures.

There is also a lens of conglomerate in the northern part of the area made up of angular, pebble- to granule-size chert fragments in a cherty matrix. Gilluly and Masursky (1965) described similar beds in the Cortez Range and suggested a local source due to the angularity of the fragments and their lithologic similarity to the enclosing beds.

No thickness measurements of the Vinini Formation were possible due to the disrupted and disordered nature of the structure.

Structure

The internal structure of the Vinini is complex. Graptolite collections taken by Smith and Ketner (1975) show no orderly

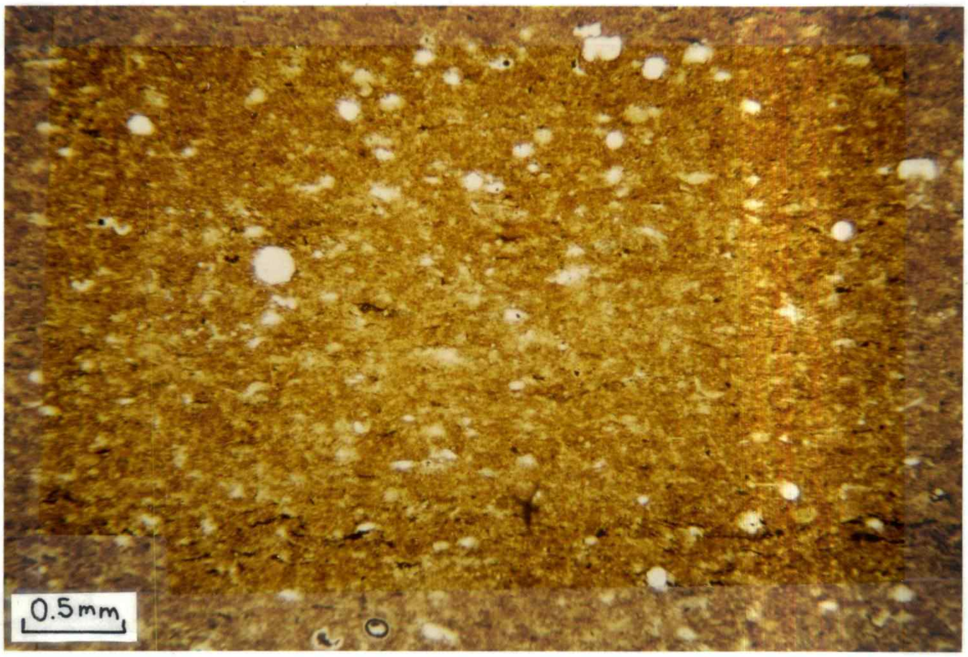


Figure 6. Photomicrograph of bedded chert. Note radiolarian molds and carbonaceous laminae. Vinini Formation. Ordovician. Plane light. NE¼ SW¼ Section 36, T.29N., R.52E.

stratigraphic succession, suggesting multiple thrust slices jumbled together. The rocks are cut by numerous closely spaced joints and small-scale open folds are common. Some tighter folds and isoclinal folds are present locally, but overall, bedding attitudes roughly parallel those of the surrounding formations.

At least part of the western contact of the Vinini with the Diamond Peak Formation is a normal fault. It appears that the Diamond Peak Formation has been faulted down with respect to the Vinini Formation. Attempts to expose the contact along Willow Creek uncovered fault gouge, and rocks along the contact to the north exhibit brecciation, alteration, and silicification suggesting that a conduit for hydrothermal fluids was created by faulting. The fault may not extend any farther north than the southern or middle part of section 13 (T29N, R52E) where the above indications disappear. A depositional contact exists on the northern contact of the Woodruff Formation and this should also be the case for the northern contact of the Vinini.

A small strip of the Vinini Formation is exposed just to the west of the main exposure. Abrupt vertical contacts along Willow Creek suggest that it is bounded by normal faults. It could logically have been faulted up from the extension of the Vinini below the Diamond Peak Formation (see Plate 2).

Depositional Environment

Although Ketner (1975) has suggested that Ordovician bedded cherts and shales need not have been deposited in deep water, most authors agree that the Vinini was deposited in a deep-water oceanic environment. The bathyal *Nereites* trace fossil assemblage has been recognized in the Vinini Formation in the Roberts Mountains by Chamberlain (*in* Stanley *et al*., 1977). Churkin (1974) has suggested that Ordovician bedded cherts were deposited below the calcium compensation depth due to concentrations of siliceous microfossils and chitinophosphatic graptolites and the lack of calcareous microfossils. The calcium compensation depth is at about 13,000 feet (4000 meters) in modern seas, but there is no evidence that such depths were typical of the Paleozoic. Bottom conditions may also have been anoxic as evidenced by the lack of bioturbation in the bedded cherts.

ROBERTS MOUNTAINS FORMATION

General Statement

The Roberts Mountains Formation was named by Merriam (1940) for exposures on the west side of Roberts Creek Mountain where it is the western, deep water equivalent of the Lone Mountain Dolomite. It consists primarily of laminated, graptolite-bearing limestones and dolomites and was probably deposited in an outer shelf basin.

In the study area, the Roberts Mountains Formation occurs in a small exposure along the northern bank of Willow Creek. Its lithology includes a sequence of interbedded calcareous shale and black chert and a sequence of dolomitic marl and silty dolomite. Both sequences are thinly bedded. This exposure is here included in the allochthon as lying in a small thrust slice between the Vinini and Woodruff Formations.

Age

Graptolite collections taken by Smith and Ketner (1975) from the dolomitic marl and silty dolomite sequence were identified as belonging to the *Monograptus uniformis* Zone of earliest Devonian (Lochkovian) age. Graptolites taken by this writer from the calcareous shale were identified by W. B. N. Berry (written communication, 1982) as *Monograptus birchensis* Berry and Murphy. This species ranges in age from latest Silurian (Ludlovian) to Lochkovian. The age range of the Roberts Mountains Formation in the type locality is from the

Llandovery (Early Silurian) to early Lochkovian (Johnson _et al._, 1973).

Lithology

Smith and Ketner (1975, p. 32) described the Roberts Mountains Formation along Willow Creek as "very dark brown to black shaly and platy carbonaceous laminated silty dolomite and dolomitic marl, which weather dark gray to black." They estimated the thickness to be between 200 and 500 feet (61 and 152 m).

Also, noted by this writer, is a sequence of platy calcareous and carbonaceous shale with lesser amounts of interbedded black chert (Figure 7). The calcareous shale is dark-gray weathering, medium to light gray and light brown and occurs in beds 2 to 10 cm thick. Weathered surfaces commonly show fine laminations which resulted from concentrations of organic matter or oxidizing pyrite crystals within the rock. The beds break easily into platy fragments 2 to 15 cm across which litter the slopes. Graptolites are numerous in places. The black chert occurs as beds 4 to 15 cm thick which alternate sporadically with the calcareous siltstone. The chert beds are more numerous towards the bottom of the sequence. The thickness of this sequence is estimated to be at least 200 feet (61 m). Cover and the possibility of structural complications prevented precise measurements.

Figure 7. Platy calcareous and carbonaceous shale. Note limonite stains after pyrite. Roberts Mountains Formation. Latest Silurian or earliest Devonian. SW¼ NE¼ section 36, T.29N., R.52E.

Structure

Smith and Ketner (1975) stated that they believed this exposure of the Roberts Mountains Formation was allochthonous, but that it might not be a part of the upper plate of the Roberts Mountains thrust. On their 1978 map they showed it as two small thrust sheets lying on top of the main thrust plate. Perhaps they thought it arrived at a later time. Ketner later said (personal communication, 1980) that these rocks might be in place here. In this report, however, the Roberts Mountains Formation exposed along Willow Creek is mapped as lying in a single thrust slice between the Woodruff Formation and the Vinini Formation, therefore arriving as part of the thrust package. Bedding attitudes in the Roberts Mountains Formation are highly variable but, in general, they conform to attitudes in the surrounding allochthonous rocks. There seems to be a higher than locally-normal degree of folding in the Woodruff and Vinini rocks surrounding the Roberts Mountains Formation which might be accounted for by the emplacement of this anomalous sliver.

The internal structure of the thrust slice is not known in detail because of the restricted extent of the exposure; however, it appears that the dolomitic marl described by Smith and Ketner (1975) overlies the calcareous shale described here. The contact between the two sequences is not visible, but it could be depositional since the dolomitic marl shows a slightly younger-age graptolite assemblage than does the calcareous shale.

Depositional Environment and Regional Significance

Smith and Ketner (1975) assigned the Roberts Mountains Formation to the transitional assemblage due to its combination of carbonates usually associated with shallow water environments and its deeper-water dark, shaly, graptolitic rocks. Winterer and Murphy (1960) have shown that the Lone Mountain Dolomite grades westward into the Roberts Mountains Formation in the Roberts Mountains. They suggested that the Lone Mountain Dolomite represents a reef complex and that the Roberts Mountains Formation represents the associated reef-flank, off-reef, and basin facies. This arrangement explained the abrupt transition from shallow-water to deep-water facies in the rocks.

Matti and McKee (1977) suggested that the Roberts Mountains Formation was deposited in an outer-shelf basin with restricted circulation and anoxic bottom conditions as evidenced by the presence of abundant carbonaceous material and lack of bioturbation. They suggested water depths of 100-250 m for this basin. Mullens (1980) argued for water depths of not more than 100 m because of evidence of scattered reefs within the basin and at its western edge, especially during the Late Silurian and Early Devonian (Mullens, 1980, p. 38). Johnson and Murphy (1984) cite physical evidence such as debris flows and graded beds in suggesting a slope-and-basin "deep" water environment for the Roberts Mountains Formation. According to their model, the basin was formed in late Llandoverian time by normal faulting along the shelf edge (Johnson and Potter, 1975 ; Johnson and Murphy, 1984, p. 1350). This faulting may have been the result of reactivation of normal faults created during Precambrian rifting (Stewart, 1972).

Other allochthonous exposures of the Roberts Mountains Formation include one about three miles south of Willow Creek in the Pinyon Range. It has a lithology and age similar to the Willow Creek exposure and is also a small thrust slice between the Woodruff and Vinini Formations (Visconti, 1982).

Most other exposures are autochthonous, however, Murphy et al. (1984) identified a folded sequence of shale and limestone in the Roberts Mountains which they suggest was emplaced in its present position by the Roberts Mountains thrust. The shale contains graptolites of Early Devonian age, perhaps slightly younger than the upper Roberts Mountains Formation but correlative to the upper Lone Mountain Dolomite. This is the nearest and most similar example of outer shelf rocks that have been displaced by the Roberts Mountains thrust.

WOODRUFF FORMATION

General Statement

The Devonian Woodruff Formation was named by Smith and Ketner (1968) for exposures along Woodruff Creek in the northern Pinyon Range. All known exposures are allochthonous. Smith and Ketner (1968) assigned these rocks to the western, siliceous assemblage of Roberts et al. (1958); however, deposition is now thought to have occurred in a slope or foreland trough environment (Murphy et al., 1984).

In the study area, the Woodruff Formation consists of interbedded chert, siliceous mudstone, and siliceous shale; dolomitic mudstone and siltstone; and lenses of siliceous dolomite and sandy limestone. The interbedded chert and siliceous mudstone and the dolomitic mudstone and siltstone have been mapped separately. Although interbedded in some places, most sequences were found to be dominantly of one or the other lithology. Lenses of siliceous dolomite and sandy limestone occur in both units.

The Woodruff Formation lies at the base of the Roberts Mountains allochthon in thrust contact with the underlying Dale Canyon Formation. It is structurally overlain by the Roberts Mountains Formation and the Vinini Formation to the west and is depositionally overlain by the Diamond Peak Formation to the north.

Age

Four conodont collections were obtained from the Woodruff Formation at Willow Creek. Two collections from limestone beds to the north of Willow Creek yielded faunas assigned to *kockelianus* Zone and the lower part of the *ensensis* Zone of the Eifelian (lower Middle Devonian). Two collections from siliceous dolomite beds to the south of Willow Creek yielded faunas assigned to the *marginifera* or *velifer* Zones of the Famennian (Late Devonian). Smith and Ketner (1975) also collected conodonts from a limestone bed to the north of Willow Creek which yielded faunas of earliest Late Devonian age (Frasnian). In the type area, the Woodruff is dated as Famennian on the basis of goniatites of the genus *Platyclymenia*.

Lithology

Laminated Quartz-Silty Dolomitic Mudstone and Siltstone

This rock type includes beds with variable amounts of quartz silt, dolomite, and clay in a chert matrix. The color is tan to dark gray, weathering tan, buff, or light gray. Bedding is generally 2 cm or less and most beds are finely laminated in layers 1 mm or less thick. Laminations are due to concentrations of organic matter, iron oxide, and pyrite; or in more dolomitic beds, to concentrations of coarser dolomite rhombs and quartz silt grains along bedding planes. Beds break into platy or blocky fragments 1 to 5 cm across which litter the slopes (Figure 8).

Thin section study reveals that the quartz silt grains are subrounded to angular and range in concentration from less than 5% to 45%. Dolomite crystals range in concentration from 0% to 55% and are generally associated with more carbonaceous laminations suggesting that they represent replacement after argillaceous lime mud. It is assumed that most of the dolomite is secondary, although Smith

Figure 8. Laminated quartz-silty dolomitic siltstone. Note platy fragments and poor exposure. Woodruff Formation. Devonian. SW¼ SE¼ section 24, T.29N., R.52E.

and Ketner (1975, p. 77) suggest that some crystals may be detrital due to evidence of sorting.

Limestone

Two lenses of limestone were identified in the Woodruff Formation. One occurs in a sequence of bedded chert and the other occurs in the quartz-silty dolomitic mudstone and siltstone. Both are less than 50 feet (15 m) thick. The limestone is thin-bedded, gray, and sandy in places (Figure 9). Thin sections of sandy beds show a quartz sand content of up to 30%. Quartz grains are angular to subrounded and commonly occur in concentrations along bedding planes, forming laminations a few millimeters thick, or less. Dolomite rhombs are present but rare.

Calcite grains are generally intergrown, suggesting origin by recrystallization during diagenesis, but others appear to have been rounded during transport and are concentrated in sandy layers. The matrix is lime mud (Figure 10).

Chert and Siliceous Mudstone

The chert is gray to black and weathers black or gray. Much of it contains silt, clay minerals, and carbonaceous material in varying amounts. Siliceous mudstone is a name used here for cherty rock having impurities roughly exceeding 15-20% (see Ketner and Smith, 1963). This nomenclature seems necessary because, although these rocks appear somewhat cherty, they also have a significant clastic content suggesting a more active depositional environment. They also lack the opalescent luster of clean cherts. The siliceous mudstone weathers

Figure 9. Thin bedded limestone of Woodruff Formation. Devonian. SW¼ SW¼ section 18, T.29N., R.53E.

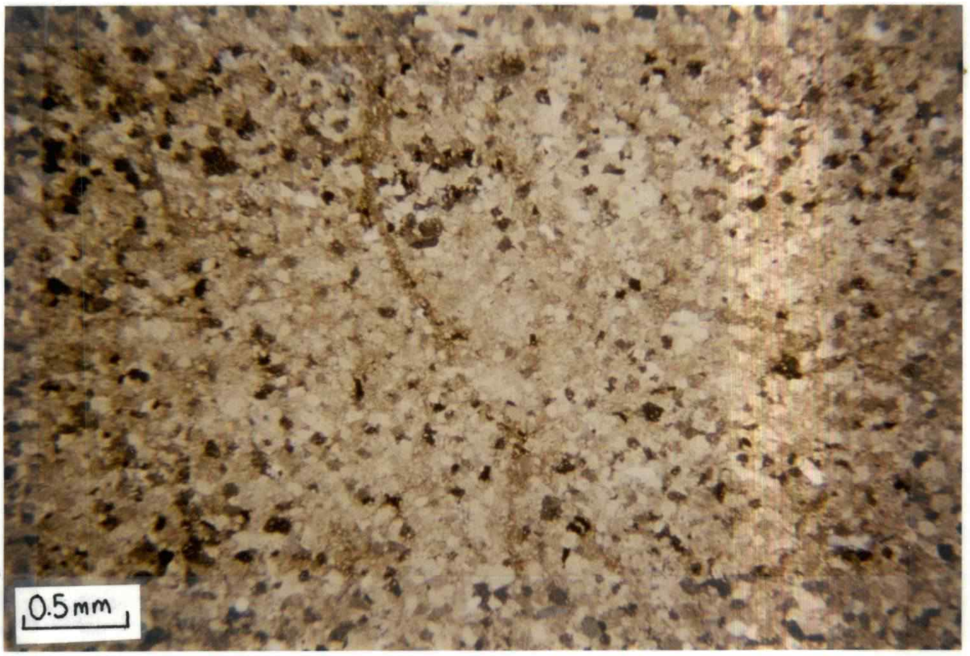


Figure 10. Photomicrograph of limestone from Woodruff Formation. Devonian. Crossed nicols. SW¼ SW¼ section 18, T.29N., R.53E.

to a light gray or buff. Thicknesses of chert beds range from 2 to 10 cm whereas the siliceous mudstone tends to occur in thinner beds, 1 to 5 cm thick. Both lithologies contain scattered thin stringers of cleaner chert which weathers dark gray to black. White-weathering stringers were also seen on weathered surfaces, but could not be identified on fresh surfaces or in thin section. They may represent concentrations of clay minerals or a different type of clay mineral. Thin sections of chert and siliceous mudstone showed numerous radiolarian molds, abundant carbonaceous material, and some pyrite (Figure 11).

Round nodules or concretions are present in places. They range in size from 1 to 8 cm across. Most small ones exhibit concentric layering and weather black, or have white and black concentric bands. They appear cherty on fresh surfaces although some white-weathering bands are slightly punky. The white bands may contain some phosphate as the nodules resemble phosphatic nodules described by Smith and Ketner (1975, p. 27) in Lower Devonian "Woodruff" siltstones which contain fossils such as plant spores and bone fragments in the northern Pinyon Range.

Siliceous shale was noted in places interbedded with both the chert and the siliceous mudstone. Shaly rocks may be more prevalent than was noted, but are not well exposed due to their relatively rapid weathering and slope-forming characteristics.

Siliceous Dolomite

The siliceous dolomite is dark gray to black and weathers orange-tan (Figure 12). Beds range in thickness from 3 cm to 20 cm.

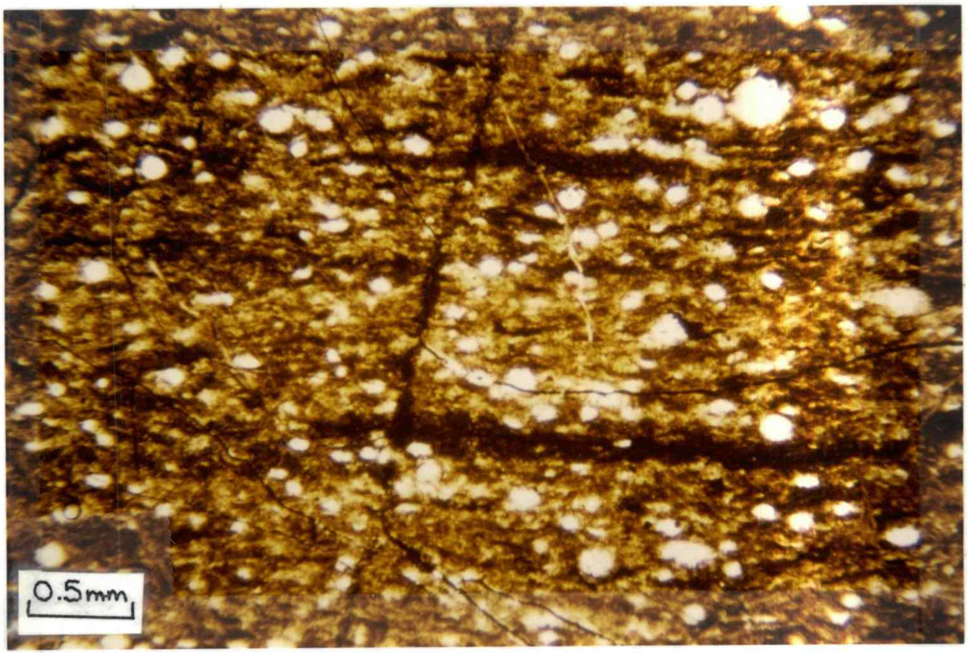


Figure 11. Photomicrograph of bedded chert. Note abundant radiolarian molds and dark color due to carbonaceous material. Woodruff Formation. Devonian. Plane light. SW¼ NE¼ section 20, T.29N., R.53E.

Figure 12. Siliceous dolomite from the Woodruff Formation. Note dark color and faint laminations. Devonian. NW¼ NW¼ section 19, T.29N., R.53E.

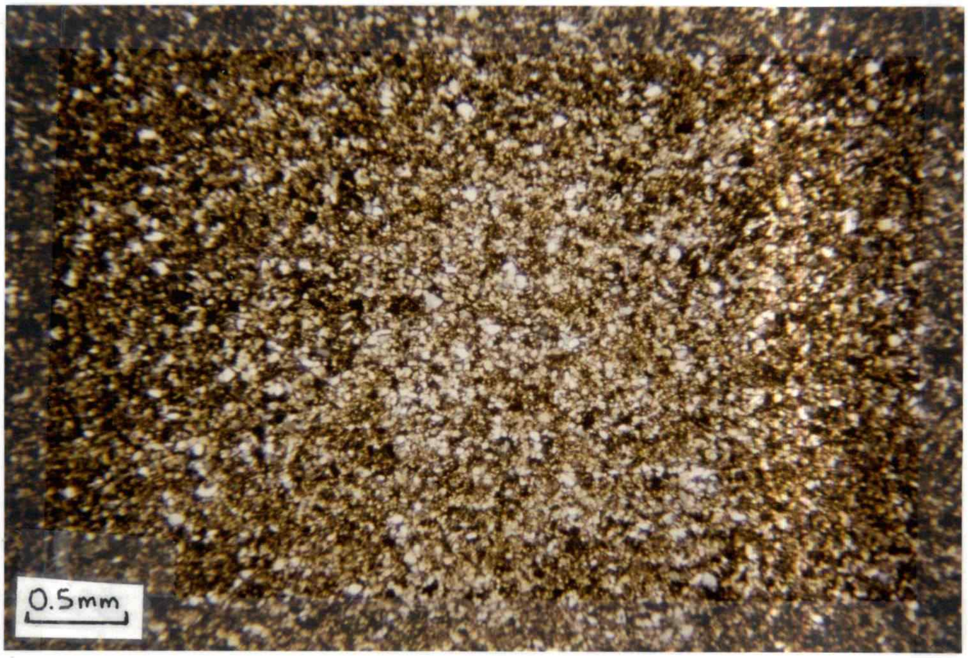


Figure 13. Photomicrograph of siliceous dolomite. Note abundant quartz silt. Woodruff Formation. Devonian. Crossed nicols. NW¼ NE¼ section 36, T.29N., R.52E.

Faint laminations are visible on fresh surfaces. Thin section study reveals a fairly structureless mosaic of angular to subangular quartz silt (45-50%) and dolomite crystals (50-55%) cemented by carbonaceous dolomite (Figure 13). Scattered stringers of carbonaceous material form discontinuous laminations 1 or 2 mm thick. Shaly intervals are present in this lithology as well.

Several samples were taken in the quest for conodonts, but only two, from south of Willow Creek, yielded diagnostic forms.

Structure and Contact Relations

Deformation in the Woodruff Formation includes small-scale open folds and isoclinal folds (Figure 14), moderate fracturing, and large-scale folds. Much of the small-scale folding is attributed to thrusting during the Antler orogeny. Large-scale folds seem to conform to deformation that includes the younger Paleozoic rocks surrounding the allochthon. This is especially visible in aerial photographs.

The lower contact of the Woodruff Formation is not exposed, but it is assumed to be a thrust because the Devonian Woodruff overlies the Mississippian Dale Canyon Formation. In the northwest corner of section 30 (T29N, R53E), erosion has exposed a small window of Dale Canyon sandstone. The four isolated exposures of the Woodruff Formation overlying the Dale Canyon Formation are assumed to be erosional remnants that were once attached to the main thrust sheet.

On its west side, the Woodruff is overlain by the Roberts Mountains Formation and the Vinini Formation. These contacts are also assumed to be thrust contacts because of inverted age relationships.

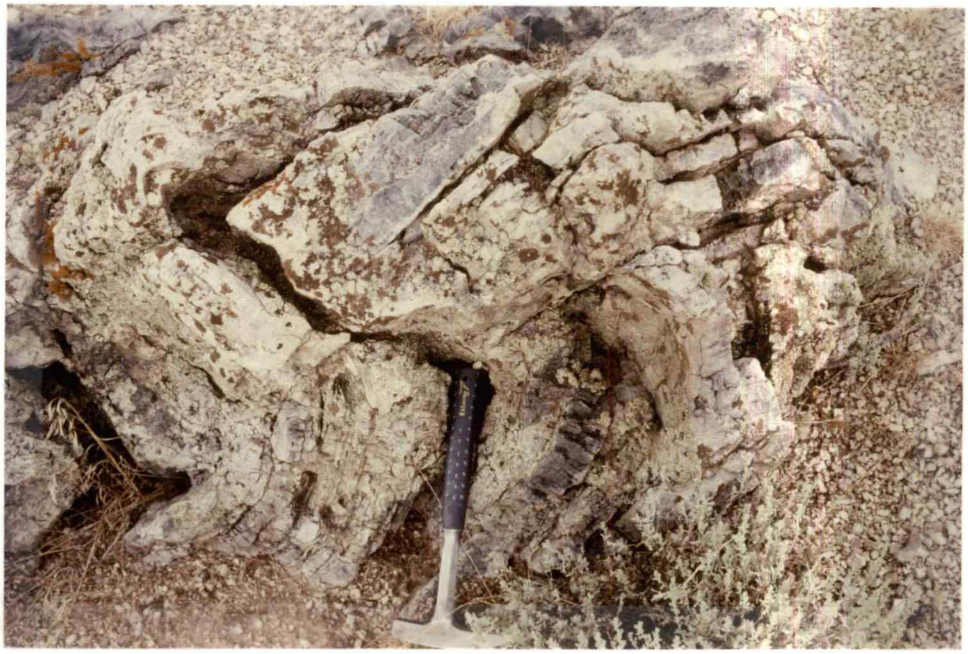


Figure 14. Tight small to medium scale folding in bedded chert of the Woodruff Formation. Structure probably produced during thrusting. Devonian. SW¼ SW¼ section 18, T.29N., R.53E.

To the north, the Woodruff is overlain depositionally by the Diamond Peak Formation. There is an exposure of this contact in the northeast corner of section 20 (T29N, R53E) (Figures 15 and 16). Smith and Ketner (1975, 1978) mapped this contact as a thrust fault, but this exposure shows clearly that the contact is not faulted. The contact is nearly vertical here, but bedding in the Diamond Peak Formation and the Woodruff Formation conform to this attitude. Local structure shows the contact to be on the steeply dipping limb of one of a succession of tight, large scale folds trending northwest and having nearly vertical axial planes.

Depositional Environment and Regional Significance

The Woodruff Formation was probably deposited in moderate to deep water west of the carbonate shelf edge. Presence of fine laminations along with abundant organic material and the lack of bioturbation indicate anaerobic bottom conditions.

The Woodruff of Smith and Ketner (1968, 1975) includes rocks that span most of Devonian time. However, Johnson and Pendergast (1981) suggested that only rocks of Late Devonian age such as those at the type area should be given the name Woodruff. At the type area, the Woodruff is depositionally overlain by siliceous rocks of the Mississippian Webb Formation. Johnson and Pendergast (1981, p. 655) suggested that the Famennian Woodruff and siliceous Webb were deposited atop the allochthon and in the foreland trough during the initial stages of the Antler orogeny. Rocks of Early and Middle Devonian age assigned to the Woodruff Formation are thought to be too

Figure 15. Outcrop exposure of depositional contact between the Devonian Woodruff Formation of the allochthon (left of hammer) and the Mississippian Diamond Peak Formation of the overlapping flysch sequence (right of hammer). Looking northwest. SE¼ NE¼ section 20, T.29N., R.53E.

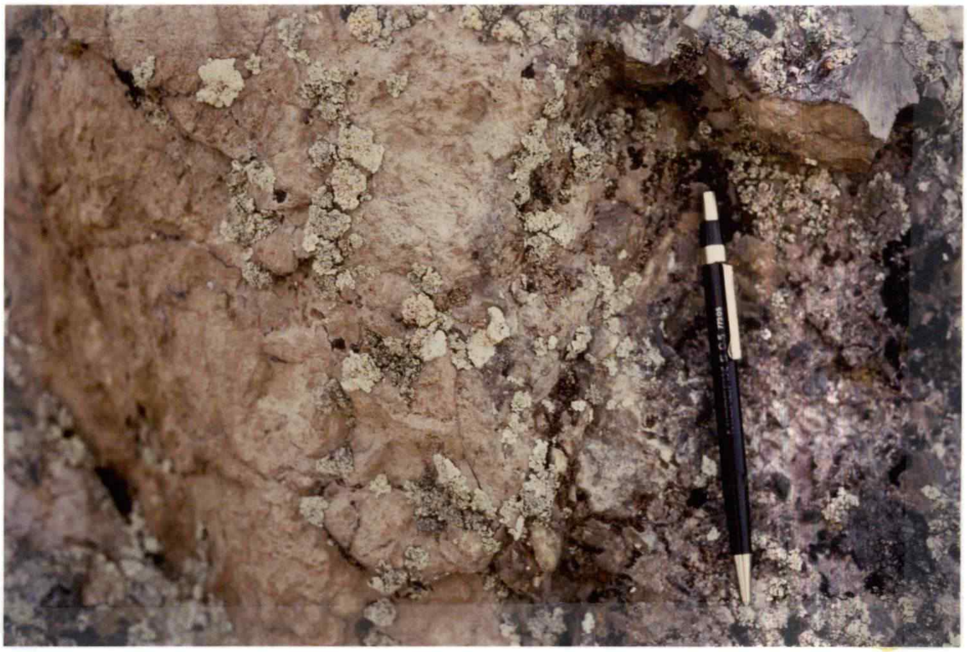


Figure 16. Close-up of depositional contact between Devonian Woodruff Formation (right) and Mississippian Diamond Peak Formation (left) shown in Figure 15. Looking southwest. SE¼ NE¼ section 20, T.29N., R.53E.

old to have the same depositional history as the type Woodruff (Johnson and Pendergast, 1981, p. 655).

In the study area, the Webb formation is absent. It may be that the Famennian Woodruff at Willow Creek was deposited to the west of rocks of the same age at the type area and did not later receive sediments of the Webb Formation. Murphy et al. (1984) described a similar situation in the Roberts Mountains where Famennian age rocks similar to the type Woodruff have been thrust over the Webb Formation.

The Middle Devonian rocks assigned to the Woodruff at Willow Creek may represent an imbricate slice that was picked up by the allochthon before it reached the site of the Famennian age Woodruff rocks. The younger Woodruff rocks may have then been picked up as an additional slice forming the new base and lowest slice at the time of final emplacement. Map locations of older and younger conodont collections do not reveal which part of the Woodruff overlies the other, however.

Although the siliceous Webb almost certainly had a western source (Ketner and Smith, 1982, p. 302; Murphy et al., 1984), the Woodruff Formation may have derived its sediment from the east. The bedded cherts and laminated siltstones resemble older eugeosynclinal or transitional rocks deposited before the Antler orogeny began and the more detrital beds contain mostly quartz silt and sand, not chert fragments as might be expected if they were derived from the west.

It is difficult to pinpoint the exact depositional site for the Woodruff rocks in the study area. A continental slope environment seems most likely; however, it is unclear how much of an effect development of the Antler highland and foreland trough was having on sedimentation patterns on the slope by Famennian time.

NEVADA GROUP

The Nevada Group includes rocks deposited in shallow water on the continental shelf. The name was first used by King (1878) and was redefined by Merriam (1940). It was divided into five members in the Eureka area by Nolan, Merriam, and Williams (1956). These were elevated to formation rank by Hose et al. (1982). Carlisle et al. (1957) divided the Nevada Formation into three members in the Sulphur Spring Range and southern Pinyon Range. Smith and Ketner (1975) also designated three members in the Pinyon Range. Their lower two members, the Beacon Peak Dolomite and the Oxyoke Canyon Sandstone, follow the nomenclature of Nolan et al. (1956). Their uppermost member, the "upper dolomite member," is essentially the same as the Telegraph Canyon Member of Carlisle et al. (1957). Only the upper two members of Smith and Ketner (1975) occur in the study area. The names Oxyoke Canyon Sandstone and Telegraph Canyon Formation are used for them here. This follows the terminology of Visconti (1982) whose study area adjoins to the south.

The Nevada Group in the study area is not well dated due to the scarcity of fossils. The Oxyoke Canyon Sandstone is dated as Lower and Middle Devonian by Kendall et al. (1983). Stromatoporoid genera of Middle and Late Devonian age were collected from the Telegraph Canyon Formation by Smith and Ketner (1975, p. 19). Thickness of the Nevada Group as a whole is estimated at about 3200 feet (975 m) by Smith and Ketner (1975, p. 19).

Oxyoke Canyon Sandstone

The Oxyoke Canyon Sandstone is exposed in the southeastern corner of the study area. Its lower contact is out of the mapped area. The upper contact is faulted on its northeastern flank and partially faulted to the west. Where the upper contact is not faulted it is gradational with the overlying Telegraph Canyon Formation. Smith and Ketner (1975, p. 22) report measured thicknesses of zero to 415 feet (126 m) in the Pinyon Range and suggest a maximum thickness of 600 to 700 feet (183 to 213 m).

The Oxyoke Canyon Sandstone consists of pink, white, and gray dolomitic quartz sandstone and quartzite. It is thin- to thick-bedded and crossbedding was noted in one outcrop.

Telegraph Canyon Formation

The Telegraph Canyon Formation is exposed in the southeastern part of the study area where it overlies the Oxyoke Canyon Sandstone. It crops out as ledges or forms slopes that in some places are covered with talus. The upper contact is conformable with the Devils Gate Limestone and has been placed where the dolomite of the Telegraph Canyon Formation changes to limestone in the sequence. This is a fairly sharp boundary, which is easily followed in the field as the dolomite is darker in color, but it cuts across bedding and the rock types interfinger with one another. This interfingering relationship is well displayed in the map pattern, especially in section 5 (T28N, R53E). Thickness is somewhat variable but Smith and

Ketner (1975) report a measured thickness of 2065 feet (625 m) from the exposure in the study area.

The Telegraph Canyon Formation consists of medium- to thick-bedded brown, pinkish brown, and gray medium crystalline dolomite. In some places, gray beds alternate with brown beds as reported by Carlisle *et al*. (1957, p. 2184) and Smith and Ketner (1975, p. 24), but brown and pinkish-brown beds seem to be dominant.

Silicification has occurred in places, especially along normal faults. Most silicification is confined to the Devils Gate Formation, however, and is discussed in detail in that chapter.

DEVILS GATE LIMESTONE

The Devils Gate Limestone was introduced as a formation by Merriam (1940) who defined it almost wholly on a faunal basis as the upper part of the Nevada Limestone of Hague (1892). The type area is at Devils Gate just to the northwest of Eureka. Nolan, Merriam, and Williams (1956) suggested that there was a sufficient lithologic basis for establishing the Devils Gate Limestone as a rock-stratigraphic unit. They designated the Devils Gate in the Eureka area as the sequence of dominantly limestone beds between the underlying Nevada Group dolomites and the overlying Pilot Shale.

In the study area, the Devils Gate Limestone is exposed to the south and east of Willow Creek. Much of the upper contact of the Devils Gate has been faulted, but in the southern part of the area, it is depositionally overlain by the lower, shaly member of the Dale Canyon Formation. To the east of Willow Creek, in sections 28 and 29 (T29N, R53E), Smith and Ketner (1975) identified a small lens of silty limestone of the Webb Formation as depositionally overlying the Devils Gate. The upper contact of the Devils Gate is reported to be an unconformity in the Pinyon Range (Smith and Ketner, 1975, p. 25, 34; Carlisle et al.,1957, p. 2184). Uplift and erosion of the shelf is attributed to deformation during early stages of the Antler orogeny (Smith and Ketner, 1975, p. 34; Johnson and Pendergast, 1981, p. 650).

The lithology of the Devils Gate Limestone is characterized by medium- to thick-bedded medium to light gray fine-grained limestone which weathers gray and bluish gray. Fine laminations are common as are beds containing concentrations of "spaghetti" of the genus Amphipora (Smith and Ketner, 1975, p. 25). Beds of dolomite are present, but rare.

Smith and Ketner (1975) report a measured thickness of 940 feet (287 m) for the Devils Gate in section 5 (T29N, R53E) of the study area; however, the upper contact there has been remapped as a fault in this study so this is a minimum thickness. The thickness of the Devils Gate in the type area is reported to be 2065 feet (629 m) (Merriam, 1940, p. 17).

Fossil collections taken by Smith and Ketner (1975) show the Devils Gate to range in age from late Middle to early Late Devonian. Younger faunas of late Late Devonian age were identified in the Eureka area (Merriam, 1940, p. 9, 16; Nolan et al., 1956, p. 50-52). Smith and Ketner (1975) suggest that younger beds may be missing from the Pinyon Range due to erosion or were faulted out, but Visconti (1982) shows the Pilot Shale to occupy the latest part of the Devonian to the south of the study area in the Sulphur Spring Range and suggests it was eroded to the north, in the Pinyon Range.

Silicification

Replacement of limestone of the Devils Gate Formation by silica has produced large masses and strips of jasperoid in the study area. Lovering (1972, p. 3), following the definition of Spurr (1898), describes jasperoid as the "epigenetic siliceous replacement of a previously lithified host rock," limestone and dolomite being the most common hosts.

The jasperoid in the Devils Gate occurs along normal faults and is presumed to be the result of the introduction of silica-rich hydrothermal fluids along these faults. The age of replacement is not known, but it must have occurred during or after faulting. Most of these faults are assumed to have formed during late Tertiary Basin and Range faulting. The mineralizing fluids may have emanated from or may have been heated and circulated by a rhyolitic stock which exists only about a mile to the east of this part of the study area. Smith and Ketner (1978) date this stock as early Oligocene.

The jasperoid varies in color from dark red to pink, brown, yellow, and gray. Dark red is by far the most prevalent color. Outcrops tend to stand out as they are resistant to weathering and do not support growths of pinyon pine and juniper as does the limestone (Figure 17). Near the faults, silica has totally replaced the limestone, but away from the faults large and small blocks of unaltered limestone can be found within the jasperoid (Figure 18) giving the impression of brecciation of the limestone and silicification along close-set fractures. The original texture of the limestone is no longer discernible where complete replacement has occurred.

Silicification has also occurred in the dolomite of the Telegraph Canyon Formation, but is not as common as in the Devils Gate Limestone. The jasperoid has been given its own map pattern (see

Figure 17. Silicified ridge of the Devonian Devils Gate Limestone. Note dark color and relative resistance to erosion. Silicified portion of ridge is approximately 1500 feet long. Looking north. Center of section 28, T.29N., R.53E.

Figure 18. Close-up of brecciated and partially silicifed Devonian Devils Gate Limestone. Note large fragments of limestone containing abundant white calcite veins, massive jasperoid in upper left. NW¼ NE¼ section 29, T.29N., R.53E.

Plate 1) as it overlaps the boundary between the Telegraph Canyon Formation and the Devils Gate Formation in many places and it was not possible to tell what the original rock type was where silicification had occurred.

WEBB FORMATION

A small lens of siliceous mudstone and limestone overlying the Devils Gate Formation in sections 28 and 29 (T29N, T53E) has been mapped by Smith and Ketner (1975, 1978) as belonging to the Webb Formation. The occurrence is about 500 feet long and is cut by a fault on its north side. This assignment seems somewhat problematic as the rocks are poorly exposed and they resemble rocks of other formations exposed nearby, such as the Dale Canyon Formation and the Pilot Shale. Also, no fossils have been taken from them so their age is not known. There are, however, similar, though more extensive, exposures of the Webb, as mapped by Smith and Ketner (1975, 1978), approximately 7 miles to the north near Trout Creek and Lee Canyon.

The Webb Formation was named by Smith and Ketner (1968) for exposures near Webb Creek in the northern Pinyon Range where it was dated as Early Mississippian, Kinderhookian (see Dombrowski Sample 2, in Johnson and Pendergast, 1981, p. 656). Lithologies near Webb Creek include thin-bedded siliceous mudstone and argillite with a few sandstone layers. To the south, the Webb contains a significant amount of silty limestone. Ketner and Smith (1982) have restricted the term Webb to the siliceous mudstone sequences like those at the type area. They suggest that this Webb is allochthonous. According to their model, the siliceous Webb was deposited on the western edge of the Antler flysch trough with a source on the Antler highland and was thrust into its present position at a later time. They go on to say that the more southerly "Webb" sequences containing limestone are autochthonous and implicate an eastern source for them. The mudstone and limestone sequence at Willow Creek belongs to the eastern autochthonous "Webb" of Ketner and Smith (1982).

The lithology of the "Webb" at Willow Creek consists of thin-bedded, dark gray to black siliceous mudstone with at least one 30-60 cm thick bed of medium- to dark-gray, tan-weathering limestone. Also, an exposure of thin-bedded, fine-grained silicified rock with a pinkish cast and liesegang banding was found near the fault on the north side of the exposure. It resembles deposits of silicified Pilot Shale identified by Visconti (1982) to the south of the study area in the Sulphur Spring Range.

Although it seems likely that the autochthonous "Webb" was deposited in deep water due to its thin bedding and dark color, the specific nature of its depositional environment is unclear. During Kinderhookian time, the Joana Limestone was being deposited on the shallow shelf (Poole and Sandberg, 1977) and the siliceous Webb was being deposited on the western side of the incipient flysch trough (Johnson and Pendergast, 1981). The rocks of the autochthonous "Webb" were deposited somewhere in the unstable region between the Joana Limestone and the siliceous Webb.

DALE CANYON FORMATION

General Statement

The Dale Canyon Formation was named by Nolan *et al.* (1974) for exposures of interbedded shale, sandstone, and conglomerate of Early Mississippian age in the vicinity of Eureka. In the study area, rocks of the Dale Canyon Formation were originally assigned to the Chainman Shale by Smith and Ketner (1975). They extended the name from its type locality in the Ely district where it was named by Spencer (1917). The Dale Canyon Formation in the study area is correlated with the type Dale Canyon on the basis of age, stratigraphic position, paleogeographic position, and lithologic similarity. The Dale Canyon Formation has also been identified in the southern Pinyon Range and northern Sulphur Spring Range by Visconti (1982).

Sediments of the Dale Canyon Formation were deposited as flysch in the Antler foreland basin in Early Mississippian time (Stewart, 1962; Poole, 1974). Harbaugh and Dickinson (1981) have shown that sediments in the Diamond Mountains equivalent to the Dale Canyon Formation represent facies of a submarine fan and basin slope complex.

The palinspastic correlation chart of Poole and Sandberg (1977, Fig. 2) shows that most of the "true" Chainman Shale is Osagean, Meramecian, and Chesterian in age (middle to late Mississippian) and was deposited in eastern Nevada and western Utah as the distal equivalent of the Diamond Peak Formation. The Dale Canyon Formation represents older, more proximal sediments.

The Dale Canyon Formation is here divided into two members on the basis of lithology. The lower member (map unit Mdcl) consists of mudstone and shale with a few sandstone lenses, and the upper member (map unit Mdcu) consists of sandstone, mudstone, shale, and conglomerate (see Plate 1).

Age

No diagnostic fossils have been found in the Dale Canyon Formation exposed at Willow Creek. In the central and northern Pinyon Range, equivalent beds have been dated as late Kinderhookian (early Mississippian) (Smith and Ketner, 1975, p. 47-50). Conodont collections taken by Visconti (1982) and by Carlisle and Nelson (unpub. data) from the Dale Canyon Formation in the northern Sulphur Spring Range indicate a late Kinderhookian to early Osagean age. In the type area, the Dale Canyon Formation contains conodonts of the *isosticha*-Upper *crenulata* Zone (late Kinderhookian) (Sandberg, *in* Johnson and Pendergast, 1981, p. 652).

Contact Relations and Thickness

The lower contact of the Dale Canyon Formation is assumed to be unconformable over the Devils Gate Limestone and possibly conformable over the eastern facies of the Webb Formation. Both relationships are displayed to the north along the Pinyon Range (Smith and Ketner, 1975, 1978), but the contact is either faulted or not exposed in the study area.

The contact between the lower member and the upper member is gradational and may vary stratigraphically from place to place. Various authors have shown that lithologic contacts within the Antler flysch sequence vary from place to place, even over short distances, due to channeling and intertonguing of the coarse and fine sediments (e.g. Nolan et al., 1956, p. 56-59; Stewart, 1962, p. 57; Harbaugh and Dickinson, 1981, p. 1226). The boundary has been placed where sandstone and conglomeratic beds become dominant over mudstone and shale in the sequence. In section 30 (T29N, T53E) a thick pebbly mudstone lens overlying mudstone and shale marks the base of the upper member. To the east and south the boundary is more gradational.

The upper contact is a thrust fault or normal fault everywhere in the study area. The thickness of the lower member is estimated at 1500 feet (457 m); however, this can vary over short distances as explained above. The thickness of the upper member cannot be determined accurately because of faulting of the upper contact and large-scale folding which is intense in places, but 900 feet (274 m) is the estimated average thickness.

Facies Interpretation

Poole (1974) showed that much of the orogenic clastics within the Antler flysch trough were deposited by sediment gravity flows in deep water. He recognized proximal and distal turbidite flows, debris-flow deposits, and hemipelagic deposits and suggested a complex system of submarine fan and basin floor depositional environments. Harbaugh and Dickinson (1981) describe in detail a retrogradational (transgressive) sequence of basin slope and submarine fan deposits in the Diamond Mountains in the lower part of their "Chainman-Diamond Peak sequence" which is essentially the same unit as the Dale Canyon Formation. They recognize an upper-slope facies at the base of the sequence which is overlain by lower-slope, inner-fan, and middle-fan facies. In the study area, a similar sequence of undifferentiated basin-slope facies overlain by inner-fan facies is recognized in the Dale Canyon Formation. Both Harbaugh and Dickinson (1981) and Poole (1974) recognize trace fossils of the Nereites assemblage in shaly beds, indicating bathyal depths.

The boundary between these two facies does not correspond exactly to the contact between the two lithologic map units as there are coarse sediments at the top of the basin slope facies which have been included in the upper map unit.

Facies analyses presented here follow the interpretive scheme of Mutti and Ricci-Lucci (1972) and Walker and Mutti (1973). Turbidite divisions follow the nomenclature of Bouma (1962).

Basin Slope Facies

The base of the Dale Canyon Formation consists of thin-bedded shaly mudstones with interbeds of fine-grained sandstone (2-6 cm thick) which belong to facies G and D respectively of Walker and Mutti (1973) (Figure 19). Some sandstone interbeds display Bouma divisions C, D, and E which together are characteristic of distal turbidites (Walker, 1967). The beds are not bioturbated and no trace fossils were noted. Laterally discontinuous massive sandstone lenses to 60 cm thick become more abundant towards the top of the sequence. They

Figure 19. Bedded shaly mudstone and sandstone of basin slope facies of lower member of the Mississippian Dale Canyon Formation. Note channel marked by base of sandstone layer in the center of the picture. Facies G and D of Walker and Mutti (1973). Distance from bottom to top of outcrop is approximately 20 feet (6 m). SE¼ SW¼ section 1, T.28N., R.52E.

belong to facies B_2 of Walker and Mutti (1973). A thick, massive lens of pebbly mudstone belonging to facies A_1 and A_3 of Walker and Mutti (1973) was noted at the top of the basin slope sequence along Willow Creek. Near its base it contains deformed mudstone clasts which appear to have been ripped up from fine beds below (Figure 20).

The sandstone and pebbly mudstone lenses probably represent channel fill deposits deposited by debris flow and grain flow mechanisms described by Middleton and Hampton (1973). The fine sediments probably represent overbank and hemipelagic deposits.

Inner Fan Facies

Rocks of the basin slope facies are overlain gradationally by a sequence of interbedded sandstone, conglomeratic sandstone, mudstone, and shale. Exposure is poor, but it is estimated that sandstone and conglomeratic sandstone make up approximately 50% of the sequence. Sandstone beds are from 20 to 70 cm thick and are generally massive or contain parallel laminations. Graded bedding is rare and poorly developed. Bouma sequences are rarely seen. Lower contacts are sharp and commonly display groove casts and deformed flute casts (Figure 21). Upper contacts are sharp and planar with concentrations of fossil plant fragments in places. Conglomeratic intervals occur discontinuously in sandstone layers and make up 10% or less of the sequence. Clasts are in the pebble to cobble size range and are supported in a sandstone matrix. Grading is rare in these intervals. Individual sandstone beds may be separated by shale partings (Figure 22) or amalgamated into packets several meters thick (Figure 23).

Figure 20. Deformed mudstone clasts in massive pebbly mudstone of the basin slope facies of the Mississippian Dale Canyon Formation. Facies A_1 and A_3 of Walker and Mutti (1973). NW¼ NE¼ section 30, T.29N., R.53E.

Figure 21. Deformed flute casts at the base of massive sandstone bed. Inner fan facies of the upper unit of the Mississippian Dale Canyon Formation. Note underlying shaly beds to the left of the hammer. NE¼ SW¼ section 30, T.29N., R.53E.

Figure 22. Massive sandstone beds separated by shaly partings. Note sharp bases to sandstone beds. Inner fan facies of the upper unit of the Mississippian Dale Canyon Formation. Facies B_2 of Walker and Mutti (1973). NE¼ SW¼ section 30, T.29N., R.53E.

Figure 23. Amalgamated platy sandstone beds. Inner fan facies of the upper unit of the Mississippian Dale Canyon Formation. Facies B_2 of Walker and Mutti (1973). NE¼ SW¼ section 19, T.29N., R.53E.

These beds belong to facies A_1, A_3, and B_2 of Walker and Mutti (1973). They may represent broad channel fill complexes as they resemble deposits described by Harbaugh and Dickinson (1981, p. 1231-1232). Poor exposure prevented the lateral extent of these beds from being determined, but Harbaugh and Dickinson (1981) traced channel fill beds as far as 3 km laterally. Debris flow and grain flow mechanisms probably acted in concert with turbidity currents to form these beds. Sequences of poorly exposed mudstone and shale occur between sequences dominated by sandstone. They belong to facies G of Walker and Mutti (1973) and probably represent overbank deposits that accumulated on the surface of the submarine fans.

Lithology

Chert-Arenite

Most sandstones of the Dale Canyon Formation are chert-arenites. They are mainly dark- to medium-gray in color though some in the upper part of the formation are brown or greenish-gray. Reddish- and yellowish-brown iron oxides stain weathered surfaces. The rocks are fine to coarse grained with pebble and cobble clasts scattered through some coarser beds. Most of the chert-arenites are massive although fine laminations are fairly common, especially in the lower part of the formation. Crossbedding is rare. Modal analyses of seven chert-arenites show that framework compositions range from 28 to 68% quartz, 22 to 58% chert, 1 to 11% argillaceous rock fragments, and 0 to 4% quartzite. Scattered feldspar and chlorite fragments were also noted. The matrix is made up of quartz and chert cement with varying amounts of clays and carbonaceous material. Syntaxial overgrowths on quartz grains are common. Quartz and chert grains commonly show a bimodal size and maturity distribution with chert generally coarser and more angular than quartz, which is generally finer and more well rounded (Figure 24). This bimodality is probably due to the quartz grains being reworked from older sand-bearing formations or along beaches and the chert grains being first cycle sediments eroded from formations containing bedded chert.

Pebbly Chert-Wacke

Pebbly chert-wacke is not a major lithology in the Dale Canyon Formation, but does form at least one 30 to 40 m thick lens at the base of the upper member along Willow Creek. Smith and Ketner (1975), p. 41-43) make note of this lithology and refer to it as "pebbly mudstone." The rock is dark olive-gray with pebble to cobble size clasts of gray, black, brown, and green chert and brown and cream quartzite in a matrix of sand, silt, and clay. The clasts weather out fairly easily and litter the slopes where this lithology is present. Deformed clasts of mudstone and shale are included in lower sections of the unit, presumably having been ripped up from fine-grained beds underlying the pebbly chert-wacke. The bedding is massive, but there is crude layering on a scale of 1 to several meters, suggestive of repeated episodes of deposition. There also seems to be an overall grading with the coarsest clasts most abundant in the bottom of the lens. Thin section study of three samples shows that

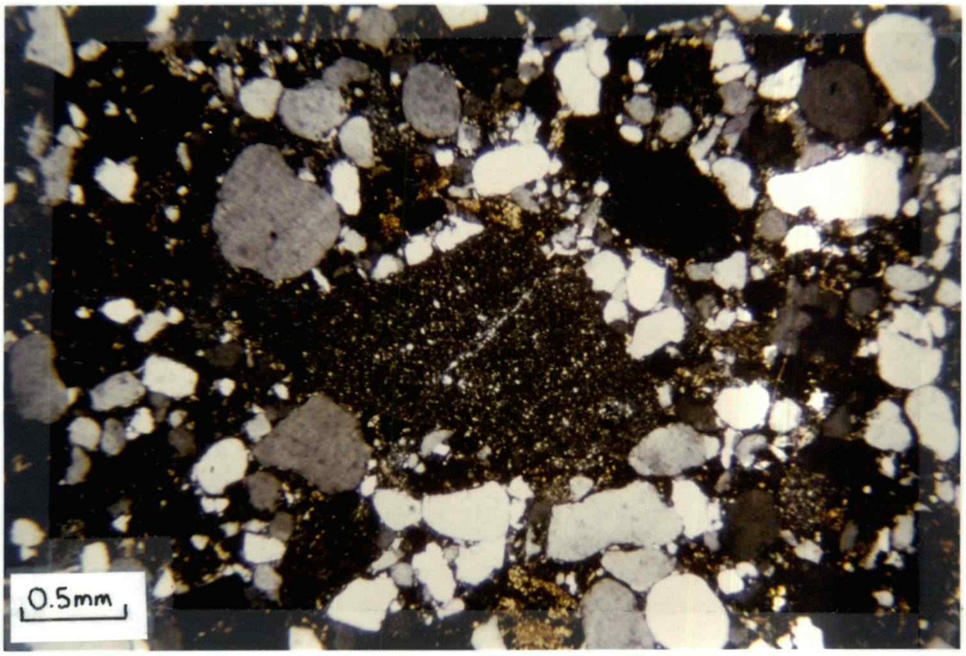


Figure 24. Photomicrograph of chert-arenite. Note the bimodal grain size and maturity distribution between large angular chert clasts and smaller rounded quartz grains. Lower unit of Mississippian Dale Canyon Formation. Crossed nicols. NE¼ NE¼ section 1, T.28N., R.52E.

the rock consists of from 60 to 80% chert and quartzite pebbles, 5 to 15% quartz and chert sand, and 10 to 20% silt and clay (Figure 25). The pebbly chert-wacke was probably emplaced by debris flow mechanisms.

Fine-Grained Rocks

Mudstone and shale occur in thick sequences near the base of the formation and in thinner intervals and as partings between sandstone beds in upper sections. Bedding ranges from 1 or 2 mm, where fissility is well developed, to 3 or 4 cm where silt content is higher. The rocks are composed of quartz silt, clay minerals, and carbonaceous material. They are mildly indurated and are easily broken apart in most outcrops. Small chips and blocky fragments litter the slopes and exposures are generally poor. Thin beds of silty dolomitic micrite and biomicrite were seen at three localities. Thin sections of these rocks show abundant quartz silt and sparse dolomite rhombs in an argillaceous, carbonaceous, and cherty matrix (Figure 26). Fossils, where present, include sponge spicules and other, unidentifiable, fragments.

Shaly beds probably represent hemipelagic deposits and deposition from the fine tails of turbidity currents and other types of sediment gravity flows. The siltier mudstone beds may represent overbank deposits related to gravity flows in nearby channels.

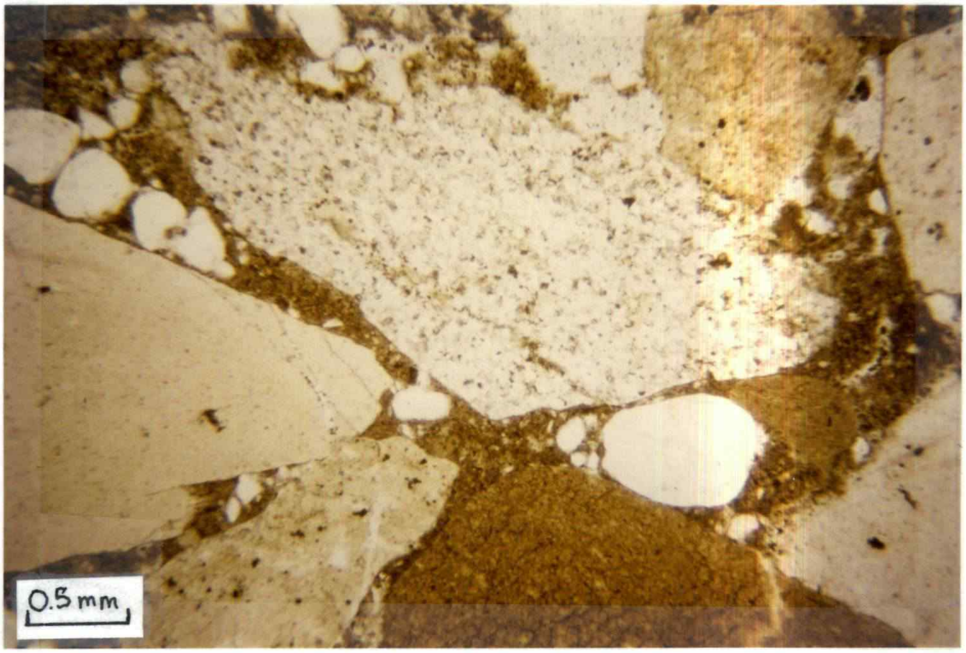


Figure 25. Photomicrograph of pebbly chert-wacke. Note large angular rock fragments and rounded quartz grains in fine argillaceous matrix. Base of upper unit of Mississippian Dale Canyon Formation. Plane light. NW¼ NE¼ section 30, T.29N., R.53E.

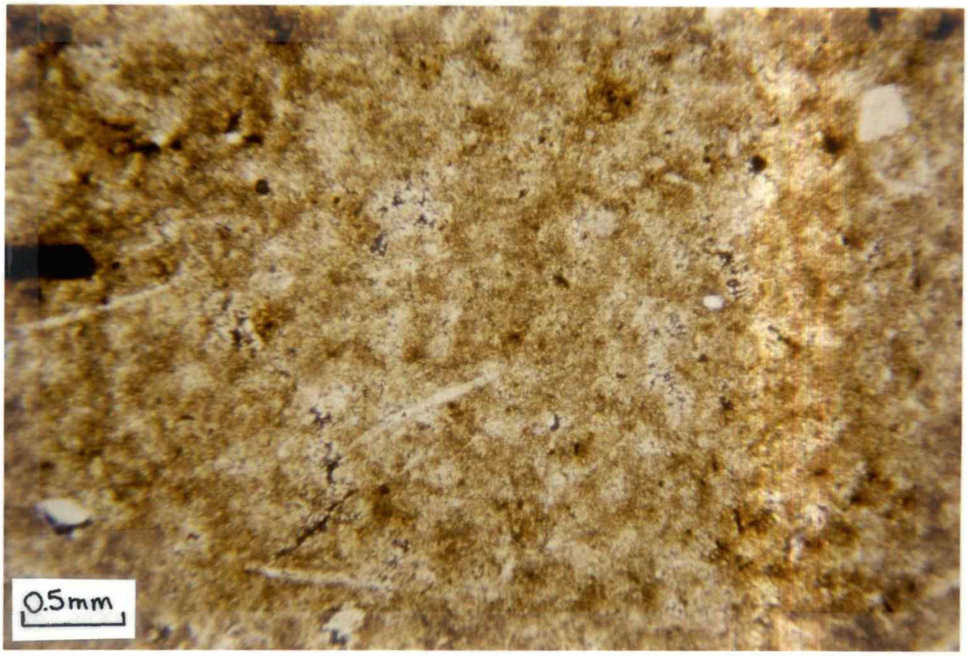


Figure 26. Photomicrograph of argillaceous biomicrite. Note silt grain (lower left); dolomite rhomb (upper right) and sponge spicules. Lower unit of Mississippian Dale Canyon Formation. Crossed nicols. NE¼ NE¼ section 29, T.29N., R.53E.

Regional Significance

Poole (1974) has shown that sediments included in the Dale Canyon Formation were deposited as flysch during late Kinderhookian time in an elongate trough formed at the leading edge of the obducted Roberts Mountains allochthon. The flysch trough was flanked on the west by the Antler orogenic highland and on the east by a carbonate bank, a starved basin, and a carbonate platform (Poole and Sandberg, 1977). Further obduction pushed the allochthon over the Dale Canyon sediments in the study area by early Osagean time. Composition of the Dale Canyon sediments indicates a source wholly within the allochthon (Poole, 1974; Harbaugh and Dickinson, 1981). Paleocurrent measurements taken by this writer on flute casts and others taken by Smith and Ketner (1975) and by Harbaugh and Dickinson (1981) indicate a northwest to southeast transport direction.

According to Johnson and Pendergast (1981, p. 654), the Dale Canyon Formation represents the first truly orogenic sediments deposited on the Antler flysch trough. They were deposited as a broad submarine fan complex which covered much of eastern Eureka County and part of southwestern Elko County (Johnson and Pendergast, 1981, Figure 4). Source rocks probably included the Webb and Woodruff Formations as well as older rocks (Johnson and Pendergast, 1981, p. 654).

Rocks equivalent to the Dale Canyon Formation probably include most of the exposures mapped as Chainman Shale by Smith and Ketner (1975, 1978) in the Pinyon Range. Other equivalent rocks may include a shale and conglomerate sequence at Devils Gate mapped by Roberts _et al_. (1967) which is on the same paleoslope as the Dale Canyon

Formation (Johnson and Pendergast, 1981, p. 652). Limestone turbidites of the Camp Creek sequence of Ketner (1970) are correlative with the Dale Canyon and occur to its north and south along the flysch trough. These sediments may represent material eroded from the carbonate bank to the east (Ketner, 1970), or they may have a source to the west on the Antler highland which may have been a shallow water environment at those latitudes during this time (J. G. Johnson, oral communication, 1984). A two-sided source has also been suggested (Gutschick *et al.*, 1980; Pendergast, 1981, p. 73).

DIAMOND PEAK FORMATION

General Statement

The Diamond Peak Formation in the study area consists of a sequence of sandstone, conglomerate, and shale with a lens of limestone. It depositionally overlies the Vinini and Woodruff Formations of the Roberts Mountains allochthon and is interpreted here as having been deposited in a delta slope environment. Its deposition is thought to have begun after final emplacement of the allochthon during Early Mississippian time (Johnson and Pendergast, 1981).

The Diamond Peak Formation was named by Hague (1883, 1892) for a sequence of quartzite, conglomerate, shale, and limestone in the Eureka district. Correlative rocks in the Carlin Canyon area at the north end of the Pinyon Range were named the Tonka Formation by Dott (1955) and were noted as being much coarser than Diamond Peak rocks near Eureka. Smith and Ketner (1975) assigned the name Diamond Peak Formation to the rocks of Dott's Tonka Formation and to correlative clastics throughout the Pinyon Range. They found that the percentage of fine-grained rocks in the Diamond Peak Formation increased southward in the Pinyon Range, suggesting that they were continuous with the type Diamond Peak.

At Willow Creek, rocks of the Diamond Peak Formation were originally assigned to the Chainman and Diamond Peak Formation undivided by Smith and Ketner (1975, 1978). They placed the boundary between the rocks of their Chainman Shale and the Diamond Peak Formation where sandstone and conglomerate became dominant over shale and sandstone in the sequence. The position of this boundary did not follow any traceable stratigraphic horizon and thus varied from place to place. Rocks of intermediate character were placed in the Chainman and Diamond Peak Formation undivided. In the study area, the clastics directly overlying the allochthon contain enough coarse material to be readily distinguishable from the rocks of the Dale Canyon Formation below the allochthon and hence are here assigned to the Diamond Peak Formation. Their apparent facies association with progradational sediments also separates them from older retrogradational rocks.

The Diamond Peak Formation is here divided into two members on the basis of lithology: a coarse-grained member consisting primarily of sandstone and conglomerate (map unit Mdp1), and a fine-grained member consisting primarily of shale and sandstone (map unit Mdp2). These two units are interlayered and interfinger.

Age

Conodonts retrieved from a limestone lens near the lower contact of the Diamond Peak Formation in the northwest corner of section 25 (T29N, R52E) (Plate 1, locality 73) were dated as Osagean (late Early Mississippian) in age. They correlate with the *typicus* Zone of Lane *et al*. (1980). This date compares favorably with the ages of thrusting and subsequent overlap indicated by the correlation chart of Johnson and Pendergast (1981, Figure 3); however, it conflicts somewhat with the age obtained by Smith and Ketner (1975) on two samples containing the goniatite Protocanites lyoni (Meek and Worthen), which is reported to be late Kinderhookian (early Mississippian) in age (Gordon and Duncan, 1961, p. 233). The strata in which the goniatites were found occur in the northeast corner of section 23 and the southeast corner of section 14 (T29N, R52E) and are apparently higher in the section than the conodont-bearing limestone described above. There is, however, a normal fault separating the two locales. The goniatite-bearing beds are finer grained and more thinly bedded than the rocks surrounding the limestone lens, suggesting that they might be from lower in the section, possibly even from the Dale Canyon Formation. However, latest movement on the fault appears to be down on the west, suggesting that the goniatite-bearing strata are higher than loc. 73, not lower in the section. Other fossils present in the goniatite-bearing beds include brachiopods which resemble Osagean species according to Gordon and Duncan (1961, p. 233). Also, Osagean fossils have been identified in strata which are apparently higher in the section, north of the study area (Smith and Ketner, 1975, p. 48, 49). The fauna with Protocanites lyoni is therefore anomolous in that the age range of the goniatites may be longer than previously thought.

Elsewhere in the Pinyon Range, the Diamond Peak Formation ranges into the earliest part of the Pennsylvanian (Smith and Ketner, 1975, p. 49, 50). A small slice of Diamond Peak rock in the eastern part of the study area (section 21, T29N, R53E) may be this young as it appears to be conformably overlain by the Pennsylvanian Moleen Formation. Its lower contact is faulted about 30 meters or less below this contact.

Contact Relations and Thickness

The lower contact of the Diamond Peak Formation is unconformable over the allochthonous rocks of the Ordovician Vinini Formation and Devonian Woodruff Formation. This contact is exposed in a small outcrop in the northeastern part of the study area, in the northeast corner of section 20 (T29N, R53E) (Figure 15). The contact is clearly depositional here as shown by the continuity of bedding across the contact and by the presence of a chert clast enclosed in the sandstone of the Diamond Peak which appears to be a rip-up of the Woodruff Formation. The lower contact does, however, appear to be faulted along at least part of its length on the western side of the study area. Rocks of both the Diamond Peak Formation and the Vinini Formation are brecciated and, in places, discolored and silicified along the contact here, especially just to the north of Willow Creek. The fault is believed to be a high angle normal fault related to Basin and Range extension. Silicification is probably the result of hydrothermal activity directed along the conduit created by the fault.

The Diamond Peak Formation is conformably overlain by the Pennsylvanian Moleen Formation. This relationship is noted in a fairly small exposure in section 21 (T29N, R53E) where the name Moleen is given to rocks previously assigned to the Cretaceous Newark Canyon Formation by Smith and Ketner (1978). The same relationship is also displayed in the northern Pinyon Range (Smith and Ketner, 1975, 1978).

An exposure of calcareous sandstone identified by Smith and Ketner (1975) as belonging to a sequence of Upper Pennsylvanian and Permian rocks undivided overlies the Diamond Peak Formation in the northern part of the study area. This contact may be an unconformity as mapped by Smith and Ketner (1975, 1978), or these rocks may be in their present position due to landsliding as proposed by Johnson (1981, personal communication). This problem is discussed in detail in a separate chapter.

The thickness of the Diamond Peak Formation cannot be determined because in the main exposure on the western side of the study area, where the lower contact is depositional, the upper contact is cut by a normal fault or is highly disconformable with the overlying Pennsylvanian and Permian rocks undivided. Minimum thickness is estimated at 2500 feet (760 m).

Facies Interpretation

The age range of clastic rocks of the Antler sequence in the Pinyon Range indicates that sedimentation related to the Antler orogeny extended from early Mississippian time into the Pennsylvanian in this area (Smith and Ketner, 1975). Poole (1974) suggested that sedimentation was primarily in deep water as flysch in a submarine fan environment. Wilson and Laule (1979) proposed that most of the Antler sediments were deposited in a shallow water deltaic environment as molasse. Harbaugh and Dickinson (1981) blended these two viewpoints for their description of clastic deposits in the Diamond Mountains. Their facies interpretation shows a retrogradational (transgressive) sequence of submarine fan sediments overlain by a progradational (regressive) sequence of deltaic sediments. According to their model retrogradation occurred as the advancing allochthon rode over and depressed the edge of the continent. Progradation began after emplacement during the stabilization period in which isostatic uplift was the primary crustal activity in the highland and the trough. Although Harbaugh and Dickinson are not specific on the timing of the reversal in sedimentation patterns, Johnson and Pendergast (1981) suggest that active subsidence had stopped by early Osagean time, implying that infilling of the trough began at this time.

The Diamond Peak Formation in the study area is interpreted to represent initial sediments in the prograding sequence on the basis of its age and sedimentary characteristics. The depositional environment was probably the base of a prograding delta slope similar to that described by Harbaugh and Dickinson (1981, p. 1231). The sequence consists of broadly lenticular bodies of sandstone and conglomerate interlayered with and interfingering with shale-rich strata. Exposure is relatively poor, but conglomeratic intervals show up as elongate hills and shale-rich sections form valleys between the hills.

The conglomerate and sandstone bodies are 2 to 10 m thick and extend along strike for as much as 5 km. They make up from 30 to 50% of the delta slope facies. Individual beds range from 10 cm to 2 m in thickness and occur in amalgamated packets or separated by thin shaly interbeds (Figure 27). Most conglomerate beds are massive, but normal grading is not uncommon. Where graded bedding is present,

Figure 27. Amalgamated sandstone packets. Note pebbly layers. Facies A_3 and B_2 of Walker and Mutti (1973). Coarse unit of Mississippian Diamond Peak Formation. SE¼ NE¼ section 18, T.29N., R.53E.

conglomeratic bases commonly grade up into sandstone tops (Figure 28). Clasts range in size from pebbles to boulders although the most common size is in the cobble range. Conglomerate beds belong to facies A_1 and A_2 of Walker and Mutti (1973) and are interpreted to have been deposited by debris flow and grain flow mechanisms as well as high density turbidity currents. Sandstone beds are massive or contain pebbly layers or lenses. Distinct alternating layers of fine and coarse or pebbly sandstone 1 to 3 cm thick are common in individual beds. Bouma sequences are generally absent although some sequences of alternating sandstone and shale interbeds could be interpreted as Bouma AE couplets, which are characteristic of proximal turbidite deposits according to Walker and Mutti (1973, p. 129). The sandstone and pebbly sandstone beds belong to facies A_3, A_4, B_2, and possibly facies C of Walker and Mutti (1973). They are interpreted to have been deposited by grain flow and turbidity current mechanisms. Fissile clay- and silty-shale makes up 50 to 50% of the delta slope facies and is poorly exposed. Shale beds dominate parts of the sequence, but also form interbeds within the sandstone and conglomerate bodies. They belong to facies G of Walker and Mutti (1973) and are interpreted to be hemipelagic deposits.

The thick bodies of sandstone and conglomerate are interpreted to have been deposited by sediment gravity flows in broad channels on the lower part of a delta slope. More thinly bedded sequences of sandstone and pebbly sandstone interbedded with shale are interpreted to be overbank deposits. Sequences dominated by shale are interpreted to be interchannel deposits or may represent quiet periods of little clastic input.

Figure 28. Graded bedding in coarse unit of Mississippian Diamond Peak Formation. Note coarse conglomeratic base grading into sandstone top. Facies A_2 or A_4 of Walker and Mutti (1973). NE¼ NE¼ section 23, T.29N., R.52E.

Lithology

Chert-Arenite

The chert arenites of the Diamond Peak Formation are similar in composition and maturity to those of the Dale Canyon Formation, but they are usually lighter in color and are commonly quartzitic. They are mainly medium brown to light tan in color and commonly weather to reddish brown due to the formation of iron oxides. The rocks are fine- to coarse-grained and are pebbly in places. They are commonly massive, but many beds show parallel stratification of grain sizes. Crossbedding was not noted. Modal analysis of ten chert-arenites show that framework compositions range from 7 to 80% quartz with an average of 53%, 17 to 81% chert with an average of 43%, 1 to 6% argillaceous rock fragments, 0 to 5% quartzite, and 0 to 1% feldspar. A bimodal size and maturity distribution of quartz grains and chert fragments as noted in the Dale Canyon Formation was also evident here with chert fragments being larger in size and more angular than quartz grains (Figure 29). The chert-arenites are bound primarily by quartz cement, but calcite cement is present in a few places. Syntaxial overgrowths on quartz grains are common and some have developed into an interlocking mosaic characteristic of quartzite. Apparent alteration is present locally along faults. The formation of sericitic material is noted in thin section and altered rocks commonly have an unusual greenish hue in hand specimens.

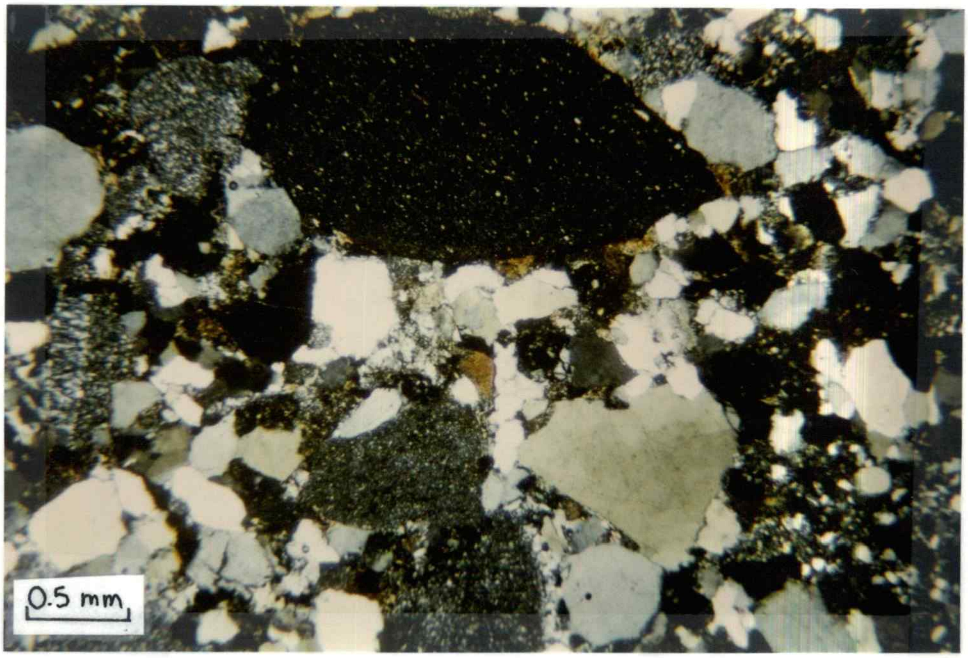


Figure 29. Photomicrograph of chert arenite. Note bimodal grain size and maturity distribution and overgrowths on quartz grains. Coarse unit of Mississippian Diamond Peak Formation. Crossed nicols. SE¼ NE¼ section 26, T.29N., R.52E.

Chert-Conglomerate

Chert-conglomerate forms thick beds in aggradational channel-fill complexes throughout the formation. They consist of pebble-, cobble-, and boulder-size clasts of angular to subrounded black, gray, green, and brown chert with lesser amounts of quartzite. Poor exposure and high degree of weathering prevented clast counts from being taken, but it is estimated that chert accounts for at least 90% of clast composition. Thin section study shows that matrix consists of quartz and chert sand with minor amounts of clay cemented by quartz (Figure 30).

Clay- and Silt-Shale

Clay and silt-shale occurs as thick sequences between channel fill complexes and as interbeds with sandstone and pebbly sandstone. The shale is dark gray to greenish gray and highly fissile. The rocks are commonly highly fractured and are poorly exposed except in stream cuts and where coarser interbeds are abundant.

Thin-Bedded Argillaceous Biomicrite

This lithology is represented at one location in the study area in a lens about 5 m thick that extends for about 30 m along strike (Figure 31). The rocks occur near the lower contact of the formation and are significant in that they contain conodonts useful in age dating. The rocks are medium to dark brownish-gray and weather light tan to buff. Beds are 5 to 15 cm thick. Thin section study shows that the rock consists of sponge spicules, calcispheres, brachiopod

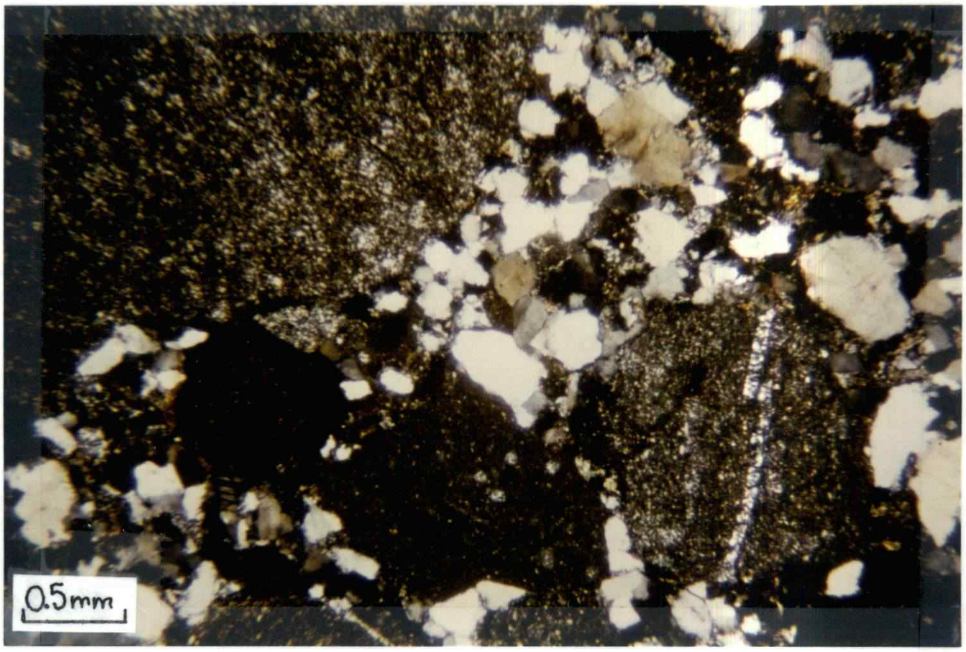


Figure 30. Photomicrograph of chert-conglomerate. Note larger rounded chert pebble (upper left). Coarse unit of Mississippian Diamond Peak Formation. Crossed nicols. SE¼ NE¼ section 26, T.29N., R.52E.

Figure 31. Thin-bedded argillaceous biomicrite lens near base of Mississippian Diamond Peak Formation. Conodont collections from this outcrop correlated with typicus Zone of Osagean time (Early Mississippian). SE¼ NW¼ section 25, T.29N., R.52E.

valves, and other fossil fragments in an argillaceous lime mud matrix (Figure 32).

Upslope from the outcrop, along the faulted contact between the Diamond Peak and the Vinini Formation, there is an outcrop of brecciated rocks of both formations in a supportive matrix of chalky limestone. It is white in color and very fine-grained. It was probably formed by the action of hydrothermal fluids moving along the fault, dissolving the bedded limestone, and transporting the $CaCO_3$ into the brecciated rocks along the fault.

Regional Significance

The Pinyon Range exposes the easternmost allochthonous rocks of the Roberts Mountains thrust system in the region and local stratigraphy shows that Diamond Peak rocks overlie the allochthon in some places and rocks of the Dale Canyon Formation (Chainman Shale of Smith and Ketner, 1975) in others (Smith and Ketner, 1978), suggesting that the original eastern limit of the upper plate was in or very near the study area. The study area was also probably at or near the depositional axis of the Antler flysch trough during Diamond Peak time as the deepest waters would be expected to be near the leading edge of the upper plate. Paleogeographic and isopach maps presented by Poole (1974) and Poole and Sandberg (1977) confirm this reconstruction.

While coarse clastics of the lower part of the Diamond Peak Formation were being deposited in the study area, fine-grained rocks of the Chainman Shale were being deposited to the east. They are now

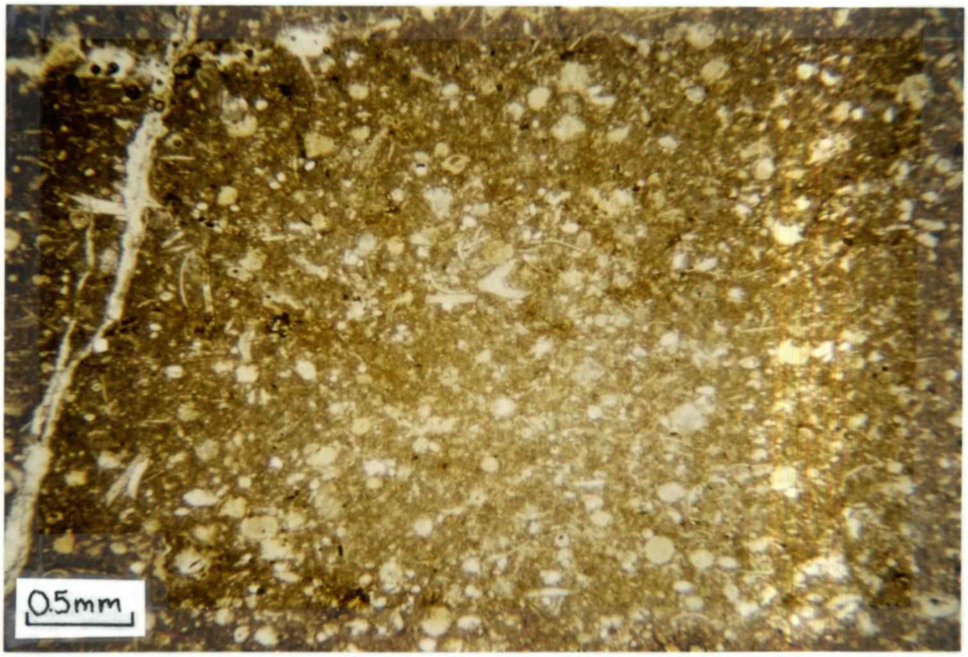


Figure 32. Photomicrograph of argillaceous biomicrite. Note abundant sponge spicules, calcispheres, and other fossil fragments. Mississippian Diamond Peak Formation. Plane light. SE¼ NW¼ section 25, T.29N., R.52E.

exposed in the Diamond Mountains and the northern Pancake Range (Johnson and Pendergast, 1981, p. 655). According to Poole and Sandberg (1977), Gutschick et al. (1980), and Johnson and Pendergast (1981), regional sedimentation patterns show that clastic deposition was confined to the flysch trough during Osagean time; it was not until Meramecian time that Antler-derived clastics spread eastward into the starved basin of eastern Nevada and western Utah. The Diamond Peak-Chainman Shale facies couplet was probably developing along most of the length of the flysch trough in Nevada at this time, although deposition of limestone turbidites such as the Camp Creek sequence and its equivalents may have continued into the Osagean (Poole and Sandberg, 1977, p. 78; Johnson and Pendergast, 1981, p. 652).

MOLEEN FORMATION

The Pennsylvanian Moleen Formation was named by Dott (1955) for exposures on and near Grindstone Mountain in the northern Pinyon Range where it is characterized by well-bedded detrital limestone containing varying amounts of quartz and chert sand. In the study area, it occurs in section 21 (T29N, R52E) and is similar in lithology to rocks at the type section (Figure 33).

The rocks consist of gray, micritic limestone in beds from about 5-50 cm in thickness. Sand and pebble sized grains of quartz and chert are present in many beds and there is also some dismicrite and intrasparite.

The Moleen Formation is considered to range in age from Early to early Middle Pennsylvanian (Dott, 1955, p. 2243). Its thickness varies widely as it is laterally gradational with the Tomera Formation (also of Dott, 1955), but Dott (1955) reports a maximum thickness of 1400 feet (426 m). The thickness of the Moleen Formation in the study area is unknown because the exposure is bounded by faults.

The exposure in the study area was originally mapped by Smith and Ketner (1975) as belonging to the Cretaceous, freshwater Newark Canyon Formation on the basis of ostracods found in limestone beds on top of the hill in the center of the exposure. However, marine fossils including solitary corals were discovered by this writer at the eastern edge of the exposure. The sequence here is thus reinterpreted as Mississippian or lower Pennsylvanian Diamond Peak Formation overlain conformably by Moleen Formation limestone with

Figure 33. Thick bedded limestone of the Pennsylvanian Moleen Formation. NW¼ SE¼ section 21, T.29N., R.53E.

landslide deposits of Newark Canyon Formation limestone lying on top of the Moleen Formation.

The limestones of the Moleen Formation are indicative of shallow conditions (Dott, 1955), but the abundance of coarse detrital chert and quartzite fragments suggests that the Antler highland was still shedding debris onto the filled flysch trough and continental shelf.

UPPER PENNSYLVANIAN AND PERMIAN ROCKS UNDIVIDED

The Upper Pennsylvanian and Permian rocks undivided, as defined by Smith and Ketner (1975) in the Pinyon Range, consist primarily of thin-bedded calcareous siltstone and sandstone ranging in age from Late Pennsylvanian to early Late Permian. They are equivalent in part to the Strathearn Formation of Dott (1955) which is Late Pennsylvanian to Early Permian in age.

In the study area, the Upper Pennsylvanian and Permian rocks undivided are characterized by thin-bedded brown, tan, and yellow quartz sandstone which is mostly calcareous. Thin cherty stringers which stand out on weathered surfaces are present along some bedding planes (Figure 34). Crossbedding was noted in places.

The rocks crop out in the northern part of the study area, in section 17 (T29N, R53E). They overlie the Mississippian Diamond Peak Formation about 100 feet (30 m) stratigraphically above the Diamond Peak's basal contact with the allochthon. Smith and Ketner (1975) suggest that this is an angular unconformity coinciding with the regional Middle Pennsylvanian unconformity first identified by Kay (1952); however, the Upper Pennsylvanian and Permian rocks overlie Diamond Peak strata at least 2000 feet higher in the section only two miles away, just north of the study area (Smith and Ketner, 1978). Because of this great difference in position the exposure of Upper Pennsylvanian and Permian rocks undivided in the study area is interpreted to be a landslide block which slid off the ridge of the Pinyon Range during Tertiary Basin and Range faulting. Such

Figure 34. Bedded calcareous sandstone of the Pennsylvanian and Permian Undivided Sandstone. Note cherty nodules and stringers standing out from weathered surface. NW¼ NW¼ section 17, T.29N., R.53E.

blocks have been noted elsewhere in this study and by Visconti (1982) in the southern Pinyon Range and northern Sulphur Spring Range.

NEWARK CANYON FORMATION

Nolan, Merriam, and Williams (1956) first used the name Newark Canyon Formation for a group of heterogeneous rocks of Cretaceous age in the Eureka area. Smith and Ketner (1976) used the name for a variety of Cretaceous nonmarine rocks in the Cortez Mountains and Pinyon Range, including conglomerate, sandstone, siltstone, mudstone, shale, and limestone.

In the study area, the Newark Canyon Formation is exposed in sections 20 and 21 (T29N, R53E) and consists of gray, platy limestone in beds 1 to 2 cm thick (Figure 35) and dark-gray thin-bedded carbonaceous shale. The limestone is sandy in places.

The Cretaceous age of these rocks is based on ostracods collected by Smith and Ketner (1976) from limestone beds and identified by Sohn (1969).

Smith and Ketner (1976) mapped these rocks as lying unconformably over Mississippian rocks of the Chainman Shale. Limestone beds at the southern and eastern edge of this exposure have been reinterpreted as belonging to the Pennsylvanian Moleen Formation on the basis of lithology, bedding style, and the presence of unidentified marine corals. It is suggested here that beds of the Newark Canyon Formation lie on the Moleen Formation as a landslide block which was emplaced during Tertiary Basin and Range faulting. This is based primarily on the absence of Upper Pennsylvanian, Permian, and Jurassic rocks which are known to lie between the Moleen and Newark Canyon Formations in other places in the Pinyon Range and Cortez Mountains.

Figure 35. Thin-bedded limestone of the Cretaceous Newark Canyon Formation. SE¼ NE¼ section 20, T.29N., R.53E.

IGNEOUS ROCKS

Igenous rocks in the study area are limited to one dike in the central part of the study area. It is approximately 3700 feet long, 5-6 feet wide at the surface, and trends roughly east-west.

It is presumably of rhyolitic composition although it is highly altered and few of the primary minerals remain. It appears to have been a porphyry as molds of phenocrysts are visible in the altered and weathered rock.

Smith and Ketner (1976) recognize several similar dikes in the Pinyon Range and suggest they are related to the rhyolite porphyry stock near Bullion which is about 10 miles to the north on the east side of the Pinyon Range. Armstrong (1970) reports a radiometric age of 36±1.3 m.y. (Oligocene) for the stock at Bullion.

There is another stock which lies just to the east of the thesis area and about 3 miles east of the dike which Smith and Ketner (1976, 1978) suggest is part of the Bullion system. It may be more directly related to the dike in the study area than is the stock at Bullion as it is much closer and the dike trends directly toward it.

Oligocene intrusions may be responsible for the silicification noted in the Devils Gate Limestone; however, the silicification seems to be localized around normal faults that coincide with the trend of Basin and Range faulting. Basin and Range faulting is thought not to have occurred until Miocene times (Smith and Ketner, 1976).

STRUCTURE

Structural features in the study area include thrust faults attributed to the Late Devonian and Early Mississippian Antler orogeny, large-scale folds of probable Mesozoic age, and normal faults associated with development of Basin and Range topography. These features are part of much larger structural trends characteristic of this longitude in Nevada, but the Willow Creek area is unique in that it shows some important temporal relationships between these structures, the emplacement of the Roberts Mountains allochthon, and the deposition of clastic sediments associated with the Antler orogeny. Specifically, an Early Mississippian age for the emplacement of the Roberts Mountains allochthon in this area is confirmed.

Thrust Faulting

Rocks of the Vinini, Roberts Mountains, and Woodruff Formations were emplaced as part of the Roberts Mountains allochthon during the Antler orogeny. The Woodruff Formation forms the base of the allochthon and structurally overlies autochthonous Dale Canyon Formation. The Vinini Formation overlies the Woodruff Formation in thrust contact and the Roberts Mountains Formation lies in a small thrust slice between the two. Mississippian clastics of the autochthonous Diamond Peak Formation depositionally overlie the thrust package. Conodont collections from the Diamond Peak Formation indicate that the allochthon was emplaced before or during *typicus* Zone time (early Osagean time).

Inverted age relationships of the three formations within the allochthon and their proposed environments of deposition suggest that younger rocks were picked up at the base of the allochthon as it moved eastward toward the craton and upward through the section. Shuffling is also suspected within the formations. Smith and Ketner (1977, p. 9) noted reversals within the sequence of graptolite zones in Ordovician allochthonous rocks at Marys Mountain. Some of this shuffling may have occurred during transport as the allochthon abutted against the edge of the continent and was compressed and elevated above sea level (see Johnson and Pendergast, 1981, p. 650).

The distance between the easternmost remnant of upper plate rocks in the Pinyon Range and the westernmost window in which lower plate rocks are exposed in the Shoshone Range (Gilluly and Gates, 1965) gives a minimum displacement of 82 km (51 mi) on the Roberts Mountains thrust fault (Smith and Ketner, 1977, p. 14). Transitional facies rocks of the Roberts Mountains Formation and the Woodruff Formation probably traveled less distance than western facies rocks of the Vinini Formation. Murphy (1968) and Murphy *et al.* (1984) have noted transitional and eastern facies rocks in the upper plate in the Roberts Mountains and suggest eastward displacement of as little as 15 miles (24 km) for some of these.

Folding

There are a number of large scale open to tight folds in the study area which trend north or northwest (Figure 36). Most of these have

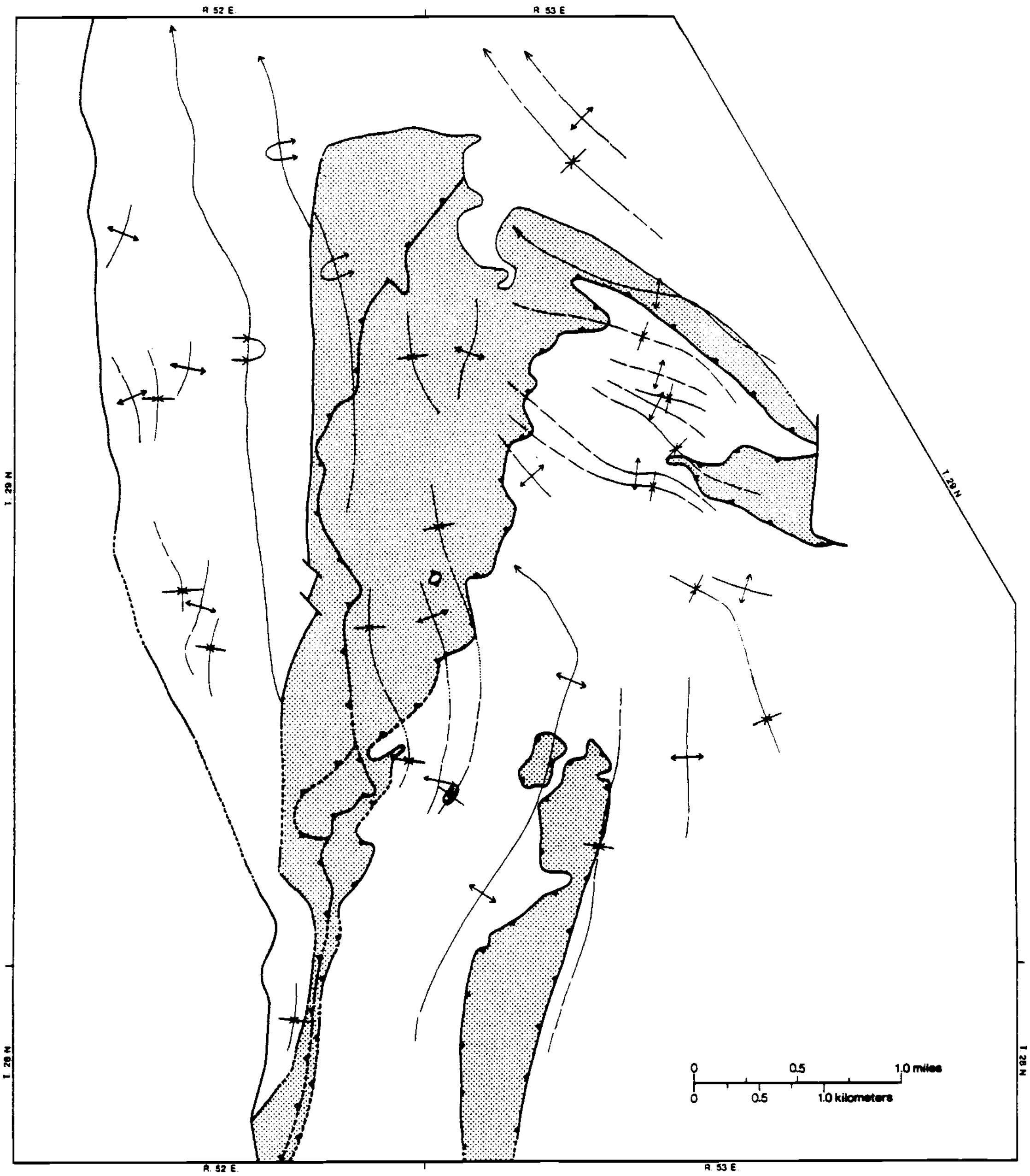
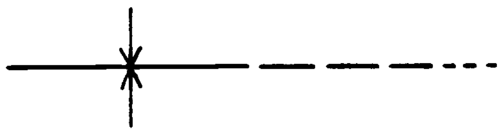
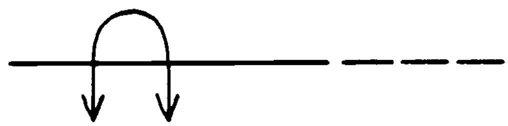


Figure 36. Structural map of the study area showing principal folds and faults. Shaded area is the allochthon. Explanation on next page.

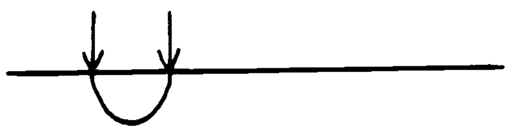
Anticline — Dashed where uncertain, dotted where concealed.



Syncline — Dashed where uncertain, dotted where concealed.



Overturned Anticline — Dashed where uncertain.

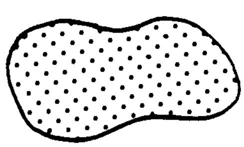


Overturned Syncline.

Normal Fault — Dotted where concealed.

Thrust Fault — Dotted where concealed.

Depositional Contact — Dotted where concealed.



Roberts Mountains allochthon.

Explanation for Figure 36.

vertical axial planes although a westward-verging overturned anticline-syncline couplet occurs in the western part of the study area. Many of the folds plunge northward, especially in the northern part of the study area. These folds extend north of the study area for at least 4 miles (6 km) and similar folds can be found elsewhere in the Pinyon Range (Smith and Ketner, 1977, Figure 2).

Smith and Ketner (1977) suggest a Late Jurassic or Early Cretaceous age for these folds because Jurassic rocks in the Cortez Range and Triassic rocks in the Adobe Range are involved in folding which can be traced into the Pinyon Range. They suggest, however, that northwest-trending folds in the Willow Creek area may have been formed initially during Pennsylvanian time because they resemble folds which appear to be truncated by gently dipping Permian strata, about 15 miles (24 km) to the north, near Spring Canyon Mountain.

The history of these folds could not be clarified by this writer although two observations were made. 1) The northwest-trending folds to the east of the allochthon in the Dale Canyon Formation seem to be distinct from the north-trending folds although they bend into one another where they meet. 2) Both sets of folds include the allochthonous rocks. Smith and Ketner (1977) suggested that allochthonous rocks at Willow Creek were thrust westward as a flat sheet during Mesozoic deformation, producing the westward-verging overturned syncline in the Diamond Peak rocks. Evidence presented in this report clearly shows that this is not the case. Comparison of stereonet projections from the allochthon and the surrounding

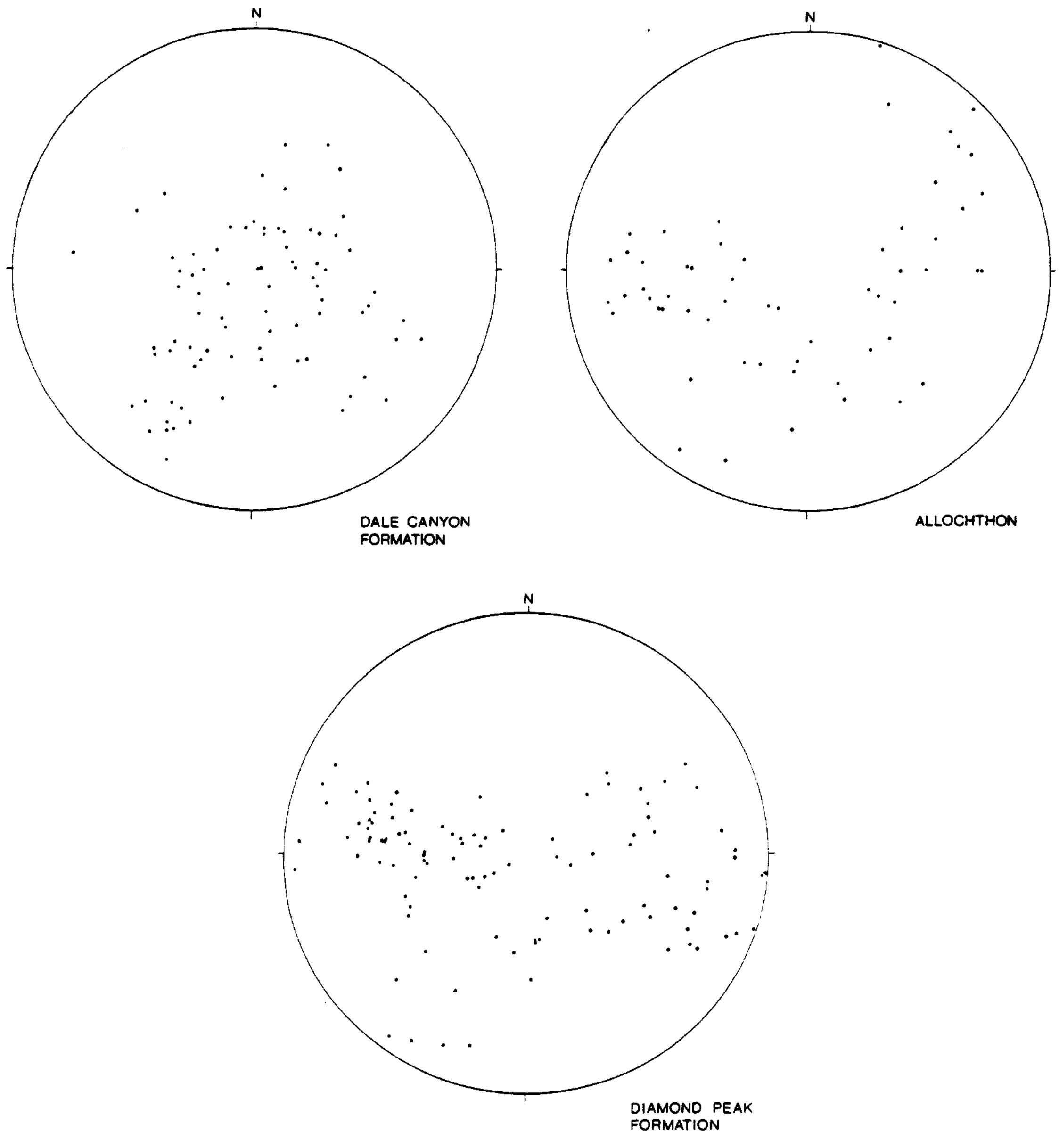


Figure 37. Pi-diagrams of poles plotted to bedding planes of rocks of the Roberts Mountains allochthon and Mississippian rocks of the Antler flysch sequence enclosing the allochthon. Allochthonous rocks include the Woodruff and Vinini Formations. Two sets of fold orientations can be seen in each diagram.

autochthonous rocks show similar patterns indicating that they were involved in the folding episodes together (see Figure 37). Field evidence and aerial photographs support this conclusion.

Normal Faulting

Normal faulting has played a major role in forming the topography and exposure in the Pinyon Range. The major normal faults in the study area are the north-trending fault which separates the Missisippian clastic rocks and the allochthon from the Quaternary deposits in the basin to the west and the faults which separate the clastics and allochthon from the lower Paleozoic carbonates on the east. Other lesser faults are present which have small amounts of displacement and are relatively short. It was not possible to decipher a clear sequence for these faults.

Normal faults in the study area are probably Miocene in age, the time during which widespread crustal extension produced the Basin and Range topography characteristic of the Great Basin.

GEOLOGIC HISTORY

A stable continental margin existed along the western edge of North America during the early and middle Paleozoic. Shallow shelf carbonates were deposited in the Pinyon Range. In the Famennian and Kinderhookian, siliceous siltstones and cherts were deposited on the outer shelf and slope.

Stable conditions ended with the onset of the Antler orogeny in early Late Devonian time (Johnson and Pendergast, 1981). A west-dipping subduction zone formed to the west in oceanic crust and began accumulating an accretionary wedge which later became the Roberts Mountains allochthon. Inception of subduction was accompanied by foreland epeirogeny on the edge of the continent; the inner shelf was downwarped, forming the protoflysch basin into which the Pilot Shale was deposited (Sandberg and Poole, 1977; Johnson and Pendergast, 1981). Visconti (1982) has identified the Pilot Shale nearby in the northern Sulphur Spring Range; however, this part of the record is absent in the study area, suggesting a period of emergence in the Late Devonian, causing nondeposition or erosion of these rocks. Deposition of deeper water sediments, such as the Famennian Woodruff Formation, was probably taking place in basins on top and in front of the allochthon as it was being formed.

As subduction continued, sediments were tectonically interleaved and shuffled. Older rocks were thrust over younger rocks as slices were picked up at the base of the allochthon. The allochthon was obducted onto the continent during late Kinderhookian and Osagean time as incipient subduction of continental crust occurred (Johnson and Pendergast, 1981; Speed and Sleep, 1982).

A flysch trough formed at the leading edge of the allochthon, probably as a result of downbending of the continent during incipient subduction (Johnson and Pendergast, 1981). Initial sedimentation in the flysch trough occurred west of the map area and resulted in the deposition of argillaceous rocks, micrites, and limestone turbidites (Johnson and Pendergast, 1981). Further telescoping within the allochthon caused it to be elevated and shed siliciclastic sediments into the trough to form a complex of submarine fans. Evidently, this phase of sedimentation began before the toe of the allochthon stopped moving because allochthonous rocks were thrust over fine clastics of the Dale Canyon Formation in the study area. This sequence was then overlapped by the coarser deltaic clastics of the Diamond Peak Formation. The oldest dated rocks in the overlapping Diamond Peak Formation in the study area are from the typicus Zone of early Osagean age, indicating that final emplacement occurred before this time.

Flysch sedimentation continued until middle Mississippian time when convergence ceased allowing the flysch trough to become filled (Johnson and Pendergast, 1981). Isostatic uplift of subducted continental crust provided continued relief in the Antler Highland and molasse was deposited through late Mississippian time and into the Pennsylvanian (Johnson and Pendergast, 1981).

Deposition of clastic sediments derived from the west continued in the Pinyon Range through the end of Paleozoic time although conditions were more quiet and limestones became more predominant (Smith and Ketner, 1975). Marine deposition ended permanently sometime in the Triassic with the onset of regional uplift (Smith and Ketner, 1975).

SUMMARY

One of the goals of this study was to test two hypotheses. In the Willow Creek area, Smith and Ketner (1975, 1978) interpreted the allochthonous rocks of the Vinini, Roberts Mountains, and Woodruff Formations as lying on flat, superficial thrusts that truncated the underlying folded Mississippian rocks of the Antler flysch sequence. However, evidence presented in this report shows that the allochthon structurally overlies the Dale Canyon Formation and is depositionally overlain by the Diamond Peak Formation. The allochthon thus lies folded within the Mississippian flysch sequence. Figure 38 illustrates the two contrasting interpretations.

Smith and Ketner (1968), in their early work in the Pinyon Range, provided evidence suggesting that the allochthon was emplaced during Early Mississippian time. They showed that sediments of the Kinderhookian Webb Formation were deposited unconformably on both the upper and lower plates and suggested that this occurred after thrusting had stopped. Recently, however, Ketner and Smith (1982) suggested that the sections of the Webb on the upper and lower plates were deposited on opposite sides of the developing Antler flysch trough and were thrust together at some later time. Relationships elsewhere in northeastern Nevada and in the Pinyon Range led them to conclude that a post-Paleozoic age for thrusting could not be ruled out.

Relationships in the study area reveal that thrusting did take place after the time of deposition of the Webb Formation, but before deposition of the Diamond Peak Formation. A Late Kinderhookian or

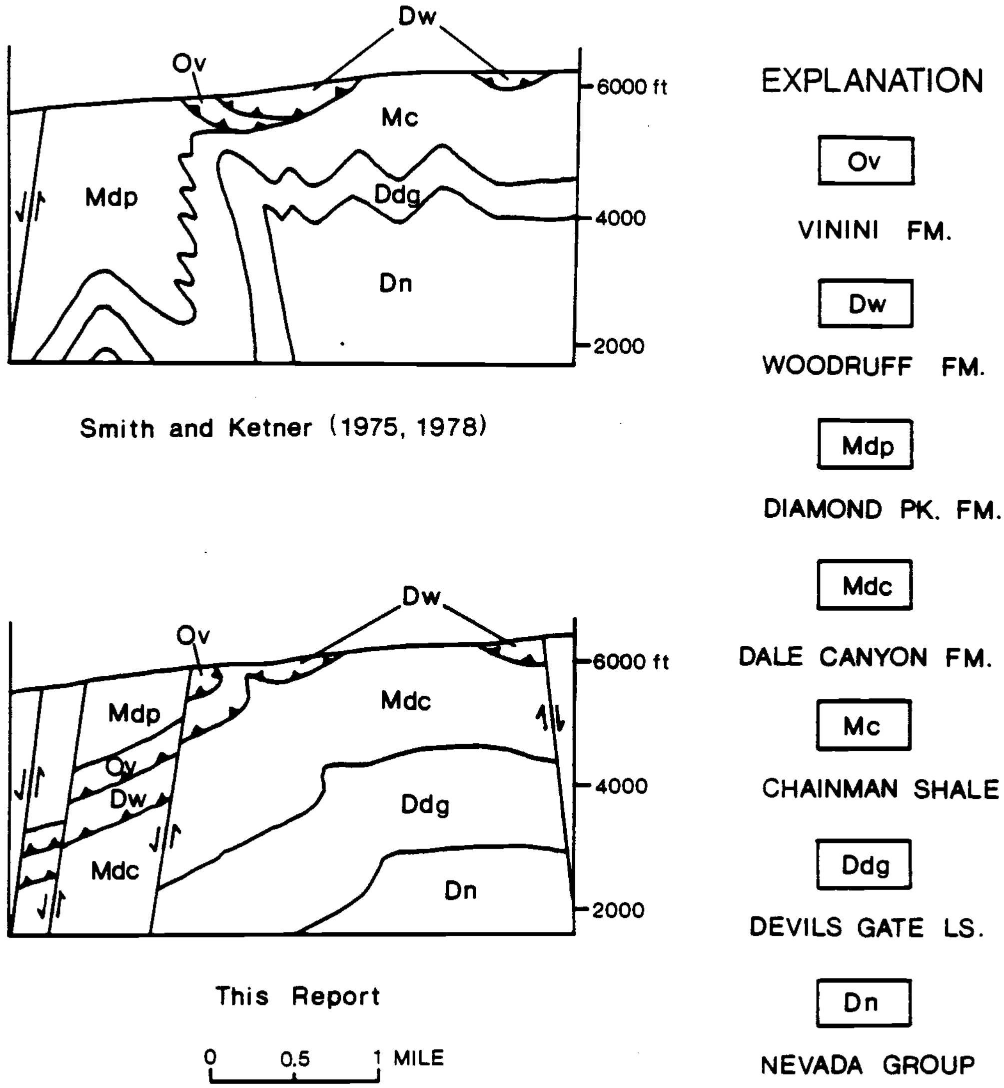


Figure 38. Cross sections showing the interpretation of Smith and Ketner (1975, 1978) and the interpretation of this report. (Location corresponds approximately to section A-A' on Plates 1 and 2).

Early Osagean age for thrusting is indicated for the Willow Creek area. Similar relationships have been noted elsewhere in the Pinyon Range and in the northern Sulphur Spring Range (Johnson and Pendergast, 1981; Visconti, 1982).

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APPENDIX

CONODONT COLLECTIONS AND LOCALITIES

The following five conodont collections were identified by Gilbert Klapper in 1982. Conodont localities are plotted on Plate 1.

Woodruff Formation

Sample: JW-15

Location: Aprox. 1120 ft. S, 1600 ft. W of NE corner of sec. 36, T.29N., R.52E.

Pa. glabra lepta Ziegler & Huddle
Pa. glabra supsp. indet.
Pa. marginifera Helms s.l.
Pa. gracilis supsp. indet.
Pa. sp. indet.
P. sp. indet.
Indet. ramiform elements

Age: *marginifera* or *velifer* Zone

Sample: JW-106

Location: Aprox. 160 ft. N, 1170 ft. E of SW corner of sec. 18, T.29N., R.53E.

Tortodus kockelianus kockelianus (Bischoff & Ziegler)
Polygnathus pseudofoliatus Wittekindt
P. xylus ensensis
P. l. linguiformis Hindle gamma morphotype
P. trigonicus Bischoff & Ziegler?
Icriodus sp. indet.
Belodella sp.
indet. ramiform elements

Age: lowermost *ensensis* Zone

Note: extremely poor preservation.

Sample: JW-239

Location: Aprox. 420 ft. S, 2640 ft. E. of NW corner of sec. 1,
T.28N., R.52E.

Palmatolepis glabra lepta Ziegler & Huddle
Pa. glabra pectinata Ziegler
Pa. glabra subsp. indet.
Pa. marginifera Helms s.l.
Pa. perlobata schindewolfi Müller
Pa. sp. indet.
Palmatolepis Pb elements
indet. ramiform elements
indet. simple cone (1)

Age: *marginifera* or *velifer* zone

Sample: JW-402

Location: Aprox. 2570 ft. S, 100 ft. E of NW corner of sec. 18,
T.29N., R.53E.

Tortodus kockelianus kockelianus (Bischoff & Ziegler)
Polygnathus sp. indet.
Belodella sp.
indet. ramiform elements

Age: *kocklianus* Zone

Diamond Peak Formation

Sample: JW-73

Location: Aprox. 2050 ft. S, 2000 ft. E of NW corner of sec. 25,
T.29N., R.52E.

Gnathodus cuneiformis Mehl & Thomas
G. punctatus (Cooper)
Siphonodella obsoleta Hass
S. spp. indet.
Palmatolepis spp. (Fammenian species, e.g. *Pa. distorta* Branson & Mehl)
Pelekysgnathus planus Sannemann (range: Frasnian-early Fammenian, catalogue, v. II, p. 263)
Polygnathus communis communis Branson & Mehl
indet. ramiform elements

Age: Lower Carboniferous (Osagean). On the association of the two species of *Gnathodus*, the sample is correlative with the *typicus* Zone (Lane *et al.* 1980, Table 2) and with that of sample M1978 (Johnson and Pendergast, 1981, p. 656).