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The Stratigraphy of the Noonday Dolomite in the Clark Mountain Thrust Complex, San Bernardino County, California

by

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THE STRATIGRAPHY OF THE NOONDAY DOLOMITE IN THE CLARK MOUNTAIN THRUST COMPLEX, SAN BERNARDINO COUNTY, CALIFORNIA

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Abstract

Three exposures of the Noonday Dolomite in the Clark Mountain thrust complex were studied extensively. Several sections were measured. Local accumulations of orthoquartzite within the dolomite were examined and described. The Noonday in the Clark Mountain area is divided into four units and correlated with the units originally described by Hazzard (1937) from the southern Nopah Range. The Noonday in the study area represents the eastern feather edge of the formation and defines the eastern end of the Late Precambrian Amargosa Aulacogen. The Noonday represents a short period of quiet shallow subtidal to intertidal stromatolitic sedimentation. The quartzite bodies are interpreted as the filling of a young karst topography by the initial transgression of the overlying Johnnie Formation.
ACKNOWLEDGEMENTS

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**TABLE OF CONTENTS**

Introduction................................................................. 1
General Setting.............................................................. 5
Late Precambrian Stratigraphy........................................... 8
Stratigraphy of the Noonday Dolomite, Southern Death Valley Area......................................................... 12
Stratigraphy of the Noonday Dolomite, Clark Mountain Thrust Complex...................................................... 15
Correlation of Noonday Units............................................ 24
Quartzite Pods................................................................. 25
Valley Veils........................................................................ 34
Environment of Deposition................................................ 39
Regional Relations............................................................ 43
Conclusions....................................................................... 46
References.......................................................................... 47
INTRODUCTION:

The Clark Mountain thrust complex lies in the northeastern part of San Bernardino County, California, west of the Nevada border and north of Interstate Highway 15 between Las Vegas and Los Angeles (fig. 1, Burchfiel and Davis, 1971). This area contains the most easterly and southerly exposures of the Noonday Dolomite.

The Noonday Dolomite was first defined by Hazzard (1937) from exposures near the Noonday Mine in the southern Nopah Range (fig. 1). It is now known to be exposed in an elongate area about 50 km wide and 130 km long, from the Clark Mountain area west-northwest to the southern end of the Panamint Range (fig. 1). The Noonday is generally considered to be Precambrian in age because it lies stratigraphically below the lowest units to yield lower Cambrian fossils (Stewart, 1970; Williams and others, 1974).

The Noonday Dolomite has been considered by many to be the lowest unit in the conformable Eocambrian and Paleozoic miogeoclinal sequence of the Cordilleran geosyncline. More recently, (Wright and others, 1974; Williams and others, 1974) it has been related to the latest stages of the filling of a Late Precambrian aulacogen (the Amargosa Aulacogen) in the area.

The stratigraphy of the southern Great Basin is just beginning to be understood in detail and the Noonday represents a significant time since in many areas it rests on Precambrian crystalline basement, suggesting it represents an initial transgression in Late Precambrian time. In the Clark Mountain thrust complex, the Noonday is much thinner than in most of its exposures and appears to represent an eastern feather edge of the formation. It also contains some peculiarities.
Explanation for figure 1:

P Panamint Range
B Black Mountains
A Avawatz Mountains
R Resting Spring Range
N Nopah Range
K Kingston Range
S Silurian Hills
M Mesquite Range
C Clark Mountain
VW Valley Wells
WP Winter's Pass
WPH Winter's Pass Hills
IH 15 Interstate Highway 15

The area outlined in yellow is the Clark Mountain thrust complex.

The green dashed lines are isopachs on the platform facies of the Noonday Dolomite (from Cloud and others, 1974).

The small, green areas inside the thrust complex are the areas studied.

The red areas are exposures of the "basin facies" (from Cloud and others, 1974).

The north-south line just west of and in the Clark Mountain thrust complex is Cima Road.

The east-west line in the Clark Mountain thrust complex is the powerline maintenance road.
Figure 1 - Location map for southern Death Valley and southern Great Basin region.
not seen in other areas. The purpose of this study is to describe these features and to attempt to explain them in the context of an overall paleogeographic picture of the area at that time.
GENERAL SETTING:

The Clark Mountain thrust complex represents the eastern margin of the southern end of the Mesozoic fold and thrust belt of the Cordilleran orogen. Late Precambrian and Paleozoic rocks in the complex lie along the hinge line between the craton to the east and the rapidly subsiding geosyncline to the west. In this complex, the classic decollement style of thrusting common in the northern Cordillera, appears to change to thrusting and folding that involves Precambrian crystalline rocks (Burchfiel and Davis, 1971, 1972, in prep.). This change in structural style is a result of the southwest trend of the Paleozoic geosyncline being cross cut by Mesozoic structures that trend south to southeast (Burchfiel and Davis, 1972).

There are three major thrust faults in the Clark Mountain complex. Most of the rocks studied here appear to be confined to the highest and most westerly thrust plate, the Winter's Pass thrust plate. This plate carries the oldest rocks exposed in the area, including basement gneiss, but apparently no rocks younger than the Cambro-Devonian Goodsprings Dolomite are present (Burchfiel and Davis, 1971, in prep.).

Late tertiary high angle faulting and the desert climate have combined to produce superb exposures. Interstate Highway 15, two county roads, a powerline maintenance road and innumerable mining roads in various states of disrepair permit easy access to all outcrops in the area.
Explanation for figure 2:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>Wood Canyon Formation</td>
</tr>
<tr>
<td>S</td>
<td>Stirling Quartzite</td>
</tr>
<tr>
<td>J</td>
<td>Johnnie Formation</td>
</tr>
<tr>
<td>N</td>
<td>Noonday Dolomite</td>
</tr>
<tr>
<td>KP</td>
<td>Kingston Peak Formation</td>
</tr>
<tr>
<td>BS</td>
<td>Beck Spring Dolomite</td>
</tr>
<tr>
<td>CS</td>
<td>Crystal Spring Formation</td>
</tr>
</tbody>
</table>
Figure 2 Generalized Columnar Section of Late Precambrian, Death Valley Region (modified from Wright and others, 1974)
Below the Noonday Dolomite in several areas is a series of Late Precambrian clastic and carbonate rocks called the Pahrump Group (fig. 2). The Noonday rests with angular unconformity on many parts of this group. Wright and others (1974) have recently described the Pahrump Group as the fill of a Late Precambrian aulacogen presumably related to the rifting event that initiated the Cordilleran geosyncline. The Pahrump Group has been divided into three formations, each of which is discussed below.

Crystal Spring Formation:

The Crystal Spring Formation, the basal formation of the Pahrump Group, is predominantly a clastic unit but consists of a wide variety of rock types and rests unconformably on the basement crystalline complex. The clastic rocks vary from conglomerate and sandstone to siltstone, shale, mudstone and chert. Near the middle of the formation is a thick cryptagalaminite (Aitken, 1967) and stromatolitic dolomite termed the carbonate member. Where the dolomite has been contact metamorphosed by diabase dikes and sills, extensive talc deposits have been formed. Roberts (1974) considers the stromatolites found in the carbonate member to be in an association typical of middle Riphean or between 1,35 and 1,2 bybp.

The lower two-thirds of the formation is intruded extensively by diabase dikes and sills that have been tentatively correlated with similar bodies in southern Arizona in the Apache Group, where they have yielded radiometric ages of 1,2 bybp (Wrucke, 1972). This correlation has been criticized, mainly because of the distance separating Apache
rocks and Pahrump rocks, but this age is consistent with Roberts' dates on the stromatolites which appear to be some of the youngest units intruded by the diabase bodies.

Beck Spring Dolomite:

Little work has been done on the Beck Spring Dolomite, the middle formation of the Pahrump Group. The Beck Spring is predominately a well-laminated to massive, fine-grained dolomite that contains some oolitic lenses and beds. It also contains rare siliceous, clastic tongues near the limits of its area of exposure (Wright and others, 1974).

Kingston Peak Formation:

The lithology of the Kingston Peak Formation is predominately clastic with some interbeds of dolomite. Coarse conglomerate and diamictite are common as well as massive to laminated and graded sandstone with subordinate siltstone and shale. The Kingston Peak is also highly variable in thickness and is interpreted to consist of the rocks representing the main filling of the Amargosa Aulacogen (Wright and others, 1974). The conglomerate and diamictite contain clasts from all three formations in the Pahrump Group which indicates the removal of most of the previously deposited Pahrump rocks from the flanks of the aulacogen. This period of erosion is also responsible for the angular unconformity below the Noonday Dolomite.

Some workers consider the upper diamictite units to be characteristic of the lower Windermere Series and they prefer to interpret the Kingston Peak Formation as the initial widespread deposits of the
Cordilleran geosyncline (e.g. Stewart, 1972). Other workers interpret the Noonday as the initiation of Windermere stratigraphy in this area. It appears likely, however, that a relatively short period of time, if any, is unrepresented between the Kingston Peak and the Noonday, because in some areas they are possibly conformable (Cloud and others, 1974).

The Latest Precambrian, or Eocambrian stratigraphy in the study area consists of four formations which are generally considered shallow water deposits, transitional into the miogeoclinal rocks to the west.

Noonday Dolomite:

The Noonday Dolomite is the oldest Eocambrian formation and will be discussed below at length. It should be noted here, however, that on a regional basis, two facies of Noonday are present. Commonly, the Noonday is an orange weathering dolomite, but Williams and others (1974) have described siltstone which they interpret as a basinal equivalent of the Noonday. Their basin "facies" is present to the west of the Clark Mountain area and south of Death Valley (fig. 1). They also include in the Noonday a narrow band of very coarse conglomerate and a considerable thickness of arkosic sandstone and siltstone and thin-bedded clastic limestone and dolomite. These rock types are present in several areas near the southern zero isopach in figure 1.

Johnnie Formation:

The Johnnie Formation directly overlies the Noonday with apparent conformity. In most areas a transitional unit of sandy dolomite and quartzite grade upward into a quartzite unit directly above the
Noonday. The sandy dolomite and quartzite are commonly crossbedded. Above them lie two to four units of interbedded quartzite, clastic dolomite, pebbly conglomerate, siltstone, laminated to massive dolomite and limestone and a remarkably persistent oolite bed (Johnnie oolite). In the Clark Mountain area this picture is complicated somewhat by rapid facies changes (Burchfiel and Davis, in prep.).

Stirling Quartzite:
Lying conformably above the Johnnie is the Stirling Quartzite. It can be divided into three units, a lower, medium to fine grained cross-bedded quartzite, a middle unit of fine grained sandstone and siltstone and an upper unit of thick bedded, coarse grained to conglomeratic quartzite. It may contain the lowest Cambrian fossils in the area (Langille, 1974).

Wood Canyon Formation:
The Wood Canyon Formation commonly shows many lateral facies changes but consists primarily of thick sequences of siltstone, arkose and locally conglomeratic sandstone with interbedded dolomite. The upper part of the Wood Canyon contains what has been considered the lowest early Cambrian fossils, trilobites and archeocyathids. It also marks the change to a northwesterly paleoslope, predominant throughout the Paleozoic (Diehl, 1974).
STRATIGRAPHY OF THE NOONDAY DOLOMITE, SOUTHERN DEATH VALLEY AREA:

The Noonday crops out over a large area in the southern Death Valley area (fig. 1). It is present in the Panamint Range, east to the Clark Mountain area, north almost to the Funeral Mountains, where it may be represented by a thin sandy dolomite (Wright and Troxel, 1966; Stewart, 1970), and south to Valley Wells.

At its type locality in the southern Nopah Range, the Noonday is divided into two units, a lower "algal dolomite" member and an upper sandy dolomite member (Hazzard, 1937). This is typical in most areas where the formation is well developed, although locally, especially toward the southwest, these units are separated by a clastic middle member (Wright and Troxel, 1967; Cloud and others, 1974) which consists of silty dolomite.

The lower unit of the Noonday is a light grey to greyish-orange cliff-forming, laminated dolomite, perhaps more precisely termed a cryptalgalaminite (Aitken, 1967). It is generally 150 to 300 m thick and occupies two-thirds or more of the thickness of the Noonday. In many areas (e.g. the southern Nopah Range) the laminations form concentrically banded mounds as much as 200 m high and 600 m long (Williams and others, 1974). In most areas the mounds are present but on a much smaller scale. These mounds have generally been interpreted as algal in origin and represent some of the largest structures of this type ever described. Associated with these large mounds are vertical tubular structures, that have long been referred to as "Scolithus-like" (Hunt and Mabey, 1966; Wright and Troxel, 1967; Stewart, 1970). More recently, Cloud and others (1974) have interpreted these tubes as defluidization channels formed by the channeling of "some combination
of gas of biologic origin with evading interstitial and artesian water to the upper parts of the larger mounds. The defluidization occurred before the middle member of the Noonday was deposited.

The middle member of the Noonday is discontinuous and consists of thinnly bedded, brown, buff to rusty weathering dolomitic siltstone and silty dolomite. Its thickness varies considerably because it appears to fill the spaces between the large mounds of the lower member and disappears across their tops (Cloud and others, 1974). Toward the southwest, this member apparently changes facies into a lavender shale and greywacke. Associated with these rocks to the southwest is a conglomerate with very large clasts of the lower member of the Noonday and Kingston Peak Formations. This facies marks the transition of the Noonday into a more basinal environment farther to the southwest (Williams and others, 1974).

The upper part of the Noonday is a brownish-grey, medium-grained clastic dolomite. Wavy laminations occur throughout most of this unit. Rapid changes in facies (sand and silt content and lamination character) and thickness are common in the upper unit and are caused by irregularities in the underlying paleotopographic surface. The upper unit is generally 45 to 90 m thick and locally, cross lamination and small scale slump features are common. The laminations are generally considered cryptalgal in origin and locally form domal mounds 20 cm to 5 m in height, near the top of the member.

The top of the unit is overlain by and locally interfingered with a cross laminated, quartzite-dolomitic sandstone unit of the Johnnie Formation. This unit is a transitional sequence into the Johnnie quartzite. This transitional sequence is generally considered to begin
at the lowest quartzite bed. The quartz grains in the dolomitic sandstone range from silt sized to medium sand sized while the quartzite contains medium to very coarse, well rounded but poorly sorted grains.

According to the paleogeographic reconstructions of Wright and others (1974) and Williams and others (1974), the units discussed above were deposited on a platform. To the southwest, they are abruptly replaced by southward thickening clastic units. The abruptness of the facies change suggests rapid change in topographic relief caused by vertical movement along faults in the area during Noonday time. This aspect of Noonday deposition will be discussed further below.
The Noonday Dolomite is well exposed in four areas in the Clark Mountain thrust complex (fig. 1). Each of these areas was studied in detail and measured sections from each location (except the powerline hills) are presented in figure 3. Thickness measurements and occasionally, the identification of units were complicated by the fact that in many places the Noonday is highly deformed and occasionally brecciated and that large faults are difficult to recognize in the Noonday.

Throughout the study area, the Noonday rests unconformably on the basement crystalline complex and the Eocambrian rocks rest conformably above it. The Noonday can be divided into four easily recognized units: 1) a basal sandstone-conglomerate, 2) a lower parallel laminated dolomite, 3) a middle wavy laminated dolomite, and 4) an upper detrital, sandy, or lithoclastic dolomite. Only the lower parallel laminated unit is found throughout the area.

The basal sandstone-conglomerate unit is present only locally. In some places it occurs in well developed channels cut into the underlying gneiss and in other places it is difficult to distinguish from the gneiss, because it is probably a cemented regolith composed of gneiss fragments. The rock is generally poorly sorted with fine to very coarse grains, poorly to well rounded, feldspathic and locally conglomeratic. The pebbles in the conglomerate are less than 1 cm in diameter and consist of well rounded white quartz pebbles. The sandstone-conglomerate ranges from 0 to 7.5 m thick and is the product of the weathering of the gneiss below. This basal unit is present only at the Winter's Pass locality.

At another locality, the Winter's Pass Hills, (fig. 1) approximately
Explanation for figure 3:

Green  Parallel laminated unit
Red    Wavy laminated unit
Yellow Sandy or lithoclastic dolomite unit
Brown  Basal sandstone-conglomerate
VW     Valley Wells
WPH    Winter's Pass hills
WP     Winter's Pass

The numbers on the Winter's Pass sections correspond to section lines on figure 4.

→ indicates probable faults.

1 inch = 35 feet
Figure 3 Measured sections of Noonday Dolomite in the Clark Mountain thrust complex
4 km west-southwest of Winter's Pass, a very different conglomerate is present between the basement gneiss and the Noonday. In an exposure 35 m long and 9 m thick, a medium grained, medium to bimodally sorted well rounded conglomeratic sandstone is exposed. It contains several layers of quartz pebble conglomerate containing white quartz pebbles up to 5 cm in diameter. The contact between the gneiss and the conglomerate appears to be planar and the Noonday (although not well exposed) appears to arch over this pod-shaped conglomerate. The conglomerate is similar to some of the Crystal Spring Formation in near-by areas (Burchfiel, pers. com.) and there are places to the north and west where the Noonday rests unconformably on the Crystal Spring Formation. The conglomerate thus may represent an erosional remnant of the Crystal Spring which formed small mounds on the pre-Noonday topographic surface.

The parallel laminated unit rests above either the basement gneiss or the basal sandstone-conglomerate and is the only unit of the Noonday present at all outcrops in the study area. It is a finely crystalline dolomite consisting of parallel laminations 0.5 to 2 cm apart, and generally weathers grey to an orangish-tan whereas fresh surfaces are light grey. The laminations are clearly visible on good outcrops and are the product of differential weathering. They appear very continuous, but can rarely be followed more than 3 to 5 m in outcrop before they are disrupted by fracture, brecciation or faulting. This unit is typically about 9 m thick and is transitional into the overlying unit.

In thin section the laminations appear to represent alternating layers of differing original materials. The layering appears to be primarily a series of dolomitized, pelleted grainstone layers and dolomitized micrite. The layers are very continuous in thin section
and range from less than 0.5 to about 4 mm thick. The micrite layers are generally thin and dark in color, whereas the pelleted layers are lighter colored and appear cloudy or mottled, which is very similar in appearance to more recently dolomitized, pelleted grainstones. No mixing of the two rock types is seen in thin section. Associated with some of the darker micrite layers are microstylolites, marked by a concentration of dark, opaque material. The suggestion has been made (J.L. Wilson, pers. com.) that they may represent thin clay layers. Staining of a few thin sections has revealed about 10% medium grained blocky calcite cement in some of the pelleted layers.

The morphology of the laminations is the characteristic which distinguishes the wavy laminated unit from the parallel laminated unit. Most of the laminations in this unit undulate with an amplitude of 3 to 7 cm and a wavelength of 10 to 30 cm. However, near the top of this unit, commonly dome-shaped, concentrically banded mounds are present. These mounds are generally less than 30 cm high and 30 to 50 cm across and are present only in the upper 3 to 4 m of the unit. The wavy laminated unit is more variable in thickness than the parallel laminated unit below, ranging from 10 to 20 m thick. The wavy laminated unit is well exposed at Winter's Pass and Winter's Pass Hills localities. It is not present at the Valley Wells Hills.

A few of the tubes described by Cloud and others (1974) are present near the measured section line, approximately 1 km north of the main road at Winter's Pass (fig. 4). They are approximately 50 cm long and 2 to 3 cm across and are filled with sandy clastic dolomite. Laminations in the tube fillings turn concave up at the edges of the tubes. The tubes have been interpreted as defluidization channels.
Figure 4 Map of the Noonday Dolomite at Winter's Pass (from Burchfiel and Davis, in prep)
Other sedimentary structures present in this unit include ripple marks and flaser-like bedding. Both of these features are seen only at the northern end of Winter's Pass and are confined to a small area. The ripple marks form a curved feature covering slightly more than 70 degrees of arc on bedding plane surfaces. In cross section they have the characteristics of climbing ripple marks, but appear to climb in both directions, perhaps indicating tidal influences. The flaser-like bedding is very well developed in one small area, consisting of small lenses of coarse clastic dolomite and quartz separated by discontinuous layers of algal dolomite and silty dolomite. Following the same bedding horizon, these structures change transitionally into ripple marks and finally into the wavy lamination common to this unit, all in less than 10 m horizontally.

In thin section, the wavy laminated unit appears almost identical to the parallel laminated unit. It consists primarily of alternating layers of dolomitized pelleted grainstone and micrite. In this unit, the laminations in thin section are generally less well defined and slightly thinner than in the parallel laminated unit. Occasional fine grained quartz is present in some of the pelleted layers, but it rarely forms more than 1% of the rock.

The sandy dolomite, more precisely termed a lithoclastic dolomite, directly overlies the wavy unit, with a slightly transitional contact. Some relief can be seen along the contact but appears to be only that caused by the mounds in the wavy unit. The unit consists of fine grained detrital (or sandy textured) orangish brown to light brown weathering dolomite, often cropping out as a ledgy slope. This unit is
also laminated with indistinct laminations 1 to 3 mm thick. They are generally continuous but rarely parallel, often exhibiting pinch and swell structures. Locally there are small sets of climbing ripples and rarely, low angle, small scale cross laminations. The most characteristic feature of the unit is rapid facies changes. It locally contains lenses of fine grained quartz sandstone, thin beds of white quartz pebble conglomerate and lenses of coarse clastic dolomite and quartz separated by 0.5 to 1 cm thick stringers of dolomitic siltstone.

This sandy dolomite unit thins rapidly and wedges out southward approximately 500 m north of the southern end of Winter's Pass. It thins from almost 30 m at the north end to 1.6 m where it is last seen near the southern end of the outcrop (fig. 4).

Above the sandy dolomite is the white to grey, fine to medium grained, massive to thickly bedded, basal Johnnie Quartzite. The contact between the Johnnie and the Noonday is always sharp and locally marked by shallow (less than 1.5 m) channels that cut into the Noonday. These channels and most of the first 0.5 m of the basal Johnnie consist of conglomerate which is a white quartz pebble conglomerate with maximum pebble diameters of approximately 2 cm. The conglomerate is very similar to the local conglomerate beds in the upper Noonday.

Erosion at the top of the Noonday suggests an unconformity. Nowhere however, are the two units visually discordant. The lack of the transitional Johnnie member, the pinching out of the sandy dolomite member and the existence of the quartzite pods (below) all provide possible evidence for the existence of an unconformity between the Noonday and the Johnnie in this area.

I believe this is an unconformity and although it may not be of
any great magnitude, I consider it an integral part of the development of other features in the Noonday in the study area.

As seen in figures 1 and 3, the Noonday thins steadily to the south. Eight km north of the Winter's Pass outcrop, Stewart (1970) measured 140 m (100 m more than at Winter's Pass) of Noonday and the thickness increased to over 330 m in some areas to the west (Cloud and others, 1974; fig. 1). Because the Noonday is not seen again to the east, the Noonday of the Clark Mountain area represents the eastern closure of the Amargosa Aulacogen in Noonday time.
CORRELATION OF NOONDAY UNITS

The units described here from the Clark Mountain thrust complex appear to correlate well with those described from other areas (Cloud and others, 1974; Williams and others, 1974; Wright and Troxel, 1966; Hazzard, 1937). However, because of the apparent lack of the middle member in the Clark Mountain area, it is not possible to make positive correlations. The parallel and wavy laminated units combine to correlate with the lower algal member of Williams and others, (1974). The sandy dolomite is the upper sandy member of Williams and others. In the section measured by Stewart (1970), 8 km north of Winter's Pass, he described 45 m of sandy dolomite interbedded with quartzite which he called transitional Johnnie. Because the sandy dolomite in this study contains no quartzite beds, except a thin local conglomerate near the top, and the Johnnie is generally considered to begin at the lowest quartzite bed, the sandy dolomite of this study appears best correlated with the upper member of the Noonday described in the rest of the southern Death Valley area.

It is possible that the sandy dolomite of the study area is a facies of the transitional Johnnie. If this is the case, then the sandy or upper member of the Noonday has pinched out to the north and west of the Clark Mountain area and the study area contains only the lower Noonday member and the transitional Johnnie member. I believe that this is not the case, but the only satisfactory way to resolve this question is to walk these units through the Kingston Range to the Nopah Range (fig. 1), where the members were originally defined (Hazzard, 1937).
QUARTZITE PODS:

Perhaps one of the most puzzling features of the Noonday Dolomite in the Clark Mountain thrust complex are local accumulations of orthoquartzite within the dolomite. They are referred to in this study as quartzite pods. These features have never been described before in the Noonday and are apparently unique to the Clark Mountain area.

The pods are all composed of nearly 100% quartz sandstone and the contrast in lithology and texture with the Noonday makes them very obvious. The grains are always well rounded and well sorted, although the sorting is often bimodal. Some pods are 100% quartz including overgrowths of quartz cement, some have carbonate cement, some contain small amounts (less than 5%) of clay matrix and a few appear recrystallized. Most pods contain rare clasts of plagioclase and microcline and many contain angular fragments of Noonday, some as large as 3 cm long.

The pods range in size from several cm to several m in the longest dimensions. They have no preferred shape or orientation and assume irregular but generally rounded or ameboid forms. Rarely do they occur in any geologically recognizable shape such as a channel or tube filling. They are in sharp contact with and crosscut, without disturbing the Noonday laminations. They are more common and generally larger near the top of the formation. The parallel laminated unit never contains pods larger than a few tens of cm across.

In the field, the larger pods occasionally appear bedded. This rather obscure bedding was nearly parallel to the lamination of the Noonday. While bedding was not obvious in the smaller pods in the field, polished slabs have revealed preferred grain orientations and
possible grading. Some pods have irregularly shaped areas within them containing only very fine grains whereas the rest of the pod is primarily medium grained to coarse grained. One pod contained a concentration of coarse grains along the outermost one cm whereas the rest was fine grained sand. Another showed a similar concentration of coarse grains along the outer margin with a coarse to fine graded sequence inside. The overall grain size in the pods throughout the area was consistently within the range of fine to very coarse sand. At Valley Wells hills, a few of the large pods contained cobbles of quartzite and blue quartz.

The pods are rarely connected in outcrop. Occasionally, a few pods in one area will be connected by thin stringers of quartzite identical to the quartzite in the pods. These stringers are generally 1 to 2 cm thick and up to a few meters in length. They appear to maintain either a very low or a very high angle to the laminations. More commonly, however, the pods are separate and not connected in any way. Very rarely, a pod will be conformable to the lamination.

The pods often contain angular fragments of Noonday Dolomite. These fragments are always much larger than the grain size in the pod. The dolomite fragments have been rotated (relative to the surrounding Noonday). All the Noonday clasts examined appeared to be completely dolomitized.

The origin of the quartzite pods is ambiguous. Evidence for their origin is not only inconclusive but contradictory. Three different models of origin will be explored below: 1) injection, 2) contemporaneous deposition, and 3) filling of solution or karstic features.

Perhaps the least likely of these three proposed origins, but one
that needs to be critically examined is soft sediment injection. The obvious facts in favor of injection are: irregular shapes of the pods, sharp contacts, and pods lined with coarse grains. Many observations contradict this idea, however. The biggest problem is the presence of bedding. This would not be expected in any kind of clastic injection feature. There is no disturbance of the lamination such as drag and the only obvious source for the material lies above the Noonday in the basal Johnnie Formation. Also, the extreme angularity of the included Noonday clasts suggests the Noonday was lithified before the introduction of the quartzite. This model then, requires the soft quartzite be injected from above into at least partially lithified Noonday and without disturbing any laminations. This is unacceptable.

The second possibility is that these features represent an overlap from a close-by, contemporaneous clastic environment. This overlap could be in the form of storm deposits, wind blown deposits, or small tidal channels. This is a particularly attractive idea since the overlying quartzite of the basal Johnnie Formation is identical to the quartzite in the pods. Deposits such as these can also account for the bedding and grading. Several other features are difficult to explain, however, such as the large angular clasts of dolomitized Noonday, which also appears to have been lithified, and the unconnected nature of the pods. Other features that would be expected in such a model are not seen; sand and dolomite mixed, laminations covering pods conformably, and thin continuous layers of sand in the dolomite. This model is also unacceptable.

The model that presents the least problems is the filling of solution or karstic features. The presence of large angular clasts of
Noonday in the pods and the sharpness and undisturbed nature of the contacts between the pods and the Noonday suggest that the Noonday was lithified (and perhaps dolomitized) by the time the quartzite was introduced. These facts coupled with the presence of an erosion surface at the top of the Noonday and the restricted occurrence of the pods make the karst filling model an attractive one. The model allows for irregular shaped bodies, bedding, and grading features and the similarity between the quartzite filling the pods and the quartzite in the overlying Johnnie Formation. This model however, is not without its problems. The biggest problem is the apparent lack of connecting features between the pods or the overlying Johnnie. The thin stringers of quartzite described above may represent these missing connecting features. Others problems include the complete filling of all the pods and the lack of preferred orientation, although these are not strong arguments against the model.

Briefly stated, this model would involve the initial deposition of the entire Noonday sequence as discussed in all later section, followed by subareal exposure of the Noonday. The quartzite pods are present only where the transitional Johnnie member is missing and where erosion is evident at the base of the Johnnie Formation. They are not reported in areas where the Johnnie conformably overlies the Noonday. If the subareal exposure was caused by local uplift of a small fault block, then this would be the only area of the Noonday exposed. More likely, however would be a slight regression exposing the eastern end of the Amargosa Aulacogen. The subareal exposure may also explain the calcite cement present in some thin sections as a secondary vadose cement filling voids left by dolomitization. The subareal exposures
produced the beginning of solution features, such as small irregular caverns and narrow solution channels in the Noonday and the initial stages of a karstic area began. Before the karst process became too advanced, the area was transgressed by quartz sand that immediately filled these solution features and formed the initial deposits of the basal Johnnie Quartzite. I believe that this model best explains the observations.

The timing of the formation of the quartzite pods can be broadly bracketed. They were formed after the Noonday was dolomitized and lithified because the pods contain large angular clasts of dolomitized Noonday (see Environment of Deposition). Most all jointing and veining features, undoubtedly of several ages, cut through the pods indicating the pods were formed before these features. If the interpretation presented above is correct, they formed during a short hiatus between Noonday and Johnnie deposition.
Explanation for figure 5:

This idealized diagram offers an explanation for the localization of the quartzite pods. The eastern end of the trough is slightly uplifted along a fault, exposing this area to solution and erosion.

- **Green**: Parallel laminated unit
- **Red**: Wavy laminated unit
- **Yellow**: Sandy or lithoclastic dolomite
- **Brown**: Basal sandstone-conglomerate
Figure 5 Idealized fault block model for the quartzite pods
Explanation for figure 6:

<table>
<thead>
<tr>
<th>Color</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Outcrop of Noonday</td>
</tr>
<tr>
<td>Yellow</td>
<td>Large quartzite pods</td>
</tr>
<tr>
<td>Brown</td>
<td>Tectonic pod of conglomerate</td>
</tr>
</tbody>
</table>
Figure 6. Map of the Noonday Dolomite at the hills northwest of Valley Wells (from Burchfiel and Davis, in prep)
VALLEY WELLS:

Valley wells is located north of Interstate 15 on Cima Road (fig. 1). The low hills just north of Valley Wells contain the most southerly exposures of the Noonday Dolomite known in the southern Great Basin. Because of that, and some peculiarities found there, it is of special interest to this study. The outcrop at Valley Wells is structurally very complex. Eocambrian rocks are apparently isoclinally folded and complexly faulted. On the north side of the Valley Wells hills, the Noonday appears to be repeated at least twice and perhaps three times by thrusts (fig. 6). Most of the Johnnie is missing, apparently because of faulting.

Three features are of particular interest here: 1) only the parallel laminated unit is exposed, 2) there are apparently some very large quartzite pods which contain some blue quartzite pebbles, previously seen only in the Johnnie further north, and 3) the presence of a thrust slice of conglomerate containing clasts of Noonday and basement gneiss that rest depositionally on a small sliver of basement.

The fact that only the parallel laminated member is exposed can be interpreted in three ways: 1) either the remainder of the Noonday was never deposited, or 2) it was deposited and was removed by pre-Johnnie erosion, or, 3) it has been faulted out. Most of the Johnnie has been cut out along a fault in much of the exposure, however, in several areas, is present depositionally on the Noonday. The exposure is not good enough to determine if the contact is erosional. I consider it likely that the contact is erosional mainly based on the large size of the quartzite pods, indicating this area underwent a longer period of subareal exposure than the Winter's Pass area.
This is a significant question, however, because it is not clear whether the Valley Wells rocks are part of the Winter's Pass thrust plate of the lower Mesquite Pass thrust plate of the Clark Mountain thrust complex (Burchfiel, pers. com.). If this outcrop is indeed a window through the Winter's Pass thrust plate, this would place it palinspastically to the east of the Noonday at Winter's Pass. Under these circumstances, a good case can be made for more erosion of the Noonday at Valley Wells than at Winter's Pass, palinspastically, back towards the main part of the aulacogen. A slight regression would have exposed the east end of the aulacogen (Valley Wells) longer than the more westerly Winter's Pass (fig. 7). This palinspastic reconstruction also allows for less deposition of the Noonday at Valley Wells. This makes it likely that a combination of less deposition and more erosion at Valley Wells than at Winter's Pass is responsible for the presence of only the lower parallel laminated unit at Valley Wells.

The quartzite pods at Valley Wells are somewhat of a problem. The small pods are common in the Noonday at Valley Wells as they are in the lower Noonday elsewhere. At Valley Wells, however, there are several very large areas of quartzite (tens of meters across) within the Noonday that are not typical of the other quartzite pods (fig. 6). They do not have the medium to coarse, well rounded quartz grains making up the entire pod, but rather appear more as brecciated quartzite. The grain size ranges from medium sand to large angular cobbles, up to 10 cm in diameter. The rounding is equally variable from well rounded smaller grains to angular large ones. Sorting is poor. Some of these larger pods also contain blue quartz pebbles, previously found only in
the Johnnie in the northern parts of the study area. Whether these are tectonic inclusions or have the same origin as the small quartzite pods is at present uncertain.

The third feature of interest at Valley Wells is the thrust slice of conglomerate. The conglomerate appears to be completely bounded by faults so its stratigraphic position is difficult to determine. The conglomerate contains large angular clasts of basement gneiss, quartzite, dolomite (probable Noonday) and siltstone. These clasts are supported by fine, rounded quartz grains and a clay matrix. Rocks in a small area in the northeast corner of this tectonic slice appear to be a conglomerate that is much more metamorphosed than the conglomerate overlying it. Pebbles in the metaconglomerate are stretched, smaller in size and develop a very good foliation. Thus, it appears that this slice contains a conglomerate deposited on a basement of metaconglomerate. This suggests the older, metaconglomerate is part of the Precambrian basement and the overlying conglomerate was being formed during or slightly after Noonday time.

I feel that rocks in the Valley Wells hills are probably within the Mesquite Pass plate of the Clark Mountain thrust complex. The presence of the blue quartzite in the large pods and the absence of the upper Noonday as well as very large clasts in the quartzite pods all fit best into a scheme whereby the Valley Wells hills are the most easterly or most landward facies of the Noonday present in this area.
Explanation for figure 7:

An idealized diagram showing the palinspastic relationships of the three main outcrops:

VW Valley Wells - where only the parallel laminated unit is exposed.
WP Winter's Pass - where all three units are present to the north and only the lower two to the south.
WPH Winter's Pass hills where only the two lower units are present.

This diagramatically represents the closure on the aulacogen to the east and shows how a small regression could expose these localities to solution and erosion while not exposing the larger areas to the north and west.
Figure 7  Idealized palinspastic relationships
ENVIRONMENT OF DEPOSITION:

The environment of deposition of the Noonday can be broadly classified as shallow water carbonate deposition. Williams and others (1974), interpret the Noonday using an excellent three stage diagram (p. 76), as the product of a shallow water shelf environment associated with an active fault trough to the south. In their interpretation the lower algal member changes to the silty, middle member because of a regional rise in sea level. The algae are submerged too deep to live, perhaps because of lack of sunlight. A sharp contact with no erosion along with a lack of shallow water and algal structures in the middle member are used as evidence to support their interpretation. A return of conditions favorable for algal mat development is recorded in the upper member followed by a large influx of quartz shed into shallow water, as seen in the transitional and basal members of the Johnnie Formation.

The model of Williams and others can be used to explain the depositional environment of the Noonday in the Clark Mountain thrust complex, however, several refinements are possible and a few specific changes are necessary. One of the obvious differences is that the Noonday is much thinner in the Clark Mountain area than in the surrounding area. This suggests a much slower subsidence rate in the Clark Mountain area. Faults active during Noonday time have been reported (Williams and other, 1974) and some areas were apparently subsiding, along these faults, more rapidly than others, such as the Clark Mountain area.

The lack of a middle member in the study area, and the slightly transitional rather than abrupt change from the wavy laminated to the sandy dolomite unit implies a different environmental change than
hypothesized for the remainder of the Noonday. The evidence suggests the algal mats were never submerged deep enough to stop their growth, i.e. the area remained in the photic zone throughout Noonday time.

The lack of obvious desication features so common in many Phanerozoic algal carbonates suggests that these rocks are subtidal in origin. However, they are not massive, structureless beds common to the continuously growing, subtidal algal mats described in the recent Bahama sediments (Gebelein, 1969). Instead, they are alternating layers of pellet grainstone and micrite, more typical of recent intertidal and supratidal mats (Shinn and others, 1969; Logan and others, 1964). This aspect of the environment of deposition is somewhat puzzling. Logan and others (1964) and Aitken (1967) both place domal stromatolites in the intertidal environment and describe desication features produced by periodic wetting and occasional long drying periods as typical of this form of stromatolite. However, most of the other features they describe as common to this form are seen. These include laminae showing encrusting relationships, rather than relief compensation, small scale disconformities, commonly abundant pellets and dense, light-colored carbonates (commonly dolomite). Both authors mention that not all these features need to be present to establish the environment, but I feel the complete lack of desication features suggests these rocks did not form in the intertidal but the subtidal environment. It is possible however, that during the Precambrian, because of the position of the moon, the tides could have been more frequent. If this was the case, these stromatolites may have been intertidal, but were never exposed long enough to form desication features.

Examination of these rocks in thin section has revealed some
details that help define the depositional conditions. The cyclicity of these sediments and distinct alternating zones of pelleted grainstone and micrite suggest: 1) If the micrite layers are the remains of algal layers, they indicate distinct cycles of deposition-mat growth-deposition. 2) The pellets are probably transported in from somewhere nearby because they are in distinct layers and rarely found mixed into the micrite layers. The pellets may also indicate some form of Precambrian fauna. 3) The discreet layers of micrite and grainstone indicate some current action, perhaps only tidal action, but currents weak enough not to have scoured or ripped up pieces of mat, as no scour or rip-ups are present. 4) In addition, the orderly laminations suggest a consistent overall environment, one in which the energy level was maintained at least throughout the time represented by the lower two dolomite units in this area.

Dolomitization of these rocks probably occurred soon after deposition. Wright and others, (1974) and Williams and others (1974) report finding partially and completely dolomitized Noonday clasts in contemporaneous silty dolomite and conglomeratic basinal units. Fragments of Noonday in the quartzite pods are completely dolomitized. The pellets appear to have undergone no compaction so they were almost certainly lithified if not dolomitized soon after their deposition. The time of dolomitization is difficult to establish with certainty, but the evidence points to early dolomitization.

Various local facies of the sandy dolomite unit contain thin layers of coarse clastic dolomite and quartz grains and much of the sandy dolomite unit appears to be nonrhombohedral silt to fine sand sized grains of dolomite (lithoclasts) deposited in an algal environment.
This may well indicate an increase in the energy levels of the area, but almost certainly indicates the erosion of the Noonday in some other location contemporaneous with deposition in the Clark Mountain area. It could be erosion of penecontemporaneous dolomite from a supratidal area farther east or erosion of some lower Noonday exposed at that time.

Generally, the study area represents a relatively stable, shallow landward platform deposit. It appears to have remained shallow with fairly constant energy levels throughout Noonday time. Because of the nature of modern algal sediments, Noonday time is probably a very short period of geologic time. Modern stromatolites accumulate at the rate of a lamination in a period of less than a day to several days. The time of Noonday deposition in the Clark Mountain area probably represents less time than in many areas to the north and west. In the study area as in other areas, Noonday deposition appears to be controlled by movement along local faults.
REGIONAL RELATIONS:

Over the years, there has been a controversy as to what rock units actually represent the initiation of the Cordilleran geosyncline. Several different views have been expressed and are briefly summarized and evaluated below.

The angular unconformity present below the Noonday in many places suggests that the geosynclinal sequence begins with Noonday. However, if the initiation of a geosyncline is a rifting event (Burke and Dewey, 1973), a carbonate of platform origin would be an unlikely initial deposit. In 1941, Noble observed that much of the Johnnie Formation was lithologically more similar to the underlying Pahrump Group than the younger Eocambrian units of the area. Apparently, he informally expressed the view that the Stirling Quartzite marked the initiation of the geosyncline (Wright and others, 1974). Stewart (1972) on the other hand held the view that the initial deposits of the geosyncline are the conglomeratic and diamictite units of the Kingston Peak Formation, and he correlated them with several similar units in other areas along the geosyncline. Wright and others (1974) and Diehl (1974) observe a southwesterly paleoslope in the rocks from the Crystal Spring to the Wood Canyon Formations in the southern Great Basin. In the upper Wood Canyon Formation a northwesterly paleoslope was developed and continued through the Paleozoic. For this reason, they believe the initiation of the geosyncline is represented by the upper Wood Canyon.

More recent evidence suggests to me that the Johnnie or Stirling are the initial geosynclinal deposits. Stewart and Poole (1975) have reported Late Precambrian-Cambrian rocks that they correlate with those of the southern Great Basin, in the San Bernardino Mountains of
southern California, thus extending the Cordilleran geosyncline west to the San Andreas fault. They report finding rocks correlative with the Johnnie Formation resting unconformably on the crystalline basement.

More recently, Tyler (1975) has disputed this correlation with the Johnnie and has suggested that the Stirling equivalents are the oldest sedimentary rocks in this area. Stewart (1974) has also reported rocks correlative with the Johnnie and Stirling as far north as east-central Nevada.

A logical criteria for defining the initiation of a geosyncline would be the beginning of widespread sedimentation, or in other words, the development of established sedimentation along a continental margin. Using this criteria, the conglomerate and diamictite units do indeed represent early tectonic activity, but are fairly local in their distribution. The Johnnie and Stirling, however, are recognized over large areas to both the north and south of the Clark Mountain area. This suggests the Johnnie (if it is present to the south) or at the latest, the Stirling, represents the initiation of the Cordilleran miogeocline.

Because of recent work by several people on the Pahrump Group and the Noonday, it now appears clear that these formations represent the filling of an active, fault-bounded trough that is elongate in a west-northwest direction. The filling of the trough appears to be in two similar stages each ending in shallow water carbonate deposition. The Noonday is the end of the second stage. It seems clear that the Noonday is restricted to this elongate area and is essentially deposited on a shelf adjacent to a basin which had an unknown extent (perhaps quite small) to the southwest. This thesis describes the eastern end of this platform. The history and orientation of this trough fits
Hoffman's (1974) description of an aulacogen and may well be a "failed arm" related to the early stages of the rifting event that formed the Cordilleran geosyncline (Burke and Dewey, 1973). The Noonday then, appears to be the last stage in the filling of this aulacogen and not the initial stage of the miogeocline.
CONCLUSIONS:

1) The exposures of the Noonday in the Clark Mountain thrust complex represent the eastern, feather edge of a shallow water platform deposit, related to the final stages of the Amargosa Aulacogen.

2) The Noonday in the Clark Mountain thrust complex represents a short period of quiet, shallow water sedimentation with carbonate pellets being deposited and bound by algal mats.

3) The Noonday was dolomitized very early in its history.

4) The quartzite pods represent the filling of solution cavities during the early stages of the development of a karst topography. They should be present in the Noonday only where the transitional Johnnie member is missing and/or where there is a significant erosion surface developed at the top of the Noonday.

5) Rocks of the Valley Wells hills lie in the Mesquite Pass thrust' plate of the Clark Mountain thrust complex and were originally east of the Noonday at Winter's Pass.
REFERENCES:


Burchfiel, B.C, and Davis, G.A., in prep. Geology of the Clark Mountain thrust complex, southeastern California


Hoffman, Paul; Dewey, J.F, and Burke, Kevin 1974 Aulacogens and their genetic relation to geosynclines, with a Proterozoic example from Great Slave Lake, Canada: in Modern and Ancient Geosynclinal Sedimentation, SEPM Spec. Pub. no. 19, p. 38-55

Langille, G.B. 1974 Problematic calcareous fossils from the Stirling Quartzite, Funeral Mountains, Inyo County, California: GSA Abs. with programs (Cordilleran Sec.) vol. 6, no. 3, p. 204-205

Logan, B.W., Rezak, R, and Ginsburg, R.N. 1964 Classification and environmental significance of algal stromatolites: Jour. Geol. vol. 72, p. 68-83


Stewart, J.H. 1972 Initial deposits in the Cordilleran geosyncline: Evidence of a Late Precambrian (less than 850 my) continental separation: GSA Bull., vol. 83, p. 1345-1360


Williams, E.G., Wright, A.W., and Troxel, B.W., 1974 The Noonday Dolomite and equivalent stratigraphic units, southern Death Valley region, California: in: Guidebook to Death Valley: Boulder, Colo. GSA p. 73-78


Wrucke, C.T., 1972  Correlation of the Precambrian diabase in Arizona and California: GSA Abs. with programs (Cordilleran Sec.) vol. 4, no. 3, p. 265