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Title: DEVONIAN STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE NORTHERN ANTELOPE RANGE, EUREKA COUNTY, NEVADA

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Lochkovian to Frasnian carbonate rocks in the northern Antelope Range reflect an eastward shift of the gradational facies boundary between the eastern assemblage of shallow-shelf dolomites, limestones, and quartz arenites and the transitional assemblage of basin and basin-slope limestones and fine-grained clastics in the Cordilleran Miogeocline. The Lochkovian upper part of the Lone Mountain Dolomite represents primary dolomite formed under peritidal conditions on the shelf. Early Pragian transgression caused onlap and deposition of the Kobeh Member of the McColley Canyon Formation over the Lone Mountain platform complex followed by subtidally deposited fossiliferous limestones of the Kobeh and Bartine Members. A continued deepening of depositional enviornments is inferred from the laminated lime mudstones and restricted fauna of the lower Coils Creek Member. Late Dalejan to early Couvinian offlap caused a brief period of shallow water sedimentation before deposition of the basinal

lime mudstones with interbedded allodapic debris flows and turbidites of the Denay Limestone. Early Givetian shallowing along the inner shelf margin is indicated by the abundant easterly derived allodapic beds present in the middle unit of the Denay. An interlude of quiet-water, suspension deposition separated the middle unit from easterly derived allodapic beds containing the *Tecnocyrtina* Fauna in the middle portion of the upper unit. Allodapic sediments of *Tecnocyrtina* Fauna age were deposited in a previously unrecognized intrashelf basin situated west of the shoal-water Devils Gate platform complex and east of the incipient Antler orogenic highland. Silty shales present in the upper portion of the upper unit represent, in part, westerly derived clastic detritus. Allochthonous quartzose packstones and grainstones of the Devonian sandstone (informal unit) represent sediment gravity-flow deposits shed eastward of the incipient Antler orogenic highland into the intrashelf Pilot Shale basin during middle and late Frasnian time.

Devonian Stratigraphy and Depositional Environments of the Northern Antelope Range, Eureka County, Nevada

by

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PRELUDE

Although the rocks may confuse us

The desert remains in all its beauty

Sunrise from the northern Antelope Range looking north towards Lone Mountain with the Roberts Mountains in the distance.

DEVONIAN STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE NORTHERN ANTELOPE RANGE, EUREKA COUNTY, NEVADA

INTRODUCTION

This study synthesizes biostratigraphic and petrographic investigations of Devonian carbonate rocks in the northern Antelope Range, southern Eureka County, Nevada (Fig. 1).

The objectives of this paper are fourfold: (1) to describe the geology and stratigraphy of Devonian strata, (2) to place the rock units in a time-stratigraphic framework, (3) to evaluate the depositional environments of these rocks, and (4) to propose correlations between these units and various rock units in central Nevada.

The faunal sequence that was collected during the course of this study represents one of the most complete biostratigraphic sections for the Devonian in western and arctic North America (J. G. Johnson, 1978, pers. comm.). This faunal sequence is summarized on Figures 2 and 3.

The Lone Mountain Dolomite, the McColley Canyon Formation, and the lower and middle units, and the lower portion of the upper unit of the Denay Limestone correlate well, both lithologically and faunally, with previously described rock-stratigraphic units present elsewhere in central Nevada. The middle and upper parts of the upper unit of the Denay and the Devonian sandstone (informal unit) are

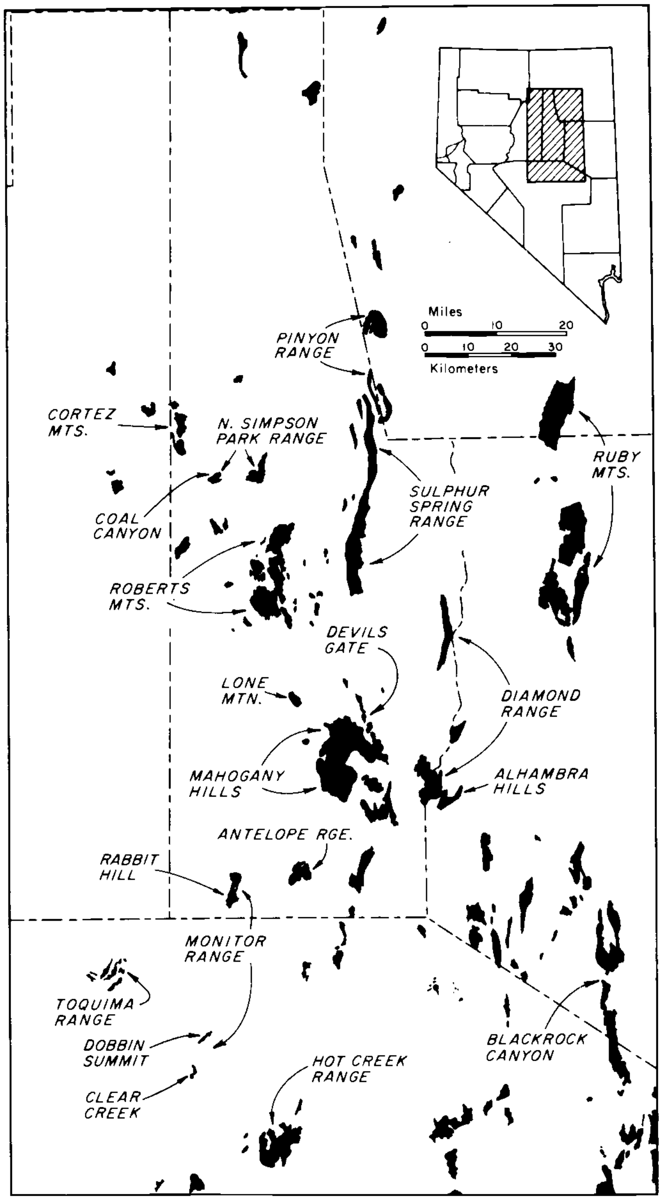

Figure 1. Index map of central Nevada with Devonian outcrops shown in black. Inset in upper right shows area covered.

Figure 2. Summary faunal sequence in the northern Antelope Range showing brachiopod faunas and zones with corresponding conodont zone. Numbers 1-30 are brachiopod intervals of Johnson (1977).

CONODONT ZONE	INT.	BRACHIOPOD FAUNAS & ZONES	STAGE
L. *PAL. TRIANGULARIS*			FRASNIAN
UPPERMOST *GIGAS*			
U. *GIGAS*			
L. *GIGAS*			
ANCY. TRIANGULARIS			
U. *ASYMMETRICUS*			
M. *ASYMMETRICUS*	30		
L. *ASYMMETRICUS*	29	*ALLANELLA* F.	
LOWERMOST *ASYMMETRICUS*	28	*TECNOCYRTINA* FAUNA	GIVETIAN
PAL. DISPARILIS F. BELOW *ASYMMETRICUS*	27		
	26		
	25	*HIPPOCASTANEA* Z.	
HERMANNI – CRISTATUS U.	24	U. *STRINGO* F.	
HERMANNI – CRISTATUS L.	23		
U. *VARCUS*	22		
M. *VARCUS*	21	*STRINGOCEPHALUS* FAUNA	
L. *VARCUS*	20	*CASTANEA* ZONE	
ENSENSIS	19		
KOCKELIANUS	18	*CORIACEA* F.	COUVINIAN
	17	U. *KIRKI* F.	
AUSTRALIS	16	*CIRCULA* ZONE	
COS. COSTATUS	15	*PENTAMERELLA* F.	
PATULUS	14	*WARRENELLA* F.	
SEROTINUS			DALEJAN
INVERSUS	13		
GRONBERGI	12		ZLICHOVIAN
	11		
DEHISCENS	10	*ELONGATA* F.	
	9	*KOBEHANA* ZONE	PRAGIAN
SULCATUS n. subsp.	8	L.	
	7	*COSTISPIRIFER* F.	
	6		
SULCATUS	5		
PESAVIS	4		LOCHKOVIAN
O. n. sp. D	3		
EUREKAENSIS	2		
HESPERIUS	1		

Figure 3. Biostratigraphic correlation chart for the northern Antelope Range. Roman numerals at top refer to measured sections aligned in relative east (right) to west (left) positions. Numbers in vertical columns below section numbers refer to footages in measured sections where faunal samples were collected. Numbers 1-30 are brachiopod intervals of Johnson (1977). Conodont zonation after Klapper (1977, Johnson (1979), and Ziegler (1971). Dots beside footages indicate zonal assignment based on brachiopods (upper dot) or based on conodonts (lower dot). Refer to Plate 1 for location of measured sections. Brachiopod identifications by J. G. Johnson. Conodont identifications by G. Klapper.

CONODONT ZONE	INT.	VI	IV	III	VIII	II	VII	Va	V	IX
L. *PAL. TRIANGULARIS*										
UPPERMOST *GIGAS*			255.							
U. *GIGAS*										
L. *GIGAS*										
ANCY. TRIANGULARIS										
U. *ASYMMETRICUS*									1530	
M. *ASYMMETRICUS*	30		63.							
L. *ASYMMETRICUS*	29		40.-50.	380.						
LOWERMOST *ASYMMETRICUS*	28		8'-20	369:					1450'	
PAL. DISPARILIS F. BELOW *ASYMMETRICUS*	27	153-160:		335.	A:-B'				1320:-1425:	
	26									
	25									
HERMANNI-CRISTATUS U.	24			258.	D.				1245.	Y.
HERMANNI-CRISTATUS L.	23									
U. *VARCUS*	22									
M. *VARCUS*	21				C.				1240. 1235.	
L. *VARCUS*	20	50.				1575:	235-265'		1120 1035: 995-1020	
ENSENSIS	19	10'-33		65:-72		1545	182:-190'			
KOCKELIANUS	18					1480:-1490.	5-10		810.	
	17					1400:			720'	
						1120'-1328:			485.	
AUSTRALIS	16					1110. 760.			440 153:-190	
COS. COSTATUS	15					665:		119.-120' 71.	95:-109:	
PATULUS	14							45.		
SEROTINUS								0.-20.		
INVERSUS	13									
GRONBERGI	12									
	11					520.				
DEHISCENS	10					325'-450.				
	9					290'				
SULCATUS n. subsp.	8					180:				
	7					124'				
	6									
SULCATUS	5					77				
PESAVIS	4									
O. n. sp. D	3									
EUREKAENSIS	2									
HESPERIUS	1									

lithologically and faunally distinct. The lower, middle, and upper portions of the upper unit of the Denay were not mapped separately because: (1) during the course of field mapping in the summer of 1977, the age of these rocks, which is the principal reason for distinguishing them from typical Denay, was not known and (2) in outcrop, the units tend to merge and no distinct, mappable horizons are present between them.

Acknowledgements

Several scientists provided help during the course of this project and I thank all of them. J. G. Johnson originally suggested studying the northern Antelope Range, served as thesis supervisor, and identified brachiopods which were an essential part of this thesis. His willingness to share his time and energy and to provide advice and encouragement will always be appreciated. G. Klapper reviewed the manuscript, served on the thesis committee, visited the map area, and identified conodonts which were invaluable for correlation. Claudia Regier processed and picked all formic acid residues for conodonts studied by Klapper. M. A. Murphy visited the map area and provided helpful advice in the field. K. F. Oles reviewed the manuscript and served on the thesis committee. R. A. Flory identified tabulate corals and W. Oliver identified tetra corals. S. Jenkins, J. D. Doucette, T. DeKeyser, W. F. Koch II, D. C. Mikulic, R. Davis, and S. Lee helped in various ways.

I especially thank my family and friends for continual support and encouragement during the duration of this project.

GEOLOGIC SETTING

Early and middle Paleozoic rocks of the Great Basin were deposited in part of the north-trending Cordilleran geosyncline, a coupled continent-ocean setting from shelf to deep-sea floor. Deposition is postulated to have occurred in a marginal basin bounded on the west by an island arc system (Stewart and Poole, 1974; Poole and others, 1977). Three distinct lithofaceis assemblages reflect three depotectonic regimes: (1) an eastern assemblage of shallow-shelf dolomites, limestones, and quartz arenites; (2) a transitional assemblage of deep-subtidal basin and basin-slope limestones and fine-grained clastics; (3) a western assemblage of basinal deep-water limestones, cherts, and volcanics (Matti and others, 1975). The thesis area is located near the gradational facies boundary between the eastern assemblage, or dolomite suite, and the transitional assemblage, or limestone-clastic suite, of Early to early Late Devonian time. Matti and others (1975) suggested that the facies boundary represented a shelf-slope break separating a broad inner-shelf platform from a basinal outer-shelf regime. The Antler orogeny, beginning in Late Devonian time, resulted from partial closure of the postulated marginal basin and resulted in displacement of the deep-water western assemblage eastward onto the shallower-water transitional and eastern assemblages along the Roberts Mountains thrust.

Late Devonian to Mississippian flysch deposits were shed eastward from the rising Antler orogenic highland into a subsiding foreland basin before, during (?), and after emplacement of the Roberts Mountains allochthon.

TERMINOLOGY

The terminology used in this report is that of Matti and others (1975). The carbonate classification I used was proposed by Dunham (1962) on the basis of primary depositional textures. Bedding descriptions are as follows: thin bedded - 1/2 to 4 inches, medium bedded - 4 to 18 inches, thick bedded - 1 1/2 to 4 feet, and very thick bedded - greater than 4 feet.

LONE MOUNTAIN DOLOMITE

Introduction

Hague (1883) originally defined the "Lone Mountain Limestone" as strata between the Eureka Quartzite and the Nevada Formation at Lone Mountain. Merriam (1940, 1963) restricted the name Lone Mountain Dolomite to the largely unfossiliferous, typically medium- to coarse-grained saccharoidal dolomites lying above the Roberts Mountains Formation and below the "Nevada Formation" and noted that the Lone Mountain Dolomite underlies the "Nevada Formation" at the northern tip of the Antelope Range. Matti and McKee (1977) indicated that the cryptalgally laminated dolomite overlain by the Kobeh Member of the McColley Canyon Formation in the thesis area is the Sevy Dolomite (=Beacon Peak) although Nolan and others (1956) and Merriam (1963) indicated and Kendall (1975) showed that the Sevy (= Beacon Peak) disconformably overlies the Lone Mountain Dolomite in the Eureka District and intertongues westward with rocks of the Kobeh and Bartine Members of the McColley Canyon Formation as discussed by Johnson and Sandberg (1977).

Light-colored, very-fine to microcrystalline "primary" dolomites described by Nichols and Silberling (1977) in the upper part of the Lone Mountain Dolomite, but below the Kobeh, at Lone Mountain and in the Roberts Mountains, and at Morey Peak in the Hot Creek

Range (Potter, 1975) are believed to be equivalent to the dense, light colored, fenestral dolomites mapped in the thesis area as the Lone Mountain Dolomite.

The unit is exposed in the northwest corner of the map area. Seven hundred fifteen feet of Lone Mountain Dolomite were measured in section I. The lower contact is not exposed and fault-related breccia in the lower 200 feet of the formation may indicate repetition of section. A minimum of 500 feet of unfaulted strata is present, however.

Lithology

The Lone Mountain Dolomite in the thesis area consists predominantly of light gray, microcrystalline dolomite that weathers to form steep, bench-like exposures. The unit is finely laminated to structureless in outcrop, although sharply defined parallel partings at medium to very thick (2-6 feet) intervals and planar cross fractures are characteristic. The color is dominantly light gray to almost white weathering, light-medium gray on fresh break, although interbedded thick (2-3 feet) beds of medium brown-gray weathering (dark brown-gray fresh) dolomite composes approximately 5% of the strata. The brown beds are finely crystalline, faintly saccharoidal, and emit a slight fetid odor on fresh break. Brown beds have gradational lower contacts, sharp or gradational upper contacts, and appear structureless in outcrop. In the upper part of the formation, fine laminations in light-gray beds are more common and the rock locally has a slight pinkish tint. One to 4 mm fenestrae and less common vugs were noted throughout the unit. Fine-grained to silt-size, well-rounded quartz constitutes less than 5% of the rock, although detrital quartz increases in abundance in the uppermost 25 feet of the formation, as seen in section II. Fe-stained quartz grains are commonly found concentrated along orange-red stylolites, which are common throughout the unit.

In thin and polished sections, an interlocking mosaic of microcrystalline dolomite is seen to preserve original mudstone to grainstone depositional textures. Much of the formation is composed of mottled or texturally massive mudstone and wackestone. Allochems are silt to fine-sand size (0.025-0.25 mm), subrounded peloids and unidentified carbonate grains. Laminae range from 1/2 to 4 mm and are defined by alternations of high and low allochem percentages and slight variations in crystal size or color. Laminae may appear even and parallel, may pinch and swell, or appear finely crenulated. Allochem-rich layers are locally micrograded and alternate with darker, organic rich (?) layers. Characteristic of the unit are 1-4 mm fenestrae which appear elongate, are aligned in the plane of stratification, and are gradational with sheet cracks up to 5 mm thick. Fenestrae are filled with dolomite spar and may contain geopetal deposits. Occasional narrow, dolomite-spar filled prism cracks 5-10 mm long and oriented normal to laminae, were noted. These are believed to be shrinkage cracks because they are sharply terminated by overlying laminae and pinch out below. Dolomite spar filling fenestrae and cracks have an outer, more finely crystalline fringe enclosing coarse spar in the central portions, indicating nucleation and growth into a void. Laminae form continuous envelopes around fenestrae. Interbeds of brown-gray dolomite are fine to very finely crystalline and contain ghosts or poorly preserved allochems. Laminae are indistinct or absent, but mottling in varied shades of brown-gray is common. Rare 2-10 mm vugs, partly infilled by dolomite spar, are present in brown beds, but are less common in the light-gray, texturally massive dolomite mudstones.

In the uppermost 20 feet of the formation, detrital quartz increases markedly from 5% to 50% locally. Well-rounded to subrounded, fine- to very-fine-grained quartz and subrounded, silt-size quartz grains are commonly concentrated, along with other allochems, in distinct laminae. At II 65 a thick bed of distinctly iron-stained intraformational breccia was noted. Finely laminated, subrounded, sandy dolomite clasts 2 to 4 inches in diameter are randomly oriented in a quartz-rich matrix of microcrystalline dolomite grainstone.

Contacts

The lower contact of the Lone Mountain Dolomite is not exposed in the northern Antelope Range. The upper contact is at 75 feet in section II where there is an abrupt change in lithology, from light-gray sandy dolomite to brownish-gray crinoidal dolomite. The upper 3-6 inches of the Lone Mountain is a dolomitic quartz arenite grainstone composed of 75-85% subrounded to well-rounded, well-sorted, fine-grained quartz sand. The surface is planar and occurs between beds. No angular discordance was noted, although small (2-3 inch) mottled clasts (?) of Lone Mountain lithology were seen in the lowest bed of Kobeh approximately 1000 feet due west of the base of section II. The quartz-rich upper contact is absent here, however. In section I, at 715 feet, the contrasting lithologies of the Lone Mountain and Kobeh are separated by a stylolite. A polished slab of the contact shows light-gray, sandy, finely laminated dolomite overlain abruptly by brown to olive gray, finely crystalline dolomite. The surface is not planar, but is slightly undulatory with relief of approximately 1 inch. Irregular isolated clasts, 1/2-1 inch in diameter, of light gray, microcrystalline dolomite and mottled white dolomite are present in the lower 2 inches of the Kobeh. Several stylolites cut across the contact at low angles.

The abrupt change in lithology is indicative of a distinct change in sedimentation and possibly a hiatus. Johnson and Sandberg (1977) discuss a Lochkovian/Pragian hiatus in detail and indicate that it is present and expands east of the thesis area. To the west, Matti and others (1975) have shown that continuous sedimentation took place from Llandoverian through Pragian time at Copenhagen Canyon. They suggested that the Lone Mountain Dolomite was a pervasively-dolomitized shoal-water platform complex and was the source of allodapic beds found in the Windmill Limestone, a level-bottom basinal deposit. Progradation of dolomite platform complex over basinal strata to the west resulted from Late Lochkovian regression. Early Pragian transgression caused onlap of the Kobeh over the Lone Mountain Dolomite platform complex.

Depositional Environments

Nichols and Silberling (1977) have interpreted lithologically similar and stratigraphically equivalent rocks in the northern Roberts Mountains as "primary" dolomite formed under peritidal conditions. Observations in the thesis area are in general agreement with their interpretations of environments of deposition.

The abundance of texturally massive, microcrystalline, light-colored dolomite mudstone, cryptalgal laminations, fenestral fabric and sheet and prism cracks (dessication features), and intraformational conglomerates suggests a tidal flat environment of deposition for the Lone Mountain in the thesis area. Alternating periods of inundation, evaporation, and subaerial exposure of the Lone Mountain tidal flat would account for the formation of primary microcrystalline dolomite (Folk and Land, 1975) and the numerous dessication features. A sabkha-like environment (Kinsman, 1965; Bathurst, 1975) is not inferred because of the apparent lack of evaporite minerals or their molds. Micrograded laminae may represent storm deposits alternating with periods of algal binding, dessication, and the formation of dolomite muds. The lensoidal bed of intraformational conglomerate observed at II 65 may represent a tidal channel in which eroded clasts of lithified sediment were deposited. The lack of abundant ooid grainstones and coarser-grained, well-sorted deposits suggests a low energy, supratidal, inner platform environment. Interbedded brown beds may represent local depressions where lagoonal or intertidal deposits accumulated. The increase in abundance of fine-grained quartz in the uppermost part of the unit may represent wind-blown detritus derived from areas to the east exposed to erosion by late Lochkovian regression. The character of the contact with the overlying Kobeh suggests a rapid change in the character of sedimentation that may be indicative of a hiatus.

McCOLLEY CANYON FORMATION

Introduction

Merriam (1940, 1963) restricted the name "Nevada Formation" to the lower two thirds of the "Nevada limestone," as originally defined by Hague (1883), and designated the remaining upper part as the Devils Gate Limestone. Carlisle and others (1957) named the McColley Canyon, Union Mountain, and Telegraph Canyon Members of the "Nevada Formation" in the Sulphur Springs and Pinyon Ranges. Johnson (1965, 1966) raised the Nevada to group status and proposed the names McColley Canyon Formation and Denay Limestone for strata disconformably (?) overlying the Lone Mountain Dolomite and overlain by the Devils Gate Limestone in the northern Roberts Mountains and in the northern Simpson Park Range. Subsequent workers (eg. Johnson and Sandberg, 1977; Murphy, 1977) have delineated the complex facies relations of the Nevada Group in the Great Basin.

The McColley Canyon Formation and the Denay Limestone were recognized in the thesis area on the basis of lithologic similarity and faunal correlation although Merriam (1963, p. 46-47) believed that the Woodpecker Limestone is present and noted:

> Only at Table Mountain was the *Stringocephalus* zone recognized, for in the Antelope Range the Nevada strata above the Woodpecker member appear to have been removed by erosion.

Murphy and Gronberg (1970) divided the McColley Canyon Formation into three members, in ascending order, the Kobeh, Bartine, and Coils Creek.

In the northern Antelope Range, the McColley Canyon Formation is approximately 510' thick and represents a gradual increase in depths of environments of deposition from the subtidal lower Kobeh to the restricted, deeper water deposits of the Coils Creek. A brief period of shallower water sedimentation in the upper Coils Creek occurred before deposition of the deep water, basinal sediments of the Denay Limestone.

Early Pragian[1] transgression across the post-Lone Mountain Dolomite erosion surface, a gently inclined "depositional ramp," caused a major shift of peritidal sedimentation eastward and deposition of the intertidal-subtidal Kobeh Member transitional between the peritidal Sevy Dolomite (= Beacon Peak) to the east and the slope-deposited Rabbit Hill Limestone to the west. The Kobeh is succeeded by the subtidal, highly fossiliferous, Bartine Member which interfingers to the east with the Sevy Dolomite. To the west, the Bartine is overlain by, and the eastern equivalent of, the offshore, deeper water, Coils Creek Member. During the late Early Devonian, Dalejan, regression, the subtidal Sadler Ranch Formation (Kendall,

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[1] Summarized from Johnson and Sandberg (1977).

1975), prograded westward over the Coils Creek and separated it laterally from the Oxyoke Canyon Sandstone, a barrier bar deposit on the westward edge of the Sevy tidal flat. The Sadler Ranch and the Oxyoke Canyon Formations represent a regressive-transgressive cycle in which the upper portion of the Sadler Ranch is an eastern correlative of the lower part of the Denay Limestone and the coarse-crystalline member of the Oxyoke Canyon Formation represents a basal transgressive sand deposit.

Kobeh Member

General

The Kobeh Member is approximately 225 feet thick as measured in section II and consists predominantly of brownish gray to medium gray, thin to medium bedded, locally fossiliferous, limestones and dolomites. The unit is typically recessive weathering and is composed of slightly fetid wackestones and packstones. The lower 30-50 feet is brownish gray to medium gray, thin-medium bedded, recessive weathering, very fine crystalline dolomite that crops out in small rounded ledges. The dolomite is blocky weathering and texturally massive, although locally finely laminated in the lower ten feet. Fine crystalline, euhedral dolomite rhombs can be seen on weathered surfaces in addition to scattered crinoid ossicles. Overlying the dolomite, the lowest beds of limestone (ex. II 122-128) are brownish gray to medium gray, medium bedded, fine-grained wackestones with rare silicified brachiopods and horn corals. Excellent exposures of the typically recessive middle portion of the Kobeh are present in Section II. Thin to medium bedded, well-bedded, brownish gray to medium gray, lime wackestones and packstones are separated by very thin interbeds of yellow to pinkish argillaceous limestone. A well preserved and abundant benthic fauna includes trilobites, horn corals, articulated and disarticulated brachiopods, and large Favosites kobehensis up to 18 x 6 inches. Fossil debris appears to be concentrated into lenses and layers forming alternations of packstone, wackestone, and argillaceous mudstone lithologies within a single bed. Packstones, however, are more commonly found in thicker beds and wackestones in thinner beds. Sedimentary structures include scour-and-fill structures with 3 to 6 inches of relief, small asymmetrical ripple marks (amplitude 2-3 inches), and fine laminations. The upper 50 feet of the Kobeh consists of small rounded ledges and platy weathering, medium gray wackestones and packstones forming a dip slope to the conformable contact with the overlying, recessive weathering Bartine Member. In thin and polished sections, the lowest beds are composed of very fine to finely crystalline dolomite mudstones and wackestones. The dolomite appears as an interlocking mosaic of subhedral rhombs containing scattered, very fine to fine sand sized peloids and subrounded quartz grains, and ghosts of totally recrystallized fine to coarse sand sized allochems. The larger allochems have distinct outlines, but have been replaced by a coarsening inward, finely crystalline mosaic of clear subhedral dolomite. Original allochems were probably leached, and the vugs later filled with dolomite spar. Alternations in abundance of elongate allochems, oriented parallel to bedding, impart a faintly laminated texture to these rocks. Detrital quartz grains form less than two percent of the volume of these rocks. Dolomite decreases in abundance upsection and appears as scattered, finely crystalline rhombs in the matrix of lime wackestone and packstone beds. Dolomite forms approximately ten percent of the volume in II 124, and less than 5 percent in the overlying portions of the Kobeh.

Lime wackestones and packstones are composed of alternating layers and lenses of whole and slightly abraded fossils, skeletal debris, peloids, and lime mud. These rocks are pelbiomicrites and pelbiosparites. Articulated and disarticulated brachiopods, echinoderm debris, and corals are the dominant bioclasts, with lesser amounts of trilobites, bryozoans, ostracodes, and gastropods. Round to ovoid, silt to very-fine sand-size peloids compose 5 to 25 percent of the volume of these rocks. Allochems are loosely packed or floating in a poorly sorted matrix of lime mud recrystallized to microspar and pseudospar. Sparry calcite is present as pore-filling cement and as syntaxial overgrowths on echinoderm debris and brachiopods, but generally does not account for more than 15 percent of the volume of these rocks.

Biostratigraphy

Faunal collections from the Kobeh in the thesis area indicate that the member is Pragian in age, (Fig. 2, Fig. 3). Conodonts from the lowest Kobeh, II 77, collected one to two feet above the contact with the underlying Lone Mountain Dolomite, were not zonally diagnostic, but are characteristic of the *sulcatus* Zone and the *sulcatus* n. subsp. Zone. A similar conodont fauna was found at II 124, 50 feet above the contact, with brachiopods indicative of the *Costispirifer* Subzone (I 7) of the *Trematospira* Zone. The basal Kobeh in the thesis area may be as old as the *sulcatus* Zone, as it is at Lone Mountain. Brachiopods of the *Kobehana* Zone and zonally undiagnostic conodonts of the *Icriodus huddlei* Group were sampled at II 245 (I 8), and at II 290 (I 8-9) which is approximately 15 feet below the gradational contact with the overlying Bartine.

Tabulate corals indicative of the *Favosites kobohensis* Zone (Assemblage Zone 12 of Flory, 1977) were collected at II 180, II 182, and II 204. A new (?) species of *Favosites* was sampled at II 290.

Solitary tetracorals appear to increase in relative abundance in the upper Kobeh and are very abundant at II 290 and II 204 and common at II 245. *Favosites gronbergi* which was previously only known from Lone Mountain, was sampled at II 124.

Depositional Environment

Early Pragian transgression across the post-Lone Mountain Dolomite erosion surface caused a general increase in depths of environments of deposition in rocks of the McColley Canyon Formation in the thesis area.

The lowest beds of the Kobeh are similar in lithology to brown beds in the Lone Mountain Dolomite and were probably deposited in an intertidal to shallow subtidal environment. The gradual increase of skeletal debris and the decrease in dolomite abundance progressing upsection in the Kobeh suggest increasing water depths, the formation of favorable biotopes, and an eastward shift of the primary dolomite lithotope. A subtidal marine environment is indicated by the abundant and diverse fauna of the *Acrospirifer kobehana* Zone. Up to fifteen species of brachiopods are present in single collections (eg. II 180, II 290). This biotope is probably contained within Benthic Assemblage 2 or 3 of Boucot (1975). Deposition was subtidal, and probably below wave base, although weak to moderate current energy is suggested by the presence of ripple marks, scour-and-fill structures, and concentrations of skeletal debris in layers and lenses. Intermittent currents are suggested by the alternations of mudstones, wackestones, and packstones within single beds. Currents were commonly strong enough to disarticulate brachiopod shells, to weakly abrade skeletal material, to concentrate bioclasts, and to winnow lime mud to form biopelsparites. In the upper approximately 100 feet, mud-supported textures and infaunal bioturbation become more abundant, suggesting a lower energy environment similar to that of the overlying Bartine.

Regional lithofacies patterns indicate that the Kobeh is a western correlative of the Sevy (= Beacon Peak) Dolomite (Johnson and Sandberg, 1977), and that an eastward shift of the primary dolomite lithotope occurred during onlap of the Kaskaskia sequence of Sloss (1963).

The Kobeh is a shallow-subtidal, platform facies, transitional between the peritidal Sevy to the east and the slope-deposited Rabbit Hill Limestone to the west (Johnson and Sandberg, 1977; Matti and others, 1975).

Bartine Member

General

The Bartine Member is approximately 110 feet thick as measured in Section II and consists of recessive-weathering, argillaceous, very fossiliferous lime wackestones and packstones. The Bartine is a distinctive unit in the field because of its recessive topographic expression, yellowish color, and abundance of whole fossils that weather free from the matrix. The unit usually forms a saddle between the more resistant weathering Kobeh and the steeper, covered slopes of the Coils Creek. The Bartine is one of the most easily recognized, persistent, and widespread lithotopes of the Nevada Group in the area west of Eureka (Murphy and Gronberg, 1970).

Because of the paucity of outcrops in the Bartine, faunal and lithologic samples were dug up from covered intervals. The unit appears to be very thin to medium bedded and composed of layers of whole fossil wackestones and packstones, and yellow, argillaceous lime mudstones. Bedding plane partings usually occur in the argillaceous layers, imparting a distinctive yellow color to weathered surfaces. On freshly broken surfaces, the rocks emit a slight fetid odor and are medium gray to olive gray in color. Articulated brachiopods, tabulate and horn corals, trilobites, and gastropods are abundant in the yellow soils derived from the Bartine. <u>Planolites</u>, <u>Helminthoida</u> (?), and <u>Chrondrites recurvus</u> are also present.

In thin and polished section, the Bartine is composed of alternating layers or lenses (5 mm - thin bedded) of well preserved, whole fossil wackestones and packstones, and argillaceous lime mudstones. The rocks are biopelmicrites and biopelsparites. Polished surfaces are olive gray to yellowish, depending on the percentage of yellow argillaceous limestone present. Mudstones and wackestones are burrowed and appear texturally massive, mottled, or faintly laminated with scattered, randomly oriented allochems. Silt to very find sand size indeterminate shell debris and argillaceous material appears disseminated throughout. Detrital quartz grains form less than 5% of the rock. Larger shell fragments are typically elongate parallel to the plane of stratification and may be in grain support (packed) or appear floating in a finer grained matrix. Many packstones fine upward and have sharp, undulatory contacts with underlying argillaceous mudstones and gradational or sharp upper surfaces. Small, 5 to 10 mm load structures may be present along the basal contact of the packstone layers.

The diverse fauna of the Bartine is dominated by brachiopods, which are commonly articulated. Disarticulated brachiopods are usually oriented concave down. Trilobites, bryozoans, tabulate and horn corals, crinoids, gastropods, ostracodes, pelecypods, and rare nautiloids are present and locally are abundant.

Well sorted, subround to ovoid shaped, coarse silt to very fine sand-size peloids locally form up to 40% of the rock. Peloids present in mudstone and wackestone layers may be barely discernible because of partial recrystallization of lime mud to microspar and pseudospar. These peloids are probably fecal in origin because of the fairly uniform, fine size and close association with an abundant epifauna.

Sparry calcite cement is locally abundant, filling voids and interstices in packstone and wackestone layers, and as syntaxial overgrowths on crinoids. Original interparticle, intraparticle, and shelter porosity has been totally destroyed by sparite infilling, often forming geopetal fabric. Sparite filling of shelter geopetal fabric beneath brachiopod and trilobite fragments is commonly syntaxial and forms parallel bladed or fibrous-shaped crystals perpendicular to, and optically continuous with, the encrusted fossils. Intraparticle and interparticle sparry calcite cement typically has a finer outer fringe and coarser central portion, indicating nucleation and growth into a void. Sparite cement appears "cleaner," in contrast to microspar and pseudospar which appear cloudy or "dirty" because of inclusions of argillaceous or organic material.

Silicification of fossils is extremely variable, even within a single thin section or shell fragment. Brachiopods, corals, and crinoids are the most susceptible to replacement by silica, which may be optically continuous with the replaced fossil, or appear as scattered blebs of fibrous chalcedony or chert. Chert-filled fractures indicate that silicification occurred after cementation, probably as a late diagenetic event. Precipitation of sparry calcite cement probably occurred as an early diagenetic event.

Biostratigraphy

Faunal collections from the Bartine in the thesis area indicate that the member is late Pragian early Zlichovian in age (Fig. 2,

Fig. 3). All sampled horizons in the Bartine yielded conodonts indicative of the dehiscens Zone. The abundance of Anoplia elongata in brachiopod collections suggests that the assemblage be named the elongata fauna, which corresponds to the lower pinyonensis Subzone (I 10). The elongata fauna is also present in the basal Bartine at Lone Mountain in collections that Niebuhr (1977) described as the Carinagypa - Atrypa Community of the Eurekaspirifer pinyonensis Zone.

Tabulate corals of the Pachyfavosites lophos Zone (Assemblage Zone 13 of Flory, 1977) were collected at II 370 and II 420. A new assemblage with common Striatopora sp. was sampled at II 345. Thamnopora sp. is present in II 420, the stratigraphically lowest occurrence of the genus Thamnopora in the northern Antelope Range. Thamnopora is the dominant taxon in tabulate coral faunas of the Denay Limestone in the thesis area.

Depositional Environment

Niebuhr (1973, 1977), and Johnson and Niebuhr (1976) studied in detail the richly fossiliferous strata of the Bartine. Niebuhr (1977) examined rocks containing the A. elongata Fauna in the basal Bartine at Lone Mountain and inferred a muddy bottom, quiet water, below-wave-base, depositional environment in which periodic bottom currents winnowed the fine-grained sediment from around peloids and bioclasts. He assigned this biotope to Benthic Assemblage 3 of Boucot (1975). Observations in the northern Antelope Range are in general agreement with Niebuhr's interpretations of environments of deposition for the Bartine.

An open marine, quiet-water environment is indicated by the abundance of micrite and argillaceous sediment and by an abundant and well-preserved epifauna and burrowing infauna. The environment was well suited for organic proliferation and was probably well within the euphotic zone. Faunal diversity is high, with up to twenty species of brachiopods identifiable in single collections (eg. II 370). In mud rich layers, brachiopods are commonly articulated, or disarticulated and oriented in the current-stable, concave-down position. Skeletal materials in packstone layers (biopelsparites) are randomly oriented, or elongate parallel to bedding. Alternations of biopelmicrite and biopelsparite are indicative of variable bottom-current energy, winnowing the mud size sediment. The currents are probably gentle, being competent enough to winnow the sediment and disarticulate shells, but not strong enough to abrade skeletal constituents. Homogenization by a burrowing infauna may have accounted for minor skeletal abrasion and destruction of suspension deposition laminae.

Kendall (1975) showed that east of the thesis area, the subtidal Bartine intertongues with the peritidal Sevy Dolomite in a complicated way. At Lone Mountain, and in the Sulphur Spring Range, the Bartine is as young as *inversus* Zone age (Johnson and Niebuhr, 1976). In the northern Antelope Range, the Bartine lithotope lies entirely within the *dehiscens* Zone, which extends into the gradationally overlying, deeper-water deposits of the Coils Creek.

Johnson and Niebuhr (1976) discussed intrazonal migration of brachiopod communities within the Bartine lithotope and demonstrated a westward migration of shallower-water communities during late *dehiscens* Zone to early *gronbergi* Zone time at Lone Mountain and in other areas of Eureka County. Immigration of a shallower-water Bartine community into the thesis area has not been demonstrated, although the abundance of *Nucleospira subsphaerica*, *Eurekaspirifer* sp., and *Thamnopora* sp. in II 420 may be suggestive of a brief period of shallower-water sedimentation occurring before deposition of the deeper-water Coils Creek lithotope (Johnson and Niebuhr, 1976, Fig. 5).

Coils Creek Member

General

The Coils Creek Member is approximately 165 feet thick and consists of recessive weathering, fine grained mudstones, wackestones, and packstones. The unit weathers into platy and flagstone-covered slopes below the ledge-forming crinoidal packstones and grainstones of the lower Denay. The lower portion of the member is transitional with the underlying Bartine and is distinguished by the lack of abundant shelly fauna. Lithologically, the lower approximately 50 feet of the unit consists of medium bedded to platy, light gray to yellowish weathering, fine grained, argillaceous, lime wackestones. Extensive burrowing by Planolites sp. is apparent on weathered surfaces along with tentaculites, crinoid ossicles, and rare brachiopods.

In thin and polished sections, the lower transitional beds of the member are lithologically similar to the gradationally underlying Bartine, but notably lack an abundant shelly epifauna. However, very fine to medium sand size, randomly oriented skeletal debris and peloids are present in abundances up to 40 percent in the argillaceous lime mud matrix. Homogenization of the sediment by a burrowing infauna has disrupted fine argillaceous laminae and concentrated allochems in cylindrical burrows up to 5 mm in diameter.

Allochems decrease in abundance upsection, tentaculites increase, and mudstones and wackestones predominate. The rocks appear finer grained, finely laminated, and have a stronger fetid odor on fresh break than the underlying Kobeh and Bartine, but not as strong as the overlying Denay. The middle portion is light-medium gray weathering, but dark gray to black on fresh break. Finely laminated, platy weathering surfaces of lime mudstones locally are covered with abundant dacryoconarid tentaculites and sparse echinoderm debris. Chondrites targionii and C. recurvus reappear in a narrow transition zone approximately 10 feet thick below the sandy, dark gray, blocky weathering beds in the upper Coils Creek.

In thin and polished sections, laminae in the lime mudstones average 2 to 10 mm, and are defined by variations in abundance of fine silt or clay size sediment. The rocks are dominated by lime mud which has recrystallized to microspar and pseudospar Tentaculitids are oriented parallel to bedding and are commonly silicified. Lens shaped layers of disseminated iron oxide, 0.5 to 2 mm thick and up to 20 mm long, are present locally.

The lower approximately 25 feet of the uppermost 80 feet in section Va consists of medium bedded, blocky weathering, ledge forming, wackestone to packstone beds in which silt to fine sand size detrital quartz increases in abundance upsection. Small asymmetrical ripple marks, fine laminations, and a small (2 to 3 cm) vertical burrow, Skolithus (or possibly Arenicolites) are present on weathered surfaces. These sedimentary structures are well preserved because the detrital quartz grains are concentrated into distinct laminae which preferentially weather out in relief.

In thin and polished sections, silt to fine sand size, angular to subrounded, detrital quartz composes 20 to 60 percent of the volume in the blocky weathering beds. Fine-grained detrital quartz, peloids, and unidentified carbonate grains are randomly oriented in a moderately packed, "dirty" matrix of lime mud recrystallized to microspar and pseudospar. Faint to distinct laminae, 0.5 to 10 mm thick, are defined by varying abundances of detrital quartz, peloids, and lime mud.

The uppermost 40 to 50 feet is composed of poorly exposed, platy weathering, sandy lime wackestones and packstones. These rocks are light to medium gray weathering, and are medium to dark gray, and emit a fetid odor, on fresh break. Coarse silt to fine sand-size detrital quartz grains are concentrated in parallel laminae and low amplitude (5 to 10 mm) cross laminae that weather out in faint relief. Scattered tentaculitids are present on weathered surfaces.

In thin and polished sections, platy-weathering beds of the uppermost Coils Creek are lithologically similar to rocks in the underlying, blocky weathering interval, with the notable addition of fine skeletal debris (Fig. 4). Unidentified skeletal debris, and fragments or disarticulated valves of small, thin shelled, nonsilicified brachiopods are concentrated with peloids into laminae and lenses. Skeletal debris, including tentaculitids, compose approximately eight percent of the volume of these beds.

Biostratigraphy

Faunal collections from the Coils Creek in the thesis area indicate that the member is Zlichovian to Dalejan in age (Fig. 2,

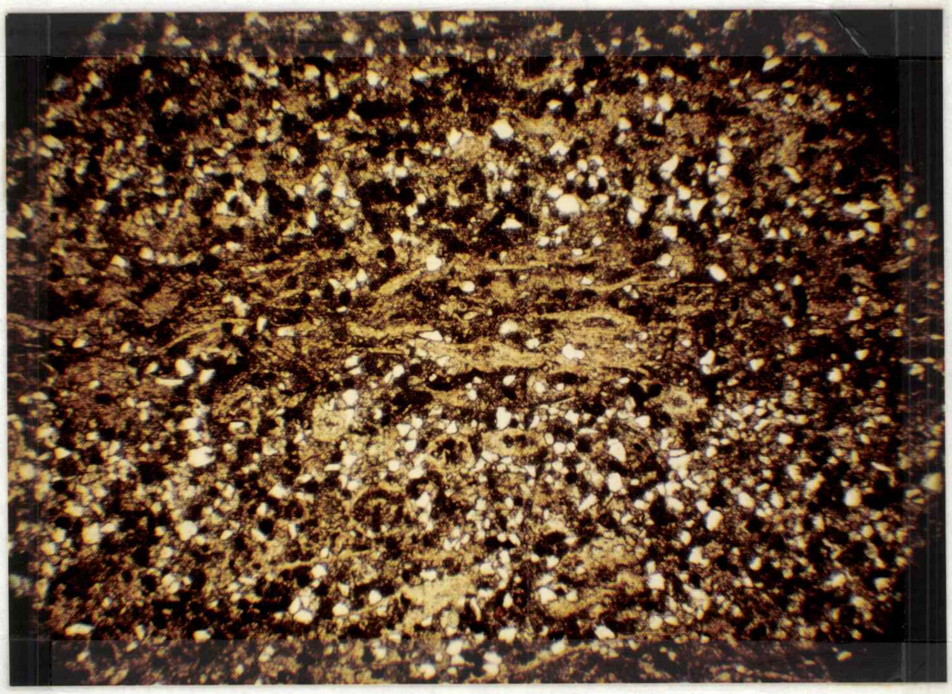


Figure 4. Photomicrograph of Va 30. Note silt to fine-sand detrital quartz, peloids, and skeletal debris. Field of view is cm.

Fig. 3). Conodonts from II 425 and II 450 are similar to those from the underlying Bartine, and are representative of the *dehiscens* Zone. The *gronbergi* Zone is probably indicated by conodonts from II 520. In the upper Coils Creek, *serotinus* Zone conodonts were recovered at Va 0 and Va 20. The newly recognized *Warrenella* sp. Fauna was collected at Va 45 with conodonts of the *patulus* Zone. This is only the second reported occurrence of *patulus* Zone conodonts in the Nevada faunal sequence (G. Klapper, 1978, pers. comm.).

Depositional Environment

Onlap of the Coils Creek lithotope, a deeper water, offshore equivalent of the Bartine, was with an eastward shift of the Bartine lithotope and migration of the *E. pinyonensis* Zone communities into more favorable biotopes. This event was markedly diachronous regionally, and occurred relatively early in the northern Antelope Range *dehiscens* Zone time. The Coils Creek is depauperate megafaunally, and consists mainly of tentaculitids, echinoderm debris, ostracodes, conodonts, trilobite fragments, and sparse brachiopods of the *inversus* Zone age *Elythyna* Fauna (Kennedy, 1977; Johnson and Kendall, 1976; Murphy and Gronberg, 1970). The *Elythyna* Fauna has not been identified in the thesis area, although the newly recognized *serotinus* Zone to *patulus* Zone age *Warrenella* sp. Fauna is found in the uppermost Coils Creek in section Va.

The lowest beds of the Coils Creek in the thesis area, although generally lacking an abundant shelly epifauna, were hospitable to a burrowing infauna that disrupted laminae and homogenized the sediment. Upsection, or with continued onlap, the bioturbation disappears and low-energy, suspension deposition formed the finely laminated deposits. This distinct change in the character of sedimentation may be related to oxygen deficiency of bottom waters in the environment of deposition.

Byers (1977) described a general model for predicting basinal water conditions by utilizing biofacies patterns:

(1) Aerobic - shelly fauna, infaunal bioturbation;

(2) Dysaerobic - shelly fauna lacking, infaunal bioturbation persists;

(3) Anaerobic - shelly fauna and infaunal bioturbation lacking, laminated sediments.

Byers model fits the Bartine to Coils Creek transition, and indicates that dysaerobic to anaerobic bottom waters may have precluded proliferation of a benthic biota in the Coils Creek biotope. Oxygen deficiency may have resulted from a combination of stagnant bottom water (Matti and McKee, 1976), or deposition in a disphotic environment. Pelagic tentaculitids locally accumulated in great abundance, because of the relatively slow rates of hemipelagic sedimentation. Wilson (1975) noted that mass mortality of pelagic organisms may be responsible for these accumulations. The accumulation of organic detritus in these rocks is evident by their fetid odor and dark gray color on freshly broken surfaces. No evidence of current activity was noted petrographically or in the field. Potter (1975) and Johnson and Sandberg (1977) described a similar deep water facies of the Coils Creek in the Hot Creek Range.

Detrital quartz in the silty-sandy upper portion of the Coils Creek probably represents wind blown detritus derived from areas to the east exposed to erosion by early Couvinian regression. Johnson and Sandberg (1977) noted that the quartzose part of the Oxyoke Canyon Sandstone and the Sadler Ranch Formation (Kendall, 1975) represent a regressive-transgressive cycle in which maximum regression probably occurred during serotinus Zone time (or patulus Zone time, J. G. Johnson, pers. comm.). They stated that

> the lower and upper parts of the Sadler Ranch correlate with the Coils Creek Member and with the lowermost part of the Denay Limestone, respectively.

The quartzose lower part of the Oxyoke Canyon Sandstone represents a high-energy, intertidal, barrier-bar deposit on the western edge of the Sevy tidal flat and the coarse-crystalline upper part represents a basal transgressive sand deposit (Kendall, 1975). The Sadler Ranch is a subtidal, offshore equivalent of the Oxyoke Canyon Sandstone that prograded westward over the Coils Creek in response to late Early Devonian, Dalejan, offlap.

Crinoidal packstones, containing dilumen ossicles and costatus costatus Zone conodonts, that are present in the upper portion of the Sadler Ranch, and in the lower portion of the Denay at Lone Mountain and in the northern Roberts Mountains, are equivalent to the crinoidal packstones marking the base of the Denay in the northern Antelope Range.

The upper portion of the Coils Creek probably represents a subtidal, restricted environment dominated by suspension deposition. Weak bottom currents were locally strong enough to form small ripple cross laminae, but were not competent enough to winnow lime mud from the sediments. A restricted environment is indicated by the fauna of tentaculitids and sparse thin shelled brachiopods. Sedimentation rates were probably increased with the added detrital influx, and the vertical burrow, Skolithus, became adapted to this sandy substrate. Water depths may have been slightly shallower in the upper portion than in the middle portion of the Coils Creek, because of Dalejan regression. Deposition was still relatively deep, however, because allodapic packstone beds of the lowest Denay gradationally overlie the Coils Creek in the thesis area.

DENAY LIMESTONE

Introduction

The name Denay Limestone was given by Johnson (1966) to rocks overlying the McColley Canyon Formation and overlain by the Devils Gate Limestone in the northern Roberts Mountains and in the northern Simpson Park Range. More recently, Murphy (1977) described the lithology, contacts, and age of the Denay and discussed correlation and facies relations with its eastern, shallower water equivalents: The Simonson, Sentinel Mountain, Bay State, Union Mountain, Guilmette Formations and the Woodpecker Limestone.

Murphy recognized three informal units in the Denay at its type section in the northern Roberts Mountains: (1) the lower part of the formation is composed of thin-bedded, laminated, lime mudstones with interbedded, allodapic, bioclastic packstones, and intraformational conglomerates and breccias. Leptathyris circula Zone brachiopods are present in the lower half of this unit; (2) the middle unit is dominantly thick-bedded, allochthonous packstones containing a shallow water benthic fauna of Leiorhynchus castanea Zone age; (3) the upper unit of the formation is composed of thin-bedded, laminated, cherty, lime mudstones and sparse allodapic packstones. The unit is typically poorly exposed beneath the cliff-forming Devils Gate Limestone. The contact between the Devils Gate Limestone and the Denay in the northern Roberts Mountains has not been dated, but is younger than the hippocastanea brachiopod Zone (Johnson, 1978).

Murphy and Dunham (1977) described a shallow-water complex, including stromatoporoid boundstones and the Lower varcus age Antistrix fauna, overlying kirki Zone age Denay at Lone Mountain. A similar boundstone sequence was noted at Roberts Creek Ranch in the southern Roberts Mountains.

Westward progradation of the shallow water, platform suite over the deep, outer shelf, basinal deposits of the Denay was markedly diachronous regionally (Murphy, 1977).

In the northern Antelope Range, the three lithologic units of Murphy (1977) are recognized, although slightly modified. The lower unit begins with graded, crinoidal packstones, intraformational breccias, and interbedded and thin-bedded lime mudstones. The packstones contain abundant dilumen crinoid ossicles, and conodonts indicative of the costatus costatus Zone. Thin-bedded, laminated, dark gray, lime mudstones predominate in the lower unit. The middle unit consists of allochthonous packstones and grainstones of limestone and secondary dolomite. In the thesis area, the unit thickens, and becomes more dolomitic, to the east. A locally abundant and silicified, shallow water benthic fauna, collected from near the top and the bottom of the middle unit, at several locations in the thesis area, is of ensensis Zone to upper hermanni-cristatus Zone age. The lower part of the upper unit of the formation consists of poorly exposed, platy weathering, argillaceous lime mudstones and wackestones containing rare, interbedded, allodapic packstone beds. Allochthonous packstones are dominant in the middle portion of the upper unit, and contain the disparilis fauna to lowermost asymmetricus Zone age Tecnocyrtina fauna. Platy-weathering limestones and calcareous siltstones with interbedded, allodapic, sandy packstones and grainstones conformably overlie the middle portion of the unit and weather recessively below the unit mapped as Devonian sandstone.

Lower Unit

General

The lower unit of the Denay is approximately 975 feet thick, and consists predominantly of dark gray, thin-bedded to laminated, locally cherty or argillaceous, basinal lime mudstones. Interbedded allodapic packstones are rare throughout most of the unit, but are common in the lowermost approximately 150 feet and are abundant in the gradationally overlying middle unit of the formation. An autochthonous fauna of thin-shelled brachiopods of the L. circula Zone is present locally. Fossiliferous wackestones and packstones present in the upper portion of the unit are overlain by approximately

180 feet of thin-bedded mudstones below the gradational contact with the middle unit.

The upper Coils Creek weathers recessively below approximately 30 to 50 feet of ledge-forming crinoidal packstone beds of the lower Denay. The packstone beds are medium- to thick-bedded, medium to dark gray (weathered and fresh surfaces), locally graded (Fig. 5), and form rounded ledges. Abundant dilumen crinoid ossicles, up to 10 mm in diameter, are present on weathered surfaces. Dark gray, very thin- to thin-bedded, argillaceous lime mudstones and wackestones are locally present as interbeds between the packstone beds, but account for less than 10% of the strata in this portion of the unit. Nonsilicified brachiopods, tabulate and tetracorals, and encrusting stromatoporoids are not abundant, but are present locally in the lower portions of graded beds, and appear to increase in abundance near the gradational change to the overlying portion of the unit.

The 50 to 60 feet interval stratigraphically above the crinoidal packstones is best described as transitional because the frequency and abundance of allodapic beds decrease, and thin-bedded mudstones increase upsection.

In thin and polished section, the crinoidal packstones are dominated by echinoderm debris, much of which are dilumen ossicles that average 3 to 5 mm in diameter. Very poorly to nonsilicified

Figure 5. Polished section of inverse-to-normally graded crinoidal packstone at Va 81.

brachiopods, tabulate and tetracorals, encrusting stromatoporoids, bryozoans, gastropods, trilobites, and scattered sponge spicules are present in varying amounts, usually minor. Most bioclasts are angular and commonly whole, indicating little or no mechanical abrasion before deposition. Bioclasts appear randomly oriented and poorly sorted in a matrix of lime mud and round to ovoid, fine sand-size peloids. Much of the lime mud has recrystallized to microspar and pseudospar. Original interparticle porosity has been further reduced by compaction, as evidenced by common stylolites, pressure-solution contacts between allochems, and the closely packed character of the sediment. These rocks have moderately compacted fabric (see below), although some sparite cement is present either as syntaxial overgrowths on crinoids and brachiopods or as a coarsening-inward filling of intraparticle pores in larger bioclasts such as corals and stromatoporoids. Medium to very thick bedded (1.5 to 5 feet), intraformational conglomerates and breccias containing 1 to 8 inch (maximum diameter), dark gray to olive gray mudstone and wackestone clasts, are interbedded with thin-bedded to laminated, cherty mudstones and wackestones (Fig. 6). Intraclasts are angular to subrounded, and many are tabular in shape. The matrix in the conglomerate and breccia beds is composed of medium gray- to olive gray-weathering, argillaceous, fossiliferous, cherty wackestones and packstones. Mudstone intraclasts and bioclasts are poorly sorted

Figure 6. Intraformational breccia at Va 153. Note tabular shapes and random orientation of mudstone intraclasts and the absence of grading.

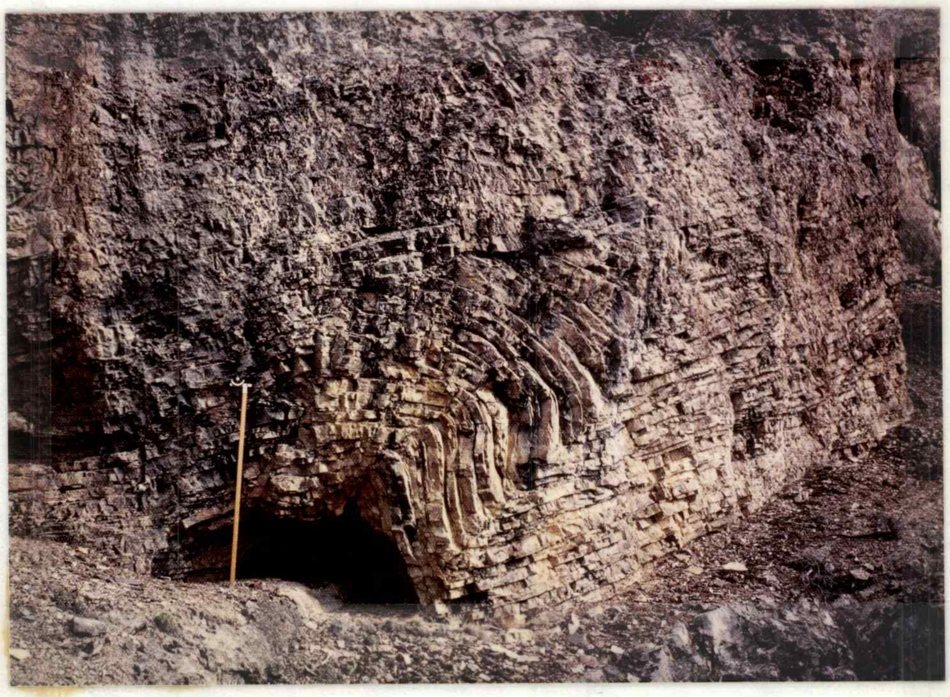


Figure 7. Penecontemporaneous fold. Slumped thin-bedded lime mudstones in lower unit of the Denay. Note horizontal attitude of beds overlying and truncating fold limb.

and randomly oriented in the matrix, although a weak preferred orientation of elongate clasts parallel to stratification was noted on favorable exposures. Some of these beds are crudely graded in the upper few inches, but most are devoid of any obvious normal or reverse grading. Most beds are well bedded, although undulatory, and have sharp lower and upper contacts. Depression or loading of underlying mudstones may be present beneath localized areas of increased bedding thickness of the breccia beds. A silicified fauna includes tabulate and tetracorals, brac hiopods, and echinoderms of the L. circula Zone. In favorable exposures, such as at Va 153 (Fig. 6), chert is present as a thin (up to 1/2 inch) fringe around, and replacing, mudstone clasts in breccia beds. Interbedded with the allodapic beds are dark gray (weathered and fresh), thin- to very thin-bedded, cherty lime mudstones and wackestones with paper thin argillaceous partings, and pinkish to yellowish medium gray, platy weathering, argillaceous lime mudstones and wackestones. These beds are usually well bedded, but locally bedding may be very undulatory or pinch out. One half to three inch chert nodules, that are elongate and locally coalesce to form layers parallel to bedding, are common in these beds. Tentaculites and rare sponge spicules are present on bedding plane surfaces. The rocks emit a strong fetid odor on fresh break. In thin and polished sections, the matrix of the breccia beds is composed of argillaceous lime mud, very fine to fine sand-size peloids, crinoidal debris (including dilumen ossicles) and rare calcispheres. Stylolites are common, especially bordering large intraclasts and skeletal debris, or as pressure-solution contacts between allochems. Peloids are faintly discernible in the poorly sorted, "dirty" wackestone matrix. Most of the lime mud in the matrix has recrystallized to microspar and appears drusy compared to relatively clear, void filling sparite. Brachiopods, corals, and less commonly crinoidal debris are typcially well silicified, having been replaced by radial aggregates of chalcedony. Skeletal constituents, including thin-shelled brachiopods, show little evidence of abrasion. Mudstone intraclasts are typically tabular, subangular, and are composed of two distinct fabrics which are distinguishable only in thin section: (1) silt to very fine sand-size peloids in a mud-dominated, locally finely laminated, "dirty" matrix similar to the compacted fabric in the breccia beds, and (2) very fine to fine sand-size peloids in a relatively "clean" or well-washed matrix (cemented fabric). These clasts are dark gray pelletal packstones or pelsparites in which the peloids are distinctly outlined by interparticle sparite cement.

Thin-bedded to laminated, dark gray, locally cherty or argillaceous, lime mudstones are the dominant lithology of the lower unit of the Denay Limestone in the thesis area. Typically, the rocks appear as a rhythmic alternation of very thin- to thin-bedded, well-bedded, dark gray lime mudstone and subordinate, lighter colored, laminated, argillaceous limestone or shale interbeds. Argillaceous limestone is typically lighter colored, appearing light to medium gray with various yellowish and pinkish tints, and is present as shaly interbeds or partings between, or as fine laminae in, dark gray lime mudstone beds. Variations in the amount of argillaceous material define stratal thicknesses and control outcrop character. Intervals dominated by argillaceous limestone, such as II 755-780 and V 188-205, weather recessively into plate- and flagstone-covered slopes. Argillaceous mudstone is typically finely laminated, and thin bedded lime mudstone generally is massive in outcrop. Thin-bedded lime mudstones with very thin shaly partings typically form ledges or cliffs, or weather into steeper slopes covered with chips and small blocks. Bedding is typically even and parallel, very-thin to thin bedded, and individual beds are laterally continuous and traceable across a given outcrop for hundreds of feet. Locally, e.g. II 735-740, II 860-865, V 180-185, V 320-325, bedding is very irregular, undulatory, and is laterally discontinuous in as little as three to five feet. All gradations appear to be present between these extremes.

On weathered surfaces, individual mudstone beds appear finely laminated to texturally massive and have a smooth, rounded appearance. All of these rocks emit a strong fetid odor on fresh break.

In thin and polished sections, the lime mudstones are evenly laminated to texturally massive. Faint or indistinct laminae, 1-10 mm thick, are defined by alternations of laminae with high and low allochem percentages, or by variations in abundance of very fine sand, silt, or clay size sediment. Elongate allochems are oriented parallel to bedding. Texturally massive or faintly laminated, "dirty" lime mud, most of which has recrystallized to microspar, is the dominant lithology. Allochems include peloids, tentaculitids, sponge spicules, unidentified carbonate grains, calcispheres, and detrital quartz.

Some of the rocks judged in the field to be lime mudstones are seen in thin section to be pelletal packstones or pelsparites. Fine to very fine sand size, 0.10-0.15 mm in diameter, and round to ovoid shaped peloids are probably fecal in origin because of the uniformity in grain size and shape. Pelletal sediments are either well sorted and cemented with sparry calcite (pelsparites), or poorly sorted with pellets barely discernible in a lime mud matrix (pelmicrites).

Calcispheres are 0.15-0.35 mm spheres of clear sparry calcite which typically shows a pseudo-uniaxial cross between crossed polars. The calcispheres commonly have an outer wall enclosing the outer chamber, and are believed to be algal spores (Bathurst, 1975). Spherical bodies with no discernible outer wall may represent ooids, alteration of radiolarians (Scholle, 1973), porphyroid neomorphism (Folk, 1964), or calcispheres. Calcispheres are present in abundances of less than five percent.

Silt to very fine sand size-detrital quartz is present in abundances of less than five percent.

"Pea chert," or small 1/4 to 1 inch round chert nodules, are locally common throughout the lower unit. Individual laminae in the mudstone beds may be continuous through the chert nodules, indicating that chert formation was by replacement rather than displacement. Chert appears as small nodules that may be aligned and which may coalesce to form thin, discontinuous layers or as small (1-2 mm) flakes on weathered surfaces.

In thin and polished sections, the chert appears as micro- to cryptocrystalline masses containing abundant unreplaced lime mud finely disseminated throughout the nodules. The chert in most cases is subordinate in abundance to the lime mud or microspar. A dark, fine-grained insoluble is concentrated along the sharp contact between the chert nodules and the enclosing sediment.

Autochthonous faunal constituents of the lime mudstones are thin-shelled brachiopods, gastropods, and crinoids. Tentaculites, scattered sponge spicules, and the burrow Planolites are locally abundant on bedding planes. Brachiopods of the L. circula Zone are small (usually less than 1/2 inch in diameter), have very thin shells, are commonly articulated and silicified, and are locally abundant enough to form whole shell packstones or coquinas.

Associated with brachiopods at II 980 and V 440 are parallel-oriented, articulated crinoid ossicles 2 mm in diameter and up to 10 mm long.

Medium- and thick-bedded allodapic packstone beds are rare in the lower unit above the lowest approximately 150 feet, but are present at II 1110 and II 1325. These beds are similar to the intraformational conglomerates and breccias present lower in the unit and contain dark gray, tabular (up to 4 inches maximum diameter) mudstone clasts in a medium gray, argillaceous, fossiliferous packstone matrix. Brachiopods, tabulate and tetracorals, trilobites, and crinoids are scattered throughout these beds, and a preferred orientation of elongate clasts parallel to stratification was noted. Some beds are crudely graded and poorly silicified (II 1110); others are not graded and are totally silicified (II 1325). These beds have sharp upper and lower contacts and are well bedded, although bedding thickens and thins along strike. Thin-bedded, medium to dark gray, crudely graded or laminated, locally silicified packstones were noted at II 1110 to II 1150, and sampled at II 1120. In thin and polished sections, the matrix in the allodapic beds is compacted. Silicification of II 1325 was largely fabric selective. Finely disseminated chert and fibrous chalcedony have replaced original interparticle matrix and allochems. Lime mud intraclasts and some crinoid ossicles remain largely unsilicified although totally enclosed in a chert matrix.

Wackestones and packstones containing upper Warrenella kirki Zone and Spinatrypa cf. coriacea Fauna brachiopods overlie lime mudstones of L. circula Zone age and are overlain by lime mudstones of the uppermost portion of the lower unit (kockelianus Zone to ensensis Zone age) of the Denay in the thesis area (Figs. 2, 3). Ninety to 120 feet of lithologically and faunally distinct strata are present at II 1400-1490 and V 700-820. The lower approximately 30 feet is composed of laminated, argillaceous, lime mudstone and wackestone, and subequal amounts of thin- to medium-bedded, poorly bedded, fine to medium sand-size lime wackestones. These rocks are medium gray (weathered and fresh) to olive gray (fresh), and have a characteristic pinkish, and less common yellowish, tint. Large, up to two inch, randomly oriented, articulated brachiopods are common, and a whole-shell brachiopod packstone or coquina was sampled at V 720 (Fig. 8). Gastropods, crinoid ossicles, and rare trilobites were noted.

In thin and polished section, these rocks are laminated biopelsparites and biopelmicrites. The parallel laminae are defined by alternating laminae with high and low allochem percentages. Very fine to fine sand-size, round to ovoid pellets are the dominant allochem. The pellets appear faint or indistinct in a poorly sorted, moderately compacted, "dirty" matrix of microspar. Skeletal components constitute between 10 and 40 percent of the volume of these rocks, show no evidence of abrasion, and consist of thin-shelled

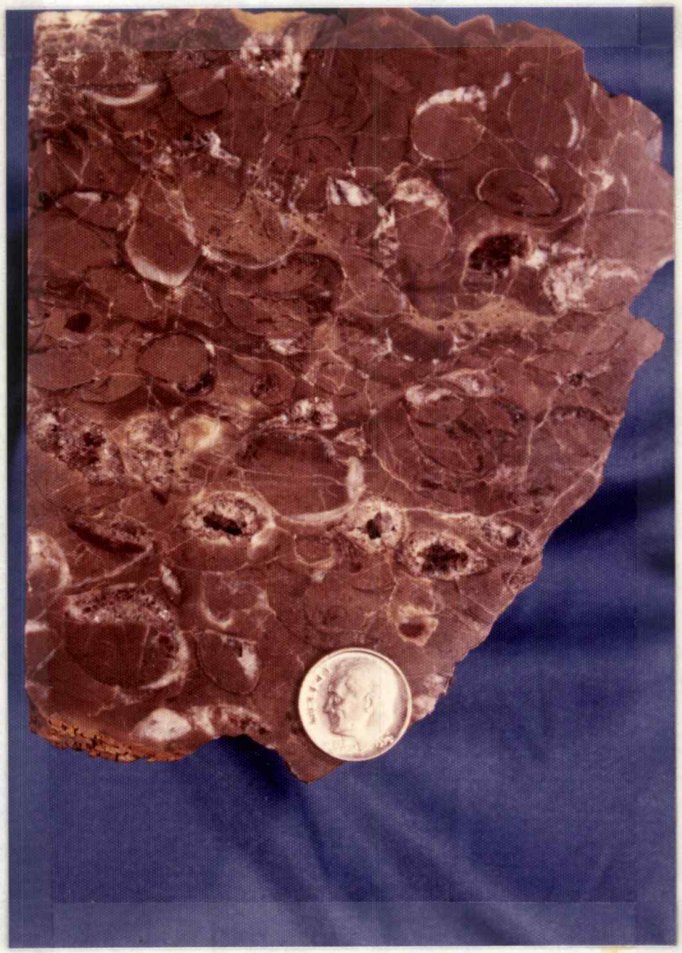


Figure 8. Brachiopod coquina of articulated Warrenella kirki in V 720. Note geopetal fabric. Polished section.

and articulated brachiopods, echinoderm debris, and sparse gastropods, trilobites, solitary tetracorals, and tentaculitids. Brachiopods and tetracorals are commonly completely replaced by radial aggregates of chalcedony.

The lower interval is well exposed in small ledges on section II, and is gradationally overlain by cliff forming crinoidal wackestones and packstones containing the newly recognized S. cf. coriacea Fauna. Receptaculites, Favosites, gastropods, and brachiopods are scattered in poorly bedded, argillaceous, crinoidal wackestones and packstones over an approximately 70 foot interval in section II (II 1425-1490) (Fig. 9). These rocks are thin- to medium-bedded, poddy or poorly bedded to well-bedded, dark gray (weathered and fresh) to olive gray (fresh), crinoidal wackestones and packstones with irregular interbeds of yellow, argillaceous, lime wackestones. This interval is gradational with the underlying interval over approximately 20 feet (II 1420-1440) and is distinguished by the presence of yellow, rather than pinkish, argillaceous limestone, the appearance of Receptaculites, common gastropods and abundant crinoid-ossicles, and a decrease in abundance of brachiopods. Yellow, argillaceous, limestone interbeds impart a distinct yellow tint to weathered surfaces. The rocks are thin- to medium-bedded (3 to 8 inches), usually irregularly bedded, but locally well bedded, and emit a strong fetid odor on fresh break. Crinoid ossicles, up to 10 mm in diameter, are scattered through

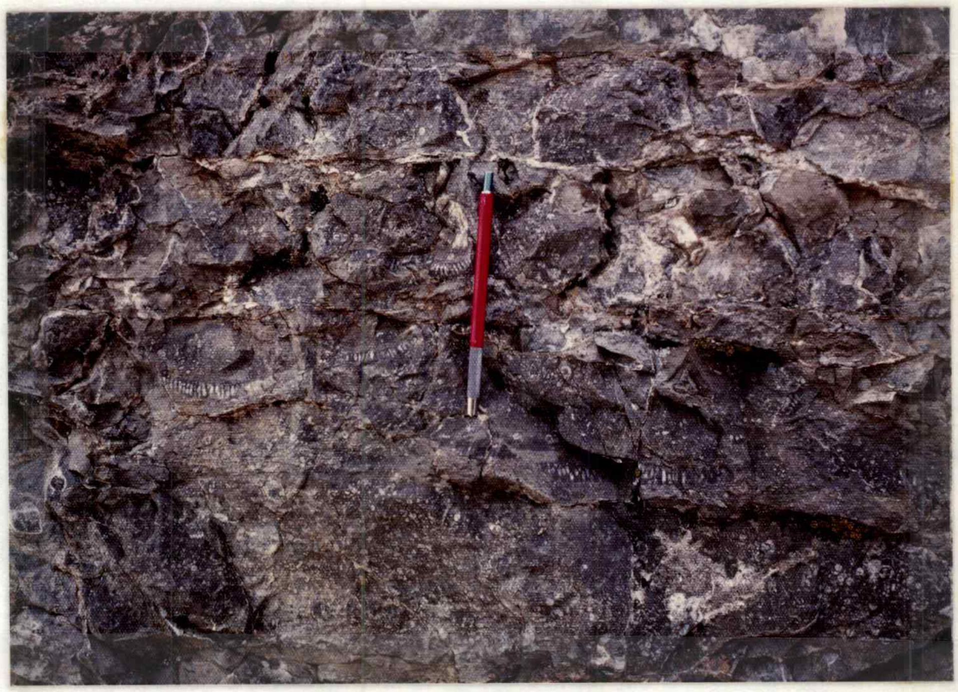


Figure 9. Outcrop of crinoidal wackestones and packstones containing the S. cf. coriacea fauna. Note irregular bedding, abundant crinoidal debris, and receptaculitids. II 1480.

this interval, and are locally abundant enough to form a packstone framework. Crinoids and fossil debris appear scattered, or concentrated into layers and lenses, but not graded. Bowl-shaped Receptaculites (up to 9 inches in diameter) and tabular Favosites (up to 4 by 9 inches), are elongate parallel to bedding in growth position. Brachiopods are commonly articulated, or disarticulated and oriented concave down. Small, less than 1/2 inch, gastropods and solitary tetracorals are more common in the lower portion of this interval and Favosites in the upper portion. Tentaculites are present on bedding surfaces.

In thin and polished section, these rocks are biopelmicrites in which peloids are faint or indistinct in a poorly sorted, "dirty," moderately compacted matrix. Skeletal constituents compose 40 to 70 percent of the rock, and consist of crinoid ossicles, articulated and more commonly disarticulated brachiopods, and sparse tabulate coral debris, gastropods, tentaculitids, sponge spicules, and calcispheres. Skeletal debris appears moderately broken and abraded, poorly sorted, and scattered in these sediments. Silicification is variable, but generally poor. Brachiopods and corals are the most susceptible to silica replacement. Silt to very fine sand-size detrital quartz is present in abundances of less than five percent.

The crinoidal wackestones and packstones are gradationally overlain by approximately 180 feet (as measured in section VII) of thin- to medium- (3-6 inches) bedded, well bedded, dark gray lime mudstones. The lime mudstones locally alternate rhythmically with light gray to rarely yellowish, argillaceous interbeds. Poddy beds or sedimentary boudinage structures were noted in the lower portion of this interval in section VII. These rocks appear similar to lime mudstones described lower in the section as the dominant lithology in the lower unit of the Denay although medium-bedded intervals and light gray rather than yellowish argillaceous interbeds are more common. Faunal elements are typically absent in these beds, except for scattered tentaculitids on bedding surfaces, but one collection of thin-shelled and articulated brachiopods was made in the lowermost portion of this interval at VII 10.

Diagenesis

Hopkins (1978) invoked differential submarine cementation of thinly bedded foreslope carbonates as a source for breccia clasts in beds below the Devonian Miette and Ancient Wall Buildups in Canada. He distinguished between cemented fabric, in which lithification occurred by precipitation of sparry calcite cement, and compacted fabric, in which lithification resulted not from cementation but from compaction and dissolution along allochem boundaries. A similar fabric distinction, although not always clear cut, is applicable to breccia beds and thin bedded lime mudstones in the thesis area.

Pelletal packstones or pelsparites that are well washed, loosely packed, and cemented by sparry calcite have cemented fabric, and show little or no evidence of compaction. In contrast, the matrix of the breccia beds has compacted fabric, as evidenced by pressure-solution contacts between or surrounding allochems and the closely packed character of the sediment. Sparry calcite cement is noticeably less abundant.

As Hopkins (1978) noted, a cemented fabric in breccia clasts contained in the matrix of beds with compacted fabric indicates that the clasts were lithified before transport, deposition, and compaction of the bed occurred. Early submarine cementation of pelsparites in dark gray, thin-bedded lime "mudstones" is implied. However, the absence of a clearly cemented fabric cannot be used as evidence of compaction. Texturally massive lime mud with faint or indistinct allochems may be the product of compaction, may represent the original suspension deposition fabric, may be the result of homogenization by a burrowing infauna (in this case Planolites), or may be a combination of the above.

In the fine-grained lime mudstones of the lower Denay, fossil breakage is present indicating compaction has occurred. Thin-shelled brachiopods of the Leptathyris circula Zone are commonly articulated and well preserved, although crushed specimens were occasionally noted in thin section, and in silicified specimens etched from the enclosing rocks with acid. Thin concentrations of insoluble residues are present on some outer surfaces of larger shells.

A brachiopod packstone or coquina of articulated Warrenella kirki was sampled at V 720. Geopetal sediment present in the lower portions of these large, thin-shelled brachiopods is composed of well sorted, loosely packed, fine sand size pellets cemented by sparry calcite. Interparticle cement present between these largely uncrushed shells is composed of texturally massive lime mud. Small patches of pelsparites and indistinct pellets are present locally in the lime mud matrix. Thin seams of insoluble residues are present on the outer surfaces of some shells and cutting across interparticle sediment, but were not noted in the intraparticle areas. Scattered, finely crystalline dolomite rhombs are present locally, but only in the interparticle areas. I believe that the interparticle matrix was originally composed of sediment similar to that found inside the shells and that post-depositional compaction has destroyed the original fabric leaving the texturally massive lime mud. Intraparticle sediment was protected from compaction by the enclosing shell walls. Rotated geopetal fabrics noted in these shells may also be the result of compaction. The layers of insoluble residues probably represent pressure-solution surfaces, although the interdigitate boundaries characteristic of stylolites were not noted. Stylolites are present locally along the contacts between larger shells.

Wilson (1975) noted that compaction of basinal sediments is relatively common but early submarine lithification precludes compaction in shallower-water sediments. Shinn and others (1977) showed experimentally that significant amounts of compaction can occur in fine-grained mud rocks without fossil breakage.

In addition to other features of these rocks described earlier compaction is further evidence of a basinal depositional environment.

Biostratigraphy

Faunal collections from the lower unit of the Denay Limestone in the northern Antelope Range indicate that the unit is Couvinian in age (Fig. 2, Fig. 3). Conodonts indicative of the *costatus costatus* Zone were collected in Va 71, the lowest exposed bed of crinoidal packstone in section Va. Brachiopods of the *Pentamerella* Subzone (I 15) and conodonts of the *costatus costatus* Zone to the *australis* Zone were sampled at Va 119, II 665, V 95, and V 109 in allodapic packstones, conglomerates, and breccias in the interval above the crinoidal packstone beds. V 153, an allodapic packstone bed, contains brachiopods of the *Leptathyris circula* Zone (I 15-16) and conodonts indicative of the *australis* Zone. Autochthonous brachiopods of the *L. circula* Zone (I 15-16) were sampled at II 760, II 980, and V 190 with *australis* Zone conodonts, at V 485 with *kockelianus* Zone conodonts, and at V 440 with zonally undiagnostic conodonts.

Brachiopods (I 16-17) and australis Zone conodonts were collected in an allodapic packstone bed at II 1110. A silicified allodapic packstone bed sampled at II 1325 contains kockelianus Zone conodonts, but no recoverable megafauna. Kockelianus Zone conodonts and an in-place brachiopod fauna (I 15-17) were collected at II 1328.

Brachiopods of the upper part of the Warrenella kirki Zone (I 17 u) and kockelianus Zone conodonts were sampled at II 1400, and at V 720 with zonally undiagnostic conodonts. Brachiopods of the kirki Zone were previously recognized only at Lone Mountain, where a distinctive upper and lower fauna are recognized (Johnson, 1977). Only the upper fauna has been found in the northern Antelope Range. In other areas in central Nevada, brachiopods have not been recovered from the interval between the circula Zone (I 15-16) and the Leiorhynchus castanea Zone (I 19-20) except in the southern Roberts Mountains (D. B. Johnson, 1976).

A sparse brachiopod fauna was sampled in crinoidal wackestones and packstones at II 1480, 80 stratigraphic feet above collections of the upper portion of the kirki Zone (I 17 u) at II 1400. The abundance of Spinatrypa cf. coriacea in this collection suggests that this fauna be called the coriacea Fauna, and that it occupies, by definition, brachiopod Interval 18. Conodonts of the kockelianus Zone were sampled at II 1440, II 1480, II 1490, and V 810 in crinoidal wackestones and packstones characteristic of this interval. Schizophoria sp. and Variatrypa sp., common taxa of this fauna, are present at V 810, however, the namesake of the fauna was not recovered. Receptaculites and a new (?) species of Favosites are also present in this interval.

A similar fauna was found in crinoidal wackestones and packstones at VII 5. At VII 10 fragments of S. cf. coriacea (?) were collected in lime mudstones with abundant thin-shelled Vallomyonia devonica, Echinocelia sp., Warrenella sp., and Emanuella sp.

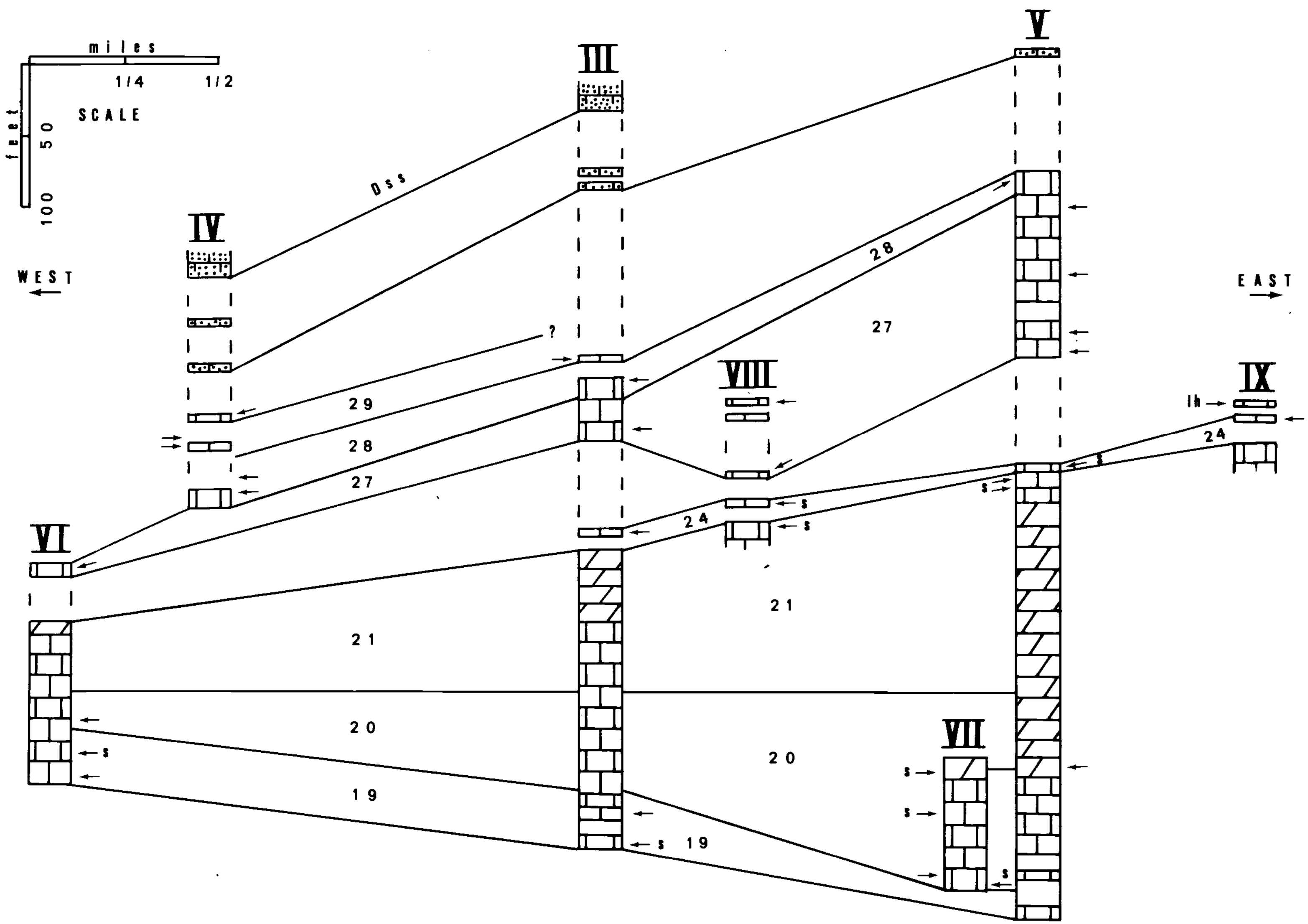
Middle Unit

General

The middle unit of the Denay Limestone is dominated by light and medium gray to brown gray, medium- to very thick-bedded, cliff forming, bioclastic packstones, grainstones, intraformational conglomerates and breccias interpreted as allochthonous gravity flow deposits which contain a locally abundant, shallow water benthic fauna. It is the most widely recognized, mappable unit in the thesis area. Faunal and lithologic samples from seven measured sections or partial sections were studied in an attempt to delineate facies relationships of these rocks and to place the unit in a time-space depositional framework.

Regional lithofacies distribution and faunal correlation, the westward thinning of the unit in the thesis area, and sedimentary structures indicate westward transport of debris flows and turbidites

Figure 10. Correlation chart of middle and upper units of Denay Limestone in the northern Antelope Range. Roman numerals at top refer to measured sections aligned in relative east (right) to west (left) positions. Numbers 19-29 are brachiopod Intervals of Johnson (1977). Arrows indicate positions of zonally diagnostic samples from Fig. 2. Dashed lines are covered intervals in measured sections. Refer to Plate 1 for location of measured sections. Generalized lithology from Plates 3-9. 'Dss' refers to Devonian sandstone (informal unit). 's' indicates *Stringocephalus* and 'lh' *Leiorhynchus hippocastanea* Zone. Note westward thinning of middle unit and middle portion of upper unit.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into the Denay depositional basin from shoal water source areas to the east during ensensis Zone to upper hermanni-cristatus Zone time.

The unit crops out in massive cliffs and rounded ledges beneath the recessive-weathering upper unit of the Denay, and the ridge-forming unit mapped as Devonian sandstone in the western and central portions, and forms a resistant core in the Antelope Peak structural block in the eastern portion of the map area.

The unit increases in thickness eastward, ranging from 115 feet in section VI, 205 feet in section III, to 305 feet in section V (Fig. 10). Apparent unit thicknesses vary considerably throughout the map area, but visual estimates during field mapping agree with an overall westward thinning of the middle unit of the Denay.

The lower contact is typically obscured by talus below steep cliffs, but is exposed in section VI. Thick-bedded intraformational conglomerates and breccias containing lime mud intraclasts and a silicified shoal water fauna sharply overlie, and are interbedded with, dark gray lime mudstones of the lower unit of the Denay. The increase in frequency and abundance of allochthonous beds is marked in the middle unit. The upper contact is typically well exposed beneath the recessive weathering, thin-bedded, argillaceous lime mudstones of the lower portion of the upper unit of the Denay.

Cliff and ledge-forming beds of the unit appear texturally massive or parallel bedded in outcrop, but close study reveals that the unit is composed of successive layers of medium to very thick, amalgamated beds of bioclastic and intraclastic allodapic limestone with inconspicuous interbeds of dark gray, laminated lime mudstone and yellowish tan argillaceous mudstone. A caliche-like covering and lichens present on most outcrops, partial or complete recrystallization to coarsely crystalline dolomite, and horizontal partings parallel to the plane of stratification, commonly obscure original bedding features.

Allochthonous deposits of the unit can be divided into two dominant, although gradational, lithologic types: (1) intraformational conglomerates and breccias, and (2) skeletal packstones and grainstones. Intraformational conglomerates and breccias are more common in the lowermost and uppermost portions of the unit whereas the middle and upper portions are dominated by skeletal packstones and grainstones.

Thick to very thick beds of intraformational conglomerate and breccia are either crudely graded in the upper few centimeters or are texturally massive (Figs. 11, 12). Clasts are poorly sorted and randomly oriented, or have a weak preferred orientation of elongate clasts parallel to the bedding plane. Crude imbrication of clasts was noted in section VI and indicated east-to-west current flow. Bedding contacts are usually poorly exposed in outcrop, but where

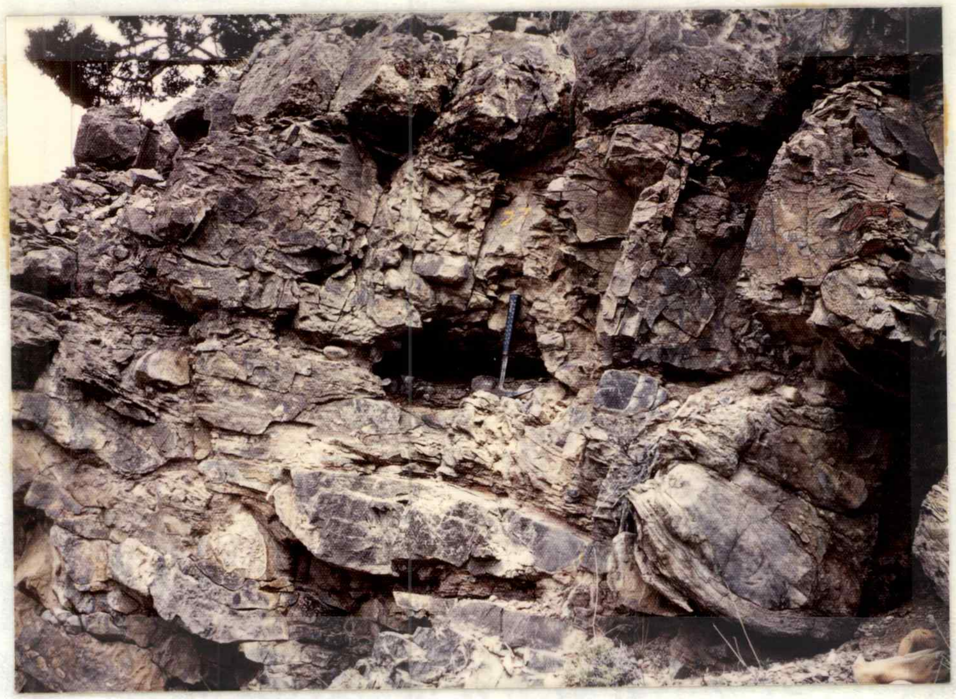

Figure 11. Three beds of intraformational conglomerates and breccias containing large mudstone intraclasts and a silicified dendroid stromatoporoid (lower left corner). Near III 27.

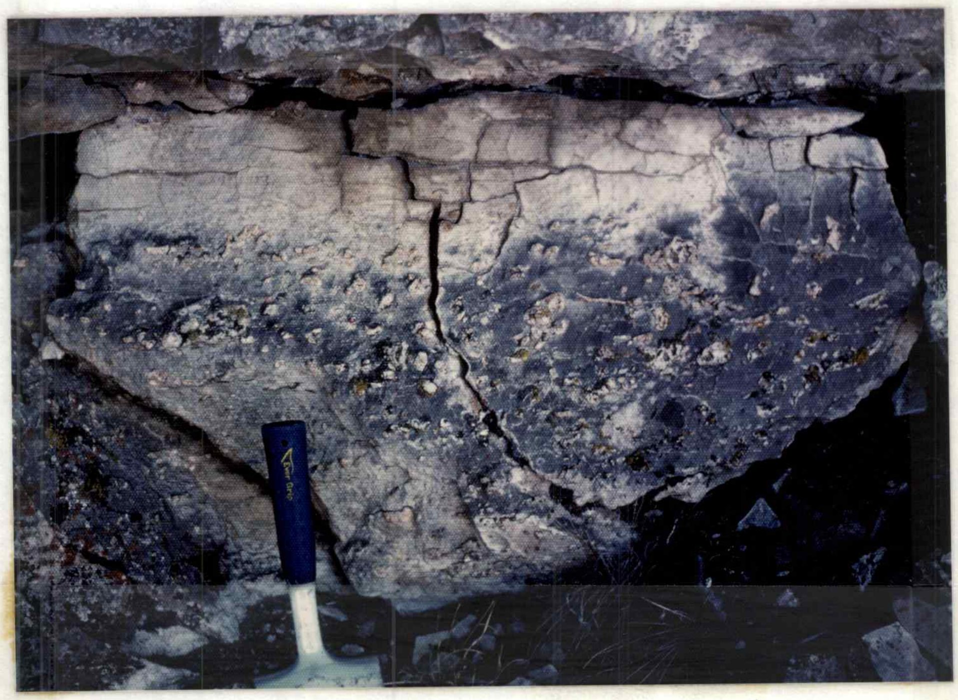

Figure 12. Crudely graded or gradational upper contact of intraformational conglomerate. Note lime mud intraclasts and a silicified fauna that is weathering out in relief. VII 235.

seen the lower contacts are sharp and roughly parallel, or slightly undulatory and upper contacts somewhat hummocky. Load structures are present locally. Breccias (debris flows) contain mudstone clasts floating in a fine-grained argillaceous matrix. Conglomerates are disorganized, stratified, or crudely graded (Walker, 1978) and the clasts are typically in grain support.

Intraclasts are a mixture of both shoal and deep water origin. The clasts are angular to subrounded and up to 14 inches maximum diameter (boulders), averaging 2 to 3 inches (pebble size). Deep water clasts are dark gray lime mudstone similar in lithology to rocks in the lower unit of the Denay; many are tabular in shape. Shoal-water clasts are light to medium gray to olive gray, packstones and grainstones that locally contain skeletal fragments of shoal-water origin. Shoal-water clasts typically exhibit a higher degree of rounding than mudstone clasts. The interclast matrix contains a shoal-water fauna of pebble to cobble size, thick-shelled brachiopods, tabulate and tetracorals, echinoderm debris and dendroid stromatoporoids, in addition to sand-size allochems, argillaceous lime mud, and skeletal debris.

Variations in the relative abundance of argillaceous lime mud and sand-size allochems in the matrix of these beds is roughly related to variations in the lithologic type of intraclasts supported in the matrix. A positive correlation between abundance of argillaceous lime mud in the matrix and abundance of mudstone intraclasts in these beds was noted. Mudstone clasts are found, almost to the exclusion of other clasts, in thick to very thick breccia beds with wackestone to packstone matrices. The matrix in these beds is medium to dark gray on weathered and fresh surfaces. Weathered beds with high terrigenous content are light brown gray. Clasts are poorly sorted and are floating in the finer grained matrix. Polymictic mudstone to packstone clasts are commonly found in graded or non-graded packstone and grainstone beds. In these beds the clasts are typically in grain support. Skeletal material is common to both breccias and packstones-grainstones.

The dominant lithology of the middle unit is medium to thick beds of calcarenite packstones and grainstones that are normally graded or crudely flat laminated, are parallel bedded, and have sharp lower contacts and gradational or sharp upper contacts (Figs. 13, 15). A, B, C, and D intervals of the Bouma sequence were recognized, although the entire sequence is rarely present within a single bed. Commonly noted sequences are the A-B and the B interval. Some of these beds are entirely massive and show no textural changes from bottom to top. A typical A-B sequence is medium bedded and consists of a lower skeletal packstone-grainstone interval grading upward into a finer grained wackestone to packstone interval. B sequences are crudely flat laminated medium-thick bedded packstones and grainstones that locally have a thin layer of convolute lamination (C interval) in the upper finer-grained portion of the bed. Upper and lower contacts are sharp and slightly undulatory. Flame structures were noted in section VI and suggest east-to-west current transport (Fig. 14).

A shoal water fauna consisting of thick-shelled brachiopods, tabulate and tetracorals, echinoderm debris, and stromatoporoids is common in these beds. Colors vary from light to medium gray to brown gray on fresh and weathered surfaces. Pebble- and cobble-size mudstone to packstone intraclasts locally are present in the lower graded portion of these beds or appear scattered in texturally massive beds. Clasts are commonly in grain support. In section V, the uppermost beds are crudely graded allodapic limestones composed of abundant large alveolitids and stromatoporoids in a coarse skeletal packstone matrix. Intraclasts are noticeably sparse relative to beds lower in the unit.

In thin and polished section, the matrix of the breccia beds is seen to be composed dominantly of round to ovoid, very fine to medium sand-size peloids, and lesser amounts of skeletal debris, all floating in a poorly sorted, "dirty," compacted matrix of argillaceous lime mud. These rocks are intrabiopelmicrites. The matrix of the packstones and grainstones typically lacks abundant lime mud, is well sorted, and moderately packed. These rocks have

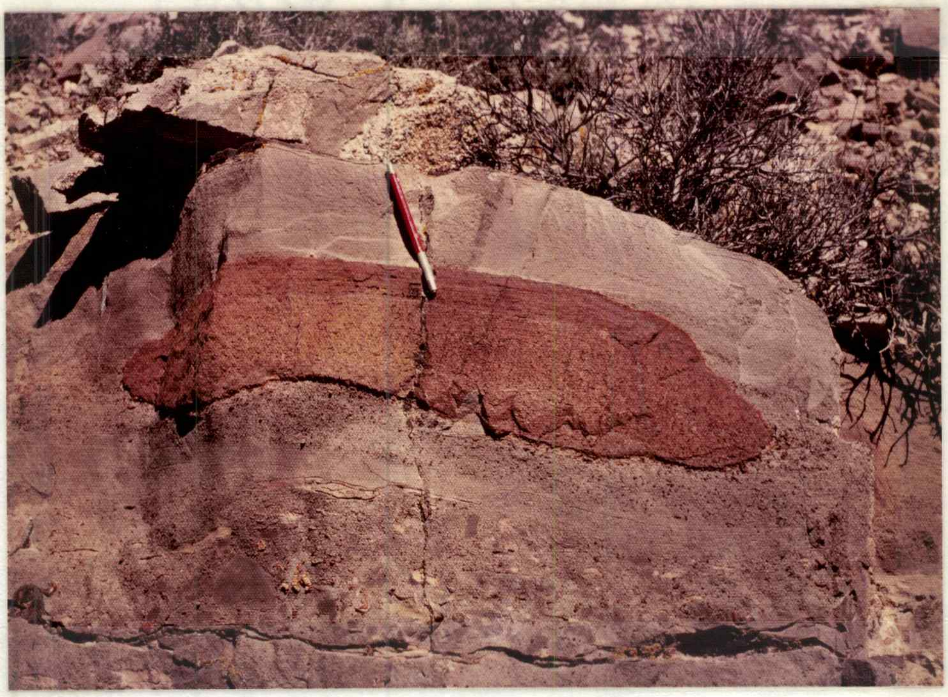

Figure 13. Graded bed of pebbly calcarenite. Note lower graded division overlain by laminated division, and large chert nodule. III 40.

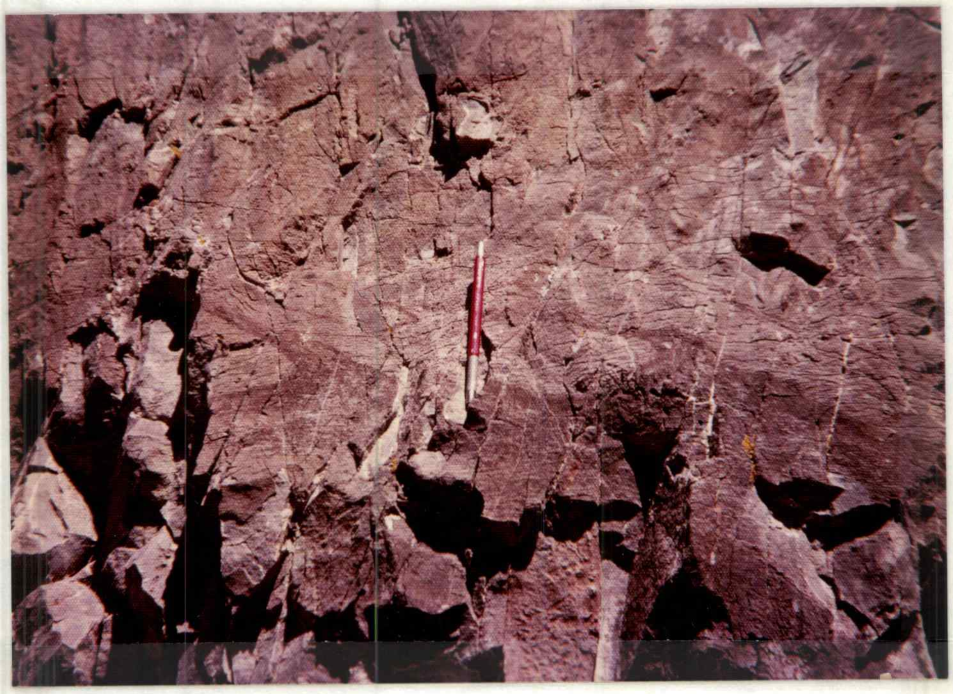

Figure 14. Flame structures indicating east (right) to west (left) flow direction. In cliff 200 feet east of section VI.

Figure 15. Graded bed at III 120. Matrix is pervasively dolomitized. Stylolite roughly follows base of bed. Upper contact is near the top of the pencil.

Figure 16. Photomicrograph of pressure-solution contact between a silicified brachiopod shell and a thamnoporid. Note peloids and scattered dolomite rhombs in matrix. Calcite is stained red. Field of view is cm. VIII D, Upper Stringocephalus Fauna.

cemented and moderately compacted fabrics and are biopelmicrites. Faunal constituents are well preserved and consist of thick-shelled, disarticulated brachiopods, tabulate and tetracorals, stromatoporoids, algae, and echinoderm debris. Calcispheres, with and without external walls, are present in amounts up to five percent. Very fine to medium sand size, well-rounded, detrital quartz composes up to ten percent of the rock locally. Authigenic overgrowths are common on the quartz grains.

Dolomite

Partial or complete recrystallization to dolomitic limestone or dolomite is the most common diagenetic feature affecting rocks of the middle unit.

Although dolomitization of the middle unit of the Denay is extremely variable, an overall west-to-east increase in dolomite abundance is present in the thesis area. In section VI, the westernmost section studied in the map area, coarsely crystalline dolomite is present only in the uppermost 10 feet of the unit. In section III, dolomitic limestone is present throughout most of the unit, and medium to coarsely crystalline dolomite is dominant in the upper 50 feet of the unit. In sections II, V, and VII, dolomite increases in abundance in the lower portion of the unit until medium to coarsely crystalline dolomite is the dominant lithology in the upper approximately 200 feet of section V. In section V, approximately 15 feet of allodapic limestone is present above the coarsely crystalline dolomite in the uppermost portion of the unit. Limy dolomite appears light brown gray and limestone appears light to medium gray on weathered and fresh surfaces. Mudstone intraclasts and skeletal constituents locally remain largely undolomitized, even where contained in a pervasively dolomitized matrix. The fine-grained, in places argillaceous, matrix in allochthonous beds appears to have been the most susceptible to dolomitization. Only in the advanced stages of recrystallization are pebble-size intraclasts and bioclasts replaced by dolomite and primary depositional fabrics totally obscured.

Complete recrystallization to fine to coarsely crystalline dolomite in most instances totally obscures the character of the original deposit. The rocks are light gray to light brown gray or slightly pinkish and appear massive to crudely parallel bedded in outcrop. The dolomite appears sugary because of the abundance of fine to coarsely crystalline euhedral dolomite rhombs and scattered, well rounded, fine-grained quartz sand on weathered surfaces. Two to 4 mm vugs, commonly elongated parallel to the plane of stratification, are present locally. Isolated thick beds of medium to dark brown gray, coarsely crystalline dolomite were noted in section V.

In thin and polished sections, progressive dolomitization to fine-to-coarsely crystalline, subhedral rhombs is apparent in rocks of the middle unit. Finely crystalline dolomite rhombs first appear filling interparticle areas between peloids or are finely disseminated in the poorly sorted, fine-grained matrix of the breccia beds. Dolomite increases in abundance until most of the interparticle matrix, including peloids and fine sand size allochems, has been replaced by fine- to medium-crystalline dolomite. Intraclasts, coarse sand- to pebble-size bioclasts, and isolated small patches of pelsparite remain unaltered in the limy dolomites. Beales (1965) noted similar relations in pelletal limestones and noted that although dolomitization is markedly variable, it is usually fabric selective and replaces fine-grained matrix ahead of grains, but the whole rock is progressively altered. Complete recrystallization to coarsely crystalline dolomite destroys the original depositional textures and constituent allochems, although faint ghosts or indistinct outlines of peloids can be seen in some of the larger dolomite crystals. Most of the coarsely crystalline dolomite appears as an interlocking mosaic of subhedral crystals, although crystals in darker beds are distinctly zoned with varying concentrations of insoluble residues. Euhedral terminations of dolomite crystals were commonly noted projecting into vugs in which authigenic quartz had been precipitated in optical continuity with the enclosing dolomite.

The fabric-selective character of dolomitization is apparent in the lowermost portion of the unit in sections II, V, and VII where medium beds of finely crystalline limy dolomite alternate with beds of skeletal lime packstones and grainstones. The contacts between these two lithologies are sharp and roughly parallel, although lenses and tongues of limy dolomite are present projecting into limestone beds.

Silica replacement of skeletal material in the middle unit is extremely variable, but generally only beds in the uppermost and lowermost portion of the unit are silicified. An inverse correlation between the abundance of silica and dolomite in these rocks is noteworthy. Complete diagenetic alteration to coarsely crystalline dolomite has destroyed any original skeletal material that may have been susceptible to silicification. Skeletal material remaining unaltered in limy dolomites is moderately to poorly silicified. Chert and radial aggregates of chalcedony are the replacing minerals.

Biostratigraphy

Faunal collections from the middle unit of the Denay in the thesis area indicate that the unit is latest Couvinian to Givetian in age. The unit is contained within the *ensensis* to upper *hermanni-cristatus* conodont Zones (Fig. 2, Fig. 3). *Stringocephalus* sp., an index fossil for the Middle Devonian, is common throughout the unit and was collected at VII 182, VII 235, VII 265, II 1575, V 1235, V 1240, V 1245, VI 28, VIII C, and III 43.

Ensensis Zone conodonts were collected at III 65. This is the first reported occurrence of ensensis Zone conodonts in the Nevada faunal sequence. By position in measured sections, VI 10, VI 28, II 1545, and III 43 may also lie within this zone. Brachiopods of the Leiorhynchus castanea Zone (I 19-20) are present with ensensis Zone conodonts.

Lower varcus Subzone conodonts were collected at VI 50, and occur with castanea Zone (I 19-20) brachiopods at II 1575 and V 1035. Collections assigned to Interval 20 on the basis of brachiopods are VII 182, VII 190, and VII 265 and by position are VII 235, V 995, and V 1020. The similarity of brachiopod faunas in V 1035 and VII 265 (both are dominated by Subrensselandia sp.), the similar modes of preservation (silicified shells in a dolomite matrix), and their relative positions in measured sections suggest that V 1035 and VII 265 may be the same bed. Thamnopora wrighti was collected at II 1575 and VI 10 and is indicative of Flory's (1977) Assemblage Zone 19.

Middel varcus Subzone conodonts were collected near the top of the middle unit at VIII C, V 1235, and V 1240 with brachiopods of the Stringocephalus Fauna (I 21).

Upper hermanni-cristatus Zone conodonts were collected at V 1245 with brachiopods of the newly recognized upper Stringocephalus Fauna (I 24). The source of V 1245 is a bed lying on top of a small ledge of amalgamated allodapic limestone at the top of the middle unit.

It occupies a position transitional between the middle and upper units of the Denay in the thesis area. One conodont subzone and the informal lower part of the hermanni-cristatus may be present in this ledge between V 1240 and V 1245. Upper varcus Subzone conodonts have not yet been reported in the Nevada faunal sequence. Lower hermanni-cristatus Zone conodonts have been reported from a single bed in the northern Roberts Mountains (Ziegler, Klapper, and Johnson, 1976).

Upper Unit

The upper unit of the Denay consists predominantly of very-fine-grained, thin bedded or laminated, argillaceous lime mudstone and calcareous shales with subordinate beds of thin to very thick bedded allodapic limestone. Beds of allodapic limestone are dominant in the middle portion of the unit, and crop out in ledges and small cliffs between the recessive-weathering lower and upper portions of the unit.

The unit forms the erosional top of the north-south-trending ridge containing Antelope Peak in the eastern portion of the map area, and weathers recessively below the ridge-forming unit mapped as Devonian sandstone in the western and central portions. The unit is approximately 305 feet thick as measured in section III. Two hundred and eighty feet of the unit are present in section V.

Murphy (1977) proposed that the contact between the middle and upper units of the Denay at its type section in the Roberts Mountains be used to divide the formation into two mappable members. He chose two mappable members rather than three because the lower and middle units merge and no mappable horizon has been found to separate them. The contrasting lithologies and the recessive topographic expression of the upper unit with respect to the middle unit form an easily recognized and mappable horizon in the Roberts Mountains (Murphy, 1977) and in the northern Antelope Range.

The lower contact of the upper unit (upper member) of the Denay is placed above the highest bed of skeletal packstones and grainstones of the cliff and ledge-forming middle unit. The upper contact of the unit is typically obscured by talus below massive cliffs of the ridge-forming Devonian sandstone in the central and western portions of the map area. The contact was placed at the base of these massive cliffs during field mapping. The upper contact is well exposed at 163 feet in section IV where thick amalgamated beds of light to medium brown gray sandy lime grainstones sharply and conformably overlie yellowish, finely laminated calcareous shales of the upper portion of the upper unit of the Denay.

Lower Portion

Because of the recessive weathering character of the lower portion of the unit, outcrops are present only in favorable topographic settings. This portion of the unit appears to be composed of thin-bedded to finely laminated, medium gray lime mudstone. Yellow argillaceous partings or interbeds impart a yellowish hue to float samples and to soils derived from this interval. The abundance of yellow argillaceous material appears to increase ~~in~~ up section. Subordinate, medium to thick beds of medium gray to brown gray, allodapic packstones and grainstones are present locally in isolated outcrops. These beds contain an abundant shoal-water fauna of pebble- and cobble-size, thick-shelled articulated and disarticulated brachiopods, tabulate and tetracorals, echinoderm debris and stromatoporoids. Alveolitids and thamnoporids are common in these beds. Bioclasts are scattered throughout individual beds, and are typically elongate parallel to the plane of stratification, but no obvious normal or reverse grading was noted. Silicified whole fossils are common. The lower contacts of these beds are rarely exposed, but are believed to be sharp and parallel. Upper contacts are typically sharp and are slightly undulatory.

The lower portion of the upper unit is approximately 75 feet thick as measured in sections V and III.

In thin and polished sections, the allodapic beds appear similar to allodapic packstones and grainstones present in the upper part of the middle unit in section V. Skeletal debris is abundant, and composes 50 to 75 percent of the volume of these rocks (Fig. 16). Very fine to coarse sand-size allochems include peloids, crinoid ossicles, and unidentified carbonate grains. The matrix is compacted and contains finely crystalline dolomite rhombs in abundances up to 15 percent. Silicification of skeletal material is variable, but generally good. Brachiopods and corals are the most susceptible to replacement by optically continuous quartz and chalcedony.

Middle Portion

The middle portion of the upper unit is composed predominantly of medium to very thick beds of parallel-bedded, medium brown gray to olive gray, graded or crudely flat laminated, allodapic lime packstones and grainstones (Fig. 17, 18, 19). These rocks crop out in ledges and low cliffs between the recessive-weathering upper and lower portions of the unit. The *disparilis* fauna to Lowermost *asymmetricus* Zone age *Tecnocyrtina* fauna is common and well preserved in these beds.

Excellent exposures of this interval are present in section V, where 130 feet of strata are present. This portion of the unit thins to the west, and is approximately 45 feet thick in section III (Fig. 10).

Average bedding thicknesses also appear to decrease westward in the thesis area. In section V, and due south of section V on the western side of the north-south-trending ridge containing Antelope

Figure 17. Graded bed at V 1320 containing the Tecnocyrtina fauna.

Figure 18. Graded bed a IV 12 containing the Tecnocyrtina fauna. Note lateral thinning of bed.

Figure 19. Polished section of graded bed. Note silicified skeletal material (white), tabular packstone-grainstone intraclasts, and imbrication dipping to right. Tecnocyrtina fauna in III 369.

Peak, cliffy exposures of this interval are composed of medium to very thick beds up to approximately eight feet maximum thickness. In section III, and in the southwest portion of the map area, medium to thick beds are common, but maximum thickness of these beds is approximately 4 feet. Thin-bedded, yellow, argillaceous limestones are present interbedded with thicker beds of skeletal packstone and grainstone.

Bedding contacts are typically sharp and parallel, although upper contacts may be undulatory. Load casts are present locally. Medium beds are commonly well graded. Thick to very thick beds are crudely flat laminated, normally graded in the upper few inches, or texturally massive. Intraformational conglomerates and breccias are not present, although scattered laminated yellow argillaceous lime mudstone intraclasts are present locally. These beds are similar to packstone and grainstone beds noted in the middle unit of the Denay, but are distinguished by slightly darker color, lack of abundant dolomite, and a lesser abundance of argillaceous lime mud intraclasts.

A silicified shoal water fauna of thick-shelled brachiopods, tabulate and tetracorals, echinoderms, and stromatoporoids is common to these beds. Large *Favosites* and *Hexagonaria* up to 1 1/2 feet maximum diameter were noted in section V.

In section V, thin beds (2 to 3 inches thick) of normal, and rarely reverse, graded beds of packstone were noted interbedded with thicker beds of packstone and grainstone and interbeds of argillaceous lime mud. The thin graded beds of packstone are similar in color to thicker packstone-grainstone beds, being medium brown gray to olive gray on weathered and fresh surfaces. Thin beds have sharp lower and gradational or sharp upper contacts and are usually parallel bedded.

Between approximately V 1380 to 1390, thin and medium-to-thick beds of graded packstone and grainstone are present filling a channel that is approximately 6 feet deep and 60 to 70 feet wide. The channel is exposed on north-south trending cliffs and the channel axis appears to trend roughly east-west. Small asymmetrical ripple marks and Planolites are present locally on bedding plane surfaces.

Upper Portion

The upper part of the upper unit is composed dominantly of recessive-weathering, thin-bedded to laminated lime mudstones and yellow, calcareous shales with subordinate interbedded skeletal packstones and sandy grainstones. This interval is typically poorly exposed on talus-covered slopes below the ridge-forming Devonian sandstone in the western and central portions, and has been largely removed by erosion in the eastern portion of the map area.

In section IV, the only well exposed section through this interval in the map area, approximately 150 feet of strata are present. One hundred eighty-five feet was measured in section III, but the true thickness is probably less because the upper contact is obscured by talus and was placed at the base of a massive cliff of the overlying unit. Seventy feet are present in section V where the upper part has been removed by erosion.

The lower contact with the middle portion of the unit is gradational, and was placed at the highest occurrence of abundant medium- to thick-bedded allodapic limestone containing the Tecnocyrtina fauna. The contact is easily recognized because of the contrasting lithologies and the recessive topographic expression of the upper part of the unit with respect to the middle part.

In section IV, the lower approximately 35 feet of the interval is composed of thin bedded to laminated, dark gray, fine-grained lime mudstones and wackestones with a strong fetid odor. These rocks are well bedded, have yellow, argillaceous partings, and appear similar to lime mudstones present lower in the Denay. An allodapic bed of skeletal packstone-grainstone collected at IV 40, 27 feet above the contact, contains Lower asymmetricus Zone conodonts and brachiopods of the Allanella fauna. This bed is normally graded, medium bedded, and dark olive gray to medium brown gray on weathered and fresh surfaces. The bed contains lime mud intraclasts, thamnoporids, and massive alveolitids.

Yellow argillaceous lime mudstones and silty calcareous shales are the dominant litholog of the upper approximately 115 feet of this part of the unit in section IV. These rocks are finely laminated, fissile or platy, and weather in various shades of yellow, red, and violet. The gradational change from dark gray, thin-bedded, lime mudstone to yellowish, platy weathering, argillaceous mudstones and shales occurs over an approximately 15 foot interval at IV 50 to IV 65. An allodapic bed collected at IV 63 (Fig. 20) yielded conodonts indicative of the Middle asymmetricus Zone, indicating that a distinct increase in detrital influx into the Denay depositional basin occurred between Lower and Middle asymmetricus Zone time.

This change in the character of sedimentation is reflected in allochthonous beds by a distinct increase in abundance of very fine-grained quartz sand and a decrease in skeletal debris. Interbedded with the yellow, limy shales are allochthonous, medium to thick beds of sandy packstones and grainstones. These rocks are medium gray, to light and medium brown gray sandy calcarenites that appear texturally massive or crudely flat laminated in outcrop. Upper and lower contacts are sharp and parallel, or slightly undulatory, and most beds have a one to two inch layer of replacement chert that roughly parallels the bedding contacts. Thicknesses of these beds can vary markedly along strike, and some are contorted by soft sediment folding. These rocks are lithologically similar to rocks in the

Figure 20. Graded bed at IV 63. The bed is totally silicified and contains Middle asymmetricus Zone conodonts. Note shale in float.

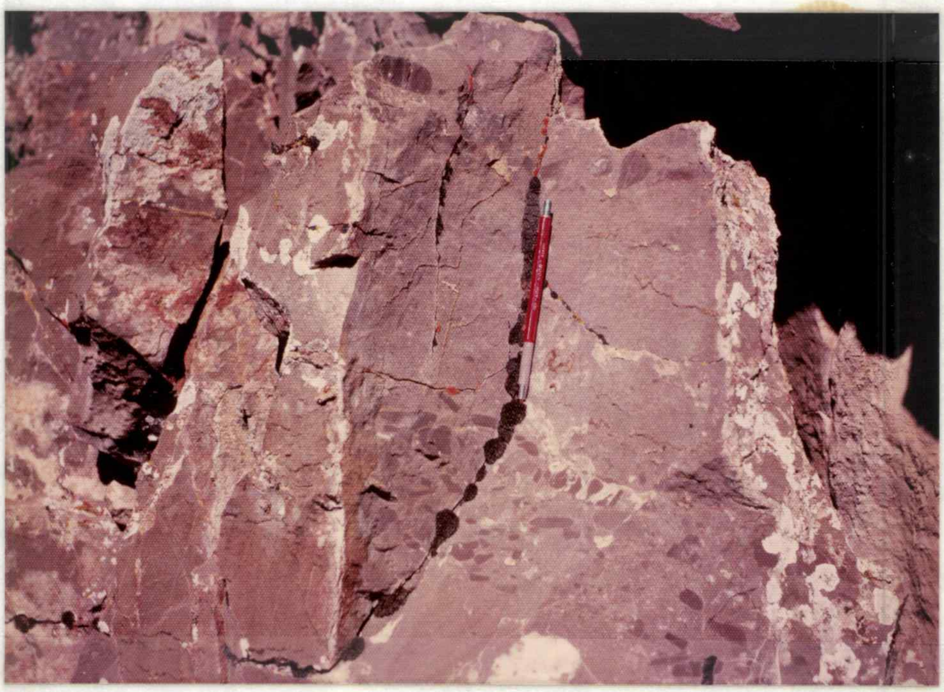

Figure 21. Graded bed in Devonian sandstone. Note tabular intraclasts and quartz-rich reddish stylolites. Top of pencil is near contact with overlying bed.

gradationally overlying, cliff-forming unit mapped as Devonian sandstone. The upper contact of the unit is placed at IV 163, where the allochthonous beds are abundant enough to be amalgamated and argillaceous interbeds are absent or indistinct. The most distinctive feature of these rocks is the abundance of well-rounded, fine-grained quartz sand.

Skeletal debris is typically absent in these allochthonous beds, except in IV 63, which lies in the lower, gradational part of this interval. IV 63 is medium bedded, medium to dark brown gray, and contains stromatoporoids, brachiopods, corals, intraclasts, and fine-grained quartz sand (Fig. 20). The bed is totally silicified except for the intraclasts, and no megafauna was recovered.

In thin and polished sections, silt to very fine sand size, subangular quartz grains compose 35 to 45 percent of the volume in these rocks. The detrital grains are floating in a poorly sorted, "dirty" matrix of argillaceous material and carbonate mud. Parallel laminae average 0.5 to 4 mm thick, and are defined by alternating laminae of high and low detrital quartz percentages. Allochthonous packstones and grainstones are composed of well-sorted, very fine to medium sand-size peloids, intraclasts, and well-rounded detrital quartz sand. These rocks are sandy intrapelsparites. Detrital quartz composes 20 to 40 percent of the volume of these rocks, and skeletal debris is virtually absent. Intraclasts and peloids are not clearly distinguishable, both being round to ovoid in shape and composed of micritic carbonate recrystallized to microspar. Intraclasts contain very fine sand-size peloids and calcispheres that are faintly to clearly discernible in the clasts. Calcispheres are commonly walled, display a pseudo-uniaxial cross under crossed nicols, and make up less than five percent of the volume of these rocks.

In thin section, the chert layers are seen clearly to be a replacement feature. Round to ovoid aggregates of spherulitic chalcedony are scattered with detrital quartz in a mass of microcrystalline chert. In plane light, the drusy outlines of peloids totally replaced by chalcedony are clearly discernible. Very finely crystalline rhombs of inclusion-rich dolomite are present locally in the chert.

Bedding contortion and folding of allochthonous beds in this interval are interpreted as soft sediment deformation (penecontemporaneous) for the following reasons: (1) no evidence of fracture lines, veins, shear planes or other indicators of brittle failure or tectonic deformation are present, even though the one to two inch chert layers, parallel to and replacing the upper and lower contacts of these beds, are also strongly contorted by folding; (2) adjacent, undisturbed beds have attitudes similar to those in the lower undisturbed part of the section; the folding does not appear to penetrate through the section.

Biostratigraphy

Faunal collections from the upper unit of the Denay in the thesis area indicate that the unit is Givetian to Frasnian in age (Fig. 2, Fig. 3). As noted earlier, upper *hermanni-cristatus* Zone conodonts were collected at V 1245, a transitional bed between the middle and upper units of the Denay. The uppermost portion of the upper unit has not been dated but is younger than Middle *asymmetricus* Zone time (IV 63) and older than Uppermost *gigas* Zone time (IV 255).

Upper *hermanni-cristatus* Zone conodonts were collected with brachiopods of the upper *Stringocephalus* Fauna (I 24) at III 258, VIII D, IX Y, and V 1245. *Davidsonia* sp. is a common element of this fauna. In III 258 *Thamnopora jaydeensis* occurs with *Alveolitella sokolovi*, which is indicative of Assemblage Zone 22 of Flory (1977).

Leiorhyncus hippocastanea Zone (I 24- I 25) brachiopods were collected at IX Y_3 and probably at X 30. Diagnostic conodonts of I 25 have not yet been recovered from these beds. *Ladjia russelli* is a dominant element of this fauna.

An early form of *Tecnocyrtina* sp. (I 27) was collected at VIII A in the lower portion of the upper unit. This bed contains *P. disparilis* Fauna conodonts and abundant *Choperella jeanette*, *Desquamatia* cf. *clarkei*, and *Schizophoria* cf. *fascicostella*. This fauna is similar to the *Choperella* Fauna (I 26) in the northern Roberts Mountains but with the notable addition of *Tecnocyrtina* sp. and the species of *Desquamatia*.

Tecnocyrtina Fauna brachiopods (I 27) were collected with P. disparilis Fauna conodonts at VI 160, V 1320, V 1340, V 1380, and V 1425. VIII B was placed in Interval 27 based on brachiopods and III 335 based on conodonts. Tecnocyrtina Fauna brachiopods (I 28) were collected with Lowermost asymmetricus Zone conodonts at III 369. Collections placed in Interval 28 based on brachiopods are IV 8, IV 12, and V 1450. Lowermost asymmetricus Zone conodonts may be present at IV 20. Desquamatia cf. clarkei is a common element of the Tecnocyrtina Fauna (I 27-I 28). Thamnopora jaydeensis is common and indicative of Assemblage Zone 22 or 23 of Flory (1977).

Lower asymmetricus Zone conodonts were collected in the upper portion of the upper unit at IV 40, IV 50, and III 380. Brachiopods of the Allanella Fauna were collected at IV 40. Middle asymmetricus Zone conodonts were collected at IV 63.

Uppermost gigas Zone conodonts were collected from the top of the Devonian sandstone at IV 255, indicating that the unit is Frasnian in age.

DEVONIAN SANDSTONE

Devonian sandstone is the informal name given to the distinct, ridge-forming unit of allochthonous sandy packstones and grainstones conformably overlying the Denay Limestone in the map area. The lower portion of the unit has not been dated, but Uppermost gigas Zone conodonts from the top of the unit at IV 255 indicate that the unit is gigas or older in age (Fig. 2 and 3). On evidence of conodonts, the unit is partly correlative with the upper member of the Devils Gate Limestone at Devils Gate Pass (Sandberg and Poole, 1977, Fig. 5).

In other areas in central Nevada, the Devils Gate Limestone conformably overlies the Denay (Murphy, 1977). The lower member of the Devils Gate is a shallow water platform complex of stromatoporoid boundstones, Amphipora packstones, and cross-bedded oolite grainstones (Murphy, 1977). The upper member of the Devils Gate consists of deep-water slope deposits, mainly debris flows and turbidites, shed eastward off the rising Antler orogenic belt into the intrashelf, protoflysch, Pilot Shale basin (Sandberg and Poole, 1977). Because the sandstone unit does not resemble, and is not underlain by the Devils Gate, it was not assigned a formation name and is informally called Devonian sandstone.

The Devonian sandstone consists dominantly of light to medium brown gray (weathered and fresh) to olive gray (fresh), medium- to very thick-bedded, cliff-forming, sandy lime packstones and grain-stones interpreted as allochthonous gravity flow deposits (Fig. 21, 22, 33). The unit weathers resistantly above the recessive upper part of the Denay in the western and central portions of the map area, and crops out in massive cliffs that form the capping strata of the roughly north-south trending, eastward-dipping, homoclinal ridges in the western portion. The unit forms a dip slope to the overlying, recessive weathering formations mapped as undifferentiated Mississippian and older Paleozoic thrust rocks.

The unit is 90 feet thick as measured in section IV, and 110 feet thick in section III.

Cliff-forming beds appear texturally massive or parallel bedded in outcrop, but close study reveals that the unit is composed of successive layers of medium to very thick, amalgamated beds of sandy lime packstones and grainstones. Pebble- and cobble-size intraclasts are present locally in the lower, crudely-graded portion of some of these beds (Fig. 21) but most beds appear texturally massive or crudely flat laminated in outcrop.

Where not masked in outcrop, bedding contacts appear sharp and parallel. Very rare skeletal material includes brachiopods, corals, and stromatoporoids.

Iron oxide-stained quartz grains are commonly found concentrated along orange-red stylolites. Stylolites are common and are parallel to, or trend at high angles across, bedding planes.

A distinctive sequence of rhythmically alternating, parallel beds in the lower middle portion of the unit in sections IV and III consists of medium beds of alternating quartz-sand-rich and lime-rich layers (Fig. 22-23). Layers with higher percentages of iron-stained detrital quartz weather out in relief relative to the medium gray, lime-rich layers. Lower contacts of the quartz-rich layers are sharp, and upper contacts are sharp or gradational with the lime-rich layers.

In thin and polished sections, packstones and grainstones are seen to be composed of well-sorted, very fine to medium sand-size peloids, subrounded to well-rounded detrital quartz, and calcispheres (Fig. 23). Sand to cobble size intraclasts are also present. These rocks are sandy intrapelsparites. Detrital quartz composes 20 to 60 percent of the volume of these rocks. Skeletal debris is virtually absent, except for rare brachiopods and coral fragments noted with pebble to cobble size intraclasts in the lower, graded portion of some beds. The matrix is well washed, may be moderately or loosely packed, and is cemented by sparry calcite. Calcispheres locally make up to eight percent of the volume of these rocks. Iron oxide is present in abundances of less than five percent.

Petrographic study of the rhythmically alternating interval indicates that the lime-rich and quartz-sand-rich layers are lithologically similar, differing mainly in abundances of quartz sand and peloids. Detrital quartz sand composes 40 to 60 percent of the volume of the quartz-sand-rich layers, and 20 to 30 percent of the volume in the lime-rich layers. Although these rocks are well sorted, the quartz-rich layers appear to have a higher abundance of medium sand-size quartz grains. These rocks are interpeted as representing hydraulic sorting and concentration of denser quartz grains in the lower portion of the beds during downslope movement of sediment gravity flows. The rocks are density graded, but not size graded, because the average size of the contained allochems rarely varies discernibly within a single bed.

Sand- to cobble-size intraclasts and composite grains are round to ovoid or tabular in shape and are composed of very fine to fine sand size peloids and calcispheres, and lime mud recrystallized to microspar and pseudospar. Some intraclasts, or composite grains, appear as well rounded, clumped aggregates of calcispheres and peloids.

Other intraclasts are similar in lithology to the matrix of sandy packstones and grainstones.

Figure 22. Rhythmically alternating graded beds in Devonian sandstone. Quartz rich layers weather in relief and are darker colored.

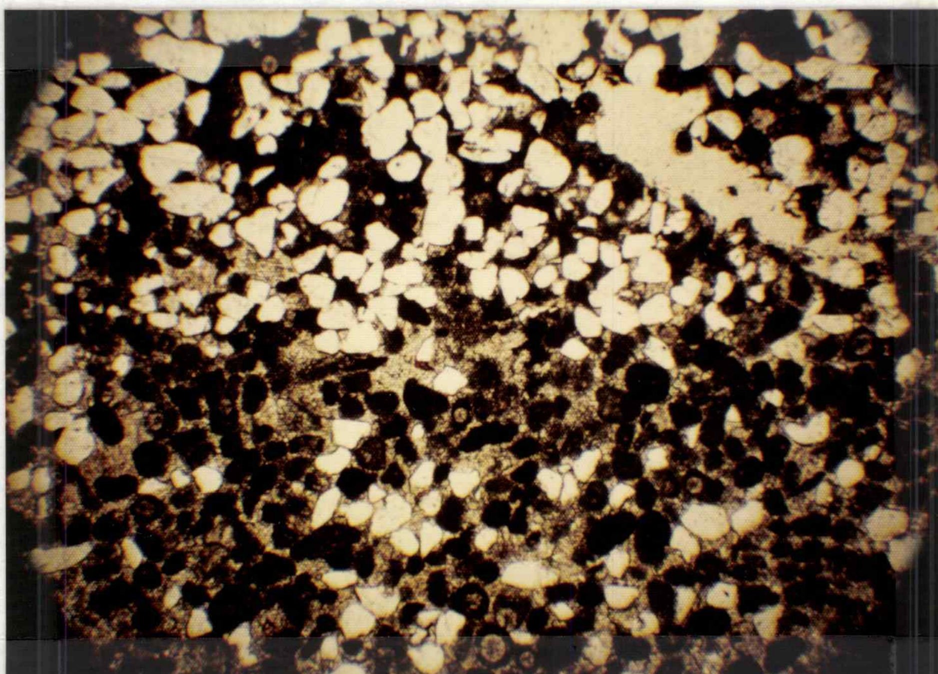

Figure 23. Photomicrograph of sharp contact at base of graded beds shown in Figure 21. Note rounded quartz grains and calcispheres (bottom center of photo). Field of view is cm.

DENAY LIMESTONE - DEPOSITIONAL ENVIRONMENT

Basinal Criteria

Murphy (1977) described the Denay in the northern Roberts Mountains as a level-bottom, basinal deposit containing interbedded allodapic limestone beds derived from shoal-water source areas to the east. In some localities, such as at Lone Mountain, the shoal-water facies prograded westward over the basinal deposits. In the northern Antelope Range, the thin-bedded to laminated lime mudstones in the Denay represent suspension-deposition marine deposits accumulated under low-energy conditions. The low-energy depositional regime is interpreted to be a deep-subtidal, below-wave-base, dysaerobic to anaerobic, gently sloping, basinal environment.

Wilson (1975) cited a number of features, characteristic of carbonate basin and basin-margin sediments, that are recognizable in the Denay of the thesis area:

(1) dark, organic-rich, cherty or argillaceous, lime mudstones and wackestones; calcisiltites and fine-grained peloidal packstones;

(2) very even, planar laminations; small-scale, rhythmic alternations of even beds of limestone and shaly interbeds; fine ripple cross-lamination;

(3) pelagic fauna preserved in local abundance on bedding planes;

microfauna includes sponge spicules and calcispheres; restricted megafauna;

(4) interbeds of allodapic limestone.

A low energy depositional environment is suggested by the predominance of mud-supported textures in the Denay. Sedimentary structures characteristic of shallow-water, low-energy, platform environments were not noted in these rocks (see Matti and others, 1975; Wilson, 1975). Parallel laminae are the result of low-energy, suspension deposition, and may reflect differential settling of silt- and clay-size carbonate sediment, or episodic or fluctuating rates of supply of these materials. The parallel laminae may also reflect periodic bottom-current activity which would partially winnow the lime mud. The parallel laminae may have been accentuated by post-depositional compaction. Periodically, increased current energy formed localized areas of irregular bedding and truncation structures. Some thin beds of peloidal packstone represent distal turbidity current deposits.

A gently sloping basinal environment is suggested by slump features (Fig. 7) indicative of deposition on a slope (Wilson, 1975).

The autochthonous fauna in these beds consists mainly of thin-shelled brachiopods, tentaculitids, conodonts, gastropods, sponge spicules, calcispheres, and sparse echinoderm debris. Abundance is locally high, but diversity in brachiopod faunas of the *L. circula*

Zone is low. Although hundreds of individuals, and up to seven taxa, may be present within a single bed, the fauna is commonly dominated by one or two species, notably Leptathyris circula and Vallomyonia devonica. Because these animals are commonly articulated and exhibit geopetal fabric, and because they are thin shelled and show little evidence of current transport or abrasion, they are interpreted as representing an in-place benthic community that locally prospered in the Denay depositional basin. This community probably corresponds to Benthic Assemblage 5 of Boucot (1975).

In contrast, brachiopod faunas contained in allodapic beds are of higher diversity than in-place faunas, but have fewer individuals. These animals are thicker-shelled, commonly disarticulated, and are associated with tabulate- and tetracorals, stromatoporoids, and alveolitids that are indicative of a shallow-water source area. Eighteen species of brachiopods were recognized in an allodapic bed at V 153.

Infaunal bioturbation is absent in thin-bedded to finely-laminated lime mudrocks of theDenay, although the meandering trail of the horizontal burrow Planolites is locally abundant on bedding plane surfaces. Planolites is known from a variety of environments, including abyssal and flysch.

The strong fetid odor and dark color on freshly broken surfaces is indicative of the presence of relatively abundant organic carbon in these rocks. The preservation of organic carbon suggests reducing conditions in the original substrate. The lack of infaunal bioturbation suggests that reducing conditions were present in the substrate soon after deposition of these fine-grained sediments. The lack of an abundant shelly epifauna and burrowing infauna suggests anaerobic bottom-water conditions during deposition of the Denay (Byers, 1977). Because the geometry of the Denay depositional basin is poorly understood, it is not known whether oxygen deficiency was the result of stagnant bottom waters in a gently-silled, outer shelf basin (Matti and McKee, 1977), or impingement of the oxygen-minimum zone on a gently-inclined, outer-continental shelf or slope environment (Fischer and Arthur, 1977). The lower portion of the Denay may have been deposited in a sheltered shelf basin because _costatus costatus_ Zone conodonts were collected from coarse grained limestone (a shallow-water buildup ?) in the Toiyabe Range (Murphy, 1977).

Depositional Mechanism for Allochthonous Beds

Packstones, grainstones, intraformational conglomerates, and breccias in the Denay exhibit a number of features indicative of sediment gravity flow deposits. That many of these beds contain a shoal-water fauna and are interbedded with strata interpreted as basinal, indicates that the term allodapic limestone (Meischner, 1964) is appropriate for these deposits.

Allodapic beds in the Denay are transitional between two end members: classical turbidites and debris flows. Several authors recently have implied that these two end members are genetically related, and that turbitites may be the distal equivalents of debris flows that form during the downslope evolution of sediment gravity flows (Davies, 1977; Walker, 1978; Middleton and Hampton, 1973; Walker and Mutti, 1973). In general, thicker-bedded, coarser-grained sediments would be deposited in relatively proximal settings, and the flows would become thinner-bedded and finer-grained in progressively distal environments as the competence of the flow waned. Walker (1978), and Walker and Mutti (1973), have shown that deposition of clastic debris flows and conglomerates on submarine fans occurs generally on the upper fan, or at the mouth of submarine canyons, where there is a pronounced break in slope causing a loss in competency of the gravity-driven, sediment flow. Massive sandstones and pebbly sandstones are deposited on suprafan lobes, and classical turbidites on the mid- and outer-fan, and on the basin plain.

Matti and others (1975) noted that, in general, allodapic beds containing a well-preserved, shoal-water fauna become more abundant, thicker and more irregularly bedded, coarser grained, and more poorly sorted as the platform margin is approached. Allodapic beds in distal environments contain a fragmented and poorly preserved shoal-water fauna, are thinner and more parallel bedded, and are finer grained and better sorted.

It should be assumed that the final deposit will also be dependent upon the character of the original sediment supplied from the source area, and the admixture of material during downslope movement. Cook and Taylor (1978) noted that carbonate conglomerates and breccias may originate in shoal water <u>or</u> slope environments by mass flow or slumping. The lack of abundant coarse-tail grading of bioclasts in massive or crudely flat-laminated beds may be a function of the skeletal materials original high internal porosities and varied shapes, hence differing hydraulic behavior, rather than more turbulent flow in proximal environments (Matti and others, 1975).

Lower Unit

The beds of normally graded packstones marking the base of the Denay represent downslope accumulations of the crinoidal unit of the Sadler Ranch Formation. Kendall (1975) suggested a quiet to moderately-agitated environment of deposition for the "prolific crinoidal gardens" in the Sadler Ranch. A quiet to moderately-agitated, subtidal environment allowed the accumulation of abundant crinoidal material and lime mud, which were later replaced by finely crystalline dolomite. Wilson (1975) noted that encrinites are a common slope and a shelf edge sediment. Loose crinoidal sands and lime muds probably became unstable, slumped, moved downslope, and became normally graded during deposition as the current energy waned. The abundance of these beds, with only sparse interbeds, suggests active sediment production in the "carbonate factory" (Matti and McKee, 1977).

The decrease in abundance of crinoidal material in allodapic beds upsection, and the increase in mud intraclasts, matrix, and interbeds, suggests changing conditions in the source area of these beds. A gradual increase in water depths caused by Couvinian transgression would have caused an eastward shift, or possibly a drowning of the shelf margin, which would have precluded deposition of calcarenite sands and conglomerates in the basin. Suspension deposition of fine grained material would have predominated on the shelf edge, slope, and in the basin. Occasional slumping of partially lithified and nonlithified lime mudstone and wackestone could have formed the intraformational conglomerates and breccias present in the 50 or 60 feet stratigraphically above the crinoidal packstones. The presence of a shallow-water fauna in these beds suggests that most of these flows originated in a shallower-water setting, and that they incorporated material into the flows during downslope transport. Johnson (pers. comm., 1978) referred to the fauna in some of these beds (e.g. V 95), as a "pioneer" community, because it differs from subjacent faunas and contains elements of both deep water (Vallomyonia sp.) and shallow water (Spinatrypa, Nucleospira) communities. These animals may have been living together in the source area, or deeper water forms may have been admixed. The flows may have originated in shoal waters and incorporated lime mudstone clasts and a deeper-water fauna during downslope movement. The disorganized or crudely-stratified fabric, the coarse size of contained clasts, medium to thick bedding, and the well preserved fauna suggest a relatively proximal depositional setting. Couvinian onlap caused a retreat of the source area for these deposits, and quiet water sedimentation predominated.

In Va 153, the clasts are in matrix support rather than grain support, indicating that this bed is a debris flow in the sense of Walker (1978) and Middleton and Hampton (1973), or a breccia bed (Cook and Taylor (1977), rather than a conglomerate (Fig. 6). The distinction is important because they differ in modes of transport and deposition, and may have originated under different conditions. The predominance of fine-grained material in the matrix, and the randomly oriented mudstone clasts in matrix support, suggests that this bed may have originated by slumping in a deeper-water slope environment than conglomerate and crinoidal packstones present lower in the section (Cook and Taylor, 1977). Va 153 was not sampled faunally, because a visible megafauna was not apparent on weathered surfaces.

Upper *kirki* Zone and *S.* cf. *coriacea* Fauna

A gradual shallowing occurred in this basinal environment during deposition of mudstones, wackestones, and packstones of the upper *W. kirki* Zone and the *S.* cf. *coriacea* Fauna.

Deposition of rocks of the *W. kirki* Zone was in a low-energy, quiet-water, deep-subtidal environment. This brachiopod fauna is of moderate diversity (eleven taxa in II 1400), and is dominated by abundant *Warrenella kirki*. The fauna is generally of higher diversity than autochthonous *L. circula* faunas which have a maximum of seven taxa, and average five. However, the coquina sampled at V 720 contains only four brachiopod taxa, and is dominated by *W. kirki*.

The absence of current-associated sedimentary structures, the overall fine-grained character of these rocks, the lack of abundant skeletal debris, and the presence of a thin-shelled, low-diversity, brachiopod fauna suggest very weak and gentle currents in a restricted environment dominated by suspension deposition. The preservation of fine laminae, and the apparent lack of infaunal bioturbation suggests a thixotropic substrate, possibly in an anaerobic to dysaerobic environment. Pellets were probably derived *in situ* during epifaunal life processes. This community probably occupied Benthic Assemblage 4 or 5 of Boucot (1975; A. J. Boucot, pers.

comm., 1978).

Environmental conditions apparently improved slightly during S. cf. coriacea Fauna time, although deposition was still in relatively deep, moderately agitated water. Brachiopod diversity remained nearly the same with ten taxa reported in II 1480, although overall faunal diversity increased with the addition of favositids, receptaculitids, and abundant echinoderm debris. Thick-shelled brachiopods of this fauna that are not present in the upper kirki Zone include Warrenella cf. franklinii, Spinatrypina sp., and Schizophoria sp. Articulated and disarticulated brachiopod shells, weakly abraded skeletal material, locally poddy- or irregularly-bedded layers, and the general lack of fine laminae, suggest that current energy was weak to moderate. Bottom currents were not competent enough to winnow lime mud or concentrate skeletal material into layers or lenses. This community probably represents Benthic Assemblage 4 or 5 of Boucot (1975; A. J. Boucot, pers. comm., 1978).

As noted earlier, characteristic upper and lower kirki Zone brachiopods have been reported only at Lone Mountain. Lower kirki Zone brachiopods have been recognized in the southern Roberts Mountains. Overlying the kirki Zone beds at Lone Mountain is approximately 200 feet of coarsely crystalline dolomite that contain algal and stromatoporoid boundstones near the top (Murphy, 1977; Murphy and Dunham, 1977). The boundstones are overlain by the

Lower varcus Subzone age Antistrix Fauna of Johnson (1972). In the northern Roberts Mountains, deep water sedimentation continued from L. circula Zone until Lower varcus Subzone time (Murphy, 1977, Fig. 2).

The kirki Zone biotope formed earliest at Lone Mountain, and at Roberts Creek Ranch in the southwestern Roberts Mountains (Johnson, 1971). The lower kirki Zone is equivalent to the uppermost circula Zone of the northern Antelope Range. As the shallowing event continued, the kirki biotope migrated offshore into the thesis area during late kirki Zone time. The pervasively-dolomitized shoal-water complex, including reefs, overlies probable lower kirki Zone at Roberts Creek Ranch (Murphy, 1977) and is probably equivalent to the deeper-subtidal deposits of the upper kirki Zone at Lone Mountain and in the northern Antelope Range.

As shallowing continued, the shoal-water facies prograded over the upper kirki Zone deposits at Lone Mountain, but the facies never reached the relatively offshore position of the thesis area. The kirki Zone biotope may have migrated farther offshore and been replaced by the shallower-water S. cf. coriacea Fauna biotope in the northern Antelope Range. The lower portion of the pervasively-dolomitized, shoal-water complex at Lone Mountain is equivalent to the subtidal deposits of the S. cf. coriacea Fauna in the thesis area.

A return to deep-water, suspension deposition after

S. cf. coriacea time is indicated by the approximately 180 feet of thin- and medium-bedded lime mudstones in the uppermost portion of the lower unit of the Denay. This deepening event has not been recognized at Lone Mountain, where pervasive dolomitization has obscured the original depositional textures. Deepening caused migration of a "kirki-like" biotope back into the thesis area, as indicated by a collection in the lowest part of this mudstone interval at VII 10. This fauna is of moderate diversity (eleven taxa) and is dominated by thin-shelled, commonly-articulated Vallomyonia devonica, Echinocelia sp., and Warrenella sp. This fauna most closely resembles the upper kirki Zone Fauna collected at II 1400; however, the fragments of Spinatrypa sp. that occur in this collection are like S. cf. coriacea and not like S. andersonensis of II 1400. Notably absent from this collection is L. circula, which apparently was extinct by this time. An in situ benthic community younger than the S. cf. coriacea fauna of VII 10 has not been identified in the thesis area. Quiet-water, suspension deposition continued until ensensis Zone time, when allodapic sedimentation predominated in the middle unit of the Denay.

Middle Unit

The middle unit of the Denay represents a proximal sequence of allodapic limestone derived from shoal-water source areas to the east during ensensis Zone to late hermanni-cristatus Zone time.

These rocks exhibit many of the features described by Matti and others (1975) for proximal allodapic sequences; thick-irregular bedding, high sand/shale ratio, coarse grain size, poor grading, and a well preserved, shoal-water benthic fauna.

Regional facies relations also indicate a proximal environment of deposition. Sedimentation began earlier (ensensis Zone time) and continued later (upper hermanni-cristatus Zone time) in the thesis area than in the northern Roberts Mountains, where the middle unit of the Denay was deposited during early varcus Zone time (Murphy, 1977; J. G. Johnson, pers. comm., 1978). The westward thinning of the unit in the thesis area (Fig. 10) is indicative of an eastern source area for these deposits.

The absence of the lower kirki Zone biotope in the northern Roberts Mountains, in addition to the above information, indicates that the middle unit of the Denay in the thesis area was deposited in a proximal setting, transitional between the shoal-water platform facies at Lone Mountain, and the relatively distal facies of the northern Roberts Mountains.

A shoal-water origin for allodapic beds in the middle unit is suggested by the abundant and diverse fauna contained in these beds. Brachiopod diversity is high, with up to twenty taxa present in single collections (e.g. VI 28). Stringocephalus sp. is common in beds throughout the middle unit. Stringocephalus has been reported in the platform facies from two horizons at Lone Mountain (Murphy, 1977, Fig. 2). Tetracorals, thamnoporids, encrusting alveolitids, algae, Davidsonia sp., and dendroid and encrusting stromatoporoids are locally abundant, and indicative of shoal-water origin.

The presence of a shoal-water fauna in debris flows and conglomerates suggests that these flows originated in shoal-water environments and incorporated mudstone intraclasts and fine-grained material into the flow during downslope movement. Komar (1970) showed that turbulent flows of sufficient competence to transport conglomerates would have enormous ability to erode and deform underlying strata. Some debris flows may represent slump deposits that originated high up on the slope, in relatively quiet waters where lime mud and an abundant benthic biota could accumulate.

Packstones and grainstones probably originated in higher-energy banks and shoals where constant wave and current energy would form well-sorted and well-washed sediments. These beds are probably analogous to classical turbidites, massive sandstones, and pebbly sandstones of terrigenous clastics (Walker, 1978). The badly worn ventral beaks of thick-shelled Warrenella cf. franklinii in VI 10 are probably indicative of shoal water abrasion before, rather than during, downslope movement into deeper waters.

The presence of pebble-, cobble-, and boulder-size intraclasts in some of these beds suggests that deposition occurred at, or near, a pronounced break in slope that would have caused a decrease in the competency of the transporting medium (see earlier discussion and Middleton and Hampton, 1973). The marked westward thinning of the unit in the thesis area (Fig. 3) suggests downslope thinning of sediment gravity flows and/or indicates that many of the flows may have been deposited before they reached the westerly localities in the thesis area. Interbedded, thin-bedded mudstones indicate that deposition occurred in a quiet water environment. Slump structures in the enclosing mudstones indicate a gently sloping, depositional environment (Fig. 7). The environment may be analogous to the upper fan and suprafan facies of clastic submarine fans (Walker, 1978; Walker and Mutti, 1973). The differing scales involved dictate that this analogy is not a straightforward one, because the Denay represents sedimentation in an intrashelf basin, rather than channelized flows deposited at the base of a continental slope.

Dolomite

Dunham and Olson (1978) noted that the regional distribution of dolomite in the Cordilleran miogeocline of Nevada was paleogeographically controlled. They stated that mixing of a fresh-water lens, derived from subaerially exposed tracts of the eastern miogeocline, and marine pore water caused diagenetic dolomite replacement of subtidally-deposited lime carbonate. Periods of marine offlap would cause a westward migration of areas of fresh-water recharge, and a westward shift of the limestone-dolomite boundary. Matti and others (1975) noted that progradation of the platform facies during periods of marine offlap would generate numerous allochthonous flows into the depositional basin. Periods of platform stability or marine onlap would reduce the potential for generating abundant allochthonous flows, and basinal sediments would reflect distal allodapic textures.

Regional lithofacies patterns indicate that the roughly north-south-trending limestone-dolomite boundary passes to the east of the thesis area (Johnson and Sandberg, 1977). Murphy (1977) has shown that the pervasively-dolomitized platform-complex, including reefs, prograded westward over basinal limestones of the Denay at Lone Mountain and in the southern Roberts Mountains, indicating a westward shift of the limestone-dolomite boundary after kirki Zone time. The dolomitized platform may have attained some topographic relief on its western edge during castanea Zone time, because a north-south trending belt of dolomite (the Bay State Dolomite Member of the Nevada Formation, Nolan and others, 1956), including reefs (Murphy, 1977), separated lagoonal deposits of the Woodpecker Limestone to the east, from the basin and basin-slope deposits of the Denay to the west (Johnson and Sandberg, 1977, Fig. 7). The abundant allochthonous deposits present in the middle unit of the Denay in the thesis area, and in the northern Roberts Mountains, indicate that this was an active period of sediment production in the buildup areas. Occasional subaerial exposure of the buildups would have caused the formation of a fresh water lens, causing diagenetic dolomite replacement of subsurface lime carbonate. The fresh-water lens may have moved downslope through lime sands of the relatively permeable foreslope and caused the partial or complete recrystallization to dolomite of the middle unit of the Denay in the thesis area.

An eogenetic origin for the dolomite in the thesis area is suggested by:

(1) coincidence of onlap and offlap sequences with migration of the limestone-dolomite boundary;

(2) the relatively proximal setting of the northern Antelope Range with respect to the limestone-dolomite boundary;

(3) the interbedded character of limestone and dolomite, as noted in the lower portions of the middle unit in sections II, V, and VII, suggests that dolomitization was controlled by the original depositional textures; permeability of the original sediment controlled the migration of the dolomitizing fluids;

(4) the general eastward increase in dolomite abundance in the middle unit of the Denay in the thesis area;

(5) silica-filled vugs indicate that dolomitization occurred before silicification.

Probably not all of the dolomite formed in this manner, however. Murphy (1978, field comm.), noted that coarsely crystalline dolomite present at the top of the middle unit on section VI (and probably on section III) may have formed by tectonic shearing similar to that present in the northern Roberts Mountains.

Upper Unit

Lower Part

A return to quiet-water sedimentation, beginning in late *hermanni-cristatus* Zone time, is indicated by the thin-bedded, argillaceous, lime mudstones, with sparse allodapic interbeds, present in the lower part of the upper unit of the Denay. This interlude of suspension deposition between two periods dominated by allodapic sedimentation (middle unit and middle part of upper unit) probably indicates a general period of marine onlap. I agree with Murphy (1977) who suggested that the abrupt end of allodapic sedimentation in the middle unit of the Denay in the northern Roberts Mountains was caused by either drowning, or retreat of the reefs and associated shallow-water facies. The presence of abundant encrusting stromatoporoids, alveolitids, *Hexagonaria* sp., thamnoporids, tetracorals, *Davidsonia* sp., and *Stringocephalus* sp., in thick allodapic beds suggests that reef-type buildups (in the sense of Murphy and Dunham, 1977) were still present in the shallow-water facies during this period.

These allodapic beds exhibit many of the characteristics of proximal deposits described by Matti and others (1975), including medium to thick bedding, coarse grain size, an abundant and well preserved shoal-water benthic fauna, and poor grading. The frequency of allodapic beds suggests a distal setting, although, as Matti and others (1975) noted, relative abundance alone does not confirm a distal depositional setting.

These deposits probably represent events, such as major storms, that formed unusually large, coarse-grained flows that were deposited farther basinward than contemporaneous flows in more proximal settings.

Middle Part

Marine offlap is indicated in the thesis area by a return to abundant allodapic sedimentation during *Tecnocyrtina* Fauna time. In other areas of central Nevada, the shallow water lower Devils Gate Limestone overlies basinal deposits of the Denay. Murphy (1977), and Sandberg and Poole (1977), described the lower Devils Gate as representing a generally light-colored, thick-bedded, shallow-water facies containing *Amphipora* packstones, stromatoporoid boundstones, and cross-bedded oolitic grainstones. A single well preserved specimen of *Tecnocyrtina* aff. *T. billingsi* was collected in the basal Devils Gate of the northern Simpson Park Range (Johnson and Norris, 1972). Numerous poorly preserved individuals of *T.* aff. *T. billingsi* were collected from the basal Devils Gate nearby at Red Hill, where the Devils Gate overlies the Red Hill beds of the Denay, which contain *L. hippocastanea* Zone brachiopods (Johnson, 1978).

The middle and upper parts of the upper unit of the Denay in the thesis area are younger than strata assigned to the Denay Limestone elsewhere in the Great Basin (except at Cortez, D. B. Johnson (1976)). These rocks correlate with the Devils Gate Limestone, the Guilmette Formation, and the lower part of the Pilot Shale.

The westward thinning of the middle portion of the upper unit in the thesis area (Fig. 3), and the general decrease in bedding thickness of the unit, indicate an eastern source for these deposits. Deep-water sedimentation west of the shallow-water Devils Gate platform complex has not been described previously in the central Great Basin of Nevada (Johnson and Sandberg, 1977). In most westerly locations, rocks of this age were tectonically eroded during emplacement of the Roberts Mountain allochthon (Poole, 1974; Sandberg and Poole, 1977; Poole and others, 1977; Burchfiel and Davis, 1975).

Johnson and Sandberg (1977) stated that the regional westward thinning of shelf carbonates in Nevada was caused by western uplift, associated with the first tectonism of the Antler orogeny. Western uplift caused a shallowing of the Denay depositional basin and progradation of the shallow-water Devils Gate complex over the quiet-water deposits of the Denay in most areas of central Nevada. During Tecnocyrtina Fauna time, in the northern Antelope Range, the westward prograding Devils Gate facies initiated deposition of allodapic sediments into a previously unrecognized intrashelf basin situated west of the Devils Gate platform margin and east of the incipient Antler orogenic highland. Concomitant with western uplift was transgression by the Taghanic onlap and deposition of biostromal and biohermal strata of the Devils Gate Limestone and Guilmette Formation on a broad shallow platform (Johnson and Sandberg, 1977). Johnson (1971) noted that "the Taghanic onlap was the largest single transgressive event of the Kaskaskia Sequence," and that transgression coincided with the first pulses of the Antler orogeny, the major orogenic event in the Paleozoic of the western United States.

A shoal water origin for allodapic beds of Tecnocyrtina age is indicated by an abundant and diverse fauna contained in these beds. Brachiopod diversity in moderate, with up to fourteen species present in single collections (e.g. III 369). Davidsonia sp. is present in the lowermost portion of the unit. Thamnoporids, alveolitids, tetracorals, Hexagonaria sp., stromatoporoids, and alveolitids are common.

Intraformational conglomerates, similar to those described earlier in the middle unit of the Denay, are not present in Tecnocyrtina age allodapic deposits, although locally, randomly-oriented, cobble-size corals and stromatoporoids were noted.

Graded or flat-laminated allodapic beds are analogous to classical turbidites and massive sandstones, and were probably deposited in a similar manner. Thick beds of texturally massive or crudely flat laminated calcarenites are probably analogous to massive sandstones and disorganized pebbly sandstones (Walker, 1978; Walker and Mutti, 1973). Walker (1978) noted that massive and pebbly sandstones are the most likely facies to be deposited on the braided channel part of suprafan lobes on clastic submarine fans. He also stated that shallow channels and turbidites may be common features on the suprafan. The similarities of features described by Walker with rocks in the thesis area (channels, thick beds of massive and disorganized pebbly calcarenites, turbidites, high sand/shale ratio) suggests deposition in a similar setting. Tecnocyrtina age deposits represent a relatively proximal sequence of sediment gravity flows that accumulated in a level(?)-bottom, basinal environment. The environment is envisioned as being more distal than deposits of the middle unit of the Denay, yet proximal with respect to the classical turbidite facies (mid- to lower fan and basin plain) of thin- and medium-bedded, well-bedded turbidites with well developed Bouma sequences and a low sand/shale ratio. The thin-bedded, graded packstones noted in section V may represent levee deposits, or small-scale turbidites. Low-amplitude, asymmetrical ripple marks on bedding plane surfaces indicate gentle bottom current activity (contour currents (?) of Bouma and Hollister, 1973).

The more distal fabric of allodapic beds in this portion of the unit, relative to the middle unit of the Denay, may indicate decreased basin-slope gradients, or basin shallowing, caused by western uplift associated with the incipient Antler orogeny.

Upper Part

The predominance of quiet-water suspension-deposition in the thesis area during Lower *asymmetricus* Zone to Lower *gigas* (?) Zone time is indicated by the abundance of yellow, calcareous, silty shales, with sparse allochthonous interbeds, present in the upper portion of the upper unit of the Denay. Rocks of this interval correlate with the Devils Gate Limestone, the Guilmette Formation, and the lower portion of the Pilot Shale (Sandberg and Poole, 1977). The Devils Gate Limestone, and its eastern equivalent, the Guilmette Formation, are overlain by, and in places laterally equivalent to, the deeper-water deposits of the Pilot Shale.

Poole (1974), Poole and others (1977), and Sandberg and Poole (1977) inferred that deposition of the Pilot Shale occurred in a slowly-subsiding, ihtrashelf basin beginning during *A. triangularis* Zone time. They noted that siltstones with interbedded turbidite and debris flow deposits, represent, in part, protoflysch sedimentation of clastic detritus shed eastward off of the rising Antler orogenic highland into the intrashelf, Pilot Shale basin. The depositional axis of this basin, where subsidence was greatest, is in eastern Nevada, western Utah, and east-central Idaho.

In section IV, the lowermost beds of this interval (early and middle *asymmetricus* Zone time) contain brachiopods, stromatopoids, thamnoporids, and alveolitids, derived from the drowning of or retreating, shoal-waters of the Devils Gate platform. The influx of terrigenous silt- and clay-size material probably represents wind-blown and current-transported detritus, derived from subaerially exposed areas to the west, that was deposited by suspension deposition in this quiet-water environment.

DEVONIAN SANDSTONE

Allochthonous sandy packstones and grainstones of the Devonian sandstone present in the upper portion of the upper unit of the Denay in the thesis area represent sediment gravity flow deposits that were shed eastward off the rising Antler orogenic highland into an intrashelf basin. This unit correlates with the basal part of the Pilot Shale and with the upper member of the Devils Gate Limestone at Devils Gate Pass.

Sandberg and Poole (1977) showed that the upper member of the Devils Gate Limestone conformably overlies the typical Devils Gate lithology of biohermal and biostromal limestone of the lower member. They indicated a gradual deepening of the Devils Gate platform beginning during late *P. asymmetricus* Zone time. The upper member of the Devils Gate consists of deep-water slope deposits, mainly debris flows and turbidites, that were shed eastward off the rising Antler orogenic belt into the intrashelf, protoflysch, Pilot Shale basin beginning during early *gigas* Zone time. The upper member of the Devils Gate is present only at Devils Gate Pass and is a lateral equivalent of the Pilot Shale.

Allochthonous sandy packstones and grainstones of the Devonian sandstone are interpreted as westerly derived because:

(1) the unit is equivalent to deposits of the upper Devils Gate Limestone and the basal portion of the Pilot Shale which have been

shown to be westerly derived (Sandberg and Poole, 1977);

(2) the relative position of the northern Antelope Range (west of the shallow-water Devils Gate platform) indicates that deposits of the Devonian sandstone would be more proximal to the Antler highland than previously recognized deposits of the Pilot Shale and the upper member of the Devils Gate, which overlie the typical shallow-water, platform-facies of the Devils Gate;

(3) in most of central Nevada, the paleoslope dipped to the east, as indicated by isopach maps which show that the depositional axis lay near the Utah-Nevada border during this period (Sandberg and Poole, 1977; Poole, 1974);

(4) inundation of the craton by Taghanic onlap caused an easterly shift of the strand line and largely removed an eastern source for the sand;

(5) the abundance of well-rounded quartz sand in these beds suggests derivation from a sedimentary source area; first cycle quartz sand probably could not attain this degree of rounding except by undergoing a period of eolian abrasion; the presence of medium-sand size quartz probably rules out wind transport as a depositional mechanism.

The lack of an abundant benthic biota in these beds, and the presence of well-sorted and well-rounded line clasts and quartz sand suggest a high-energy source. These deposits probably originated on high-energy banks and shoals on the eastern edge of the rising Antler highland. The environment was not favorable to a benthic biota, especially sessile filter-feeders, because of turbid water caused by suspended sand-, silt-, and clay-size terrigenous detritus, and a shifting substrate. Calcispheres and peloids were the dominant source of lime carbonate. Calcispheres are believed to be algal spores and are common in restricted environments (Scholle, 1978). As western uplift continued, this shoal water facies prograded basinward (east) and generated the numerous allochthonous sheets present in the Devonian sandstone in the thesis area. Progradation, or marine offlap, continued at least until Uppermost gigas Zone time.

UNDIFFERENTIATED MISSISSIPPIAN AND OLDER PALEOZOIC THRUST ROCKS

Deposition of the lower Pilot Shale and its eastern equivalents, the Guilmette Formation and the West Range Limestone, continued until middle Fammenian time when regional uplift concomitant with emplacement of the Roberts Mountains allochthon formed a major hiatus (middle Fammenian to earliest Mississippian time) between the lower and middle units of the Pilot Shale (Poole, 1974; Sandberg and Poole, 1977).

Rocks overlying the Devonian sandstone probably include the Pilot Shale, the Chainman Shale, the Diamond Peak Formation, and older Paleozoic thrust rocks although these rocks were not studied in detail because of their recessive weathering character and structural complexities. Actual outcrops are rare in these units.

Lower Mississippian conodonts including Gnathodus punctatus, indicative of faunal unit 2 of Lane (1974), as well as reworked Palmatolepsis spp. of Late Devonian age were collected in "Diamond Peak-like" rocks overlying the Devonian sandstone in the westernmost portion of the map area (Fig. 24). These rocks are medium gray to red brown (weathering), dark gray to brown gray (fresh), sandy and silty line wackestones and packstones with interbedded, graded, chert-pebble conglomerates. Poole (1974) noted that the Mississippian Diamond Peak Formation represents coarse flysch

Figure 24. Graded bed of Mississippian chert-pebble-conglomerate from "Diamond Peak like" lithology.

detritus derived from older Paleozoic rocks on the Antler orogenic highland. This detritus was shed eastward into the Antler foreland basin, a rapidly subsiding exogeosynclinal trough.

In the northern Antelope Range, continuing tectonism associated with Antler orogenic pulses caused renewed movement of the Roberts Mountains allochthon and caused it to override its own clastic debris during early (?) Mississippian time.

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