THE SEDIMENTOLOGICAL AND STRUCTURAL ANALYSIS OF
VININI AND VALMY FORMATIONS (ORDOVICIAN)
NORTH-CENTRAL NEVADA

by

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As with any work of this nature, the first acknowledgement must always be bestowed upon the wife of the author. I do this now with great sincerity. It was only through her great forebearance and inspiration this manuscript was completed. To my wife Sandra, I offer my greatest thanks.

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-ABSTRACT-

Detailed analysis of selected sections of the Vinini and Valmy Formations (Ordovician) in the Toquima and Toiyabe Ranges in North-Central Nevada indicates that the depositional characteristics of components of these formations are consistent with the model developed by by Horne and Ferm for sedimentation in deltaic environments.

The Vinini Formation in the Pete's Summit area (Toquima Range) is dominated by a coarsening upward sequence of interbedded shales, siltstones and minor amounts of chert near the base, overlain by thick-bedded to massive orthoquartzites. The lower part of the section consists of very thin- to thin-bedded dark grey to black shales and siltstones. Bedding is laterally continuous with sharp planar to wavy contacts with underlying and overlying strata. Primary structures in siltstones, including small-scale trough-cross-bedding, climbing ripples, and planar laminations, indicate episodes of rapid sedimentation in the generally low energy regime in which shale accumulated. The lower section also contains sandstones (typically 1.5 meters thick) that fine upwards and pinch out laterally over several meters; the bases of the sandstones are conglomeratic and sharply truncate the underlying beds.

The capping rock is a thick-bedded to massive, well-sorted orthoquartzite with a minimum thickness of 12 meters, displaying only poorly-preserved primary structures; bedding thickness decreases towards the top. The unit is a linear,

elongate body, 150 to 200 meters in length, often cut by trough-shaped surfaces.

The lower portion of the sequence is interpreted as representing bayfill deposits, with minor channel-filling sands, of a lower deltaic system. It is suggested that the upper orthoquartzite unit represents a period of transgression of barrier island environments following delta-lobe abandonment.

The Valmy Formation in the Big Creek area (35 kilometers west of Pete's Summit) is comprised of interbedded shales, siltstones and cherts. The units are thin- to thick-bedded and are laterally continuous. Ripple laminations, climbing ripples, current laminations and cross-bedding are dominant primary structures found in both siltstones and cherts. Small stringers of sand within the siltstones indicate sporadic influx of coarse detritus into a relatively quiescent environment.

The Valmy Formation is interpreted here to represent part of the seaward portion of the lower deltaic system.

The presence of marginal to shallow marine components of the Roberts Mountains Allochthon imposes significant restrictions on possible modes of origin and emplacement of this tectonic unit. It is interpreted here that this tectonic regime is one that includes an island arc/forearc basin developed near a subduction complex. The nature of this configuration enables the incorporation of a range of lithologies, including shallow water, deltaic environments described above.

CHAPTER I
INTRODUCTION

Recent investigations in North-Central Nevada have shown a clear record of discrete Paleozoic depositional and structural regimes. Detailed synthesis of these environments provides a framework from which a broader interpretation of the development of the Cordillera of the United States may be constructed.

The tectonic and broad sedimentological characteristics of Paleozoic strata have been described in the pioneering works of many authors (Gilluly, 1963; Kay and Crawford, 1964; Roberts, 1972) who have detailed several models. Within the framework of plate tectonic theory, fundamental concepts of plate motion on a broader scale have regional implications with respect to the development of North-Central Nevada.

The early Paleozoic development of the western continental margin of the United States has been described as being characterized by shallow water deposits that formed along a broad stable shelf along the western margin of the North American craton (Ross, 1977). The deposition of shallow water carbonates, mudstones, siltstones, sandstones, and conglomerates are characteristically miogeosynclinal in nature (Stewart and Suczek, 1977). A cratonic land area lay to the east of this area and a deep water ocean basin to the west. Abundant greenstones, chert and siltstones are characteristic to this latter environment and comprise the eugeosyncline (Stanley, Chamberlain, and Stewart, 1977) (fig. 1).

The Paleozoic distribution of major sedimentary rock types shows an east to west change from broad stable shelf sediments rapidly grading into deep water sediments along and beyond a continental slope. Shallow water carbonate rocks are nearly all limestone and are abundant in Silurian and younger Paleozoic sections. Faunal evidence indicates that these limestones can be identified as having been deposited in shallow marine conditions, occasionally in conjunction with reef development (Churkin and Eberlein, 1977) (fig. 2). In some areas, these carbonates directly overlay boulder beach conglomerates or vesicular lave breccia that may have broken up in a surf zone (Churkin and Eberlein, 1977).

The carbonate deposits are found over an enormous area covering southeastern Idaho, Utah, Nevada and southern California (fig. 2). Included in the overall carbonate deposition are areas in which such specific depositional regimes as patch reefs and stromatolites occur indicating, at least, an intertidal or shallow subtidal waters (Ross, 1977). Furthermore, the various types of carbonate sedimentation suggests that conditions changed intermittenly from supratidal to shallow subtidal over most of the area (Ross, 1977).

Terrigenous rocks composed of quartzite, siltstone and minor conglomerates are typically interbedded with units of fine- to medium-grained sandstone or orthoquartzite (Stewart and Suczek, 1977). Structures such as crossbeds, reactivation surfaces, current ripples, flaser and lenticular bedding found in these units are all imprints of shallow water deposition.

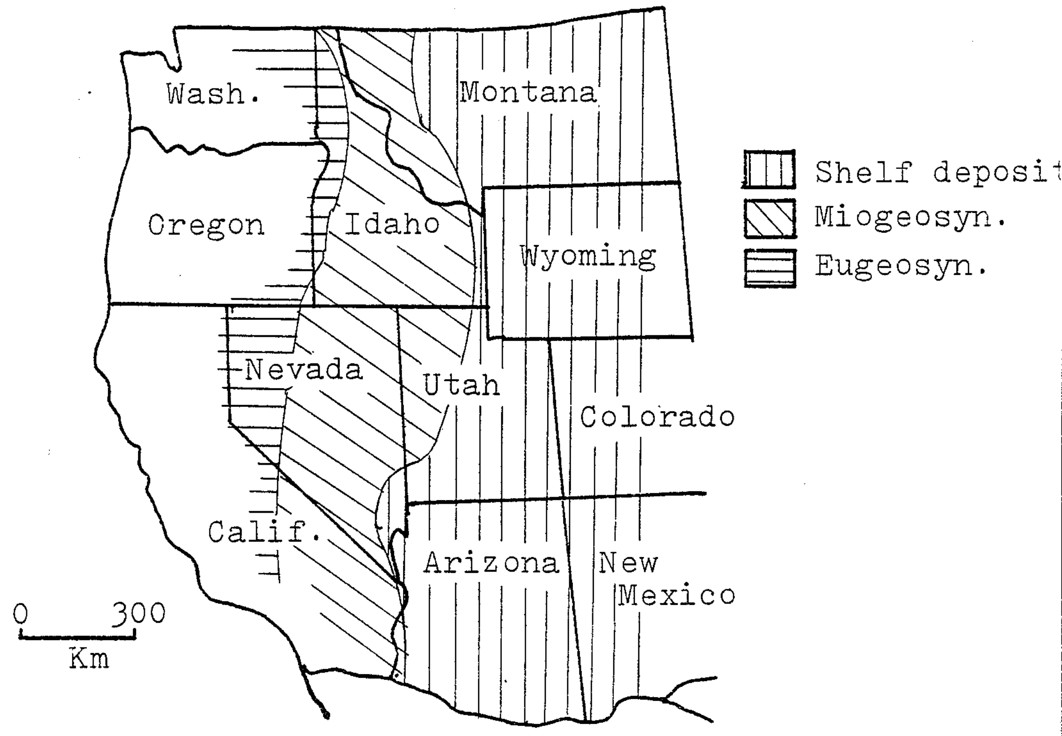


Figure 1. General pattern of shelf and synclinal rocks comprising the Cordillera of the west coast of the United States. After Gilluly, 1963.

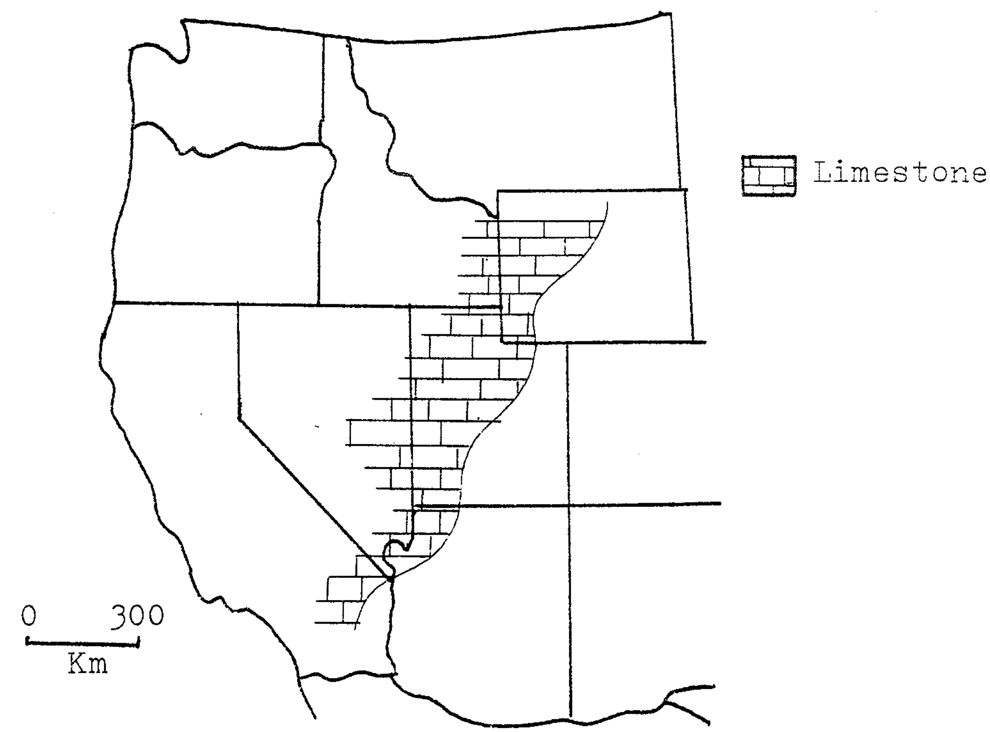


Figure 2. General pattern of carbonate deposits including patch reef development. After Ross, 1977.

Flow directions show multi-directional tendencies, likely indicators of tidal currents (Barnes and Klein, 1975).

Deep water turbidite and pelagic deposits generally west of the limestone terrain are mainly siltstone, mudstone and conglomeratic rocks, rich in volcanic debris (Stewart and Suczek, 1977). Interbedded with the siltstones are conglomerate and sedimentary breccias that contain boulders of granitic to gabbroic rocks, and rarely, blocks of limestone and very thinly bedded siltstone. Fine-grained siltstone deposits appear to represent either distal turbidite facies or interchannel deposits of deep sea fans (Churkin and Eberlein, 1977). Sedimentary structures are well-preserved and are characteristic of the Bouma cycle of turbidite deposition (Stanley _et al._, 1977). Interbedded with the turbidites are rhythmically bedded black cherts and siliceous shales with graptolitic partings that are interpreted to be pelagic deposits (Stanley _et al._, 1977).

Igneous activity is represented by volcanic rich sediments and blocks of volcaniclastics in conglomerates. Pillow lavas, structureless lava flows, basalts, and tuffs indicate a diverse volcanic regime and are widespread throughout the length of the Cordillera. Assemblages include welded tuffs, indicative of subaerial dispersion and lava flows, with both pillowed and vesicular textures, suggesting a deep water environment (Ross, 1958). Interbedded volcanic and sedimentary rocks throughout the Cordillera give evidence that magmatic evolution occurred as discrete cycles through time and geographic distribution (Churkin and Eberlein, 1977).

The rapid facies changes, recurrent and sporadic volcanic activity and high diversity of facies types implies a high tectonic mobility during the Paleozoic for the west coast of the United States. Throughout most of the late Precambrian to late Paleozoic this western margin was characterized by a broad Atlantic-type continental shelf on which accumulation of thick sediments developed along a generally eastern (shallow water) to western (deep water) trend. Transitional assemblages of interlayered deep and shallow water sediments mark the change along the continental slope.

The late Devonian marked the period in which the deeper water (eugeosynclinal) assemblages were thrust eastward across the continental margin and onto the shelf (miogeosynclinal) rocks. Thrusting has been attributed to the partial closure of a small ocean basin offshore of the continent and behind an island arc, the latter possibly developed over an east-dipping subduction zone (Burchfiel and Davis, 1972). This period of tectonic movement and thrusting has been designated as the Antler orogeny resulting in the emplacement of the eugeosynclinal Roberts Mountains Allochthon (Roberts, 1972).

Later Paleozoic thrusting again involved eastward translation of sedimentary rocks of an inner arc basin onto the continental margin during the Sonoma orogeny. Unlike the earlier deformational event, this thrusting resulted in the island arc welding to the continent causing a major westward shift of the continental margin (Burchfiel and Davis, 1972).

Within the framework of modern plate tectonic theory researchers have detailed a more complex development for the west coast of the United States. Stewart and Suczek (1977) have suggested that an Atlantic-type continental margin existed on the western margin throughout the upper Precambrian. This margin was later transformed into a rift zone, creating a system of rift valleys. The model purposes that the terrigenous detrital sequence is related to erosion of the initial rift bulge that was caused by thermal expansion during continental rifting. Later cessation and contraction of the bulge lowered the land area allowing transgression of a sea thereby becoming a quiescent site for carbonate deposition (Dickinson, 1977).

The basic configuration then is envisioned as a continental margin bordered by a marginal ocean basin and associated island arc (Dickinson, 1977). Emplacement of the allochthon of the Antler event can thus be described as underthrusting of the continental edge beneath oceanic rocks, emplacing oceanic (eugeosynclinal) strata over shelf (miogeosynclinal) strata (fig. 3).

The wide range of terrains bordering the North American craton has led others to develop a model in which widely differing structural and sedimentological regimes are interpreted to represent a mosaic of microplates (Churkin and Eberlein, 1977). The recognition of ophiolites, suture zones, complex fault zones, igneous activity and widely

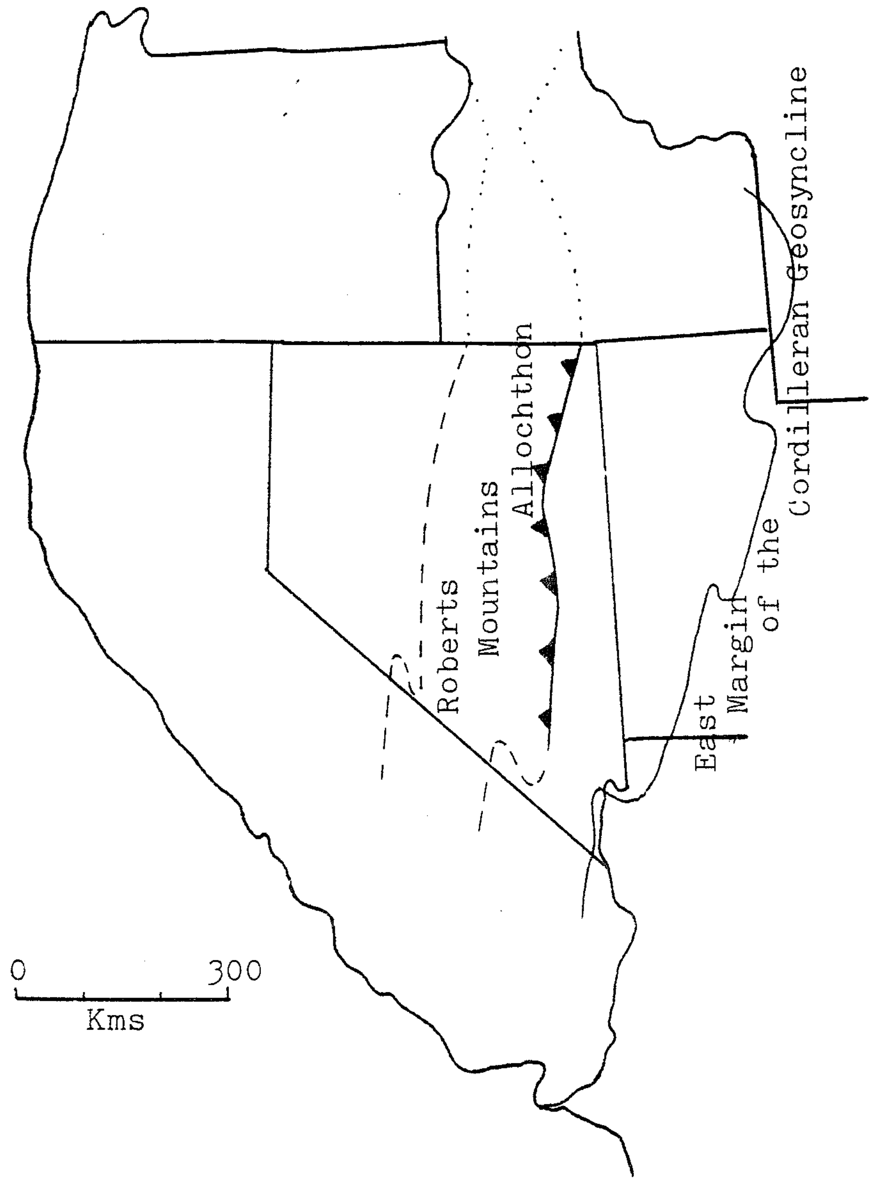


Figure 3. Extent of overthrusting of oceanic sediments over shelf deposits. After Burchfiel and Davis, 1972.

differing sedimentological regimes has suggested that the borderlands vary both in age and type. That is, it represents a more diversified and complex history than previously envisioned.

The summary of differences in these terrains can be shown to follow significantly different paths in their early geological development. Churkin and Eberlein (1977) suggest that these differences can be best interpreted as a series of at least six microplates rather than a single lithospheric plate.

The Antler orogeny may thus be interpreted as the closing of a marginal basin by collision with its frontal arc. Deep sea pelagic deposits and slices of underlying ophiolite from the consumed oceanic lithosphere may have been uplifted into a subduction complex by imbricate underthrusting along a west-dipping subduction zone. Gravity sliding may also have operated in assisting eastward emplacement of oceanic facies onto the shelf.

Precise reconstruction of the ancient borderlands of the west coast of the United States requires a clear understanding of subsequent events following the Antler orogeny. Many authors have suggested at least two major tectonic events that have left a stamp of their specific structural development (Gilluly, 1963; Dickinson, 1977). The Devonian Antler event has, therefore, been overprinted by later deformational events.

The characteristics of a highly mobile tectonic regime both on the grand scale and in limited view requires a complex interaction of diverse structural and depositional systems. Tectonic overprinting, volcanic intrusion and other geologic processes have stamped their own unique imprint in North-Central Nevada. This problem not only lends itself to uncertain correlations within the immediate area but also to surrounding terrains. Masking by granitic intrusions of the Sierra Nevada Mountains in California and the Idaho batholith and flood basalts prohibits concise correlation between the areas.

Certain constraints can be placed on any reconstruction by examining the environment of deposition and source types of the sediments involved in the Antler orogeny. Understanding the mechanism of emplacement of the allochthon can be further enhanced by the examination of the deformational style. The problem is recognizing and accurately identifying discrete structural and depositional regimes on a local scale and developing a conceptual framework in which these environments may logically fit. Building upon the foundation of previous investigation and the development of a suitable model for reference in terms of modern plate theory permits the reconstruction of the history of the west coast of the United States prior to the Antler orogeny for North-Central Nevada.

OBJECTIVES

The purpose of this study is to examine some hitherto undescribed characteristics of the western (eugeosynclinal) facies, a primarily siliceous assemblage, in North-Central Nevada. The detrital sequences range from shale to conglomerate, with bedded chert, greenstone and carbonate as additional components (Ketner, 1977). Derivation of these clastics has been widely discussed and a number of opposing models have been developed.

Ketner (1977) suggests a northwestern source for the siliclastics that were shed eastward from an uplifted mass, traversing contemporaneous eastern carbonate deposition, depositing these sediments across a basin of unknown dimensions. The uplifted area initiated gravity sliding of small plates eastward onto the retreating carbonate depositional trough. The process involves a slow advance in which eastward-shed clastic material was incorporated into the advancing plate(s) or overridden by a gravity-spalled front.

Others have suggested an eastern source for the siliclastics that were shed from the cratonic platform westward across a shallow continental shelf environment (Poole, Sandberg and Boucout, 1977; Ross, 1977). Widespread tectonic fluctuations were responsible for the variability of depositional regimes in northern Nevada. Crustal movements previously discussed initiated subduction and thrusting of western assemblages eastward onto the autochthonous eastern shelf deposits during the late Devonian Antler Orogeny.

The eastward displacement of the Roberts Mountains Allochthon was of the order of 80 to 100 kilometers. The allochthon has been characterized as a complex system of tectonically interleaved series of imbricate slices (Stanley *et al.*, 1977). The expression of the Antler orogeny is evident in North-Central Nevada in which western assemblages are telescoped together and thrust over eastern assemblages. The complexity of these units is not well understood on the larger scale and few attempts have been made to distinguish and examine the individual components preserved in distinct thrust wedges.

The area under investigation represents a segment of the much larger Roberts Mountains Allochthon. Detailed investigation by the author of limited areas has concentrated on a study of little-deformed assemblages. Within individual thrust wedges relatively undeformed successions have been shown to represent a range of lithological and depositional regimes.

Detailed sedimentological analysis of some of these components indicate a regional relationship compatible with models that accomodate an island arc/marginal basin terrain system. This existed during the lower Paleozoic, west of the North American continental margin, and acted as a source for siliclastics. The nature of the terrain offers a range of lithofacies that may have been incorporated into an active subduction complex.

These include:

1) pelagic sediments, cherts, mafic volcanics;
2) turbidites, fan and channel sediments;
3) transitional continental slope assemblages;
4) shallow marine clastics and carbonates;

Within an active subduction complex, stacking, upward movement and rotation of imbricate slices results in a complex intercalation of contrasting facies types (Moore and Karig, 1976; Schull, Christiansen, Von Huene, and Marlow, 1970). The ongoing subduction complex in itself produces a highly variable sedimentological and structural regime. Relatively emergent land areas in association with deep basinal deposition contribute to the development of a wide range of facies types. The recognition of these lithofacies within the Roberts Mountains Allochthon provides a framework to reconstruct parts of the tectonic evolution.

This study has investigated two formations of the Roberts Mountains Allochthon, the Vinini and Valmy Formations located in the Toquima and Toiyabe Mountains, respectively. They outcrop extensively in North-Central Nevada within 50 kilometers of Austin (fig. 4), and relatively undeformed sequences can be located within individual thrust wedges. It should be noted, as will be discussed in more detail below, that the formational definitions within the allochthon are not always viable.

The study undertakes a sedimentological and structural analysis of a number of sequences and addresses the nature of their specific depositional and deformational regimes.

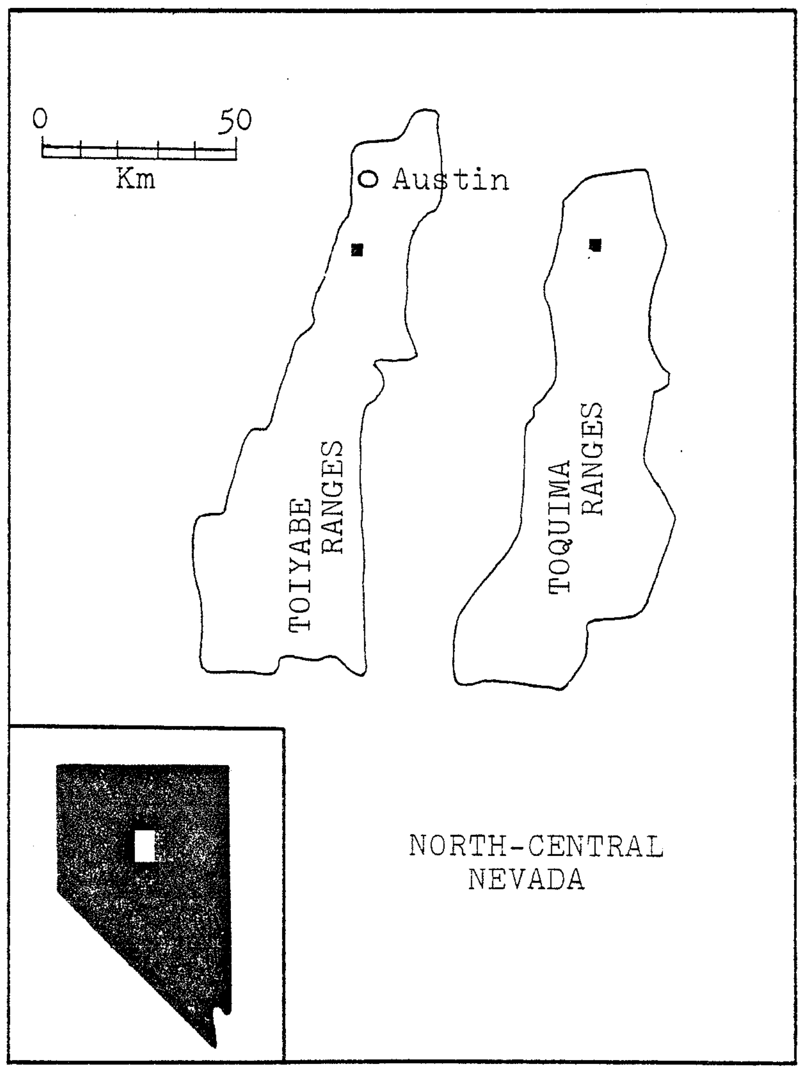


Figure 4. Location map of measured sections in the field area in North-Central Nevada

Their relation to the overall sedimentological and tectonic evolution is less well-understood. This paper will attempt to define the limits of the structural events, lithological type and depositional regime, and present a framework in which tectonic reconstruction may be approached.

The study forms part of an ongoing series of projects by the faculty and students of Wayne State University, Department of Geology, Detroit, Michigan, under the direction of Dr. Michael J. P. Welland and Dr. Joseph P. Makurath and represents only a part of the research in North-Central Nevada.

CHAPTER II

Location of Study Area and Methods

Sections of the Valmy and Vinini Formations were examined for this study. The Valmy Formation (Ordovician) extensively outcrops throughout northern Nevada, but well-exposed sections in the North Fork of the Big Creek Canyon of the Toiyabe Mountains (Plate I) were selected for detailed analysis. The North Fork is 15 kilometers south of Austin, the principal municipality of the area (fig. 4). A total of over 100 outcrops were examined.

The Toiyabe Range is a prominent example of a basin and range fault block. The North Fork is set back 3 kilometers into the range but shows the pervasive effect of the high-angle faulting. The canyon itself is rugged and shows a relief of 1000 meters (Plate II). Systematic field examination involved sampling, photography, and description of lithology, bed thickness, lateral continuity, primary structures, etc. Composite sections, allowing for structural complexities, were constructed from these data. Laboratory petrographic examination of a total of 98 representative thin sections were conducted later.

The same approach was applied to outcrops of the Vinini Formation in the Toquima Mountains 35 kilometers east of Austin (fig. 4). The Toquimas are much like the Toiyabe Mountains with respect to relief and topography (Plate III). The area investigated is near Pete's Summit located 5

PLATE I

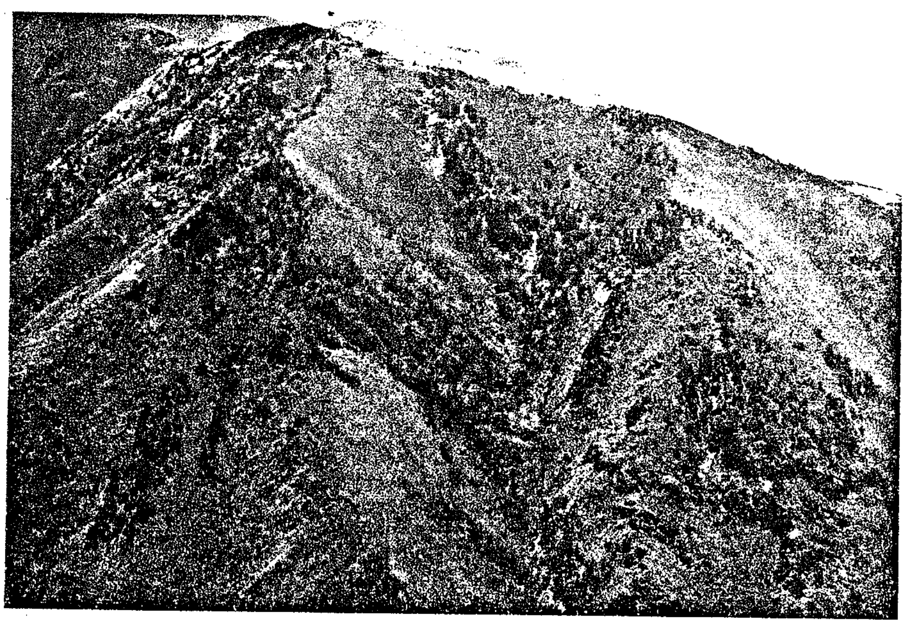


PLATE II

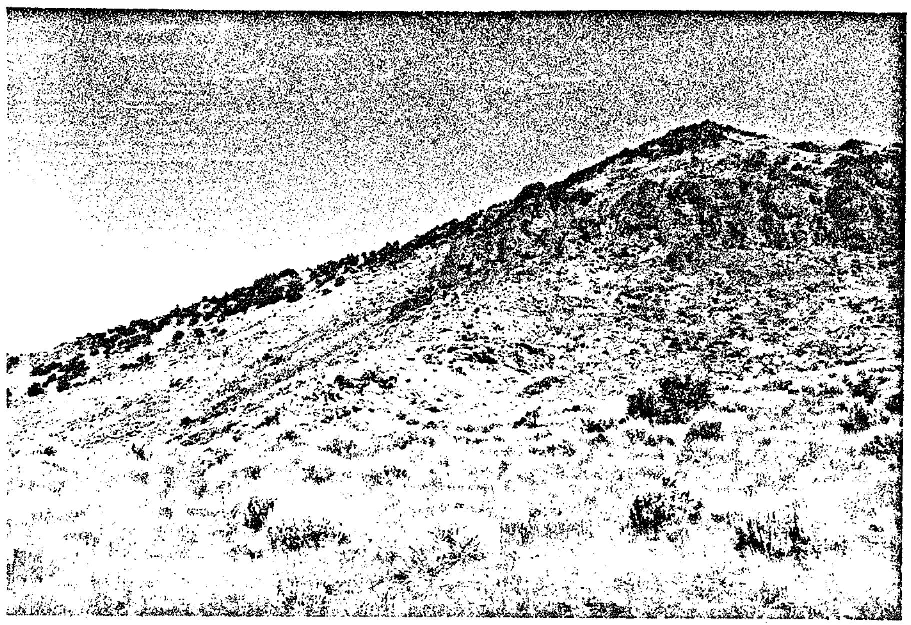


PLATE III

kilometers eastward of the western margin of the mountains. The Vinini Formation tends to show greater variation in quality of exposure than the Valmy Formation. The Vinini section measured was less complete than the Valmy as a result of covered intervals but critical primary relationships were preserved in over 60 outcrops and at least the minimum stratigraphic thickness was measured.

Deformation within the Vinini was intense in places, particularly near what is interpreted by the author to be a thrust contact. In spite of these difficulties, stratigraphic measurements were made with certainty where the structural complexities were resolved.

In both study areas access to the surrounding canyons was excellent and other sections of the Vinini and Valmy Formations were examined, although in less detail; locations of other areas examined are shown in figure 5. Although tectonic complexity was generally more profound outside the primary areas of investigation, variations in the sections could be examined. For example, a prominent marker bed of orthoquartzite in the Vinini Formation defined a more or less continuous exposure of the complete stratigraphic sequence.

This study was undertaken in a five week period during the summer field season of 1977, and included field examination of other project areas in related units of the allochthon. The opportunity to examine other areas of study provided a perspective on lateral variations in the Vinini,

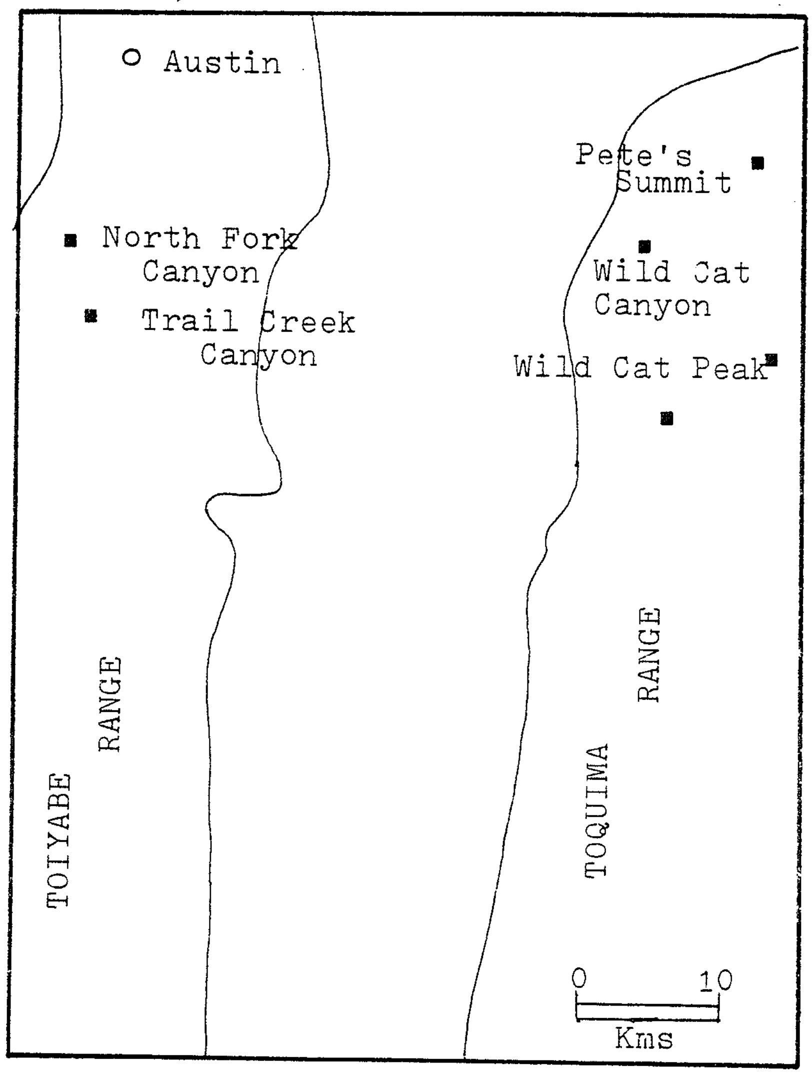


Figure 5. Location map of reconnaisance geology field area.

Valmy, and associated formations, and confirmed the existence of a critical problem that this project had not originally identified at the outset. Examination of the outcrop pattern over a large area has shown that the designation and differentiation of the Vinini and Valmy (and other allochthonous) formations can be questioned. That is, the identification of the formational boundaries between the Vinini and Valmy are vague and not specifically identifiable. Because of this relationship, the recognition of formations and their boundaries will be explored in the following section.

The Formational Problem

The study of any specific rock unit requires that limits be established such that each unit may be defined on the basis of visible objective criteria. Rock units that are the product of particular depositional evnironments or an alternation of related depositional units are called Formations. A formation is a mappable unit that has been defined to represent a distinct physical lithology with recognizable physical boundaries. The boundaries of these rock units may or may not coincide with time boundaries and often transgress them as they are traced laterally.

The concept of "formation" is further enhanced when areal separation exists between different lithological units. The first impulse is to restrict the units to individual and distinctive formational boundaries. When no evidence suggests that they may be in any way linked either through time or depositional continuity, the formational distinction is a natural consequence.

Strict adherence to the definition of "formation" requires that for two formations to be equivalent they must be shown to be within the bounds of the same depositional system and that they are contemporaneous. The "new" approach in looking at sedimentary sequences utilizes the concept of "vertical packaging". That is, the stacking of lithological units one upon another represents a sequence of events transgressing both time and changing depositional environments. The ability to recognize these changes in environment results in the delineation of formational boundaries.

The problem is then recognizing where a depositional boundary exists that defines a distinctive formation. Confusion arises where the formational restrictions are drawn when facies types are interpreted to represent different depositional environments. Within different formations, many distinct facies exist both in vertical succession and lateral relationships.

Three dimensional studies have disclosed that the vertical organization of lithologies and structures constitutes the best guide to paleo-environments. Reliance solely upon the interpretation of individual facies, with their assortment of textures and structures, limits an interpretation of the total environment. The pattern of sub-environments and their interactions represents a sequence of events both within the <u>same</u> depositional environment and in the same time period. The ability to recognize these interactions and subsequent facies types enables the reconstruction of the total depositional regime, possibly indicating a single environment and formation.

Where faunal evidence is abundant in biostratigraphic units, correlation between separate rock units is simplified if parallel suites are in common. Where this evidence is sparse or non-existent, correlations are impossible. Therefore, other criteria must be utilized to determine and identify the depositional regime. With respect to the Vinini and Valmy Formations, each have been designated to be Ordovician in age, based upon the faunal evidence. Recent faunal data (radiolaria) have shown that "Ordovician Valmy" is not strictly defined. Rather, some faunal species have been identified to the Devonian in age (Jones and Wrucke, 1978).

In areas of high tectonic mobility, as that envisioned for North-Central Nevada, the problem of recognizing formational boundaries is compounded by faulting. A recognizable fault does not in any way define a formational boundary within the allochthon. Such tectonic contacts may or may well not correspond to formational boundaries.

Until more detailed work is completed, the allochthon should be described in terms of component facies and the lateral and vertical relationships between them. That is, recognizing individual facies and defining their environment enables the reconstruction of the total regime through the pattern of interactions between them. Hence the method utilized here is the vertical profile approach to environmental reconstruction. Formal stratigraphic designations are of less importance, and where compelling evidence warrants it, are minimized.

CHAPTER III

Lithologies of the Vinini and Valmy Fms.

The Vinini Formation at the Pete's Summit Area of the Toquima Mountains comprises a complex intercalation of siltstone, chert, sandy limestone, minor amounts of nodular limestone, and quartz sandstone. The stratigraphy can be divided into four district lithological associations:

1) rhythmically bedded shale, siltstone and minor cherts;
2) irregularly bedded shale, siltstone and limestone nodules and quartz siltstone;
3) regular interbeds of shale and siltstone;
4) massively-bedded quartz sandstone.

Depositional structures are well-preserved in most beds and include small-scale trough cross-stratification, climbing ripples, wavy and planar horizontal laminations. The top and bottom contacts of beds are in sharp juxtaposition with adjacent beds and tend to be laterally continuous with variable bedding thicknesses. Other units are in continuous gradational contact with upper beds. Some sandstone units show sharp contacts and a laterally uniform decline in thickness transversely across outcrop. Other sandstone units contain marked gradation of grain size upwards within a single bed.

The stratigraphic sequence of Lower Paleozoic rocks of this area is uncertain due to complex faulting, minor faulting, and poor exposure. Where relatively undisturbed exposures occur (up to 300 meters) sedimentological evidence indicates a repetition of stratigraphic units. In the absence of structural evidence indicating tectonic repetition, these units appear to be rhythmically bedded in the vertical sequence.

The Valmy Formation at the North Fork Canyon in the Toquima Mountains is a succession of rhythmically bedded sequences of shale, siltstone, chert, and minor amounts of quartz sandstone. Internal structures include horizontal and wavy laminations, some climbing ripples, some crossbeds (planar), and banding in chert. Bedding is planar, uniformly thick, and laterally continuous along outcrop. All contacts between adjacent units are sharp for the most part, with some gradational contacts between shale-siltstone interbeds.

Deformation is less intense in the Valmy Formation, permitting measurement of a relatively undisturbed succession of rock units. Evidence discussed below suggests that the Valmy Formation, like the Vinini Formation, is a series of discrete lithological packages, vertically stacked in a recognizable rhythmic succession.

Environmental interpretations require a clear understanding of sediment type and depositional style. Recognition of these parameters provides a framework from which distinctive sedimentological regimes (lithofacies) may be defined. A sedimentological history can therefore be based not only upon physical parameters (texture, mineralogy, and sedimentary structures), but also, and more importantly, by the vertical profile and geometry of the sedimentary bodies. Clearly then, there are two problems; one deals with the immediate local environments responsible for a particular bed; the other with the larger assemblage of strata and the nature and tectonics of the overall regime in which this assemblage has accumulated. The task then is to reconstruct the depositional environment through the analysis of stratigraphic section, recognizing patterns of deposition and fitting these parameters into a viable depositional model. Therefore the analysis of specific components on the basis of physically recognizable criteria is necessary to outline the proposed depositional environment.

The following section analyzes individual components of both the Vinini and Valmy Formations. Attention is given to both microscopic data collected through thin sections, polished slabs, field notes and photographs. Environmental discussions follow this section, suggesting possible depositional environments based upon the evidence presented.

SANDSTONES

Vinini Formation

The sandstones of the Vinini Formation are of three types:

1) extremely "clean" orthoquartzites, i.e., quartz arenites;
2) "dirty" sandstones, i.e., sublithic arenites;
3) sandstones with calcareous cement.

The latter two types are found throughout the stratigraphic sequence but are particularly dominant near the bottom and lower middle section (see fig. 6). They are discrete horizons with sharp planar upper and lower contacts. They are commonly found in association with interbedded siltstone and shale but are sometimes absent from this package.

The most resistant unit (fig. 6) of the Vinini Formation found in the lower section of the sequence is comprised mainly of dirty sandstone and sandstone with calcareous cement. It has a lens-shaped geometry in outcrop and pinches out laterally in at least two directions. It occurs in variable sizes; the larger reaches lateral extents varies from a maximum of 10 meters to others less than 1 meter (Plate IV). It attains a maximum thickness of 2 meters at the center, pinching out across the outcrop. This and other similar units are found in association with interbedded siltstone and shale, truncating these beds with very sharp contacts. Limestone nodules occur along the flanks of these

Figure 6. Stratigraphic column of the Vinini Formation, Toquima Ranges, Nevada.

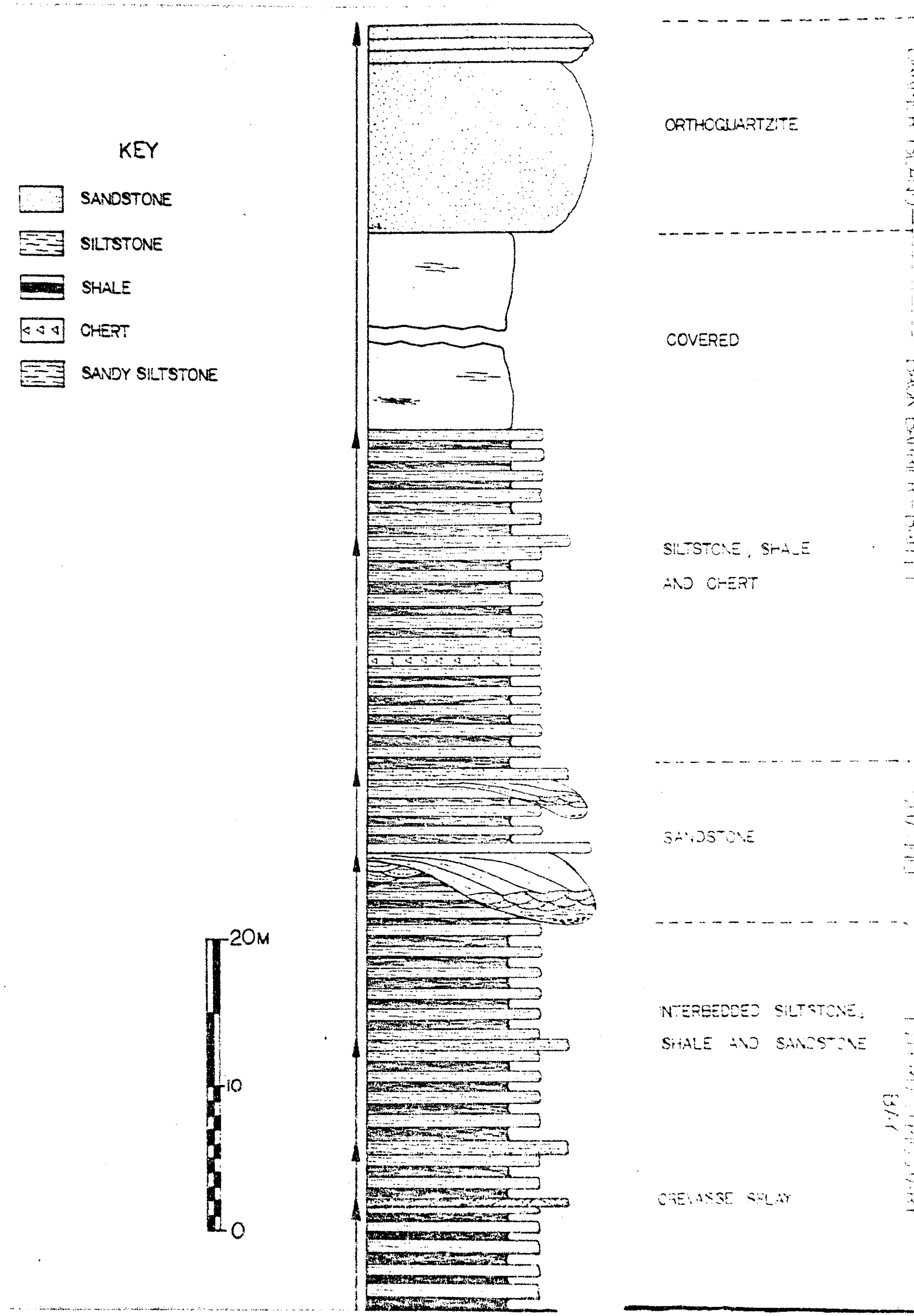

KEY
SANDSTONE
SILTSTONE
SHALE
CHERT
SANDY SILTSTONE
20M
10
0
ORTHOQUARTZITE
COVERED
SILTSTONE, SHALE
AND CHERT
SANDSTONE
INTERBEDDED SILTSTONE,
SHALE AND SANDSTONE
CREVASSE SPLAY
BARRIER ISLAND
BAY

Fig. 6

PLATE IV

PLATE V

lenses and appear to conform with internal structures traced from the surrounding sandstone (Plate V).

Typically, at the base of the central portion of a lens-shaped sandstone body a horizon of coarse, poorly-sorted, conglomerate (lithic arenite) occurs that grades upwards into a finer-grained sandstone. Fining-upwards takes place over a thickness of 5 to 15 centimeters but is more pronounced near the bottom.

Internal structures found in this unit vary from straight laminations to small-scale trough cross beds (Plate VI). Beginning at the base of this unit, current laminations grade upwards into wavy laminations (Plate VII) to straight laminations (Plate VIII) and finally into no discernible laminations. Along the flanks of this unit, cross bedding dominates the internal structures locally grading into wavy laminations and straight laminations downward to the bottom and ends of the unit (Plate IX).

The orthoquartzites occur only at the top of the stratigraphic column and cap the complete stratigraphic section of the Vinini Formation (fig. 6). They form a prominent ridge along at least 500 to 1000 meters in length in this area (Plate X). The entire ridge is cut by trough-shaped depressions. The base of the orthoquartzite unit is massively bedded (Plate XI), but at the top bedding becomes more obvious in outcrop (Plate XII).

Valmy Formation

Sandstones found in the Valmy Formation at North Fork

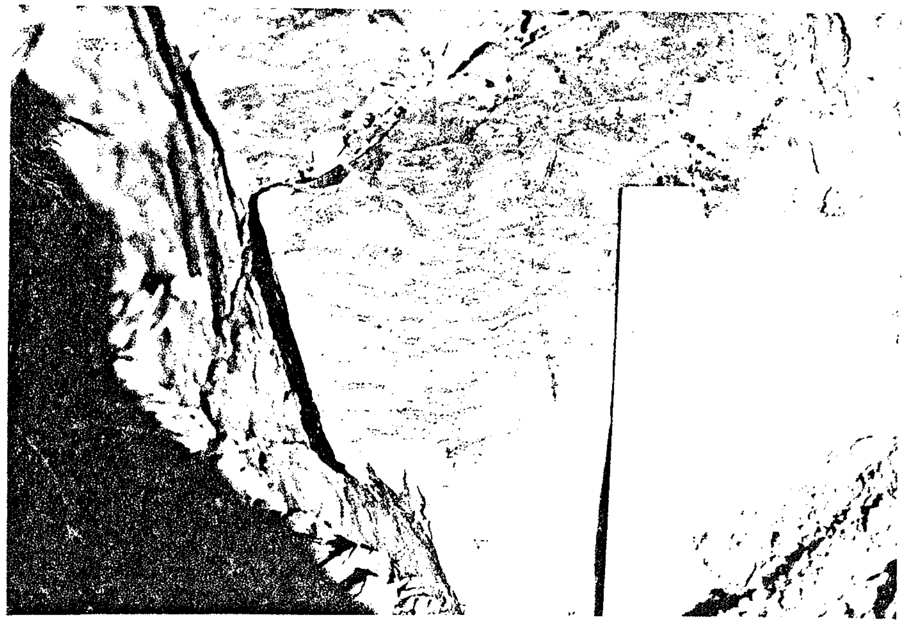


PLATE VI

PLATE VII

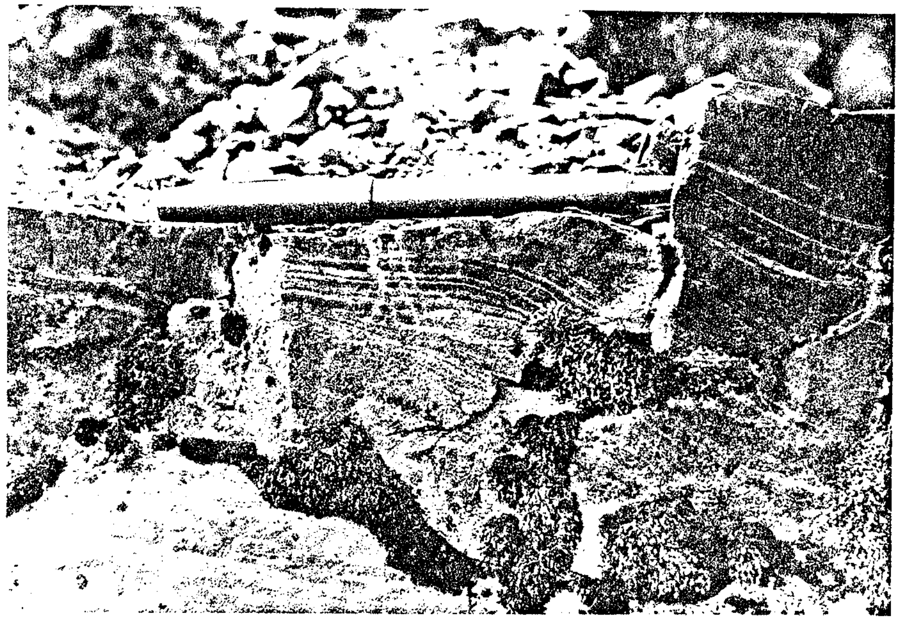


PLATE VIII

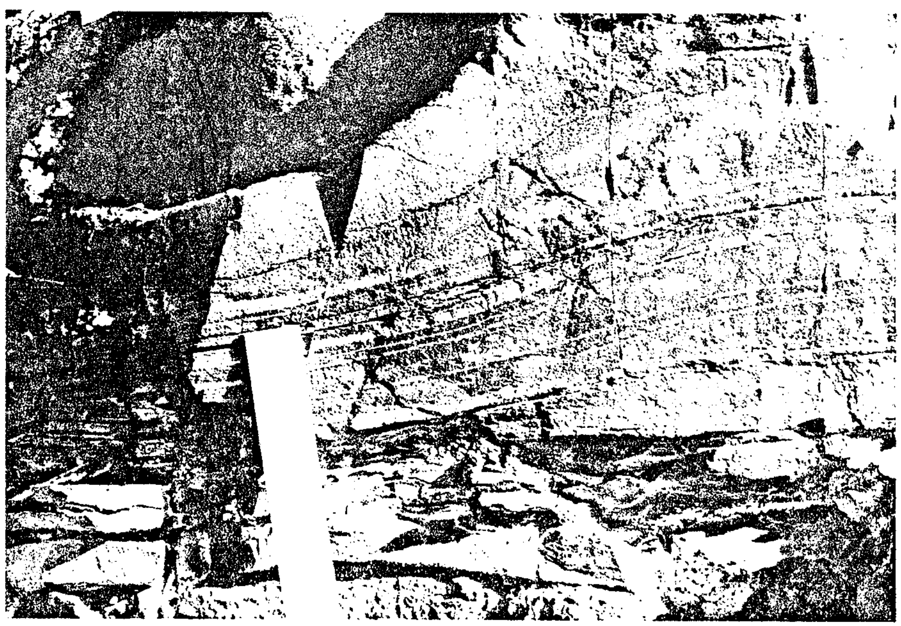


PLATE IX

PLATE X

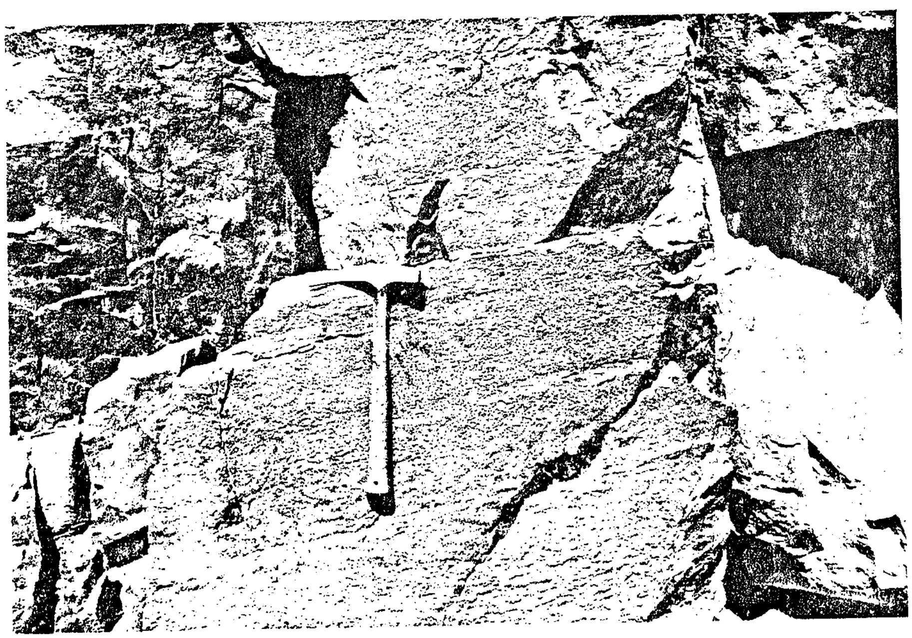


PLATE XI

PLATE XII

Canyon appear to be relatively sparse and show little variability throughout the stratigraphic sequence. In some outcrops the sandstones are found as coarse stringers in a siltstone interbed (Plate XIII). Other units are recognized as sandstone beds but have a high degree of silt as matrix material. Where appropriate, these have been designated as "sandy-siltstone" or "silty-sandstone" according to their petrographic character.

Within this stratigraphic sequence (fig. 7), deformation has had a profound affect on alteration, dissolution, and recrystallization within sandstone beds. Evidence that will be presented later suggests that these sandstones have been altered to chert. The abundance of chert in the stratigraphic section places obvious restrictions upon the interpretation of the depositional regime and therefore has been the subject of close examination (see below).

The sandstones of the Valmy Formation thus fall into three categories:

1) sandstone with calcareous cement;
2) silty sandstone;
3) altered sandstone.

These have been found to be generally thinner and more continuous than those found in the Vinini Formation. Bedding is planar with sharp contacts across outcrop (Plate XIV). Internal structures are primarily wavy and straight laminations (Plates XV and XVI). Organization of internal structures show dominantly straight laminations near the base of

Figure 7. Stratigraphic column of the Valmy Formation, Toiyabe Ranges, Nevada.

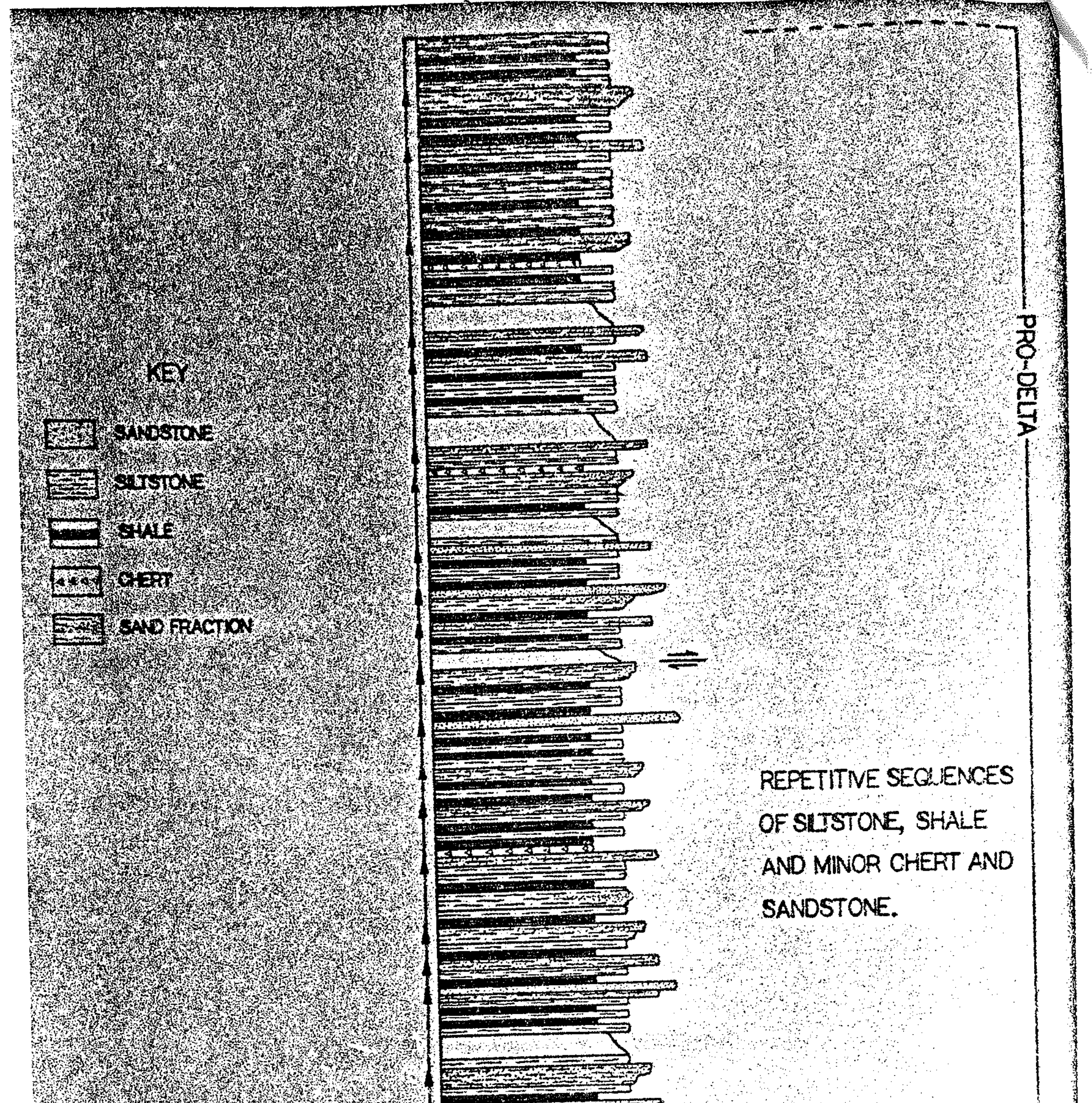

KEY
SANDSTONE
SILTSTONE
SHALE
CHERT
SAND FRACTION
40M
20
0
REPETITIVE SEQUENCES OF SILTSTONE, SHALE AND MINOR CHERT AND SANDSTONE.
PRO-DELTA
PRO-DELTA

Fig. 7

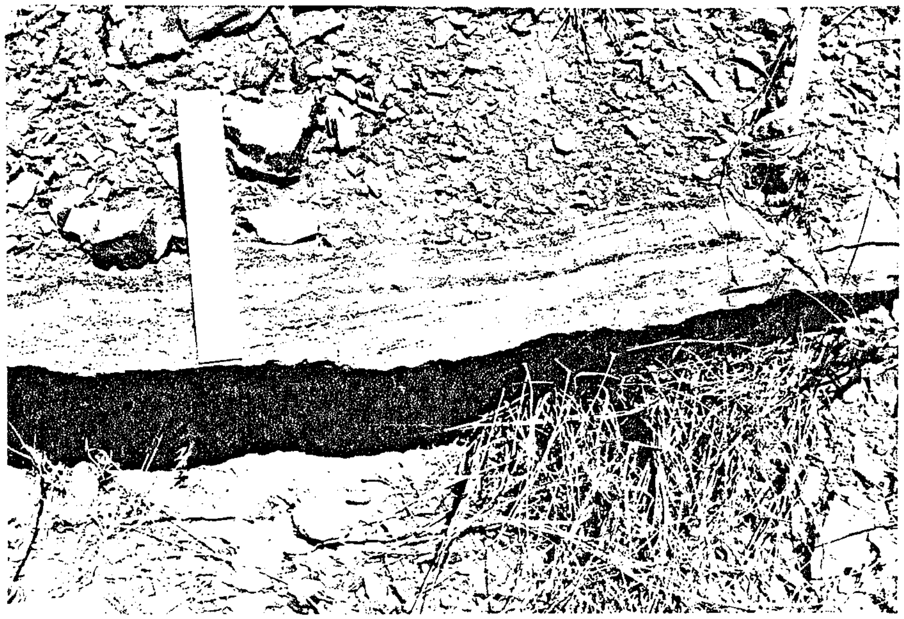


PLATE XIII

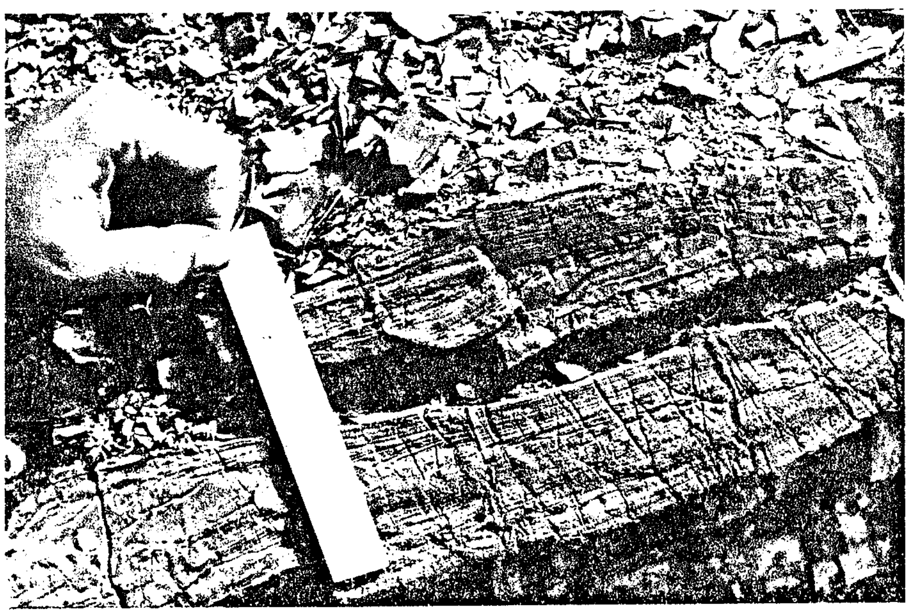


PLATE XIV

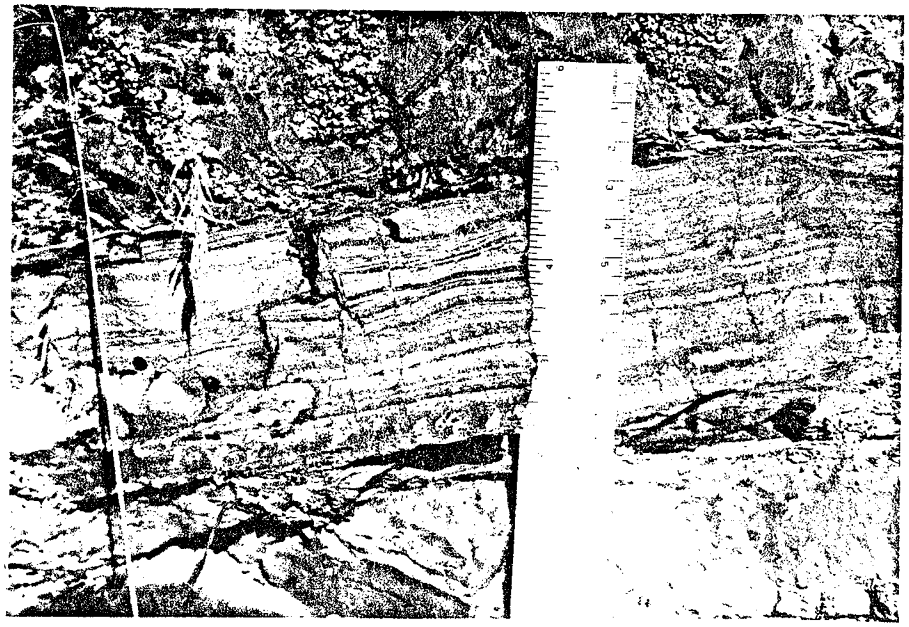


PLATE XV

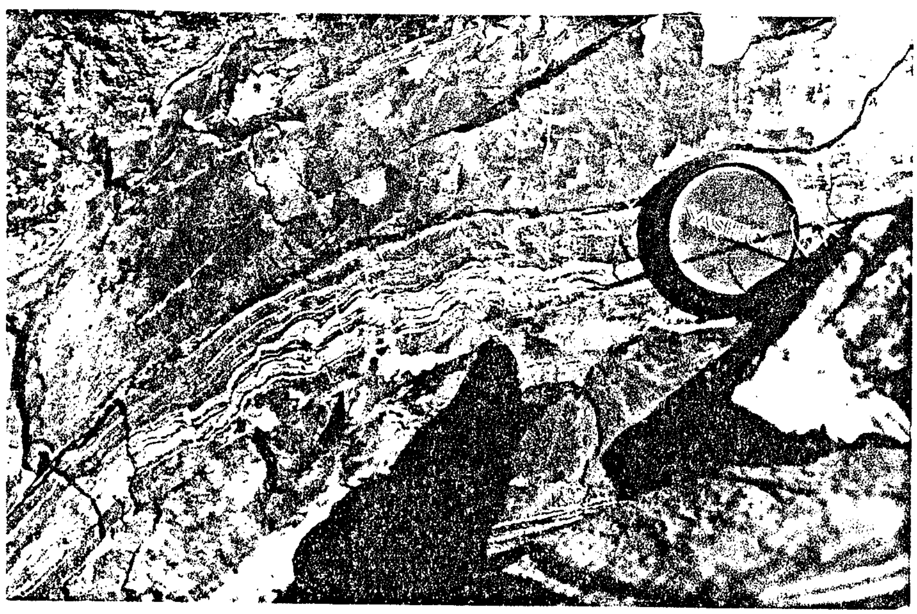


PLATE XVI

the bed grading upward into wavy laminations near and at the top of the same bed (Plate XVII). Other units contain cross-stratification and cross-bedding and ripple laminations (Plates XVIII, XIX and XX).

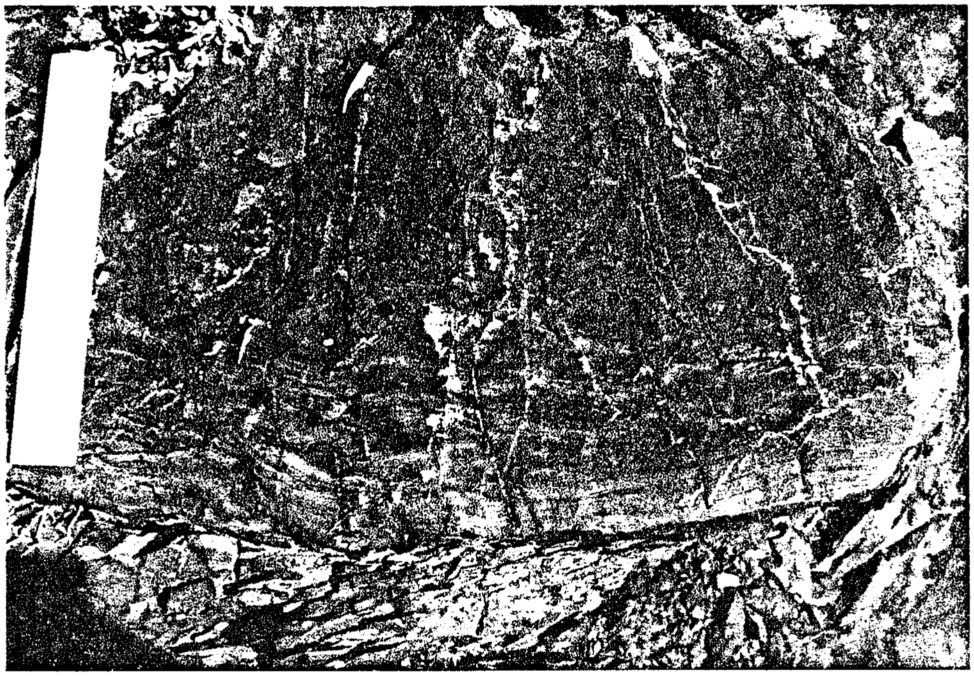


PLATE XVII

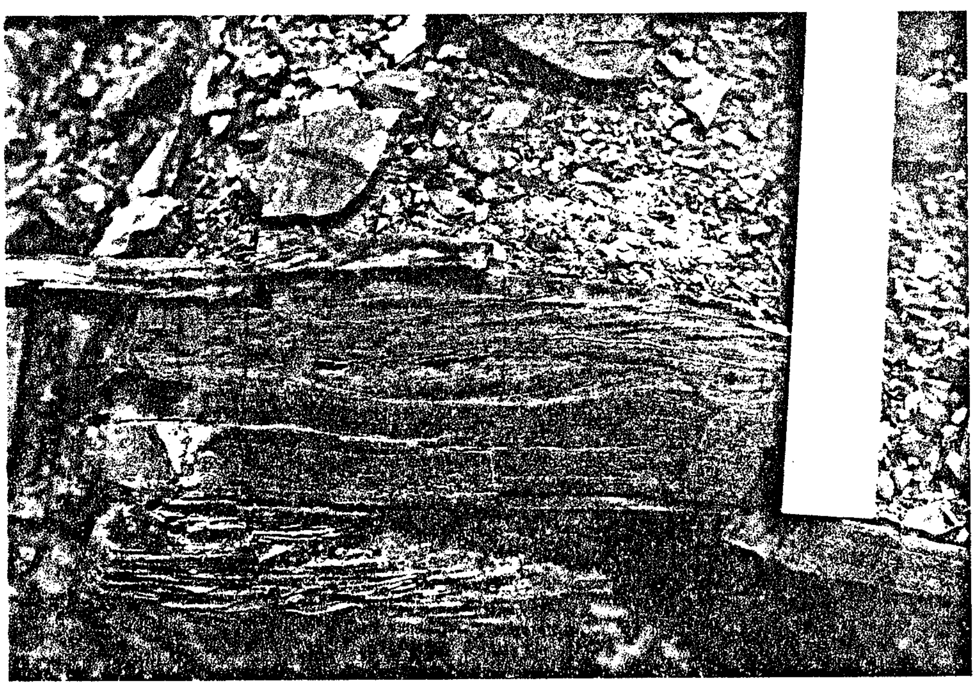


PLATE XVIII

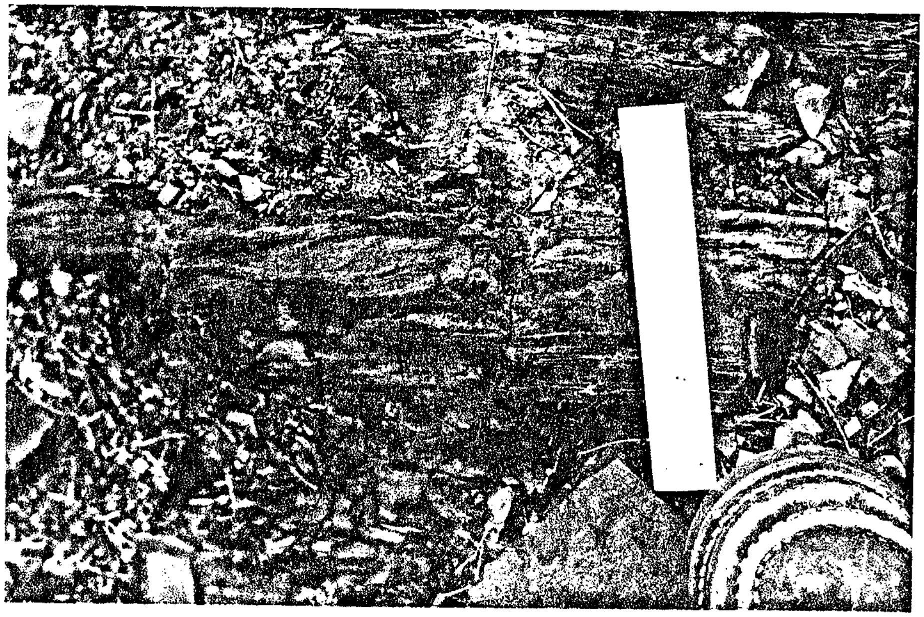


PLATE XIX

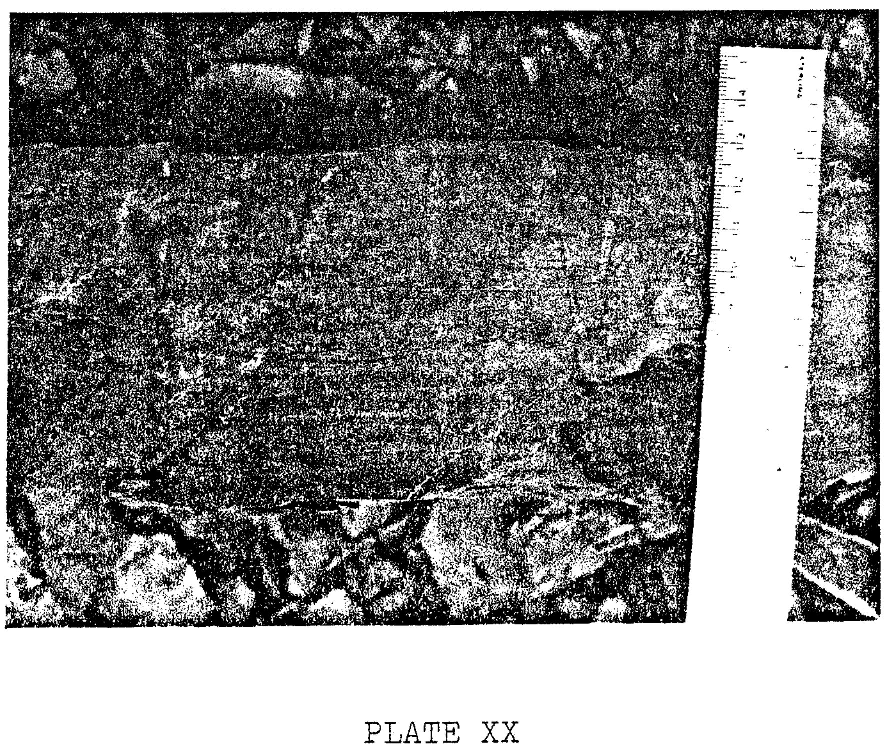


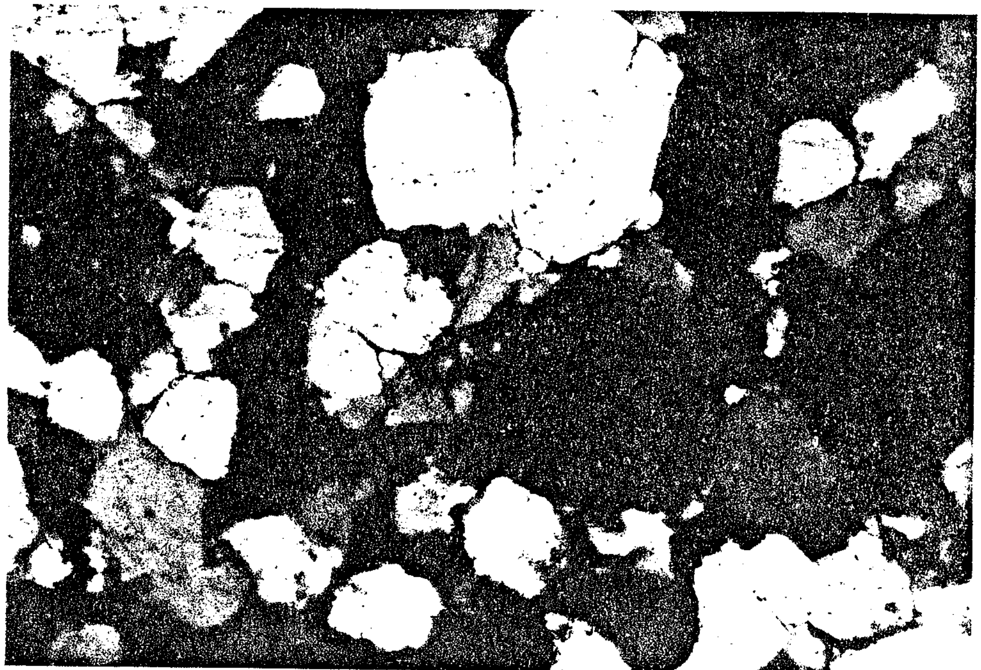
PLATE XX

PETROGRAPHIC ANALYSIS

Vinni Formation sections of the Vinini Formation sandstones show little variability in the lowermost stratigraphic units. Most fall into the fine to medium sand-sized category (0.5 mm to 0.1 mm). Where dissolution by calcite is not intense, mono-crystalline quartz grains are well-rounded in some units, and less well-rounded (Plate XXI) in others. Quartz grain boundaries are irregular and show intense corrosion and embayments by calcite (Plate XXII) or are in pressure and suture contact with adjacent grains (Plate XXIII). Sorting is poor to good depending upon the unit analyzed. Generally, well-sorted members are found in the orthoquartzite unit and those that grade upward into fine sandstone beds. Poorly-sorted members are found in those beds that are a part of a lithological package that includes shale and siltstone.

The conglomeratic sandstone (lithic arenite) found at the base of the lens-shaped unit previously mentioned is made up of fragments and grains of chert, mudstone, well-rounded and angular quartz grains and siltstone fragments in a matrix of mud and silt (Plate XXIV). Grain size varies in the fragments from fine to coarse sand-sized particles (0.5mm to 0.1 mm). There is a crude orientation of grain parallel to the bedding surface, possibly indicating flow or deposition by bottom currents. Gradation in grain size occurs upward from this unit into a fine sand (Plate XXV) to siltstone (Plate XXVI) at the top.

The predominant cementing agent in the sandstone of this



PS 2

0 mm .5

PLATE XXI

NFS 19

0 mm .5

PLATE XXII

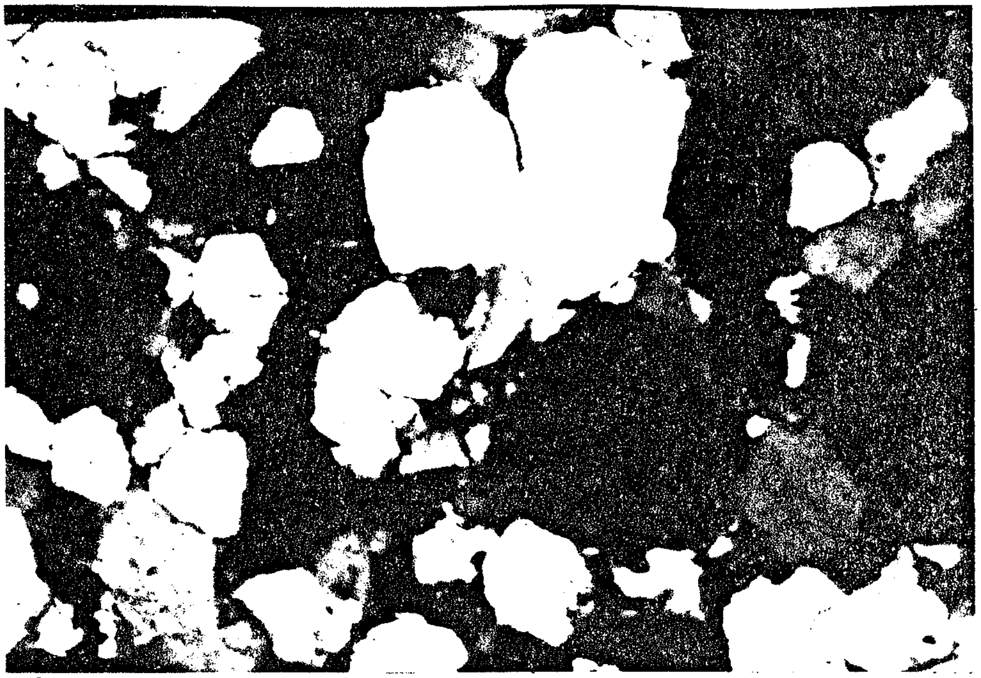


PLATE XXIII

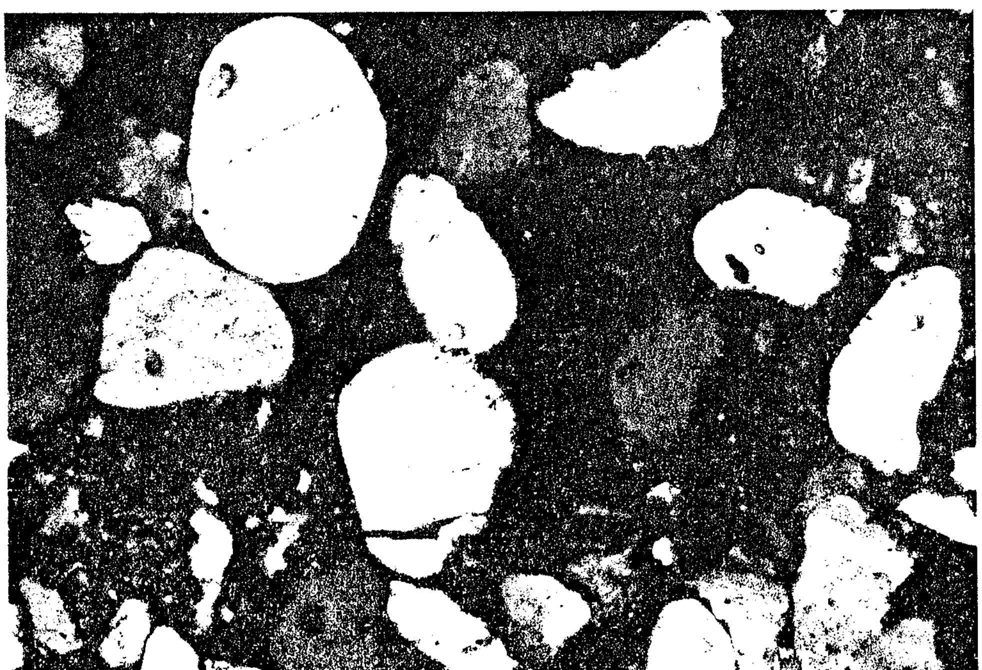
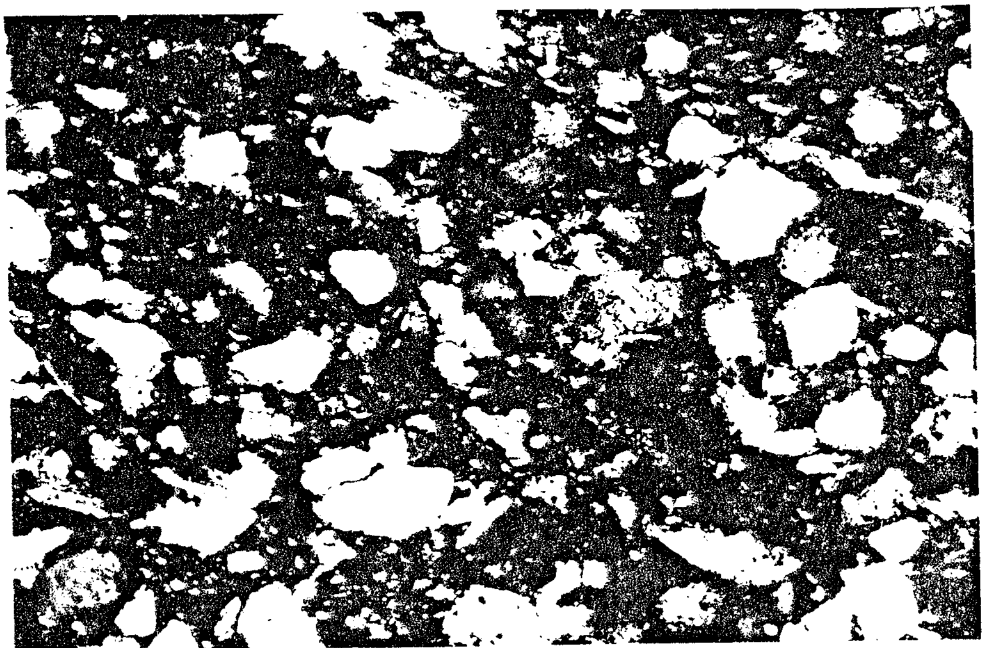
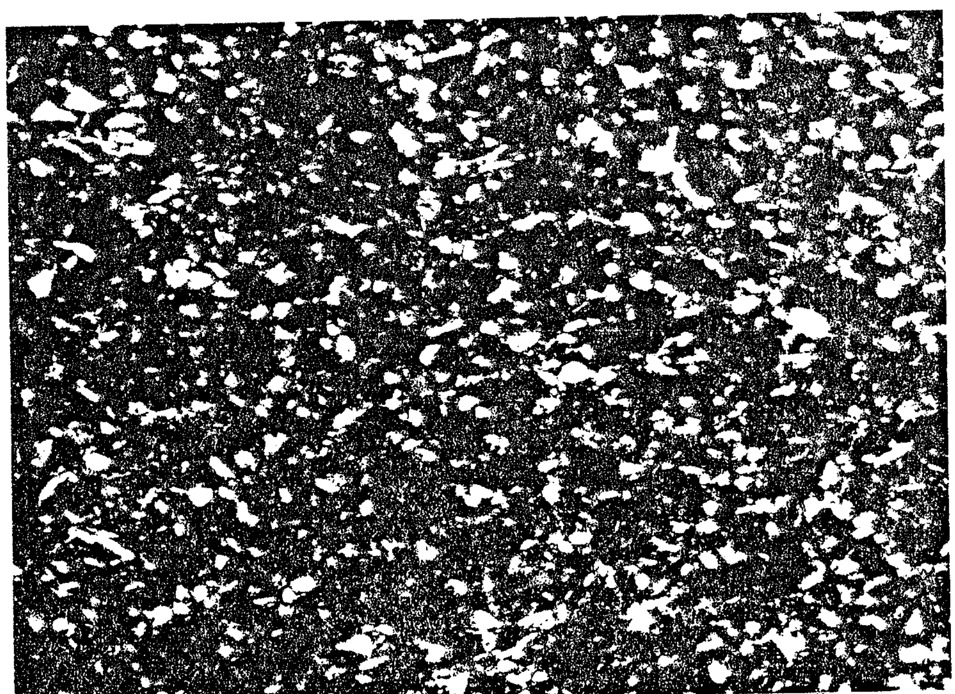


PLATE XXIV



PS 17a   0 mm 5

PLATE XXV



PS 17b   0 mm 1 2

PLATE XXVI

lower section is calcite with minor amounts of silica. Leaching, replacement, and embaying in quartz grains by calcite is pervasive, indicating that carbonate-charged waters circulated through the sand bodies and deposited carbonate as either the original cementing material or a secondary introduced, component after lithification (Folk, 1974). Other replacement by chert is indicated along grain bounaries that are consumed and altered to chert (Plate XXVII).

Fine laminae of mud are found in some sandstone units but are scarce and finely dispersed. Other mineral constituents are widely dispersed throughout the thin sections and are difficult to identify due to their scarcity and size. Dolomite rhombs are predominant but appear to be secondary minerals because of their fresh appearance and unaltered state. Authigenic mica flakes (Folk, 1974), tourmaline and feldspar comprise the main bulk of minerals. The feldspar has been tentatively identified as plagioclase from its twinning (Plate XXVIII), but more detailed measurements have been inhibited because of its scarcity and fine grain size.

The most prominent sandstone type in the Vinini Formation is the orthoquartzite that occurs at the top of the stratigraphic column. It is moderately- to well-sorted, subrounded to well-rounded in grain shape and falls in the medium sand-sized category (0.50 mm). Grain boundaries are in pressure contact and sutured in places, and are extremely clean and comprised of at least 95% quartz (Plate XXIX). Where a cementing agent is observed, it is mainly silica with calcite as a minor constituent. Its composition places this

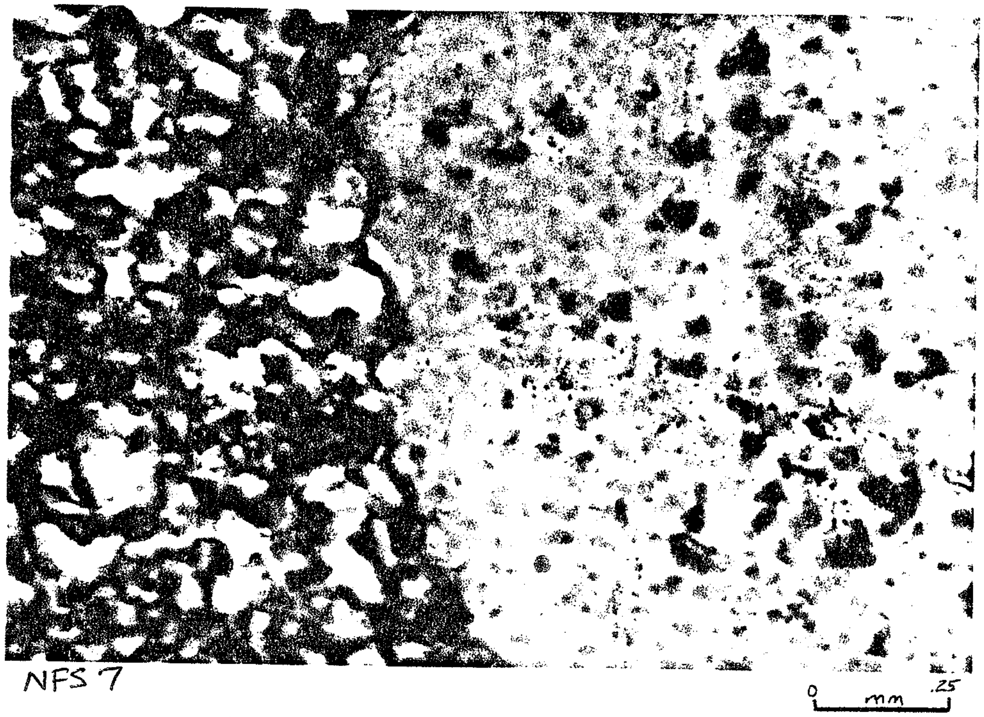


PLATE XXVII

PLATE XXVIII

PS 38

0 mm .5

PLATE XXIX

unit in the "ortho" quartzite range as defined by Tieje (1921).

Summary

Sandstones found in the Valmy Formation at the North Fork Canyon of the Toiyabe Ranges are similar to those of the Vinini Formation. The geometry of the sand bodies show a greater lateral extent but, on the average, they are much thinner than the Vinini sandstones.

Thin section analysis has shown that most of the monocrystalline quartz fall into the medium sand-sized catetory (0.25 mm to 0.50 mm). They are characteristically rounded to well-rounded grains with a small angular fraction. Sorting ranges from poorly-sorted to well-sorted, but the bulk is moderately sorted.

There is a high degree of alteration evident in the sandstones in this stratigraphic section. As previously mentioned, chert is an abundant constituent in this section. Thin section analysis of these cherts indicates that these units were originally clastic rocks that have undergone intense and profound alteration. Microscopic evidence reveals an abundance of "ghosts" or relic shapes of well-rounded grains of approximately medium sand-sized particles. Under plane-light illumination, thin sections of chert display an outline that has been interpreted to be grain shapes (Plate XXX); under cross-polarization, they clearly are grains of chert (Plate XXXI). Examination of other chert thin sections shows large, well-rounded quartz grains "floating" in a matrix of chert. Along the quartz grain

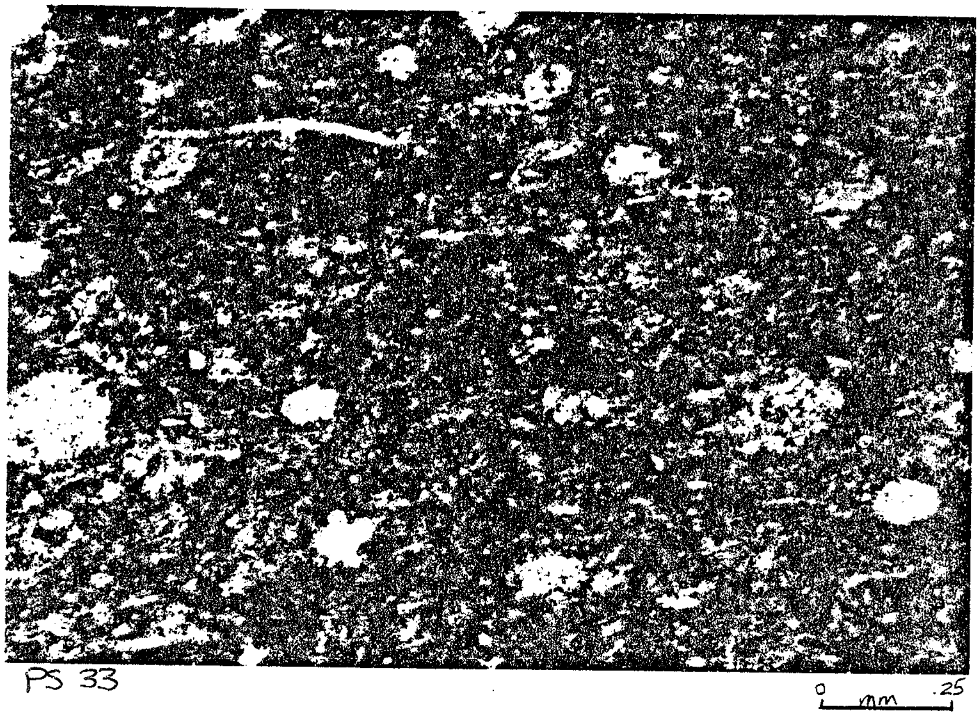


PLATE XXX

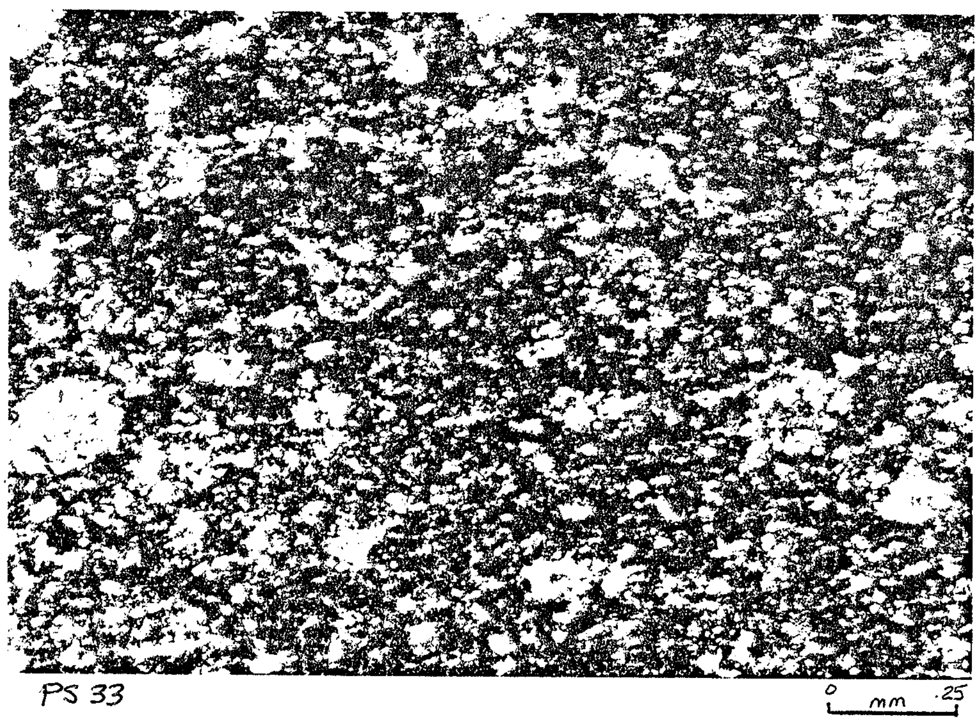


PLATE XXXI

boundaries, alteration to chert is clearly evident (Plate XXXII). The implication is that these chert units were originally deposited as detrital grains of quartz, later altered to chert though intense leaching and replacement in a highly siliceous medium. Where convincing evidence is present, these "cherts" are designated as sandstone or siltstone according to the mean grain size found in the relic structures.

Corrosion and alteration of quartz grains by calcite is also evident in the Valmy Formation sandstones. Embayment, alteration, and replacement along grain boundaries by calcite is pervasive and widely dispersed throughout most sandstone units.

Another sandstone type found in the Valmy Formation is a "dirty" sandstone (sublithic arenite), i.e., a sandstone in which the matrix material is dominantly mud or silt. Average composition is 50-60% mud, 40-30% quartz grains, and 10% or less calcite. Mud laminations also appear in some units but are minor and scarce.

Average composition of sandstones of both the Vinini and Valmy Formations indicates that they are similar and appear to be derived from the same source area. Differences exist where a unique geometry in a sandstone body (e.g., lens-shaped bodies or the orthoquartzite ridge) argues for a different depositional regime. Further discussions in the following section will determine the nature of the depositional regime

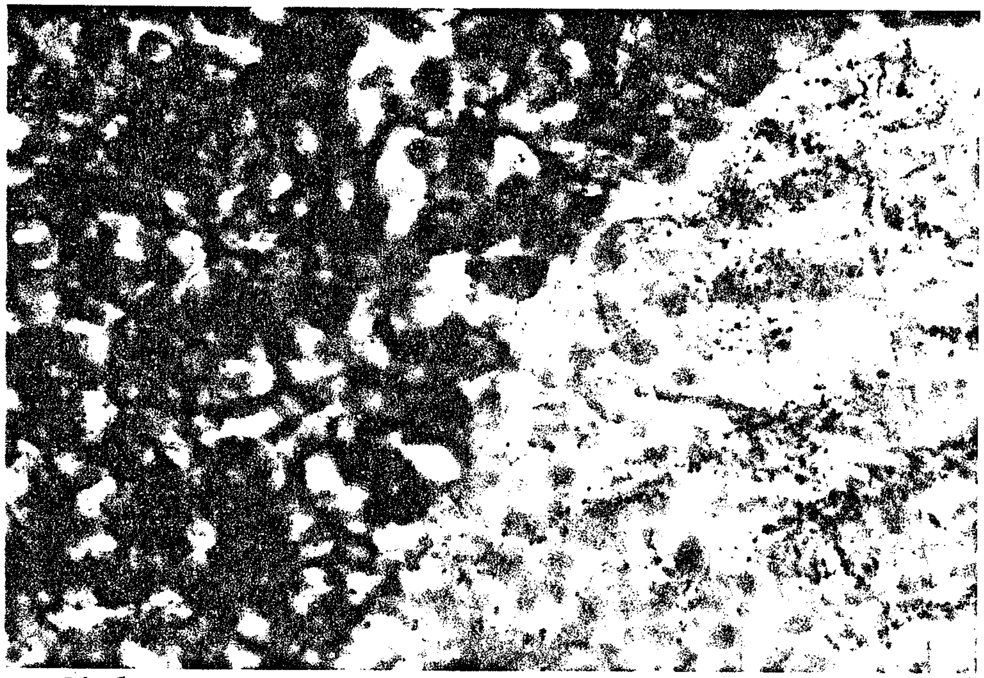


PLATE XXXII

and present an over-all framework for the complete strati-graphic associations.

SILTSTONES

Vinini Formation

The siltstones found in the Vinini Formation vary in thickness from 3 cm to 25 cm. Bedding is planar and laterally persistent across outcrop, and has sharp upper and lower contacts (Plate XXXIII). Other siltstone units are in gradational contact with a lower shale member. These lithological associations are often found in thicknesses of 5 to 10 meters (Plate XXXIV). Generally, they are capped by a thick or thin bed of sandstone.

Bedding is well-preserved in most outcrops, but a high degree of deformation at the bottom of the Vinini Formation sequence obliterates all bedding surfaces, developing multidirectional cleavage planes (Plate XXXV). Where deformation is minimal, internal primary structures are well-preserved.

The dominant structures evident in these siltstone beds are wavy and straight laminations (Plate XXXVI), cross-bedding and ripple laminations, and small scale climbing ripples (Plate XXXVII). In some siltstone beds, ripple laminations grade upwards into straight laminations, probable indicators of decreasing current energy. Other units show small-scale cross-beds overlain by horizontal laminations (Plate XXXVIII).

Valmy Formation

The siltstone beds of the Valmy Formation range in thickness from 2 cm to 10 cm, with most beds 5 cm or less (Plate XXXIX). Bedding is persistent across outcrop with most layers in abrupt contact with an overlying shale bed

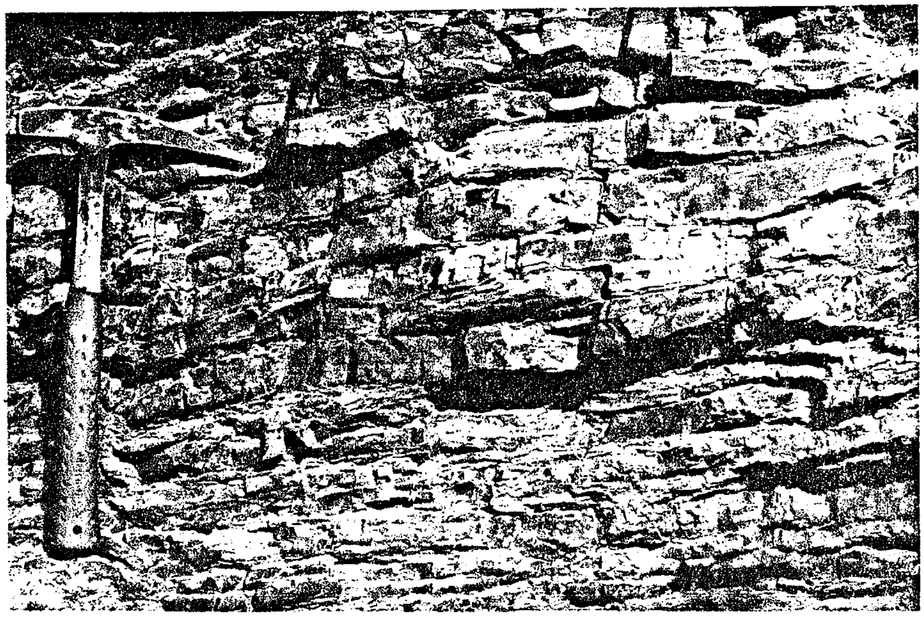


PLATE XXXIII

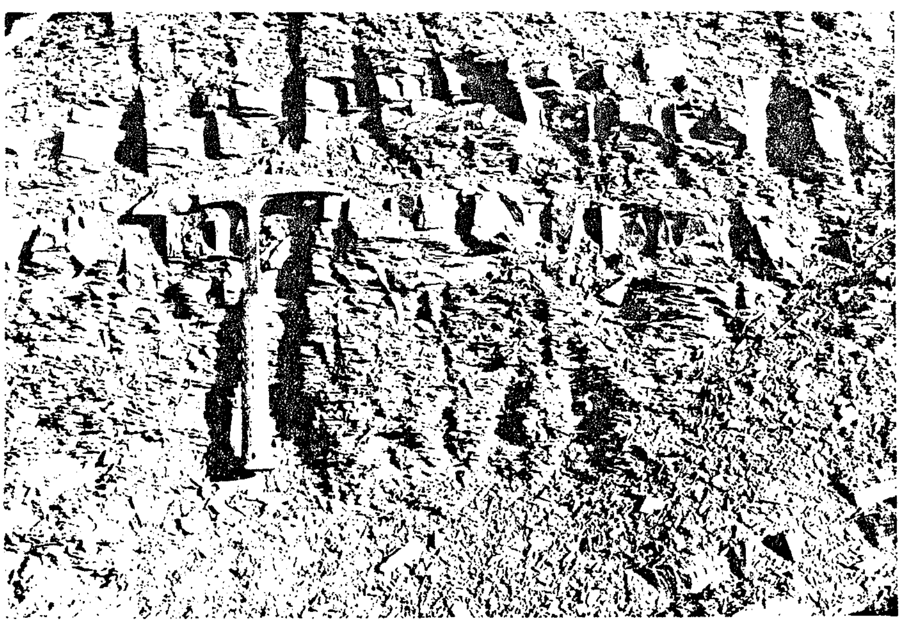


PLATE XXXIV

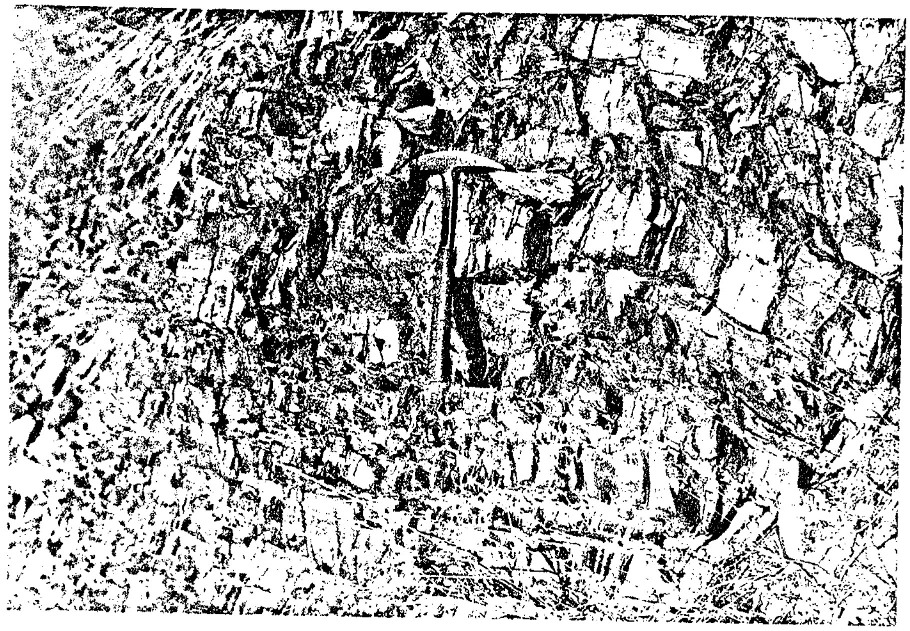


PLATE XXXV

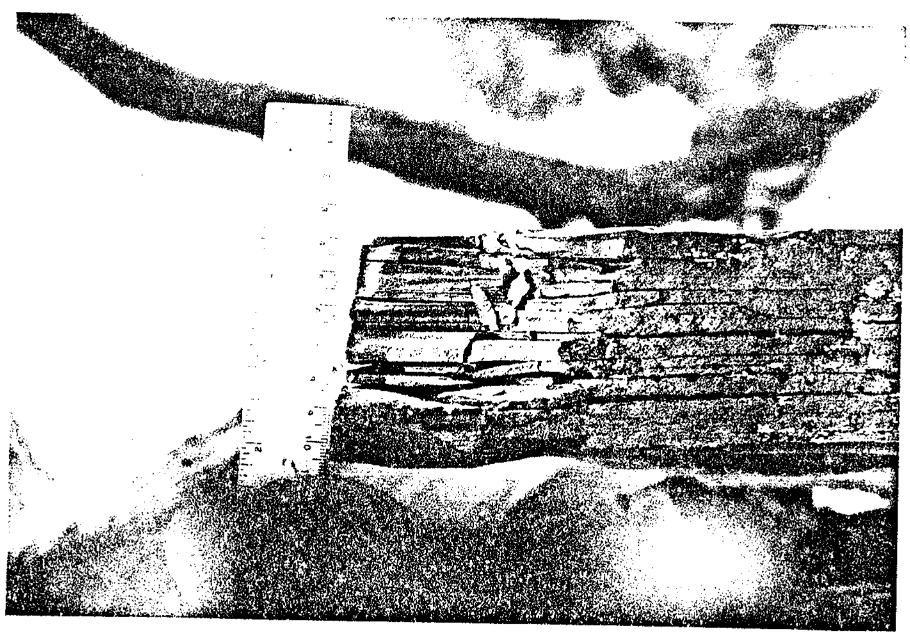


PLATE XXXVI

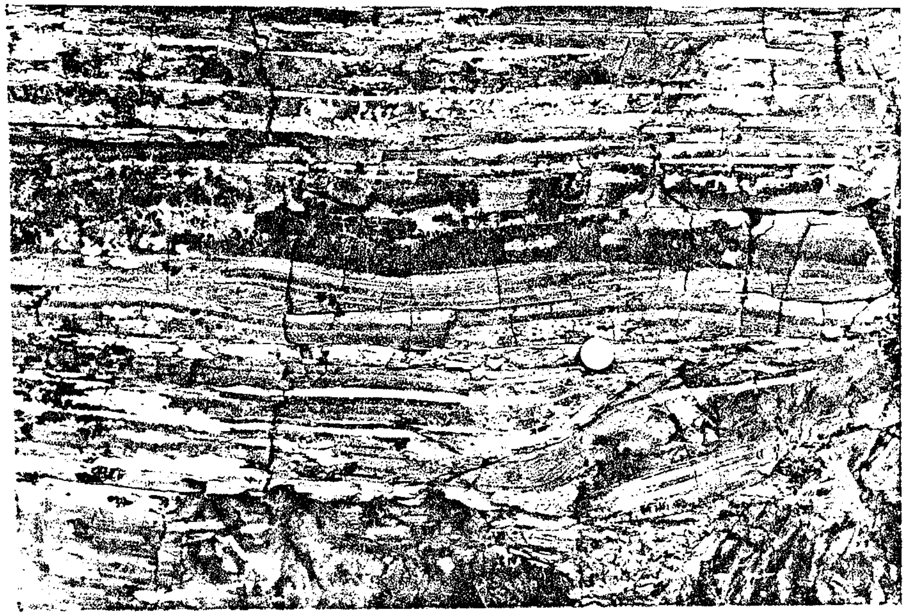


PLATE XXXVII

PLATE XXXVIII

(Plate XL). Grading between shale and siltstone is also evident (Plate XLI). The siltstones form a vertical package of repetitive lithologies of shale-siltstone-shale-siltstone-sandstone. This package is monotonous in outcrop, with the only variability occurring with the absence of sandstone at the top.

North Fork Canyon has many large and small-scale faults in which some bedding is destroyed or at least tectonically overprinted. Where bedding is intact, it preserves many distinct internal primary structures. These include horizontal and wavy laminations, ripples, climbing ripples, and cross-bedding. Similarities between outcrop appearance and identical internal structures of both the Vinini and Valmy Formations are striking and clearly these two formations are alike in many ways.

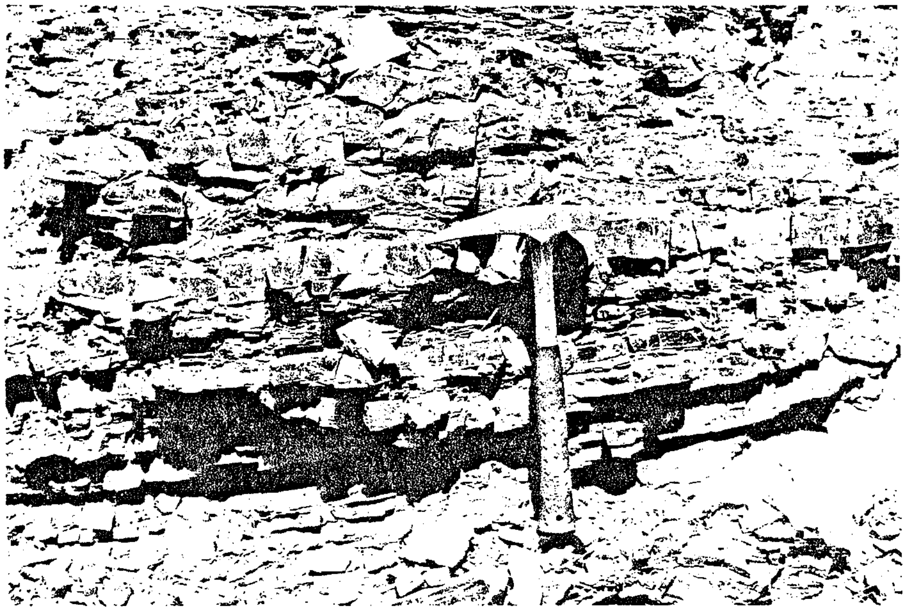


PLATE XL

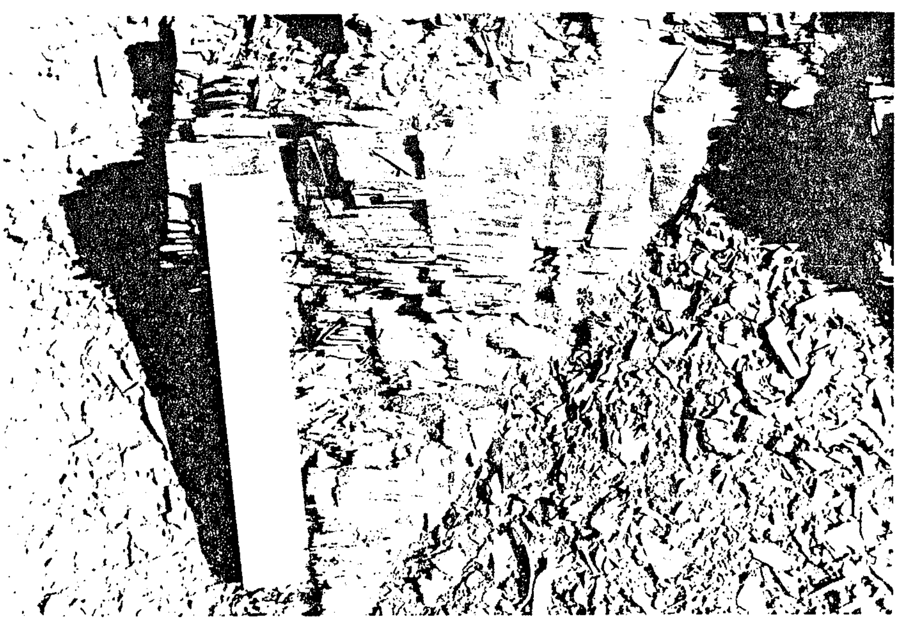


PLATE XLI

PETROGRAPHIC ANALYSIS

In both the Vinini and Valmy Formations the siltstones range from coarse-grained rocks to very fine-grained rocks (Plate XLII). Grain shapes vary considerably throughout the samples from very angular to rounded quartz (Plate XLIII). Sorting is poor with samples displaying a range of sizes throughout a single thin section (Plate XLIV). Others contain an abundance of mud-sized material or mud laminae that parallels the bedding surfaces (Plate XLV).

Where large silt-sized quartz grains are observed, a high degree of corrosion by calcite is evident. Calcite comprises the main cementing agent (up to 50%) in the siltstone in both stratigraphic sections. Leaching, embayment, and complete replacement (in some cases) by secondary calcium-charged port fluids are common. Silica occurs as a minor cementing agent in very few siltstone samples.

Siltstones are found in association with shale and commonly occur as a package of lithologies throughout both the Valmy and Vinini Formations. Gradational contacts are frequent, the shale grades upward into fine- to coarse-grained siltstone beds. This coarsening upward sequence is identified by a fine shale member gradually coarsened by shale bed, the sequence grades to silty-shale to shaly-siltstone to siltstone. This sequence is repetitive and pervasive throughout both stratigraphic sections, often attaining thicknesses of 10 or more meters. It is often capped by a sandstone unit or a coarse siltstone bed. The succession

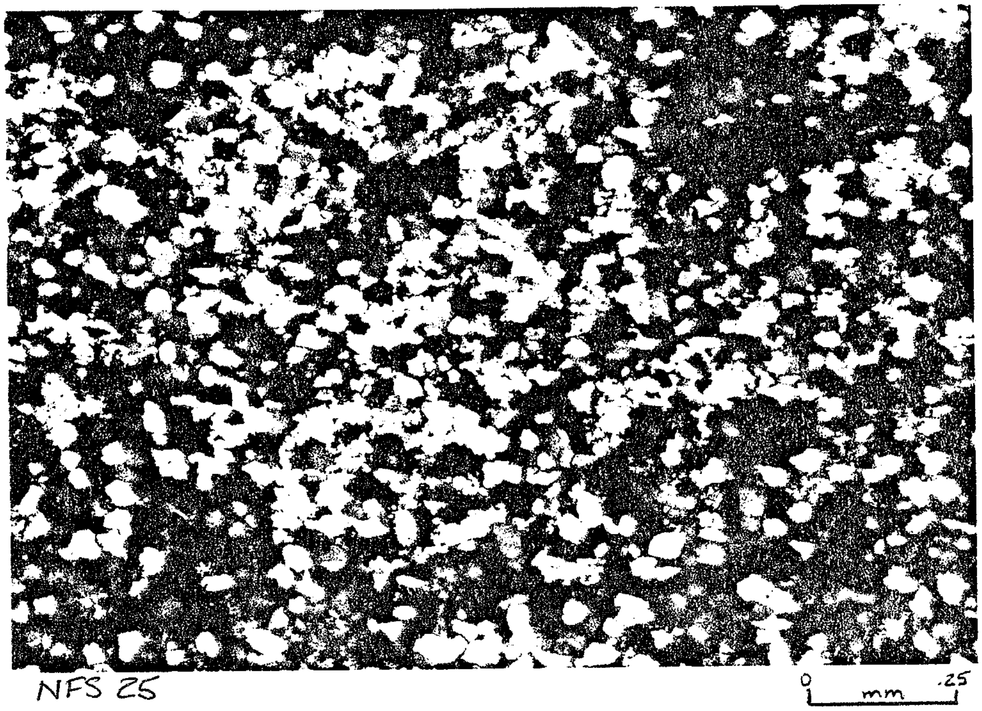


PLATE XLII

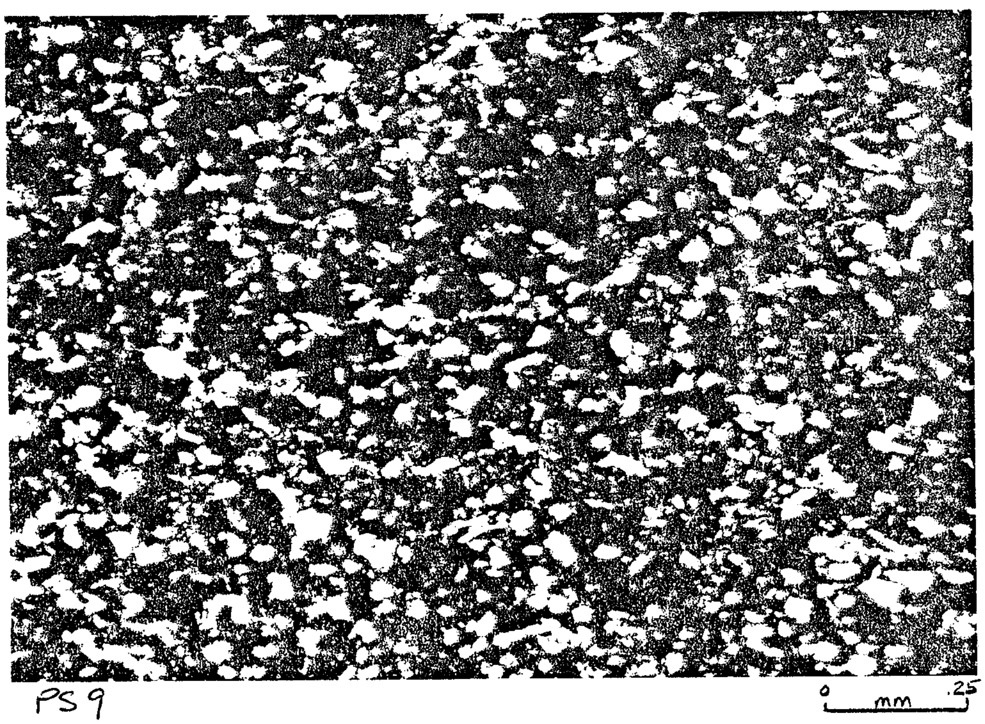


PLATE XLIII

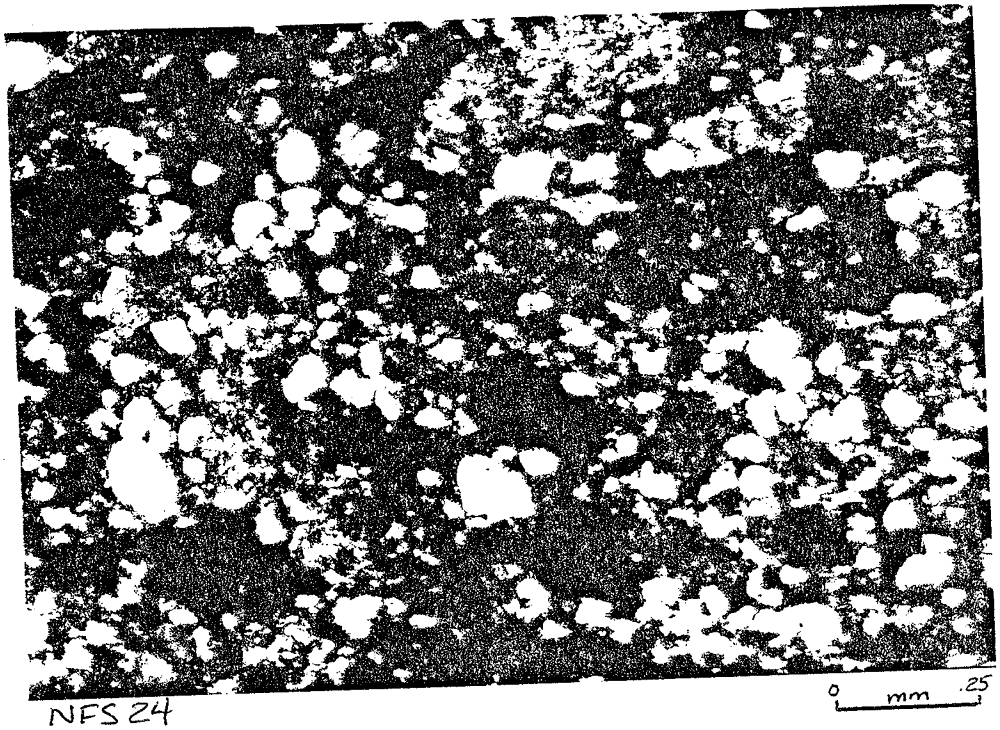


PLATE XLIV

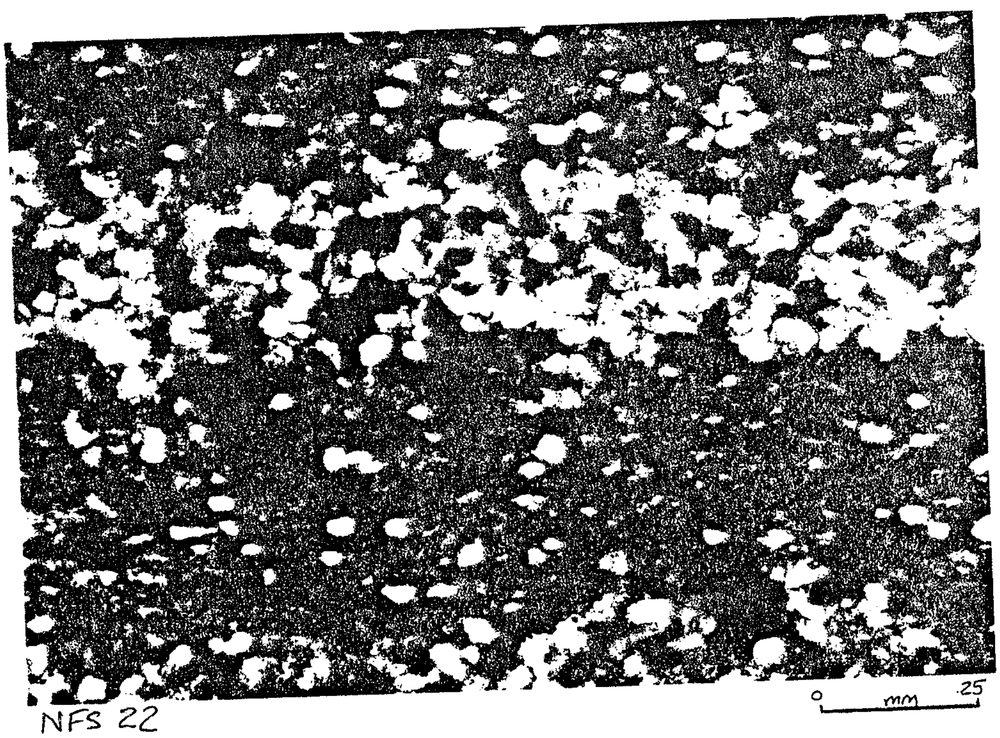


PLATE XLV

is monotonous and clearly repetitive, indicating a singular depositional regime through time.

SHALE

The shales studied in the Valmy and Vinini Formations are thin- and thick-bedded (2 cm to 25 cm) (Plates XLVI and XLVII) and laterally persistent. They are highly fissile, breaking into splintery, finger-shaped pieces (Plate XLVIII). Bedding is generally abrupt with sharp upper and lower contacts. Some beds show continuous gradational contacts with upper siltstone beds. They tend to be variegated green to black but dominantly gray in color.

Internal structures are absent in most shale beds, but a few horizontal laminations can be seen in some. These appear to be fine laminations of dark, mud-sized material that is highlighted against a lighter colored shale bed.

Bedding associations are consistent with siltstone throughout the stratigraphic sections and nowhere does shale outcrop without interbedded siltstone. These lithological units are consistently 5 cm to 10 cm thick as individual beds and occur in 5 to 35 meter thick packets. They comprise the bulk of the Valmy and Vinini Formations and are found from top to bottom in the stratigraphic sections.

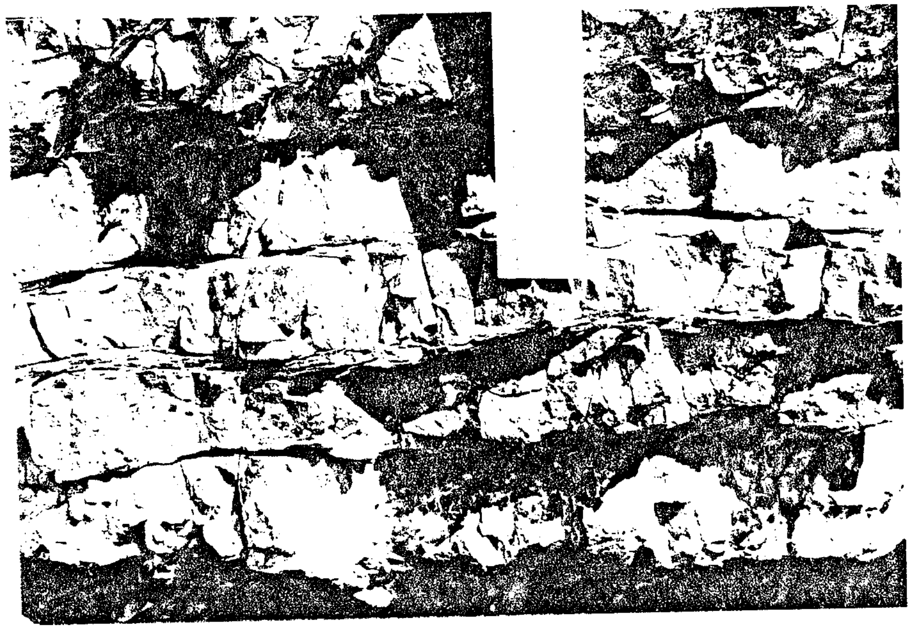


PLATE XLVI

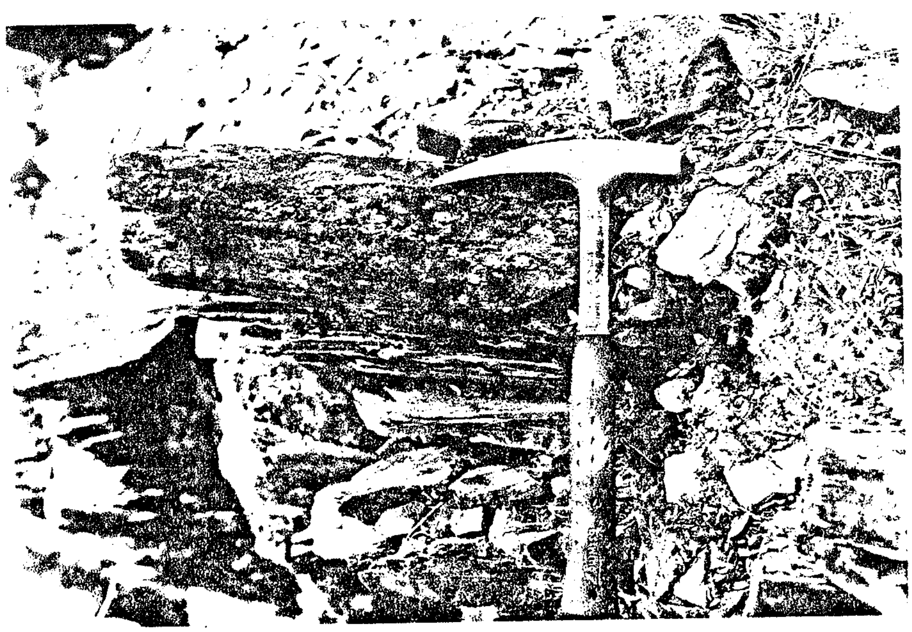


PLATE XLVII

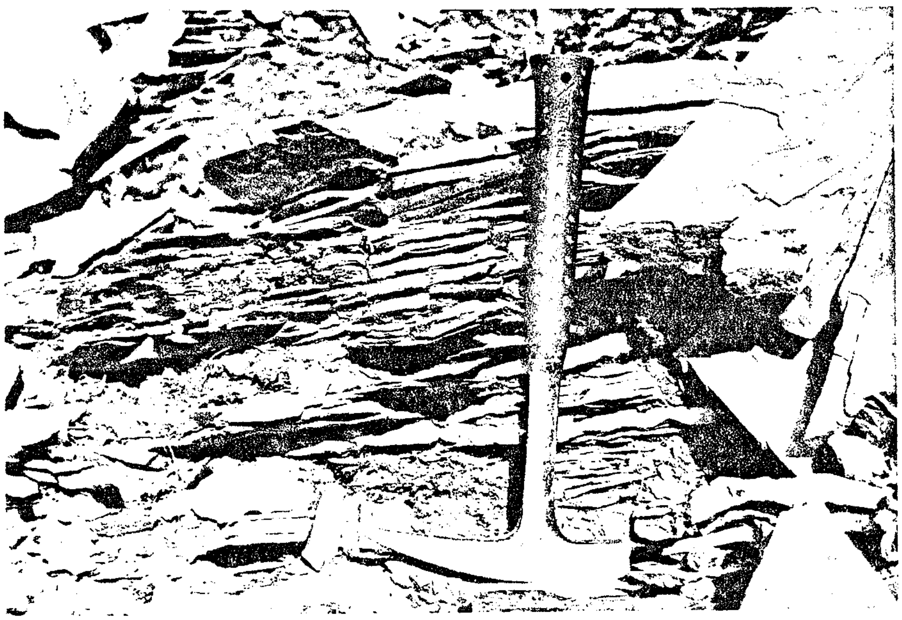


PLATE XLVIII

PETROGRAPHIC ANALYSIS

Thin section analyses of the shales from the Vinini and Valmy Formations were found to show little variability and are typical of most shales studied in other areas. The grains are consistently clay-sized (0.00006 mm to 0.0039 cm) in thin sections with some quartz as detrital material. In each thin section, irregularly shaped and poorly sorted quartz grains are found dispersed throughout.

The shale units that grade upward into siltstone show increased percentage of quartz grains moving up the bed. Other detrital material, chert for example, is random and scarce and may be related to diagenetic changes or pore fluids introduced after consolidation. Calcite is found as cement in some shale units, but evidence of leaching and replacement of detrital quartz grains suggests that calcium-charged fluids here also alter the primary composition of the shale bed.

Little variability is found in the shale throughout the two formations. As part of a lithological package with siltstone and sandstone, shale becomes an important indicator of changing environments or, at least, changes in the energy of the depositing medium. Later discussion will attempt to place this unit in a framework in which a suitable model of deposition may be constructed.

CHERT

Chert commonly occurs throughout the Valmy and sporadically in the Vinini Formation stratigraphic sections. It is found in combination with interbedded siltstone and shale, forming recognizable lithological packages. Chert beds are continuous in outcrop with sharp upper and lower contacts (Plate XLIX). Bedding thickness is commonly 5 cm to 15 cm with the bulk 10 cm thick. The cherts tend to be variegated in color with gray dominating. Internal structures are sparse with the exception of color banding (Plate L). Some units do contain faint internal structures such as ripple and horizontal laminations (Plate LI).

These structures place obvious constraints upon the interpretation of the origin of cherts. Arguments that suggest that the chert here is entirely a result of precipitation from silica-saturated waters do not allow for evidence of the dynamic medium of deposition required to form ripples. Further evidence in thin section will suggest possible modes of deposition or recrystallization of these cherts.

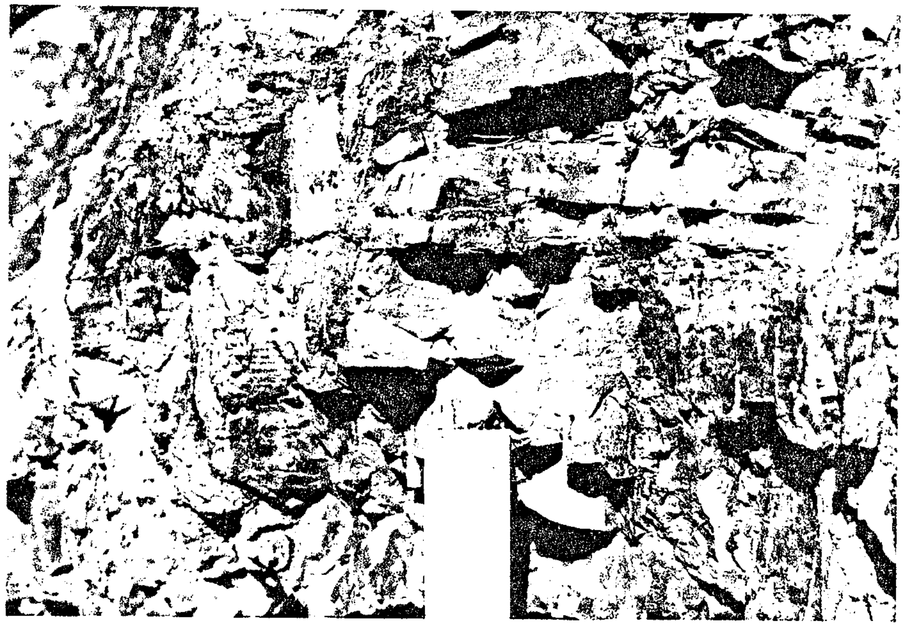


PLATE XLIX

PLATE L

PLATE LI

PETROGRAPHIC ANALYSIS

Thin section analysis has shown two types of chert are prevalent in the Vinini and Valmy Formations: (1) homogeneous chert and (2) replacement chert. Homogeneous cherts are those in which no evidence suggests that their origin is secondary, and appear to be directly deposited. The homogeneous chert is hard, dark gray chert in outcrop, and in thin section, is a colorless and an exceedingly fine-grained aggregate. Replacement chert is similar in outward appearance but microscopically contains ghost-like outlines of fine sand-sized grains. As mentioned in preceding sections, plane-light illumination of the thin section highlights these "ghosts" readily (Plate XXX). Cross-polarization masks these grain shapes, making them indistinguishable from the surrounding microcrystalline chert (Plate XXXI).

Other thin sections contain widely-disseminated quartz grains in the chert groundmass. High-powered microscopic examination of these grains show that the boundaries are in various stages of replacement or alteration to chert (Plate LII). Interpreting these grains as radiolaria is suspect in the light of evidence of quartz grains readily altering to chert. There is a high degree of similarity between the size and shape of the "ghost" outlines and those of the unaltered quartz grains in associated sediments (compare Plate LIII and LII). Coupled with the presence of ripple and horizontal laminations, the implication is that these cherts represent originally clastic rocks that have undergone

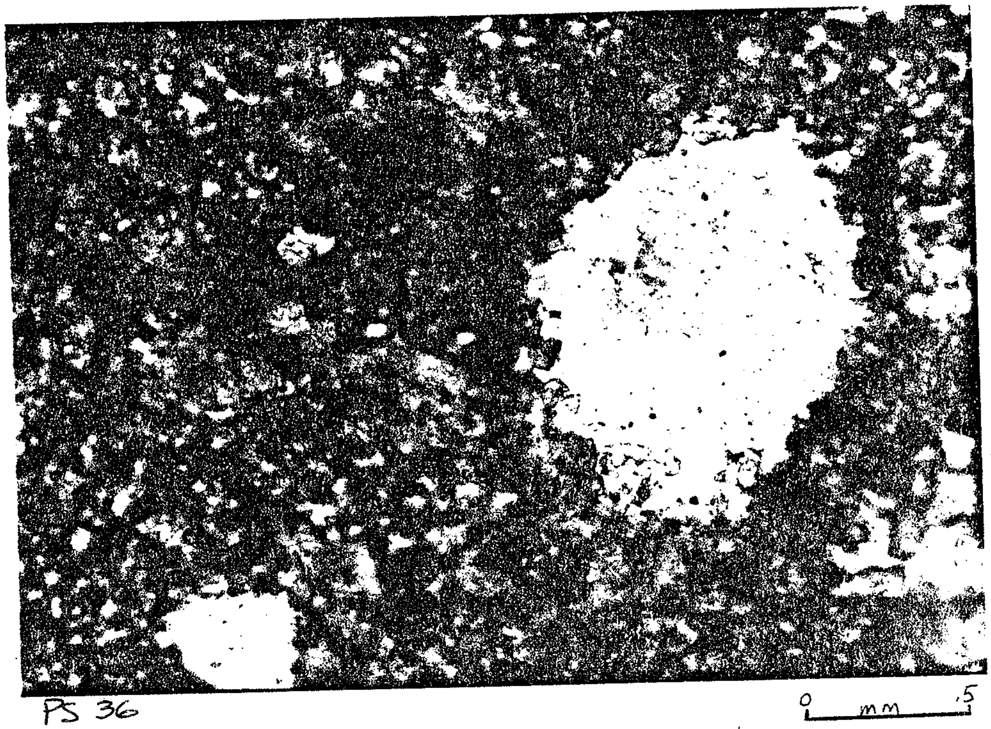


PLATE LII

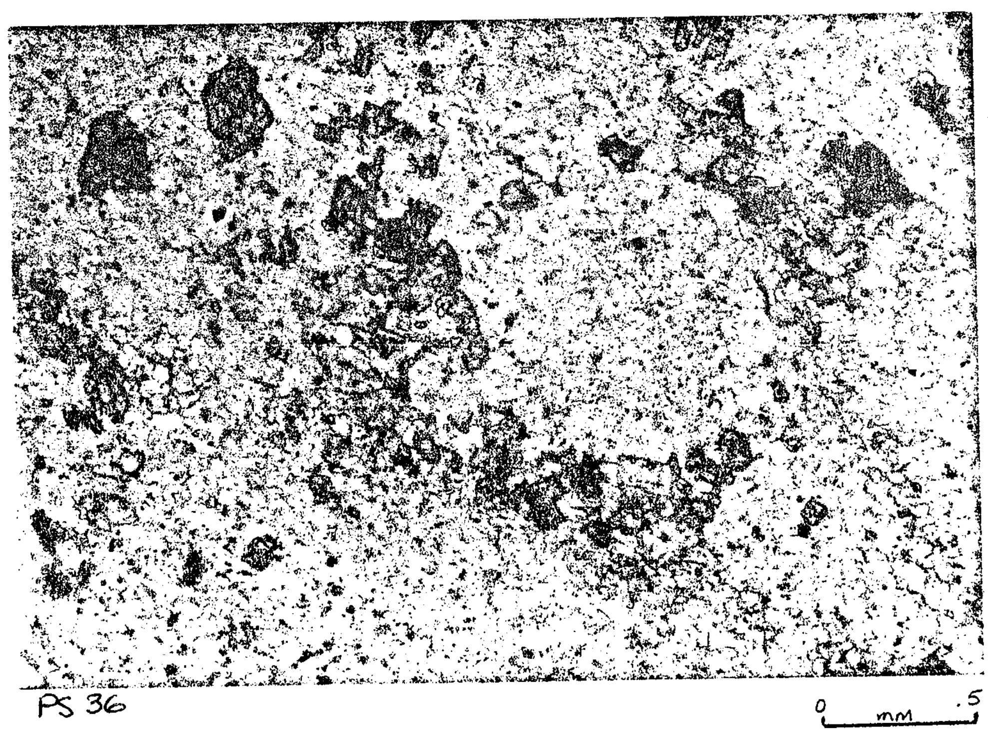


PLATE LIII

these chemical constituents into a restricted basin through time could affect the primary deposited sedimentary material, altering and replacing original detrital grains into secondary chert. This latter interpretation appears likely for the origin of cherts in the Vinini and Valmy Formations and will be discussed fully in the following section.[1]

The depositional framework to be developed for the Valmy and Vinini Formations provides a framework for an interpretation of the origin of the chert beds. Thin section analysis reveals the presence of clastic quartz in the chert, and the presence of "ghost" outlines suggest that these cherts were originally clastic rocks. Where convincing evidence is available, cherts have been designated as shale, siltstone, or sandstone when the mean grain size could be established.

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[1]Folk (1974) and Pettijohn (1975) discuss the origin of cherts and refer to replacement chert as a product of alkaline waters circulated in a restricted basin altering any carbonate rocks <u>in</u> association with clastic siliceous rocks.

VERTICAL PACKAGING

As suggested in the previous discussion, a dominant pattern of lithological associations has been observed in both the Vinini and Valmy Formations. The dominance of shale-siltstone-sandstone emerges not as a random association of rock types but as a recognizable pattern of common lithologies.

The gross stratigraphy depicted in the stratigraphic column of The Vinini Formation (fig. 6) shows an overall coarsening-upward trend of sedimentation. The lower section is characterized by finer-grained rocks that are capped by an orthoquartzitic sandstone. The pattern of sub-environments within the column suggests that individual lithological packages are also identified by trends to coarsen-upwards. The criteria for recognizing an individual package includes the identification of a basal member and its capping rock. With respect to the Vinini and Valmy Formations, the basal units are identified as the fine-grained shale and siltstones topped by a sandstone unit that lies conformably above shale and siltstone sequence. Specific units will be shown to fine upward, but these may be the result of local conditions and become less significant when looking at the entire stratigraphic column.

The stratigraphic sequence of the Valmy Formation (fig. 7) depicts this relationship by the small arrows on the margin. There are thirty-two of these units that form the shale-siltstone-sandstone package. This combination varies with the inclusion of chert as either a fine-grained member or a clastic component based upon its petrographic analysis. Other variations occur where sandstone is absent and/or a coarse siltstone caps the discrete lithological package.

In the Valmy Formation, this relationship varies in thickness from 2 meters to 25 meters (see stratigraphic column, fig. 7). Each package is clearly evident through thin section analysis and in outcrop. The stratigraphic column shows this relationship where the indented beds represent decreased resistance to erosion and decreased grain size (i.e., sandstones tend to be more prominent in outcrop).

The Vinini Formation shows this coarsening-upward relationship more strikingly due to the more abundant sandstone members. There are at least ten discrete lithological packages in this formation, varying in thickness from 2 meters to 15 meters (see stratigraphic column, fig. 6). Interbeds of shale and siltstone repeat continuously until capped by sandstone or a coarse siltstone bed. These units are represented by the small arrows in the margin of the stratigraphic column. A large covered interval prevented measurement of possibly more individual lithological packages.

Shown in the stratigraphic column of the Vinini Formation (fig. 6) at the height of 30 meters, beds of unique internal depositional style are apparent. They are characterized by cross-bedding and ripple laminations, convincing indicators of a high energy regime. They tend to be abrupt, truncating and scouring the underlying shale and siltstone beds. Petrographic analysis has shown this unit to be extremely coarse sandstone fining-upwards from a thin conglomeratic base.

In both the Vinini and Valmy Formations, the recurrent depositional style of coarsening-upward vertical packages dominates both stratigraphic columns. They differ in only the thickness of each package and the degree of coarseness of the capping rock. The Valmy Formation packages tend to be thicker than those of the Vinini Formation, but the Vinini contains more sandstone units that effectively define individual packages. Most bedding contacts are sharp in both formations with some units grading upwards from shale to siltstone without a perceptible break in bedding.

This vertical package governs the entire stratigraphic column of the Vinini and Valmy Formations and reflects their depositional histories. Although tectonic complexity inhibits delineation of complete lateral and vertical relationships in these sequences, the coarsening-upward packages place significant constraints upon the depositional regime and suggest possible models for sedimentation. There are a number of depositional patterns in which this type of sedimentation occurs. Included are deep water abyssal environments (turbiditic shelf-slope deposition or sub-sea-fans) to near-shore shallow water environments (deltaic).

The following section will discuss possible depositional regimes in which the Valmy and Vinini Formations could occur. The range of sediment types, vertical packaging and interformational relationships will be discussed in terms of two principal depositional environments: deep water (abyssal) and shallow water (near-shore) environments.

Within these boundaries, the deep water interpretation will include turbidites or deep sea fan-type deposition. Shallow water depositional types will include near shore environments, specifically deltaic sedimentation. Each area will be examined in the context of sedimentation, sediment types, facies relationships, and time equivalency. The criteria for recognition of these depositional environments will serve as the context in which both the Vinini and Valmy Formations may be logically placed.

CHAPTER IV

DEPOSITIONAL ENVIRONMENTS

Deep Water Associations

The Vinini Formation has been described as pelagic or hemipelagic sediments deposited where normal marine bottom conditions prevailed, much like that found on the continental slope and rise (Stanley, et al., 1977; Wrucke, Churkin and Heropoulos, 1978). It has been further suggested that the bedding sequences are representative alterations of two rock types possibly deposited in contour current deposition by clear-water bottom currents similar to those in deep ocean basins (Stanley et al., 1977).

Irregular alterations of siltstones, shales and cherts could represent "cyclic" deposition described by Bouma (1962) for turbidites. These fine-grained rocks in conjunction with quartz siltstone and coarser units have been interpreted to represent an ABCD "top-truncated" turbidite in some locations or a BCDE "bottom-truncated" system at others (Stanley et al., 1977). The sharp upper and lower contacts of most quartzite beds of the western facies rocks could indicate rapid deposition in turbid flow in deep water on a continental rise and slope environment (Ketner, 1977). Ketner (1977) points out that the dark color of the siltstone and shale may result from deposition of unoxidized organic material in deep sea sites, but further points out these same characteristics have been observed in modern, nearshore, lagoonal sites.

The mechanics of turbidite deposition require a relatively quiescent environment for deposition of fine-grained sediments. Thick accumulations of these sediments are well known and reasonably well documented near continental slopes and shallow portions of deltaic front environments. Deposition of these shallower water sediments can occur along the continental shelf edge until overburden and failure along the slope causes gravity-induced turbulent flow downslope to deeper environments. As the current wanes, deposition progresses in such a manner as to yield the observed upward sequence of structures that mark the Bouma sequence. The presence of shallow water fossil assemblages in the turbiditic wedge confirms the original shallow water origin for these types of sediments.

Pettijohn (1975) distinguishes a range of turbidite types including two end members: the proximal and distal facies. The proximal facies he describes is marked by regularly-bedded sandstones 10 cm to 1 meter thick and a sand/shale ratio of 5 to 1. Sands of this kind are coarse and generally graded (Bouma's "A"). Laminations are rare, making proximal turbidites an AE-type sequence. In the distal facies type, the sands are finer-grained, with beds ranging in thickness from 1 to 10 cm. The sand/shale ratio is 1 to 1 or less. They commonly begin with a laminated interval (B) or a rippled phase (C). This description suggests a BCD turbidite sequence. These two types generally grade into one another and represent parts of deep sea-fan environments.

The undisturbed beds and internal structures of deep water sedimentation suggest that local infauna were absent, typical of deep sea ocean basins where oxygen levels are too low to support a large burrowing population (Stanley et al., 1977). The inclusion of thick sequences of chert that are interpreted to have accumulated in deep basins, with Bouma-like turbidites indicate that a deep water interpretation is viable.

Shallow Water Model

Although a deep water environment appears to be the consensus for the depositional site for the Vinini and Valmy Formations, Ketner (1977) has suggested that a range of environments could be represented in the western facies rocks under investigation here. Modern shallow water or near-shore environments are numerous but none so conspicuous as deltaic deposition. The following discussion will point out the main components of the deltaic system, particularly the lower delta sections and delta front environments, and the criteria for recognizing these environments.

The major components of the delta that will be examined here are found in the lower delta plain (fig. 8). These include the interdistributary bays and prodeltaic barrier island and the back-barrier lagoonal environments. These are characterized by a range of rock types from fine-grained

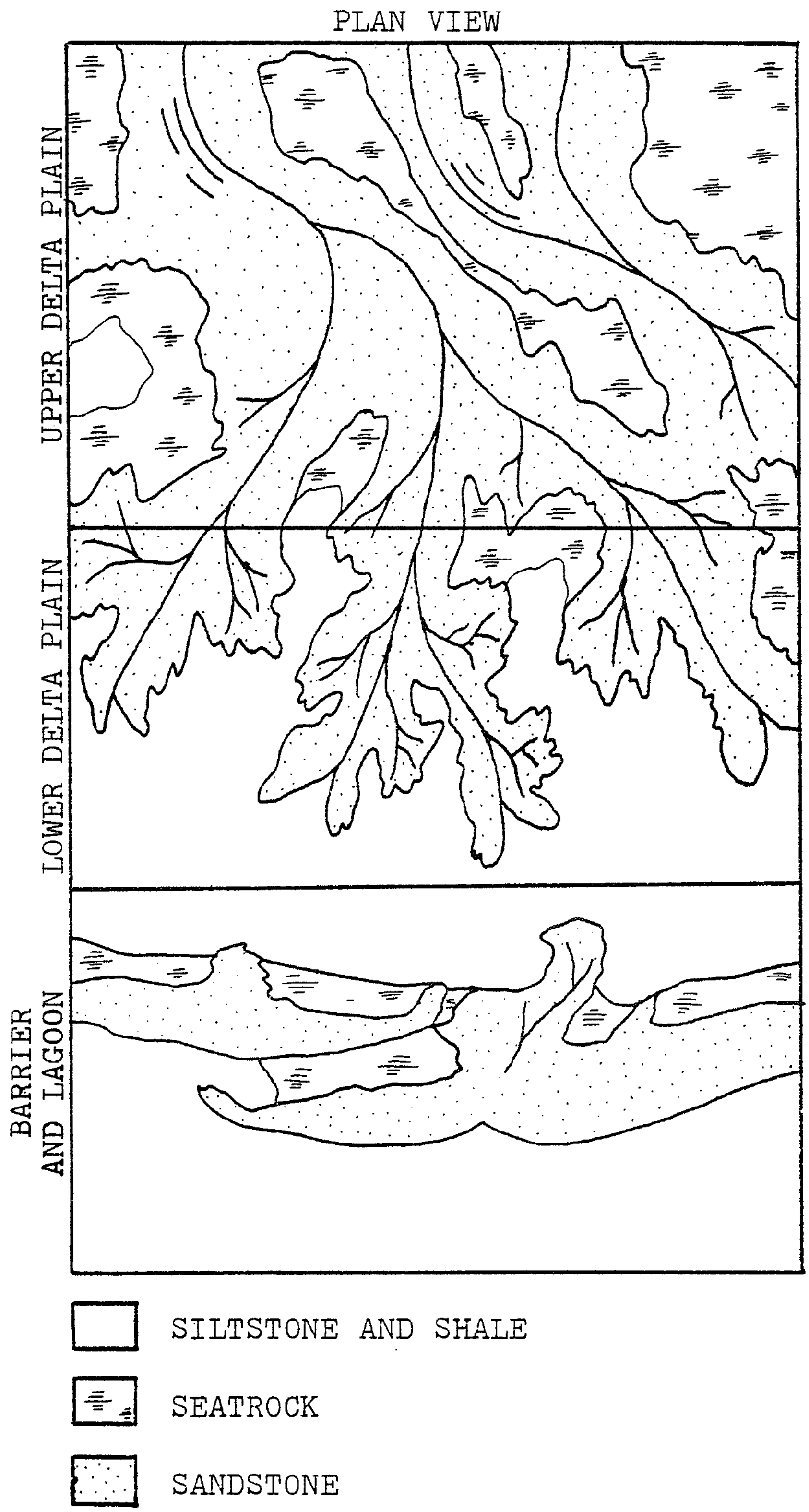

Fig. 8 . Major components of a deltaic system. Modified after Horne and Ferm, 1965 .

shales to coarse-grained orthoquartzitic rocks that generally coarsen-upward an idealized stratigraphic column.

Interdistributary bays are located between the leveed channeled arms of the lower delta fluvial system (fig. 9). They are relatively quiet environments and would, therefore, be sites of shale and siltstone accumulations, particularly in the basal sections. In the upper part of these sequences, sandstones with ripples and other current-related structures are common, reflecting the increased energy of shallowing waters as the bays fill with sediments (Horne and Ferm, 1965). This coarsening-upward pattern includes tongues of coarse-grained detritus introduced into the interdistributary bay through breaks in the channel levees that rapidly distribute these sediments as a sudden, localized depositional event. These so called "crevasse splays" are characterized by a bed of relatively "dirty" sandstones that pinches out laterally, scouring the underlying siltstone or shale horizon. These generally become coarser upward and toward their source.

The distributary channels are characterized by two types of sediment fill: active and abandoned (Horne and Ferm, 1965). These channels found in the lower delta plain are straight and exhibit little tendency to migrate laterally. Active channel fill material containing point bar accretions and other common depositional and sedimentary structures associated with active fluvial deposition are uncommon. The deposits associated with abandoned channel fill material are found to fine-upwards from a coarse, pebble conglomerate

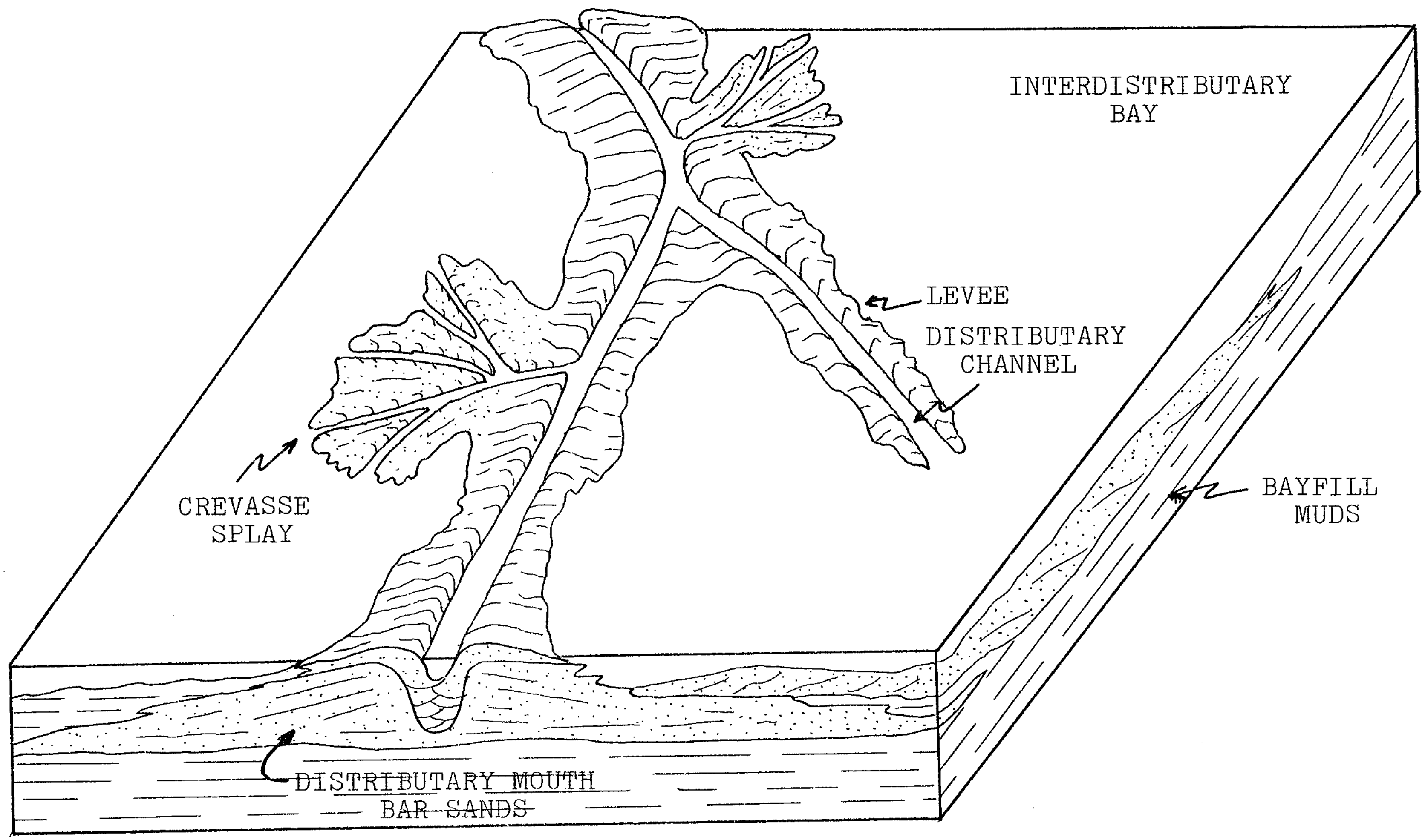

Fig. 9. Schematic diagram of some major features of the lower delta plain system. Modified after Horne and Ferm, 1965.

at the base to sandy siltstone and siltstone at the top. These channels truncate the underlying beds, scouring the surface on a wavy contact. The internal structures are organized from trough cross-beds at the base to flaser bedding at the top (Horne and Ferm, 1965).

The levees associated with the distributary channels are thin and poorly-developed. They consist of poorly-sorted, irregularly-bedded siltstone and sandstone (Horne and Ferm, 1965). Geometrically, they have a pronounced dip away from the channel. The levees are often breached, permitting an immediate flood of sediment (crevasse splay) into the adjoining bay.

The most complex conponents of the prodelta environment are the barrier islands. They are elongate, linear sandstone bodies that form in a shoreline position at a locus of high energy (Horne and Ferm, 1965). The principal criteria for recognizing barrier environments are the lateral relationships and the mineralogy of the sandstones. Seaward, they intercalate with marine shales and siltstones, landward, with brackish lagoonal shales. The sandstones of the barrier island tend to be more quartzose than those of the surrounding environments. They are cut by tidal channels at a trend of 90 to 120 degrees to the barrier island. In areas of tidal channeling, the offshore deposits are truncated by a scour surface formed at the base of the migrating channel (Horne and Ferm, 1965). In a prograding shoreline situation, landward features overlie the marine features, whereas in a transgressive shoreline sequence, either the opposite would be true, or the transgression would destroy the former barrier islands leaving only thin sands.

Towards the land, the back barrier lagoon is the last major component of the prodeltaic system. It is characterized by organic rich, dark siltstone and shale. The lagoonal-bayfill sequences coarsen-upwards and seaward and intertongue with orthoquartzitic rock of barrier island origin. Landward, lagoonal sediments intertongue with the "dirty" sandstones of the lower delta plain environments.

The dominating feature of the deltaic system is the gross coarsening-upward nature of the sediments going up a vertical sequence. Shale and siltstone beds are vertically packaged in such a manner as to represent a monotonous or "cyclic" stacking of beds. The influx of coarser sands or complete sandstone unit may cap a single lithologic package. The nature of the sands (texturally and mineralogically) determines the position of any segment of the delta with respect to a complete deltaic framework.

Compatibility with Models

A case can be made for a deep water interpretation for the Vinini and Valmy Formations. The Valmy Formation, previously described, exhibits a strong Bouma-type turbidite depositional style. Thin- to medium-bedded siltstone and shales with sparse, thin-bedded sandstone are typical vertical packages. Following Bouma's interpretation, the Valmy represents a BCDE or "bottom truncated" turbidite (fig. 10).

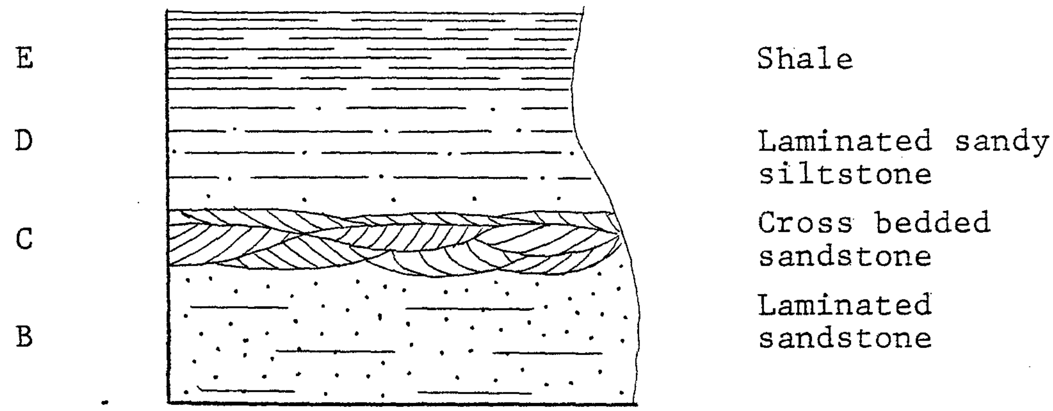

Fig. 10. Idealized vertical package that characterizes the Bouma turbidite depositional package. After Bouma, 1962.

Internal structures and vertical stacking of the units in the Valmy Formation are compatible with this interpretation. The stratigraphic column of the Valmy (fig. 7) shows a package of lithologies almost identical to the diagram for an idealized turbidite package (fig. 10). The dominance of straight, horizontal laminations in the shale and siltstones and minor trough crossbedding in the sandstones are typically indicative of mass flow in turbidites.

The problem arises in this interpretation for the Valmy Formation when considering the graded bedding that is so common in turbidites. The nature of the mass flow, hydraulic sorting, and deposition in down slope flow necessitates a dominant pattern of graded beds. The Valmy

Formation has few graded beds; most upper and lower contacts are very sharp, without the slightest tendency to be graded.

The Vinini Formation, located eastward of the Valmy, contains a greater percentage of sands and sandstone beds. The vertical organization of beds shows a slight contrast between the two formations. The Vinini tends to be less continuous in outcrop, particularly in the sandstone component, and contains more internal structures that are indicative of a higher flow regime. Trough cross-beds, climbing ripples, and scoured surfaces all point to an active depositional environment. The occurrence of the lens-shaped sand body that has no counterpart in deep water turbidite flow also argues for a different interpretation of the depositional regime.

Further, there is no mechanism in turbidite flows that produces orthoquartzitic sands such as those found in this formation.

The orthoquartzite unit at the top of the Vinini Formation stratigraphic column presents its own unique problem. Orthoquartzites, or clean, pure quartzose rock (at least 95% quartz) originates in one of three ways according to Horne and Ferm (1965):

1. Diagenetically, due to the intense weathering where leaching of less stable minerals occur. Quartz grains in these sandstones show extensive overgrowths.

2. By the erosion of a pure quartz source area. Orthoquartzite deposits would be ubiquitous in all depositional environments in the study area.
3. By accumulation in environments where sands have been cleaned of non-quartz material due to reworking with consequent winnowing of finer-grained materials. This deposition most likely occurs in high-energy, shoreline environments.

Evidence previously presented has shown that the quartz observed in thin section has no extensive overgrowths and the field analysis of the Vinini and Valmy Formations has shown that the orthoquartzite is not widespread, thereby refuting the first two possibilities listed above. The remaining possibility for the occurrence of the orthoquartzite appears to be the more likely case: the orthoquartzite of the Vinini Formation is probably the result of a high-energy regime.

A shallow water site appears to be the more likely depositional regime for the Vinini Formation. The evidence for this interpretation that may be applicable to the Valmy is less clear. The deltaic model that has been discussed in the preceding section has very similar characteristics to the rock record observed in the Vinini Formation and to a lesser extent, in the Valmy Formation. Of particular interest are similarities with respect to prodeltaic barrier island and lagoonal systems and lower delta plain distributary channels and interdistributary bayfill material.

The stratigraphic column of the Vinini Formation (fig. 6) depicts the coarsening-upward trend up the vertical column. Discrete units of shale - siltstone - sandstone form these lithological packages and are confirmed, texturally, through laboratory analysis.

This monotonous succession of siltstone and shale in the lower section of the Vinini Formation is similar to the bayfill material in interdistributary bay systems previously described and adapted after Horne and Ferm (1965). Horizontal and wavy laminations indicate a low energy regime permitting the gradual accumulation of finer-grained sediments characteristic of the interdistributary bay environments. Occasional thin- to medium-beds of coarse siltstone or sandstone, directly over a thick accumulation of siltstone and shale interbeds and are in sharp contact with these beds, and are interpreted to be crevasse splay material that originated from breached levees of adjoining channels. Resumption of the shale and siltstone beds over these crevasse splays further indicates that these coarse units were deposited in sudden depositional events that have occurred through time, later covered by finer-grained sediments after returning to a quiet bay environment.

Incised into these bayfill materials are channels and their associated levees. These lens-shaped units found in the lower section of the Vinini Formation stratigraphic column bear the same geometry as those described for distributary channels of the lower delta plain (Horne and Ferm, 1965).

The pronounced dip away from the common center is identical to the dip described for levees that form along the channel. The channel bottom scours the underlying units of siltstone and shale, indicating that its higher energy flow regime was introduced into a relatively quiet interdistributary bay environment. Field evidence shows that these channels do indeed scour the basal shales and siltstones, truncating them with very sharp contacts.

The rapid abandonment of a channel causes a fining-upward accumulation of sediments from a coarse, pebble-laden sandstone to siltstone or shale at the top of the channel. This relationship has been observed for the channels found in the Vinini Formation. The trough cross-beds near the base of the channel grade upward into straight laminations indicating decreased energy within this environment. As was observed in the model, the levees associated with the observed channel deposits were thin and poorly-developed. Internal structures such as planar crossbeds and ripples indicate that the levees were sites of rapid deposition, later experiencing waning current energy until finally abandoned and overlain by finer sediments.

Overlying the channel and levee deposits are thick shale and siltstone beds. Sporadic and random beds of sandstone or sandy siltstone are found interbedded with the finer-grained deposits. The fine-grained siltstones and shales are interpreted here to be back-barrier lagoonal deposits. The sandstone and sand fraction in some siltstones represent lower delta sands or fluvial derived sediments that have dispersed into the lagoonal section through storms or as the natural consequence of a dynamic environment. The absence of orthoquartzite deposits in the exposed section of this outcrop suggests that this section was located landward of the barrier island. The unexposed interval in the stratigraphic column is interpreted to be lagoonal deposits and is assumed to contain orthoquartzite sands.

The massive orthoquartzite units found at the top of the stratigraphic column are interpreted here to represent barrier island deposits. The manner in which orthoquartzites are found has already been discussed, leading to the conclusion that these sands are the product of a high energy regime. Constant reworking and winnowing of material removes the unstable components, leaving well-sorted quartz grains. Thin section analysis of this unit confirms the purity and sorting of the quartz grains, permitting this observation as to its depositional environment.

A strong linearity is characteristic in present-day barrier island complexes, where they often parallel the shoreline, roughly perpendicular to the distributary channels. They include tidal channels that are also perpendicular to the island, cutting trough-shaped depressions through them. Dominant flow patterns are reflected in the strong orientation of crossbeds perpendicular to the barrier island (Horne and Ferm, 1965).

The ridge-like outcropping of the orthoquartzite beds has a distinct linearity that is very similar to that of barrier island complexes. Although the paleo-shoreline can not be established here, the outcrop is roughly perpendicular to the interdistributary channels found in the lower section of the stratigraphic column. The ridge contains many trough-shaped depressions that distinguishes one barrier island from another. They are interpreted to be tide-generated channels, although internally the structures are poorly preserved, making flow direction impossible to determine.

The entire stratigraphic column of the Vinini Formation contains many components of delta front environments. They range from barrier island to lower delta plain channels and interdistributary bays. The coarsening-upward nature of the vertical packages suggests a dynamic environment that alternates from quiet depositional sites permitting accumulations of fine-grained sediments to an active environment that constantly reworks sediments forming pure quartzitic rocks. The evidence presented here strongly points to a deltaic interpretation for at least this portion of the Vinini Formation.

Environmental interpretation of the Valmy Formation is less straightforward than for the Vinini. As noted earlier, the Valmy Formation contains components that can be interpreted to be deep water-deposited, specifically, mass flow or turbiditic deposition. It was also noted that the conspicuous absence of abundant graded beds so prevalent in turbidites argues for a different environmental interpretation.

Reconstruction of the environment that includes a shallow water deltaic depositional regime provides a framework in which the Valmy may be placed. Thick accumulations of shales and siltstones that dominate the stratigraphic column of the Valmy points to a quiet depositional environment. The random inclusion of sandstones and coarse stringers of sand found in outcrop indicates an occasional influx of detrital material from a nearby source. Microscopic evidence suggests that these sand stringers must be derived from a nearby source of well-sorted and rounded quartz grains. In terms of the depositional site of the Valmy Formation with respect to a ready source of quartz, the Vinini Formation with its associated orthoquartzitic deposits appear to be a likely source area.

The Valmy Formation is interpreted here to represent distal delta front deposition, seaward of the barrier islands. The record of the Valmy Formation requires a depositional environment in which shales and siltstones may accumulate in relative abundance in an undisturbed environment. Either storm-derived deposits or the deposition of an advancing delta front provides the detrital quartz found as thin sand bodies or stringers in the Valmy stratigraphic column.

The depositional environment thus envisioned for the Vinini and Valmy Formations requires a framework in which shallow water and deeper water sites are situated in a relatively close association. The deltaic nature of the Vinini Formation is clearly established, based upon the model for deltas described by Horne and Ferm (1965). The geographic and areal separation between the two formations permits speculation on the nature and relationship of the Valmy Formation to the delta. Accumulations of shales and siltstones clearly establishes its quiescent character. The sporadic occurrences of sandstones and sand particles confines the depositional site to one in which quartz is readily available, interpreted here to be Vinini orthoquartzite sands.

The nature of the stacking of the beds shown in the measured vertical sections is interpreted to represent a transgressive deltaic sequence. The barrier island component overlies the more landward delta front lagoonal and channel sequences (fig. 6). Gradual encroachment of marine environments onto the delta shifts these delta front components landward atop the previously deposited delta lobe. The resulting vertical column would then show a stacking of environments from lower, shallow water-type sediments and environment upward into a progressively deeper water representation of sediments. Reconnaissance geology above the barrier island deposits shows a thick accumulation of siltstone and shale that could represent deeper water deposition, but the structural and depositional relationships are not clear and therefore remain speculative.

The interpretation based upon the examination of the Vinini and Valmy Formations requires that deposition at both sites be contemporary and equivalent. Offshore accumulations of shale and siltstone have a lateral relationship to deposition along and in the deltaic environment. The equivalency, then, is one of time and connective depositional environments. The Vinini and Valmy Formations are two parts of a single and laterally-persistent depositional environment and therefore represent one environment. The formational separation, then, is misleading and does not wholly describe the interrelationship between what have been termed the Vinini and Valmy Formations.

Source of Clastics

The source of the clastic material that has been deposited in the Vinini and Valmy "Formations" has been the subject of speculation by many authors. Some authors suggest a generally eastern source for the clastic material (Stanley *et al.*, 1977; Ross, 1977) that was spread into the eugeosynclinal western regime across a carbonate shelf from the North American craton. Ketner (1977) suggested a western source for the clastic material, derived from a gravity spalled front of tectonic blocks shedding material progressively eastward.

Arguments in support of each of these interpretations cite a general framework for the entire west coast of the United States. The interpretation here for the clastic derivation is based upon the localized and geographically-limited nature of deltaic deposition. Its framework is based upon a general interpretation for the Lower Paleozoic development of this segment of the western margin of the United States by Welland *et al.*, (1978) that includes island arc affinities. Within this environment, clastic material is not strictly derived from a single direction, but because of the nature of the ongoing tectonic event requires a shift according to the then prevailing tectonic pattern. The complete framework will be detailed in a later section. It is important to point out here, though, that speculation as to directions of transport of the clastic material is limited until a general tectonic profile is established.

CHAPTER V

Structural Analysis

General Statement

The Roberts Mountains Thrust is a major structure in North-Central Nevada that telescopes western assemblages (siliceous) eastward over eastern assemblages (carbonate). The extent of thrusting has been interpreted to be at least 100 km and probably more (Stanley, et al., 1977). Major movements took place during the Antler Orogeny in the Late Devonian and Early Mississippian (Meriam and Anderson, 1942).

Overall Imbricate Geometry of Allochthon

The Vinini and Valmy Formations are found in the allochthon of the Roberts Mountains thrust belt. These units form parts of the western assemblages and are therefore interpreted to be part of the upper plate of the thrust block. In the area of the Big Creek Canyon of the Toiyabe Range, the difference is striking between the siliceous western allochthon and windows of the eastern carbonates. This relationship is less clear in the Pete's Summit area of the Toquima Range.

Within the area of the North Fork Canyon, normal faulting associated with Tertiary basin and range faulting has brought the allochthon into juxtaposition with the autochthon. Throughout this field area, evidence of such normal faulting is pervasive on all scales, masking and overprinting earlier deformational events (Plate LIV). The latest deformational event resulted in block faulting and a general tilting to the west (Hansen, 1960).

The structure of Pete's Summit area contains less contrast between the allochthon and autochthon and, therefore, remains less clearly defined. The area investigated is part of the allochthon of the Roberts Mountain Thrust and has later undergone extensive basin and range-type faulting.

Although the general structure is regionally well-defined, structure within the allochthon is exceedingly complex and less well understood. Recent work by Evans and Theodore (1978) represents one of the few attempts at systematic study of the minor and major movements found in the allochthon in the Roberts Mountains. Although the area investigated in the study by Evans and Theodore is generally north of the area investigated here and data from these areas cannot represent the deformation over the entire allochthon, clearly certain similar methods can be used to establish the tectonic pattern found in the allochthon investigated in the field area described in this paper.

Systematic Deformational Analysis

Faulting, both major and minor, is ubiquitous throughout the study area. Large-scale faulting is well documented in the Vinini and Valmy Formations (Stewart and Carlson, 1978). Within the measured section of the Valmy Formation

PLATE LIV

at North Fork Canyon, a large, normal fault is apparent in outcrop, displacing beds at least 15 meters on the down-thrown side (Plates LV and LVI). The fault can be traced for at least 1000 meters through the entire stratigraphic section. A component of movement is rotational along a curved fault plane and is probably related to slumping rather than Tertiary block faulting because no associated faulting was observed.

Most folds are generally isoclinal, or very tightly folded (Plates LVII and LVIII). Others tend to be broad, open folds nearly symmetrical in profile (Plates LIX and LX). Evidence of large-scale folding is absent and nowhere is consistent large-scale inversion or tectonic repetition, other than by thrusting, apparent. Asymmetric minor folds are evident (Plate LXI) in the field area and appear to be related to shortening along bedding surfaces. Their relationship to intraformational deformation is unclear, but they probably occur as a result of movement along the limb a large scale antiform or synform (Dennis, 1972, p. 227).

Other units are nearly upright (Plate LXII), displaying little deformation except for a small homoclinal tilt. This particular unit is near the Pete's Summit area and is below what is interpreted to be a thrust contact, thereby owing its attitude to movement along the thrust plane.

Some minor faulting is genetically related to folding. Plate LXIII shows a zone of shearing at the hinge of a tightly folded chert bed. Deformational stress transmitted

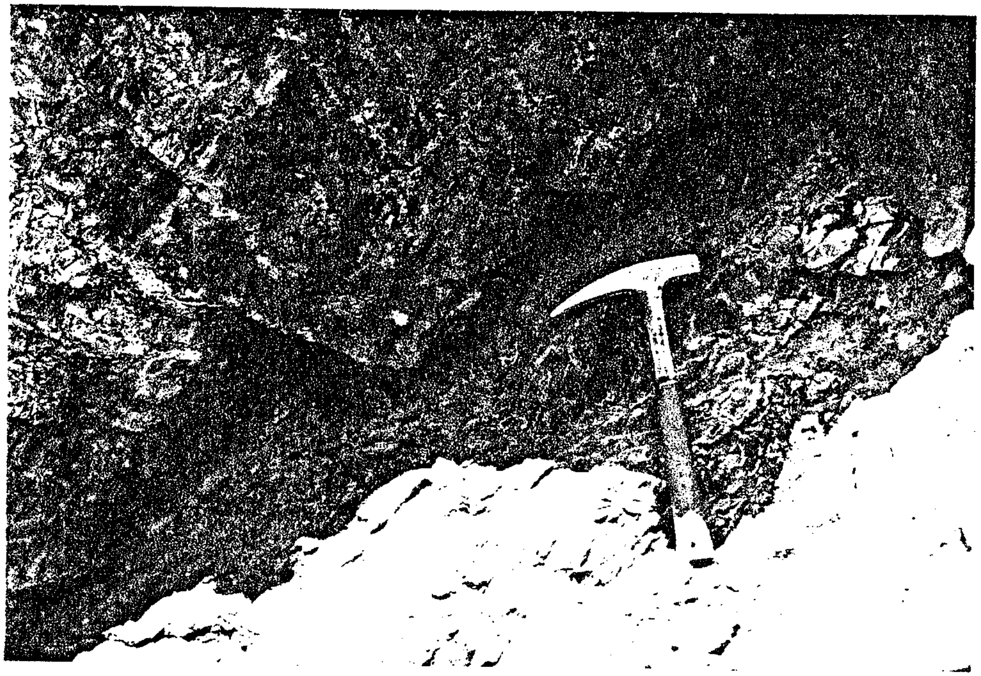

PLATE LV

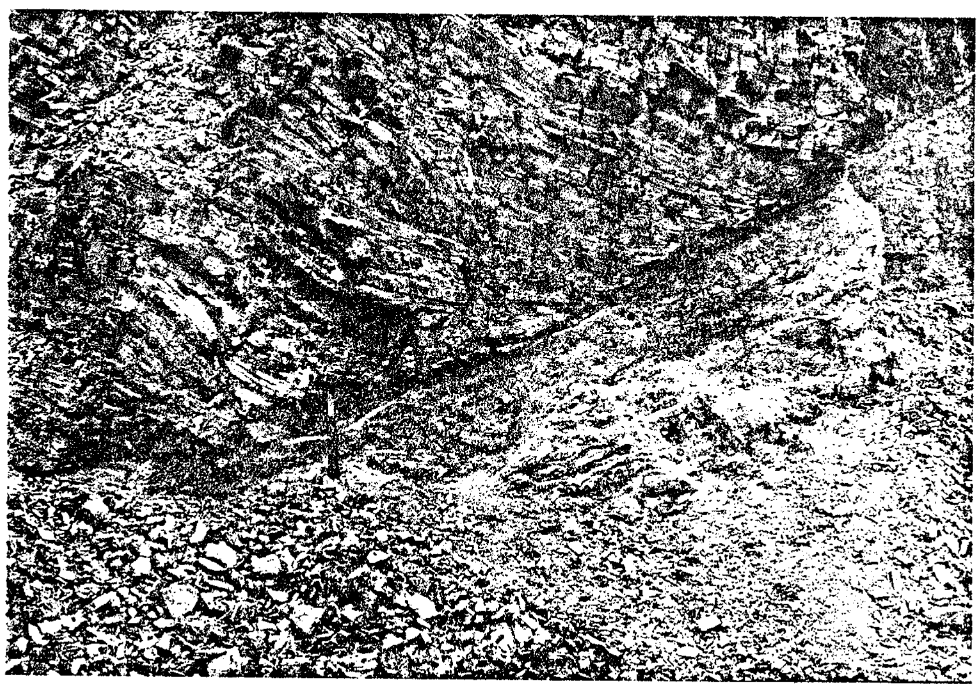

PLATE LVI

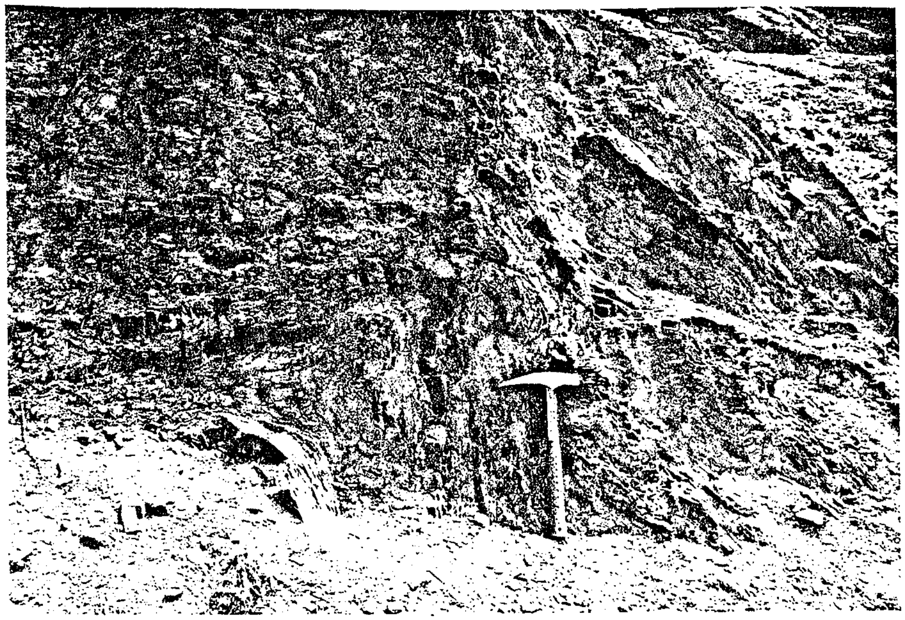

PLATE LVII

PLATE LVIII

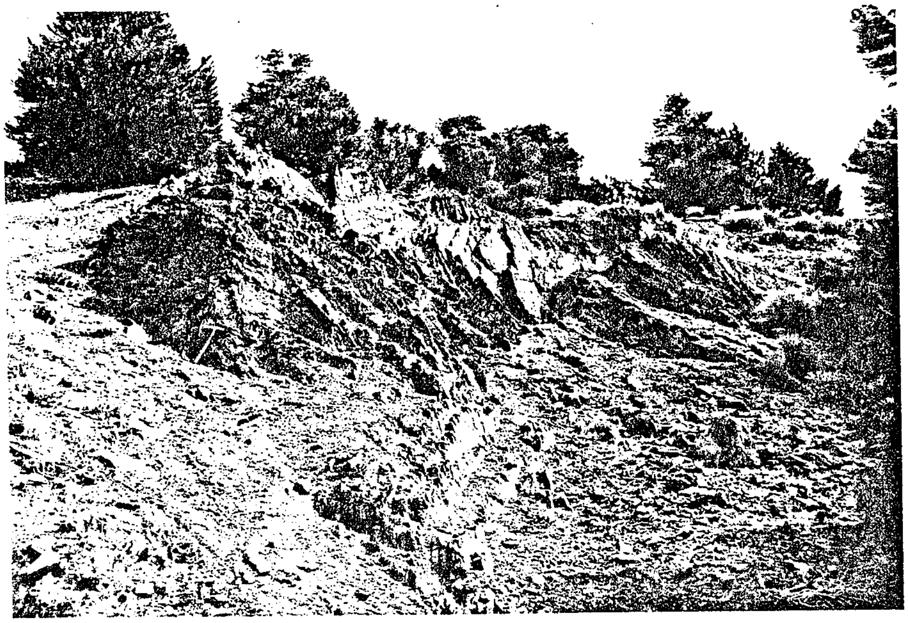

PLATE LIX

PLATE LX

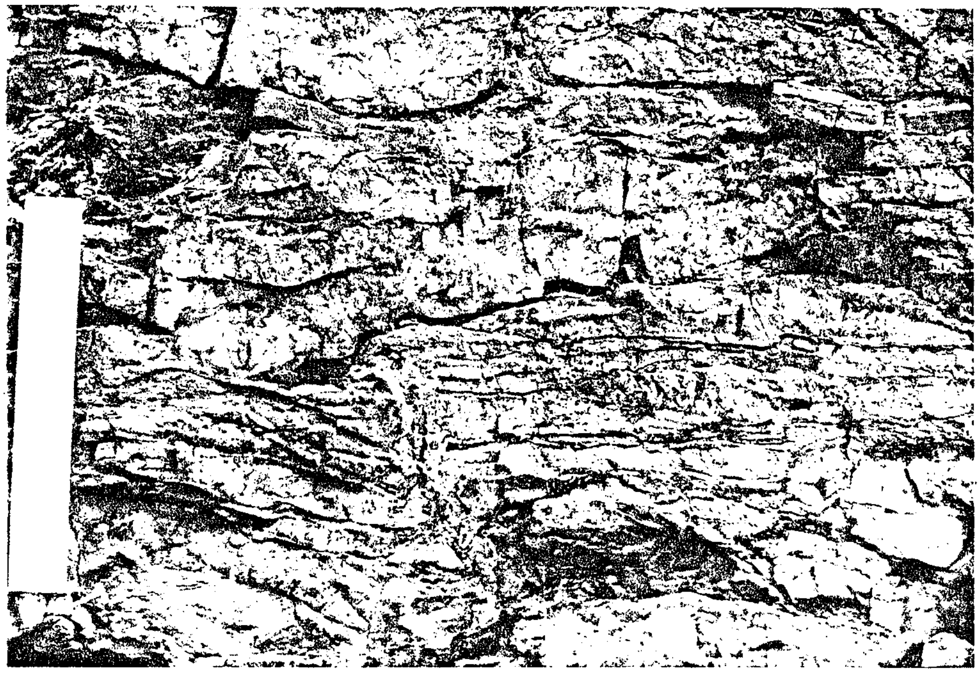

PLATE LXI

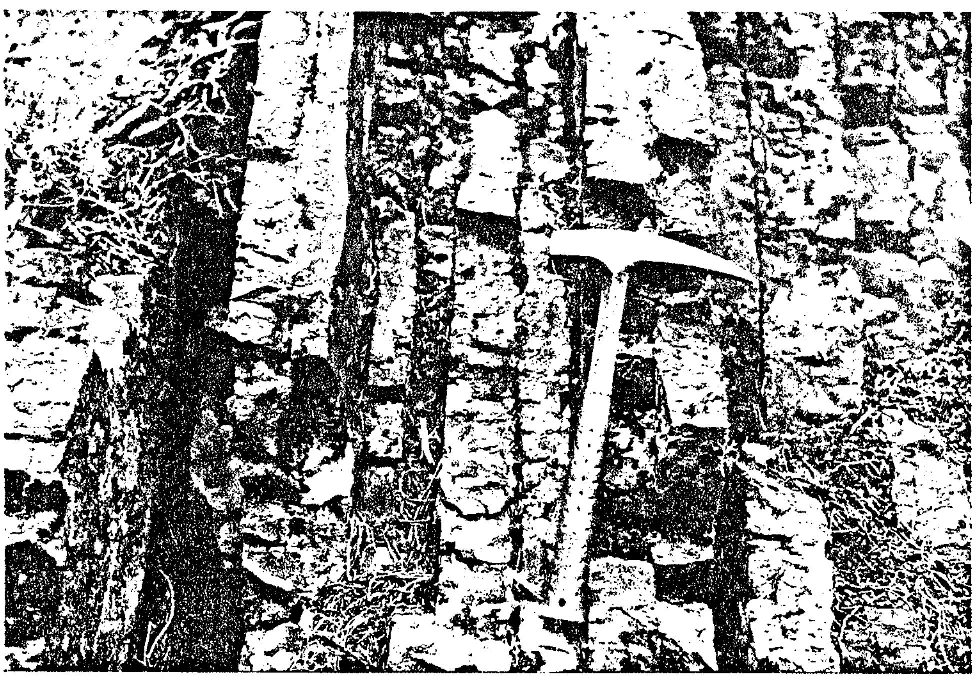

PLATE LXII

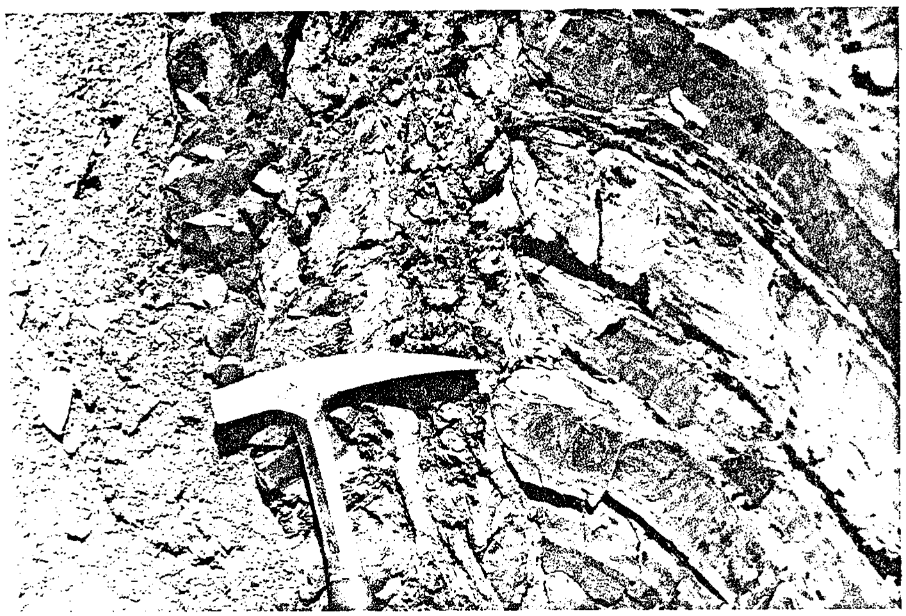

PLATE LXIII

through folding causes failure at the stress point located at the point of greatest curvature (hinge) resulting in movement along a shear zone. The strain is laterally resolved along a plane of shearing in this zone. This same kind of stress causes minor overturning and reverse faulting in more competent beds. Plate LXIV shows a reverse fault in a sandstone bed that has been tightly folded. Other minor faulting is related to Tertiary basin and range faulting resulting in simple displacement of blocks (Plate LXV).

Valmy Formation

Methods employed in this and the following section are based upon those described by Ragan (1973) for structural analysis of deformed units. Data have been plotted on the Schmidt equal area stereographic net and contouring was accomplished using a counting net described by Kalsbeek (1963).

The bedding orientations in the outcrop area of the Valmy Formation at North Fork Canyon are represented by the S-diagram in figure 11a. Poles to bedding form a broad girdle that runs northeast to southwest. Two point maxima suggest two preferred orientations of beds steeply dipping to the northeast and less steeply to the southwest. Two preferred orientations strongly suggest a series of antiform/synforms asymmetric to the northeast. This relationship indicates a northeast to southwest shortening in the Valmy Formation.

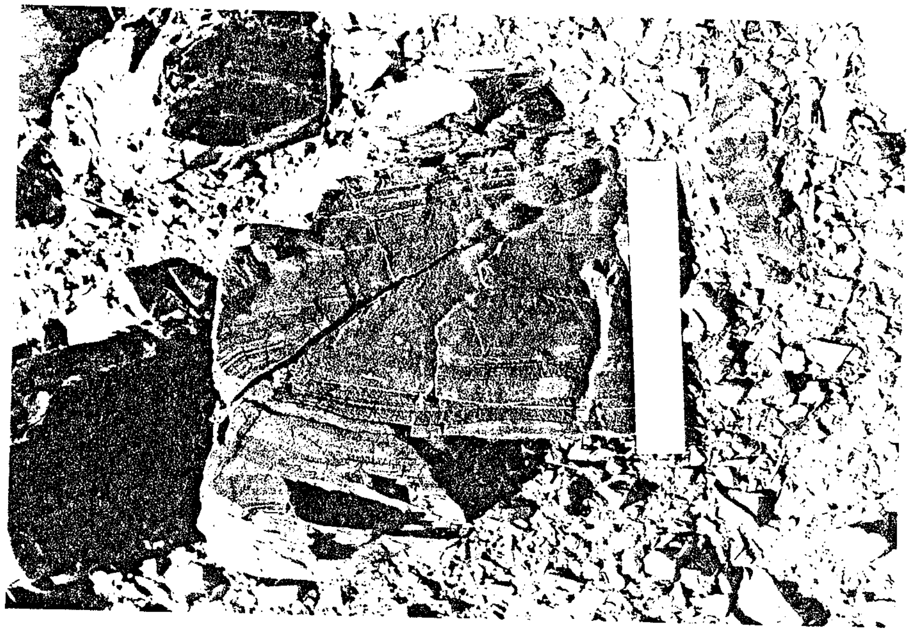

PLATE LXIV

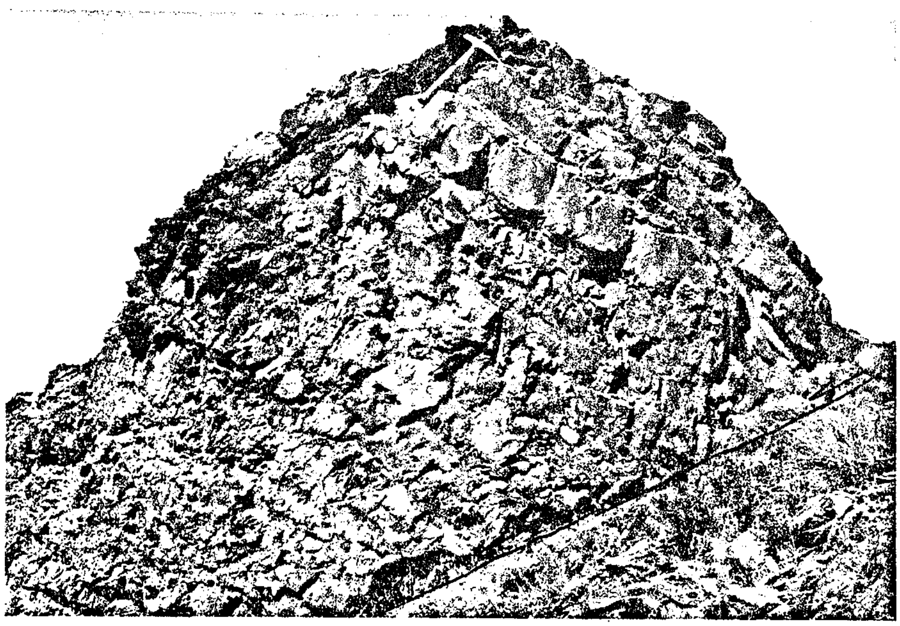

PLATE LXV

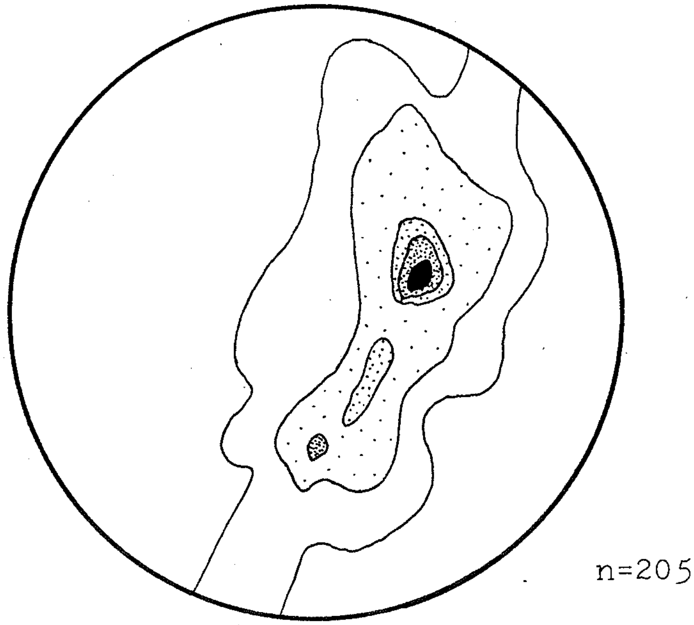

Figure 11a. Contoured pole to bedding diagram for the Valmy Formation.

14-12% 11-9% 8-6% 7-4% 3-1%

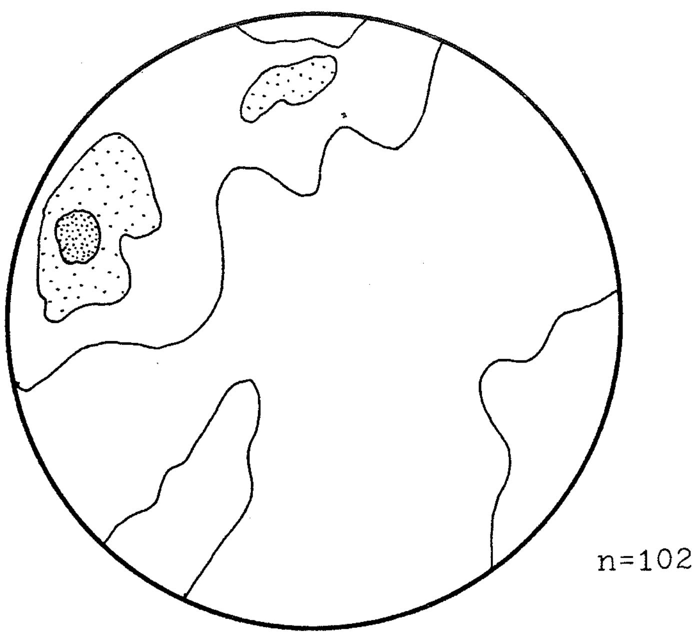

Figure 11b. Contoured fold axes diagram for the Valmy Formation.

Variability of preferred orientations of fold axes is represented by the dominant northwest orientation shown in figure 11b and less apparent north-northeast direction. This pattern suggests a curvilinear fold axis, suggestive of polyphase deformation. Figure 12 shows this relationship in which a cylindrical fold that had an originally planar axial plane has undergone another phase of deformation causing curvature of the axial plane. Exact timing of these deformational events is not clear.

Deformation within the Valmy Formation represents shortening in a general northeast to southwest direction. Refolding of the first-phase deformational remnants is indicated statistically through the occurrence of two point maxima in the fold axes diagram. On the smaller scale, deformation probably occurred as a response to major thrusting in a relatively easterly direction by the Roberts Mountains Thrust. Overprinting and rotation by the same or later deformational events are apparent in outcrop and are statistically indicated on the plots.

Vinini Formation

The orientation of poles to bedding in the Vinini Formation of the Toquima Range shows a point maximum (fig. 13a) indicating steeply dipping beds striking northeast to southwest shown by the orientation of fold axes (fig. 13b). Profiles show that folding is relatively broad and open (Plate LIX). Its proximity to a thrust fault biases the

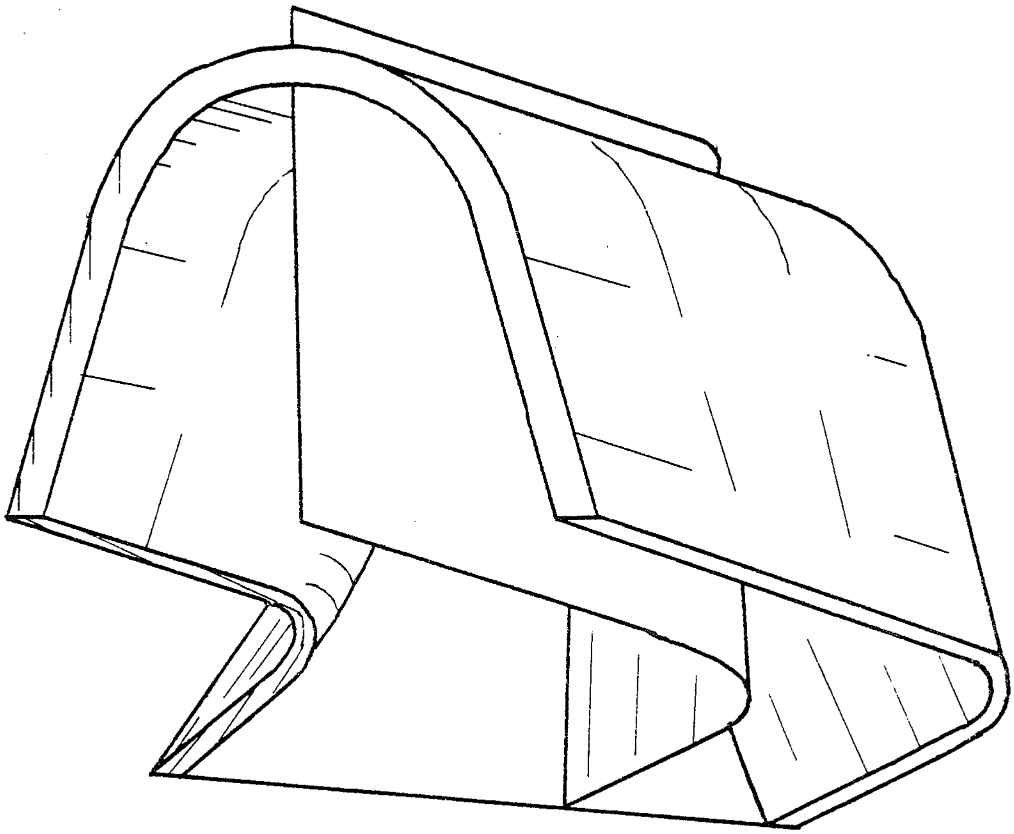

Figure 12. Curvilinear fold axis of deformed cylindrical fold.

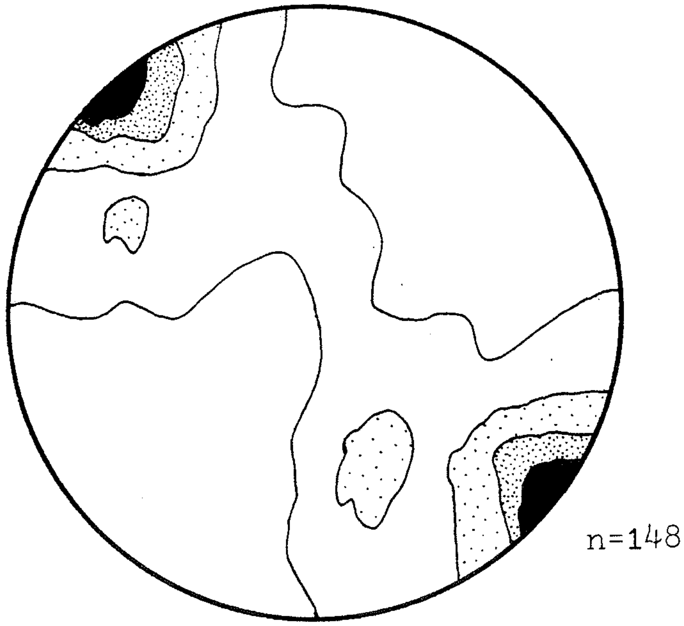

Figure 13a. Contoured pole to bedding diagram for the Vinini Formation.

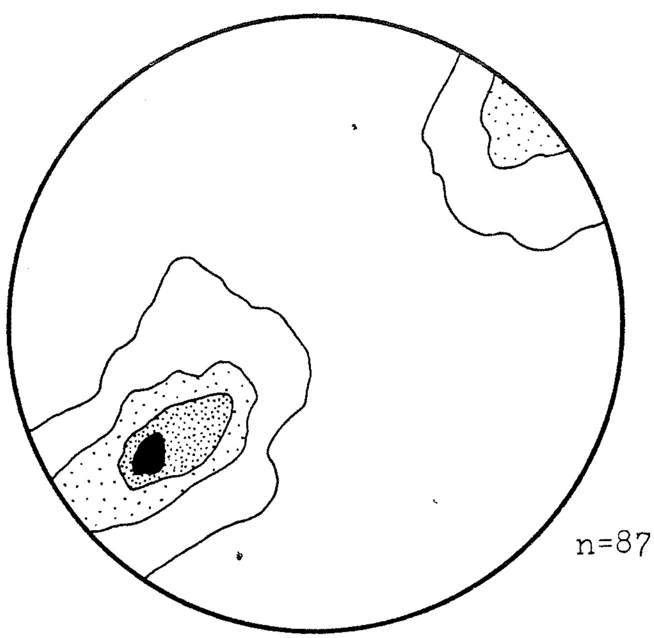

Figure 13b. Contoured fold axes diagram for the Vinini Formation.

plots indicating its steeply dipping orientation. Figure 14 shows this relationship of folding to the thrust plane.

This section of the Roberts Mountains Allochthon shows little or no evidence of polyphase deformation, probably due to its proximity to a thrust contact. Resolution of stresses could occur along the pre-existing thrust surface, thereby minimizing the impact of the transmitted stress field at this point. There is evidence of rotation along this thrust surface by the attitude of similar beds above and below the thrust contact. Figure 14 shows this relationship where movement along the thrust surface may have rotated the lower block to an upright attitude. Clearly, the difference in attitudes is striking and must result from deformation localized at the thrust contact.

Shortening occurred in a general northwest to southeast direction but remains ambiguous due to the presumed rotation along the thrust faults in this area. The Vinini and Valmy Formations show similar tectonic patterns and are therefore presumed to be affected by similar tectonic events comprising the Antler Orogeny. The differences in directions of shortening and movement indicated by the S-diagrams (figs. 11 and 13) (i.e., northwest to southeast in the Vinini Formation and northeast to southwest in the Valmy Formation) are interpreted here to be the result of rotational movements that occur in slices that are incorporated in active subduction complexes.

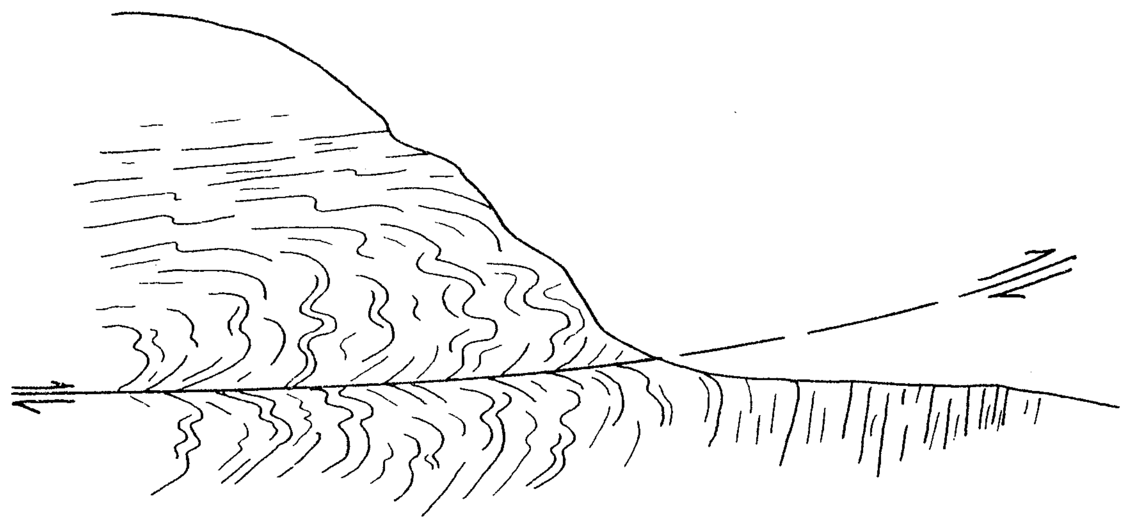

Figure 14. Cross sectional view of a thrust fault examined at Pete's Summit, Toquima Ranges. Note the degree of deformation in the upper block near the thrust fault.

Conclusions

Relative east to west movements envisioned for the Roberts Mountains Thrust are apparent on a minor scale in the sections examined here. This is consistent with the conclusions reached by Evans and Theodore (1978). Their investigation of the structural development of the area north of the Toquima and Toiyabe Ranges near Battle Mountain has shown that there remains a northwest to southeast shortening in that area much like that found in the Vinini Formation. This direction is consistent with the eastward direction of movement accepted for the allochthon. A possible post-Antler episode of folding is evident in the curvilinear fold axes found in the Valmy Formation. This is consistent with conclusions reached by Evans and Theodore for the northern section of the Roberts Mountains Allochthon.

The implication here is that the tectonic regime that has operated on the area north of Pete's Summit and North Fork Canyon is probably similar to, if not the same as that operating in this study area.

CHAPTER VI

Components of the Tectonic Setting

The tectonic setting is one that interleaves deltaic and associated sediments with turbidites and other deep sea sediments described by others (including radiolarian chert and mafic pillow lavas) (Stanley <u>et al</u>., 1977; Kay and Crawford, 1964; Ross, 1958; Wrucke, Churkin, and Heropoulos, 1978). It is proposed here that the framework in which these associations are common is one that includes an active subduction complex.

Detailed examination of the range of subduction complexes is beyond the scope of this thesis (for reviews see Dickinson and Seely, 1979; or, Karig and Sharman, 1975). Figure 15 is a schematic diagram of the important components of a subduction complex, including the arc-trench system, based upon the work of Karig and Sharman (1975).

The major components that are important to the interpretation here are the forearc basin and the structural high created by the stacking of off-scraped wedges in the trench. The sediments in the forearc basin typically consist of clastic deposits derived from the volcanic arc and its roots (Dickinson and Seely, 1979). Continental margin, arc-massif basin sediments are, in part, non-marine. Where river systems empty into forearc basins, the basins fill longitudinally and quickly and are composed of large volumes of shallow marine facies (Dickinson and Seely, 1979).

This framework offers the possibility of a range of

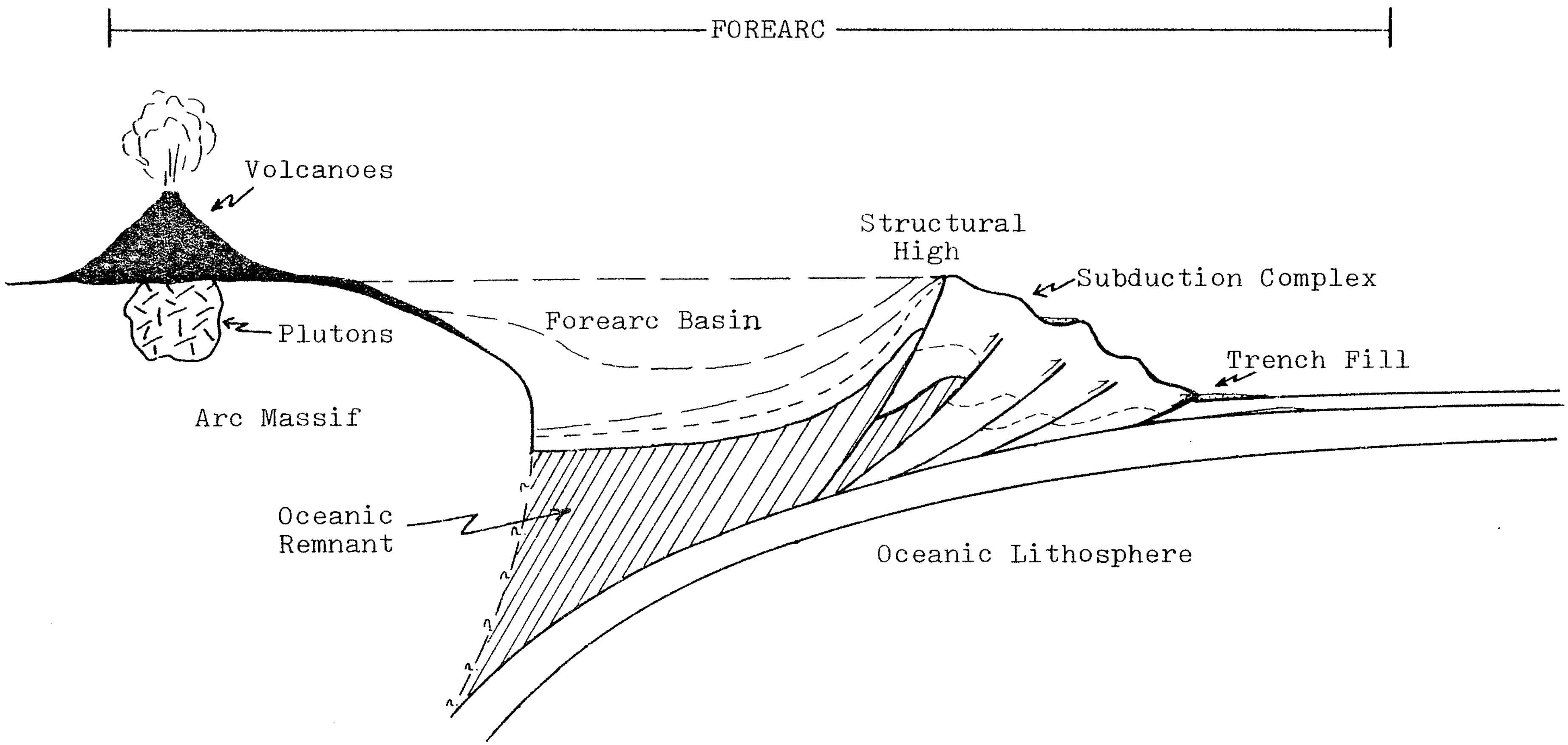

Figure 15. Schematic cross section of a marginal island arc/subduction complex noting the important characteristics referred to from the text. After Karig and Sharman, 1975.

facies that can be incorporated into an active subduction complex. Large-scale imbricate slicing above the trench juxtaposes a wide range of different lithologies that are common in the Roberts Mountains Allochthon. Entire units are preserved in one such imbricate slice, permitting a relatively undisturbed view of a complete facies-type. The nature of this tectonic framework portrays the kind of relationships seen in the field areas of the Vinini and Valmy Formations.

The relationship of thrusting and emplacement of the various facies onto the continental margin will be examined in the following section. The complete framework will be examined in terms of a specific regime that includes an island arc and forearc basin that is interpreted here to be the setting for the emplacement of the Vinini and Valmy Formations in the Roberts Mountains Allochthon.

Reconstruction of the Tectonic Setting

Critical to any reconstruction of the tectonic regime in this study area is the establishment of the depositional environment. Preceding sections have shown that shallow water and near-shore environments characterize the complete framework represented by the Vinini and Valmy Formations. It has also been shown that the formational boundaries are not clearly established here and only one, laterally persistent depositional environment is represented. It has become apparent, however, from detailed studies discussed in previous sections, that the Roberts Mountains Allochthon is comprised of a complex association of widely ranging depositional environments, tectonically juxtaposed. Deep water turbidites, radiolarian cherts and mafic pillow lavas are, in part, represented in other areas of the allochthon. Clearly, the tectonic setting must include a system that intercalates these diverse environments, preserving them as slices like those observed in the allochthon.

Detailed work by Ketner (1977) and other workers (Stanley et al., 1977) has shown that an easterly source for siliclastics for most of the allochthon appears to be unlikely. It now appears probable that these units may have been derived from a broadly western source, either from island arcs or ancient borderlands that may have been marginal to the North American continental margin at that time. Therefore, the tectonic setting must allow for the dispersal of clastic material in a generally easterly direction. Furthermore, the complex intercalation of deep and shallow water depositional regimes must be accounted for.

Recent work by some authors (Welland, Makurath, and Marchel, 1977; Welland, Makurath, Sarniak, and Lee, 1978) has suggested that the framework within such a tectonic association might develop and subsequently emplaced includes an island arc/subduction complex. This type of setting has been described by many authors and have been discussed in preceding sections. From these studies, a clearer picture of the entire tectonic setting has been drawn.

Based on previous work and recent investigations, it is proposed here that this tectonic setting includes:

1) an arc/marginal terrain system west of the North American margin;
2) a west-dipping subduction zone, for at least a part of the development of the complex;
3) a gently-dipping subduction zone that results in a wide forearc basin, possibly floored by remnant oceanic lithosphere;
4) the development of a broad ridge subduction complex or accreting prism.

Figure 15 depicts the schematic cross-section of this kind of tectonic complex. For simplicity, the west-dipping thrust of the Roberts Mountains Allochthon suggests a west-dipping subduction zone existing for at least a portion of the history of this segment of the belt.

Tectonic Development

The nature of the subduction complex, particularly during periods of active subduction, causes movements (both horizontal and vertical) in the area that has been termed the subduction zone. The descent of oceanic lithosphere beneath this marginal terrain results in the off-scraping of oceanic sediments (chert, siltstone, and shale) and the accreting of these sediments onto the edge of the marginal edge as prismatic wedges. Accretion occurs at the base of the inner trench slope just above the downgoing slab and continues stacking up the trench slope, building up the structural high. This development may cause this part of the subduction complex to be a relatively emergent feature. Seismic evidence suggests that the internal configuration in the inner slope has a strong landward tilt of thrust faults (Seely, Vail and Walton, 1974).

The thrust faults that are interpreted to be beneath the inner slope of the trench appear to become progressively older and more steeply-dipping in the landward direction (fig. 15). The progressively steeper dip of the thrust faults may be attributed to the insertion of new, wedge-shaped slices, often containing asymmetric folds, beneath closely spaced, landward dipping, concave upward thrust faults at the foot of the trench inner slope. As these slices underthrust older thrusts and sediments higher on the inner slope, the latter are tilted more landward and produce fan structures.

Ongoing deformation within the subduction complex, repeated stacking, and rise and rotation (including gravitational spreading) of lower, older slices in association with further thrusting, results in tectonic imbrication of contrasting facies slices typical of the Roberts Mountains Allochthon. Clearly, the intercalation of the different facies is the result both of the juxtaposition of wedges at the trench within the subduction zone and the structural kneading of facies deposited on higher levels of the complex.

Sedimentation

Within the framework of a marginal island arc terrain, a range of lithologies exists, including shallow water components. The source of these shallow water lithologies could be derived from the reworking of the sediments that have been shed from the emergent tectonic wedge (structural high). Previous work has shown that small amounts of sediments are ponded behind ridges in troughs on the thrust wedges (Moore and Karig, 1976). These sediments are most often redeposited hemipelagic material that slumped off adjacent topographic highs in the form of turbidite flows.

The development of sedimentary basins in these settings forms part of a continuing cycle of reworking and redeposition as subduction progresses. This type of sedimentation probably results in the formation of both large- and small-scale deltas at the structural high if this feature has risen above sea level. Progradation of the deltas from this high point can occur either landward or seaward, depending upon relative movement of rotation of the stacked wedges within the subduction complex. If rotation is small, then the building out of the delta would likely be landward because the amount of tilt would remain small and the inner trench slope would be greater. Deposition of sediments into the trench would be swept down the slope and reincorporated into the subducting wedge, whereas the smaller angle would be more conducive to deltaic buildup.

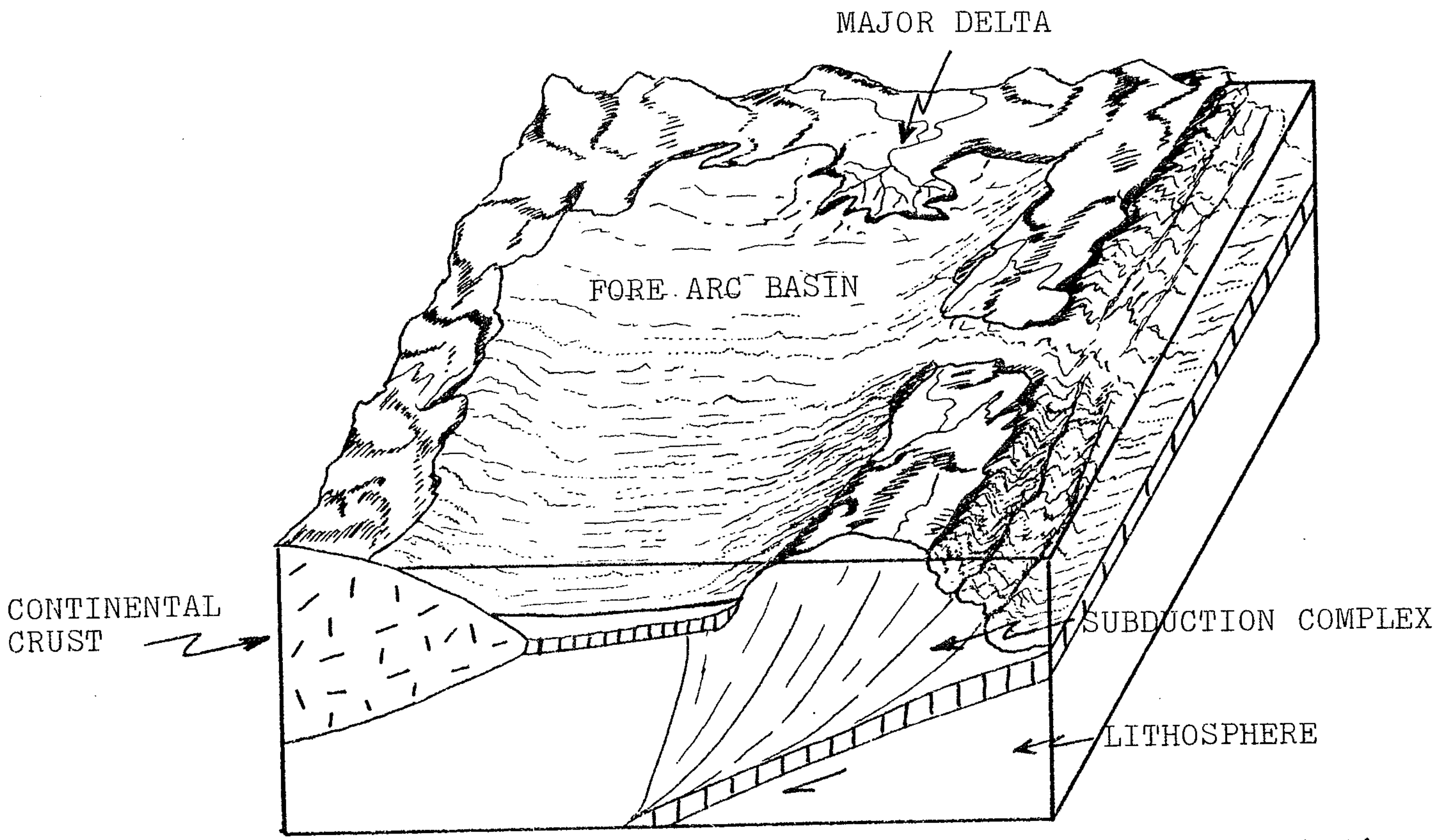

Figure 16. Stylized block diagram depicting the relationship of deltaic development in a forearc basin. After Welland, 1978.

Other settings can be envisioned in which a large delta is built in the forearc basin. Sediments are deposited laterally from the continental portion of the marginal arc system, filling this sedimentary basin longitudinally, Figure 16 is a highly stylized version of this kind of setting modeled after the version discussed by Welland et al., (1978)

It is proposed that a forearc basin of unnamed size was the site of the shallow water deltaic sedimentation. Sources of sediments may be derived as a result of variations in the width of the forearc basin and also from marginal continental sources. Deposition within the basin continued in response to the degree of tectonic movement in the entire regime. Pulses of subduction localized at the trench could cause rapid emergence of the tectonic structural high, thereby exposing more area to erosion, transport, and deposition in the forearc basin. Fluvial systems that drain into the forearc basin from marginal continental terrains might respond to fluctuation of sea level, initiating progradation or degradation in the delta built at the mouths of these rivers. Adjustments to tectonic movement control the deposition or erosion of deltaic systems by maintaining eustatic equilibrium in a highly mobile environment.

Volcanic Associations

The overall tectonic regime envisioned in this thesis includes a volcanic magmatic arc. The relative absence of volcanic material (or, at least, the difficulty in identifying the components) in the Vinini and Valmy Formations suggests that geometric positioning has played a large part in the island arc system. The dip of the subduction zone and the width of the forearc basin may have determined the proximity of the subduction complex to the magmatic arc. The dip of the oceanic lithosphere into the mantle is directly proportional to the amount of surficial displacement of volcanic constituents in the tectonic model. The greater the angle of descent, the closer the magmatic arc is to the subduction zone (Dickinson, 1973). The result of a low-angle configuration could lead to the unavailability of volcanic material for deposition into the delta.

Ross (1977) points out that the configuration of continents throughout the Lower Paleozoic must have been different from today, causing a change in oceanic currents and trade winds. Paleomagnetism suggests that this part of the continent may have been in the zone of southeast tradewinds during the Lower Paleozoic, deflecting volcanic material away from the subduction zone and resulting in little or no accumulation or deposition in the prevailing setting.

Basin Closure

The setting thus envisioned requires a highly mobile and dynamic tectonic regime like that found in an island arc - subduction complex. The evolution of this setting includes ongoing subduction and eventual closing of the ocean basin. This event is marked by the collision of at least segments of the North American continental margin and the subduction complex. The associated tectonic movement would further initiate uplift, deformation and imbrication, and renewed thrusting along the pre-existing thrust planes. Continued movements would result in thrusting of the subduction complex and remnant forearc basin and other diverse sediments onto the continental margin. The emplacement of this allochthonous component is interpreted here to correspond to the Roberts Mountains Allochthon thrusted over the miogeosyncline during the Antler Orogeny.

This thrusting of the subduction complex, including all associated depositional regimes, forms part of the field area examined in this thesis. It is suggested here that the Vinini and Valmy Formations represent a shallow water component of a small portion of the complete tectonic package that constitutes the allochthon.

Concluding Remarks

Segments of the Roberts Mountains Allochthon, particularly those preserved in the Vinini and Valmy Formations, form the basis for delineating the tectonic setting proposed above. The diversity of sedimentological regimes has been established, at least in part, for portions of the allochthon by examining detailed sections in selected locations. The synthesis of this date provides a framework for any reconstruction of the paleo-environment and serves as a basis for establishing a clearer picture of events.

Structural and depositional relationships can be worked out on a limited basis, permitting observations on the local scale for the portion examined in this paper. Overall tectonic settings would then be the result of formulating a model that best serves the requirements of the specifically established structural and depositional regime.

Other research previously cited sought to establish and define the limits of the "eugeosyncline" and "miogeosyncline" for the western margin of the United States. With respect to modern plate theory, the conceptualization of these parameters (strictly defined) places restrictive bounds upon the models proposed by those authors. This thesis has attempted to show that this framework too rigidly confines the tectonic regime envisioned here. The concept of eu/mio-geosyncline does not permit the range of depositional regimes that have been found in so-called eugeosyncline of the western margin of the United States. For that reason, the author suggests that these terms be limited in use when looking further at this area.

Although this thesis addressed only a very small portion of the Roberts Mountains Allochthon, it clearly suggests that further work is needed before an adequate tectonic regime is established. It is hoped that this paper has pointed out significant differences in interpretation for the origin and development of depositional regimes in the Roberts Mountains Allochthon. More work is called for in this area both in limited perspective (as this paper has attempted to do) and in a larger scale.

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APPENDIX

THIN SECTIONS
Valmy FM.

NFS 1 — Fine-grained siltstone
Well-sorted, angular to subangular quartz grains, less than 0.031 mm; silica cement in places comprising less than 20% of total cement, remaining cement is calcite; some mud in layers parallel to bedding; plagioclase feldspar(?) less than 1%.

NFS 5 — Sandy siltstone
Well-sorted, angular to subangular quartz grains in siltstone constituent at 0.05 mm; sand-sized quartz grains at 0.125 mm make up 25% of total; corrosion of sand-sized quartz grain boundaries by calcite includes embayments and boundary deterioration.

NFS 7 — Chert/fine sandstone
"Ghost" outlines of grain shapes throughout the thin section under plane-light illumination; "ghosts" have well-rounded shapes and fine sand-sized about 0.175 mm; widely disseminated sand-sized quartz grains unaltered to chert, but boundaries are indistinct and altering to chert that is indistinguishable from groundmass chert; "ghost" outline disappear and is indistinguishable from homogeneous chert under cross-polarization.

NFS 24 — Very coarse siltstone to sandy siltstone
Poorly-sorted, angular to subangular quart grains, grain size ranges from 0.045 mm to 0.10 mm; pyrite in cubes appears to be secondary, plagioclase (?) feldspar flake showing twinning; many quartz grains are tectonically (?) fractured and are internally altering to chert; some silica cement but main agent is carbonate.

NFS 36 — Chert
microcrystalline chert totally homogeneous throughout; no evidence of ghost outlines; widely dispersed silt-sized quartz grains

NFS 55 — Siltstone
Well-sorted, angular quartz grains 0.015 mm; calcite cement; few widely dispersed sand-sized quartz grains; few mica flakes not parallel to bedding; appears to be less coarse and contain less quartz grains (sand sized) than two previous thin sections (fining upwards?)

See page 139 for correlation to stratigraphic log.

"NFS" abbreviation of "North Fork Section"

THIN SECTIONS
Vinini Fm.

PS 3 Fine-grained sandstone
Moderately well-sorted quartz grains at 0.175 mm, angular to well-rounded; alteration at boundaries and embayments by calcite that comprises the primary cementing in this section; mud laminae near the top parallel to bedding; includes fresh dolomite rhombs and one plagioclase (?) feldspar flake; some corrosion by chert of larger quartz grains at edges.

PS 11 Siltstone
Well-sorted angular silt-sized quartz grains (0.015 mm) in a silica cement; mud laminae parallel to bedding; chert grains that may have been altered quartz grains; some pressure and sutured contact of quartz grains; evidence of alteration to chert in some quartz.

PS 16 b Coarse sandstone - conglomerate
At the bottom of this section, detrital grains of poorly-sorted quartz, chert and calcite in a mud and clay matrix, crude orientaion of grain shapes parallel to bedding; range of sizes from coarse silt-sized to coarse sand-sized particles, also ranges in degree of roundness from well-rounded to very angular; appears to fine upward into a poorly sorted sandstone; grains of quartz dominate upper part that are angular and in pressure contact.

PS 16 t Siltstone
Directly above previous thin section; moderately well-sorted quartz grains in pressure contact; silica cement with some mud laminae at the bottom and none near and at the top; grain shapes are angular but may be due to grain to grain contact; appears to fine grained constituent of a fining-upward sequence.

PS 21 Fine sandstone
Poorly-sorted, subangular to well-rounded quartz grains; 0.20 mm; silica cement comprises about 15% of total section; some grains are fractured and altered to chert along grain boundaries; calcite corrosion along quartz grain edges.

PS 33 Chert/sandstone
Microcrystalline chert with widely dispersed quartz grains that are altering to chert along boundaries; plane-light illumination highlights "ghost" outlines of sand- and silt-sized grains; alteration of portions of thin section by calcite; contains fresh dolomite rhombs.

See page 139 for correlation to stratigraphic log.

PS 38 Orthoquartzite

Moderate to well-sorted angular to rounded quartz grains; grain size at 0.50 mm; over 90% quartz in pressure and suture contact; some silica cement; relatively clean and free of any other constituent or detrital component.

See page 139 for correlation to stratigraphic log.

"PS" abbreviation for "Pete's Summit"

APPENDIX

Stratigraphic Log
Vinini Fm.

Height (meter)	Description
	Base of stratigraphic column
0-17.5	Interbedded siltstone and shale with minor amounts of sandstone. Siltstones are 3 to 10 cm thick containing some primary structures including cross-bedding, ripple and horizontal laminations, climbing ripples. Shale is black to gray and breaks into splintery pieces, contains horizontal and wavy laminations. 2 to 10 cm thick Sandstones are thin (3 cm and less) and contain primarily wavy laminations with minor cross-bedding. All contacts are sharp and laterally persistent across the outcrop area. Deformation increases near the top.
17.5-22	Highly deformed interbeds of siltstone and shale. Bedding planes are preserved but internally structures are obliterated. Appears to be altering to chert. Folding is broad and relatively open but axial planes are steeply plunging.
22-34.1	Deformation decreasing. Preserved beds of shale and siltstone interbedded with sharp contacts. Minor occurences of sandstone that contains faint cross beds and ripple laminations.
34.1-36	Lens-shaped unit of sandstone that is crossbedded and contains wavy to straight laminations going upward. Base is sharp and truncates the underlying siltstone and shales. Unit is 6 meters in outcrop length, decreasing in thickness laterally. These flanks contain limestone nodules (about 15x20 cm in dimension) internal primary structures are traced from surrounding sandstone into the limestone nodule. Base center of unit contains a thin (5 cm) conglomerate, fining upward to a siltstone.
36-40	Interbedded siltstone and shales lying conformably over lower channel (?). Thicknesses are identical to basal interbedded siltstone and shale.
40-42.5	Identical lens-shaped unit observed below but dimensions are smaller. Lateral extent reaches only 4. 5 meters.

42.5-67.5	Interbedded siltstone and shales similar to the interbeds observed at the base of the stratigraphic section. Includes few minor beds of sandstone that are thin and contain faint cross-beds. Few chert beds 5-10 cm thick that contain faint internal structures as wavy and horizontal laminations and are interbedded with the siltstones and shales.
67.5-217.5	Large covered interval that contains sporadic outcrops of interbedded siltstone and shale that is similar to those observed in the basal section. Entire slope is covered with splintery pieces of shale that is identical to the shale seen in outcrop. Near the top of this section, begin to observe large orthoquartzitic rocks as talus.
217.5-230	Massive outcrop of white to gray colored quartzitic rock. Base is in sharp contact with underlying units that are covered by talus from this outcrop. Appears to be highly quartzose and free of detrital material in hand sample. This unit is laterally extensive, and persist for at least 1000 meters as a prominent ridge-forming outcrop. Trough-shaped depressions separate individual units.
230-232	Same unit but develops bedding, 15-25 cm thick. Hand sample does not appear to change and is identical to that observed in the basal section of this outcrop.

Top of stratigraphic column

Stratigraphic Log
Valmy Fm.

Height (meter)	Description
	Base of stratigraphic column
0-20	Interbedded siltstone and shale. Contacts between units are sharp and laterally persistent. Siltstone units are 3 -7 cm thick and shales units are 2- 5 cm thick. Internal structures are primarily straight or wavy laminations with an occassional cross-bedded unit observed. Contains minor amounts of sandstone with some cross-bedding observed internally. Chert units are sparse and 5 cm or less in thickness. These contain some banding with some containing faint internal laminations. Deformation and shearing intense at top due to fault at the top of this unit.
@ 20	Normal fault. Outcrop traced along fault plane to determine if there is tectonic repetition.
20-160	Rhythmically interbedded siltstone and shales, siltstones vary in thickness in this section from 3 to 25 cm, increasing from those observed in the lower section. Contains some chert units that are banded and show no internal structures. Sandstones are thin and laterally continuous and contain some cross bedding and ripple laminations. Other units appear as coarse stringers in a siltstone bed. Some beds are in gradational contact that fine upwards from sandstone to siltstone. Contains sporadic covered intervals. Top of this unit is marked by a normal fault that can be traced laterally to locate identical stratigraphic unit down dip.
160-260	Above fault find monotonous succession of identical lithologies and packages observed in the lower section of stratigraphic section. Few small normal faults are observed but appear related to slumping rather than basin and range faulting and are easily traced.
above 260	Tertiary volcanics that obliterates bedding in this unit. Approximately 15-25 meters of Valmy indistinguishable due to the volcanics.
	Top of stratigraphic column.

Correlation of Thin Sections to Stratigraphic Logs

Vinini Formation

PS 3	15 meters above base
PS 11	17 meters above base
PS 16 b	34 meters above base
PS 16 t	34 meters above base
PS 21	42 meters above base
PS 33	56 meters above base
PS 38	220 meters above base

Valmy Formation

NFS 1	17 meters above base
NFS 5	19 meters above base
NFS 7	20 meters above base
NFS 24	26 meters above base
NFS 36	43 meters above base
NFS 55	89 meters above base

AUTOBIOGRAPHICAL STATEMENT

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