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STRUCTURE AND STRATIGRAPHY OF THE GOODSPRINGS DISTRICT,
SOUTHERN SPRING MOUNTAINS, NEVADA

by
Michael David Carr

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Doctor of Philosophy

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HOUSTON, TEXAS

MAY, 1978
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INTRODUCTION

The Goodsprings district (Fig. 1), a prominent Nevada mining district at the turn of the century, is located at an important junction between the Paleozoic paleogeographic and Mesozoic tectonic trends of the western Cordillera. Isopach lines for the Paleozoic geosynclinal strata trend southwestward through Utah and Nevada then continue into southern California (Fig. 2). The Early Paleozoic platform-miogeosynclinal hinge, marked by the first appearance of Ordovician strata at the Cambro-Devonian unconformity, passes through Nevada southeast of Las Vegas to cross the California state line south of Goodsprings (Burchfiel and Davis, 1975). It has now been traced west to the vicinity of the San Andreas Fault (Miller, 1977). The Mesozoic magmatic arc (Fig. 3) trends southeast along the Nevada-California border (Burchfiel and Davis, 1975), and the Goodsprings district lies along the eastern limit of the Mesozoic magmatic arc. Goodsprings is in the area where the Early Paleozoic geosynclinal hinge line intersects the eastern edge of the Mesozoic magmatic arc.

Early Mesozoic to late Jurassic deformation east of the magmatic arc involves eugeosynclinal(?) and miogeosynclinal rocks in western Nevada and southeastern California (Fig. 3). Several significant thrusts in the miogeosynclinal terrane of south-central Nevada are also attributed to this phase of deformation (Burchfiel and others, 1970). Early Mesozoic

-1-
FIGURE 1 - Map showing the location of the Goodsprings district and of geographic features mentioned in the text. Abbreviations: MS-Mountain Springs, S-Sandy, J-Jean, and G-Goodsprings
FIGURE 2 - Sketch map of late Precambrian through Devonian paleogeography (from Burchfiel and Davis, 1975).
Sketch map of late Precambrian through Devonian paleogeography and areas affected by Mid-Paleozoic deformation. On all paleogeographic maps, the only deformation eliminated is right-lateral displacement on the San Andreas fault. Right-lateral displacements in southern Nevada have not been removed. Isopach lines are from Poole and others (1967) for the maximum thickness of Devonian rocks, Stewart (1970) for the 900 and 530 m (3000 and 1750 ft) isopachs in the Precambrian-Cambrian Wood Canyon Formation, and Ross (1964) for the 30 m (100 ft) isopach in the Eureka Quartzite. Dotted areas east of the geosynclinal boundary are sites of possible Belt-age anulacogens. Black areas are exposures of ophiolites.
FIGURE 3 - Sketch maps of early Mesozoic to Late Jurassic (left) and latest Jurassic to latest Cretaceous (right) paleogeography (from Burchfiel and Davis, 1975).
Sketch map of early Mesozoic to Late Jurassic paleogeography and areas affected by deformation during this time period.

Sketch map of latest Jurassic to latest Cretaceous paleogeography and areas affected by deformation during this time period. Left-lateral displacement of approximately 65 km on the Garlock fault in southeastern California (Davis and Dutchech, 1973) has been removed.
thrusts are well-dated in southeastern California (Burchfiel and Davis, 1971; Burchfiel and Novitsky, 1973). These thrusts involve Precambrian crystalline and Paleozoic platform rocks (Fig. 4).

From the Spring Mountains north, thrusting progressed eastward in time until in the Late Mesozoic the easternmost thrusts disrupted the miogeosyncline to platform transition (Fig. 3). The eastern extent of the thrusts appears to have been controlled by the geosynclinal transition zone. Thrusts in this region are of a decollement type and carry laterally extensive sheets of miogeosynclinal rocks eastward over more cratonal facies. These thrusts are largely controlled by Paleozoic stratigraphy and paleogeographic trends. With only one exception, the Contact-Red Spring thrust (Fig. 4) (Davis, 1973; this study), the thrusts become younger to the east.

In southeastern California, plutons of the Mesozoic arc intrude Paleozoic cratonal rocks (Fig. 4). The thin cratonal sequence exerted no significant control over the thrust geometry. Thrust plates are characterized by involvement of the crystalline Precambrian basement on which the Paleozoic rocks were deposited. In this region, Late Mesozoic thrust faults and structures are superposed on or reactivate earlier Mesozoic structures. Thrusting is confined to a narrow belt along the eastern margin of the Mesozoic arc.
FIGURE 4 - Generalized geologic map of the Spring Mountains and Clark Mountain Thrust Complex (modified from Burchfiel and Davis, 1971). Shows the locations of geologic features outside of the Goodsprings district that are mentioned in the text. Abbreviation: LV-Las Vegas, Nevada
GENERALIZED GEOLOGIC MAP OF THE SPRING MOUNTAIN RANGE

- Tertiary volcanic rocks
- Mesozoic plutonic rocks
- Autochthonous rocks
  - Paleozoic and Mesozoic sedimentary rock
  - Precambrian crystalline rock
- Allochthonous rocks
  - Paleozoic and Mesozoic sedimentary rock
  - Precambrian crystalline rock

Modified from Burchfiel and Davis (1971)
The Goodsprings district lies at the transition between these two diverse structural terranes (Fig. 4) and bears affinities to both. Thrusts in the Goodsprings district, as in the region to the north, are decollement thrusts that cut at approximately the same stratigraphic horizon in each of the major thrusts exposed there. However, unlike in the northern region, the frontal thrust in the Goodsprings area is not the youngest. The Goodsprings district is akin to the southern region, because 1) thrusting shows no consistent spacial-temporal pattern, 2) rocks of the autochthon are deformed, and 3) Mesozoic volcanic and plutonic (?) rocks occur in the area. This unique transitional position within the fold and thrust belt has resulted in some complicated and interesting structural relations in the Goodsprings area.

Three major thrust faults or zones of thrust faults are present west of Goodsprings (Plate I). The through-going Keystone thrust (Fig. 4), traceable from the Muddy Mountains south to the New York Mountains (Burchfiel and Davis, in preparation), is the middle structural unit and also the youngest. It undergoes a westward recess, the Keystone re-entrant, in the Goodsprings area. Remnants of the older Contact thrust plate (Hewett, 1931) are exposed within the re-entrant and below the Keystone plate. The third thrust fault is the Green Monster (Hewett, 1931) and structurally equivalent Sub-Green Monster (this study) thrusts and lies to the west of the Keystone thrust.
The purposes of this study were to:

1) determine the timing, extent, and nature of Mesozoic structures in the Goodsprings area,

2) attempt to understand the evolution of the Keystone re-entrant,

3) determine the detailed geometry of thrusts in the area,

4) evaluate the extent to which the structure of the area is a product of its unique transitional position in the fold and thrust belt, and

5) relate structural events affecting the area to those known from adjacent areas.
GEOGRAPHIC SETTING

The Goodsprings district is located in the southernmost portion of the Spring Mountain Range in Clark County, Nevada (Fig. 1). Goodsprings, a formerly prosperous mining community and the only settlement within the area, is approximately 35 miles (56km) southwest of Las Vegas, Nevada. The district is covered by parts of the Shenandoah Peak, Nevada-California and Goodsprings, Nevada 15 minute quadrangles published by the United States Geological Survey. Nevada highway 53, a paved road connecting Goodsprings with Interstate 15 at Jean, Nevada, provides access from the east. The road travels eight miles (13km) from Jean to Goodsprings then continues westward over Columbia Pass to Sandy Valley (Mesquite Valley) forming the southern boundary of the map area. The district is under the authority of the Bureau of Land Management, which maintains a network of gravel roads throughout the area. In addition to these, there are numerous gravel mining roads, in various stages of repair, which traverse the range making it easily accessible in most places.

Topography in the district is typical of the southwestern desert region. Rugged peaks and ridges are isolated by broad alluvium-filled valleys. The area is virtually barren, with the only vegetation consisting of cacti, Joshua and yucca plants, and a few varieties of hearty desert shrubs. Occasional pinon pines dot the highest portions
of the area and become abundant in the higher parts of the range north of the district. Because of this lack of vegetation, exposure in the range approaches one hundred percent except where covered by talus. The climate is hot and dry, with summer temperatures commonly in excess of 105°F. The only available water is from private wells in Goodsprings and Sandy Valley.

The mapped area (Plate I) includes the main body of the Spring Range south of Potosi Mountain to the Goodsprings-Sandy road (Highway 53), and Green Monster Mountain, a prominent ridge extending westward from the range into Mesquite Valley. The highest elevation, more than 6600 feet (2000m), is on a ridge along the northern boundary of the area. The lowest area, near the Green Monster Mine, is less than 3200 feet (1066m) above sea level.
PREVIOUS WORK

The earliest reports to include descriptions of the geology of the southern Spring Mountains are those of the geologists attached to government and railroad surveys of the southwestern desert regions during the last half of the nineteenth century. (A brief history of the exploration of this region is presented in Hewett, 1956.) Notable among these early works is that of G. K. Gilbert who was the geologist for the Wheeler Expedition (1871-1872). Gilbert (in Wheeler, 1875) described the general structure and stratigraphy of the Spring Mountains and presented a cross section of the range and a measured section at Cottonwood Spring, 15 miles (24km) north of Goodsprings.

Mining interests in the Goodsprings district prompted the United States Geological Survey to study the area during the early 1900's. The earliest study of the southern Spring Mountains was by R. E. Rowe in 1900 and 1901. Unfortunately, Rowe died before his work was published. However, his observations are preserved through a discussion of his field notes by Spurr (1903). Rowe recognized a "great fault" (portions of the Contact and Keystone thrusts) along the eastern flank of the Spring Mountains juxtaposing Paleozoic carbonate rocks over red Jurassic sandstone. Hill (1914) conducted a brief survey of the mines and geology of the Goodsprings (Yellow Pine) district. He also noted the fault along the east flank of the Spring Range. In addition, he
recognized an east-west trending fault which turned to join the "great fault" south of Goodsprings and a major north-south trending fault in the valley west of Potosi Mine. Those are both portions of the fault now known as the Keystone thrust. Hill's major contribution is that he was the first to characterize the style of deformation in the area, writing: "The deformation of the south end of the Spring Mountain seems to have been due to compressive stresses that acted in an east north-east direction and resulted in thrust faulting of considerable magnitude..." (Hill, 1914 p. 236).

The first detailed study of the Goodsprings area was the classic work of D. F. Hewett (1931, 1956). Hewett began his mapping of the Ivanpah quadrangle with the Goodsprings area in 1921 and there defined much of the stratigraphy now used throughout the southern Great Basin. He also recognized and named most of the major structures in the area. Much of his effort, however, was centered around the mining activities of the district. His mapping particularly outside of the Goodsprings quadrangle was, of necessity, on a reconnaissance basis. Hewett's work was invaluable to the present study. In addition to the reports of Hill and Hewett there are numerous short papers published prior to 1931 which deal with various aspects of the mining operations at Goodsprings. A bibliography is presented in Hewett (1931). Albritton and others (1954) published a detailed report on some of the mines in the district.
Recently, detailed mapping has been completed both north and south of the Goodspring area. The northern and central Spring Mountains have been mapped by Burchfiel and others (1974) and the Clark Mountain thrust complex to the south (Fig. 1) has been studied by Burchfiel and Davis (in preparation). Both studies present valuable data concerning the timing and nature of structural events in the foreland fold and thrust belt. Clary (1967) mapped the easternmost portion of the Clark Mountains and Cameron (1978) remapped the Potosi Mountain area immediately north of the area of this report.

Gans (1974) measured several stratigraphic sections in the Spring Mountains from Red Rock Canyon, 10 miles (16km) west of Las Vegas, to the Nevada-California state line. Based on these sections, he has redefined the stratigraphy of the Goodsprings Formation, recognizing several mappable units which were used in this report. One of these sections, the Keystone section, was measured in the Goodsprings district. Bereskin (1976) also measured sections near Goodsprings in conjunction with a study of the Devonian Sultan Formation throughout the southeastern Great Basin.

Note:

Detailed maps of many of the mines in the Goodsprings district were prepared by Hewett (1931) and later by Albritton and others (1954). No effort was made during the present study to re-map any of the mine areas in greater
detail, because: 1) most of the mines were no longer safe
to enter, 2) many of the mine areas are now covered by
extensive tailing piles, and 3) greater detail would not
have measurably improved interpretaiton of these areas. I
have made free use of underground data presented in the U.S.
Geological Survey reports. However, in some instances my
interpretation of these data differs from that of the origi-
inal author.
PRESENT STUDY

Geologic mapping was done on a topographic base that was photographically enlarged from portions of United States Geological Survey 15 minute series topographic maps to a scale of 1:24,000 (7.5 quadrangle scale). The maps used were portions of the Shenandoah Peak, Nevada-California (1956) and Goodsprings, Nevada (1960) quadrangles. Mapping was conducted during the spring and summer months of 1976 and the summer of 1977. In all, approximately five months were spent mapping. Aerial photographs were used as mapping aids, particularly in locating alluvium-bedrock contacts.

Stratigraphic thicknesses presented in this report were obtained in part by measurement in the field using a Jacob's staff. Four sections, one in each structural unit, were measured. Thicknesses not included in the measured sections were estimated from maps, cross sections, and aerial photographs. Thin sections were studied to supplement field and hand specimen descriptions as necessary.

The K-Ar radiometric date reported herein was determined by Dr. J. A. S. Adams of Rice University using a sample of biotite separated by heavy liquid and magnetic methods by the author.
STRATIGRAPHY

Pre-Pleistocene sedimentary rocks exposed in the Goodsprings district range in age from Middle Cambrian to Upper Jurassic. All but the youngest of these were deposited prior to the inception of the tectonic activity affecting the region. The majority of the Paleozoic rocks are represented by a sequence of shallow marine carbonate rocks. The first significant influx of terrigenous material did not occur until the Permian. Both carbonate and terrigenous rocks were deposited in the Early Triassic, but beginning in the Late Triassic shallow marine and continental terrigenous deposition dominated the remainder of the Mesozoic. The upper portion of the section, Permian to Jurassic, is exposed in the autochthon and additional outcrops of Permian terrigenous and carbonate rocks are found in the Keystone thrust plate (Plate I). Older Paleozoic rocks only crop out in the allochthonous terrane.

STATIGRAPHIC NOMENCLATURE

Hewett (1931) published one of the first systematic stratigraphic nomenclatures for the southeastern Great Basin, defining most of his Upper Cambrian through Permian units from exposures in the Goodsprings district. Few new names were introduced for units of Mesozoic age, because Hewett was able to correlate these with formations already
named and described from the platform sequence of the Colorado Plateau.

The name Goodsprings Dolomite (Hewett, 1931) was applied to the oldest rocks in the district. According to Hewett, this formation, which consists of a sequence of dolomites and cherty or silty dolomites, ranged in age from Late Cambrian to Devonian(?). Gans (1974) redefined the Goodsprings Formation recognizing that it contains a sequence of rocks that are divisible into units that can be correlated with the Bonanza King and Nopah Formations defined in the Providence and Nopah Ranges (Hazzard and Mason, 1936; Hazzard, 1937). In addition, Gans proposed the name Mountain Springs Formation for the sequence of rocks equivalent to the uppermost part of the Goodsprings Dolomite and disconformably overlying the Nopah Formation. Based on meager fossil evidence, Gans assigned a Late Ordovician to Devonian(?) age to the Mountain Springs, suggesting that a major disconformity is present between it and the Nopah. The formation is not lithologically distinct and is difficult to identify, thus it was included in the Nopah Formation in this study.

The stratigraphic nomenclature outlined by Hewett (1931) will be followed in this report with the exception of dropping the term Goodsprings Dolomite in favor of the redefined units of Gans (1974) and the discussion of a Jurassic unit not recognized by Hewett.
BONANZA KING FORMATION (original reference: Hazzard and Mason, 1936; type section: Providence Mountains, San Bernardino Co., California)

Distribution: The Bonanza King Formation has been subdivided into two mappable members, the lower Papoose Lake Member and the upper Banded Mountain Member (Barnes and Palmer, 1961). In the Goodsprings area, the Papoose Lake is exposed at only one locality (NE $\frac{1}{4}$ sec. 5, T.24S., R.57E.), immediately above the trace of the Green Monster thrust (Plate I). The outcrop width is less than 330 feet (100m). The Banded Mountain crops out in all three of the thrust plates. The most extensive exposure in the Contact plate is a steeply dipping, overturned section in the west limb of the Potosi Mine syncline east of the road from Wilson Pass to Potosi Spring. Three fault-bounded blocks of massive to bedded mottled dolomite and laminated calc-silicatated dolomite east of the Contact block near Iron-Gold Mine are also assigned to the Banded Mountain Member based on lithology. Rocks of the Banded Mountain from the basal unit of the Keystone place for its entire length except along the southern edge of Lavinia wash, where the younger Nopah Formation is adjacent to the fault trace. In the Green Monster plate, the Banded Mountain forms much of the rugged terrane west of the southern exposure of the thrust trace. The unit does not occur north of the high angle fault zone south of Green Monster Peak.
FIGURE 5 - Measured stratigraphic sections of the Banded Mountain Member of the Bonanza King Formation. Locations of the measured sections are listed in Table 1 (following Figure 8). Possible correlations with subunits of Gans (1974) are shown in the Keystone plate section. No correlations are proposed for either the Contact plate or the Green Monster plate sections.
STRATIGRAPHY OF THE BANDED MOUNTAIN MEMBER
OF THE BONANZA KING FORMATION IN THE
GOODSPRINGS AREA
Description: The outcrop along the Green Monster thrust exposes the upper 295 feet (90m) of the Papoose Lake Member. The lithology is monotonous, consisting of massive to thick-bedded, dark grey, coarsely crystalline limestone mottled with lighter grey, fine-grained dolomite. The mottles, which account for 50 percent of the rock, are less resistant to erosion than the surrounding dolomite. This gives the outcrop an irregular surface texture. Freshly broken surfaces have a characteristic sulfurous odor.

The Banded Mountain Member was subdivided into ten informal lithostratigraphic units (Gans, 1974). The lowest of these (Cbb-1 of Gans) is an orange-brown weathering, well bedded, silty dolomite that divides the Papoose Lake from the Banded Mountain (Fig. 5). The most complete exposure of this unit is in the Green Monster plate where it conformably overlies the Papoose Lake. There 65 feet (23m) of silty dolomite crop out. The rock contains onkoids and rip-up clasts indicating shallow water deposition. The silty unit is also exposed sporadically along the base of the Keystone thrust plate in the vicinity of Keystone Wash (Plate I). Elsewhere, the silty beds are cut out along the Keystone thrust or obscured by alluvium. It is the only one of Gans' units that can be confidently correlated from the Keystone to the Green Monster plate.

The remainder of the Banded Mountain Member consists of a variety of dolomitic lithologies that Gans subdivided
on the basis of color, mottling, presence or absence of
cert, banding, and bedding character. The lower half of
the member is characterized by several dark grey, mottled,
massive to thick-bedded, cliff-forming units that are inter-
layered with less resistant intervals of light and dark grey
banded dolomite (Fig. 5). Some units contain distinctive
cert nodule-bearing horizons. One such cherty interval
near the middle of the Keystone plate section (Cbb-6, Fig. 5)
may be correlative with the chert-bearing interval just below
the middle of the Green Monster section, but the correlation
cannot be confirmed unequivocally. The upper part of the
Banded Mountain consists of lighter grey, well-bedded to
laminated dolomites, which are variously mottled or banded,
and rarely contain abundant cert. The upper contact of
the member is clearly defined by the abrupt transition to
the silty Dunderburg Shale.

Only the upper few hundred feet of the Banded Mountain
Member is exposed in the Contact plate (Fig. 5). A 975 foot
(300m) Banded Mountain section was measured in the Keystone
plate, but the basal part of the section is faulted. Gans
(1974) measured 1500 feet (460m) of Banded Mountain at Key-
stone Mine. Tectonic slicing of the base of the Keystone
plate may make his measured thicknesses too large. In any
case, there is a thickening of the Banded Mountain Member of
at least 500 feet (150m) and not more than 1000 feet (305m)
from the Keystone plate to the Green Monster plate where
more than 2000 feet (610m) of Banded Mountain were measured. It has not been possible to correlate individual units between the two sections.

Age and Correlation: Gans (1974) correlated the lower part of Hewett's (1931) Goodsprings Formation with the Middle to Upper Cambrian Bonanza King Formation defined by Palmer and Hazzard (1956). This subdivision and correlation was followed in the present mapping.

NOPAH FORMATION (original reference: Hazzard, 1937; type section: Nopah Range, Inyo County, California, inclusive of the MOUNTAIN SPRINGS FORMATION of Gans (1974)).

Distribution: The base of the Nopah is marked by the distinctive Dunderburg Member (Fig. 6), which forms a narrow but persistent orange-brown weathering slope above the Bonanza King Formation. The dolomitic upper part of the Nopah is a moderate ridge-former in both the Keystone and Green Monster plates (Plate I). The Nopah is also exposed in the upturned limb of the syncline at the western edge of the Contact plate.

Description: The Dunderburg Shale Member is composed of 50-100 feet (15-30m) of well-bedded silty dolomite and brown shale (Fig. 6). The lower beds, transitional from the Bonanza King, are typically a coarse grey dolomite with silty laminations. The silty dolomite, which forms most of the unit, is often laminated and contains layers of fossil
FIGURE 6 - Measured stratigraphic sections of the Nopah and Mountain Springs Formations in the Goodsprings district. Locations of the measured sections are listed in Table 1 (following Figure 8). A possible lithostratigraphic boundary between the Nopah and Mountain Springs Formations is indicated.
STRATIGRAPHIC SECTIONS OF THE NOPAH AND MOUNTAIN SPRINGS FORMATIONS IN THE GOODSPRINGS AREA

DATUM IS BASE OF DUNDERBURG SHALE
hash, rip-up clasts and onkoids. The shale intervals rarely crop out and are usually represented by brown weathering zones.

Overlying the Dunderburg is a unit consisting of light to medium grey, bedded dolomite that is characterized by occasional zones of silty laminae and layers of onkoids or lithoclasts (Fig. 6). The unit is locally banded or mottled. It contains zones of chert in the Green Monster section. This interval has been called the transition unit (Cn-1, Gans, 1974).

The remainder of the Nopah is predominantly massive coarse crystalline, white, sugary dolomite. This is the ridge-forming unit of the Nopah. The upper part of the unit becomes thin-bedded to laminated making the location of an upper contact with the lithologically similar Mountain Springs Formation (Gans, 1974) difficult. The Nopah contains an anomalously large amount of chert throughout the Keystone section. Two thin 6 foot (2m) units of white orthoquartzite and orthoquartzite interlaminated with silty dolomite were observed in the Green Monster section.

Nature of the Nopah-Mountain Springs contact: Gans (1974) proposed the name Mountain Springs Formation for the well-bedded dolomite overlying the Nopah and below the basal Ironside Member of the Devonian Sultan Formation. He concluded that these rocks were in the most part Upper Ordovician in age. Gans suggested that the uppermost strata could
be Devonian resting unconformably above the Upper Ordovician and conformable below the Sultan Formation. The upper contact of the Mountain Springs is clearly defined at the base of the distinct stromotoporoid-bearing Ironside Member; the lower contact is less clear.

According to Gans, the basal contact of the Mountain Springs corresponds with a major unconformity between Upper Cambrian and Upper Ordovician strata. A basal conglomerate is present in Red Rock Canyon, west of Las Vegas, but in sections to the south the conglomerate is absent and there is no unequivocal lithologic criterion to mark the contact. Gans placed the Nopah-Mountain Springs contact below the first occurrence of chert nodules in the section above the massive sugary dolomite unit of the Nopah. Cameron (1978) also uses the first occurrence of chert as the criterion for defining the base of the Mountain Springs. There are only two units above the massive sucrose unit of the Nopah in the Contact plate that are not composed completely of dolomite. These are a massive, one-foot-thick (.3m) chert layer present 150 feet (46m) below the Sultan Limestone and a 70 foot thick (20m) unit of silty dolomite, the base of which is 300 feet (90m) below the Sultan. A lithostratigraphic boundary could be defined by either of these units, but without the support of reliable biostratigraphic data the significance of such a boundary is not clear.

A massive chert layer similar to that in the Contact plate is present 300 feet (90m) below the Sultan in the
Keystone plate. It, too, overlies a unit containing silty dolomite. In the Keystone plate, chert nodules are abundant from the top of the massive sucrose unit of the Nopah to the base of the Sultan. Clearly, the presence of chert nodules in the Keystone section does not define a significant stratigraphic boundary. The lithologic succession from massive sucrose dolomite to well-bedded dolomite to well-bedded, laminated, silty dolomite to a one foot (.3m) massive chert layer overlain by more well-bedded dolomite, a succession seen in both the Contact and Keystone plates, may have some stratigraphic importance. However, the relation of this succession to the Mountain Springs Formation as defined by Gans (1974) is not clear. Further study will be necessary to determine reliable lithologic criteria on which to base the mapping of the Mountain Springs. The thickness of the section between the massive chert layer and the base of the Sultan in Keystone plate, 300 feet (90m), is similar to that reported for the Mountain Springs Formation at Keystone Mine, Potosi Mine, and Mountain Springs Pass, 260, 380, and 325 feet (80, 115, and 100m), respectively (Gans, 1974). Cameron (1978) reports a thickness of 345 feet (105m) for another section near Mountain Springs Pass. This may indicate that the massive chert layer is at the base of the Mountain Springs.

Rocks of the Nopah Formation in the Green Monster thrust plate are not similar to those of the Keystone and
Contact plates. In the Green Monster plate, the lower 500 feet (150m) of rocks above the Dunderburg Shale consist of bedded, light grey, sucrose dolomite with clots of coarse-grained white dolomite (Fig. 6). The remainder of the section contains similar sucrose dolomite interstratified with layers of clinkery-weathering black dolomite. One of the two orthoquartzite units present in the Nopah is present 145 feet (44m) above the Dunderburg marking the top of the transition unit of the Nopah. The second quartzite is about 740 feet (225m) above the Dunderburg. It is interesting to note that the upper quartzite unit is at approximately the same stratigraphic level above the Dunderburg as the massive chert layers of the contact and Keystone sections.

Only three terrigenous units known from the Spring Mountains are present in the interval between the top of the Dunderburg Shale and the base of the Sultan Limestone. Those are 1) Eureka Quartzite, 2) Ninemile Formation, and 3) a sandstone at the base of the Nevada Formation (Burchfiel and others, 1974). These are not present in the eastern Spring Mountains but appear at the Cambro-Devonian unconformity when it is followed toward the west (Fig. 7). The Lower Ordovician Ninemile and Middle Ordovician Eureka appear first in the central Spring Mountains. The Nevada Formation (Middle Devonian) appears in the northwestern Spring Mountains section (Burchfiel and others, 1974). The interlaminated silty dolomite and quartzite in the Green
FIGURE 7 - Stratigraphic sections from Frenchman Mountain to the northwest Spring Mountains (from Burchfiel and others, 1974).
Monster section could represent any of the three terrigenous units, but because it is the only unit of this type in the section (lower quartzite is presumed to be related to the transition unit) the upper quartzite may correspond to one of the units in the central Spring Mountains. Further detailed stratigraphy will be required to determine which one.

Clearly, detailed biostratigraphic data are needed to determine the ages and define the boundaries of formations present between the Cambrian and Devonian rocks in the Goodsprings district. Lithologic criteria alone prove insufficient for defining the stratigraphy. Because of the lack of macroscopic fossils, conodont biostratigraphy will probably provide the key to the resolution of these stratigraphic problems. Unfortunately, no study of conodonts was undertaken during this study. Therefore, the Nopah and Mountain Spring Formations were not separated in this study.

Age and Correlation: The Dunderburg Shale Member is an important marker horizon, known throughout the Basin and Range for its distinctive Upper Cambrian trilobite fauna (Palmer, 1960). The correlation of the shale unit in the Goodsprings area with the Dunderburg Shale (Walcott, 1908) was based on lithology and stratigraphic position. The rocks overlying the Dunderburg at least as high as the massive sugary dolomite unit are considered to be equivalent to the upper part of the Nopah Formation (exclusive of the
basal shale unit) of Hazzard or the restricted Nopah recognized by Burchfiel (1964). The upper quartzite unit in the Green Monster section (Fig. 6) is tentatively correlated with either parts of the Eureka Quartzite (Middle Ordovician) or the Ninemile Formation (Lower Ordovician) based on lithology and stratigraphic position (Fig. 7). The interlayered dark and light grey dolomite above the quartzite probably correlates with the Upper Ordovician Ely Springs Dolomite or equivalent Mountain Springs Formation (Gans, 1974). The upper part of the dolomite section below the Sultan Limestone in the Keystone and Contact plates may be correlative with the Mountain Springs. The lower contact of the Mountain Springs Formation may be marked by the massive chert horizon found in both plates. The author realizes that further data are required to confirm these speculative correlations.

SULTAN LIMESTONE (original reference: Hewett, 1931; type section: Goodsprings district, Nevada)

Distribution: The Sultan Limestone is widespread throughout the Goodsprings district, with excellent exposures occurring in all three of the allochthons (Plate I). Commonly, the Sultan crops out on the lower flanks of the persistent ridges that develop above the recessive slopes formed by the rocks of the Mountain Springs.
Description: In his original description, Hewett (1931) subdivided the Sultan into three mappable units, which he called (from oldest to youngest) the Ironside, Valentine, and Crystal Pass Members (Fig. 8). The ledge-forming Ironside is the lowermost Stromotoporoid-bearing dolomite in the stratigraphic succession. It is poorly bedded to massive and consists of coarse crystalline, medium to dark grey dolomite, commonly with large four inch (10cm) light grey mottles which give the outcrop a blochy appearance. Stromotoporoids occur as brown cherty nodules throughout the unit, but a distinctive layer of organic build-ups is usually present near the base. The upper contact of this member is difficult to establish in many areas because it is gradational.

The Valentine Member is a unit of varied rock types. Three rock types are characteristically present. The dominant lithology is massive, medium grey, sugary dolomite with clots, veins, or laminae of coarse white dolomite. In some intervals bedding and laminations are developed. Interclated with these rocks are beds of massive dark grey dolomite similar in lithology to the Ironside and layers of light grey, fine crystalline, porcelain-like limestone, which is rarely dolomitized. Fossils, including occasional stromotoporoid build-ups, are found throughout the member except in the fine-grained limestones. Chert nodules are found in some horizons.

-31-
FIGURE 8 - Stratigraphic sections from each of the major thrust plates and the autochthon (Goodsprings) in the Goodsprings district. Locations of measured sections are listed in Table 1 (following this figure) along with the measured thicknesses of individual units.
<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY OF APPROXIMATE STRATIGRAPHIC THICKNESSES OF UNITS EXPOSED IN THE GOODSPRINGS DISTRICT</td>
</tr>
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<tr>
<th>AUTOCLAY</th>
<th>CONTACT THRUST PLATE</th>
<th>KEYSTONE THRUST PLATE</th>
<th>GREEN MONSTER THRUST PLATE</th>
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<tr>
<td></td>
<td>Goodsprings Hills Section</td>
<td>Copper King Mine Section</td>
<td>Potosi Spring Road Section</td>
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<tr>
<td>JURASSIC- CRETACEOUS(?)</td>
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<td></td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>Moenkopi Formation</td>
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<tr>
<td>Ironside Member</td>
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<td>CAMBRIAN-ORDOVICIAN(?)</td>
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<tr>
<td>Banded Mountain Member</td>
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<td>975+</td>
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<tr>
<td>Papoose Lake Member</td>
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<td>-</td>
<td>#</td>
</tr>
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</table>

ALL THICKNESSES MEASURED IN FEET

* present - present in section but not measured due to poor or incomplete exposure
* # - complete section of unit not exposed
* - unit exposed in structural block but not in measured section

LOCATION OF SECTIONS

- Goodsprings Hills Section - S. ½ sec. 26, T. 24S., R. 58E.; Goodsprings Quadrangle
- Copper King Mine Section - E. ½ sec. 35, T. 23S., R. 57E.; Shenandoah Peak Quadrangle
- Potosi Spring Road Section - W. ½ sec. 35, T. 23S., R. 57E. (Bonanza King to Mountain Springs), N. ½ sec. 4, T. 24S., R. 57E. (Sultan to Monte Cristo); Shenandoah Peak Quadrangle
- Green Monster Section - N. ½ sec. 5, T. 24S., R. 57E. (Bonanza King), SW. ½ sec. 6, T. 24S., R. 57E. (Nopah to Sultan), W. ½ sec. 1, T. 24S., R. 56E. (Monte Cristo); Shenandoah Peak Quadrangle
Hewett (1931) has reported local brown sandstone lenses in the middle of the Valentine Member. Silty or sandy units are present near the middle of the Valentine in both the Keystone and Green Monster sections. A lens of pure white quartzite occurs in an incomplete section of Sultan in the western part of the Green Monster area (SE of peak 4127, sec. 26, T.23S., R.56E.). This lens is continuous for more than 200 feet (60m) and attains a maximum thickness of 20 feet (6m).

The uppermost member of the Sultan Limestone, the Crystal Pass Limestone, is distinctive lithologically but often forms a gradational contact with the Valentine. Like the limestone units of the Valentine, the Crystal Pass is a light grey, finely-crystalline, porcelain-like limestone that is devoid of fossils. The unit is commonly well bedded to laminated but may be massive. The lower contact of the Crystal Pass was mapped at the base of a thick continuous limestone unit in the Sultan Formation.

There is a consistent westward thickening of all of the members of the Sultan (Fig. 8). The thickness approximately doubles from 400 feet (122m) in the Contact plate to about 800 feet (144m) in the Green Monster. The Valentine Member does not thicken appreciably between the Keystone and Green Monster sections, but both the Ironside and Crystal Pass double in thickness.
Bereskin (1976) interpreted the Ironside as a quiet-water, shallow-shelf deposit. He viewed the heterogeneous rocks of the Valentine Member as representing an environment fluctuating between supratidal, intertidal and subtidal muddy shelf conditions. The Crystal Pass was interpreted as a quiet-water, intertidal to subtidal(?) deposit.

Age and Correlation: The Sultan Formation was originally defined in the Goodsprings district by Hewett (1931). He assigned it a Middle to early Late Devonian age based on fossil evidence. More recently, Bereskin (1976), who studied fossils from the Sultan throughout the Great Basin, concluded that both the Ironside and Valentine were time transgressive, Middle Devonian in the western part of the basin and Upper Devonian to the east. A Late Devonian (Frasnian to Fammenian) age was assigned the Crystal Pass.

MONTE CRISTO FORMATION (original reference: Hewett, 1931; type section: Goodsprings district, Nevada)

Distribution: Like the Sultan, the Monte Cristo Formation crops out in all three of the allochthonous structural units (Plate I), and is a major ridge former in the area.

Description: Hewett (1931) subdivided the Monte Cristo into five subunits (Fig. 8). Although all of these units are recognizable, a three-fold subdivision combining several units was found to be most appropriate for mapping purposes. The lowest map unit (Mmd-a) combines the Dawn and Anchor
Members of Hewett. Rocks equivalent to the basal Dawn Member of Hewett sharply overlie the Crystal Pass Limestone. The Dawn contains Early Mississippian fossils. The Devonian-Mississippian contact has been discussed by Langenheim (1963) who suggests it is paraconformable and by Pelton (1966) who interprets it as marked by an epeirogenic unconformity. Local discontinuous lenses of intraformational limestone cobble conglomerate are present along the contact in the Goodsprings area and indicate local erosion. In general, the Dawn is a dark grey, poorly bedded to bedded, fine-grained limestone which is commonly altered to dolomite. Fossils are common. Layers of orange-weathering chert nodules are present, but a chert-free lithology is dominant. In the Green Monster area, several distinct layers of thin-bedded, less than 6 inches (15 cm), limestone with silty partings are present within the unit. Overlying the Dawn is the Anchor Member of Hewett, which contains limestone identical to the Dawn and abundant chert nodules and layers that form up to 50 percent of the rock. Because of their lithologic similarities, the gradational nature of boundary between cherty and chert-free units, and the large lateral variation in the relative thicknesses of the Dawn and Anchor, the two members were mapped as a single unit.

A monotonous sequence of massive or poorly bedded, light grey dolomite resting above the Anchor is assigned to the Bullion Member of Hewett (1931). The lower contact
of the Bullion was mapped at the top of the limestone containing abundant chert. A light-dark grey color change occurs near the contact but the color change is within the upper Anchor where chert is still abundant. With the exception of one prominent chert-bearing horizon that is present consistently in the upper 100 feet (30m) of the member, chert is rare in the Bullion. Fossils are also rare, but a few poorly preserved, silicified colonial corals are present consistently near the top of the unit.

Sharply overlying the Bullion is a thin, 5-10 foot (2-3m), unit consisting of thin-bedded, fine-grained limestone with orange-weathering silty partings. These rocks are the Arrowhead Limestone Member of Hewett (1931). The basal contact of the Arrowhead is the horizon mapped as the upper contact of the Bullion. The ledge-forming Yellow Pine Limestone Member sharply overlies the Arrowhead. The Yellow Pine, one of the principal ore producing units in the Goodsprings mining district, was named for the largest mine in the district. It is a thick-bedded, fine-grained limestone that has been irregularly altered to coarse-grained white dolomite. Dolomitization is most common in the lower part of the member. Fossil colonial and solitary corals are common. Because the Arrowhead Limestone is thin, it was mapped with the Yellow Pine as a single unit (Mmy).

The Monte Cristo Limestone is approximately 700 feet (215m) thick in both the Contact and Keystone plates (Fig. 8).
In the Green Monster plate it is approximately 1000 feet (300m) thick. The change in thickness takes place primarily by thickening of the Dawn-Anchor and Bullion Members.

Age and Correlation: Hewett (1931) defined the Monte Cristo in the Goodsprings district. He assigned an age of Early Mississippian to the Dawn, Anchor, and Bullion Members and reports Middle Mississippian fossils from the Arrowhead. He suggested a probable Middle Mississippian age for the Yellow Pine, as well. Later, Hewett (1956) reported the age of the formation simply as Early Mississippian.

**BIRD SPRING FORMATION** (original reference: Hewett, 1931; type section: Bird Spring Range, Clark County, Nevada)

Distribution: The type section of the Bird Spring Formation is in the Bird Spring Range, two miles east of Goodsprings. The Bird Spring forms the main body of rocks in the Contact thrust plate (Plate I). It crops out continuously in the highest part of the range from Shenandoah Peak north to near Potosi Mountain. A nearly complete section is exposed in the Keystone plate along the crest of Green Monster Mountain. A one-half square mile exposure of the Bird Spring forms the westernmost outcrop of the Green Monster plate.

Description: A satisfactory lithologic subdivision of the Bird Spring has yet to be devised. The basal clastic unit is widely recognized and has been named the Indian
Springs Member (Longwell and Dunbar, 1936). The carbonate sequence, which comprises the bulk of the formation, remains undivided.

The Indian Springs rests disconformably over rocks of the Monte Cristo Formation. Locally, almost the entire Yellow Pine Member below the basal contact of the Indian Springs has been removed by erosion. The Indian Springs consists of a thick, 50 foot (15m), basal channel conglomerate at the center of section 8 (T.24S., R.58E.). The conglomerate contains angular to well-rounded, pebble to cobble-sized clasts of brown and black-weathering chert in a matrix of calcite-cemented quartz sandstone. The channel deposit reaches a maximum width of about 500 feet (150m) before it is overlapped by 10 feet (3m) of finer grained conglomerate and buff-weathering sandstone, which is a more typical rock type for the Indian Spring. Elsewhere, Hewett (1931) reported the Indian Spring Member directly overlying the Bullion Member of the Monte Cristo. Generally, the Indian Spring is characterized by up to 30 feet (9m) of well-bedded, buff, silty sandstone with interlayered brown shale. It forms a brown weathering slope in an otherwise grey carbonate sequence. Burrowing and cross-bedding are common in the sandstone beds. Limestone-clast conglomerate and calcarenite beds are present locally.

The main body of the Bird Spring Formation is a diverse sequence of carbonate rocks with subordinate fine-grained
clastic rocks. Generally, the basal 50 feet (15m) of rocks are cross-bedded calcarenite. Above the calcarenite, limestone alternates with dolomite, sandstone, and shale in beds that are usually not more than a few tens of feet thick. The diverse, interlayered rock types give the formation a distinctive banded appearance. Hewett (1956) estimated that the Bird Spring contained 70 percent limestone, 10 percent sandstone, 15 percent dolomite, and 5 percent shale. Chert nodules are common throughout the formation and are often silicified fossils. Coral build-ups or brachiopod-rich beds are commonly preserved through replacement by chert. Fusulinid-bearing limestone beds are common throughout the formation.

The thickness of the Bird Spring in the Keystone plate is estimated to be between 5770 and 6370 feet (1760 and 1940m) depending on the position of the upper contact, which is buried in Potosi Wash. No complete sections of Bird Spring are exposed in any of the other structural units in the Goodsprings district.

Age and Correlation: Hewett (1956) reported both Early and Late Pennsylvanian faunas from the Bird Spring in the Goodsprings area, but reports the age limits of Late Mississippian to Permian based on fossil evidence from the Las Vegas quadrangle to the north. Fusulinid studies by Rich (1961) in the Lee Canyon area 30 miles (48km) to the north support a Late Mississippian (Chesterian) to Permian age. Although the upper limit of the Bird Spring was not
clearly defined because of faulting, Rich found fusulinid-bearing strata as young as Leonardian. The lack of any reported Mississippian fossil from the Bird Spring in the Ivanpah Quadrangle (Hewett, 1956) and the presence of a distinct basal disconformity in the Goodsprings area, rather than a paraconformity as reported elsewhere (Langenheim and others, 1962), may indicate that the base of the Bird Spring is time transgressive, but there is no faunal evidence to support this suggestion at present.

PERMIAN RED BEDS (redesignated: Longwell and others, 1965)

Distribution: Rocks mapped as Permian red beds crop out in both the autochthon and the Keystone thrust plate (Plate I). Autochthonous exposures occur along the south flank of the ridge south of Goodsprings. Red beds that are part of the Keystone plate crop out in two isolated exposures adjacent to the jeep trail in Potosi Wash.

Description: South of Goodsprings, less than 50 feet (15m) of the red beds are exposed immediately beneath the Kaibab Limestone. The upper 10 feet (3m) are fine-grained, poorly-beded to massive, buff sandstone mottled with a red-orange stain. Lower in the section exposure is poor, but float indicates red or buff-colored, fine-grained sandstone is present. Pentagonal crinoid segments were found in the uppermost beds.
The best outcrop of Permian red beds in the Keystone plate is south of the jeep trail in Potosi Wash. There approximately 35 feet (10m) of brick red, well-bedded, fine-grained sandstone is exposed. Beds range from a few inches to one foot (0.3m) thick. Cross-lamination is common. The outcrop is approximately 600 feet (183m) stratigraphically above the nearest exposure of the Bird Spring Formation, which dips beneath the red beds from the southeast. Possibly another 1900 feet (580m) of red beds could be hidden below the valley fill between this outcrop and the next outcrop in the isolated hills to the northwest.

Overturned red sandstone beds that are lithologically identical to those just described crop out just east of the sub-Green Monster thrust trace in the hills north of the Potosi jeep trail. These rocks were also mapped as Permian red beds.

Measurements from the map suggest that the Permian red bed unit buried beneath Potosi Wash could be as thick as 2500 feet (760m). Hewett (1931) reported a thickness of 1150 feet (350m) for an autochthonous section in the Bird Spring Range.

Age and correlation: Hewett (1931) correlated the red beds between the Bird Spring and Kaibab Formations with the Supai Formation of the Grand Canyon region. However, Longwell and others (1965) suggested the term Permian red beds for these strata because 1) McKee (1939) expressed
reservations regarding the correlation of the Supai to southern Nevada based on data indicating that the type Supai grades westward into limestone, and 2) Permian fusulinids from the upper Bird Spring Formation indicate that it may in part be time equivalent to the Supai. The designation of Longwell and others is followed here.

KAIBAB FORMATION: (original reference: Darton, 1910)

Distribution: The Kaibab Limestone crops out in the autochthon and in the Keystone thrust plate (Plate I). The Kaibab forms the U-shaped ridge that closes eastward around Goodsprings and the isolated north-northwest trending ridge in the Goodsprings Valley, two miles (3.2km) north of town. Kaibab Limestone also crops out in the easternmost of the three small hills in Potosi Wash (SE corner sec. 24, T.23S., R.56E.).

Description: The lower part of the Kaibab section near Goodsprings consists of massive, lightgrey, fossiliferous limestone with horizons composed of up to 50 percent brown chert nodules. The upper part of the section is more regularly bedded, but poorly exposed and the upper contact is not exposed.

The lower 50 feet (15m) of the section exposed in Potosi Wash contains 1 to 15 foot (.3 to 5m) beds of silty limestone interlayered with green shale. The upper 250 feet (76m) of section is composed of 5 to 55 foot (2 to 16m)
thick layers of massive to thick bedded, mottled, grey limestone separated by intervals of shale, silty limestone, and thin-bedded limestone. Bioturbation of the massive limestone units is common.

Age and Correlation: Hewett (1931) correlated the Permian limestones of the Goodsprings district with the Kaibab Limestone of the Grand Canyon area based on 1) lithologic similarity and 2) similarity of fossil assemblages. Hewett (1956) mapped the outcrop in Potosi Wash as Bird Spring Limestone, but because of its stratigraphic position above the Permian red bed unit, the limestone and shale sequence there must be Kaibab. The Kaibab Formation is known to occur elsewhere in the Keystone thrust plate (Clary, 1967; Burchfiel and others, 1974).

MOENKIPPI FORMATION (original reference: Ward, 1905)

Distribution: The Moenkopi Formation is present only in the autochthon (Plate I). It forms the low hill west of Goodsprings and crops out in the eastern part of Lavinia Wash.

Description: The Moenkopi disconformably overlies the Kaibab Limestone (Hewett, 1931). Hewett reported a basal conglomerate developed locally along the contact, but none was observed in the map area.

The Moenkopi can be subdivided into a lower limestone member, the Virgin Limestone, and an upper red bed member.
The Virgin Limestone is a sequence of fine-grained, yellowish-grey, well-bedded limestone. Beds are up to 3 feet (1m) thick. Above the Virgin Member is a 50 foot (15m) transition zone consisting of interbedded limestone and laminated beds of red quartz arenite. The red bed member consists of laminated, well-bedded, fine to medium-grained, brick red quartz arenite with interbeds of red shale. Cross-laminations and ripples are common structures in the sandstone beds. The red beds are overlain sharply by the Shinarump Conglomerate.

Age and Correlation: Hewett (1931) correlated the basal conglomerate, Virgin Limestone member, and red bed member of the Moenkopi in the Goodsprings district with the lowest three members of the Moenkopi recognized in southwestern Utah (Reeside and Bassler, 1922). The basal contact is interpreted as a widespread unconformity. Hewett reported an Early Triassic age.

SHINARUMP CONGLOMERATE (original reference: Powell, 1876)

The Shinarump Conglomerate is exposed in a small outcrop near the mouth of Lavinia Wash, half a mile west of Goodsprings (NW 1/4 sec. 26, T.24S., R.58E.) (Plate I). The lithology consists of pebbles jasperoid and yellow chert in an olive-colored sandstone matrix. The outcrop is so poor that the thickness of the unit could not be determined. Nearby, are isolated outcrops of limestone and sandstone.
cobble conglomerate which are assigned to the Jurassic-Cretaceous (?) sedimentary sequence because they do not possess the red and yellow chert pebbles characteristic of the Shinarump. The contact between the two conglomerate units is not exposed, nor are the red beds of the Chinle exposed above the Shinarump.

CHINLE FORMATION (original reference: Gregory, 1917)

The Chinle Formation is characterized by red sandstone and shale with a few thin but prominent limestone horizons. The red bed sequence is only exposed in a small outcrop at the northwest corner of section 4 (T.24S., R.58E.) (Plate I). Hewett (1931) mapped that outcrop as Aztec Sandstone, but the thin-bedded, laminated, small-scale-cross-bedded sandstone and red shale in the outcrop are more typical of the Chinle. On the other hand, the more massive buff and red quartz arenite that is interbedded with these rocks is a characteristic Aztec lithology. The sequence of rocks exposed in the outcrop is similar to that at the top of the Chinle section east of Mountain Springs, 10 miles (16km) to the north. There the thin-bedded quartz arenite and shale of the upper Chinle contain thick lenses of Aztec-like sandstone just below the gradational contact with the Aztec Sandstone. The outcrop northwest of Goodsprings probably represents a similar Chinle-Aztec transition. Hewett (1956) reported the age of the Chinle Formation as Late Triassic.
Aztec Sandstone: The Aztec Sandstone is not exposed in the map area. It is present just to the north in the Potosi Mountain area (Cameron, 1978) where it was first described and named (Hewett, 1931). The Aztec is important to the geologic history of the Goodsprings area because it was the last areally extensive deposit prior to Mesozoic deformation. It was presumably removed from the Goodsprings area during a period of deep localized erosion that predated the deposition of a sequence of Jurassic-Cretaceous (?) synorogenic deposits. Hewett (1931) assigned the Aztec a Jurassic age and correlated it with the Navajo Sandstone to the east (Hewett, 1956). It is probably Early to Middle (?) Jurassic in age, but an upper age limit has not been clearly established. The Jurassic-Cretaceous (?) sedimentary sequence discussed below provides some new data limiting the age of the Aztec to pre-Late Jurassic.

JURASSIC-CRETACEOUS (?) SEDIMENTARY DEPOSITS (new unit)

Distribution: A heterogeneous sequence of clastic sedimentary rocks with a small volcanogenic component crops out locally at the head of Lavinia Wash (Fig. 9, Plate I). This will be informally referred to as the Lavinia Wash sequence. Exposures are limited to isolated outcrops in Lavinia Wash, south and east of Lavinia Mine (sec. 21, T.24S., R.58E.) and to the wash east of Prairie Flower Mine (sec. 17, T.24S., R.58E.). The most continuous outcrops
FIGURE 9 - Map showing the distribution of the facies of the Lavinia Wash sequence in the western part of Lavinia Wash (T.24S., R.58E.). Symbols: conglomerate pattern - Carbonate-clast facies, v-pattern - Volcanic-clast facies, vertical lines - transitional units containing elements of both facies. Traces of measured sections (Figs. 10 & 11) are shown as bold lines labeled with the name of the section.
and quartzite with minor amounts of chert and granitic clasts occur in a green-weathering matrix of arkosic sandstone. A pebble count (100 pebbles) showed that volcanic and quartzite cobbles are approximately equal in abundance while chert and granitic rock account for one percent of the clasts. Clasts average 2 to 6 inches (5 to 15 cm) but may be as large as 8 inches (20 cm) and range downward to coarse sand-size. The conglomerate is clast supported. Boulders (0.5 to 1.0 m) of welded tuff on the weathering slope around the pit were also derived from the conglomerate.

The conglomerate unit is overlain gradationally by interlayered pebble conglomerate, coarse to medium grained arkose and minor mudstone. The pebble conglomerate contains rounded to angular clasts of green, grey, and red chert, volcanic rock, and other lithic fragments. The largest clasts are about 3 cm. Beds are from one-half (.15 m) to two feet (.6 m) thick. The color of the pebble conglomerate and interlayered coarse sandstone varies laterally from greenish to brick red. Buff-colored, well-bedded sandstone dominates the upper part of the unit. These are laminated and cross bedded. Occasional thin, less than 6 inches (15 cm), layers of conglomerate occur in the lower third of the sandstone beds and isolated pebbles of chert occur throughout. The sediments are arkosic and contain grains of feldspar, quartz, volcanic fragments, chert, and minor carbonate rock and sandstone fragments. The matrix consists primarily of shards of volcanic glass.
are along the base of the low, alluvium-capped ridge that separates the two washes.

The sequence is divided into two facies based on the composition of the terrigenous material (Fig. 9). Rocks of the volcanic-clast facies crop out in the area of Greenstone Claim in Lavinia Wash (center sec. 28, T.24S., R.58E.). These rocks are derived from a Mesozoic volcanic and clastic source terrane. They also contain some volcanic tuff. The more extensive carbonate-clast facies, which intertingers laterally and vertically with the volcanic-derived rocks, crops out along the edges of Lavinia Wash and along the north side of the wash east of Prairie Flower Mine. The carbonate-clast facies contains rocks derived from a Mesozoic clastic source along with 50-80 percent Paleozoic carbonate clasts.

Description: The rock types present in the Lavinia Wash sequence include conglomerate, very coarse to fine-grained sandstone, red shale, tuff, and layered opal. All of these are present in both the volcanic and carbonate clast facies, but the source terranes for the two facies are distinct.

Volcanic-clast facies: Rocks of the volcanic-clast facies rocks were described and sections were measured at Greenstone Claim (Fig. 10). The lower part of the measured interval is composed of cobble conglomerate subcrop. The conglomerate is exposed in a pit west of the main Greenstone Adit. Clasts of volcanic rock, mostly tuffaceous,
FIGURE 10 - Measured stratigraphic sections of the volcanic-clast facies of the Lavinia Wash sequence from the vicinity of the Greenstone Claim (Fig. 9). Correlations are traceable contacts.
MEASURED STRATIGRAPHIC SECTIONS OF THE JURASSIC SYNOROGENIC DEPOSITS
VOLCANIC CLAST CONGLOMERATE FACIES

RAVINE EAST OF THE GREENSTONE CLAIM

subcrop of cobble to boulder conglomerate with volcanic and sandstone clasts

Im. diameter boulders at this horizon identical in lithology to unit 3 of the Del Monte volcanics

buff, medium-grained, well-bedded arkose sandstone; laminated or cross-laminated; 15-20 cm thick pebble layers in lower 1/3 of unit

conglomerate subcrop containing clasts of sandstone, volcanic rocks, and granitic rocks
Westward, the pebble conglomerate-sandstone unit inter-
fingers with a layer of volcanic rock at Greenstone Adit. The layer of fine-grained intermediate volcanic rock overlies altered sandstone in the adit. Feldspar phenocrysts increase in abundance upward from the contact. Rocks at the top of the adit section are fine-grained, similar to those at the base of the volcanic layer. This fine-grained material was sampled for radiometric dating (Table 2). The upper contact of the volcanic unit is not exposed.

Cobble to boulder conglomerate forms the upper unit of the measured section and is best exposed in the ravine east of Greenstone Claim. Average clast size is larger than in the conglomerate at the base of the section. Forty centimeter clasts are common. Several sub-rounded boulders (1 m) of red, glassy, intermediate pyroclastic volcanic rock scattered in the ravine could only have been derived from the conglomerate. All of these have abundant plagioclase phenocrysts and some contain flattened xenoliths of igneous rock. The boulders are lithologically similar to rocks of unit 3 of the Delfonte Volcanics exposed in the Clark Mountain area (Burchfiel and Davis, in preparation).

The lithology of the sediments of the Greenstone Claim sequence indicate that they were derived from a terrain of volcanic and clastic rocks in which granitic plutons were exposed. The nearest exposed terrain of this sort is in the Clark Mountain area, 30 miles (48km) southwest. The
### Table 2 - Data for Radiometric Date

<table>
<thead>
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<th>SAMPLE</th>
<th>MINERAL</th>
<th>POTASSIUM %</th>
<th>RADIOGENIC ARGON-40 $10^{-9}$ mol/g</th>
<th>RADIOGENIC ARGON-40 %</th>
<th>AGE in Ma</th>
<th>RELATIVE AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>98-V</td>
<td>biotite</td>
<td>4.78</td>
<td>1.37</td>
<td>52</td>
<td>150±10</td>
<td>LATE JURASSIC</td>
</tr>
</tbody>
</table>

**Decay Constants:**

$$\lambda_p = 4.72 \times 10^{-10} \text{ year}^{-1}$$

$$\lambda_e = 0.585 \times 10^{-10} \text{ year}^{-1}$$

**Number of Analyses:** 1

**Rock Type:** Lavinia Wash Tuff

**Sample Location:**

Greenstone Mine Claim Goodsprings, Nevada
15 Minute Quadrangle Center of Section 28
T.24S., R.58E.

**Analyst:** B. Moed, G. Fryer; J.A.S. Adams K-Ar Laboratory, Rice University
Delfonte Volcanics could easily have been the source of the volcanic debris in the Greenstone Claim sequence while the quartzites in the sequence could have been derived from the Mesozoic red bed units exposed at many places in the autochthon. The large size of the volcanic boulders in Lavinia Wash suggest a nearby source area. The intervening terrain between Clark Mountain and Greenstone Claim is covered by allochtonous rocks of the Keystone thrust plate. Thus, it is not unreasonable to assume that the Delfonte Volcanics were once more areally extensive north of their present outcrop area. The presence of tuff interlayered with the sediments in Greenstone Adit and the volcanic glass shards in the matrix of the sandstones further argue for proximity and contemporaneity of a volcanic source.

Carbonate-clast facies: The carbonate-clast facies of the Lavinia Wash sequence was also measured in two incomplete sections, one along the base of the ridge north of the Lavinia Mine road and another north of the old Yellow Pine railroad grade in the wash east of Prairie Flower Mine (Fig. 11). In contrast to the rocks of the volcanic-clast facies, those of the carbonate-clast facies contain no igneous debris. The conglomerates are, instead, composed of clasts of Mesozoic clastic and Paleozoic carbonate rocks. Carbonate clasts representing most of the formations exposed in the Contact thrust plate were identified. Clasts of Shinarump Conglomerate and red sandstone were derived from
FIGURE 11 - Measured stratigraphic sections of the carbonate-clast facies of the Lavinia Wash sequence in the western part of Lavinia Wash (Fig. 9).
LAVINIA WASH NORTH OF MINE ROAD

NORTH OF RAILROAD GRADE, EAST OF PRAIRIE FLOWER MINE

conglomerate subcrop
conglomerate subcrop
red and white clay soil with opal layers

B layer of white opal
sandstone with lenses of conglomerate
pebble conglomerate grades to sandstone
abundant opal in float
fine-grained sandstone with interbedded opal layers
white opal layer
older alluvium

older alluvium
conglomerate and conglomerate subcrop
limestone-sandstone cobbles conglomerate grades upward to sandstone

red weathering quartz sandstone
red weathering shaly slopes with occasional sandstone beds
plast-supported limestone and sandstone cobbles conglomerate with red sandstone matrix

MEASURED STRATIGRAPHIC SECTIONS OF THE JURASSIC SYNOROGENIC DEPOSITS
LIMESTONE CONGLOMERATE FACIES
the Mesozoic section in the autochthon. It was not possible to determine which of the Mesozoic red bed units was the source for individual sandstone clasts.

The conglomerates of this facies are also clast supported. Clast size averages 2 to 4 inches (5 to 10 cm) but some beds of 6 to 8 inch (15 to 20 cm) clasts are present. Larger clasts are consistently well-rounded whereas smaller cobbles may be angular to rounded. Individual conglomerate layers are up to 33 feet (10 m) thick.

Interbedded with the conglomerate are buff sandstone and red shale units. The latter from red weathering slopes and do not crop out. Layers of white opal are sometimes present within the shale horizons. In one locality north of the Lavinia Mine road, limestone is interbedded with opal. The sandstone intervals are gradational with the conglomerate, and the sandstone also forms the conglomerate matrix. These sandstones are medium to coarse-grained and are composed predominantly of rounded quartz grains and lesser rounded lithic fragments cemented by calcium carbonate. Pebbles of chert or limestone are common. Beds are laminated to bedded (less than 1 m). Cross bedding and channeling are common sedimentary structures.

Each of the three rock types, sandstone, shale and conglomerate, account for about a third of the section along the mine road. Conglomerate dominates the section north of the railroad grade. Elsewhere, the conglomerate beds are the only outcrop formers.
The conglomerate of the carbonate-clast facies is interpreted as having a source in the allochthonous terrane. Only the thrust plates to the west could provide a sufficient source of Paleozoic carbonate clasts. The source of the clasts derived from the Mesozoic section could have been in the autochthon.

In the southwest part of Lavinia Wash, the volcanic and carbonate-clast facies appear to be related by lateral inter-fingering. That part of the sequence is in a fault-bound block that has been upthrown northeastward over a block in which only the rocks of the carbonate-clast facies are exposed. The block to the north is broadly folded into a syncline and the Lavinia Wash strata preserved in its core are thought to represent the highest exposed portions of the sequence (Plate III, E-E’). The southern block consists of a south-dipping homocl ine containing both the volcanic and carbonate-clast facies. The volcanic clast facies rocks at the Greenstone mine strike west toward carbonate clast facies rocks at the head of Lavinia Wash.

Several small adits near the center of the block (SE corner, NW ½ sec. 28, T.24S., R.58E.) contain outcrops of buff-colored sandstone with pebbles of volcanic rock and chert in a predominantly-quartz sandstone. A few meters south of the adits is a 15 foot (4.6m) thick layer of carbonate and sandstone clast cobble conglomerate in which there is no trace of any volcanically derived material. The conglomerate
is cross-bedded indicating that it overlies the volcanic-clast facies sandstone in the adits to the north. A hundred meters to the east and stratigraphically down-section are interbedded red sandstone and cobble conglomerate containing clasts of volcanic rock, chert, red sandstone, and limestone. These relations suggest that the facies of the Lavinia Wash sequence grade vertically, as well as laterally into one another. This is further supported by outcrops south and stratigraphically up section from Greenstone Adit. Following the wash south toward the Keystone thrust, the first sub-crop consists of conglomerate containing clasts of volcanic and igneous rock, as well as limestone. Further south, about half way between the adit and the Keystone thrust, there is no outcrop, but the red-weathering soil and float of layered white opal suggest the presence of fine-grained clastic rocks similar to those in the Lavinia Wash sequence preserved in the syncline to the north. Immediately adjacent to the thrust are outcrops of carbonate conglomerate with no volcanic clasts.

The depositional environment of the Lavinia Wash sequence was an alluvial-fluvial system with a dual source area. One source, probably local, was an active volcanic terrane in the autochthon, presumably to the southwest in the direction of the Delfonte volcanic exposures in the Clark Mountains. The volcanic terrane may now be hidden beneath the Keystone thrust plate. This was the source of
sediments and pyroclastic debris for the volcanic-clast facies. A second source was to the west in the allochthonous rocks of the Contact thrust plate. As thrusting progressed, the newly exposed rocks of the Paleozoic carbonate sequence were eroded and their debris transported eastward as alluvial fans into a basin which was probably similar to the present intermontane basins of the region. It is possible (see Structure of the Autochthon) that this basin was fault-bounded to the north restricting the areal extent of the Lavinia Wash sequence and exposing a scarp from which the quartz arenites of the autochthonous Mesozoic sequence, common as clasts in the Lavinia Wash rocks, could have been eroded. The depositional model must also account for the layers of bedded opal in the Lavinia Wash sequence, which could be interpreted as tufa deposits related to hydrothermal activity associated with the volcanism in the area. More likely, however, they represent precipitates forming on the beds of shallow ephemeral lakes in an arid environment. Similar deposits are present in Pleistocene lake deposits in Nevada and are currently forming in Australia. The lacustrine interpretation is supported by the association of limestone with the opal north of the Lavinia Mine road.

Age and Correlation: The age assignment of the Lavinia Wash sequence is based on 1) the correlation of structural events in the Goodsprings district with dated events outside of the area, 2) radiometric data from within the
sequence, and 3) provenance date from the conglomeratic units. A meaningful lower age limit cannot be determined because the basal contact of the sequence is never exposed, nor are there any unequivocal sedimentary contacts with the older units. The sequence is presumed to have filled a canyon cut into the Aztec, Chinle, and Shinarump. A concealed contact with the Shinarump a half mile west of Goodsprings is interpreted as disconformable. Shinarump clasts occur in the conglomeratic units of the Lavinia Wash sequence confirming, at least a post-Shinarump age. Orthoquartzite clasts, some of which are probably Aztec and Chinle debris, also occur in the conglomerate. Because these clasts cannot be differentiated from those derived from the Moenkopi or Permian red bed units, they are not sufficient age constraints.

Biotite from the tuff layer exposed at Greenstone Mine were radiometrically dated yielding a K-Ar age of 150±10 m.y.b.p. (Table 2). This dates at least part of the sequence as Late Jurassic. The structural interpretation of the Lavinia Wash area suggests that the Greenstone Mine sequence is one of the lowest stratigraphic horizons exposed. Because a thick unexposed section could occur stratigraphically below the Greenstone Mine section, the age cannot be considered a lower limit. It may approximate the age of the basal section. Large (1m) boulders of volcanic rock in a conglomerate interbedded with the dated tuff layer are
lithologically identical to rocks of Delfonte Volcanics Unit 3 from the Clark Mountains. A preliminary Ar 40/Ar 39 radiometric age determination on the Delfonte Volcanics has yielded a fusion age of 150 m.y.b.p. (John Sutter, personal communication). This supports the interpretation that the base of the sedimentary sequence is not much older than Late Jurassic.

The upper age limit for the sequence can presently only be limited by the inferred age of emplacement of the Contact thrust plate which overrides the rocks in Lavinia Wash. Structural evidence (see Timing of Structural Events) suggests that the Contact event is correlative with a 138 m.y. old folding event in the Clark Mountains (Davis, 1973). An 138 m.y.b.p. date (Sutter, 1968) has been obtained for the syntectonic Ivanpah Pluton which cores an anticline related to the folding event. Deposition of the Lavinia Wash sequence need not have ceased until the arrival of the Contact plate. Therefore, the youngest part of the sequence may be somewhat, but probably not significantly younger than the 138 m.y.b.p. date. Assuming that the structural interpretation and correlation are correct, the Lavinia Wash sequence is Late Jurassic to Early Cretaceous(?) in age.

Hewett (1931) recognized that the rocks in Lavinia Wash were unusual, but did not appreciate their full significance. He, in questioning language, tentatively correlated the conglomerates and red beds of the carbonate-clast facies with the Shinarump Conglomerate and Chinle red beds,
respectively. He assigned rocks of the volcanic-clast facies to the Moenkopi Formation primarily based on a misinterpretation of the carbonate-clast facies rocks to the west. The data presented above do not completely limit the age of the Lavinia sequence, but they are sufficient to invalidate these early correlations.

Extensive exposures of rocks similar to those in Lavinia Wash are not known elsewhere in the southern Cordillera. There are, however, reports of channel conglomerates that unconformably overlie the Aztec Sandstone and underlie the Contact thrust or its supposed equivalent, the Red Spring thrust, further to the north. The Red Spring thrust, exposed 10 miles (16km) west of Las Vegas, Nevada, was correlated with the Contact thrust (Davis, 1973). Longwell (1926) described and Davis (1973) restudied conglomeratic channel fills up to 8 m in thickness that overlie the Aztec Sandstone and are overridden by the Red Spring thrust. They interpreted these conglomerates as syntectonic deposits on the erosional surface over which the Red Springs block was emplaced. Davis described one deposit in which clasts of Precambrian or Cambrian quartzite, grey chert, Shinarump Conglomerate, and jasperoid derived from the Shinarump fill the base of the channel. The upper part of that channel contains as much as 50 percent Cambrian to Late Palaeozoic carbonate clasts that could only have been derived from the overlying thrust plate. He
interpreted the sequence as recording an initial channel filling from a local source of Mesozoic platform rocks with the later influx of carbonate material heralding the arrival of the Red Springs thrust plate. Davis assigned a Cretaceous(?) age to these conglomerates.

The similarity in age, rock types, and stratigraphic-structural position strongly suggest a correlation of the Lavinia Wash sequence with the channel deposits at Red Springs. Less extensive, but similar, channel conglomerates overlying the Aztec and beneath the Contact thrust in the Potosi Mountain area (Cameron, 1978) are probably also correlative. Channel deposits overlying the Aztec and overridden by the Keystone-Muddy Mountain thrust have been recognized in the Muddy Mountains (Brock and Engelder, 1977), northern Spring Mountains (Secor, 1963), and Clark Mountains (B. C. Burchfiel and G. A. Davis, oral communication). These deposits, although genetically similar to those beneath the Contact-Red Springs thrust, are probably younger and herald the approach of the Keystone-Muddy Mountain thrust plate.

Jurassic-Cretaceous(?) deposits in the Goodsprings district and their correlatives are the oldest known foredeep deposits related to the Mesozoic Cordilleran fold and thrust belt in the United States.
IGNEOUS ROCKS

Only one phase of intrusive igneous activity has affected the map area, although more extensive plutonism and volcanism are reported from adjacent areas to the south (Hewett, 1931). Sills and dikes are intruded along the Yellow Pine-Bird Spring contact and along high-angle faults in the area known locally as Porphyry Gulch, the vicinity of Yellow Pine Mine (Plate I). An additional sill intrudes the Yellow Pine-Bird Springs contact along strike to the north near the Pilgrim Mine (E. \( \frac{3}{4} \) sec. 8, T. 24S., R. 56E.). A major dike intrudes a tectonic contact between the Contact plate and the Lavinia Wash sequence at Lavinia Mine. Other small dikes intrude rocks of the Keystone plate in Keystone Wash, at the Keystone Mine and north of Columbia Pass.

The intrusive rocks are a granitic porphyry which forms rounded, yellow-weathering outcrops in an otherwise rugged grey carbonate terrain. Where best exposed at Yellow Pine Mine, the rock consists of phenocrysts of euhedral potassium and plagioclase feldspar and rounded to euhedral quartz, up to 1 cm in length, set in a fine-grained crystalline ground mass composed of the same minerals. Fine-grained crystals of pyrite are disseminated throughout. The orthoclase phenocrysts are largely sericitized, and weather red.

The Yellow Pine Sill in Porphyry Gulch is intruded along the base of the Bird Spring Formation. It is offset
by and intruded along high angle faults, which for the most part do not displace the entire sill, but rather affect only one contact. The fact that the intrusive rocks are displaced by but also intrude the high angle faults suggest that the two features formed synchronously. Hewett also considered these intrusions to be syntectonic. The faulting in Porphyry Gulch is thought to be related to the last tectonic events associated with the emplacement of the Mesozoic thrusts (see Timing and Correlation of Structural Events). A radiometric date on the porphyry, therefore, would provide an upper limit on the age of Mesozoic structural activity in the area, but because of intensive hydrothermal alteration and lack of mafic minerals no radiometric dating was attempted. Hewett (1931) concluded that the porphyry was either Late Cretaceous or Early Tertiary in age, but there is no data from which to assign an age to the intrusion.

QUATERNARY DEPOSITS

Older Alluvium: Two generations of older alluvium were recognized in the Goodsprings district by Hewett (1931); he designated them as early and later alluvium. They were not differentiated in the present study. The only outcrop of Hewett's early alluvium observed is that which caps the knoll west of the center of section 17 (T.24S., R58E.). It is distinct from the other older
alluvium because of the presence of quartzite boulders which could not have been derived from the nearby range (Hewett, 1931). The later alluvium (Qoa) is more widespread. Extensive outcrops occur between Potosi and Keystone Washes and along the ridge west of Goodsprings. West of Goodsprings the unit consists of locally derived clasts of sandstone and carbonate rocks cemented by calcite. The alluvium is about 300 feet (90m) thick and rests on an eastward dipping erosional (pediment?) surface developed on the deformed Mesozoic rocks. The later alluvium represents dissected alluvial fan deposits.

Recent Alluvium (Qal): The Recent alluvium is locally derived and is characterized by alluvial fan and intermittent stream deposition in the washes which drain both east and west from the range into the Ivanpah and Mesquite Valleys.

SIGNIFICANCE OF STRATIGRAPHIC DATA

In southern Nevada, there is a marked transition from the platform sequence in the east, represented by the Frenchman Mountain and Sheep Mountain sections, to a fully developed miogeosynclinal sequence in the northwestern Spring Mountains (Burchfiel and others, 1974) (Fig. 7). Ordovician and Silurian units are added at the Cambro-Devonian unconformity and they are thicker in each successive Devonian thrust plate westward across the frontal thrust belt in the Spring
Mountains. In addition, other formations already present in the platform sequence thicken westward.

The presence of the Upper Ordovician Mountain Springs Formation in each of the thrust plates in the Goodsprings area suggests that they were all cut from a terrane transitional between the miogeosyncline and the platform. The autochthonous or parautochthonous rocks in Lavinia Wash and the Goodsprings Valley probably represent a platform sequence, more or less continuous with the Sheep Mountain section. If thickness can be used as a criterion for the establishment of the paleogeographic position of a stratigraphic section, then the Contact and Keystone plates were probably derived from nearly the same paleogeographic belt. The thicknesses of formations exposes in both of those plates increases only slightly from the Contact plate to the Keystone plate. The fact that the Mountain Springs is the only formation to appear at the Cambro-Ordovician unconformity in both plates also suggests a close proximity between the two source terranes. Cameron (1978) came to the same conclusion in his study of the Potosi Mountain area.

The Green Monster plate appears to have been derived from a slightly more basinward position in the miogeosyncline. The stratigraphic interval from the base of the Dunderburg to the base of the Bird Spring thickens approximately 40 percent from the Keystone plate to the Green Monster plate. The appearance of terrigenous rocks in the Nopah-Mountain
Springs interval of the Green Monster section is significant even though the identity of the unit has not yet been established. These rocks may represent the eastern feather-edge of one of two Lower-Middle Ordovician clastic units, either the Eureka Quartzite or the Ninemile Formation. Because both of those formations first occur in the same thrust plate in the central Spring Mountains (Burchfiel and others, 1974), it is not clear which of the units appears first at the unconformity. On the basis of lithology, one might speculate that the interlaminated white orthoquartzite and orange siltstone unit in the Green Monster section is the eastern edge of the Eureka Quartzite. Detailed biostratigraphy will be critical.

The stratigraphic sections from the Goodsprings district can be compared with sections across the platform-miogeosyncline transition from Frenchman Mountain to the northwest Spring Mountains (synthesized in Burchfiel and others, 1974; Cameron, 1978). Rocks of the Keystone and Contact sections from the Goodsprings area belong in a position between those of the Keystone plate in the eastern Spring Mountains and the autochthonous rocks at Frenchman Mountain, an analogous position to that proposed for the Contact and Keystone sections in the Potosi Mountain area (Cameron, 1978). Rocks of the Green Monster plate represent a terrain which is intermediate between the central (Lee Canyon thrust plate) and eastern (Keystone thrust plate) Spring Mountain sections of Burchfiel and others (1974). This is consistent
with the structural position of the Green Monster thrust which is analogous to that of the Deer Creek thrust plate, the structural intermediary between the Lee Canyon and Keystone thrusts in the northern Spring Mountains (Fig. 4).

The stratigraphic significance of the Lavinia Wash sequence should also be re-emphasized. Because no complete section was present, the sequence was not given a formal name. None the less, the Lavinia sequence is one of the most important stratigraphic units in the area because 1) it provides valuable information regarding the timing of thrusting in the area, 2) it documents the proximity of Late Jurassic volcanic activity, 3) it places interesting constraints on the style of thrusting in the district, and 4) it provides an upper limit on the age of the Aztec sandstone.
STRUCTURE

The structural style developed in the Goodsprings district is in most ways typical of that in most of the Mesozoic frontal thrust belt from Nevada to Canada. Thrusting and associated folding are of a decollement geometry with detachment in each of the major thrust plates occurring near the same stratigraphic horizon, the base of the Banded Mountain Member of the Bonanza King Formation. The Goodsprings district is atypical of the thrust belt to the north, because 1) thrusts in the district did not develop progressively from west to east, the pattern in most of the northern thrust belt. Faults near Goodsprings show no consistent spacial-temporal relationships. 2) Platform rocks east of the frontal thrust exhibit deformation which predates the emplacement of that thrust. 3) Mesozoic volcanic and plutonic (?) rocks occur within the thrust belt and in synorogenic deposits below the frontal thrust. In these respects, the Goodsprings district is more like the fold and thrust belt further south in the Clark Mountain Thrust Complex (Burchfiel and Davis, 1971). However, unlike the thrust belt to the south, thrusts in the Goodsprings area do not involve Precambrian crystalline rocks or pre-Middle Cambrian clastic rocks at the surface.

The structure of the Goodsprings district is dominated by three main zones of west-dipping thrusts (Plate I), which are from west to east: the Green Monster and Sub-Green Monster zone, the Keystone thrust, and the Contact thrust.
GREEN MONSTER THRUST PLATE

The Green Monster thrust plate is the highest structural unit exposed in the mapped area (Plate I). It occupies the tip of the westward projecting lobe of hills referred to as Green Monster Mountain, and carries slightly thickened (relative to more easterly thrusts) carbonate section from the upper Papoose Lake to the lower Bird Spring Formation.

The thrust first appears from beneath the alluvium in the saddle east of peak 4435 (W. ½ sec. 9, T. 24S., R. 57E.). The fault does not crop out in the saddle but its tract can be located within a few meters between outcrops of Bonanza King and Bird Spring rocks. Southward, although obscured by alluvium, the thrust is indicated by the juxtaposition of the Bonanza King with younger units across a narrow canyon extending for a mile south-southeast from the saddle. The fault cannot be traced along strike to the hills south of the Wilson Pass road, which are composed entirely of rocks of the Keystone thrust plate. It is presumed that the Green Monster thrust is offset in an apparent right-lateral sense by the northeast trending Ironside fault zone. Further south, across the Ironside fault, the displaced portion of the Green Monster plate may be represented by the Sultan thrust mapped by Hewett (1931).

Northward, the position of the thrust can be traced as far as the saddle north of peak 4455 (north part of sec. 5,
T.24S., R.57E.), but again the thrust surface is not actually visible. At the saddle, the thrust is cutting near but not in the silty unit at the base of the Banded Mountain Member. The Papoose Lake Member is exposed above the thrust to the east. Up to this point the thrust is assumed to have approximately the same attitude as bedding in the frontal part of the thrust plate (dipping 30 to 50 degrees west).

The Green Monster thrust turns west-southwest from the saddle and begins to cut up stratigraphic section (Fig. 12). The thrust is then truncated in the canyon southeast of Green Monster Peak by a complicated system of east-west and northeast trending high-angle faults. The thrust surface is only exposed north of here as isolated remnants at the tip of Green Monster ridge. However, its former presence not far above the present erosional surface at Green Monster Mountain is indicated by two structural features. 1) Layering in the Bird Spring Formation generally dips moderately northeast on the ridges leading west from Green Monster Peak, but on the highest parts of the spurs in the western part of this terrain, layering becomes increasingly steeper and finally overturned to the southwest just below their crests. Bedding has been rotated into an overturned syncline immediately beneath the eroded, northeastward-moving thrust plate as demonstrated northeast of peak 4127 (sec. 36, T.23S., R.56E.) where a small slice of the Green Monster
plate is preserved in the saddle above overturned Bird Spring and Yellow Pine beds. 2) Slicing of the Bird Spring terrane related to Green Monster thrusting is developed in the western portion of the area.

The fault bounded block which rests on Bird Spring rocks northeast of peak 4127 is one of two exposures of the Green Monster thrust plate present north of the high-angle fault zone (Fig. 12). This block consists primarily of Sultan Limestone but also contains some of the uppermost Mountain Springs Formation. It is bounded to the southwest by a near vertical fault and beneath by the Green Monster thrust. The thrust surface is exposed in an adit on the southeast side of the saddle just below the level of the saddle where its attitude is N25W; 33SW. Rocks above the thrust are highly fractured and bedding readings may not be reliable.

The second exposure of the Green Monster thrust plate is about a half mile to the west along the same northwest-trending high-angle fault which bounds the block described above. The second fault block contains units of both the Sultan and Monte Cristo Formation. Layering in the block strikes at right angles to the thrust surface which has an attitude of N62W, 18SW, and is at a high angle to the general northwest trend of beds in both the main body of the Green Monster plate and the underlying structural units. The Green Monster thrust is cutting rapidly up stratigraphic
section in this area. In the small thrust block exposed near peak 4127, the thrust is located in the uppermost Mountain Springs and basal Sultan. In the block to the northwest, the fault places basal Sultan over Bird Spring at the southeast end of the block while superposing Bullion over the Pennsylvanian beds at the northwest tip of the exposure, not more than a half mile away. Projecting the thrust along strike into the edge of the Mesquite Valley, isolated outcrops of folded and faulted Bird Spring rocks on both sides of the inferred fault trace are present. Apparently, the displacement on the Green Monster thrust is decreasing toward the north as the fault zone dies out into a folded terrain. The discordant bedding attitudes in the northwesternmost fault block of the Green Monster plate are on the northeast limb of an anticline developed over the thrust. The core area of this fold is partially exposed along the southern margin of the block. The structure has been modified by the later high-angle faults.

A series of lenticular thrust slices involving Bird Spring rocks occurs in the lower plate immediately below the Green Monster thrust in the area between the two remnant thrust blocks. There is a northeast-vergent fold couple with northwest-trending horizontal fold axes in the largest of these slices. The fold attitudes may indicate general northeast transport on the thrust zone.
The only internal deformation of the Green Monster plate that is not associated with the complicated high-angle fault zone is a thrust faulted anticline in the Bird Springs Formation west of Green Monster Mine (Fig. 12). The upthrown block of the thrust contains a northeast overturned anticline with a sub-horizontal, northwest-trending axis. The thrust, which is marked by a 10 m thick zone of fault breccia, dips to the southwest and cuts across the axial plane of the fold from south to north from the overturned to the upright limb of the fold. The footwall is disharmonically folded into a series of smaller (wavelength several tens of meters) folds of the same general attitude.

The zone of high-angle faults referred to previously begins in the canyon at the northeast corner of sec. 6 (T.24S., R.57E.) (Fig. 12). It is believed to have a composite history of movement which begins with tear faulting related to the Green Monster thrusting event. One fault trends southwest down the axis of the canyon. This fault is not exposed but is inferred beneath the alluvium in order to explain the apparent left-lateral offset of the Nopah-Bonanza King contact across the canyon. Because there is no apparent disturbance of Bird Spring rocks along its trend in the lower plate, the fault must either predate Green Monster thrusting or be related to it as a tear fault.

An east-west branch of faulting also begins in the canyon in sec. 6. This fault trends west-southwest across the spurs south of Green Monster Mountain and is sub-vertical
to southeast dipping. It juxtaposes Bonanza King rocks of the Green Monster plate against Monte Cristo units of the lower plate and, therefore, must have a significant component of south-side-down dip-slip displacement which postdates the emplacement of the Green Monster thrust. The fault continues westward into the next alluvium-filled valley where it splits into two branches; one continues along an east-west trend while the other trends northwest. The south branch passes north of peak 4193 (sec. 1, T.24S., R.56E.) and dies out in the canyon north of Green Monster Mine. Near its western end, the fault is vertical, trends N82E, and has slickensides which rake 23 degrees from the west. Movement of the fault appears to have been left-lateral. It is possible that this segment of the fault zone is related to the period of tear faulting associated with the Green Monster event and has not been modified by later dip-slip movement.

The northern branch is part of a later dip-slip faulting event. This sub-vertical fault continues to the edge of the map area, juxtaposing rocks of the Green Monster plate to the south against lower plate rocks and remnants of the Green Monster plate to the north. Throw on the fault cannot be great as shown by three factors. 1) The stratigraphic separation of the Sultan-Monte Cristo contact at the west end of the fault is not more than a few tens of meters. 2) The Ironside Member is exposed in the Green Monster thrust remnant north of peak 4127; the projection of the Ironside Member on the south side of the fault
cannot occur more than a few tens of meters below the erosional surface in the down-thrown block. 3) At the east end of the fault system there is no significant displacement of the lower plate rocks. A few east-west or northeast trending high-angle faults were observed in the Bird Spring along strike with the fault zone at the southwest corner of sec. 32 (T.23S., R.57E.). Their displacements are only a few meters and, at the time of mapping, they were not considered to be of sufficient magnitude to be mapped.

Two other faults are present near the west tip of the Green Monster area (Fig. 12). One is a northwest-trending, high-angle fault that is truncated by the dip-slip fault in the valley west of peak 4127. The other, also a high-angle fault, trends west-northwest in the Green Monster thrust block north of the dip-slip fault. It only affects the rocks of the Green Monster plate. That fault is also cut by the dip-slip fault. Because they are both truncated by the dip-slip fault zone, both of the high-angle faults at the tip of Green Monster Ridge are thought to belong to the earlier phase of faulting. They may be related to the anticline developed in the Monster plate exposed north of the high-angle, dip-slip fault.

The high-angle faults of both generations are characterized by sharp clean fracture surfaces. Some faults have moved along a single surface, while others are marked by zones of a meter or more in width that are composed of many anastomosing fracture surfaces. More small displacement
faults were observed in the field than could be shown on the map, and only major faults were mapped.

Thus, two generations of high-angle faults have affected the Green Monster terrain—an early event, probably with strike-slip displacement, related to the emplacement of the Green Monster thrust and a second event which involves rocks of both the upper and lower plate and shows significant dip-slip displacement.

SUB-GREEN MONSTER THRUST PLATE

A second thrust, smaller in displacement, cuts the Green Monster terrain further east. For want of accepted geographic names in the area, this will be called the Sub-Green Monster (SGM) thrust. The SGM thrust begins as an overturned, northwest-plunging syncline emerging from Keystone Wash east of the Green Monster thrust (Plate I). The syncline is part of a set of large northwest-plunging folds (wavelength of several kilometers) present in the terrain between Keystone and Potsi Washes, which is now part of the Keystone thrust plate. This folding event predated the emplacement of the Keystone plate as indicated by cross-cutting of these structures by the Keystone thrust and by truncation of the southern end of the overturned syncline by the Keystone-related Ironside fault zone.

The SGM thrust surface first appears as fault dipping 40 degrees to the southwest in the core of the overturned syncline and parallel to its axial surface (sec. 9, T.24S., -79-
R.57E.). A zone of brecciation marks the fault. Traced to the northwest, the faulted syncline is overridden by the Green Monster thrust. The SGM thrust appears again in the saddle east of Green Monster Mountain. This segment is truncated to the south by the Green Monster thrust and disappears under Potosi Wash to the north (Fig. 12, Plate I). The thrust here only involves rocks of the Bird Spring Formation at the surface. The upper plate is folded into an overturned anticline while rocks in the lower plate dip homoclinaly to the west. The thrust surface is exposed in the canyon southeast of Green Monster Mountain where it dips 32 degrees west. The fault is marked by a 2 to 3 m zone of sheared rocks with a 3 m zone of shattered rock beneath. Rocks above the fault are not visibly disturbed.

The SGM thrust crops out again in a group of low hills in Potosi Wash two miles northwest of Green Monster Mountain. There displacement on the fault has increased as it thrusts rocks of the Bird Spring Formation over the Premian red beds exposed in the Keystone plate. Kaibab Limestone is exposed in the lower plate a quarter of a mile east of the thrust trace. A tight eastward overturned anticline is exposed in the small hill southwest of the thrust. The lower plate is folded into an overturned, synclinal, chevron fold beneath the SGM fault.

The thrust may correlate with thrusts or folds mapped further to the north in the Spring Mountains. However, the rapidity with which the Green Monster thrust died out
suggests that correlating thrusts over so large a covered interval may be improper. Cross-cutting relationships show that the SGM plate predates the Green Monster thrusting event, however, the two events were probably closely related in time. The shortening represented by the Green Monster thrust to the south was taken up on the SGM thrust to the north.

KEYSTONE THRUST PLATE

Hewett (1931) was the first to map and describe the Keystone thrust, naming it for exposures at Keystone Mine in the south of the map area. Rowe (in Spurr, 1903) and Hill (1914) had recognized overthrusting along portions of the Keystone but, because of the reconnaissance nature of their surveys, had no appreciation for its aerial extent. The Keystone is a laterally extensive thrust sheet which can be traced almost continuously and with reasonable confidence from the northern Spring Mountains (Burchfiel and others, 1974) south to the New York Mountains of California (Burchfiel and Davis, 1977). It has been correlated even further to the north across the Las Vegas Valley shear zone with the Muddy Mountain thrust (Longwell, 1960). The thrust is of particular interest in the Goodsprings area because there the trace bends sharply westward forming a recess extending from south of Goodsprings to north of Potosi Mountain (Fig. 4. Plate I). The depth of the recess is more than seven miles. Little has been written about its geometry or origin.
The Keystone thrust is not exposed in the area between Keystone and Potosi Washes where it is covered by older alluvium. The trace, however, can be approximately located through structural discordance and anomalous stratigraphic relations (Plate I). At its north end within the mapped area, the thrust emplaces Bonanza King rocks in the upper plate over the same unit in the upturned limb of the Potosi Mine syncline (Hewett, 1931) of the Contact plate. Further south the thrust cuts across the Potosi Mine syncline and emplaces Bonanza King on Bird Spring rocks exposed in the core of the fold. The Keystone thrust does not appear to be as strictly controlled by stratigraphy in this area as it is further to the north where "detachment always occurs immediately above or immediately below the basal silty unit of the banded Mountain Member (of the Bonanza King)" (Cameron, 1978). Instead, because the thrust cuts across the earlier northwest-trending folds of the Sub-Green Monster event, the fault surface is located at higher stratigraphic levels in the Banded Mountain as it cuts across synclines in the upper plate.

South of the Wilson Pass road, the Keystone plate is torn by the northeast-trending Ironside fault zone (Plate I). In the area north of the Keystone Mine road (NW 1/4 sec. 24, T.24S., R.57E.), at the end of the Ironside zone, the thrust surface is folded by east-west trending sub-horizontal folds which are apparently unrelated to the tear faulting (Fig. 13). Two anticlinal hinges with an intervening syncline are
FIGURE 13 - Detailed geologic map of the Keystone Wash area (T.24S., R.57E.).
DETAILED GEOLOGIC MAP OF THE
KEYSTONE WASH
GOODSPRINGS DISTRICT, NEVADA

MIPPbs  Bird Spring
Ds  Sultan
En  Naph
Cbb  Bonanza King

breccia
slide block
thrust fault
high angle fault

SCALE
0  0.5  1.0
MILES
contour interval 80 feet
exposed. Both anticlines are faulted through their northern limbs offsetting the Keystone thrust, but neither fault shows more than a few meters of displacement. The hinge fault related to the southern anticline has an attitude of N65E; 35SE and approximately parallels the axial plane of fold. This north vergent folding event is of extreme importance because it involves rocks not only of the Keystone plate but of the underlying Contact plate, as well. Because the Keystone thrust is itself folded these structures represent a period of north-south compression which postdates final movement on the Keystone thrust. The folds are probably related to other east-west trending structures along the recess of the Keystone thrust.

South from the Ironside fault zone, the Keystone thrust trace begins to curve to the southeast (Plate I). Locally, granitic porphyry rocks are exposed along or near the thrust surface. Hewett (1931) considered these intrusive rocks to be late syn-Keystone thrusting in age, possibly late Cretaceous or early Tertiary.

The thrust zone is exposed near the eastern boundary of sec. 24 (T.24S., R.57E.) where it is a zone of lenticular slices bounded by anastomosing fracture surfaces which strike north-west and dip approximately 30 degrees to the southwest. Slicing at this locality appears to be limited to the Bird Spring rocks of the lower plate. The slices were of too small a scale to be included on the map. Further to the southeast, at Keystone mine, Map scale slicing
affects the rocks of the Keystone plate. Because these slices involve only rocks of the Bonanza King Formation they are difficult to trace and can only be mapped where structural discordance is obvious. Discordant attitudes in the Bird Spring Formation all along this segment of the thrust suggest that small-scale slicing of the type observed in sec. 24 occurs all along the boundary. The anomalously thick section of Banded Mountain Member in the area of the bend indicates that repetition of section by slicing is more prevalent than mapped in the Keystone plate.

Two features in the Keystone Mine area lead to the conclusion that the Keystone plate was moving over a subaerial erosion surface along this segment of the fault.

1) A small ravine east of the loop in the Keystone Mine road (marked by an adit symbol on the topographic map) contains exposures of the Bird Spring formation in which karstic solution features were developed and were later filled with clastic sediments. The solution features are primarily joints and bedding plane partings that have been widened into small cavities; the infillings include reddish-orange to buff weathering calcareous siltstone, calc-arenite, and sedimentary breccia with angular pebble-size clasts of carbonate rock, chert and sandstone(?) in a carbonate sand matrix. The infillings indicate that the network of solution cavities were open to a surficial sediment source. No unfilled cavities were observed. Sedimentary structures in the cavity fillings include graded bedding, cross-stratification,
channeling, coarse crystalline calcite vug fillings, and polygonal desiccation cracks in mudstone and siltstone layers, which are filled by coarser debris from subsequent sedimentary influx. In addition to the karstic cavities and infillings which occur stratigraphically only a few meters below the thrust trace, there is a laterally extensive zone beneath the thrust in which Bird Spring rocks are patchily weathered to a deep red color and brecciated texture which may be indicative of terra rossa development.

2) At Keystone Mine and along the segments of the thrust which extends east to Belle Mine, and juxtaposes rocks of the Keystone plate against Bird Spring rocks in the Contact plate, the fault trace is marked by a 2 to 4 m wide orangish-red weathering zone. The fault zone is exposed in several places at the head of Kirby Wash where it is explored by three shallow prospects. In the lowest of three prospects the fault zone is marked by a 2 to 3 m wide zone of dense brick red clayey material with a rudimentary cleavage beginning to develop parallel to the fault surface, oriented N84E; 40SE. Flutes and slickensides on the fault surface are generally subhorizontal indicating that the fault had a large component of strike-slip movement. Plunges of 0, 21SE, and 36SE were measured. Less frequent down-dip slickensides indicate late movement in that sense. The material in the red weathering zone contains sporadic horizons with well rounded pebbles of limestone, gypsum and clay in a sheared clayey matrix. Well rounded, sheared
pebbles were also collected from the highest of the three adits. In addition, the adit at the base of the hill had zones of thin-laminated, alternating light-and-dark-colored layers which were isoclinally folded about an axial plane parallel to the fault surface. These zones are interpreted as being interlayered soil or fine-grained sediments with occasional pebble horizons that were exposed on the erosional surface at the time of thrusting. The dominant red clayey material in the fault zone may again be indicative of terra rossa.

As the thrust curves east from Keystone Mine it also steepens. The maximum dip was measured in an adit at the boundary of the quadrangle sheet where the fault surface is inclined 75 degrees to the southeast (Plate I). This is the last actual exposure of the fault in the map area. The zone of red weathering continues east to Belle mine where the Keystone is offset along a vertical left-lateral fault on which horizontal slickensides indicate pure strike-slip displacement. Three hundred meters further east the Keystone thrust truncates a small thrust block of Bird Spring rocks derived from the Contact plate. Along the remainder of its trace, the Keystone juxtaposes Middle Cambrian rocks against the units of the autochthon. The Keystone thrust is not a decollement fault along the south side of Lavinia Wash. Rather it is a relatively high-angle fault which cuts rocks in the Keystone plate as high as the Nopah Formation. When viewed from the north across Lavinia Wash the
Keystone block is involved in a broad synclinal downwarp which is truncated, without regard for stratigraphic controls, by the thrust trace. The thrust can be located within a few meters along Lavinia Wash by stratigraphic juxtaposition.

According to Hewett (1931), the Keystone turns south again to the southeast of Goodsprings and continues with a shallow west dip along the front of the Spring Mountains to the State Line area.

Ironside Fault Zone: The Ironside fault zone is a system of northeast-trending, anastomosing, high-angle faults which cut the Keystone plate in a position which roughly corresponds to the Wilson Pass road (Plate I). It is a complex zone in which individual fault surfaces show a wide range of attitudes, and slickensides indicate both strike-slip and dip-slip displacement. The character of the fault surfaces is variable, as well. Many are composed of a single sharp fracture surface with little or no deformation of the surrounding rocks. Some consist of a 1 to 4 m wide shear zone with many anastomosing shear surfaces (e.g. Ironside Mine). Other portions of the fault, notably the segment trending south from Oro Amigo Mine, are marked by wide breccia zones which affect rocks adjacent to the fault for several hundred meters. Small scale folds are present in the Crystal Pass Member (Sultan Formation) adjacent to the Oro Amigo segment. Again, many more shear surfaces were observed than could be represented on the map and only major ones are indicated.
Stratigraphic and structural relations along the Ironside fault indicate both a strike-slip and dip-slip component of overall relative motion. If Green Monster structures are correlative to the south with those of the Sultan block (Hewett, 1931), then apparent right-lateral slip is indicated. This is consistent with the apparent offset of stratigraphic units across the Ironside fault. Structures which indicate drag on the fault zone show a north side up relative displacement. In the area of Ironside Mine, the northern block is involved in an anticline along the fault zone. The north limb of this structure dips shallowly to the northwest while the southern limb dips steeply and is locally overturned into the fault zone.

Hewett (1931) recognized that the Ironside fault affects only the rocks of the Keystone block (the Green Monster and Sub-Green Monster plates are presumed to have been inactive at the time of Keystone thrusting) and concluded that it was related to Keystone thrust emplacement. This work supports Hewett's tear fault interpretation and suggests that the fault zone is also genetically related to the curve in the Keystone thrust. The Ironside fault zone marks the boundary between the "typical" decollement style of the Keystone thrust to the north and the anomalous east trending part of the thrust in the south which is more steeply dipping, has a significant strike-slip component of displacement, and appears to have moved over an erosional surface.
Internal Structures of the Keystone Plate: As discussed above, the northwest trending folds affecting the terrane between Potosi and Keystone Washes, now part of the Keystone plate, are related to the movement of the Sub-Green Monster plate. Cross-cutting relationships with the Keystone thrust show that these folds were transported passively during Keystone thrusting (Plate I).

South of the Ironside fault zone rocks in the Keystone plate are involved in a system of east-west trending folds which tighten and become faulted to the east. The syncline preserves Sultan Formation while rocks as old as Banded Mountain are exposed in the anticlinal core. South of the anticline, bedding flattens rapidly in a sequence capped by rocks of the Bird Spring Formation. The fold couple is offset in a left-lateral sense at Belle Mine by the same high-angle fault (Cosmopolitan fault) which displaces the thrust trace there. This fault, along with many similar faults cutting the Keystone plate at Kirby Wash and south of Lavinia Wash, developed late in the sequence of events surrounding the emplacement of the Keystone thrust. These faults are all sub-vertical and fall in two groups according to their strike, those which strike northeast and those striking northwest. Generally, but not without exception, the faults which strike northeast show left-lateral offset while those striking northwest are right-lateral. Most of the slickensides on the faults are sub-horizontal. These observations suggest that the
faulting was related to a stress field with the axis of maximum principal compressive stress oriented horizontally and trending north-south.

CONTACT THRUST PLATE

The fault-bounded remnant of what is thought to have been a once extensive thrust sheet along the eastern front of the Spring Mountains (Davis, 1973) has been called the Contact block in the Goodsprings district (Hewett, 1931). The Contact thrust plate rests on a shallow westward dipping thrust fault, the Contact thrust. The thrust is truncated to the north by the high-angle Cottonwood fault (Hewett, 1931, Cameron, 1978) (Fig. 4) and to the south by the east-west trending portion of the Keystone thrust. Rocks of the Contact plate, units from the Banded Mountain through the Bird Spring Formation, underlie the main body of the southern Spring Mountains from Shenandoah Peak north to Potosi Mountain.

An exposure of the Contact thrust is present at the northwest corner of section 4 (T.24S., R.58E.), a half mile (.8km) northeast of (low) Potosi radio tower and two miles (3.2km) south of the type locality of the thrust at Contact Mine. The fault superposes rocks of the Bird Spring Formation in the overturned limb of an anticline over rocks of the Chinle Formation in the autochthon (Plate I). Hewett (1931) originally mapped the rocks sub-adjacent to the fault as Aztec Sandstone, but for reasons
discussed above, they are here considered to be uppermost Chinle. The thrust is exposed, dipping 47 degrees to the west, in a ravine cutting through the head of an alluvial fan. The rocks beneath the thrust dip steeply to the west and may be overturned like Aztec beds that are upturned below the fault at Contact Mine (Hewett, 1931). Rocks above and below the thrust are fractured and weathered.

The fold above the thrust is an east vergent structure with a shallow north-plunging axis and steep west-dipping axial plane. Monte Cristo Limestone is exposed in the core area to the south. The structure is not seen south of Yellow Pine Wash where it was presumably truncated by a northeastward extension of the Alice fault.

The Alice fault is a high-angle fault of predominantly strike-slip displacement (Hewett, 1931; Albritton and others, 1954). Trending northeast from the Alice Mine, it displaces the basal contact of the Bird Spring 900 m in a left-lateral sense. Hewett (1931) reports that in the upper workings of the Alice Mine the fault dips steeply southeast while in the lower workings the dip is northwest. He reports that striae on the fault in the mine are uniformly horizontal. A fault zone of similar geometry but lesser displacement is reported at Yellow Pine Mine and in the mine's underground workings (Hewett, 1931; Albritton and others, 1954). The area is now largely obscured by mine tailings. Hewett interprets the northeast-trending faults as strike-slip. Albritton and others (1954), on
the other hand, interpret the Alice fault as a "rift", although their data are similar to Hewett's and they admit that much of the displacement must have been strike slip. They state that the Alice fault cannot be considered a tear as its sense of displacement, left-lateral, is opposite that of the northwest trending tear faults which abound along the ridge north of Yellow Pine Mine. They conclude, as did Hewett, that both the northeast-trending faults of the Alice-type and the northwest-trending faults north of Yellow Pine Mine are of the same generation because they show no consistent cross-cutting relations. The apparent dilemma regarding sense of offset noted by Albritton and others can be explained by considering the faults as a conjugate shear set formed in response to north-south compression. Thus, both fault sets can be considered tear faults, as originally suggested by Hewett. The required northward compressive stress only occurred in the area during the emplacement of the Keystone thrust. Hewett (1931, p. 48) observed that "The northeastward-trending faults near Alice Mine seem to be transcurrent breaks produced during the eastward movement of the rocks near Columbia Pass (Keystone plate)". Thus, the tear faults in the Alice and Yellow Pine Mine area are not related to the emplacement of the Contact plate, which they cut, but rather to northward compression produced during the Keystone thrusting event.
South of the Alice fault, the rocks of the Contact plate dip to the west. Devonian rocks are the oldest exposed there. It is assumed, however, that Cambrian rocks were also involved in thrusting because rocks identified as Banded Mountain occur as slivers along the Ruth fault zone which bounds this portion of the Contact block on the south. Whether or not the frontal anticline exposed on the radio tower ridge continued this far south is not known. The thrust trace along the front of this block is covered by older alluvium. Although the southern terminus is not exposed, the Contact thrust is presumed to be truncated by the northeast-trending Ruth fault near Lavinia Mine. The thrust is not exposed again further south. Hewett (1931) suggested that two blocks of Bird Spring rocks resting in thrust contact over conglomerate deposits at Cosmopolitan Mine (SE 1/4 sec. 29, T.24S., R.58E.) were the southernmost exposure of the Contact plate, but another explanation for their origin will be offered.

Ruth Fault: The Ruth fault trends northeast from the highly sheared Ruth Mine area (Plate I). It is readily traced along the head of Lavinia Wash as a sharp contact between the carbonate rocks of the Contact plate and the heterogeneous Jurassic-Cretaceous (?) sedimentary sequence to the east. A related shear surface was measured dipping 65W at Ruth Mine.

The fault zone is intruded at its north end by a granite porphyry dike. A 35 foot wide zone of gouge
grades imperceptibly into shattered granitic rock along the western boundary of the dike, separating it from the carbonate rocks to the west (Hill, 1914). Shear planes paralleling the fault dip 55W (Hill, 1914). East of the dike, fault bounded blocks of contact metamorphosed carbonate rocks, lithologically similar to the Banded Mountain, are taken as evidence that the Contact thrust involved Cambrian rocks in its frontal area. These are thought to be slivers of Banded Mountain caught in the fault zone prior to the intrusion of the granite porphyry. A later reactivation of the fault, at least along the western boundary of the dike, is evidenced by the gouge zone which contains angular pieces of carbonate rock in a sheared matrix of granitic material. North of Lavinia Mine the fault again juxtaposes rocks of the Contact plate against Jurassic-Cretaceous (?) sedimentary rocks to the east.

The sense of displacement on the fault is not clear. Hewett (1931) has suggested both right-lateral and normal fault interpretations. Dip separation could be as much as 3600 feet (2000m) if a decollement model for the Contact thrust is assumed.

The Ruth fault ends at the Ruth Mine where it intersects a high-angle, strike-slip fault trending S15W through Cosmopolitan Mine (Cosmopolitan fault). The fault offsets the Keystone plate south of Cosmopolitan Mine by more than 150 m in a left-lateral sense. A mile west of
Columbia Pass on the road to Sandy, an exposure of the fault contains horizontal slickensides. Both the autochthon and Contact plate are faulted in Lavinia Wash. The Cosmopolitan fault does not appear to extend northward beyond its intersection with the Ruth fault. This geometry requires that the northward translated eastern fault block is related to the Contact plate rocks to the north by renewed movement of the Ruth fault.

The Contact plate is truncated along its southern and western border by the Keystone thrust. This relation indicates that the Contact thrust is the older of the two structures.

Thrust Blocks in the Cosmopolitan-Ruth Mine area: Hewett (1931) described two thrust blocks containing rocks of the Bird Spring Formation occurring east of the Cosmopolitan fault between the Keystone thrust and Ruth fault. These blocks rest on Jurassic-Cretaceous(?) synorogenic rocks (Lavinia Wash sequence) along a shallow west-dipping fault. Hewett considered this to be the Contact thrust, however, the emplacement of the blocks postdates deformation in the autochthon that is thought to be related to emplacement of the Keystone thrust and, therefore, must be younger (See - Evolution of the Keystone Re-entrant).

Internal Structures of the Contact Thrust Plate: Hewett (1931) noted that the southern portion of the Contact plate showed more internal folding than any other
structural block in the Goodsprings district. This he attributed to local accumulation of stresses due to the unusually steep dips of minor thrust faults within the plate. Hewett mapped two minor thrusts in the Contact plate, the Potosi and Wilson thrusts. According to him, the Potosi thrust began near the Keystone thrust north of Potosi Mountain. It could be traced southward, passing east of Potosi summit, to the ravines north of Red Cloud Mine (passing east of the present site of low Potosi radio tower). The Wilson thrust was mapped from the east flank of Shenandoah Peak to Wilson Pass. It was then traced to the head of the canyon north of Wilson Pass, Cave Spring Canyon, where it turned to the west and was lost in the vicinity of the Potosi Mine syncline. The results of the present mapping differ from Hewett's in the correlation of the various exposed fault segments constituting his Potosi and Wilson thrusts.

Potosi Thrust Fault: Cameron (1978) remapped the Potosi thrust in the area around Potosi Mountain. His mapping generally concurs with that of Hewett except at the southernmost boundary of the area where Hewett shows the fault continuing south to Red Cloud Mine and Cameron indicates a westward curve toward the head of Cave Spring Canyon. During the present study, the fault in Cave Spring Canyon (Hewett's Wilson thrust) was traced north to join with the Potosi thrust trace as mapped by Cameron, indicating that these are one in the same fault.
The thrust in Cave Spring Canyon involves only rocks of the Bird Spring Formation (Plate I), unlike the Potosi thrust to the north which has rocks as old as Devonian in the upper plate. Near the head of the canyon, its trace is located high on the western ridge where, although largely covered by talus, it can be located approximately by bedding discordance. The beds above the fault dip steeply east to slightly overturned in the eastern limb of an overturned anticline. Northward, the anticlinal hinge is cross-cut by the fault plane. Toward the south, the fault trace can be followed obliquely down the east face of the ridge until it reaches the canyon floor, downstream from Cave Spring. The gap between the trace of the anticlinal axial surface and fault widens southward and other north-south trending folds are present in the intervening rocks. Beyond Cave Spring the thrust loses displacement and becomes difficult to locate as it dies out to the south in a complexly folded terrain near Wilson Pass. Because the thrust in Cave Spring Canyon cannot be traced to Wilson Pass and cannot be correlated with any structure to the south, it is recommended that the name "Wilson fault" be dropped in favor of applying the name Potosi thrust to the fault segment in Cave Spring Canyon, which is continuous with the Potosi thrust to the north.

Structures in the Cave Spring area represent the zone of initial dislocation of the Potosi thrust. The area is characterized by a 1.6 km wide zone of north-south-trending,
east-vergent folding of the Bird Spring Formation. Northward, up the canyon, the thrust becomes more clearly developed as displacement increases. Hewett (1931) and Cameron (1978) both recognized a continuous northward increase in displacement on the Potosi thrust zone until it is truncated by the Keystone thrust near Potosi Pass. Devonian rocks are involved in the overthrust plate at its northernmost exposure and presumably even older rocks are involved at depth. Cameron's data indicate an east directed azimuth of relative slip on the fault plane.

Other Minor Thrusts: Two faults mapped by Hewett (1931) as the southern extensions of his Potosi and Wilson thrusts were found to be bedding plane faults or faulted folds within and at the base of the Bird Spring Formation.

The faulted ridge east of (low) Potosi radio tower was mapped by Hewett as the southern end of his Potosi thrust. The informal name Radio Tower (R.T.) fault will be used here to avoid confusion with the actual Potosi thrust exposed to the west in Cave Spring Canyon. Where exposed in the ravine north of Red Cloud Mine the R.T. fault is a bedding plane fault at the base of the Indian Springs Member of the Bird Spring (Plate II, B-B'). Slip occurred in response to the flexural slip folding of the frontal anticline of the Contact plate. Local granite porphyry sills intruded along the contact are probably the northern end of the more extensive Yellow Pine Sill intruding the same stratigraphic horizon further to the south.
Followed northward, the Indian Springs sandstone grades laterally into a coarse conglomerate which fills a channel eroded into the underlying Mississippian carbonates. The mechanical difficulty of slip along the irregular base of the channel proved too much for the bedding plane fault which cuts up section into the Bird Spring upon encountering the channel deposit. The discordance is clearly visible beneath the radio tower. The fault flattens into bedding within the Bird Spring section at the head of the ravine and cannot be traced further to the north. More small sills and dikes of granite porphyry are intruded along the fault where it cuts up section into the Bird Spring and at the base of the Indian Spring Member north of the conglomerate-filled channel.

The faulting and folding on the east flank of Shenandoah Peak is another example of disharmonic shortening within the thick Bird Spring sequence in the Contact plate. Hewett (1931) considered this fault to be the south end of his Wilson fault. Again, to emphasize the different interpretation, the name Shenandoah fault will be used here in reference to this fault. The Shenandoah fault also begins as a bedding plane fault, but followed to the north it cuts obliquely up section faulting the core of an overturned anticline developed in the hanging wall. The fault then splits into two branches, the upper branch remaining in the core of the anticline whereas the lower branch faults a coupled syncline to the east. Northeast
of Shenandoah Peak the faults again merge to a single surface on which displacement gradually decreases. The fault terminates south of Red Cloud Mine where the shortening is represented in a pair of east-vergent chevron folds. The Shenandoah fault is not correlative with the R.T. fault to the north as the former is localized in a higher stratigraphic horizon, nor is it traceable through the terrane south of Wilson Pass to the Potosi thrust.

North-South Trending Folds: There are several north-south trending folds or zones of folding which are also of some importance in the development of the Contact plate. A locally overturned anticline-syncline pair can be traced from the zone of folding at the end of the Potosi thrust south to the northwest flank of Shenandoah Peak. Near its southern end the fold couple is faulted through the common limb. The most significant feature regarding these folds is that they are refolded by a system of east-west trending structures, clearly establishing a younger relative age for the latter.

The Contact plate is upturned along its western boundary at the head of Potosi Wash by the Potosi Mine syncline (Plate I). The structure is exposed continuously from Potosi Spring (Hewett, 1931) to the north fork of Keystone Wash. It is truncated to both the north and south by the Keystone thrust. The Potosi Mine syncline involves rocks as old as the Banded Mountain Member and, if a decollement model for the Contact thrust plate is assumed,
must also fold the Contact thrust. Because of cross-cutting relationships, the syncline must predate the emplacement of the Keystone thrust but, because it involves the entire Contact plate, folding postdates Contact thrusting. The fold is probably the result of early Keystone compression.

East-West Folding: Rocks in the southern part of the Contact plate, south of the Wilson Pass road, are involved in a system of east-west-trending, north-vergent folds which postdate the north-south folding events. Most impressive of these structures is an anticlinal structure along the north face of Shenandoah Peak. A monocline along much of its trace, the fold overturns near its west end refolding north-south trending structures. Half a mile (.8km) to the north, an east-west trending fold couple clearly refolds the axial plane of a north-trending anticline. The entire Bird Spring terrane which underlies Shenandoah Peak is also broadly warped about east-west axes. The most significant of the east-west structures are those already described that fold not only the Contact plate but the Keystone plate and thrust surface, as well. This relationship, along with the refolding of structures within the Contact plate, indicates that north vergent folding occurred after movement on the Keystone thrust had ceased. East-west structures are only present adjacent to the east-west trending portion of the Keystone thrust and are considered to be genetically related to that boundary.
Additional small-scale east-west and sub-vertical fold axes immediately adjacent to the Keystone thrust surface are thought to be related to movement of the Keystone plate.

Summary of Internal Structure: The underlying factor controlling the internal behavior of the Contact plate is the mechanical behavior of the relatively thin-bedded Bird Spring rocks, the most widely exposed formation in the block. The complex deformation of the southern portion of the Contact plate cannot be attributed to a single event, but is the composite effect of several interferring structures.

1) The Potosi thrust, the only significant minor thrust in the Contact plate, dies out at Cave Spring Canyon into an associated zone of north-trending disharmonic folding.

2) Bedding plane slip at various stratigraphic horizons in the Bird Spring Formation is the result of flexural-slip folding of the frontal part of the Contact plate. These structures may have been reactivated during the emplacement of the Keystone plate as granite porphyry sills and dikes located along them are thought to have been intruded during a late Keystone event.

3) Development of the Potosi Mine syncline early during the emplacement of the Keystone thrust resulted in a broad down-warping of the entire Contact plate between the syncline and the frontal anticline. This must have
resulted in some inhomogeneous shortening of the Bird Spring rocks in the core of the downwarp.

4) North-vergent folding in response to compression along the east-west trending southern boundary of the Contact block complicated the geometry late in the sequence of structural events. Albritton and others (1954) have commented that stresses operating in the Bird Spring were relieved by warping attended by gliding along the closely spaced bedding, a process facilitated by shaly partings, while the more massive underlying rocks have yielded by fracturing and faulting which does no affect the Bird Spring.

STRUCTURE OF AUTOCHTHONOUS ROCKS

The Structural block here considered autochthonous is bounded to the west by the Contact thrust and the south by the Keystone thrust (Plate I). Northward, rocks of the autochthon are exposed almost continuously east of the Contact plate, then east of the Keystone plate after the Contact thrust is truncated by the Cottonwood fault zone ten miles (16km) north of Goodsprings (Hewett, 1931). The relationship of the autochthonous rocks near Goodsprings with the platform rocks exposed at Sheep Mountain (Fig. 1), a half mile (.8km) east of Jean, Nevada, is obscured by structural complications and alluvial fill in the Goodsprings and upper Ivanpah Valleys (Hewett, 1956). There is no suggestion of any discontinuity interrupting
a normal stratigraphic succession from the Paleozoic
sequence exposed in the Bird Spring Range to the Kaibab
Limestone exposed in isolated hills north of Goodsprings.
In this respect, the rocks of the Goodsprings Valley are
part of the Bird Spring block, which is allochthonous or
para-autochthonous with respect to platform rocks in the
Sloan block further east (Hewett, 1956). The southern
extent of the Bird Spring block is not known. Further
detailed mapping to determine the extent and nature of
the Bird Spring thrust and geophysical investigation of
the northern Ivanpah Valley will be necessary before the
exact relation of the rocks in the Goodsprings Valley with
those at Sheep Mountain can be determined.

Folding and Faulting in Lavinia Wash: The dominant
structure of the Goodsprings Valley is a shallow, west-
plunging, north vergent fold coupled in Lavinia Wash, which
involves rocks from the Permian red bed unit to the
Jurassic-Cretaceous(?) syntectonic deposits (Lavinia Wash
sequence). The nose of the syncline closes eastward at
Goodsprings, the axial trace trending toward Lavinia Mine
(Plate I). The constructed axial plane dips 40 degrees to
the south. It is a broad, open fold and, like other large
scale folds in the area, has a parallel form. The coupled
anticline is exposed a mile west of Goodsprings where
lower Moenkopi and upper Kaibab limestones are involved
in an open fold with a sub-vertical axial plane. Massive
limestone beds in the core of the fold are faulted in the
hinge, but displacement dissipates quickly in the overlying thin-bedded units. Westward, the fold is truncated by the Keystone thrust. Steepening of beds in the autochthonous units adjacent to the thrust trace has resulted during the later movement of the Keystone block.

Geometric considerations require a fault through the common limb of the fold couple in the Lavinia Wash area (Plate III, E-E'). The fault, however, is not exposed. The trace of the inferred fault approximately parallels the dirt road from Goodsprings to the mine workings at the head of Lavinia Wash (Plate I). The upthrown block on the south side of this fault is cut by a northeast-trending high-angle fault exposed east of the Greenstone Adit juxtaposing syntectonic sedimentary rocks at the mine against the red beds of the Moenkopi Formation to the southeast. That fault is of the same style and generation as the Ruth fault to the west. East of the high-angle fault, faulting of the fold couple is indicated by more than 1000 feet (300m) of horizontal separation of the basal contact of the Moenkopi red bed member along the inferred fault trend (Plate I). Rocks of the Jurassic-Cretaceous (?) syntectonic sequence are exposed both north and south of the inferred fault in the western part of Lavinia Wash. North of the mine road bedding in these rocks describe the broad, open folding of the Goodsprings syncline while to the south of the fault, beds dip moderately to steeply south and are stratigraphically upright.
This geometry can be explained by a south-dipping fault which superposes rocks from the south limb of a north vergent anticline northward over the core of a coupled syncline. Jurassic-Cretaceous(?) deposits exposed in the upthrown southern block are of both the volcanic-clast and carbonate-clast facies and presumably represent a lower stratigraphic horizon of the syntectonic sequence than do the rocks to the north of the inferred fault, which are exclusively of the carbonate-clast type. Continuity of units north of the inferred fault across the trace of the northeast-trending high-angle fault at Greenstone Mine, suggest that the latter is a tear fault confined to the upthrown block of the faulted fold couple.

Structures related to the west-trending fault and folds are not continuous across the Cosmopolitan or Ruth faults nor do they affect the two small thrust blocks of Bird Spring rocks at the head of Lavinia Wash. These structures are, therefore, confined to the autochthon and, predate the emplacement of thrust blocks.

Inferred Pre-Contact Faulting: Sandstone which represents the Aztec-Chinle transition or upper Chinle Formation crops out directly beneath the Contact thrust east of low Potosi radio tower (NW\(\frac{1}{4}\) sec. 4, T.24S., R.58E.). Only a mile to the north, and directly along strike of the Chinle outcrop, a thick section of Aztec Sandstone is exposed below the thrust (Hewett, 1931; Cameron, 1978) (Fig. 14). The Chinle-Aztec contact shows more than a
kilometer of separation across the drainage that forms the northern boundary of the map area. North of the map boundary, two prominent ridges of Aztec Sandstone extending south from Aztec tank end abruptly upon reaching the drainage (Hewett, 1931). These relations are suggestive of a period of faulting and erosion in the area of the boundary drainage that predated the Contact thrust such that the Contact plate was emplaced over an erosional surface on which rocks of several different ages were exposed. The geometry of this faulting event is not known, but two possible models can be suggested.

1) High-angle faults that repeat the clastic sequence at Aztec tank (Hewett, 1931) may be more extensive beneath the alluvial fill of the Goodsprings Valley (Fig. 14). Hewett shows one fault being truncated by the Contact thrust and another being offset by the Ninety-nine fault zone. These relations indicate a pre-Contact age for at least one of the faults. In contrast, Cameron (1978) does not map a fault truncated by the Contact thrust and correlates the fault east of Aztec tank with a more northerly fault that offsets the Contact plate.

2) Cameron (1978) and Carr (1977) have suggested that a northwest-trending high-angle fault may be buried below the alluvium in the boundary drainage. Cameron has called this the Boundary fault. The fault is inferred to have a similar relation to the thrust belt as known younger faults (e.g. Cottonwood, La Madre, and Ivanpah faults;
FIGURE 14 - Geologic map of the area south of Aztec Tank (secs. 32, 33, and 34, T.23S., R.58E.; secs. 3, 4, 5, 8, 9, and 10, T.24S., R.58E.) showing the relations that suggest a period of high-angle faulting that pre-dated the emplacement of the Contact thrust plate. The high-angle faults south of Aztec Tank (from Hewett, 1931) and the inferred Boundary fault are representative of this event.
Fig. 4). The southwestern fault block is considered to have moved relatively up.

This model is attractive because in addition to explaining observed offsets and truncation, the Boundary fault offers a mechanism for uplift and erosion of the Aztec Sandstone in the area south of the boundary drainage where Aztec is now nowhere exposed. Once the Aztec had been removed from the uplifted fault block, the underlying rock-types would have offered little erosional resistance in comparison. Thus, the uplifted block to the south would have become a topographic low while the northern block, capped by the resistant Aztec, could have been an area of positive relief. The Lavinia Wash sequence would then have been restricted to a fault-bounded valley incised into lower Mesozoic formations. A detailed geophysical survey of this part of the Goodsprings Valley might resolve the geometry of the faulting event. It seems evident, however, that a period of faulting in the autochthon did occur prior to the emplacement of the Contact plate.

GRAVITY SLID BLOCKS

There are two masses of allochthonous rocks within the map area that are considered to be of a gravity slide origin, one northeast of Lavinia Mine and the other near the mouth of Keystone Wash. Both masses rest on sub-horizontal detachment surfaces and are characterized by intense brecciation.
The slide mass near Lavinia Mine is 650 m long and 200 m wide. Small erosional remnants of dolomite to the east and west may suggest even greater dimensions at the time of emplacement. The block consists of dolomite megabreccia which Hewett (1931) identified as Monte Cristo Limestone. Because of the intense brecciation and a lack of fossils, the rocks were mapped here merely as monolithologic breccia. The slide rests over vertically-dipping beds of the Lavinia Wash sequence. The trace of the slide surface is overlapped by older alluvium on the west side of the block.

The block at the end of Keystone Wash is of similar dimension to the one near Lavinia Mine. This slide mass also contains megabreccia but the original rock units are still identifiable as the members of the Sultan Formation. The slide overlies rocks of the Sultan and Nopah Formations, as well as fault traces of the Ironside fault zone. It is not cut by faults of the Ironside fault zone. The slide surface is best exposed along the east side of the mass where it is sharp and overlain by a zone of intense brecciation that grades upward into megabreccia. The degree of brecciation decreases upward in the block. Hewett (1931) recognized this block as a product of mass wastage and mapped it as older alluvium.

The gravity slid block at Lavinia Mine must postdate folding of the autochthonous rocks in Lavinia Wash and predates the deposition of the older alluvium deposits,
probably Pleistocene in age. The source of this slide must have been the Contact block to the west. The slide mass at the Ironside fault may be less far traveled as indicated by its lesser degree of brecciation. The largest nearby source terrane of Sultan Limestone is to the south-west.

TIMING AND CORRELATION OF STRUCTURAL EVENTS

The structural evolution of the Goodsprings area can be viewed in a sequence of events, dated on the basis of cross cutting relations. Some of these events can be placed in an absolute time frame based on data from the immediate area, while others can be correlated with dated events known from the surrounding region. The events which predate the emplacement of the Keystone thrust plate can be subdivided successfully within the confines of the immediate area which they effect. However, the relative timing of events affecting the Green Monster terrane with respect to those only occurring east of the Keystone thrust are not at all clear. Certain constraints can be placed on the relative timing of pre-Keystone events through correlation with better dated structural events in areas to the north and south, but these only limit and do not resolve the problem. The events are named rather than numbered sequentially in deference to the ambiguity surrounding the pre-Keystone events. A summary of events
is presented (Table 3), but this is based, in part, on speculation.

PRE-KEYSTONE EVENTS IN THE GREEN MONSTER AREA

Sub-Green Monster Event: Folding and thrusting associated with the emplacement of the Sub-Green Monster thrust plate appears to have been the first phase of deformation to affect the terrain west of the Keystone thrust (Table 3). The critical relations are the cross cutting of the northwest-trending folds below the SGM thrust by the Keystone thrust and the truncation of the SGM thrust, itself, by the Green Monster thrust southeast of Green Monster Peak.

Green Monster Event: The SGM thrusting event was followed by the thrusting, folding, and northeast-trending, high-angle tear faults accompanying the emplacement of the Green Monster thrust plate. The Green Monster thrust is truncated to the south by the Ironside fault, a Keystone related structure. The Green Monster and SGM events must have been closely related in time and space, because as the SGM thrust dies into folding to the south, the shortening which it represents is transferred to the Green Monster thrust. The faulted anticline west of Green Monster Mine is probably also related to the Green Monster event, or slightly postdates it. The critical relation between the faulted anticline and the northeast-trending tear fault a mile northwest of Green Monster Mine is covered by alluvium.
### Table 3

**Summary of Timing and Correlation of Tectonic Events**

<table>
<thead>
<tr>
<th>Clark Mountain Thrust Complex (Mechial and Davis, 1977)</th>
<th>Goodsprings District</th>
<th>Potsdam Mountain Area (Cameron, 1978)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event 1: Thrusting and folding</td>
<td></td>
<td>Brent 1: High-angle faulting</td>
</tr>
<tr>
<td>Event 2: Thrusting and folding</td>
<td></td>
<td>Brent 1: High-angle faulting</td>
</tr>
<tr>
<td>Event 3: High-angle faulting</td>
<td></td>
<td>Brent 2: Major folding</td>
</tr>
<tr>
<td>Event 4: Thrusting and folding</td>
<td></td>
<td>Brent 3: High-angle faulting</td>
</tr>
<tr>
<td>Event 5: Intrusion (200 m.y.b.p.)</td>
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<td>Brent 4: High-angle faulting</td>
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<tr>
<td>Event 6: Folding, thrusting, and intrusion (150 m.y.b.p.)</td>
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<td>Event 7: High-angle faulting</td>
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<tr>
<td>Sub-Goodsprings Events:</td>
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<td>Thrusting and folding</td>
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<td>Green Monster Events:</td>
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<tr>
<td>Thrusting and folding</td>
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<tr>
<td>East-west High-angle Faulting Event</td>
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<td>Event 8: Thrusting and folding</td>
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<tr>
<td>Event 10: Late but minor folding and thrusting</td>
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<td>Event 11: High-angle faulting</td>
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<td>Event 12: Gravity sliding</td>
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<tr>
<td>Late Gravity Sliding Event</td>
<td></td>
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</tr>
</tbody>
</table>

**Extrusive Thrusting Events**

- Event 5: Folding, bedding plane fault and initial thrusting
- Event 6: Tear faulting
- Event 7: Deformation along south boundary of the re-entrant

**Inferred Northeast-trending Events**

- Event 1: High-angle faulting
- Event 2: Major folding
- Event 3: High-angle faulting

**Deposition of Volcanic Sequence (150 ± 10 M.Y.B.P.)**

**Transcription of Contact:**

- Flote to South

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*Horizontal lines are time lines or correlations
Vertical lines indicate possible ranges of poorly bracketed events*
East-West High-Angle Faulting Event: The last event to affect the Green Monster terrane was the east-trending, high-angle, faulting of the south flank of Green Monster Ridge. This event involved rocks of both the SGM and Green Monster plates and offset the Green Monster thrust, as well as some of the northeast-trending tear faults. The age of the east-west, high-angle faulting event relative to the Keystone thrusting events is not known. The high-angle faults may have developed at any time after the emplacement of the Green Monster thrust. This faulting probably represents an adjustment in the SGM-Green Monster terrain while it was being carried passively as part of a younger, more easterly thrust sheet. The location of the fault zone may be related to a zone of weakness associated with the termination of the Green Monster thrust.

Correlation and Absolute Timing: The Green Monster and SGM thrusts occur in the same structural position relative to the Keystone thrust as the Mesquite Pass Basal thrust in the Clark Mountain Thrust Complex (Burchfiel and Davis, in preparation). Burchfiel and Davis tentatively correlated the Mesquite Pass thrust with the Sultan (Hewett, 1931) and Green Monster thrusts. The SGM thrust was not known at the time of that correlation.

The Mesquite Pass thrust involves Precambrian crystalline rocks in the Clark Mountain area. However, southeast of Winters Pass, at its northernmost exposure in the Clark Mountain Complex, the thrust places lower
Goodsprings Dolomite (Papoose Lake) over the Bird Spring Formation (Burchfiel and Davis, in preparation). East of the Ivanpah fault, a fault mapped as the displaced continuation of the Mesquite Pass thrust (Clary, 1967) places Goodsprings over the Moenkopi and Bird Spring Formations. Mapping of the Sultan thrust (Hewett, 1931) shows that it, too, involves no rocks older than Goodsprings in the upper plate. Burchfiel and Davis suggest that the Mesquite Pass thrust loses displacement toward the north. This is clearly demonstrated by relations in the Goodsprings area. They concluded that the Deer Creek thrust and associated folds represented the Mesquite Pass structural trend in the northern Spring Mountains and that the Glendale thrust in the northern Muddy and Morman Mountains was also part of the same trend, but not the same fault. The relations in the Green Monster area show that the Deer Creek thrust must also be a different fault than the Mesquite Pass thrust. It may be correlative with the SGM thrust fault. Thus, the Mesquite Pass structural trend is represented by, at least three distinct thrust faults.

The Mesquite Pass thrust has undergone at least three phases of folding and thrusting in the Clark Mountain area (Burchfiel and Davis, in preparation). The first two events predate the intrusion of the 200 m.y. old Breccia Pluton (Fig. 15) (Events 2 and 4, Burchfiel and Davis, 1977, Table 3). The last movement of the Mesquite Pass thrust is regarded as early Late Cretaceous (post-138
FIGURE 15 - Map showing the locations of rocks that have yielded radiometric dates pertinent to the absolute chronology of geologic events affecting the Goodsprings district. Data are from Sutter (1968), Fleck (1970), and this study (Table 2).
Muddy Mountains
Willow Tank and Baseline
Formations - 98.4 to 98.4 m.y.
(Fleck, 1970)

Las Vegas
SCALE
0 10
miles

N

Keystone thrust
Contact thrust
Nevada - California
Mesquite Pass thrust
94-95 m.y. Ocheltira Springs granite
200 m.y. Copper World Mine granite
138 m.y. Gila Peak granite
Dikes in Clark Mountain Area from Sutter, 1968
to pre-95 m.y.) (Event 8, Burchfiel and Davis, 1977). Burchfiel and Davis (in preparation) consider the early phases of deformation to be restricted to the area south of the Spring Mountains. At the northern end of the Mesquite Pass structural trend, the Glendale thrust is thought to be earlier than or synchronous with the Late Cretaceous to Early Tertiary Overton Fanglomerate (Longwell, 1949; Armstrong, 1968). No other absolute chronology data is reported from the Mesquite Pass trend. The segmented nature of the Mesquite Pass trend makes it difficult to assign ages to the structural events in the Goodsprings area based on correlation with surrounding areas. As suggested by Burchfiel and Davis (in preparation), the thrusting in the northern Spring Mountains is probably of Sevier age (Late Cretaceous). It would follow that the correlative SGM thrust is also of that age. Cross cutting relations in the Green Monster terrane, then, would indicate Late Cretaceous movement for the Green Monster thrust, as well. However, in light of the multiple movement history of the Mesquite Pass thrust in the Clark Mountains, the possibility cannot be discounted that the present relation between the Green Monster and SGM thrusts is the result of recurrent movement on the Green Monster thrust. The geologic history may actually be more complex than it appears.

PRE-KEYSTONE EVENTS IN THE CONTACT PLATE AND AUTOCHTHON

Inferred Northwest-trending High-Angle Fault Event: The first structural event to affect the autochthon is an
inferred event (Table 3), but supported by geologic relations in the northern part of the area. Observed faults which are cut by the Contact thrust south of Aztec Tank (Hewett, 1931) are thought to be part of this event. Those faults displace the Aztec Sandstone and are therefore post-Aztec (Lower to Middle Jurassic) in age. If the interpretation that this faulting restricted the deposition of the Lavinia Wash sequence is correct, then faulting must be pre-150 m.y.b.p., the age of the oldest exposed strata in the sequence.

Volcanism (150 m.y.b.p.): The oldest documented event to affect the autochthon is an episode of 150-10 m.y. old volcanism, represented by the tuff layer in the Lavinia Wash sequence. This event may, in part, be equivalent to the eruption of the Delfonte Volcanics in the Clark Mountain area (Table 3). The Delfonte Volcanics have yielded a minimum age of 150 m.y.b.p. based on preliminary Ar 40/Ar 39 data by Sutter (personal communication). Clasts of the Delfonte Volcanics are incorporated into conglomerate interbedded with the tuff layer in Lavinia Wash, indicating that part of the Delfonte sequence must be older.

Contact Event: The Contact event is characterized by the folding and thrusting associated with the emplacement of the Contact thrust plate. Structures belonging to this event include the Contact and Potosi thrusts, the overturned anticline immediately above the Contact thrust, and the north trending folds associated with the southward
termination of the Potosi thrust (Plate I). The Shenandoah and Radio Tower faults could be a part of this event, but could equally reflect shortening in the Bird Spring Formation during the formation of the overturned syncline, along the west side of the Contact plate during emplacement of the Keystone thrust. Structures formed during the Contact Event are truncated to the north by the Cottonwood fault. The Cottonwood fault is one of several northwest-trending high-angle faults that were formed between the emplacement of the Contact and Keystone thrust plates, but are not present in the Goodsprings area (Event 4, Cameron, 1978) (Table 3).

The age of the Contact thrusting and folding must postdate 150±10 m.y.b.p., the age of the tuff in the Lavinia Wash sequence, which is overridden by the Contact thrust plate. The sequence of events surrounding the emplacement of the Contact thrust consists of 1) thrusting and folding during the emplacement of the plate, 2) high-angle block faulting of the Cottonwood-type, which dismembered the plate, and 3) the thrust emplacement of the Keystone plate, which overrode and truncated the Contact plate (Table 3). A similar sequence of events surrounds the development of the Red Springs thrust blocks (Fig. 4) west of Las Vegas (Davis, 1973). Davis, on the basis of that similarity, correlated the Contact and Red Spring thrusts stating that they were once part of a single laterally extensive thrust sheet along the front of the...
Spring Mountains. He extended his correlation to include a folded and thrust faulted para-autochthonous terrane east of the Keystone thrust in the Clark Mountain area. There folds in the autochthonous section were truncated by the northwest trending Ivanpah fault before the terrane was overthrust by the Keystone plate (Fig. 4). One of these folds is cored by the syntectonic Ivanpah pluton, dated at 138 m.y.b.p. (Sutter, 1968; Burchfiel and Davis, 1971) (Fig. 15). Assuming these correlations are valid, the age of emplacement of the Contact thrust is approximately 138 m.y.b.p. This is consistent with radiometric data from the Goodsprings area.

EVENTS RELATED TO THE EMPLACEMENT OF THE KEYSTONE THRUST

Structures related to the emplacement of the Keystone thrust plate are considered as a single event to the north in the Potosi Mountain area (Cameron, 1978, Event 5) and to the south in the Clark Mountain Complex (Burchfiel and Davis, in preparation, Event 8). The geometric complexities encountered in the Goodsprings area as a result of interference caused by the earlier Contact plate demand a more detailed treatment of Keystone structures. A sequence of structural events (numbered K-1 through K-4) has been determined from cross cutting relations (Fig. 16).

Event K-1: North-Trending Folds and Bedding Plane Faults

The initial emplacement of the Keystone thrust was accompanied by the formation of north trending folds, the
FIGURE 16 - Schematic of model for the development of structures related to the Keystone re-entrant. Panels depict structural events discussed in the text. The letter "u" designates the upthrown side of a high-angle fault. The approximate scale is 1":3.75 miles (1cm:1.8km).
most spectacular of which is the eastward overturned Potosi Mine syncline along the west side of the Contact plate and beneath the Keystone thrust (Plate I). The development of the Potosi syncline must have slightly predated actual fracturing along the Keystone thrust surface because the thrust cuts across the axial plane of the fold, truncating it both to the north and south. This folding resulted in an overall synclinal bending of the Contact plate which must have been compensated in the core by bedding plane slip in the Bird Springs Formation. Perhaps, the Shenandoah and Radio Tower faults and some of the minor north-trending folds in the Contact plate did not form until this time.

Event K-2: Tear Faulting

Following the initial ramping of the Keystone thrust (see Thrust Geometries), the Keystone plate broke into two blocks along the northeast-trending Ironside fault zone (Plate I). The Ironside fault is placed in a separate event in order to emphasize its importance and because its early establishment is required to allow for the differences in behavior between the northern and southern blocks during later deformation. The activity along the Ironside fault zone must have continued during all of the succeeding events until the cessation of movement on the Keystone thrust, but the lack of anomalous east-trending structures north of the fault and absence of "normal" north-trending
structures in the southern block argue for the early establishment of the Ironside zone.

Event K-3: Continuation of Event K-1 Structure (Northern block); Strike-slip, Slicing, Folding, and High-angle Faulting (Southern Block)

Structures developed in the northern block of the Keystone plate during Event K-1 persisted during and after the Ironside faulting event. In fact, the emplacement of the northern block, like that of the Keystone plate in the Potosi and Clark Mountain areas, could be characterized as a single structural event, except for the northeast-trending fold at the southern edge of the block along which part of the Keystone plate folded along the Ironside fault zone.

Following the initial break-up along the Ironside zone, the southern block deformed in response to strike-slip movement along and shortening across the southern boundary of the re-entrant. Many of the structures assigned to this event developed continuously through the remaining movement history of the Keystone plate, but several local events occurring at the head of Lavinia Wash during this time are of special significance and will be discussed separately as Events K-3a and K-3b. The structures formed during this event that are of general importance are 1) slicing along the Keystone thrust in the area of Keystone Wash, 2) folding about east-trending axes of the Contact and Keystone plates adjacent to the thrust,
3) east-striking reverse faulting in the hinges of the folds north of Columbia Pass road, and 4) the northeast and northwest-trending, small-displacement, high-angle faults in the Kirby Wash-Columbia Pass and Prophyry Gulch(?) areas. These structures probably developed synchronously as there are no definitive cross cutting relations between them. They do not affect the terrain north of the Ironside fault nor do the structures extend more than two miles north or south of the southern boundary of the re-entrant.

Event 3a: Folding, High-Angle Faulting and Minor-Thrusting in upper Lavinia Wash: Structures assigned to this event include 1) the northeast-trending, high-angle faults which cut the autochthon and/or the Contact plate at the head of Lavinia Wash, 2) the west-northwest-trending, north-vergent fold couple affecting the autochthon west of Goodsprings, and 3) the inferred reverse fault which cuts the common limb of the fold couple in Lavinia Wash (Plate I). Considered in the classification "northeast-trending, high-angle faults" are the Ruth fault, the fault juxtaposing the Lavinia Wash sequence against the Moenkopi Formation east of Greenstone Adit, and possibly the Alice fault. Those structures are thought to predate the initiation of major strike-slip along the southern boundary of the re-entrant because, in its present configuration, the steep, east-striking portion of the Keystone thrust truncates one of the high-angle faults south of Greenstone
Claim. The Alice fault formed either during this event or during the later K-4 Event. It is not thought to be a tear fault related to the emplacement of the Contact plate, because Cameron (1978) reports slickenside data indicating an east-northeast direction of transport for the Contact plate. The east-west compression suggested by this transport direction is not consistent with left-lateral slip on a northeast trending tear fault. A fault of this orientation and offset would be more likely to form in a stress field related to north-south compression. Such a stress field is not thought to have been active in the Good springs area until Keystone time. Hewett (1931) also considered the Alice fault to be a Keystone-related structure. Although the latest movement along the Alice fault may have occurred during the later Event K-4, the major movement is considered to belong to Event K-3a because the granite porphyry probably intruded during Event K-4, clearly intrudes along the Alice fault (Plate I).

Event K-3b: Minor Thrust Faulting at the head of Lavinia Wash: Two fault-bounded blocks of Bird Spring Limestone resting on top of the Lavinia Wash sequence at the southwest corner of Lavinia Wash are assigned to this event. The critical relations indicating that these structures postdate those of Event K-3a are 1) the thrust surface at the base of the Bird Spring blocks is undeformed, while the conglomerate beds below the block are steeply dipping as a result of the folding in Lavinia Wash
and 2) it is necessary to have had the autochthonous Lavinia Wash rocks faulted against higher parts of the Contact plate prior to Event K-3b so that rocks from a high stratigraphic level in the Contact block could be emplaced laterally over autochthonous rocks (Plate II, C-C'). The initiation of major strike-slip motion along the east-trending portion of the Keystone thrust at this time is thought to have been responsible for the emplacement of these blocks by drag.

Event K-4: Folding (east-trending), Reverse Faulting and High-Angle Strike-Slip Faulting

Following their emplacement, the small Bird Spring thrust blocks were truncated by the Cosmopolitan fault. This fault is one of a generation of structures which deform the Keystone thrust and, thus, postdate the final movement on the thrust surface. Structures which belong exclusively to this event are 1) the east-trending folds and associated reverse faults which deform the Keystone thrust near the mouth of Keystone Wash (sec. 24, T.24S., R.57E.) and 2) the Cosmopolitan fault. Other structures which may have formed or, at least underwent their last episode of movement during this event include 1) the north-east and northwest-trending, high-angle faults in Porphyry Gulch and in the Keystone plate north of the Columbia Pass road, 2) the east-trending folds and associated reverse faults in the Keystone plate north of the Columbia Pass road, 3) the east-trending folds in the Bird Spring
Formation in the vicinity of Shenandoah Peak, and 4) the west-northwest-trending structures affecting the autochthon in Lavinia Wash. The intrusion of the granitic porphyry may also have occurred at this time.

The amount of time elapsing between the last movement on the Keystone thrust and the initiation of Event K-4 structures is not known. These structures could have been the last in a continuous sequence of events resulting from the compression responsible for the emplacement of the Keystone thrust plate, or they could have resulted from a separate, later period of deformation. The former hypothesis is favored because later events which might have resulted in this deformation are not known from the surrounding region.

Absolute Age of Keystone Thrusting: No new data are available from the Goodsprings district that will aid in defining the absolute timing of Keystone-related events. A zircon age for the syntectonic granitic porphyry could prove valuable in this regard.

Our present knowledge of the age of the Keystone thrust depends on two widely separated data points. The lower limit comes from the Muddy Mountain area where the Willow Tank and overlying Baseline Sandstone rest unconformably over the Aztec Sandstone (Longwell, 1949) (Fig. 15). No pre-Silurian detritus is known from terrigenous sediments in that region prior to the deposition of the Baseline Sandstone. The lack of pre-Silurian debris in the
Willow Tank Formation suggests that the Muddy Mountain thrust, which contains pre-Silurian rocks in the upper plate, was not yet emplaced at the time of Willow Tank deposition (Fleck, 1970). The Willow Tank has been dated on fossil evidence as early Late Cretaceous (Longwell, 1949) and radiometrically as 98.4 and 96.4 m.y.b.p. (Fleck, 1970). Because the Keystone and Muddy Mountain thrusts are thought to be correlative (Longwell, 1960), the lower age limit of Keystone thrusting is taken as 96.4 m.y.b.p. (Fleck, 1970; Burchfiel and others, 1974). The upper limit of Keystone thrusting is from the Clark Mountain area, some 70 miles (110km) to the south. There the Keystone thrust is intruded by the Teutonia monzonite dated at 94.2 m.y.b.p. (K/Ar whole rock; Sutter, 1968) (Fig. 15). Assuming that the emplacement of the thrust was synchronous along its entire length the Keystone thrust is post-96.4 and pre-94.2 m.y.b.p. or early Late Cretaceous in age.

Late Gravity Slide Event

During the last structural event to affect the area gravity slide blocks were formed in Lavinia Wash and near the mouth of Keystone Wash. The age of this event is only loosely bracketed. The Lavinia Wash block rests on top of deformed beds of the Lavinia Wash sequence and is overlapped by older alluvium (Pleistocene?). The Keystone Wash block overlies the Ironside fault zone, which is presumably no younger than early Late Cretaceous in age.
Similar gravity slid blocks are known from throughout the Great Basin. Some of these are known to be Cretaceous in age while others are presently active.

THRUST GEOMETRIES

A Basis for the Construction of Cross Sections

Five interpretive cross sections were constructed across the map area, three in an east-west direction and two north-south (Plate II, Plate III). A strict geometric construction technique, based on the constraints dictated by a series of assumptions concerning the style of deformation, was adhered to rigorously wherever possible. Those assumptions were as follows:

1) The thrusts are all of a decollement type, with the detachment horizon occurring at or near the base of the Banded Mountain member of the Bonanza King Formation. This assumption is employed with some reservation in the case of the Green Monster thrust, because in correlative thrust plates to the south, the thrust cuts down section through the Papoose Lake and eventually, in the Clark Mountain area, involves Precambrian crystalline rocks in the upper plate. However, the assumption is considered reasonable over the short distance for which surface control is available. The decollement nature of the Keystone thrust cannot be based on data from the Goodsprings area alone because of the anomalous structure related to the re-entrant. It appears to be consistent with data for the
Keystone thrust to the north and south (Burchfiel and Davis, in preparation) and will, therefore be applied at depth in the Goodsprings area, as well. The assumption is applied in the case of the Contact plate because no unit older than the Banded Mountain is exposed by that thrust, while the Banded Mountain is exposed at both the forward and rearward edges of the plate. Cameron (1978) has discussed some further evidence for a decollement model based on data from the Potosi Mountain area.

2) Stratigraphic thickness does not change within a thrust plate. Stratigraphic measurements from the Goodsprings area are in accordance with data reported along strike in the Contact and Keystone plates (Gans, 1974; Cameron, 1978). The thicknesses of units are assumed to be relatively constant in an east-west direction, as well. This seems reasonable at least over short distances.

3) The base of the Bird Spring Formation is an important detachment surface above which rocks may deform disharmonically from the underlying massive Lower Paleozoic sequence. This style of behavior is clearly seen in the surface geology.

4) Folding in the area follows a concentric geometry based on surface observation.

GREEN MONSTER THRUST

Section B-B' indicates that the Green Monster thrust flattens westward with depth. Cross cutting relations with the lower plate rocks demonstrate that the thrust ramps
along its eastern front; surface data indicate that the Green Monster also ramps to the north, cutting up section in the upper plate and losing displacement. The high structural position of the Green Monster relative to the projected trace at depth of the Keystone thrust requires that 1) the frontal ramp is a long gently-dipping structure extending far to the west or 2) the thrust flattens for a distance at a high stratigraphic level in the underlying plate, then ramps again to the west in order to reach the same structural and stratigraphic level as the decollement at the base of the Keystone plate. The SGM thrust is still in a primitive stage of development as a thrust fault cutting the axial surface of a fold in the Goodsprings area, but its position corresponds closely with the Green Monster ramp. Little can be said regarding the amount of displacement on these faults other than it decreases northward on the Green Monster and increases in the same direction on the SGM thrust. A northeast direction of transport for these thrusts is inferred from the associated folding.

CONTACT THRUST

Because a complete stratigraphic section down to the basal decollement surface cannot be measured in the Contact plate, the stratigraphic thickness for the Banded Mountain Member was assumed to be equal to that in the Keystone plate. This is based on the conclusion that both plates were cut from nearly the same paleogeographic
terrain. Surface control of section B-B' is good because a silty unit of known stratigraphic position in the Bird Spring can be mapped continuously across two-thirds of the width of the plate and can be projected into the line of the cross section from the south.

The Contact thrust is ramped in its frontal parts. This is a geometric necessity in both sections A-A' and B-B'. The surface control also requires that the thrust flatten westward with depth at a structural horizon near present sea level. This geometry, which is dictated in sections A-A' and B-B', is extended as an interpretation to section C-C' where the surface control is less conclusive. The geometry of the Potosi syncline suggests that the Contact plate is a structural "klippe", completely cut off from its root. It is important to note that the frontal part of the Contact plate is also cutting up section in the upper plate. This ramp geometry may imply that only the thin frontal lip of the Contact thrust plate actually moved over an erosional surface to create the present surface relations. An alternate interpretation is that the entire Contact plate moved on an erosional surface, and that the frontal ramp in the Goodsprings area is only a local response to topography created by pre-Contact high-angle faulting and the diverse rock types exposed at the surface at the time of thrusting. This model seems better suited to data from the Potosi Mountain area (Cameron, 1978). Whatever the nature of the
frontal ramp, it is clear from the high structural position of the basal decollement of the Contact plate relative to the level of the base of the Banded Mountain in the autochthon, that a second ramp must have been present west of the present west edge of the Contact plate. Assuming the east-directed transport on the Contact thrust indicated by slickenside data (Cameron, 1978), the minimum amount of demonstrable displacement on the thrust is approximately 5 miles (8km). This is far less than the actual minimum, because as pointed out by Cameron (1978), it does not take into account the position of a western ramp.

KEystone Thrust

The Keystone thrust also flattens westward and ramps its front. North of the Ironside fault, the Keystone ramps across the west edge of the Contact plate, truncating the earlier thrust and folding it into the Potosi syncline (Plate II; A-A', B-B'). The Keystone flattens westward within the area of the cross section. It is important that the Keystone thrust does not cut across stratigraphic boundaries in the upper plate except where it cuts pre-existing upper plate structure. This suggests that the thrust is presently eroded to a structural level below its original front.

South of the Ironside fault zone, the geometry of the thrust is different. In section C-C' the thrust ramps east or northeast over the southwest part of the Contact plate. Surface geology indicates that the thrust was
moving over an erosional surface. Impingement on topographic irregularities is taken as the explanation for the slicing and irregularity at the basal part of the plate near the surface. The thrust flattens at a horizon approximately 500 feet (150m) above present sea level for a short distance before reaching the Ironside fault zone. West of the Ironside zone, in the northern block, the thrust dips moderately to the west as it does in the sections to the north. Ramping is also apparent along the east-trending portion of the Keystone thrust as indicated by cross sections D-D' and E-E'. In D-D' the Keystone ramp dips south or southwest overriding the Contact plate to the north. The thrust again flattens near the 500 foot (150m) level, but in this case, the frontal portion of the Keystone plate is broken through and deformed by a structurally higher thrust rising from a second ramp to the south. An alternative interpretation of this cross section would be to continue the Keystone thrust to the south maintaining its surface dip until it merges at depth with the higher thrust. This model, however gives rise to the problem of what to do with the gap that is created between the projected trace of the Keystone and the constructed base of the Banded Mountain, which is up-turned in a syncline as dictated by surface geology. The folded thrust model is preferred for this reason. The small displacement of the structurally higher thrust fault and the fact that it does not always break to
the surface along strike suggests that the ramp from which the thrust originates is a major ramp of the Keystone thrust, and that the flattening of the Keystone thrust at the 500 foot (150m) level occurred over only a short distance as in section C-C'. In section E-E', east of the front of the Contact plate, the Keystone plate is faulted directly against rocks of the autochthon on a moderately steep ramp which is analogous to the southern ramp in the previous section. Both the southern ramp of D-D' and the ramp in E-E' are thought to flatten to the south not far beyond the map boundary. This is required by the fact that, although they are complicated by faulting, the rock units for many miles south of Columbia Pass road dip gently to the south or southwest forming a monocline. Such a surface structure would result in a gently southwestward dip for the constructed base of the Banded Mountain.

In summary, north of the Ironside fault zone, the easternmost portion of the Keystone thrust surface has a ramp geometry as it rides east over the Contact plate. There is no evidence that this thrust moved on an erosional surface. The fact that the thrust does not cut across stratigraphic boundaries in the upper plate suggests that the thrust has been eroded to considerable depth. The thrust flattens westward, within the map area.

South of the Ironside fault zone, there is a major ramp in the Keystone plate which approximately coincides in position with the Columbia Pass road. East of the front
of the Contact plate this ramp places Keystone plate rocks directly against the autochthonous sequence. South of the Contact plate the ramp is only evident below the 500 foot (150m) altitude in the subsurface. In that area the thrust flattens for a short distance to the north of the ramp at a 500 foot (150m) altitude, then ramps again to the north over the Contact plate. Along this portion of its surface trace, karst fillings and terra rossa indicate that the Keystone thrust was moving on an erosional surface.

It is important that the Keystone ramp, as well as the surface structure of the Keystone thrust, follows the trend of the Keystone re-entrant. The structural level 500 feet (150m) above present sea level is also thought to be of great importance in the hypothesis presented here for the genesis of the Keystone re-entrant. This is thought to be the level of surface erosion in the area south of a topographic high created by the Contact plate at the time of Keystone thrusting.

A minimum of two miles of shortening is required by the folding and thrusting associated with the ramping of the Keystone plate over the Contact plate. Another seven miles of displacement is indicated by the depth of the re-entrant. Further estimates of shortening within the map area depend on the model used for the Keystone at depth and are equivocal.
DISCUSSION: AN INTERPRETIVE GEOLOGIC HISTORY OF THE GOODSPRINGS AREA

The following is an interpretive history of the geologic evolution of the Goodsprings district (Table 3). Particular attention is paid to the genesis of the Keystone re-entrant. The history combines 1) observations on surface geology, 2) timing information based on observed relations, as well as interpreted events, and 3) subsurface data based on interpretive cross sections.

There exists a possibility that the first deformation to affect the area was associated with pre-200 m.y. old thrusting along the Mesquite Pass structural trend in the Clark Mountain area (Fig. 1). It is unlikely that the effect of the event was felt as far north as the Green Monster area. The inferred northwest-trending, high-angle fault in the autochthon formed during the earliest proven structural event to affect the map area. This high-angle faulting event, hypothesized to explain a stratigraphic mismatch across the drainage at the northern boundary of the map area, can also be used to explain the localized deposition of the Lavinia Wash sequence. The fault may be one of the earliest in a system of northwest-trending, high-angle faults active in the region throughout Late Mesozoic time. This fault may be part of a northwest-trending fault system that developed along the eastern limit of the Mesozoic magmatic arc from southern Nevada and
southeastern California to southeastern Arizona (King, 1969). W. Bilodeaux of Stanford University (1978, personal communication) finds Late Jurassic to Cretaceous normal faults along this trend in southeastern Arizona. He has mapped relations indicating that those faults limit the aerial extent of syntectonic conglomerate deposition. The faults are similar in age and geometry to that envisioned for the inferred fault in the Goodsprings area, and may belong to the same fault system.

The Lavinia Wash sequence records an active period of tectonism which began with the fault just discussed and ended with the arrival of the Contact thrust plate. The 150±10 m.y. old tuff layer near the lowest exposed part of the sequence records volcanic activity, probably centered to the southwest, in early Late Jurassic time. Paleozoic carbonate debris in strata below the tuff unit herald the approach of the Contact plate. The actual arrival of the thrust plate must be post-150 m.y.p.b. and was probably in the latest Jurassic or Early Cretaceous based on regional correlation.

The Contact thrust, correlative with the Red Spring thrust west of Las Vegas, is a gentle west dipping thrust which appears to have been emplaced on an erosion surface, at least in its frontal parts. The thrust plane flattens to the west and is truncated by the later Keystone thrust. Following its emplacement, the Contact-Red Spring thrust plate was dismembered by high-angle, normal faults along
the same northwest trend as the earlier inferred Boundary fault. During an ensuing period of erosion, the fault-bounded Contact block was left as an isolated topographic high, bordered to the south by a valley, the floor of which appears to have been at a level approximately 500 feet (150m) above present sea level.

At some time prior to the emplacement of the Keystone plate, thrusting occurred in the Green Monster terrain far to the west. This event is manifested in the Goodsprings area by two thrusts which occupy the same structural position, the Green Monster and Sub-Green Monster thrusts. Cross-cutting relations show that the SGM thrust actually predates the emplacement or, at least the last phase of movement on the Green Monster thrust, but both thrusts are considered to be closely related in time and space. The decreasing displacement on the Green Monster thrust as it dies into folds to the north is compensated by a northward increase in displacement on the SGM thrust.

EVOlUTION OF THE KEystone RE-ENTRANT

The events discussed above were followed by deformation associated with the emplacement of the Keystone thrust plate (Fig. 16). That deformation was greatly influenced in the Goodsprings area by the geometry and surface morphology following erosion of the earlier Contact thrust plate and its northwest-trending bounding faults. A fault in the subsurface bounding the south part of the Contact block is inferred to explain the geometry of the Keystone
re-entrant. The existence of such a fault is supported by the presence of an extensive system of northwest-trending, high-angle faults mapped (Hewett, 1956) cutting the autochthon and Keystone plate immediately south of the area of this study. Those faults may represent later movement on a system of pre-Keystone faults that was similar to late activity on the Cottonwood fault which bounds the Contact block to the north. Further mapping of the southern fault zone is needed to test this hypothesis.

Cross sections in the map area (Plate II, Plate III) show that the Keystone thrust ramps eastward over the western edge of the Contact plate. North-south cross sections also show that the Keystone ramps up from the south along the southern boundary of the Contact plate and against the autochthonous sequence east of the Contact plate. Geometric constraints imposed by mapping in the area to the south (Hewett, 1931) suggest that the ramp again turns to strike north-south southeast of Goodsprings. Thus, the frontal ramp of the Keystone thrust follows the same changes in orientation through the Keystone re-entrant as the surface structures. The arcuate trend of the ramp is thought to be a primary feature related to refraction of the stress field responsible for initial fracturing along the thrust surface due to the anomalous boundary condition and zone of weakness created by a pre-existing high-angle fault south of the Contact block. A contrast in lithology across the bounding fault may also have
contributed to the greater eastward propagation of the Keystone thrust south of the Contact plate. An anomalously high loading condition present locally due to the extra mass of the Contact plate may have affected the local stress field, but the nature of this effect is not known. Studies elsewhere have demonstrated that arcuate patterns in frontal fold and thrust belts can result from refraction of the stress field by local boundary conditions (Laubscher, 1972; Beutner, 1977). Once established, the arcuate geometry of the ramp, itself would serve to refract the local stress field during continued compression, thus controlling the configuration of later, more superficial structures.

The Keystone thrust ramp coincides with what is now the western edge of the Contact plate in the northern part of the map area. Where the Contact plate had presumably been removed by erosion to the south, beyond the southern bounding fault, the ramp raised the Keystone plate to the level of surface erosion. Because of erosion, the surface trace of the southern bounding fault, which controlled the position of the later ramp, would not have coincided with the southern boundary of the topographic high created by the Contact block. Consequently, the Keystone plate must have moved over an erosion surface for a short distance to the east and north of the ramp head before encountering interference from the topography of the Contact block. That area of erosion surface thrusting is thought
to coincide with the 500 foot (150m) level plateau in the Keystone thrust trace of cross sections C-C' and D-D'. The thrust trace in both sections steepens again at a position which represented the knick point in surface slope to the north. An eastward decrease in the distance between the topographic knick point and the head of the thrust ramp is noted from the north-south cross sections. These relations indicate that a wedge-shaped portion of the Keystone plate was moving over the ground surface between the southern slope of the Contact topographic high and the head of the Keystone thrust ramp. The wedge is further bounded to the west by the Ironside fault zone which is thought to approximately coincide with the point at which the Keystone plate broke onto the erosional surface. The eastward translation of the Keystone plate coupled with a northward refraction of the axis of maximum compressive stress resulted in north-south compression with a component of strike-slip displacement along the southern boundary of the re-entrant. Thus, the wedge was translated eastward into a space which was continually narrowing in the northsouth dimension and in a local stress field compatible with north-south compression. A gravitational instability, produced as the northern edge of the Keystone plate rode up onto the Contact topographic high east of the Ironside fault, locally increased stresses felt by the wedge. This scenario is envisioned as responsible for the local tectonic
environment at the southern boundary of the Keystone re-entrant at the time of Keystone thrusting.

The wedge of Keystone plate caught between the ramp head and the topographic high to the north deformed by folding. The increase in the tightness of those folds eastward from the Ironside fault attests to the convergence of the two bounding elements controlling the shortening. That the wedge was being deformed over an erosion surface is supported by the presence of karst topography below and terra rossa along the thrust surface. No similar folding affects the area south of the position of the ramp. The northern boundary did not prove as unyielding. East-west trending folds affect the Contact block as far north as the Wilson Pass road. The autochthon east of the Contact plate which was not protected by the buttressing effect of the topographic high, underwent considerable shortening by folding and northward thrusting in response to compression across the ramp boundary. Tear faulting associated with the structures in the autochthon faulted the Lavinia Wash sequence up against the front of the Contact block and, further east, the Moenkopi against the Lavinia Wash sequence. A phase of strike-slip movement along the southern boundary of the re-entrant followed, as evidenced by the eastward translation of Bird Spring rocks over the upraised autochthon on a shallow fault surface. This was presumably accomplished by drag in response to left-lateral slip along the Keystone thrust surface. Further evidence
of strike-slip movement is from small-scale vertically plunging folds in the Contact plate immediately north of the Keystone thrust.

The strike-slip phase was followed by a period of renewed north-south compression across the re-entrant boundary. This phase was characterized by high angle faults (Cosmopolitan fault), west-trending folds, and reverse faults. Some of these structures deform the Keystone thrust surface, itself. Therefore, this deformation postdated movement on that surface. Although there is no evidence to preclude the possibility that this deformation was separated in time from Keystone events, the similarity in style to Keystone structures and the fact that there is no known phase of later deformation in the nearby region to which the structure can be attributed, suggest that these structures belong to the Keystone deformation. A mechanism to explain the cross cutting relation of those structures to the Keystone thrust is inspired by cross section D-D'. In that section, a minor thrust is shown breaking out of the ramp and cutting off the portion of the Keystone plate that was emplaced on the erosion surface. This fault is intermittently traceable along strike, but does not always break through to the surface. The fault trend coincides with the northernmost end of the Fredrickson thrust mapped to the south (Hewett, 1931) and may indicate a transfer of displacement to a higher thrust after continued movement on the Keystone surface became
mechanically impossible. This phase of deformation, then, was one in which the refracted stress system continued to compress the re-entrant boundary even after active motion on the frontal part of the Keystone thrust had ceased. During that time the former thrust surface behaved passively, deforming along with both upper and lower plate rocks.

This marked the last period of compressive tectonism to affect the Goodsprings area. It was followed in the Tertiary by tectonic denudation in the form of large and small gravity slid blocks and, in the surrounding region, by basin and range tectonism, though the latter did not strongly affect this portion of the southern Cordillera.

Thus, the unique position of the Goodsprings area was indirectly responsible for the development of the Keystone re-entrant. The fortuitous mixture of decollement thrusting, typical of the region to the north, superposition of younger thrusting events over older in the same terrain, typical of the southernmost Cordillera, and the northwest-trending, high-angle faults associated with the front of the magmatic arc all combined to yield a complicated and interesting structural style that, in detail, is unique to the Goodsprings district.

The presence of the northwest-trending faults presents an enigma to the structural geologist. It is hard to envision an environment in which large scale compressional and tensional structures exist so intimately. The high-angle faults appear to be related to the eastern margin of
the Mesozoic magmatic arc. Structures of this age and style are not known to cut the frontal thrust belt to the north where it becomes further removed from the arc. Burchfiel and Davis (1977) have suggested that strike-slip in the arc may be responsible. This is an attractive model for many of the faults, but some are proven to be primarily dip-slip faults (Burchfiel and Davis, in preparation). Normal faulting may also be consistent with arc tectonics, in which case, the superposition of the magmatic arc and frontal thrust belt in the southern Cordillera explains the interfering tectonic styles.

The mechanics of emplacing a thrust sheet over an erosional surface is also a perplexing problem which has a bearing on the structure of the Goodsprings district. No new data are presented here that will aid in the solution of this apparent paradox, so it will not be discussed further. Mention is made only to point out that the Goodsprings district is another example of an area where evidence clearly indicates that thrust plates can be translated over erosion surfaces.

A third interesting structural phenomenon exemplified in the Goodsprings area is that while the Keystone and possibly the Contact and Green Monster thrusts are stratigraphically controlled, they appear to be detached within the thick dolomites of the Banded Mountain and Papoose Lake Members of the Bonanza King Formation and not at the Bright Angle or Carrara Shale horizons. The mechanics of this geometry are not understood.
CONCLUSIONS

Conclusions and speculations regarding the details of the geologic evolution of the Goodsprings district have been discussed, so that only the major conclusions of this work will be summarized here.

The Paleozoic history of the southeastern Cordillera is dominated by quiescent deposition of a westward thickening miogeosynclinal carbonate sequence. The basinward thickening of the carbonate sequence was accomplished by thickening of individual units already present on the platform and by addition of new units at the Cambro-Devonian unconformity, characteristic of the platform sequence (Burchfiel and others, 1974). The three thrust terranes exposed in the Goodsprings district were cut from a paleogeographic terrane transitional between the platform and miogeosyncline. This is indicated by the presence of a thin sequence of Ordovician rocks at the position of the Cambro-Devonian unconformity. That the westernmost thrust, the Green Monster, was cut from a more basinward terrain than the other thrust plates is supported by the appearance of Ordovician terrigenous rocks.

A newly recognized sequence of synorogenic mollasse-like deposits, here named the Lavinia Wash sequence, records the effects of early Late Jurassic volcanism and the onset of thrusting in the Goodsprings area. The Lavinia Wash deposits are Upper Jurassic to Cretaceous(?) in age and
are believed to have been shed as an alluvio-fluvial apron in front of the advancing Contact thrust. A tuff layer near the lowest exposed strata in the sequence yielded a K/Ar date of 150±10 m.y.b.p. (Late Jurassic).

Mesozoic thrust faulting continued in the area until the early Late Cretaceous. The upper age limit is based on correlation of the through-going Keystone thrust with better-dated occurrences to the south. Potential for establishing an upper age limit within the Goodsprings area lies in the future dating of the syn-orogenic granitic porphyry intrusions.

High-angle faulting occurred before and after the emplacement of the earliest thrust, the Contact thrust. The latter event dismembered the thrust plate in horsts and grabens. Ensuing erosion left an irregular topography in which the more resistant carbonate rocks of the thrust plate, preserved in the graben, became a topographically positive element.

During the emplacement of the Keystone thrust plate, interference resulting from a pre-existing zone of weakness along the southern bounding fault of the Contact block led to the establishment of an arcuate geometry in the Keystone thrust ramp. The refraction of stresses resulting from this arcuate boundary and interference from the topographic high of the Contact plate upon the subsequent ramping of the Keystone thrust to the erosional surface, resulted in north-south compression along the southern boundary of the
newly established Keystone re-entrant. Deformation result-
ing from this geometry was responsible for the surficial
structure associated with the re-entrant.

Indirectly, the transitional position of the Goodsprings
district in the Mesozoic frontal thrust belt is responsible
for the unusual detail geology of the area. Unlike the
"typical" fold and thrust belt to the north, thrusts in
the Goodsprings district did not develop progressively,
becoming younger to the east. Instead, the Contact thrust,
the easternmost thrust, is also the oldest. This is a
result of the crossing of the Paleozoic miogeosyncline-
platform hinge line by the Mesozoic magmatic arc. Northward
in the frontal thrust belt, the eastern limit of decollement
thrusting east of the magmatic arc is controlled by the
anisotropy and geometry of the geosyncline. Southward, as
the two paleogeographic elements converge, decollement
thrusting is confined to a continually narrowing zone
until, in southern Nevada, older and younger structures
compete for the same terrain and are superposed. Further
south, decollement structure ceases to exist as Precambrian
crystalline rocks are involved in all thrust faults. Thus,
the locally anomalous structural trends in the Goodsprings
district are consistent with the overall structural
evolution of the southern Cordillera.
REFERENCES


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NORTH-SOUTH GEOLOGIC CROSS SECTIONS OF THE GOODSPRINGS

Vertical scale in feet above mean sea level
EAST-WEST GEOLOGIC CROSS SECTIONS OF THE

Vertical scale in feet above mean sea level
Vertical scale in feet above mean sea level
GEOLOGIC MAP OF THE GOODSPRINGS AREA, NEVADA

EXPLANATION

MAP SYMBOLS

Contacts
definite, approximate, inferred

Strike and dip of bedding
upright, overturned, vertical

Faults:
Thrust fault: bars on upper plate,
open bars indicate small displacement
definite, approximate, inferred

High-angle fault: U-upthrown and
D-downthrown block, apparent
relative displacement in vertical
plane, small arrow indicates dip

Fault at base of gravity-slip block

Large arrow indicates trend and plunge
of slickensides on fault surface

Axial trace of anticline, syncline, overturned
anticline, overturned syncline; arrow
indicates direction of plunge

Brecciated rock near faults or in gravity-slip blocks

SEDIMENTARY

Recent Alluvium
Qa1

Older Alluvium
Qoa
unconformity

Jurassic Sediments
Jsd
unconformity

Chinle Formation
Tcs
Shin

Moenkopi Formation
Tmr
Red
Virg
unconformity

Kaibab Formation
Pk

Permian Red Beds
Prb

Bird Spring Formation
MIPBs
OF THE GOODSPRINGS A, NEVADA

EXPLANATION

MAP SYMBOLS

- d dip of bedding
- overturned, vertical

- fault barbs on upper plate, arrows indicate small displacement, approximate, inferred
- single fault, U-thrown and n'thrown block, apparent displacement in vertical; small arrow indicates dip

- paired arrows indicate strike-slip

- base of gravity-slip block

- arrow indicates trend and plunge on fault surface

- of anticline, syncline, overturned e, overturned syncline; arrow as direction of plunge

- rock near faults or in gravity-slip blocks

SEDIMENTARY ROCKS

- Recent Alluvium

- Older Alluvium

- Jurassic Sedimentary Deposits

- Chinle Formation

- Moenkopi Formation

- Kaibab Formation

- Permian Red Beds

- Bird Spring Formation

QUATERNARY

CRETACEOUS (†)

JURASSIC

TRIASSIC

PERMIAN

PENNSYLVANIAN
Chinle Formation

Maekopk Formation

Triassic Red Beds

Bird Spring Formation

Kaibab Formation

Permian Red Beds

Monter Cristo Formation

Sultan Formation

Nopah Formation

Bonanza King Formation

unconformity

unconformity

unconformity

unconformity

monolithologic breccia
unconformity

Chinle Formation

\[ \text{Tc} \quad \text{Tcs} \]
Shinarump Conglomerate

Moenkopi Formation

\[ \text{Tm} \quad \text{Tmv} \]
Red Beds
Virgin Limestone

unconformity

Kaibab Formation

\[ \text{Pk} \]

Permian Red Beds

\[ \text{Prb} \]

Bird Spring Formation

\[ \text{MIPPbs} \]

unconformity

Monte Cristo Formation

\[ \text{Mmy} \quad \text{Mmb} \quad \text{Mmd} \]
Yellow Pine Member
Bullion Member
Anchor Member
Dawn Member

Sultan Formation

\[ \text{Ds} \quad \text{Dsv} \quad \text{Dsi} \]
Crystal Pass Member
Valentine Member
Ironside Member

unconformity

Nopah Formation

\[ \text{En} \quad \text{End} \]
Dundurburg Member

Bananza King Formation

\[ \text{Cbk} \quad \text{Cbb} \quad \text{Cbp} \]
Banded Mountain Member
Papoose Lake Member

IGNEOUS ROCKS

monolithic breccia

\[ \text{mb} \]

Granite porphyry

\[ \text{gp} \]