

GEOLOGY OF THE
LA MADRE MOUNTAIN AREA
SPRING MOUNTAINS, SOUTHERN NEVADA

by

Gary James Axen

B. S. Geology
Massachusetts Institute of Technology
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Signature of Author *Gary James Axen*
Department of Earth and Planetary Sciences
May 27, 1980

Certified by *B.C. Burchfiel*
B.C. Burchfiel
Thesis Supervisor

Accepted by _____
Chairman, Departmental Committee
on Graduate Students

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Abstract

The La Madre Mountain area lies about 20 km west of Las Vegas, Nevada on the easternmost edge of the belt of Mesozoic thrust faults in the Cordilleran orogen. Paleozoic miogeosynclinal carbonates have been transported eastward on two major thrust faults, the Keystone and Red Spring thrusts, with a total minimum transport of 26 km.

The geologic history of the area is as follows. Deposition of marine, mainly miogeosynclinal rocks occurred from Middle Cambrian to Early Triassic time. Terrigenous clastic and eolian sediments were deposited from Middle Triassic to Jurassic or Early Cretaceous time. The youngest of these, the Brownstone Basin Conglomerate, was deposited synchronously with the first major structural event, emplacement of the Red Spring thrust plate. The Red Spring thrust sheet overrode the land surface and its own forethrust debris. A period of high-angle normal (?) faulting on north to northwest trending faults broke the Red Spring plate and autochthon into northeast tilted blocks. A period of deep erosion followed. Emplacement of the Keystone thrust sheet over these tilted fault blocks followed, and renewed movement on the high-angle faults displaced the Keystone thrust. Deposition of a large (7 km²) mass of Tertiary (?) landslide breccia post-dated the high-angle faulting. The last (?) event to occur was Miocene dextral oroclinal flexure of the entire La Madre Mountain area due to right-lateral movement on the Las Vegas Shear

Zone. This flexure bent north-trending strata and structures to northeast strikes.

A new correlation of Mesozoic structures across the Las Vegas Shear Zone is proposed. The Keystone thrust probably correlates with the Glendale thrust of Longwell (1949) in the Muddy Mountains. The Red Spring thrust is probably equivalent to the Muddy Mountain thrust.

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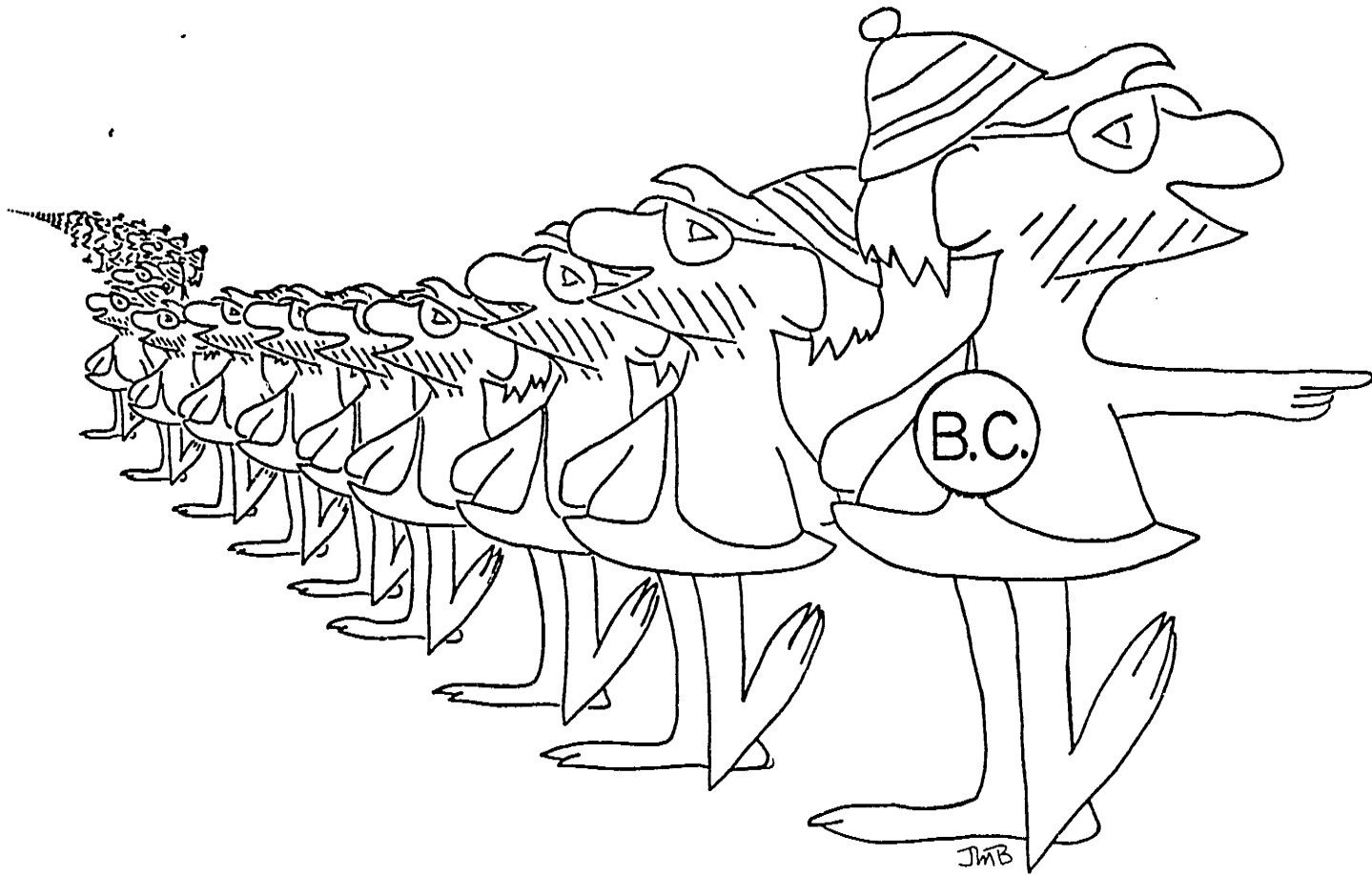
I would like to thank all of the "clones" here at M.I.T. - all the rest of Clark's students (figure 1) - for countless hours of fascinating conversation about the geology of Nevada and the rest of the world. They have all helped to broaden my understanding of this science as well as aided in the completion of my class and thesis work. When possible they have led me through their field areas. These special people are John "Noah" Bartley, Scott Cameron, Peter "The General" Guth, Kip Hodges, John Sharry, Jon "Smoothie" Spencer, Brian "B.W." Wernicke, and James "Igor" Willemin. Thank you all very much.

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Figure 1. B.C. and his Clones.



**ANOTHER
CLONE CONTRIBUTION**

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I. Introduction

A. Location

La Madre Mountain is in Clark County, Nevada, about 20 km west of Las Vegas. It lies on the eastern edge of the Mesozoic Cordilleran foreland thrust belt (figure 2). The area contains two large thrust faults, the Keystone and Red Spring thrusts, and several important high-angle faults (figure 3).

La Madre Mountain is a 15 km long, northeast-trending ridge in the eastern Spring Mountains (figure 4). The highest point, La Madre peak (figure 5), is at 8154 feet (2485 m) above sea level. The lowest point in the map area (plate 1) is at about 2900 feet (885 m) elevation.

B. Environment

The area has a desert climate with less than 15 cm (6 inches) of average yearly rainfall in the surrounding valleys. Temperatures in the summer can fluctuate from 46°C (115°F) to below 12°C (60°F). Temperatures well below freezing are common in the winter.

Due to the extreme aridity of the area, outcrop is often nearly 100%, especially on the south and east sides of La Madre Mountain. Above about 5500 feet (1675 m) on the northwest side of La Madre Mountain the outcrop is less complete.

The area is in the northeast portion of the Mojave Desert, and flora and fauna typical of the desert habitat predominate. These include various species of cacti (such as

Figure 2. Approximate eastern limit of Mesozoic thrusting. The La Madre Mountain area contains the lowest and easternmost Mesozoic thrust faults in southern Nevada.

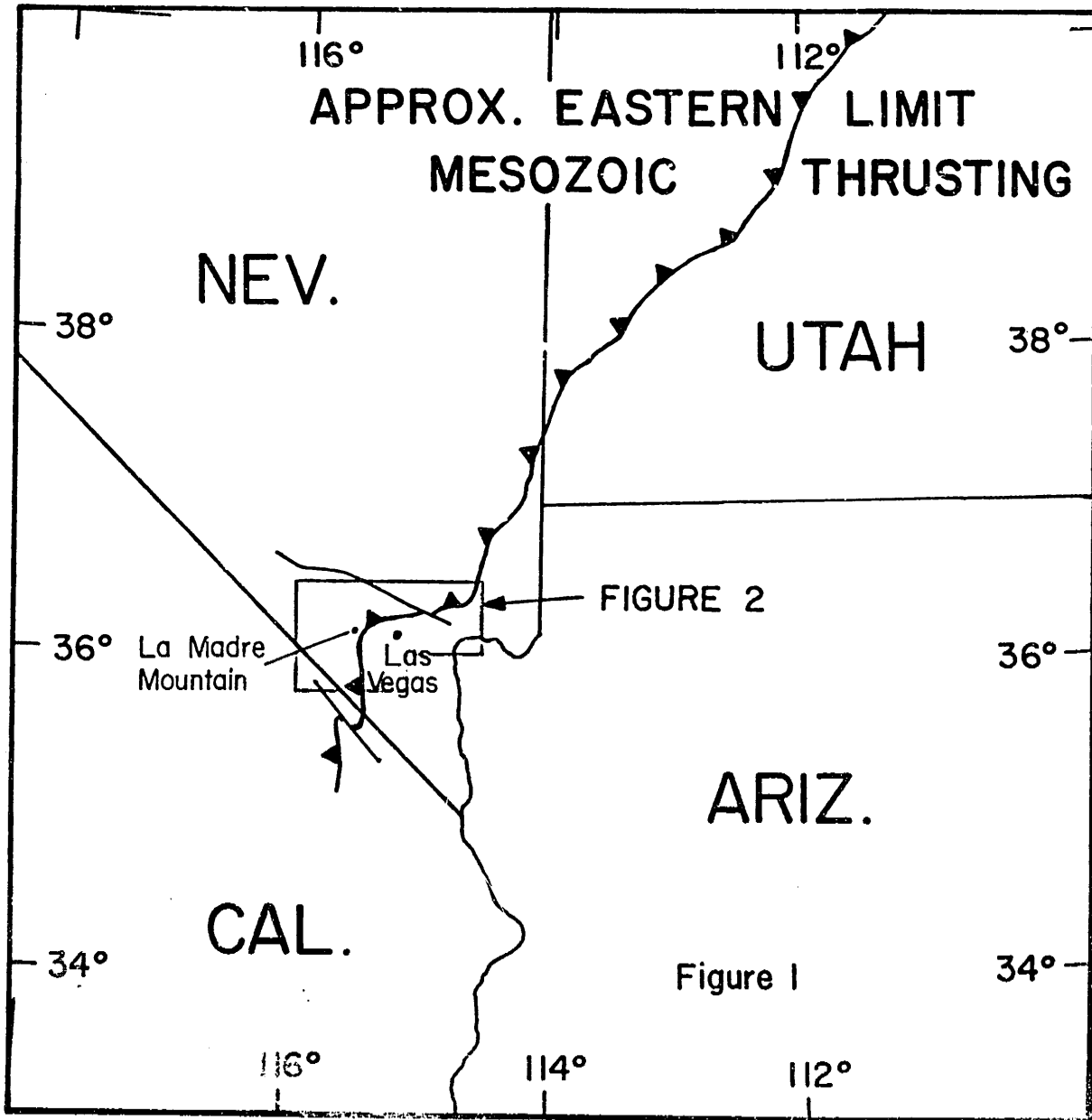


Figure 3. Tectonic map of the Las Vegas area, showing major thrust plates. The area of plate 1 is shown. The new correlation with structures in the Muddy Mountains (proposed here) is shown. (see Timing section).

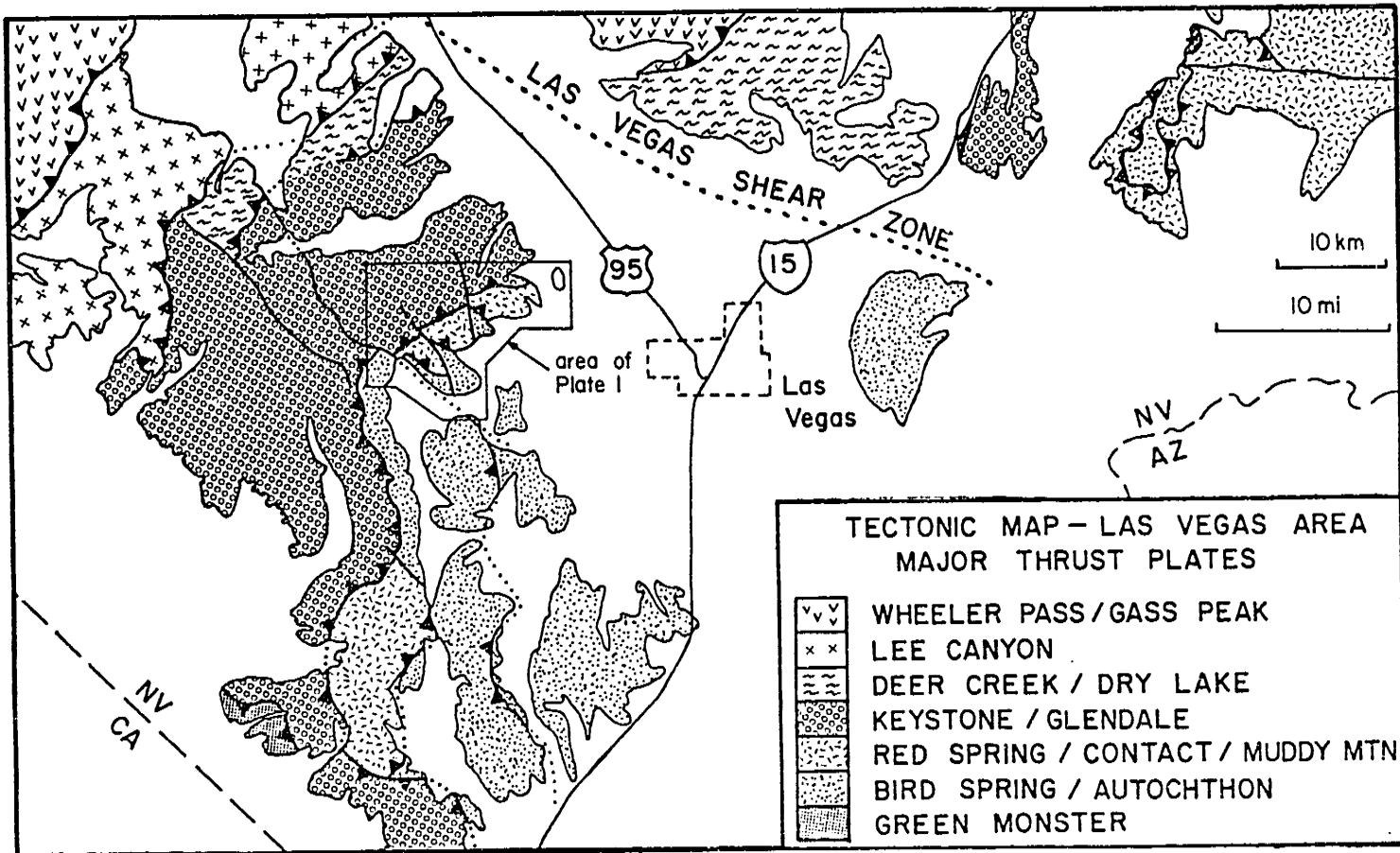


Figure 4. Place names in southern Nevada and adjacent California and Arizona. ACR=Arrow Canyon Range, BR=Bird Spring Range, CM=Clark Mountain, DL=Dry Lake Range, FM=Frenchman Mountain, G=Goodsprings, KC=Kyle Canyon, KR=Kingston Range, LMM=La Madre Mountain, LVSZ=Las Vegas Shear Zone, MM=Mesquite Mountains, PM=Potosi Mountain, RSR=Resting Spring Range, SM=Sheep Mountain.

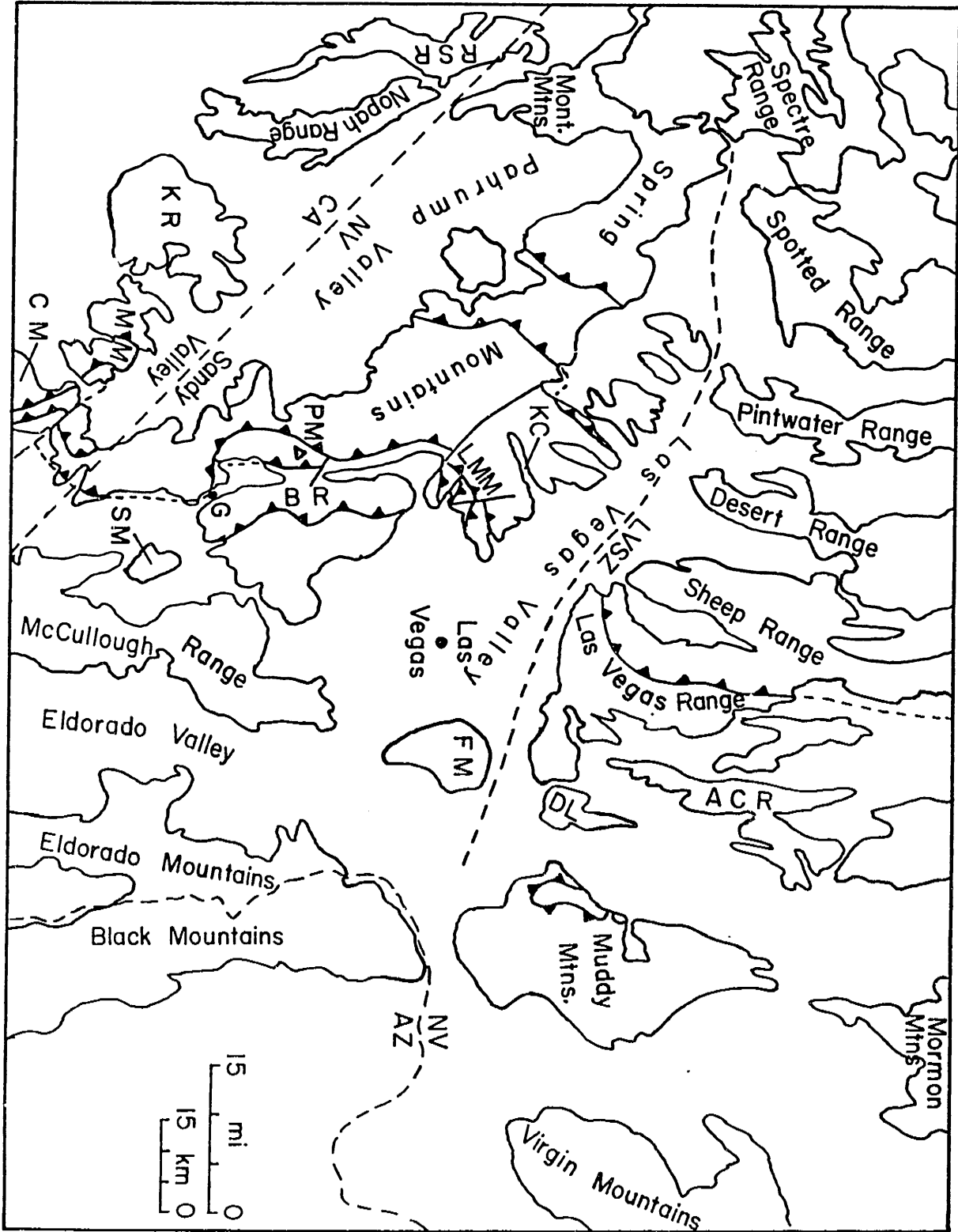


Figure 5. La Madre Mountain, looking west from peak 5835. La Madre Mountain is the ridge in the distance with three peaks, the center of which is La Madre Peak. Peak 5330 is on left. The steep cliffs are formed by Mississippian and Devonian strata.



Figure 5

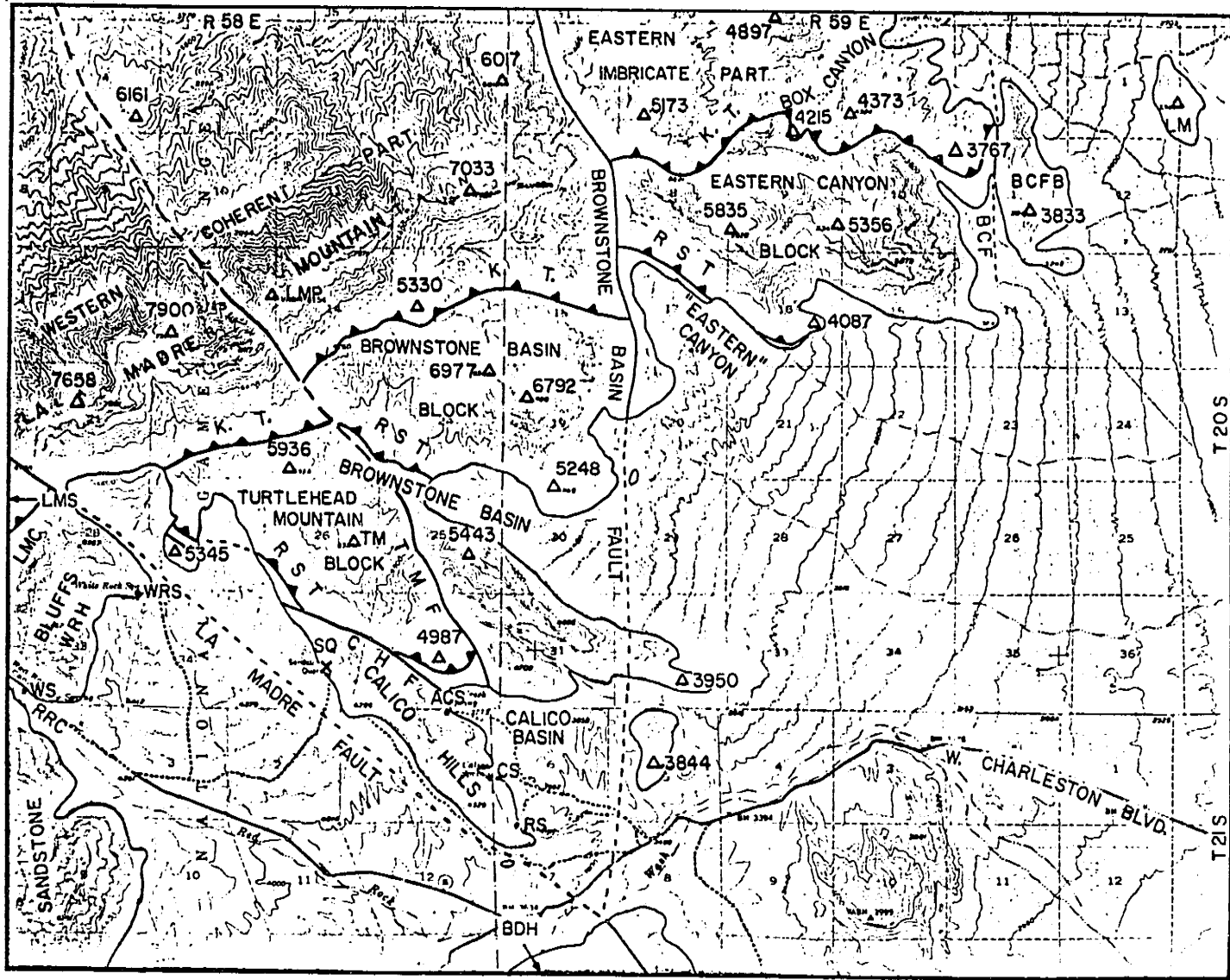
prickly pear, barrel, cholla and hedgehog) and desert plants (yucca, agave, sage, desert willow, desert trumpet). Wildlife is scarce at La Madre Mountain, but the careful observer may see desert bighorn sheep, bobcats, coyotes, rattlesnakes, and various birds, especially hawks, owls and hummingbirds.

At the higher elevations, particularly on the northwest side of the mountain, the scrub oak-pinon pine ecosystem is encountered. The dominant trees are juniper, pinon pine and scrub oak. Small burrowing owls are often seen, along with the occasional mule-eared deer.

Several springs are present in the area that generally flow only during and after rainy seasons. Around these springs are limited ecosystems, often with specialized life forms. Noteworthy springs are La Madre spring, White Rock spring, Willow spring, Ash Creek spring, Calico spring, and Red spring (figure 6, place names). Camping is restricted near most of the springs, and water from most of them has been deemed unfit for human consumption. Two small ponds have been constructed in Brownstone Basin to catch run-off water for use by local wildlife, especially the bighorn sheep. Although murky and partly filled in by cattails, the larger pond offers a refreshing dip for the summer denizen of the desert. Camping should be done some distance away from the springs and pond in order to not interfere with wildlife behavior.

Evidence of past inhabitation by Homo sapiens can be

Figure 6. Place names in the La Madre Mountain area.
ACS=Ash Creek Spring, BCF=Box Canyon fault, BCFB=Box Canyon
fault block, BDH=Blue Diamond Hill, CHF=Calico Hills fault,
CS=Calico Spring, KT=Keystone Thrust, LM=Lone Mountain,
LMC=La Madre Canyon, LMP=La Madre Peak, LMS=La Madre Spring,
RRC=Red Rock Canyon, RS=Red Spring, RST=Red Spring thrust,
TM=Turtlehead Mountain, TMF=Turtlehead Mountain fault,
WRH=White Rock Hills, WRS=White Rock Spring, WS=Willow
Spring



found throughout the area. American Indians seem to have particularly favored the Aztec Sandstone, and several pictographs are present in various locations. In addition, the remnants of fire pits used to cook yucca fruit can be found. These are ring-shaped mounds, about five meters in diameter, left from excavation of the cooked fruit.

Visitation by the modern counterparts of the Indians is represented by litter and randomly criss-crossing tracks of dune buggies, four-wheel drive vehicles and motorbikes. Care should be taken when leaving vehicles behind that valuable items are not left in sight, as theft is a problem. When the lower elevations where roads abound are left behind these irritating features are for the most part left behind also. Although hunting is prohibited in much of the area, recreational shooting is common in the parts of the area which are easily accessed from Las Vegas.

C. Access

Access to most of La Madre Mountain is easily obtained. The west sides of the Calico Hills and Turtlehead Mountain are easily reached from a paved road, the Red Rock Canyon scenic drive. Good dirt roads are present in Calico Basin. The west end of La Madre Mountain is most easily reached from the La Madre spring area, although the State Park Service is letting the road to the spring fall into disrepair.

Brownstone Basin may be accessed by dirt roads north from West Charleston Boulevard in sections 2 and 3 T21S, R59E. However several dead end roads leave West Charleston

Boulevard at this point and cross the Red Rock Wash, so care should be taken. A powerline road from Calico Basin crosses the best road into Brownstone Basin and was used by the author. Both the powerline and Brownstone Basin roads are only marginally passable by most two-wheel drive vehicles.

Dirt roads into the eastern canyon leave from the same point on West Charleston Boulevard and from the end of Smoke Ranch Road. The continuation of Smoke Ranch Road is by far the better and easier to find of the two.

Lone Mountain and Box Canyon are accessible from the Lone Mountain Road, west from U. S. Highway 95, the Tonopah Highway.

Only one road provides access to the northwestern portion of the map area. It is a dirt side-road that runs south from the road between Harris spring and lower Kyle Canyon. One steep gully may require four-wheel drive if wet.

The portion of the map area near the northern end of the Brownstone Basin fault may be reached by a bad dirt road which leaves the Kyle Canyon Road almost directly north of where the Brownstone Basin fault dies out north of Plate 1. Four-wheel drive is absolutely necessary on one portion of this road. Two-wheel drive vehicles with high centers can drive east down the wash that runs parallel to and south of the Kyle Canyon Road from the road to Harris spring mentioned above. Season to season flood conditions may not allow this.

D. Regional Geologic Setting

The La Madre Mountain area lies within the Basin and Range physiographic province, and in the eastern Spring Mountains. The Spring Mountains are a coherent block which remained mostly undisturbed during Basin and Range development (Burchfiel and others, 1974). To the east and north large amounts of extension are documented. Northward this extension is characterized by north-trending high- and low-angle normal faults which are bounded on the south by the Las Vegas Shear Zone (figure 4), a right-lateral fault zone with about 40 km of offset at its eastern end (Longwell, 1960, 1965, 1974; Fleck 1967, 1970; Guth, 1979). To the east and southeast this extension is expressed by the southern Las Vegas Valley, a large basin between the Spring and Eldorado Mountains (Anderson, 1971). To the northeast is another large shear zone with left-lateral offset of tens of kilometers (Bohannon, 1979a and b; Longwell, 1974; Anderson, 1971).

Prior to inception of Basin and Range extensional tectonics the state of crustal deformation in southern Nevada was compressional. Large east directed thrusts and related folds mainly of Mesozoic age are the dominant structures. Some thrusts were formed during the Sevier Orogeny of Armstrong (1968) but others may belong to earlier events. The La Madre Mountain area lies on the easternmost edge of this thrust belt (fig 2). Two major thrusts are exposed at La Madre Mountain, the Keystone thrust and Red Spring thrust (figure 3 and plate

1).

The younger, structurally higher Keystone thrust crops out nearly continuously for seventy kilometers to the south, where it merges with the higher Mesquite Pass thrust in the Clark Mountains of California (Burchfiel and Davis 1971). Thrust faults of similar character and position are present in the New York Mountains farther south, but cannot be followed south with confidence (Burchfiel and Davis 1977). The Keystone thrust has been correlated with the Muddy Mountain thrust of Longwell (1921, 1922, 1928, 1949) to the northeast. I believe that the Keystone thrust is more appropriately correlated with the Glendale thrust of Longwell (1949). This interpretation is discussed in the Timing and Correlation section and is shown on figure 3.

Rocks of the Keystone thrust plate in the Spring Mountains range in age from late Middle Cambrian to Triassic. These rocks have been transported eastward over autochthonous and parautochthonous rocks thought to be as young as Cretaceous (Burchfiel and others 1974, Secor 1963) and over the remnants of the allochthonous Red Spring and Contact thrust plates.

The Red Spring thrust crops out only within the La Madre Mountain area in three major northeast-tilted, normal-fault-bounded blocks. It is correlated with the Contact thrust of Hewett (1931) west of Goodsprings, Nevada (Davis, 1973; Burchfiel and others, 1974). I believe that evidence strongly suggests correlation of the Red Spring thrust with the Muddy

Mountain thrust of Longwell (1921,1928) as shown on figure 3 and discussed in the Timing and Correlation section. New work by Bohannon (pers. commun. Burchfiel, 1979) has caused him to suggest that the Summit thrust of Longwell (1949) may be correlative to the Red Spring thrust. The Red Spring thrust contains late Middle Cambrian to Carboniferous age rocks which were transported approximately eastward over autochthonous or parautochthonous rocks of Late Jurassic or (?) Cretaceous age.

Both the Keystone and Red Spring thrusts are interpreted to have overridden the land surface east of La Madre Mountain. This conclusion is drawn from the existence of channels cut into the upper surface of lower plate rocks which are filled with conglomerates derived in part from the advancing thrust plates (Longwell 1926, 1960, Secor, 1963, Davis 1973, Burchfiel and others 1974, Camreon 1977a and b, Carr 1977, 1978).

Several structurally higher thrusts crop out in the Spring Mountains northwest of La Madre Mountain. From east to west these are the Kyle Canyon, Deer Creek, Lee Canyon, Macks Canyon and Wheeler Pass thrusts. Of these the Deer Creek, Lee Canyon and Wheeler Pass thrusts have the largest eastward displacements (Burchfiel and others 1974). Figure 3 is a tectonic map of the Las Vegas area showing correlations of major thrust plates.

During and prior to Mesozoic thrust faulting, movement

on northwest-trending high-angle faults cut portions of the autochthonous and allochthonous rocks. Particularly noteworthy in the southern Spring Mountains are the Cottonwood and Boundary faults near Potosi Mountain (Cameron 1977b, Hewett 1931) and the Kokoweef fault in the Clark Mountains of California (Burchfiel and Davis 1971, in prep.) Several such faults are present in the La Madre Mountain area.

During most of the Paleozoic era southern Nevada was the site of deposition of cratonal and miogeosynclinal rocks (Armstrong 1968). A westward-thickening wedge of strata consisting mostly of carbonate rocks was deposited above a Late Precambrian to Early Cambrian age sequence of predominantly terrigenous rocks. The entire sedimentary pile thickens westward through three mechanisms (Burchfiel and others 1974): 1) addition of the Precambrian to lower Cambrian rocks, 2) westward thickening of individual units, 3) addition of units at unconformities.

Several unconformities are present in the sequence at La Madre Mountain. At least two unconformities are present within the time period between Late Cambrian and Middle Devonian. These poorly understood unconformities are parallel to bedding and have similar rock types above and below, making them difficult to recognize and map.

The Paleozoic rocks of the Keystone and Red Spring thrust plates at La Madre Mountain are transitional between miogeosynclinal facies of the western Spring Mountains and cratonal

facies of eastern autochthonous sequences such as are present on Sheep and Frenchman Mountains. A "hinge line" follows the zero isopach line of Ordovician age rocks and lies just east of La Madre Mountain. Other isopach lines are more difficult to define, but the area can be regarded as lying in a broad transition zone between cratonal and miogeosynclinal regions.

Mesozoic thrusting seems to be localized within or just west of this transition zone, moving thicker miogeosynclinal sections eastward over thinner sections with more cratonal affinities (Armstrong 1968, Burchfiel and others 1974). This "stratigraphic control" of the locus of thrusting in the Mesozoic is present at least from the Idaho-Wyoming thrust belt to the southern end of the Spring Mountains.

For most of its length in the Spring Mountains the Keystone thrust is within a few hundred meters of a particular horizon in the Cambrian Bonanza King Formation. Whether this apparent stratigraphic control is maintained at depth is unknown (Burchfiel and others 1974). To the south in the Clark Mountains, New York Mountains and Old Woman Mountains of California crystalline basement is involved in the thrusts (Burchfiel and Davis 1971, 1977, in prep., Howard, 1980). This is probably due to the intersection of Paleozoic stratigraphic trends with a Mesozoic arc terrain, with thrust trends in the upper crust being controlled by thermal mechanical contrasts rather than stratigraphic mechanical contrasts (Burchfiel and Davis 1972).

E. Purpose

Detailed geologic mapping was undertaken to provide timing, geometric and mechanical constraints on the various episodes of deformation recorded by the rocks of La Madre Mountain. Special emphasis was placed on the timing, geometry and mechanics of emplacement of the Keystone and Red Spring thrusts. Also of special interest was the effect of Basin and Range deformation on La Madre Mountain.

Secondary to these structural considerations, but also of importance, was study of the stratigraphy of the allochthonous and autochthonous rocks. Problems of particular interest were the nature of the unconformities in the Devonian to Ordovician age strata, and the nature and significance of the Jurassic or Cretaceous conglomerates beneath the Red Spring thrust.

F. Methods

Field work was done during the summers of 1978 and 1979. Mapping of about 125 km² (45 mi²) was done on United States Geological Survey 7-1/2 minute quadrangle topographic sheets (scale 1:24,000) with contour intervals of 20 and 40 feet. Portions of two quadrangles were mapped: the La Madre Mountain and Blue Diamond Northeast quadrangles.

Attitudes of bedding and other linear and planar features were measured using the standard Brunton pocket transit. Limited petrographic studies have been used to supplement the field work.

Due to time constraints and the emphasis placed on structural relationships in this study no stratigraphic sections were measured in the field. Thicknesses given are visual estimates (for thin units) or calculated averages from the map pattern or cross sections.

G. Previous Investigations

G. K. Gilbert (1875) traversed the southern Spring Mountains with the Wheeler Survey. R.B. Rowe worked in the central Spring Mountains, but died before his work was published in J.E. Spurr's article of 1903. Rowe recognized rocks ranging in age from Cambrian to Mesozoic, and was the first to report the existence of the large overthrusts in the Spring Mountains when he noted the fault now known as the Keystone thrust.

Chester Longwell mapped much of the Las Vegas region in reconnaissance or detail, including the La Madre Mountain area. He was the first to recognize the existence of the Red Spring thrust and gave it that name in his publication of 1926. Longwell noted most of the important structural relations at La Madre Mountain and proposed various interpretations of them.

D. Foster Hewett mapped a large terrain south of the present study and was responsible for naming the Keystone thrust (1931). He also recognized and named the Contact thrust, the southern correlative of the Red Spring thrust, in 1931. Hewett named many of the formations of Paleozoic age

now mapped in much of southern Nevada and southeastern California.

The work of Chester Longwell and D. Foster Hewett provides a basic framework in which more detailed studies in southern Nevada may be placed. Any geologist working in southern Nevada owes a great debt of gratitude to them. Many of their interpretations remain essentially unaltered, and the great degree of accuracy they obtained in their mapping, given their working conditions, must be highly commended.

W.S. Glock, a student of Longwell, mapped the east-central part of the Spring Mountains, including La Madre Mountain, in some detail. He published an accurate article in 1929 in which he described the major structural history of the area.

Gregory Davis (1973) did a short, detailed study of parts of the La Madre Mountain area, concentrating on relationships between the Keystone and Red Spring thrusts. Only minor revisions of his interpretations have been made in this study.

William Gans (1974) did a detailed stratigraphic study of the Middle Cambrian to Devonian Goodsprings Dolomite of Hewett (1931). He divided the thick Goodsprings Dolomite into several regionally continuous units. Without his work mapping at La Madre Mountain would have been much more difficult. Gans measured sections near the map area and located important unconformities within the section.

Adjacent areas to the north and west were mapped at the

scale of 1:62,500 by Robert Fleck (1967 and in Burchfiel and others 1974) and Donald Secor (1963 and in Burchfiel and others 1974) respectively. These two studies provide most of the current detailed understanding of the main (northern) portion of the Spring Mountains.

Also important to this work are detailed studies by Scott Cameron (1977b) and Michael Carr (1978) of the Potosi Mountain area and the Goodsprings District respectively. The depth of our present understanding of the Contact-Red Spring thrust system is in large part due to their work.

John Shelton (1966), in his book Geology Illustrated, has several excellent pictures of the La Madre Mountain and Sandstone Bluffs areas. He has followed Longwell's interpretations of the geology, hence some reinterpretation of his figures is necessary as discussed in later sections.

H. Availability of the Thesis and Plates 1, 2, and 3.

The text of this thesis is available from the M.I.T. Microreproductions Laboratory; room 14-0551; M.I.T.; 77 Massachusetts Avenue; Cambridge, MA 02139.

Black line and/or blue line copies of plates 1, 2 and 3, the geologic map, cross sections and stratigraphic column are available from the author at cost. Copies of the map are available at the scale of 1:25,000 with a subdued background or at a scale of approximately 1:14,000 as drafted, with no topography. Cross sections are also available at either scale. My current address may be obtained from the Geological

Society of America membership register, or the Department of Earth and Planetary Sciences or Alumni Association of M.I.T.

II Stratigraphy

A. Introduction

The stratigraphic sequence at La Madre Mountain is best divided into two portions, the Paleozoic section, which is dominated by carbonate rocks, and the Mesozoic section, which is primarily composed of terrigenous units.

Paleozoic rocks are of a transitional facies between miogeosynclinal facies to the west and more cratonal facies to the east. Dolomite dominates in the pre-Devonian rocks, and limestone in the post-Devonian. Minor terrigenous input is present in the rocks older than Carboniferous, and these influxes form important marker beds. Terrigenous input forms a major part of the Carboniferous and Permian strata.

Paleozoic rocks are present mainly in the autochthons, which have been thrust eastward over rocks of more cratonal facies.

Early Mesozoic rocks record the last marine deposition in the area. Younger rocks are mainly terrigenous clastic and eolian strata. Deposition of Mesozoic rocks in the La Madre Mountain area was largely terminated by post-Early Jurassic thrust faulting and associated deformation. Minor amounts of syn-orogenic deposits, of great importance to interpretation of the structural history of the area, are present.

Plate 3, Stratigraphic Column, La Madre Mountain, shows

the basic stratigraphy of the section, and gives thickness estimates. Thicknesses were not measured in the field; those given are either visual estimates or calculated averages from the map pattern or cross sections, unless attributed to another author.

B. Bonanza King Formation

The Bonanza King Formation was named by Hazzard and Mason (1936) from exposures in the Providence Mountains of California. They assigned it an age of Middle to Late Cambrian. Gans (1974) identified the Bonanza King Formation at the base of Hewett's Goodsprings Dolomite in the southern Spring Mountains. Barnes and Palmer divided the Bonanza King Formation into two members, the upper Banded Mountain Member and the lower Papoose Lake Member (1961) in the Nevada test site. Since then these two members have been widely recognized in southern Nevada and southeastern California. In this study three units were mapped in the Bonanza King Formation. The thin silty unit that Gans included as the basal unit of the Banded Mountain Member was mapped separately.

1. Papoose Lake Member

The Papoose Lake Member is present at only one locality at La Madre Mountain, in a small fault-bounded wedge immediately southeast of peak 5345 (figure 6). It consists of distinctive brownish-grey mottled dolomite. About 15 m of beds are exposed.

2. Silty Unit

The silty unit of the Bonanza King Formation overlies the Papoose Lake Member at the locality above and lies at the base of the Red Spring thrust north of peak 5345. Another (fault bounded) exposure occurs at the base of the Keystone thrust plate in the northern 1/2 of section 8, T20S, R59E. The silty unit consists of an orange-weathering, thin-bedded to laminated silty dolomite about 15 m (50 feet) in thickness.

3. Banded Mountain Member

The Banded Mountain Member, the upper member of the Bonanza King Formation, is present throughout both major thrust plates, although rocks of its lower parts are usually missing, having been truncated by the basal thrust. When the lower contact of the member with the silty unit is exposed dark dolomites sharply overlie the silty dolomite.

The Banded Mountain Member crops out as low hills below Massive broken cliffs formed by the Nopah Formation. The upper beds of the Banded Mountain Member are massive light dolomite that is sharply overlain by the orange-weathering Dunderberg Shale Member of the Nopah Formation.

Gans (1974) divided the Banded Mountain Member into ten units, most of which can be recognized throughout the La Madre Mountain area. The following description of the Banded Mountain Member uses Gans' subdivisions where they are recognized.

The basal part of the Banded Mountain Member at La Madre

Mountain consists of light and dark dolomites in beds averaging 1/2 to 2 m in thickness. Dark- or blue-grey chert nodules are present. These strata correspond to Gans' units Cbb2 and Cbb3 (the silty unit is unit Cbb1 of Gans). They are overlain by a distinctive dark grey to black dolomite with brown mottles which weather as irregular elongate pockets in the surrounding dolomite. These beds belong to unit Cbb4 of Gans.

Unit Cbb5 of Gans is a "cyclic sequence of light- and dark-grey weathering dolomicrites occurring in bands 1 to 3.6 m thick" and is easily recognized at La Madre Mountain. It is overlain by a dolomite with blue-black or grey chert nodules that is unit Cbb6 of Gans. Unit Cbb7 is another dark grey to black dolomite with brown mottles. It resembles unit Cbb4, and is only distinguishable by its tendency to form small cliffs and resistant outcrops.

Units Cbb8 and Cbb9 of Gans are not usually distinguishable at La Madre Mountain, as they seem to be transitional between rock types of units Cbb7 and Cbb10. These rocks are generally light- to dark-grey, medium- to fine-grained dolomicrites. The "peppery" appearance of unit Cbb9 described by Gans as due to small pellets is only locally developed.

Unit Cbb10 of Gans, the uppermost unit of the Banded Mountain Member, is a pinkish- to whitish-grey weathering, massive sugary textured dolomite which is very similar to the rocks of the Nopah Formation upper unit, but has some chert.

Thickness estimates for the Bonanza King Formation, or even the Banded Mountain Member are impossible to make accu-

rately because the rocks are nearly always bounded at the base by a thrust fault and are often repeated by small imbricate thrusts. Gans measured three complete sections of the Banded Mountain Member in the Spring Mountains (1974, figure 3) which average to about 445 m (1455 feet) in thickness.

C. Nopah Formation

The Nopah Formation was first described by Hazzard (1937) from the type local in the Nopah Range of Inyo County, California. He assigned the formation a Late Cambrian age which was verified by Palmer (1956). Palmer also correlated the Nopah Formation with the Cornfield Spring Formation of Hazzard and Mason (1936) from the Providence Mountains of California. It is probably equivalent to the Buffington Formation of the Muddy Mountains (Longwell 1921). In the eastern and southern Spring Mountains the Nopah Formation was originally mapped by Hewett (1931) as part of the Goodsprings Dolomite. Gans (1974) recognized the presence of the Nopah Formation in the Goodsprings Dolomite and divided it into three units.

Three members of the Nopah Formation are commonly mapped in southern Nevada. These members, the lower Dunderberg Shale, the middle Halfpint Member and the upper Smoky Member were named by Christiansen and Barnes in 1966 and the upper two are different from the upper two units of Gans. Gans divided the upper portion of the Nopah Formation into a lower unit

which is transitional between the Dunderberg Shale and the upper "sugary unit". At La Madre Mountain I have mapped only two units in the Nopah Formation; the Dunderberg Shale and an upper unit which includes the transitional unit and sugary unit of Gans. This unit is equivalent to the Halfpint and Smokey Members of Christiansen and Barnes. I will hereafter refer to the part of the Nopah Formation above the Dunderberg Shale as the upper unit. This upper unit of the Nopah Formation is labeled "En" on plate 1.

1. Dunderberg Shale Member

The Dunderberg Shale Member conformably overlies the upper beds of the Bonanza King Formation. The lower part of the member consists mainly of coarse-grained medium-grey limestones which often contain trilobite hash. Distinctive, laminated, orange-weathering rip-up clasts about one centimeter in thickness and 3 to 7 cm in length are characteristic. The limestone beds vary from about 0.5 to 1 m in thickness and are interbedded with poorly exposed green shale.

The upper half of the Dunderberg is similarly bedded, silty, tan-weathering dolomite with rip-up clasts. These dolomite beds are also interbedded with poorly exposed green shale. Algal nodules with an oval shape about 1.5 to 2 cm on the long axis (Osagia, Gans 1974) are often found in these upper beds.

The Dunderberg Shale Member usually crops out as a broad orangish slope or bench between the more massive dolomite above and below. It varies from 23 to 45 m (75-150 feet) in

thickness, and is thicker in the Keystone thrust plate than in the Red Spring thrust plate.

2. Upper Unit of the Nopah Formation

The Dunderberg Shale Member is sharply overlain by massive, poorly bedded light grey to white dolomite of the upper unit of the Nopah Formation. Algal nodules are common in the lower 10 m of the upper unit. These beds are equivalent to the transitional unit (Cn 1) of Gans, but are not laterally continuous enough to be mapped separately.

The dolomite of the upper unit is medium-grained, with a sugary granular texture on weathered surfaces which is characteristic of the upper unit of the Nopah Formation. Primary sedimentary features are rare because of destruction by secondary dolomitization, but include cross-beds and algal mounds. Slight color variation is typical throughout the upper unit, alternating from light grey to white every 20 to 40 m. Locally, indistinct mottling is present in the upper unit.

The upper unit of the Nopah Formation crops out as massive, blocky and rubbly cliffs or steep slopes. It is about 300m (1000 feet) thick in both thrust plates. The contact with the overlying Pogonip (?) Group rocks is usually sharp and is marked by a distinct break in slope above the massive Nopah Formation.

D. Pogonip Group (?) undifferentiated

Clarence King (1878) named the Pogonip Group for rocks in eastern and central Nevada. Nolan (1956) redefined the

Pogonip Group in the Eureka District of east-central Nevada . Nolan recognized three formations within the Pogonip Group which have been mapped in Nevada and parts of southeastern California: the lower Goodwin Limestone, the middle Ninemile Formation and the upper Antelope Valley Formation. Gans first recognized that rocks of the Pogonip Group are present in the Goodsprings Dolomite of Hewett (1931), although microfossil studies necessary to prove this correlation have not been completed. Gans based his correlation on lithological similarity to the Goodwin Limestone and similar stratigraphic position to the Monocline Valley Formation in the Muddy Mountains (Longwell and Mound 1967), both of which are known to be of Early Ordovician age.

Pogonip Group (?) rocks are present throughout most of the length of the Keystone thrust plate on plate 1, and in all three normal-fault bounded blocks which contain exposures of the Red Spring thrust. Gans (1974, figure 5) shows approximately 145 m (475 feet) of Pogonip Group (?) strata in his "lower Red Rock Canyon" section, and 195 m (640 feet) in his "upper Red Rock Canyon" section. Estimates made from the map pattern at La Madre Mountain average to 100 m (330 feet) in the Keystone thrust plate and 55 m (180 feet) in the Red Spring thrust plate. Pogonip Group (?) rocks pinch out southward, north of Mountain Pass (Gans 1974).

At La Madre Mountain the Pogonip Group (?) rocks are

fine- to coarse-grained, medium- to light-grey dolostones and occasional limestones. Blue-grey or grey-white chert lenses averaging about 1 cm by 5 to 15 cm are fairly common. Bedding thickness varies from a few centimeters to less than 3 m and is thicker overall in the Keystone plate than in the Red Spring thrust plate.

The lower contact is nearly always covered, but appears to be sharp, and usually forms a bench above the more massive dolomite of the Nopah Formation. In the Keystone thrust plate the upper contact is sharp (when exposed) and is marked by a carbonate and chert pebble conglomerate at the base of the Mountain Springs Formation. This conglomerate is not present in the Red Spring thrust plate and the contact is difficult to define. It is usually exposed as a narrow bench between the Pogonip Group (?) bedded dolomites below and the silty thin bedded dolomite of the Mountain Springs Formation above. The upper contact of the Pogonip Group (?) is a disconformity between lower Ordovician strata of the Pogonip Group (?) and upper middle or upper Ordovician rocks of the Mountain Springs Formation (Gans 1974, Miller and Zilinsky, in prep.)

E. Mountain Springs Formation, Including Devonian-Ordovician Undifferentiated Strata

The Mountain Springs Formation was defined by Gans (1974) for rocks near Mountain Springs Pass in the southern Spring Mountains, Nevada. These strata formed the top of Hewett's Goodsprings Dolomite (1931).

An age of Late Ordovician was assigned to the lower

strata of the formation on the basis of Reseptaculites Oweni occurrences (Secor 1963, Gans 1974), a sponge typical of the upper Ordovician Ely Springs Formation. Miller and Zilinski (in prep.) identified conodonts in the lower Mountain Springs Formation of late-Middle or Late Ordovician age.

Gans tentatively placed the age of the upper portion of the formation in the Middle Devonian on the basis of "non-Ordovician" fossils, the presence of quartz detritus (equated with deposition simultaneous with that of the terrigenous detritus present in the Nevada Formation of Middle Devonian age), and on the basis of lithologic similarity to the overlying middle Devonian Sultan Limestone. Miller and Zilinski (in prep.) found conodonts of the Icriodus sp. type in the upper forty meters of the formation that indicate an Early to Middle Devonian age. They also noted the conspicuous absence of Silurian conodont forms in the formation, along with evidence of unconformity in the section, such as "irregular contacts with evident topography, solution of the underlying layers, and scattered patches of limestone pebble conglomerate." John Bartley (pers. commun. 1980) reports stromatoperoids from the upper Mountain Springs Formation southwest of Good-springs Nevada, a fauna typical of the basal member of the Middle Devonian Sultan Limestone.

On the basis of evidence presented above I divided the Mountain Springs Formation into two units. The lower unit, probably Late Ordovician in age, was designated "Om" on plate 1. The upper unit, probably Early to Middle Devonian in age

was designated "DO" on plate 1 (Devonian-Ordovician undifferentiated rocks of the upper unit of the Mountain Springs Formation). Properly these Devonian-Ordovician undifferentiated rocks should be mapped with the Sultan Limestone, however to include them in the Sultan Formation would violate established nomenclature. Perhaps when more stratigraphy and paleontology has been done on these rocks a revised nomenclature will be proposed.

1. Lower (Ordovician) Unit

Strata mapped as the lower unit of the Mountain Springs Formation are typically thinly bedded (10 to 50 cm) with rare thin limestone layers. The dolomite weathers cream to light orange and frequently contains orange or tan silty laminations and irregular stringers. The rocks form a more orange-colored slope than rocks of the underlying Pogonip Group (?) or the overlying upper unit of the Mountain Springs Formation.

In the Red Spring thrust plate the lower contact is apparently sharp, although seldom clearly exposed, and tends to form a narrow bench above the greyer, more massive rocks of the Pogonip Group (?).

In the Keystone plate the basal beds of the Mountain Springs Formation at La Madre Mountain and for a few kilometers to the south is a carbonate and chert pebble conglomerate. This distinctive bed varies from 2 to 5 m in thickness and contains less than 5% chert pebbles. The clasts are well sorted (about 1 to 2 cm in diameter) and are well rounded.

The contact between the conglomerate and underlying rocks is interpreted as a disconformity between rocks of Early Ordovician age (Pogonip Group ?) and late Middle or Late Ordovician age (Mountain Springs Formation). To the south, at Mountain Springs Pass, the Pogonip Group (?) is missing and rocks of the Mountain Springs Formation rest directly on the Nopah Formation strata of Late Cambrian age.

The contact between the two units of the Mountain Springs Formation is somewhat difficult to define, but was drawn at the point where the silty content disappears upwards, and lithologies begin to more closely resemble those of the overlying Sultan Limestone. This contact represents a disconformity between rocks of Late Ordovician (lower unit) and Early or Middle Devonian (upper unit) ages.

2. Upper Unit (Devonian-Ordovician Undifferentiated)

Rocks mapped as "D0" on plate 1 are lithologically similar to the lower Valentine Member of the Sultan Limestone. At the bottom, gritty, medium-grained dolomite of cream or light grey color is found. As one walks up section layers that are lithologically identical to the Ironside Member of the Sultan Formation become common: dark brown or black, coarse-grained, rough weathering dolomites with white coarse-grained calcite or dolomite vugs. Stromatoperoids were not found below the Ironside Member at La Madre Mountain. The upper contact is gradational into the Ironside Member, and was drawn below the first stromatoperoid-bearing unit.

F. Sultan Limestone

The Sultan Limestone was named by Hewett (1931) from a type section near the Sultan Mine in the southern Spring Mountains. He assigned the Sultan Limestone an age of late Middle to early Late Devonian in that work, but in 1956 assigned it a Middle Devonian age.

Hewett divided the Sultan Limestone into three members, from bottom to top they are the Ironside, Valentine and Crystal Pass Members. The Sultan Limestone usually crops out as a cliff above the slope-forming Mountain Springs Formation. The Ironside and Crystal Pass Members consist of very distinctive rock types whereas the Valentine Member is a mixture of rock types and is transitional between the other two members. Secondary dolomitization occasionally overprints all or parts of the Valentine and Crystal Pass Members.

1. Ironside Member

The Ironside Member is composed of dark brown or black weathering dolomite which is coarse-grained and has a granular texture. Stromatoperoids about 10cm in diameter are abundant and are characteristic of this unit. They are often silicified and weather as resistant mounds on the outcrops. Elongate and irregular white calcite or dolomite filled vugs with maximum dimension of about 15 cm are common. The Ironside Member tends to crop out in 1 to 4 m thick ledges. Both the upper and lower contacts of the Ironside Member are gradational over several meters. The lower contact was taken at the base of the lowest

lowest stromatoperoid bearing bed.

In the Red Spring thrust plate the upper contact of the Ironside Member is drawn in a transitional sequence of medium-grained, light- to medium-grey dolomite or limestone typical of the Valentine Member lithology and dark dolomites typical of the Ironside Member. The transitional sequence can be up to 10 m thick. In the Keystone thrust plate beds of Valentine lithology occur throughout the thickness of the Ironside Member. The Ironside Member was mapped with the Valentine Member in the Keystone plate as "Dvi" - Valentine-Ironside Members undifferentiated.

2. Valentine Member

The Valentine Member is a mixture of carbonate lithologies which are transitional between the Ironside and Crystal Pass Members of the Sultan Limestone. Well-bedded limestone and dolomite occurs throughout, with coarser-grained, gritty, light and dark dolomite dominating in the lower part and lighter grey limestone dominating upward. Beds tend to be thicker at the base than at the top but are rarely thicker than 4m.

Coarse, intraformational breccias are present in the the Valentine Member at La Madre Mountain. The breccias are composed of angular blocks that vary in diameter from less than one centimeter to several meters across, although they are usually less than one meter in largest dimension. The breccias are locally derived and grade into competent rock. Spaces between blocks and clasts are filled by a matrix of

coarse-grained calcite or dolomite.

Thin (1/4 to 1 m thick) beds of quartzitic dolomite are present locally within the Valentine Member. Quartz grains vary from 1/2 to 1 mm in diameter and compose up to 50% of some beds. Quartz rich beds pinch out laterally over distances of a few tens of meters.

3. Crystal Pass Member

Limestone of the Crystal Pass Member overlies the Valentine Member gradationally. The contact was drawn at the top of the uppermost coarse- or medium-grained dolomite or limestone of the Valentine Member. Crystal Pass limestone is a very distinctive, very fine-grained, light- to pinkish-grey or white, laminated, pure limestone. The Crystal Pass Member commonly forms steep cliffs. It often weathers into thin plates which produce a clear, crisp tinkling sound when walked upon. Algal mounds approximately 7 to 15 cm in diameter are present occasionally. The upper contact of the Crystal Pass Member is either sharp or gradational over less than three meters with the dark, coarse-grained limestone of the Dawn Member of the Monte Cristo Limestone.

4. Thickness of the Sultan Limestone

The following thicknesses are estimated for the Sultan Limestone:

Crystal Pass Member	45-60 m	150-200 feet
Valentine Member	110-125 m	350-400 feet
Ironside Member	3-15 m	10-50 feet
Total (approximate)	<u>200 m</u>	<u>650 feet.</u>

G. Monte Cristo Limestone

Hewett (1931) named the Monte Cristo Limestone for rocks that crop out near the Monte Cristo Mine in the southern Spring Mountains. He subdivided it into five members, the lower three of which are assigned an Early Mississippian age and the upper two of which he thought were Middle Mississippian in age. Later, (1956) he assigned the the entire formation to the lower Mississippian.

The contact between the Monte Cristo Limestone and the underlying Sultan Limestone is likely marked by a period of erosion or non-deposition. Langenheim (1963) thought the contact was paraconformable and Pelton (1966) an epeirogenic unconformity. Carr (1978) found discontinuous intraformational conglomerates at the basal contact of the Monte Cristo Limestone. Although no clear evidence suggesting an unconformable contact was found at La Madre Mountain the distinct lithologic change suggests that it may be unconformable.

Generally the Monte Cristo Limestone is composed of dark, medium- to coarse-grained limestone, often with fossil hash. It is a resistant formation and tends to form steep cliffs. Rugose and colonial corals are common, and a distinctive feature of the formation. The cherty Anchor Member comprises one of the most easily recognize units in the entire stratigraphic section. Coarse secondary dolomitization is present occasionally throughout the formation, but is most common in the Bullion Member.

1. Dawn Member

Lying with sharp to rapidly gradational (less than 3 m) contact on the uppermost beds of the Sultan Limestone is the Dawn Member of the Monte Cristo Limestone. The Dawn Member is composed of dark- to medium-grey, medium- to coarse-grained limestone in beds that vary from 1/2 to 4 m in thickness. It is often very fossiliferous or composed of fossil hash of broken crinoids, gastropods and brachiopods. Large (up to 10-12 cm) solitary corals are common locally. Occasional cross-beds are present as well as rare chert.

2. Anchor Member

The Anchor Member overlies the Dawn Member along a sharp contact defined by the base of the lowest beds containing abundant nodular chert. The Limestone of the Anchor Member is very similar to that of the Dawn Member. Two to four units occur within the Anchor Member which have abundant black chert as layers up to 10 cm thick or as lenses three to ten centimeters thick and 15 cm to 1 m in length. The lenses and layers of chert usually have smooth outlines. Cherty units are usually separated by chert-free intervals, although the entire Anchor Member can be cherty. The chert may comprise up to 40-50% of the rock, and weathers orangish, blue or black. Since the Anchor Member is defined on the presence of chert, and the amount of chert and cherty layers varies vertically and laterally, the member is variable in thickness. This causes fluctuations in the thickness of adjacent members as well.

3. Bullion Member

Above the Anchor Member is massive to poorly bedded, medium to coarse grained limestone of the Bullion Member. The Bullion Member is typically unfossiliferous, although occasional beds containing fossil hash, rugose or colonial corals are present. A single or sometimes double layer of chert is commonly present about 10 m below the top of the member. It usually weathers reddish-orange and is between 1/4 and 1-1/2 m in thickness. Coarse white or pinkish-grey dolomitization is common in the Bullion Member, and is usually contained between the chert of the Anchor Member below and the chert layer of the Bullion Member or the overlying Arrowhead Member.

4. Arrowhead Member

Above the Bullion Member, and in sharp contact with it, is thin-bedded, fine-grained, light-grey limestone of the Arrowhead Member. Beds are 3 to 10 cm in thickness and separated by silty partings less than three centimeters thick. The Arrowhead Member is between 2 and 4 m thick and forms a recessive bench between the massive rocks above and below. Hewett (1931) reported Middle Mississippian fossils from the Arrowhead Member, but in 1956 gave the age of the entire formation as Early Mississippian. In this study the Arrowhead Member has been mapped with the Yellow Pine Member.

5. Yellow Pine Member

The Arrowhead Member is overlain by the Yellow Pine Member, a massive, dark, medium- to coarse-grained limestone with sharp upper and lower contacts. Large, abundant rugose corals (up to 3 cm in diameter and 30 cm in length) are characteristic of the Yellow Pine Member. Usually these corals are scattered through the member, although occasional beds are present in which they are very abundant. Often the corals are wholly or partially silicified and weather in relief. Colonial corals, fossil hash and cross-beds are also present locally. Rare, round nodules of dark-grey or black chert 8 to 15 cm in diameter are present in the upper few meters of the member.

6. Thickness of the Monte Cristo Limestone

Estimated thickness (from map pattern except for Arrowhead Member) are as follows:

Yellow Pine Member	30 m	100 feet
Arrowhead Member	2-4 m	6-12 feet
Bullion Member	120-150 m	400-500 feet
Anchor Member	60-90 m	200-300 feet
Dawn Member	30-60 m	100-200 feet
Total (approximate)	300 m	1000 feet.

H. Bird Spring Formation

Hewett (1931) named the Bird Spring Formation for rocks in the Bird Spring Range, Clark County, Nevada. On fossil evidence he assigned it to the Pennsylvanian system. Dunbar (Longwell and Dunbar, 1936) studied fusulinids from the formation and determined that more than half of it was Permian in age. Longwell and Dunbar also designated the basal terrigenous beds the Indian Springs Member. M. Rich (1961) found

fossils in the section at Lee Canyon in the Spring Mountains as old as Late Mississippian (Chesterian) and as young as late Early Permian (Leonardian). No physical basis has been recognized to further subdivide the formation for mapping.

Hewett reported a thickness of 760 m (2500 feet) for the Bird Spring Formation near Goodsprings (1931) and Longwell reports a thickness of 1070 m (3500 feet) at La Madre Mountain (1965) which is close to my estimates measured from cross sections.

The Bird Spring Formation crops out over an area of about 23 km² (9 mi²) in the northwest corner of the map area (plate 1) in the Keystone thrust plate. The lower part of the formation is also present in the Red Spring thrust plate, west of the Box Canyon fault. The Bird Spring Formation is not as resistant as the underlying formations, and weathers into cliff-and-bench type topography.

Hewett (1931, 1956) described the lower contact as an unconformity. He reported that the Bird Spring Formation rests locally on rocks as old as the Bullion Member of the Monte Cristo Limestone. No obvious angular unconformity or thinning and thickening of the underlying Yellow Pine Member of the Monte Cristo Limestone was evident in the map area however.

1. Indian Springs Member

The Indian Springs Member in the Keystone plate consists of orange-weathering, limey sandstone, siltstone and conglomerate. Its total thickness is 8 to 15 m. In the Red Spring

plate the Indian Springs Member is thinner, about 5 to 10 m, and is composed of interbedded red sandstone, shale and thin limestone. The section in the Red Spring thrust plate is sheared by small thrusts below the Keystone thrust and may be attenuated.

The Indian Springs Member forms a slope above the massive cliff forming Monte Cristo Limestone. In the Keystone thrust plate the first terrigenous rocks were mapped as the base of the Bird Spring Formation. In the Red Spring plate a distinctive red-weathering limestone with abundant calcite vugs about 0.5 cm in diameter was used to mark the base of the Bird Spring Formation.

2. Upper Beds of the Bird Spring Formation

Above the Indian Springs Member, and in gradational contact with it, lies a thick sequence of variably alternating beds of limestone and dolomite. Silt is fairly common, both in the carbonate rocks and as siltstone interbeds. Chert layers and nodules up to 1 m in the largest dimension are present. Cross-bedding and other sedimentary features are common. Individual beds or sequences of similar beds are seldom more than 10 m, and often less than 2 m thick.

Fossils are common throughout the Bird Spring and include corals (especially in the lower portion), brachiopods, gastropods, crinoids, and abundant fusulinids, which are characteristic of the formation.

I. Permian Redbeds

Longwell (1965, Secor 1963) suggested the use of the term Permian Redbeds for the red and cream colored siltstone and sandstone which overlie the Bird Spring Formation and are overlain by the Kaibab or Toroweap Formations. Longwell (1928) and Hewett (1931) originally correlated these sedimentary rocks with the Supai Formation of the Grand Canyon on the basis of similar lithology and stratigraphic position. McKee (1939) challenged this correlation after finding that the Supai Formation grades westward into carbonate rocks. Identification of Permian fusulinids within the underlying Bird Spring Formation supported McKee's views, and the designation Supai Formation was dropped in the Spring Mountains.

Only limited exposures of the redbeds occur in the northern halves of sections 8, 17 and 18, T21S, R59E. At these localities the rocks consist of tan cross-bedded sandstone, mainly composed of quartz and feldspar fragments less than one millimeter in diameter. In section 8 large scale cross-beds are present, 1-3 m in height and 3-5 m in length.

J. Kaibab and Toroweap Formations

Darton (1910) named the Kaibab Formation from exposures on the Kaibab Plateau. Hewett (1931) correlated Permian limestones in the southern Spring Mountains with the Kaibab Formation. McKee (1938) separated the formation into two formations; an upper Kaibab Formation and a lower Toroweap Formation. The division was made at a shaley gypsiferous interval between the two cherty limestone units. Dunbar and

others (1960) assigned the Kaibab and Toroweap Formations a late Early Permian (late Leonardian) age.

Longwell and others (1965) described a minor unconformity between the two formations. He also reported that the two formations have similar lithology and fauna. At La Madre Mountain the base and top of the limestone units are seldom exposed. Outcrops of limestone south of Red Spring and the La Madre fault may belong to the Toroweap Formation based on their position on strike with Permian limestones on Blue Diamond Hill which lie directly above the Permian Redbeds. Limestone on and south of peak 3844 appear to represent a complete section (although not completely exposed) of the Kaibab and Toroweap Formations. They project beneath the Virgin Limestone Member of the Moenkopi Formation north of peak 3844, and the basal contact with the Permian Redbeds is exposed near the junction of West Charleston Boulevard and the road into Calico Basin. The contact is slightly disturbed, but is thought to represent the original sedimentary contact. The siltstone and gypsiferous beds that separate the two formations are not exposed in this section however. Longwell (1965) described locations in the Spring Mountains where the basal Moenkopi Formation lies unconformably on Permian Redbeds with all of the Kaibab and Toroweap Formations missing. It is possible therefore that all of these exposures of Permian limestone at La Madre Mountain could belong to either formation. For these reasons the Kaibab and Toroweap Formations have been mapped together.

The Kaibab and Toroweap Formations consist of highly fossiliferous, medium-grey, very cherty limestone. The chert occurs as reddish-brown or orangish weathering nodules and lenses with irregular outlines. Chert forms up to 50% of the rock.

The complete (?) section discussed above is calculated to be about 340 m (1130 feet) thick from map pattern and cross section. Hewett (1931) gives a thickness of 170 m (555 feet) at Mule Mountain in the Goodsprings District. Longwell and others (1965) report about 315 m (1050 feet) of these rocks.

K. Note on the Permian System

Age and correlation problems exist with rocks of the Permian system in southern Nevada. Current knowledge of the Permian system is summarized in table 1. Hewett (1931) reports 170 m (555 feet) of Kaibab and Toroweap Formations and 335 m (1100 feet) of Permian Redbeds in the Goodsprings District. Dunbar (1960) reports a late Leonardian age for the Kaibab and Toroweap Formations in Nevada. Rich (1961) shows over 380 meters (1250 feet) of Leonardian age strata in the upper Bird Spring Formation in Lee Canyon. Several tens of miles and major thrust faults separate these sections and must be considered when interpreting the composite section in table 1. It seems unlikely however, that over 885 m of strata were deposited in the Leonardian stage. Because age assignments for the formations have been established from widely separated areas there is probably some overlap in age of the Kaibab and Toroweap Formations with the Bird Spring Formation. Apparently

Table 1 - Review of the Permian System

<u>Formation</u>	<u>Thickness</u>	<u>Age</u>
Kaibab and Toroweap	170 m (555 feet) (Hewett 1931) 315 m (1050 feet) (Longwell 1965)	Late Leonardian (Dunbar and others 1960, Longwell 1965)
Permian Redbeds	335 m (1100 feet) (Hewett 1931)	No fossils known in Spring Mtns.
Top of Bird Spring	380+ m (1250 feet) (Rich 1961)	Leonardian (Rich 1961)

the rock units are time transgressive. More work needs to be done in the region to understand the age relations between these formations. This would help with correlation problems between the Permian systems of southern Nevada and northwestern Arizona.

Continuous sections from the Bird Spring Formation to the Kaibab Formation are present in the Bird Spring Range and in several places in the Spring Mountains. Paleontologic studies of these sections would help resolve some of the problems with the Permian system in this area.

L. Moenkopi Formation

The Moenkopi Formation was first named by Ward (1905) from rocks in northern Arizona. Gregory (1917) suggested a type locality along the Little Colorado River. Hewett (1956) assigned exposures of similar rocks in the Spring Mountains to the Moenkopi Formation and designated them Early Triassic in age.

Two members are recognized at La Madre Mountain, the upper Redbed Member and the lower Virgin Limestone Member. Outcrop of the two members is restricted to one exposure of each. The lower part of the Upper Redbed Member crops out in La Madre Canyon, and part of the Virgin Limestone Member is exposed in the southern 1/2 of section 32, T20S, R59E.

Longwell (1965) reported that the basal contact of the Moenkopi Formation is an unconformity. He gave variable thicknesses in the region as follows:

Valley of Fire, Muddy Mountains	490 m	(1600 feet)
East of Frenchman Mountain	715 m	(2340 feet)
Goodsprings District	230-	(750-
	290 m	950 feet).

Because of incomplete exposure, accurate estimates of thickness are impossible to make at La Madre Mountain. The following section in the lower part of the Upper Redbed Member of the Moenkopi Formation is exposed in La Madre Canyon. It is present in the overturned limb of the large syncline beneath the Keystone thrust. Thickness may be attenuated or thickened due to thrusting, and were estimated visually.

top: Shinarump Conglomerate	
red shale	15 m
medium-grained tan sandstone with trough cross-beds	8 m
fine-grained, sandy red shale	25 m
medium-grey limestone with yellow silty stringers and calcite veins and vugs	10 m
bottom: Keystone thrust	

The Virgin Limestone Member consists of yellow-weathering limestone in beds from 3 to 100cm thick, interbedded with yellow or green siltstone and sandstone. The limestone is fossiliferous, containing abundant brachiopods and gastropods.

M. Shinarump Conglomerate

The Shinarump Conglomerate was first named by Powell (1876) from rocks in the Uinta Mountains, Utah. Hewett (1931, 1956) assigned it to an upper Triassic position in the Spring Mountains.

The Shinarump Conglomerate is a thin formation, between 30 and 60 m (100-200 feet) in thickness. At La Madre Mountain

it consists of 1 to 3 m thick beds of jasper pebble conglomerate with poorly exposed intervals of sandstone, siltstone and shale. The distinctive conglomerate is composed mainly of well- to sub-rounded pebbles and cobbles of yellow, orange or red-brown jasper up to 5 cm in diameter set in a red sandstone matrix. Planar-tabular cross-beds in sets up to 30 cm thick are present locally.

The only outcrops of Shinarump Conglomerate in the map area are in Calico Basin and La Madre Canyon. In La Madre Canyon the upper and lower contacts are exposed. They are sharp, parallel to the beds above and below, and appear to be conformable.

N. Chinle Formation

The Chinle Formation was named by Gregory (1917) from the type locality in Chinle Valley, Arizona. He suggested a Late Triassic age. Longwell (1928) correlated the upper Triassic redbeds present in the Muddy Mountains and Spring Mountains with the Chinle Formation of Arizona. Hewett (1956) assigned a Late Triassic age to the Chinle Formation strata in the southern Spring Mountains.

Only scattered or structurally disturbed outcrops of the Chinle Formation are present in the autochthon at La Madre Mountain. The formation is composed of red siltstone and shale which form a slope below the massive Aztec Sandstone, or crop out in valleys and gullies.

The upper contact with the Aztec Sandstone is fairly sharp. Increasingly sandy beds are present in the upper 5 to

10 m of the formation and form a sharp contact with thick sandstone of the Aztec. The upper contact appears to be conformable. The lower contact with the Shinarump Conglomerate was drawn at the top of the highest jasper conglomerate bed. It is not well exposed, but appears to be sharp and conformable.

Due to poor exposure the thickness of the Chinle Formation is impossible to measure directly at La Madre Mountain, but small outcrops of the underlying Shinarump Conglomerate in Calico Basin allow an estimate to be made geometrically from the map pattern. The Chinle Formation is approximately 460 m (1500 feet) thick. Longwell (1965) reports the following thicknesses:

West of Blue Diamond	230 m	750 feet
Near Goodsprings	260 m	855 feet
East of Frenchman Mountain	300 m	975 feet
Valley of Fire, Muddy Mountains	370-	1205-
	1005 m	3300 feet
South Virgin Mountains	230 m	750 feet.

My estimate, although thicker than nearby sections (especially west of Blue Diamond) is well within thickness variations reported for the Chinle Formation.

O. Aztec Sandstone

Hewett (1931) named the Aztec Sandstone from the type locality near the Aztec Tanks in the Spring Mountains. He correlated it with the similar massive sandstone in the Muddy Mountains described by Longwell (1921) and with the Navajo Sandstone of Reeside and Bassler (1922). He assigned a probable Jurassic age to the Aztec Sandstone.

Carr (1978) reports a K/Ar date of 150 ± 10 m.y. on biotite from a tuff in the Lavinia Wash Sequence near Goodsprings. The Lavinia Wash Sequence is nowhere deposited on the Aztec Sandstone, but clasts of the Delfonte Volcanics occur stratigraphically below the tuff dated by Carr. In the Clark Mountains of California the Delfonte Volcanics are deposited on the Aztec Sandstone (Burchfiel and Davis 1971). Therefore the Aztec Sandstone is older than 150 ± 10 m.y.

Peterson and Pipiringos (1979) assigned the Navajo Sandstone to the Toarcian and Late Pleinsbachian stages of the Early Jurassic, although they note that this age assignment is not yet officially accepted by the U.S. Geological Survey. Based on the evidence above, the Aztec Sandstone is probably Early Jurassic at La Madre Mountain.

The Aztec Sandstone crops out extensively in the autochthon of La Madre Mountain. It is a resistant, monolithologic quartz sandstone, apparently of eolian origin. Massive crossbeds in lenticular sets up to 10 m thick and 20 to 25 m long occur throughout. Attitudes are practically impossible to determine accurately in the Aztec Sandstone. Each cross-bed set is made up of laminae that vary in thickness from less than 0.5 to 2 cm. The color is buff to cream or brick red, and color contrasts cut across primary sedimentary features. Hewett (1931) suggested that the cream-colored areas are a result of secondary leaching of the iron from the rock.

Sand grains in the Aztec Sandstone are well-sorted, with

Figure 7. Upper contact of the Aztec Sandstone with the Brownstone Basin Conglomerate, northwest of Calico Basin. BBC=Brownstone Basin Conglomerate, WZ=weathered zone of Aztec Sandstone, Ja=Jurassic Aztec Sandstone. Hammer for scale. Large, elongate clasts in top of view are locally derived from the Aztec Sandstone.

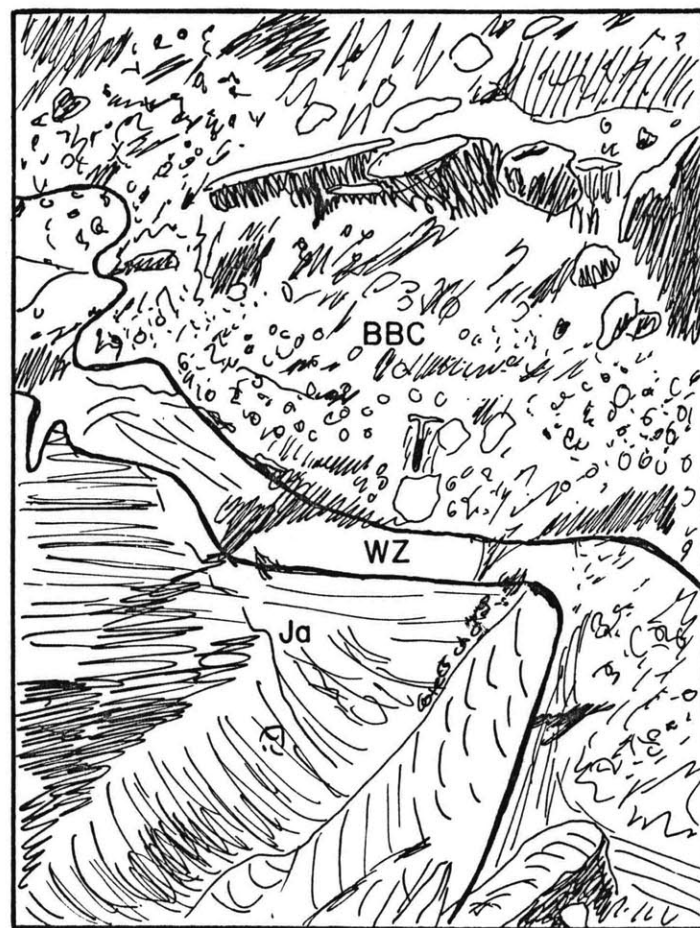


Figure 7

almost all grains less than 0.5 mm in diameter. Grains range from subangular to subrounded and are cemented by calcite.

The lower contact is sharp with the underlying Chinle Formation. The upper contact is marked by erosion and is unconformably overlain by the Brownstone Basin Conglomerate. Often a distinct weathering rind up to 20 cm thick is present below the conglomerate (figure 7). The upper contact is frequently a thrust contact, with the Brownstone Basin Conglomerate missing or cut out.

Thickness of the Aztec Sandstone is difficult to measure at La Madre Mountain because of discontinuous outcrop and the unreliable nature of attitudes taken in the massive, cross-bedded sandstone. One semicontinuous exposure east of Turtlehead Mountain yielded a thickness of 665 m from a cross section construction. This measurement corresponds well with estimates in excess of 2000 feet (600 m) reported by Hewett (1931) at the spectacular exposures in the Sandstone Bluffs south of La Madre Mountain.

P. Brownstone Basin Conglomerate (New Name)

The Brownstone Basin Conglomerate is an informal name here assigned to thin synorogenic conglomerates found locally beneath all major outcrops of the Red Spring thrust. This conglomerate was first recognized by Longwell (1926). Glock (1929), Davis (1973) and Burchfiel and others (1974) all recognized the importance of this unit. Hewett (1931), Carr (1978, Lavinia Wash Sequence) and Cameron (1977) mapped conglomerates that lie in a similar position below the Contact thrust which are

probably contemporaneous with the Brownstone Basin Conglomerate.

Carr (1978) dated a tuff unit in the Lavinia Wash Sequence as 150 ± 10 m.y. (or Late Jurassic) by the K/Ar method on biotite. The tuff lies above detritus derived from the Delfonte Volcanics which lie depositionally above the Aztec Sandstone in the Clark Mountains (Burchfiel and Davis 1971). The Brownstone Basin Conglomerates must be older than the Red Spring thrust, but their age is poorly constrained. High-angle normal (?) faulting, erosion and emplacement of the Keystone thrust plate followed emplacement of the Red Spring sheet (see Structure and Timing sections). The Keystone thrusting was probably Middle or Late Cretaceous in age. Thus data limit the Brownstone Basin Conglomerate to a Late Jurassic or (?) Early Cretaceous age.

A thin lense of the conglomerate crops out at the southeast end of the Red Spring thrust exposure north of peak 5345. At this locality approximately 2 m of conglomerate of grey and white quartzite clasts in reddish matrix of reworked Aztec Sandstone lie on the Aztec Sandstone. Above this conglomerate are sandstone beds that consist mainly of reworked Aztec Sandstone. Above this sandstone lense and below the thrust contact is a 2 m thick conglomerate composed mainly of jasper clasts from the Shinarump Conglomerate set in a matrix of sand and silt.

Outcrops of the conglomerate in the western 1/2 of section 26, T20S, R58E, below the Red Spring thrust are thinner and more poorly exposed than those described above. At this locality

the conglomerate contains clasts of jasper and quartzite, with subsidiary clasts of carbonate, chert and Aztec Sandstone.

A thicker (up to 5 m), fairly continuous exposure of the Brownstone Basin Conglomerate is present below the Red Spring thrust northwest of Calico Basin, below peak 4987. Clasts in this lense are dominated by wellrounded quartzite and jasper set in a matrix of reworked Aztec Sandstone. Clast sizes range up to 10 cm for the quartzite and up to 4cm for the jasper. Lenses composed primarily of reworked Aztec sand interfinger with the conglomerates. A distinctive zone of weathered Aztec Sandstone about 10 to 20 cm in thickness is present below the conglomerate (figure 7). The weathered sandstone is colored purplish-pink and is more friable than normal Aztec Sandstone. The basal contact is extremely irregular with up to 3 or 4 m of relief.

Davis (1973) accurately described the best exposures of the conglomerate, in Brownstone Basin. The outcrops are above and southeast of the dam in Brownstone Basin. He reported well rounded "clasts of Cambrian or Late Precambrian quartzites, grey chert, cobbles of Shinarump conglomerate and pebbles of red and yellow jasperoid derived from this conglomerate" in a matrix of reworked Aztec Sandstone in the lower parts of the exposure. The upper part of the conglomerate contains up to 50% of subrounded cobbles of Paleozoic carbonate rocks up to 10 cm in diameter. Approximately 10% of the cobbles are jasper. Similar lithologies were noted in thinner outcrops of the conglomerate in lower Brownstone Basin.

Conglomerates exposed beneath the Red Spring thrust in the eastern canyon have similar clast content, quartzite, jasper, carbonate and chert. Vertical zonation of clasts as above was noted locally, although the conglomerate lenses are generally thinner and more discontinuous than in Brownstone Basin. Jasper typically makes up about 2 to 3% of the clasts, but locally may comprise as much as 20% of them.

1. Provincance of the Clasts

Clearly the clasts and reworked sand from the Aztec Sandstone were derived locally from the autochthonous rocks exposed at the surface during deposition of the Brownstone Basin Conglomerate.

A similar scenario can be envisioned for the jasper clasts, although this seems more unlikely due to the stratigraphic position of the Shinarump Conglomerate well below the Aztec Sandstone. At present levels of exposure the Red Spring thrust never rests on rocks older than the Aztec Sandstone, a fact that suggests that the Shinarump Conglomerate may not have been locally exposed prior to emplacement of the Red Spring thrust plate.

In the Goodsprings area (Carr 1978) the Lavinia Wash Sequence rests depositionally on units as low as the Moenkopi Formation. Therefore units stratigraphically lower than the Aztec Sandstone were exposed to the south and may have been exposed near La Madre Mountain prior to inception of the Red Spring thrust event. However, the Goodsprings area is an unlikely source area, as clasts in the Lavinia Wash Sequence

appear to have been derived locally. Carr(1978) gives thicknesses of 120 to 180 m (400-600 feet) for the Lavinia Wash Sequence, which suggest that a large drainage had been established at least locally.

Recent work by Burchfiel (pers. commun. 1979) suggests that the large overturned syncline at the north end of the Sandstone Bluffs may be related to the movement on the Red Spring thrust (see Structure), not the Keystone thrust as previously postulated (Secor 1963, Burchfiel and others 1974). This would allow a local source for the jasper material and would nicely explain the fact that the jasper content in the Brownstone Basin Conglomerate is higher in the western exposures. If folding of this syncline predated failure by thrusting the vertical zonation (inverted stratigraphy) of some of the outcrops of the conglomerate would be expected.

Davis (1973) suggested a Late Precambrian or Early Cambrian age for the quartzite clasts. I agree, although I feel that the possibility exists that some are from the Ordovician Eureka Quartzite. Most quartzite clast are grey and show no signs of the stratification common in the white Eureka Quartzite. Outcrops of the Precambrian-Early Cambrian quartzites occur in the Wheeler Pass thrust plate, and at Frenchman Mountain. Evidence constraining the movement on the Las Vegas and Lake Mead Shear Zones (Bohannon 1979) and the cratonal facies of the Paleozoic rocks at Frenchman Mountain suggest that the lower Cambrian rocks there were not exposed

during Mesozoic time. Therefore I suggest that the source terrain for the quartzite clasts was to the west in the Wheeler Pass thrust plate. This implies that the Wheeler Pass thrust event pre-dated the Red Spring thrust event.

Davis (1973) suggested that the Paleozoic carbonate clasts were deposited as forethrust debris, and represent the approach of the Red Spring thrust plate. My work fully supports this interpretation.

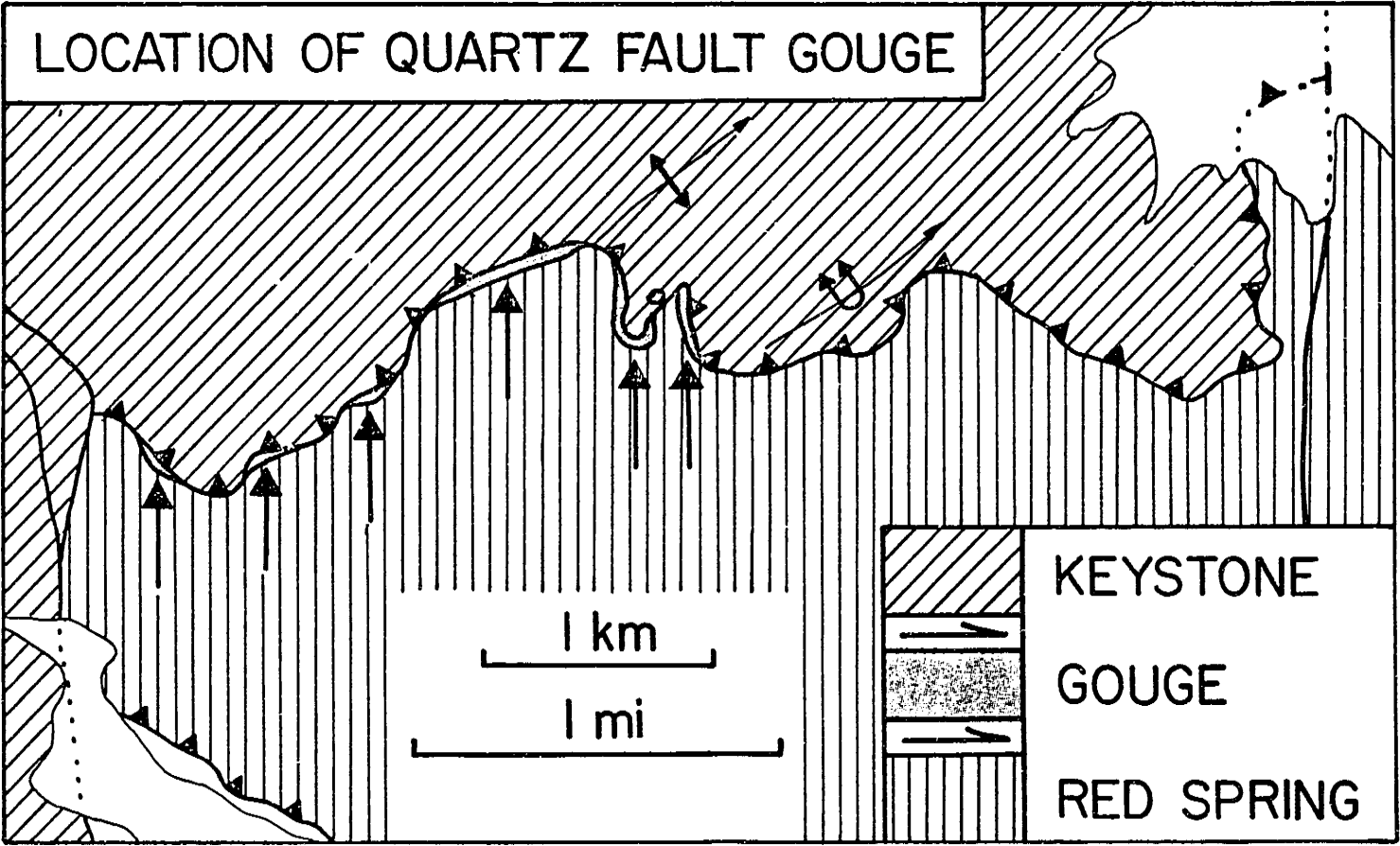
Q. Injection Breccia and Fault Gouge

Crushed quartz sandstone and carbonate fragments form fault gouge and dikes injected into the lower 0 to 20 m of the Red Spring thrust plate. Lenses and slivers of similar material up to 4 m thick are present below the Keystone thrust east of the Brownstone Basin fault (figure 8). Injected dikes of this gouge are present in the basal part of the Keystone plate also.

The gouge is composed mainly of cataclastic grains of Aztec Sandstone with intermixed angular carbonate fragments. Generally the carbonate fragments show extensive and densely developed twinning in thin section. Carbonate usually composes 0 to 5% of the gouge volume, although locally it can comprise up to 70 or 80%. These fragments appear to be derived entirely from rocks at the base of the thrust plates.

The cataclastic Aztec Sandstone grains vary from the normal, undeformed sizes to sizes which are indistinguishable optically. The gouge is partially cemented by calcite, which makes up a very small percentage of the nearly non-

Figure 8. Location of quartz fault gouge along the Keystone thrust in the eastern imbricate part of the Keystone thrust plate. Brownstone Basin fault on left. Thickness of the gouge zones are exaggerated. Slanted lines show Keystone thrust plate, stippled regions show gouge zones, vertical lines show Red Spring thrust plate.



porous rock.

The gouge is clearly transported from its original site of crushing or injection. Along the Keystone thrust lenses of crushed Jurassic sandstone occur below Cambrian rocks of the Keystone thrust plate and above Mississippian rocks of the Red Spring thrust plate (figure 9). Injections of gouge into the Keystone thrust plate commonly end at the thrust plane where Cambrian (upper plate) rocks lie directly on Mississippian (lower plate) rocks. Injections of gouge are seldom present in the lower plate, and never extend more than 1/2 m below the thrust plane. Lenses of gouge do not occur below the Red Spring thrust, but injections of gouge are present above lenses of the Brownstone Basin Conglomerate, and no conglomerate is found in the injections.

The injections vary in size from 1 to 4 m wide and 10 to 20 m long to less than 2 mm in thickness and just a few centimeters in length. Most dikelets fall into the lower end of this size range.

Two large injections are notable however. One occurs on the south side of peak 4987, northwest of Calico Basin (plate 1). The dike is a maximum of two meters thick and extends about 20 m above the Red Spring thrust. The other large body of injected gouge occurs south of Box Canyon on the east side of peak 4215. It is roughly circular in plan, about four meters in diameter, and about ten meters above the basal Keystone thrust. Neither of these large injections can be traced to the thrust surface.

Figure 9. Interleaved quartz-rich fault gouge with carbonate rocks of the Keystone thrust plate. Gouge shown dotted in drawing. Geologist for scale. Local is on the west side of peak 4215 (looking east).



Figure 9



Occasionally the injected material forms planar dikes. but more commonly forms very irregular shapes (figure 10). No preferred orientation of dikes is present, and most dikelets appear to have been injected into pre-existing, non-planar fractures near the base of the thrust plates. While I am tempted to appeal to high fluid pressures in the gouge to aid hydrofracturing and/or injection, I do not feel that the evidence is compelling in this regard. After injection the nearly non-porous gouge may have been able to act as a seal for high fluid pressure, although this is hard to imagine in the case of the Red Spring thrust which overrode the highly porous Aztec Sandstone.

Brock and Engelder (1977) noted similar lenses and injections in the base of the Muddy Mountain thrust plate. There the thrust plate overrode the Aztec Sandstone and "molasse" deposits of reworked Aztec Sandstone and carbonate fragments. They noted that finer grained gouge was present in the dikelets than in the thick lenses. Not enough petrological work has been done on the gouge from La Madre Mountain to prove this true, but it appears to be the case from field examination.

Brock and Engelder also noted that the injections are always connected to the thrust surface, which is not the case at La Madre Mountain. They report that when dolomite fragments are present within the gouge it is usually near the top. While this is generally true at La Madre Mountain it is by no means ubiquitous.

Dike injection at La Madre Mountain was probably syntec-

Figure 10. Thin irregular injection dikes of quartz-rich fault gouge. Note the intensely fractured host rock, and irregular, thin nature of injections into these pre-existing fractures.



Figure 10

tonic, as evidenced by cross-cutting relations between dikes and small, subsidiary thrusts. Dikes are present which both cut and are cut by the small thrusts.

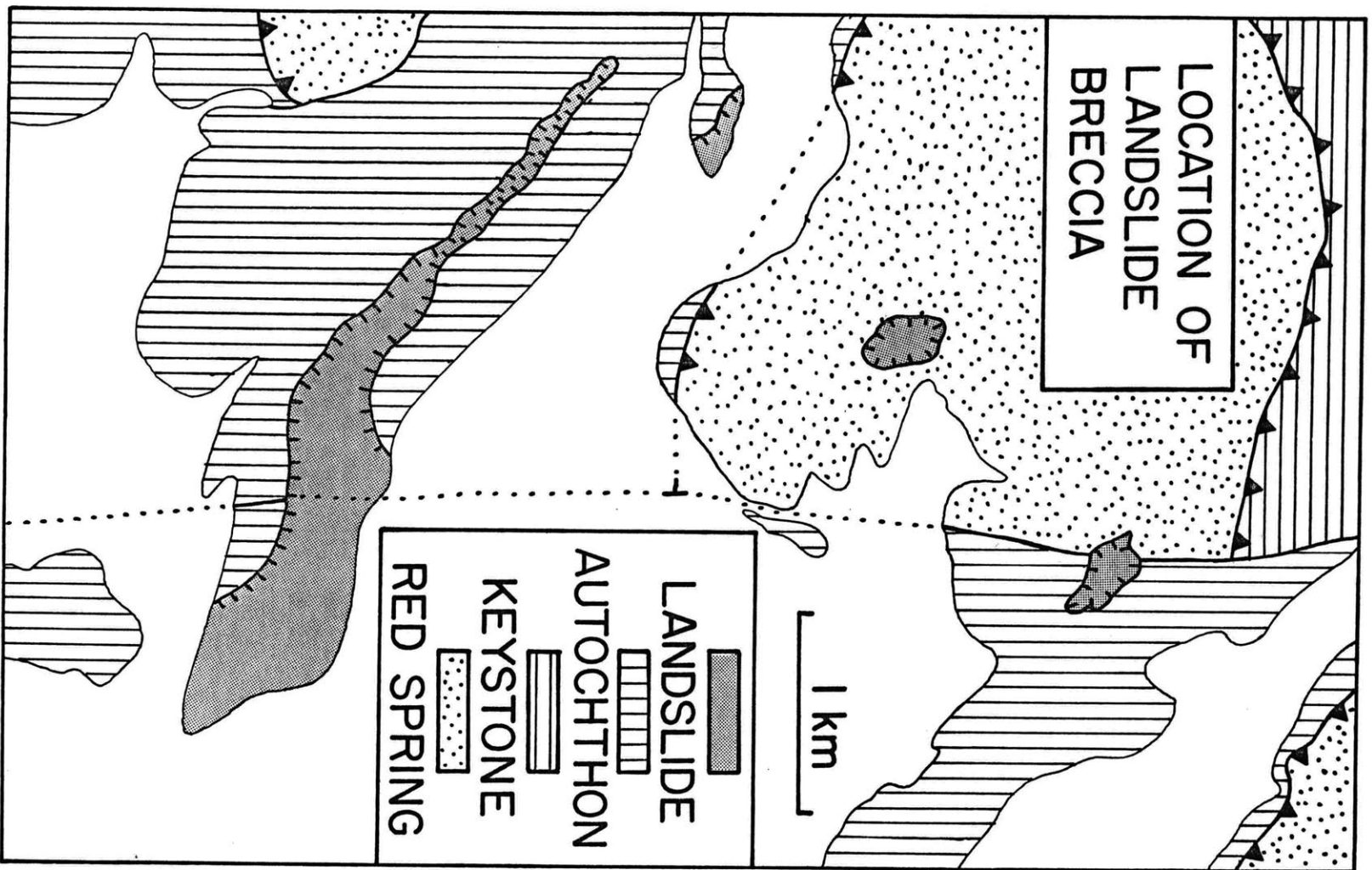
R. Tertiary (?) Landslide Breccia

Cemented landslide breccia is present in scattered outcrops (figure 11). The largest caps the ridge of peaks 5443 and 3950. Smaller outcrops are present in Brownstone Basin and on the south and east flanks of peak 6792. Longwell (1960) and Glock (1929) originally mapped the southern mass of breccia as a continuation of the Red Spring thrust plate, as pictured by Shelton (1966, figure 303). Davis (1973) recognized the landslide nature of these deposits, but on the basis of geometry of the southern exposures he postulated that they might be older than the Red Spring thrust. Two of the exposures (figure 11) cover the Brownstone Basin fault, indicating an age younger than the Keystone thrust, hence the designation Tertiary (?).

These landslide deposits consist of angular Paleozoic carbonate fragments (mainly Mississippian) which are cemented by greyish white dolomite. Angular clasts of the the Aztec Sandstone were caught up in the base of the slide locally as shown excellently in figure 302 of Shelton (1966).

A minimum area of 7 km^2 was covered by this landslide. It has an extremely irregular basal contact with tens of meters of relief locally and hundreds of meters of relief over the base of the entire deposit. The present topography of Brownstone Basin and peak 6977 must nearly mimic the

Figure 11. Location of Landslide Breccia, outcrops are shown in stippled pattern. Autochthonous rocks are vertically lined, Keystone thrust plate is horizontally lined and Red Spring thrust plate is dotted. Original extent of the landslide was a minimum of 7 sq km. The Brownstone Basin fault, covered by the breccia in two places, runs vertically through the center of the map.



original depositional surface as indicated by deposits of the breccia in present day valleys and on ridges.

III Description of Structural Relationships

A. Introduction

The La Madre Mountain area consists of complexly deformed Paleozoic and Mesozoic sediments. Two periods of thrust faulting and at least two periods of high- and low-angle faulting have occurred. The older and structurally lowest thrust plate, the Red Spring thrust plate, consists of Cambrian through Carboniferous rocks which rest above Jurassic or Early Cretaceous (?) autochthonous or parautochthonous rocks. Rocks of the Red Spring thrust plate are now exposed in five major northeast-tilted blocks bounded by north to northeast trending high-angle normal (?) faults. The younger and structurally higher Keystone thrust plate overrode these tilted fault-blocks and now crops out in the northern portion of the map area. Rocks of Cambrian to Permian (?) age are present in the Keystone thrust plate. Renewed movement on the old high-angle faults has displaced the Keystone thrust by amounts generally less than the older movements (figure 12).

All of the observed deformation is brittle in character. No significant ductile (plastic) deformation is associated with any of the structures.

Plates 1 and 2, figure 13 - Tectonic Map of the La Madre Mountain area, and figure 14 - Generalized Geologic Cross Sections should be referred to during the discussion of structure. On plate 2, Geologic Cross Sections, I have not projected

Figure 12. Areal view of the La Madre Mountain area looking northwest. BB=Brownstone Basin, C=Calico Hills fault, CB=Calico Basin, CH=Calico Hills, K=Keystone thrust, R=Red Spring thrust, T=Turtlehead Mountain fault, TM=Turtlehead Mountain. La Madre Mountain in the background. This view shows the fault relations in the La Madre Mountain area. Note the large displacement of the Red Spring thrust, and the relatively minor displacement of beds in the Keystone thrust plate, both displaced by the Turtlehead Mountain fault. The La Madre fault is buried just to the left (southwest) of the Calico Hills. The Tertiary (?) Landslide Breccia caps the ridge in front of Brownstone Basin, but is not discernable. This view is very similar to Figure 303 of Shelton (1966).



Figure 12

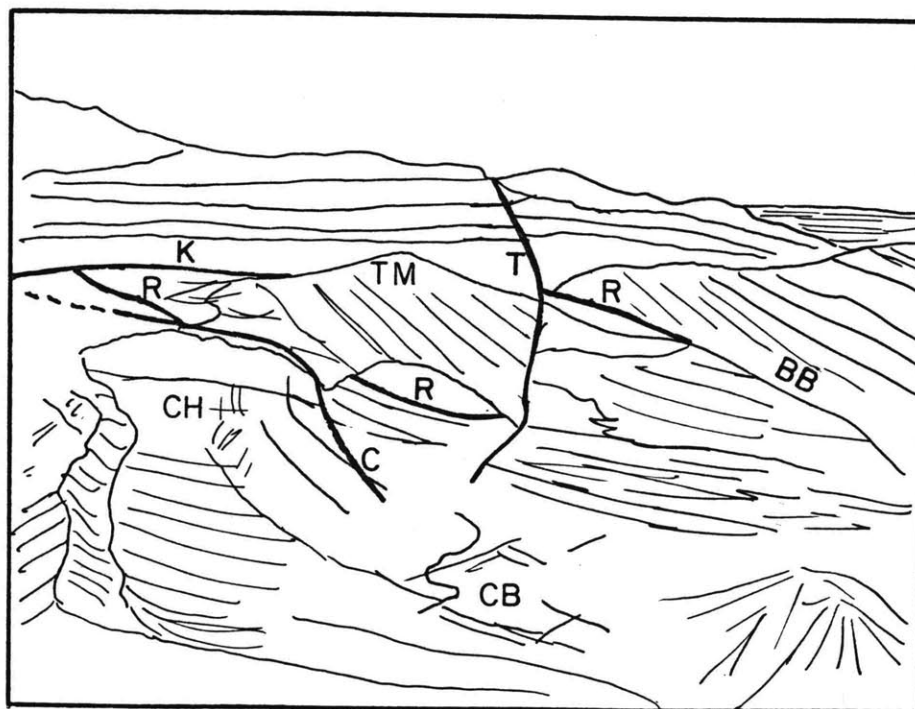


Figure 13. Tectonic Map of the La Madre Mountain area, showing major folds and faults. Section lines refer to Figure 14. Keystone thrust plate is dotted, Red Spring thrust plate is vertically lined, and "autochthon" is hatchured. See text (Structure, Red Spring thrust plate, Turtlehead Mountain Block) for explanation of area patterned with broken horizontal lines. Section lines shown correspond to section lines on plate 1 as follows: AA'=CC'C", BB'=BB', and CC'=FF'F".

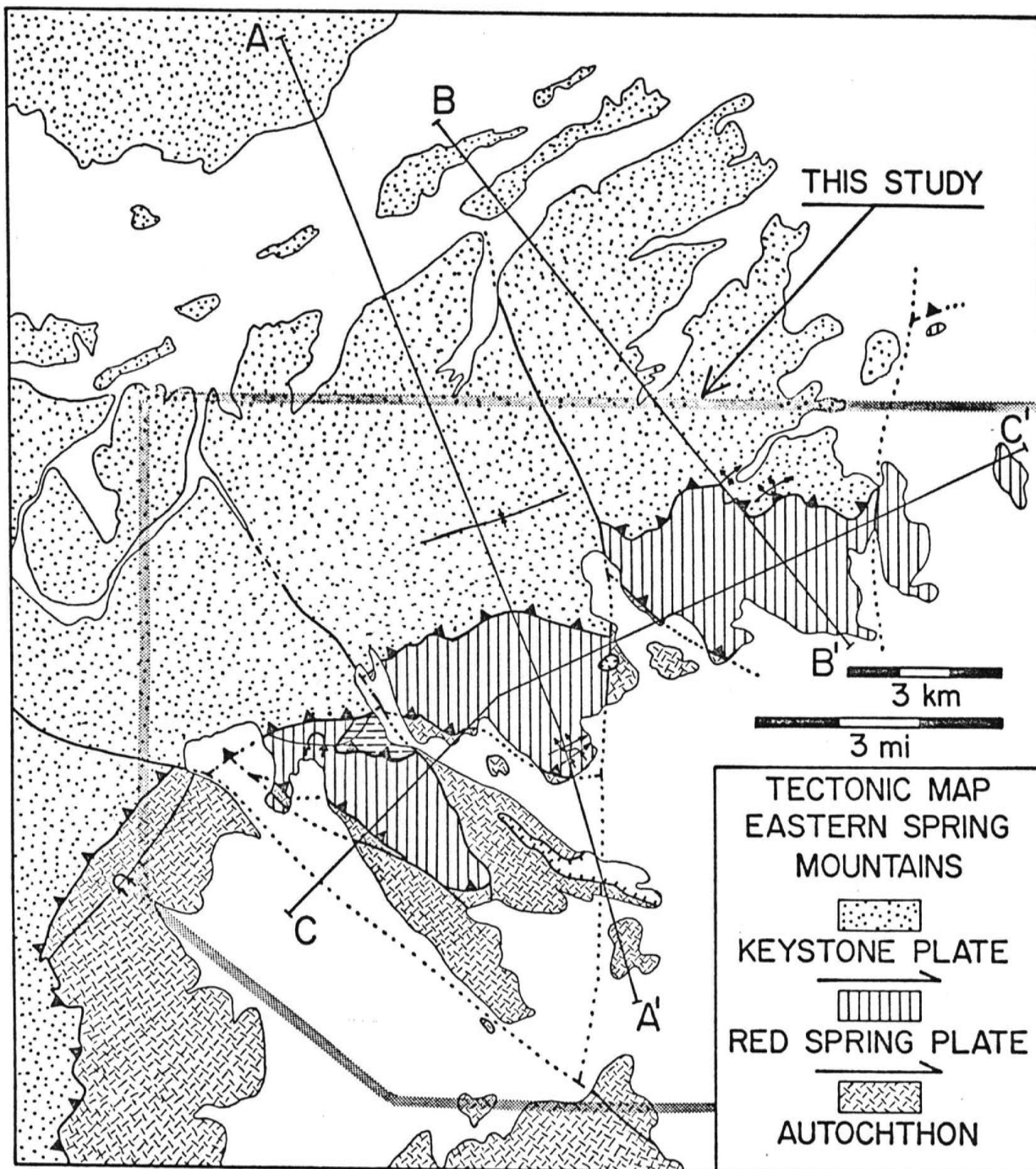
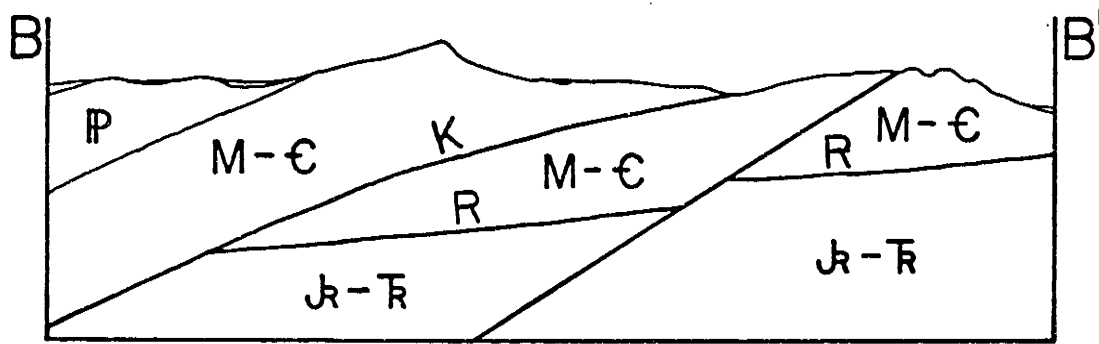
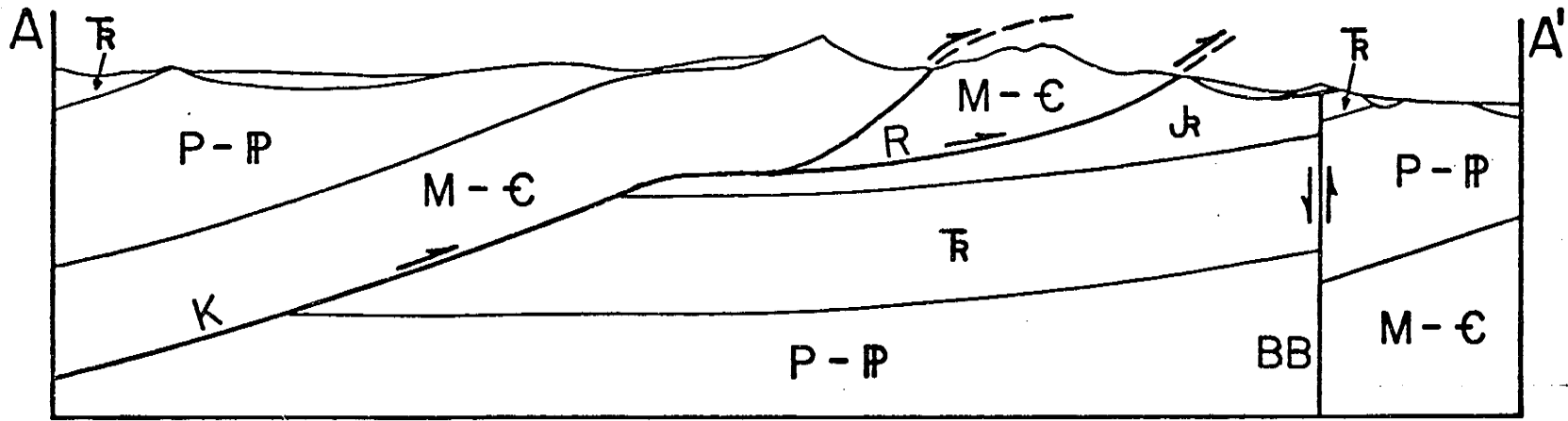
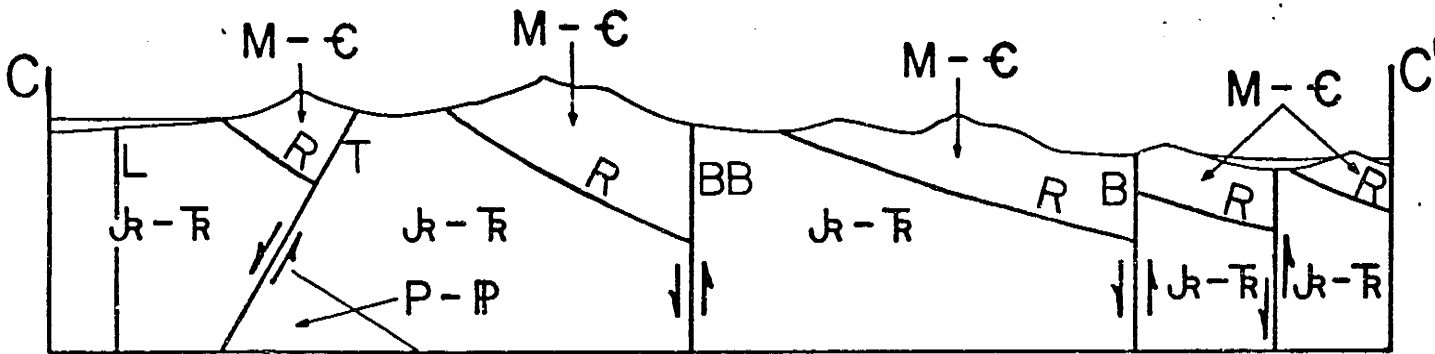


Figure 14. Generalized Geologic Cross Sections. Section lines shown on Figure 13. Sections AA' and BB' are extended to the north, using data from Burchfiel and others (1974), and are extended to greater depth than those in plate 2. Sections here correspond to sections on plate 2 as follows: AA'=CC'C", BB'=BB', CC'=FF'F". B=Box Canyon fault, BB=Brownstone Basin fault, K=Keystone thrust, L=La Madre fault, R=Red Spring thrust, T=Turtlehead Mountain fault.



NO VERTICAL
EXAGGERATION

[1 km] [1 mi]



the geology to great depths. Some interpretation was necessary in construction of the sections, but I have tried to limit the geology in the sections to what is constrained by the geology on plate 1. Slightly more information (mainly bedding plane attitudes) was available during the construction of the sections than is shown on plate 1, due to drafting and reproduction limitations. Figure 14 shows more speculative cross sections, extended to greater depths and incorporating information from the geologic map of the Spring Mountains published by Burchfiel and others (1974) north of the La Madre Mountain area. All place names are identified on either figure 4 or figure 6.

B. Structure of the Keystone Thrust Plate

The Keystone thrust of Hewett (1931) can be traced south through the Spring Mountains (Burchfiel and others 1974, Cameron 1977b, and Carr 1978) and into the Clark Mountains (Burchfiel and Davis 1971, in prep.) Through most of its length the trace of the thrust and upper plate strata generally strike north-south and dip west. At the northern end of the Sandstone Bluffs in the Spring Mountains the fault trace and upper plate strata bend sharply eastward, and maintain a northeast trend through most of the La Madre Mountain area.

The Keystone thrust has been correlated with the Muddy Mountain thrust (Longwell 1960, Fleck 1967, 1970, Burchfiel and others 1974). I believe that it is more appropriately correlated with the Glendale thrust in the Muddy Mountains (Longwell, 1949). In either case the offset across the Las Vegas Shear Zone is

approximately 40 km.

Along the entire length of the Keystone thrust plate Cambrian age rocks are found at the base. These rocks range from the lower Cambrian Bright Angel Shale in the Clark Mountains (Burchfiel and Davis in prep.) to the upper Cambrian Nopah Formation at La Madre Mountain (this report) and in the Goodsprings District (Carr, 1978). However for most of its length in the Spring, Clark and Muddy Mountains (Temple, 1977) the thrust is in the Middle Cambrian Bonanza King Formation. In the Spring and Clark Mountains the thrust is usually near the silty unit that divides the Bonanza King Formation into 2 members (Burchfiel and others 1974). The Keystone thrust has overridden various terrains, from Precambrian crystalline basement to Jurassic rocks in the Clark Mountains (Burchfiel and Davis in prep.), the Contact thrust plate in the Goodsprings area (Cameron 1977b, Carr 1978), and Jurassic Aztec Sandstone in the Sandstone Bluffs south of La Madre Mountain.

At La Madre Mountain the Keystone thrust plate overrode the tilted blocks containing the Red Spring thrust, and can be divided into two parts on the basis of different structural styles. A fairly coherent part makes up most of the Keystone thrust plate, west of the Brownstone Basin fault (figure 6). The rocks are locally broken by high-angle faults, thrust imbrication is limited to a zone less than one kilometer from the basal thrust, and there is a large flexure of the entire plate.

East of the Brownstone Basin fault the structure is more

complex. Imbricate thrust slices are common. The basal thrust cuts into younger rocks in the upper plate by truncation of one limb of a northeast trending anticline in Box Canyon. Quartz-rich fault gouge and injection dikes (derived from the Aztec Sandstone) are commonly present along the thrust contact. These zones will be referred to as the "western coherent" and the "eastern imbricate" parts of the Keystone thrust plate respectively.

1. Western Coherent Part of the Keystone Thrust Plate

The Keystone thrust enters the western edge of the map area at the northern end of the Sandstone Bluffs above a large syncline overturned to the southeast. At this point Cambrian rocks of the Banded Mountain Member of the Bonanza King Formation rest upon steeply overturned beds of the Upper Redbed Member of the Moenkopi Formation.

Jurassic Aztec Sandstone is in the core of this syncline, which has long been thought to be related to movement on the Keystone thrust (Secor 1963). Recent work by Burchfiel (pers. commun. 1979) suggests that the folding may in fact be due to earlier overthrusting by the Red Spring plate (see Structure of the Autochthon).

Rocks of the Banded Mountain Member in the lowest part of the Keystone thrust plate strike northeast into, and are truncated by the La Madre fault, which juxtaposes them against rocks of the Nopah Formation and the upper Banded Mountain Member. Rocks within 10 to 20 m of the La Madre Fault are extremely sheared and brecciated. Rocks of the lower Banded

Mountain Member are exposed in a stream bed immediately northeast of the northern end of the Sandstone Bluffs, strongly suggesting that the Keystone thrust is cut by the La Madre fault with a vertical separation (northeast-side-down) of approximately 100 to 200 m.

Northeast of the La Madre fault a more complete section in the Keystone thrust plate is exposed. The strata strike northeast and dip 20° to 50° to the northwest, with dips generally increasing toward the thrust.

Northwest of Turtlehead Mountain the Keystone thrust is exposed above a syncline overturned to the south in the Red Spring plate. Moderately to steeply dipping or steeply overturned strata of the Nopah Formation and the Banded Mountain Member are present below the thrust.

The overturned syncline is a structure related to the emplacement of the Keystone thrust plate. Nested in the core of the syncline are imbricate slices of Banded Mountain and locally Dunderberg Shale Member strata. Because these infolded slivers contain uppermost Banded Mountain and Dunderberg Shale Member rocks they are interpreted as originating in the Red Spring plate (see discussion of the Turtlehead Mountain block of the Red Spring thrust plate below). These rocks must have been sheared from the northwest side of the Red Spring thrust plate and transported to their present location prior to infolding during the emplacement of the Keystone thrust plate. Both ends of the axial trace of the syncline are truncated by

the Keystone thrust.

The Keystone thrust is cut by the Turtlehead Mountain fault beneath the alluvium of upper Brownstone Basin. It is offset with left-lateral separation of approximately 0.6 km, or a vertical separation, northeast-side-up, of 200 to 300 m. The Turtlehead Mountain fault continues northwest into the Bird Spring Formation of the Keystone plate where it is covered by the alluvium of a straight, narrow canyon. Displacement of individual units across the canyon is hard to document due to the monotonous sequence of strata and the poor outcrop of the Bird Spring Formation.

The Keystone thrust is exposed almost continuously for for most of 2.5 km east of the Turtlehead Mountain fault. A series of imbricate slices and minor folds is exposed

in the lower Banded Mountain Member above this portion of the thrust. North and northeast of peak 6977 the thrust is covered by alluvium of an east-west trending canyon. The zone of imbricate thrusts and folds is exposed north of the canyon. The thrust zone is truncated by the Brownstone Basin fault and juxtaposed against Aztec Sandstone of the autochthon. Left-lateral separation of about 2 km of the trace of the Keystone thrust is present on the Brownstone basin fault. Vertical separation is harder to estimate because of the differing structural styles east and west of the fault, but is approximately 1200 m as measured on section E E'E". The eastward continuation of the Keystone thrust will be discussed in the

section about the eastern imbricate part of the Keystone plate.

Between the the Turtlehead Mountain and Brownstone Basin faults the Keystone thrust plate overrode northeast dipping strata of the Red Spring Plate, which vary in age from Cambrian on the west to Mississippian on the east.

North of peak 7033, in the eastern end of the western coherent part of the Keystone plate a large synformal flexure is present. The axial trace of the flexure is about 3 km in length and trends approximately east-west. Bedding dips generally northward on both limbs of the flexure, but is much steeper on the south (50° - 70°) than on the north (0° - 20°). The western end of the synform appears to be slightly offset by a small north-trending fault west of peak 7033. The flexure is terminated to the east by the Brownstone Basin fault, although minor folds and faults in this area make location of the axial trace of the symform impossible.

When well exposed, the Keystone thrust in the western coherent part is generally a sharp fault with fracturing or brecciation limited to within 10 to 15 m of the fault, although brecciation may be more pervasive locally. When brecciation is scarce, pervasive fracturing that does not seriously disrupt bedding is common for up to 20 m above the thrust. Minor folds and imbricate thrusts are common in the lower portion of the Banded Mountain Member.

The dip of the Keystone thrust in the western coherent part of the Keystone thrust plate is difficult to estimate. One direct measurement on the fault southeast of peak 5330 was

was 30° to the north-northeast. Dips on higher subsidiary thrusts are generally to the north and range from 30° to 54° . Bedding attitudes in the plate are similar. If the thrust is roughly stratigraphically controlled, and higher subsidiary faults generally parallel the basal thrust, then the Keystone thrust probably dips about 40° to 45° in the western coherent part.

2. Eastern Imbricate Part of the Keystone Thrust Plate

East of the Brownstone Basin fault, rocks in the base of the Keystone thrust plate are much more disturbed than in the western coherent part. Imbricate thrusts, folds and high- and low-angle faults are ubiquitous throughout the Banded Mountain Member and affect rocks as young as the lower Ordovician Pogonip (?) Group.

a. Keystone Thrust in the Eastern Imbricate Part

The Keystone thrust dips more shallowly beneath the eastern imbricate part than below the western coherent part of the Keystone thrust plate. One measured dip is 31° west-northwest, and three point solutions give dips as low as 10° to 15° and as high as 33° . Sections AA' and BB' of figure 14 illustrate the difference of dip in the two parts of the Keystone plate, and sections AA' and BB' of plate 2 show the low dip below the eastern imbricate part. The trace of the Keystone thrust is sinuous and follows topography more closely than in the western coherent part. Dips on subsidiary thrusts in the eastern imbricate part vary from near zero to 30° . Strike of bedding does not follow the thrust trace as closely as it does in the coher-

ent part, and is probably not indicative of the attitude of the thrust.

Fleck (1967 and in Burchfiel and others 1974) mapped the ridge south of Kyle Canyon and north of the imbricate thrusts in the map area. The ridge is formed by an undisturbed section from the Nopah to the Bird Spring Formations. The dips are consistent on the ridge, varying from 20° to 35° to the northwest. The thrust may follow these dips in the subsurface, an interpretation which was followed in the construction of section BB' of figure 14. This is necessary in order for the Keystone thrust in the subsurface to be at approximately the same level north of where the Brownstone Basin fault ends.

West of peak 4215, the Keystone thrust at the base of the imbricate part is generally a sharp contact between Cambrian Banded Mountain strata above and the Mississippian Bullion and Anchor Members below. One small sliver of the silty unit of the Bonanza King Formation is present south of peak 5173. Lenses and injected dikes of quartz-rich fault gouge are present along this portion of the thrust and are discussed below. Upper plate deformation near the thrust between peak 4215 and the Brownstone Basin fault is restricted to small, asymmetric folds and what appear to be tear-faults. Axial traces of the folds trend north-northeast to northeast and the folds verge to the east-southeast or southeast. Some of the folds are cut by the tear-faults, but cannot be matched across the faults.

Peak 4215 is made of steep east- and southeast-dipping

strata in the truncated limb of a large anticline. East of the fold the Keystone thrust cuts up section so that the Banded Mountain Member has been almost entirely faulted out of the upper plate. Rocks of the uppermost Banded Mountain Member or Dunderberg Shale are at the thrust contact, above rocks of the upper Monte Cristo and Bird Spring Formations. Imbricate thrusts and folds are common within 700 m of the thrust east of peak 4215. The trace of the Keystone thrust curves around the east side of peak 3767 and is covered by alluvium. The thrust is presumably truncated beneath the alluvium by the north-trending Box Canyon fault. It is probably present in the subsurface about three kilometers to the north (figure 13).

b. Internal Structure of the Imbricate Part

Approximately the western two-thirds of the imbricate part consists predominantly of faulted and folded rocks of the Banded Mountain Member. Thrust imbrication is present throughout the Banded Mountain Member and also is present in the lower Nopah Formation, especially directly east of the Brownstone Basin fault. North- to northwest-trending, southwest-dipping high- and low-angle faults are also common. These faults were active during (and after ?) formation of some of the imbricate thrusts, because they have many of the characteristics of tear-faults. The fault immediately east of the Brownstone Basin fault displays this character particularly well: imbricate thrusts on its west side have rocks as low as the Dunderberg Shale in their upper plate, while those on the east have only Banded Mountain Member involved. The more westerly faults have

steeper dips (55° to 65°) than the eastern faults (approximately 30°). These faults appear to have formed from upward propagation of older faults in the Red Spring plate.

In the western end of Box Canyon the Banded Mountain Member is folded into a large, northeast-plunging anticline, beds in the southeast limb of which dip into and are truncated by the Keystone thrust. Truncation of this limb of the anticline has cut out much of the Banded Mountain Member from the upper plate of the Keystone thrust. Most of the rest of the Banded Mountain Member is cut out by small thrusts and overturned, and truncated folds east of peak 4215.

A concealed fault in Box Canyon and the small side canyon east of peak 4215 is required by the geometries of structure and strata flanking those portions of the canyon. This fault may be the subsurface continuation of a fault exposed northwest of peak 4373, which puts Dunderberg Shale Member strata against rocks of the upper Nopah Formation on the south side of Box Canyon.

East of this inferred fault the basal part of the Keystone thrust plate contains mostly rocks of the Nopah Formation with minor amounts of upper Banded Mountain Member strata present in slivers near the basal thrust. Imbricate thrusts are present in the Nopah Formation but are not as numerous away from the basal thrust as they are in the well-bedded, lithologically more variable Banded Mountain Member to the west.

On peak 4897, north of the anticline described above, strata of the upper Banded Mountain Member and the lower

Nopah Formation are complexly cut by imbricate thrust faults and high- and low-angle faults. This intense zone of faulting may be related to shortening taken up by the anticline in western Box Canyon, and extends for approximately 4 km to the north of peak 4897 as mapped by Fleck (1967, and in Burchfiel and others 1974). Strata of the Nopah Formation, and possibly Ordovician formations as well, are probably present north of peak 4897, but these rocks were all mapped as Bonanza King Formation by Fleck. Ordovician Pogonip strata are present on the north side of Box Canyon at its mouth.

Strata from the Nopah Formation (a small portion of which is present immediately east of the Brownstone Basin fault at the northernmost edge of plate 1) through the Bird Spring Formation form a northeast-trending ridge north of plate 1 and south of Kyle Canyon. This ridge is mapped as unaffected by the thrusting south of it by Fleck. However at least one thrust truncates the Dunderberg Shale and upper Banded Mountain Members beneath the upper part of the Nopah Formation at the southwest end of the ridge, shown on plate 1. From a distance this ridge appears to be unaffected.

c. Quartz-Rich Fault Gouge

Lenses and injection dikes of quartz-rich fault gouge are present along and above the basal contact of the Keystone thrust in the eastern imbricate part (figure 8). The gouge is only present along the western part of the imbricate part of the Keystone plate in sections 4, 8 and 9, T20S, R59E. The easternmost exposures of the gouge are some of the thick-

est and most easily accessible. These outcrops are in the side canyon south of Box Canyon and east of peak 4215. A dirt road in good condition ends less than 50 m from them. More westerly exposures are best reached from the side canyon west of peak 4215.

Lenses of gouge vary from 0 to 4 m in thickness and are up to about ten meters in length. They are typically composed of 90% to 100% cataclastized quartz fragments from the Aztec Sandstone with 0-10% carbonate (with some chert) fragments. In two cases "tectonic bedding" is present roughly parallel to the thrust contact. At one locality the tectonic bedding was expressed by color-banding in a predominantly quartz-rich zone and at the other the tectonic bedding was formed by inter-layered quartz-rich and carbonate-rich layers.

The lower contact of the gouge lenses with the Anchor or Bullion Member limestones of the Red Spring plate is typically sharp, with only occasional, minor injections of gouge less than 1/2 m into the lower plate. The upper contacts of the gouge are nearly always irregular. Thick or thin injections of gouge up to 3 to 4 m from the contact, tectonic interleaving of gouge with carbonate slices (figure 9), or increasing carbonate content upward in gouge lenses are common. Sharp upper contacts are present only rarely.

Injections of fault gouge are present up to ten meters above the thrust. The largest of these is located on the east side of peak 4215. It is roughly circular in plan, about 4 m in diameter, and about ten meters above the basal thrust. It

cannot be traced to the basal contact, but may be connected in the subsurface.

More commonly, injected gouge is present in irregular fractures with dimensions measured in millimeters or centimeters (figure 10). Planar injections are not common and a preferred orientation was not observed. Fractures which contain gouge are similar to fractures present at the base of the thrust plate elsewhere, which suggests that the gouge was injected into pre-existing fractures, rather than opening new cracks through hydrofracture. Relations between gouge-filled fractures and thrusts indicate that the gouge was injected contemporaneously with thrusting. Dikelets are present which are both cut by and cut through small thrusts that parallel the basal Keystone thrust.

The fault gouge has clearly been transported from its original place of crushing and injection. Gouge zones of crushed Jurassic Aztec Sandstone are present below Cambrian upper plate rocks and above Mississippian lower plate rocks. This requires transport of several kilometers from the position of original crushing, where the Keystone thrust plate overrode Aztec Sandstone north or northwest of the present position of the gouge above the Red Spring plate.

Section BB' of figure 14 is an attempt to project the geometry of section BB' of plate 2 at depth in order to estimate the transport distance of the gouge. Several problems were encountered in constructing this section: 1) the assumption of approximate stratigraphic control of the thrust used

for sections to the west is not valid, 2) location of the Red Spring thrust at depth is difficult to establish accurately, 3) the dip of the Keystone, as discussed above, appears to be much shallower in this part of the plate than in the coherent part, making extrapolation of the thrust's position to the point of intersection with the autochthon rocks at depth imprecise. With these problems in mind a minimum transport of 6.8 km (4.25 miles) can be estimated. This estimate is close to more accurate estimates of overlap of the Keystone plate with the Red Spring plate in the western coherent part (section C C'C", plate 2).

It is of interest that this gouge is present only along the western portion of the imbricate part of the Keystone plate, where rocks of the Banded Mountain Member make up the base of the thrust plate. Particularly noteworthy is the fact that the gouge is present in and below rocks of the truncated limb of the northeast-plunging anticline in Box Canyon. This indicates that the anticline, and possibly much of the imbrication to the north have been transported at least as far as the gouge.

C. Structure of the Red Spring Thrust Plate

Longwell named the Red Spring thrust in his publication of 1926. Davis (1973) correlated it with the Contact thrust to the south named by Hewett (1931) on the basis of structural and stratigraphic similarities: both thrust plates are present beneath the Keystone thrust plate, both are cut by pre-Keystone high-angle faults with large displacements, and both overrode

autochthonous or parautochthonous rocks of Mesozoic age. It is now known that conglomerates similar to those found by Longwell (1926) beneath the Red Spring thrust (Brownstone Basin Conglomerates) are present beneath the Contact thrust (Cameron 1977a and b, Carr 1977, 1978).

Davis proposed that the Red Spring-Contact thrust was once a laterally continuous sheet which overrode an erosional surface, as indicated by the Conglomerate of Brownstone Basin (also Longwell 1926). Later high-angle faults cut the sheet into several fault-bounded blocks (see figure 3). The Sandstone Bluffs were apparently a horst block from which the Contact-Red Spring thrust sheet was removed by erosion prior to emplacement of the Keystone plate. The Keystone plate overrode the Contact plate in the south, the Sandstone Bluffs horst and the Red Spring plate in the north.

No definite correlative structures are known south of the Goodsprings District (Contact thrust). Several possible correlations can be made in the Muddy Mountains to the north. New work by Bohannon (pers. commun. Burchfiel 1979) in that area has caused him to suggest that the Summit thrust of Longwell (1949) may be correlative to the Red Spring thrust. As described below (Timing and Correlation) I believe that the Muddy Mountain thrust is the equivalent of the Red Spring thrust.

Rocks of the Red Spring thrust plate are exposed in five northeast-tilted, fault-bounded blocks. From west to east they are named as follows (figure 6):

1) Turtlehead Mountain block, bounded by the Calico Hills and La Madre faults on the west and the Turtlehead Mountain fault on the east,

2) Brownstone Basin block, between the Brownstone Basin and Turtlehead Mountain faults,

3) eastern canyon block, between the Brownstone Basin and Box Canyon faults,

4) Box Canyon fault block, east of the Box Canyon fault,

5) Lone Mountain, the isolated hill on the east side of plate 1.

The Red Spring thrust is exposed in the three western blocks, where Cambrian Banded Mountain Member strata lie above Jurassic or Early Cretaceous (?) Brownstone Basin Conglomerate or Jurassic Aztec Sandstone. Rocks as young as Devonian, Mississippian, and Pennsylvanian (?) are exposed in the Red Spring plate in these three blocks. Only Devonian and Mississippian rocks are exposed in the Box Canyon fault block and at Lone Mountain. A concealed, north-trending fault of large displacement must separate the Box Canyon fault block from Lone Mountain.

Structures related to the emplacement of both the Keystone and Red Spring thrust plates are present in the three western blocks. The ages of structures in the Box Canyon fault block and at Lone Mountain are more speculative, but probably belong

to the Keystone age deformation. Exposed structures of the eastern canyon block are more complex than those of the other four blocks.

1. Turtlehead Mountain Block

The Turtlehead Mountain block is bounded on the west by the La Madre Mountain and Calico Hills faults. The Calico Hills fault has northeast-side-down separation and is tentatively correlated with a similar fault on peak 5345 (plate 1). If this is true, then the Calico Hills fault would be later than, and truncate the northeast-side-up fault immediately northeast of peak 5345, which juxtaposes Red Spring plate rocks against lower plate Aztec Sandstone. A continuation of the Red Spring thrust must be present in the subsurface south of peak 5345. The only exposures of the Papoose Lake Member of the Bonanza King Formation at La Madre Mountain are on peak 5345.

The Turtlehead Mountain block is bounded on the east by the Turtlehead Mountain fault, which dips west-southwest at about 50° to 60° . The Turtlehead Mountain fault has about 1200 to 1500 m (4000-5000 feet) of east-side-up normal separation of the Red Spring thrust (sections E E'E" and F F'F", plate 2). It juxtaposes Cambrian through Devonian strata of the Turtlehead Mountain block against the Aztec Sandstone of the autochthon. A sliver of Nopah Formation approximately 600 m long is present in the fault zone east of Turtlehead Mountain.

The Red Spring thrust crops out in four separate places on the south and west sides of the Turtlehead Mountain block.

Figure 15. Southeast side of peak 4987, viewed from Calico Basin. The heavy line in the drawing shows the Red Spring thrust. La Madre Mountain is in the left background.

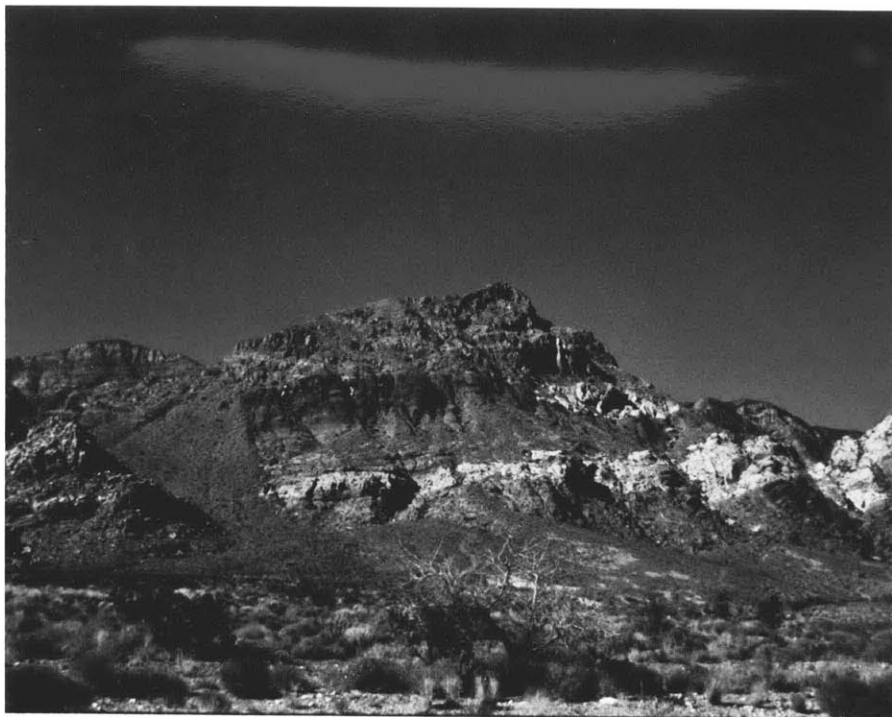
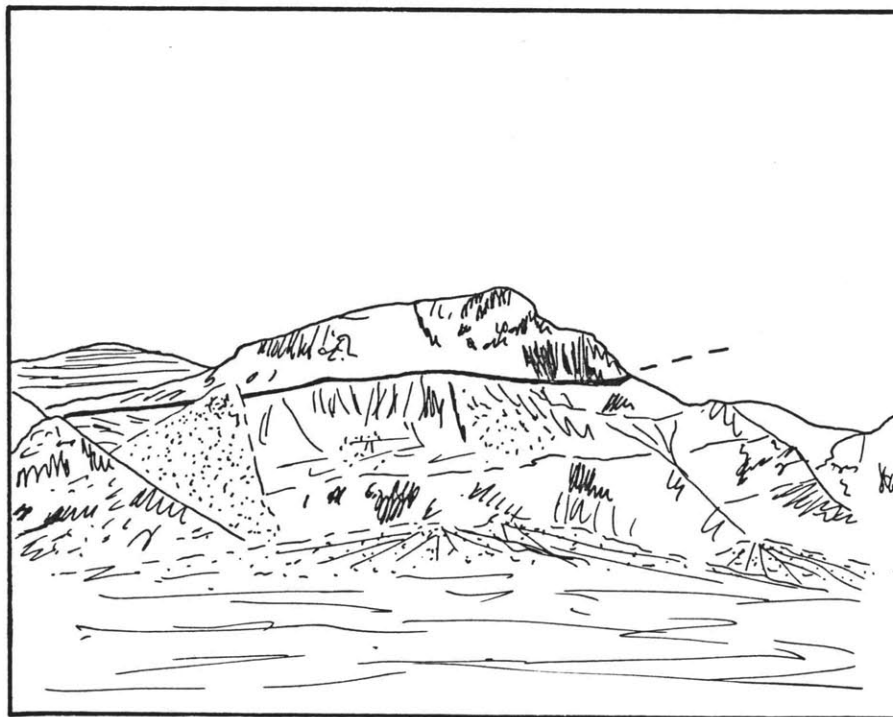


Figure 15



The three outcrops west of Turtlehead Mountain are separated by alluvium. The fourth outcrop (fig. 15, peak 4987) is separated from the rest by the Calico Hills fault and a northwest trending splay from the Calico Hills fault. The thrust dips northeast about 35° beneath the Turtlehead Mountain block.

For most of the lengths of these exposures the Red Spring thrust overrode the Brownstone Basin Conglomerate, which generally dips 25° - 44° northeastward. Lithology of the conglomerates is discussed in the Stratigraphy section above. Attitudes of bedding near the thrust are generally parallel to the Red Spring thrust in this block.

Imbricate thrusts and folds are not as well developed above the thrust in this block as in the two to the east of it. However the Red Spring thrust cuts up section to the southeast in the upper plate rocks; the silty unit and the Papoose Lake Member of the Bonanza King Formation are present in the upper plate near peak 5345, but the thrust is less than 180 m (600 feet) below the Dunderberg Shale where section FF' of plate 2 crosses the thrust and at the exposure south of peak 4987.

A large injected dike composed mainly of crushed Aztec Sandstone is present in the Red Spring thrust plate south of peak 4987. The dike trends north-northeast and is about 20 m long and 0 to 2 m wide. It cannot be traced to the thrust at the surface, but is located at a position above the Brownstone Basin Conglomerate, so probably was transported some unknown distance from its original site of injection.

The northeast part of the Turtlehead Mountain block contains complexly folded and faulted strata. Several nested thrust slices form a thrust "flap" of Banded Mountain Member and Dunderberg Shale above strata ranging from the Nopah to the Sultan Formations. The entire structural sequence is folded into an overturned syncline, vergent to the south.

Ordovician to Devonian age rocks beneath the southeast end of this flap have been thrown into a northeast-plunging syncline-anticline pair overturned to the southeast. The core of the anticline of this pair contains complexly slivered and folded Ordovician undifferentiated strata. Several small thrust faults and bedding-plane exit to the southeast from this core zone. The folds appear to have detached at the level of the basal Ordovician strata.

The northwest parts of the thrust faults within the flap have been folded along with the underlying Cambrian strata into a south-vergent, overturned syncline beneath the Keystone thrust. The axial trace of this syncline is approximately 2 km long and is overridden by the Keystone plate on both ends. The syncline may be dying out to the west, as strata are not overturned at that end. Whether or not the Red Spring thrust is folded also in the subsurface is not known (section D D'D", plate 2).

Davis mapped the western end of the axial trace of this syncline as trending southwest until covered by alluvium. He tentatively correlated this syncline with the one in parautochthonous rocks of the White Rock Hills. This interpretation is

is possible but new work by Burchfiel (pers. commun. 1979) suggests that the syncline above the White Rock Hills may be related to emplacement of the Red Spring thrust plate. This work is discussed in the section on autochthonous rocks below.

The place of origin of the thrust slices in the flap is somewhat ambiguous. The presence of Dunderberg Shale strata in depositional contact with Banded Mountain Member rocks in the lowest slice suggests an origin within the Red Spring thrust plate. The Keystone thrust would have had to cut up section in its upper plate all the way through the Banded Mountain Member for the flap to have originated in the Keystone Plate. This relationship is not seen at the surface for at least 9.5 km to the northeast and for 40 km to the south where a complex reentrant in the Keystone thrust occurs above the south end of the Contact plate (Carr 1978, 1979). However the Keystone thrust moved over rocks of the Banded Mountain Member of the Red Spring thrust plate at several places, including the site of this flap. After being torn from the Red Spring plate and transported to its present location the flap was folded into the core of the syncline.

This flap is made up of Red Spring plate rocks and sits below the through-going trace of the Keystone thrust, but was emplaced during the Keystone event. For these reasons I have chosen not to include it with either the Keystone or Red Spring plates on figure 13, Tectonic Map of the La Madre Mountain Area. Instead I have given it a different pattern (broken horizontal lines) than either major thrust plate.

2. Brownstone Basin Block

The Brownstone Basin block is bounded on the west by the Turtlehead Mountain fault and on the east by the Brownstone Basin fault. The Brownstone Basin fault appears to be very steep east of peak 6792, where it juxtaposes Cambrian to Mississippian strata of the Red Spring plate against Aztec Sandstone of the autochthon. Approximately 1500-1800 m of vertical separation of the Red Spring thrust occurs on this portion of the fault (sections E E'E" and F F'F", plate 2).

The Red Spring thrust is exposed in four outcrops separated by alluvium in Brownstone Basin. The thrust contact is generally covered by 1/2 to 3 m of rubble. The Brownstone Basin Conglomerate is present for most of the length of the thrust in this block.

Structure in the lower part of the Red Spring plate is much more complicated in this block than in the Turtlehead Mountain block. The thrust cuts up section to the southeast in the Banded Mountain Member of the upper plate, until only about 300 m of Banded Mountain Member strata are present (section C C'C", plate 2). Complex folds and imbricate thrusts are present locally in the Banded Mountain Member rocks northeast of upper Brownstone Basin. North of lower Brownstone Basin, on peak 5248, rocks of the Banded Mountain Member and Nopah Formation are folded into a syncline-anticline pair overturned to the southeast. The axes of these folds plunge about 35° to the northeast.

The dip of the thrust is poorly constrained, but bedding,

subsidiary thrusts, and most folds usually dip or plunge between 25° and 45° to the northeast. This is probably representative of the attitude of the thrust plane, which was taken to be about 35° in sections E E'E" and F F'F" of plate 2.

Generally, rocks of the Nopah through Sultan Formations of the Brownstone Basin block appear to be unaffected by thrusting of either the Red Spring or Keystone events. North and east of peaks 6977 and 6792 however, Devonian and Mississippian age rocks of the Red Spring thrust plate contain folds and small thrusts (plate 1) which are interpreted to have formed because of the overriding Keystone plate. The folds plunge to the north and are asymmetric, verging to the east.

3. Eastern Canyon Block

The eastern canyon block is bounded by the Brownstone Basin and Box Canyon faults. The structure of this block is more complex than that in blocks to the west. Northwest- to southwest-dipping, high- and low-angle faults, along with imbricate thrusts are common. Strata generally dip to the northeast between 25° and 50° .

The Box Canyon fault has about 600m (200 feet) of west-side-down vertical separation of the Mississippian strata (sections E E'E" and F F'F", plate 2). The magnitude of separation is less than the amounts present on the Turtlehead Mountain and Brownstone Basin faults.

The Red Spring thrust is present in four outcrops in the eastern canyon, although never completely exposed. It places Cambrian Banded Mountain Member strata on either the Aztec

Sandstone or the Brownstone Basin Conglomerate (figure 16). The conglomerates are thinner and more poorly exposed in this fault block than in the western blocks. Imbricate thrusts are common above the basal thrust in the Banded Mountain Member and the Nopah Formation.

Locally, compacted and hardened Aztec Sandstone is present beneath the Red Spring thrust. In thin section these rocks show reduced (nearly nonexistent) pore space and cataclastic textures, but contain no evidence of recrystallization.

Dip of the thrust is largely unconstrained. One dip of 15° to the north-northwest was measured on an exhumed planar surface at the top of the Aztec Sandstone, below carbonates of the southeasternmost outcrop of the thrust. There the thrust strikes northeast toward peak 4087, an unfaulted hill of Banded Mountain Member strata, and must bend sharply eastward under the alluvium, indicating a shallow dip. Imbrications west and northwest of peak 4087 dip 11° west, 24° and 30° north as measured on outcrops. Viewed from the southeast however, it is clear that they must dip more steeply than the basal thrust (figure 16). Bedding of strata above the thrust has variable attitudes, but dips generally range from 25° to 50° .

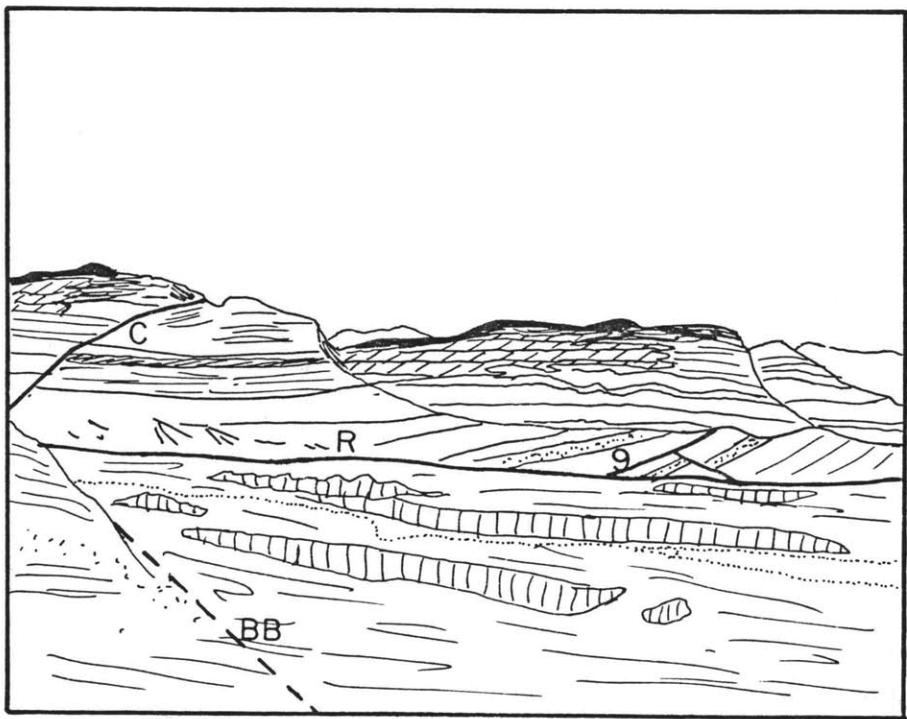
Small injections of quartz-rich fault gouge are present locally in the base of the Red Spring thrust plate in the eastern canyon. These injections are non-planar and have probably been injected into pre-existing fractures in the base of the upper plate.

Structure in the interior of the Red Spring thrust plate

Figure 16. Southwest sides of peaks 5835, 5356, and 4087. Peak 5835 is on the left, peak 5356 is in the center right distance, and peak 4087 is on the right end of the low ridge above the Red Spring thrust. Eastern canyon is in the foreground. Aztec sandstone is shown vertically lined, roads are shown dotted. Blackened areas on the tops of peaks 5835 and 5356 are the Yellow Pine Member of the Monte Cristo Limestone. The dolomite pattern (slanted brick pattern) shows the secondary dolomitization in the Bullion Member of the Monte Cristo Limestone. The dark band below the "C" is the Ironside Member of the Sultan Limestone. BB= Brownstone Basin fault, R= Red Spring thrust, C and 9 are faults shown on figure 17.



Figure 16



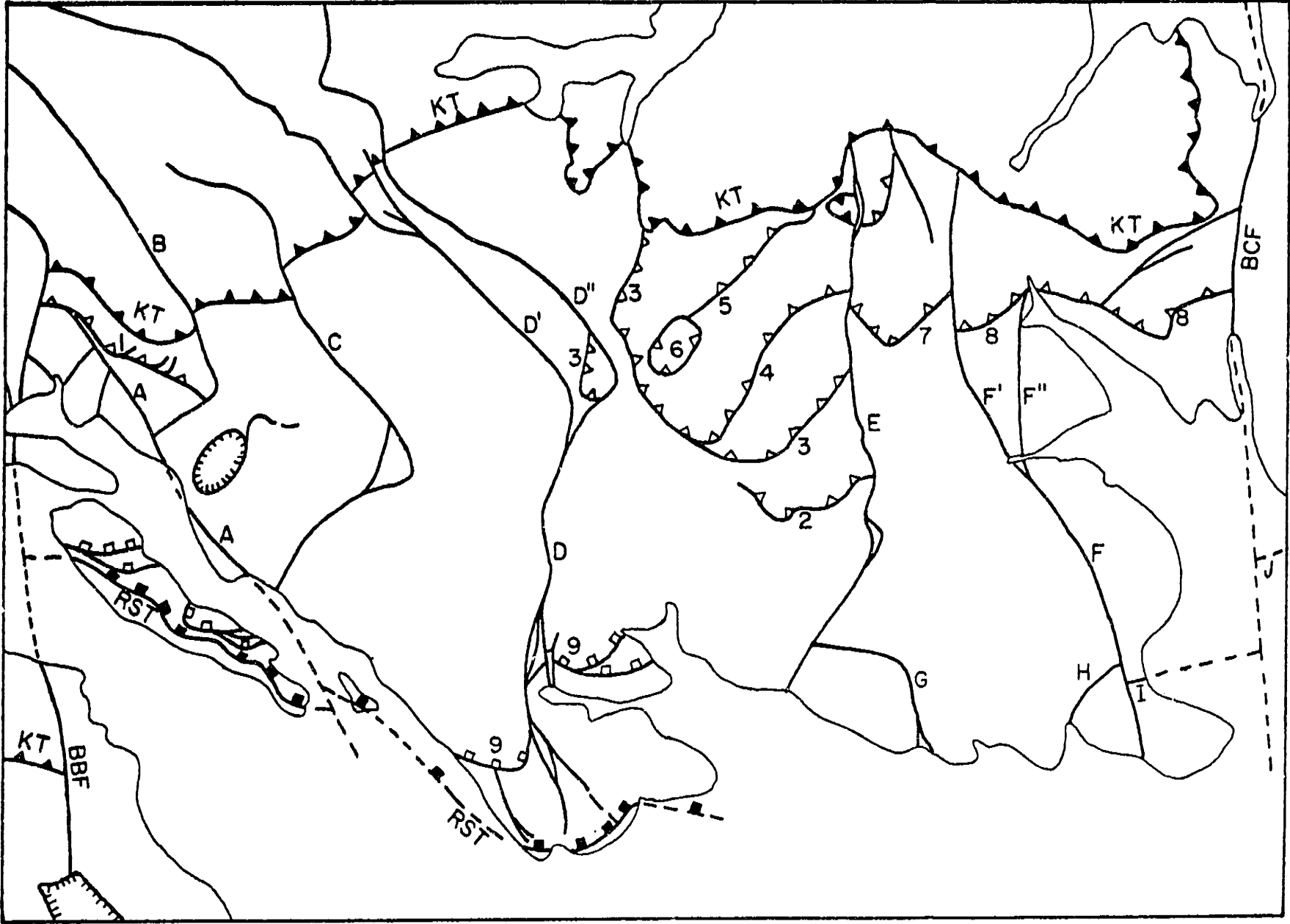
in the eastern canyon block structure is complex, consisting of westerly dipping, high- and low-angle faults and imbricate thrust faults. Figure 17 is a fault map of the eastern canyon block and adjacent areas, showing the more important faults. High- and low-angle faults are labelled with letters A through J, and thrust faults are labelled with numbers 1 through 9.

The fault system with the most informative relationships is D-D'-D". Faults D' and D" appear to be splays from fault D. Dips on these faults vary between 22° and 54° generally southward. The southern end of fault D is cut by the Red Spring thrust, but cuts a small imbricate thrust, number 9, indicating that fault D acted as a tear-fault contemporaneously with movement on the Red Spring thrust. Whether or not fault D existed prior to movement on the Red Spring thrust is not known.

To the north however, faults D' and D" cut the Keystone thrust, and folds in its upper plate, which suggests that they acted as tear-faults in the final stages of emplacement of the Keystone plate. How far into the Red Spring plate this Keystone age movement on faults D' and D" went is hard to evaluate. Near the southern end of splay D" the fault surface is fluted, with a wavelength of approximately 2 m and an amplitude of about 1/2 m. These flutes plunge 18° to the west and the whole fault plane dips 22° to the northwest (plate 1). At this point fault D" cuts thrust 3, which is interpreted to be of Keystone age.

Faults B and C display relationships within the Keystone

Figure 17. Fault map of the eastern canyon block of the Red Spring thrust plate. BBF = Brownstone Basin fault, BCF = Box Canyon fault, KT = Keystone thrust, RST = Red Spring thrust. Other letters and numbers are referred to in the text.



thrust plate which are quite similar to faults D' and D". Fault B shows evidence of a tear-fault history in the Keystone plate particularly well: imbricate thrusts carrying upper Banded Mountain Member and Nopah Formation strata are present west of and truncated by fault B, whereas imbricate thrusts cut only Banded Mountain Member strata east of fault B. The style and stratigraphic level at which the imbricate thrusts occur is different on the two sides of fault B.

Relationships of faults B and C with the Red Spring thrust are highly speculative, and rest mainly on the interpretation of fault A. Fault A clearly truncates fault B and can be inferred to truncate fault C. Although firm evidence is lacking, on the basis of similar strike and dip of faults B, C and D, I have interpreted faults B and C as tear faults formed during emplacement of the Red Spring thrust plate. On the evidence and reasoning above I have shown fault A cutting the Red Spring thrust on plates 1 and 2. This is an interpretation and fault A may not cut the Red Spring thrust. In this interpretation faults B and C would not cut the Red Spring thrust.

At its northern end, fault A is cut by thrust 1 of figure 17. Relationships between thrust 1 and faults A and B require that all three moved at the same time during the Keystone event: fault A cuts fault B, fault B cuts thrust 1, and thrust 1 cuts fault A. All of these cross-cutting relations occur within the Red Spring plate, but were caused by movement on the Keystone thrust.

Faults E and F may have functioned as tear faults in the

Red Spring event similar to fault D, but the necessary relationships to prove this are not present. These two faults definitely acted as tear-faults during movement on small, Keystone thrust age imbricate thrust faults in the uppermost Red Spring plate. Fault E truncates imbricate thrusts 3-5 and 7, but does not cut the Keystone thrust. Fault E probably continues for an unknown distance beneath the Keystone thrust. Fault F' cuts thrusts 7 and 8, but fault F" is cut by thrust 8.

Thrusts 3-5 are of decollement geometry, having detached within the thinly bedded Arrowhead Member of the Monte Cristo Formation. The thrust sheets climb small "ramps" and override strata of the Yellow Pine Member and Bird Spring Formation. Thrusts 7 and 8 detached at a stratigraphically lower position within the Bullion Member. Thrust 8 cuts up section to the east, in both the upper and lower plates, into the Bird Spring Formation and is truncated on the east by the Box Canyon fault.

The structural significance of faults G, H, I, and J is unknown. They are cut by faults E and F, so are probably older, although synchronous movement cannot be dismissed. Fault G dips moderately to the east at its western end, but eastward it curves and follows a gully, indicating that it probably steepens to the east. Dips of the other faults are unknown. Faults I and J may be correlative.

4. Box Canyon Fault Block and Lone Mountain

Only rocks of Devonian and Mississippian age are present in the Box Canyon fault block and at Lone Mountain. Small

thrust faults similar to those in the eastern canyon block are present at both places, along with north to northeast trending high-angle faults which usually have minor displacements. A major fault must be present between the Box Canyon fault block and Lone Mountain, with vertical, east-side-up separation of approximately 600 to 900 m (2000-3000 feet).

D. Structure of the "Autochthon"

Rocks here referred to as autochthonous may in fact be parautochthonous. The Bird Spring thrust is present on the east side of the Bird Spring Range (figures 3 and 4) and Blue Diamond Hill (figure 6). At the southernmost exposures of the Bird Spring thrust plate, Goodsprings Dolomite is in fault contact above the Triassic Moenkopi Formation. Stratigraphic separation decreases northward until Permian Redbeds rest on Moenkopi Formation strata south of the La Madre fault. Minor displacement might be present on the Bird Spring thrust in the subsurface east of La Madre Mountain, north of the La Madre fault, beneath "autochthonous" rocks of this report.

Autochthonous rocks are exposed beneath the Keystone thrust in the White Rock Hills, beneath all exposures of the Red Spring thrust, and in the Calico Basin area and to the south. Most of the autochthonous rocks are gently dipping, generally to the north. The massive, relatively competent Aztec Sandstone makes up more than 80% of the exposed autochthonous rocks. The attitude of bedding in the Aztec Sandstone is highly variable within short distances due to the large-scale cross-bedding, and is not indicative of the true, overall

dip of the formation. For this reason very few attitudes were measured in the Aztec Sandstone.

Autochthonous rocks have only limited exposures, but their structure is simple, consisting mainly of high-angle faults. The important faults are the La Madre, Calico Hills, Turtlehead Mountain, and Brownstone Basin faults. These faults all converge in the Calico Basin area.

The La Madre fault has about 6 km of horizontal, right-lateral separation of the Aztec Sandstone-Chinle Formation contact. Vertical separation can only be estimated roughly due to lack of geometric control on the attitude of bedding, the location of contacts and scanty knowledge of the thickness of strata. A reasonable estimate can be made near the southern end of the Calico hills where Chinle Formation north of the fault is juxtaposed against the undifferentiated Kaibab and Toroweap Formations on the south. The stratigraphic thickness of this interval, from the top of the Kaibab-Toroweap undifferentiated to the top of the Chinle Formation, is approximately 720 m. This estimate uses the minimum thicknesses for the Moenkopi Formation in the Goodsprings District (Longwell and others 1965), Shinarump Conglomerate and the Chinle Formation (this study) and includes none of the Kaibab-Toroweap undifferentiated. Thus this estimate of stratigraphic separation is considered a minimum. Maximum thicknesses of those units yields a stratigraphic separation of 810 m, but still includes none of the Kaibab or Toroweap Formations.

At the northern end of the Sandstone Bluffs (White Rock

Hills) the contact between the Aztec Sandstone and the Chinle Formation southwest of the La Madre fault is at approximately the same altitude as the Red Spring thrust northeast of peak 5345. Additional faults between these two places complicates the interpretation of an estimate of separation. However, most of the displacement across the zone is on the La Madre fault, so this estimate is meaningful with respect to the La Madre fault. The stratigraphic separation across this zone is approximately equal to twice the thickness of the Aztec Sandstone, or 1330 m. Total vertical separation on the La Madre fault is probably approximately one kilometer.

On the geologic map of Clark County, Nevada (Longwell and others 1965) the stratigraphic section south of the La Madre fault appears to be complete and undisturbed. My mapping north of the fault clearly indicates that major faults must be truncated by the La Madre fault south of Calico Basin. At the southern edge of plate 1, on northern Blue Diamond Hill, the La Madre fault has juxtaposed Permian Redbeds on the south against undifferentiated strata of the Kaibab and Toroweap Formations on the north. This stratigraphic separation is small (a few hundred meters at most) and is due to the fact that two large faults are truncated by the La Madre fault on its north side. Their sense and amount of stratigraphic separation reduce the separation across the La Madre fault.

One interpretation of the fault pattern below the alluvium south of Calico Basin is shown on plate 1. Although other interpretations which fit the outcrop pattern are possible the

one shown on plate 1 is supported by several lines of evidence.

In the eastern canyon the Brownstone Basin fault juxtaposes Aztec Sandstone on its eastern side against the Red Spring thrust plate on the west, with approximately 1500-1800 m of vertical separation. Farther south, west of peak 3950, Aztec Sandstone west of the fault is against rocks of the Virgin Limestone Member of the Moenkopi Formation on the east. Because the lower contacts of these two units are at approximately the same elevation the vertical separation can be estimated. The thickness of the stratigraphic interval is between 720 and 810 m as estimated for separation on the La Madre fault above. The trace of the Brownstone Basin fault probably continues southward under alluvium, between Permian rocks of peak 3844 and the Shinarump Conglomerate in Calico Basin. The Brownstone Basin fault is probably truncated by the La Madre fault, because semicontinuous outcrops of Permian rocks occur east of the projection of the Brownstone Basin fault all the way to the La Madre fault.

The Brownstone Basin fault is overlapped by the Tertiary (?) cemented landslide breccia in two places: east of peak 6792 and west of peak 3950. This overlap indicates a young age for these deposits, which were originally thought to be an extension of the Red Spring thrust (Longwell 1926, Glock 1929, Longwell and others 1965, Shelton 1966). Davis (1973) recognized the landslide nature of these deposits, but tentatively suggested a pre-Red Spring thrust age on the basis of the geometry of the southern outcrops.

The Calico Hills fault trends northwest and has northeast-side-down separation. It is tentatively correlated with a similar fault on peak 5345. Only minor separation is required on the Calico Hills fault, but the true amount of separation is impossible to estimate.

The Turtlehead Mountain fault trends north-northwest, and places Aztec Sandstone on its east side against the Red Spring thrust plate and Aztec Sandstone on the west. East-side-up separation of 1200-1500 m is estimated (sections E E'E" and F F'F", plate 2). The Turtlehead Mountain fault is interpreted to truncate the Calico Hills fault beneath the alluvium of Calico Basin. It probably is the structural control for the trend of the northeast side of the ridge formed by the Calico Hills. On the surface, east of peak 4987, the Turtlehead Mountain fault truncates what I interpret as a splay from the Calico Hills fault.

On the west edge of plate 1 the autochthonous rocks are folded into a syncline which is overturned to the southeast beneath the Keystone thrust. Aztec Sandstone forms the core of this fold, and rocks of the Shinarump Conglomerate, Chinle Formation and Upper Redbed Member of the Moenkopi Formation are present in the overturned limb. The overturned rocks strike northeast and dip steeply (approximately 75° to the northwest).

The large overturned syncline northwest of Turtlehead Mountain, and below the Keystone thrust may be the continuation of the fold in the White Rock Hills, as suggested by Davis

(1973). However, Burchfiel (pers. commun. 1979) has completed new, detailed mapping above the Sandstone Bluffs southwest of plate 1 which suggests that the syncline may be a structure of Red Spring thrust age, which only coincidentally lies below the Keystone thrust.

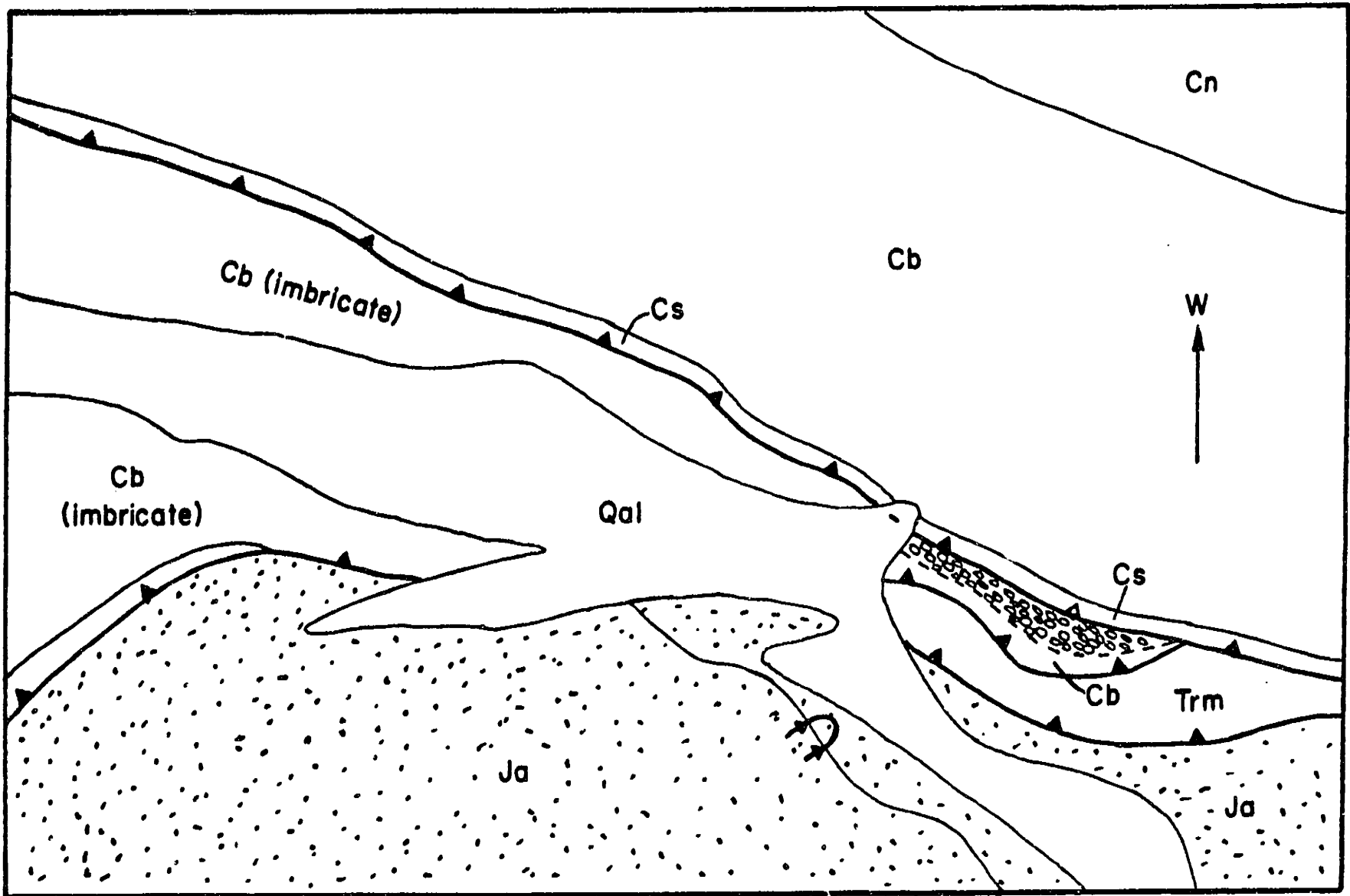
Figure 18 is a sketch map of relations above the southern end of the overturned syncline in the northern Sandstone Bluffs area as mapped by Burchfiel. In structural order from bottom to top above the overturned Aztec Sandstone beds are:

- 1) a thrust sliver of the Upper Redbed Member of the Moenkopi Formation,
- 2) a badly fractured and brecciated lense of Banded Mountain Member strata, the upper contact of which is not exposed,
- 3) a thin lense (about 15 m thick) of undeformed conglomerate with subangular carbonate clasts in a matrix of Aztec Sandstone,
- 4) Banded Mountain Member rocks of the Keystone thrust plate.

These relationships are not unequivocal, but nevertheless, the presence of a conglomerate lense above a sliver of Banded Mountain Member is intriguing.

The basal contact of the conglomerate is not exposed, but bedding is parallel to the lower contact, which suggests the possibility of a depositional contact. If this is the case, then the sliver of Banded Mountain Member strata may be an erosional remnant of the Red Spring thrust plate. The conglomerate would record the period of erosion between the Red Spring

Figure 18. Sketch map of the Red Rock Canyon area, as mapped by Burchfiel (pers. commun. 1979). The arrow points west. Cb = Banded Mountain Member, Cs = silty unit, Cn = Nopah Formation, Ja = Jurassic Aztec Sandstone (shown dotted), Trm = Moenkopi Formation, Qal = Quaternary alluvium. The conglomerate lense discussed in the text is shown by small open circles.



and Keystone events. Unfortunately the possibility of that crucial contact between the conglomerate and the underlying brecciated Cambrian dolomite being a thrust cannot be dismissed.

Farther south along the Sandstone Bluffs mapping by Burchfiel has shown that the basal part of what is currently considered the Keystone plate is cut by several imbricate thrusts for at least 1.5 to 2 km from the basal contact with the Aztec Sandstone. The uppermost thrust of this imbricate sequence appears to be localized near the silty unit of the Bonanza King Formation in its upper plate. In places however, this upper thrust overrode rocks belonging to the upper part of the Banded Mountain Member, thus having a substantial stratigraphic throw. This may indicate that this imbricate zone is also a relict of the Contact-Red Spring thrust plate. This interpretation seems even more likely when one considers the fact that the Keystone thrust generally follows the silty unit of the Bonanza King Formation for most of its length. Hopefully continued mapping in this area will resolve this important dilemma.

If the syncline in the northern Sandstone Bluffs is a structure formed during emplacement of the Red Spring thrust plate, then the syncline north of Turtlehead Mountain cannot be its continuation. The presence of a continuation of the syncline in the northern Sandstone Bluffs in the subsurface northeast of the La Madre fault can only be postulated at this time.

E. Major High-Angle Faults

Several major north- to northwest-trending high-angle normal (?) faults of large displacement are present at La Madre Mountain. Most of these faults have complex histories, and can be shown to have moved at least twice. Table 2 is a review of the major high-angle faults, and their separations at various times.

The La Madre fault forms the western structural boundary of the La Madre Mountain area. It has moved both in post-Red Spring thrust time, and post-Keystone thrust time. Movement was probably mainly dip-slip during both times of activity, although this cannot be proven. The La Madre fault extends to the northwest beyond the map area for at least another 25-30 km, and may connect to, and have moved with, the Las Vegas Shear Zone. It may intersect the shear zone near the Specter Range where a conspicuous bend in the Las Vegas Shear Zone is present.

The Calico Hills fault probably has moderate vertical separation, and apparently has only moved in the pre-Keystone thrust time, although this cannot be proven.

The Turtlehead Mountain fault trends north-northeast, and appears to have had most of its movement in pre-Keystone thrust time (table 2, figure 12). Displacement on the fault probably dies out northward, and it may have acted to some degree as a tear fault during the Keystone thrust event. This cannot be proven however, and late movement on the fault may be entirely post-Keystone thrusting. The Turtlehead Mountain fault probably

Table 2 - Review of High-angle Faults

	La Madre Fault	Calico Hills Fault	Turtlehead Mountain Fault	Brownstone Basin Fault	Box Canyon Fault
Trend	N45W	N45W	N30W	N to N20W	N to N10E
Dip	steep	steep	50°-60° W	steep	steep (?)
Total Vertical Separation with sense (a)	1000 m ± east-side down	less than 300 m east-side down	1200-1500 m east-side up	1500-1800 m east-side up	600 m east-side up
Syn- and/or post-Keystone Separation with sense (b)	100-200 m east-side down	none (?)	200-300 m east-side up	1200 m ± east-side up	?
Pre-Keystone Separation (a-b)	800-900 m east-side down	less than 300 m east-side down	1000-1200 m east-side up	300-500 m east-side up	?

truncates the Calico Hills fault and is probably truncated by the La Madre fault (see Structure of the "Autochthon").

The Brownstone Basin fault trends north-south, and displacement on the fault dies to the north before the ridge immediately south of Kyle Canyon Road (see figure 13). This fault has probably had three periods of movement, during pre-Keystone, syn-Keystone and post-Keystone time, although the last two cannot be distinguished with complete confidence. The dramatic structural style changes in the Keystone plate east and west of the Brownstone Basin fault attest to it acting as a tear-fault. Post-Keystone thrust movement can only be inferred on the basis of the large separation of the Keystone thrust relative to separation on faults to the west. The Brownstone Basin fault is overlapped by the Tertiary (?) landslide breccia, which clearly dates this breccia as post-Keystone thrust.

The Box Canyon fault is only exposed for a short stretch west of the Box Canyon fault block, but probably extends for some distance to the north, as shown on figure 13.

It is of interest that the pre-Keystone thrust vertical separation on the high-angle faults generally decreases, and the post-Keystone thrust vertical separation increases on each more easterly fault. To what cause this change in displacement is due is unknown. The latest movement on the high-angle faults at La Madre Mountain cannot be easily related to movement on the Las Vegas Valley Shear Zone, although the La Madre fault may have moved at that time. Other major high-angle

faults lose displacement northward, and are truncated by the La Madre fault to the south.

F. Las Vegas Shear Zone

The Las Vegas Shear Zone trends northwest and bounds the Spring Mountains on the northeast. It has displaced Mesozoic structures in a right-lateral sense both through faulting and folding (oroclinal flexure). No fault trace is exposed, but clockwise oroclinal bending is apparent in the strikes of structures and bedding both north and south of the shear zone. The entire length of La Madre Mountain is interpreted to have been bent from a north to a northeast strike by movement on the shear zone. The La Madre fault may have been active in this period. Movement on the Las Vegas Shear Zone apparently occurred between approximately 10 and 17 m.y. ago (Bohannon 1979, Fleck 1967, Anderson 1971).

Approximately 40 km of offset of structures is present between the Muddy Mountains and La Madre Mountain. The separation decreases to the northwest; only oroclinal bending is apparent in the Specter Range (Burchfiel 1965). This changing offset is believed to be compensation between an area of no extension to the south of the shear zone (Spring Mountains) and an area of large extension to the north of the shear zone (Guth 1980, in prep).

IV Timing and Correlation of Events

Age constraints on structural events at La Madre Mountain are poor. The major deformation can only be dated as post-Early Jurassic (Aztec Sandstone) and pre-Late Cenozoic (Qua-

ternary alluvium). More precise constraints, based on structural and stratigraphic relations with units which are datable by radiometric or paleontologic methods are present to the north and south.

In the first part of this section, I will review the age constraints in the Spring and Clark Mountains, and compare the sequence of events from the Clark Mountains (Burchfiel and Davis 1971, 1977, in prep.), the Goodsprings District (Carr 1978), and the Potosi Mountain area (Cameron 1977b) with the sequence of structural events in the La Madre Mountain area. In the second part, I will discuss timing and structure in the Muddy Mountains and propose a new correlation scheme for the easternmost thrusts across the Las Vegas Shear Zone.

A. Timing and Correlation of Structures in the Eastern Spring Mountains and Clark Mountains

Carr (1978) dated a tuff unit from the lower Lavinia Wash Sequence by the K/Ar method on biotite and obtained an age of 150 ± 10 m.y. The Lavinia wash sequence contains detritus from Mesozoic rocks as young as the Delfonte Volcanics, which lie above the Aztec Sandstone in the Clark Mountains of California (Burchfiel and Davis 1971, in prep.), as well as Paleozoic carbonate fragments believed by Carr to be fore-thrust debris from the Contact thrust plate. In structural and stratigraphic position the Lavinia Wash Sequence is analogous to the Brownstone Basin Conglomerates, which are here assigned an age of Late Jurassic or Early Cretaceous (?).

The Red Spring thrust was correlated with the Contact

thrust by Davis (1973) on the basis of their similar structural positions in fault-bounded blocks below the Keystone thrust. The fact that both the Red Spring and Contact thrusts overrode forethrust debris (Davis 1973, Cameron 1977a and b, Carr 1977, 1978, this study) supports this conclusion.

In the Clark Mountains of California, Burchfiel and Davis (1971) found a similar structural pattern: northwest plunging folds in autochthonous Mesozoic rocks were juxtaposed against the Precambrian crystalline rocks on the Kokoweef fault prior to emplacement of the Keystone thrust plate. One of these folds is cored by the Ivanpah pluton, which is interpreted as syntectonic by Burchfiel and Davis (1977). Sutter (1968) obtained an age of 138 m.y. for the Ivanpah pluton using the K/Ar method of dating. Davis (1973) considered that these folds could have been contemporaneous with the emplacement of the Contact-Red Spring thrust sheet. This conclusion is supported by Carr's date of the Lavinia Wash Sequence.

The Keystone thrust in the Clark Mountains cuts the Ivanpah pluton and is intruded by the Teutonia quartz monzonite. Sutter obtained a K/Ar date on hornblend of 92 m.y. for the Teutonia pluton. The Keystone thrust is therefore thought to be post-138 m.y. and pre-92 m.y. in the Clark Mountains.

Through cross-cutting relations a relative sequence of structural events can be established at La Madre Mountain. This sequence is somewhat complicated by incomplete new evidence (Burchfiel, pers. commun. 1979) in the Red Rock Canyon area which suggests a possible Red Spring thrust age for the

large syncline above the White Rock Hills (see Structure of the Autochthon). From oldest to youngest the relative sequence of structural events is:

1) emplacement of the Red Spring thrust plate, possibly with major folding of autochthonous rocks in the White Rock Hills area,

2) High-angle normal (?) faulting of the Red Spring thrust and autochthon,

3) emplacement of the Keystone thrust, possibly with folding of autochthonous rocks as above,

3a) imbricate thrusting and folding in the upper and lower plates, with injection of quartz-rich fault gouge and

3b) final emplacement with tear-faulting in the eastern imbricate part of the Keystone plate,

4) renewed high-angle faulting on faults active during event 2,

5) oroclinal flexure of the entire La Madre Mountain area and emplacement of the cemented Tertiary (?) landslide breccia.

Structures formed during event 1, the emplacement of the Red Spring thrust plate, are folds, imbricate thrust faults, and tear-faults in the lower parts of the Brownstone Basin and eastern canyon blocks.

Event 2, high-angle normal (?) faulting, must have occurred on the La Madre, Turtlehead Mountain, Brownstone Basin, and Box Canyon faults as well as on the unexposed fault to the west of Lone Mountain. The Calico Hills fault was probably developed during this event.

Event 3a is marked by the emplacement of thrust slices of Banded Mountain Member strata over the Turtlehead Mountain block, and folding and imbrication in the eastern imbricate part of the Keystone plate prior to injection of quartz-rich fault gouge into the truncated limb of the anticline in Box Canyon.

Event 3b includes the final emplacement of the Keystone thrust plate, with imbricate thrusting, folding and tear-faulting in both the upper and lower plates.

Event 4 is recognized through displacement of the Keystone thrust on the La Madre, Turtlehead Mountain, and Brownstone basin faults, by amounts generally less than the displacement of the Red Spring thrust in event 2.

Event 5 contains two events which cannot be placed relative to each other in time, but are both later than event 4. Oroclinal flexure of the entire northeastern Spring Mountains is apparent in the strikes of all the strata and thrusts present. Whether this oroclinal flexure occurred before, during or after the emplacement of the landslide breccia is unknown.

This sequence of events is nearly identical to that found by Cameron in the Potosi Mountain area (1977b). He recognized two additional events, both earlier than those identified at La Madre Mountain. The first was high-angle faulting of the autochthon (Boundary fault) and the second was folding of rocks in the Contact plate, into folds which are cut by the Contact and Potosi thrusts.

Carr (1978) found a sequence of events in the Goodsprings area which is similar to, but more complex than that of Cameron. In his mapping Carr found two structurally higher thrusts, the Green Monster and Sub-Green Monster thrusts, as well as the Keystone and Contact thrusts. Burchfiel and Davis (1971, 1977, in prep.) have published a somewhat similar sequence of events for the Clark Mountain thrust complex.

Table 3 compares the sequence of events at Potosi Mountain, the Goodsprings District and the Clark Mountains with the sequence at La Madre Mountain. I have deleted events pertaining only to the Green Monster and Sub-Green Monster thrusts discussed by Carr in order to simplify table 3 and to focus directly on correlative structures.

While details of the four timing sequences are different, most major phases of deformation can be correlated with confidence. Events 1 through 5 in the Clark Mountains appear to be absent in the eastern Spring Mountains. Structurally higher, but older thrust faults and related structures are present in the northwestern Spring Mountains and in the western Goodsprings District (i.e. the Green Monster and Sub-Green Monster thrusts) and may be correlative with early structures in the Clark Mountains.

B. Structure and Sequence of Events in the Muddy Mountains and Correlation with the Eastern Spring Mountains

The Muddy Mountains lie northeast of Las Vegas, west and northwest of the Overton arm of Lake Mead. Complexly deformed Mesozoic and Paleozoic rocks form most of the Muddy Mountains.

Table 3

Comparison of Structural Sequences of Events, Eastern Spring Mountains

<u>Clark Mountains</u>	<u>Goodsprings District</u>	<u>Potosi Mountain</u>	<u>La Madre Mountain</u>
1) thrusting and folding			
2) thrusting and folding			
3) high-angle faulting			
4) thrusting and folding	inferred NW-trending high-angle faults	Boundary fault	
5) intrusion 200 m.y.	volcanism, 150±10 m.y. and deposition of Lavinia Wash Sequence	deposition of conglomerate	deposition of Brownstone Basin Conglomerate
6) folding, thrusting and intrusion at 138 m.y.	Contact thrust event	folding in the Contact thrust plate Contact thrust event	Red Spring thrust event
7) high-angle faulting	truncation of Contact plate on S (?)	high-angle faulting	high-angle faulting
8) thrusting and folding	Keystone thrust events K1 -K4	Keystone thrust event	Keystone thrust events 3a and 3b
9) 84-94 m.y. intrusion			
10) minor thrusting and folding			
11) high-angle faults		minor high-angle faulting	high-angle faults
12) gravity slide	late gravity sliding event	gravity slides and minor high-angle faults	gravity slides and oroclinal flexure

Two thrust faults, the Muddy Mountain and Glendale thrusts and one major high-angle fault, the Arrowhead fault, are present in the Muddy Mountains. Mesozoic rocks of the north Muddy Mountains are folded into a large, faulted recumbent syncline, the Weiser syncline. These structures and their timing of formation prove to be key for correlation with structure in the eastern Spring Mountains.

In his work of 1960, Longwell recognized the striking structural similarities between the eastern Spring Mountains and the Muddy Mountains, which caused him to postulate the existence of the Las Vegas Shear Zone. In that paper he proposed the idea that the Las Vegas Shear Zone, and the Keystone, Red Spring and Muddy Mountain thrusts were all active contemporaneously, in response to the same regional stress field. He thought that the Red Spring thrust was the frontal edge of the Keystone thrust, which had been tilted into fault-bounded blocks by rotational strain associated with the Las Vegas Shear Zone and was then overridden by itself.

It is now known that the Red Spring-Contact thrust sheet was once continuous and that its emplacement pre-dated movement on the Keystone thrust significantly (Davis 1973, Cameron 1977a and b, Carr 1977, 1978, this study). This interpretation was originally proposed by Longwell in 1926. The Las Vegas Shear Zone is now known to post-date all of the major thrust faults in the area (Fleck 1967, Bohannon 1979). However, later workers in the region have continued to follow Longwell's correlation of the Muddy Mountain thrust with the Keystone thrust,

assuming that no structure equivalent to the Contact-Red Spring thrust exists in the Muddy Mountains (Burchfiel and others 1974, Cameron 1977b, Carr 1978, Fleck 1967, 1970, Temple 1977).

On the basis of evidence outlined below I propose a new correlation scheme between the eastern Spring Mountains and the Muddy Mountains. I suggest that the Muddy Mountain thrust is equivalent to the Red Spring-Contact thrust system, and that the Glendale thrust, younger and structurally higher than the Muddy Mountain thrust, is the lateral equivalent of the Keystone thrust.

The following evidence supports this conclusion.

1) The Muddy Mountain thrust plate is present only above the Aztec Sandstone and "molasse" deposits which lie unconformably on the Aztec Sandstone (Longwell 1928, 1949, Brock 1973, Brock and Engelder 1977). Bedding above and below the thrust is parallel to the thrust (Longwell 1928).

2) The Muddy Mountain thrust plate was cut by the Arrowhead fault prior to being overridden by the Glendale thrust plate (Longwell 1949, 1962).

3) Remnants of the Glendale thrust sheet lie on complexly deformed rocks of Mesozoic and Paleozoic age (Longwell 1949).

4) Structures related to the Glendale thrust involve rocks at least as young as Late Cretaceous (Longwell 1949, 1952, Fleck 1967, 1970).

5) If the previous correlation scheme is followed, no obvious equivalents exist for the Red Spring thrust in the

Muddy Mountains or the Glendale thrust in the Spring Mountains. These points are discussed in detail below.

1) Longwell (1949) reported that the Muddy Mountain thrust is always present above the Aztec Sandstone, with bedding in both plates usually parallel to the thrust fault. Brock and Engelder (1977) re-examined deposits of reworked Aztec Sandstone and carbonate fragments which Longwell interpreted to be fault breccia. Their petrologic and field studies clearly revealed that the sequence above the Aztec Sandstone were sedimentary deposits. They correlated these deposits, which are up to 50 m thick, with the Baseline Sandstone of Longwell (1949). I suggest that these deposits are the lateral equivalent of the Lavinia Wash Sequence (Carr 1978) and the Brownstone Basin Conglomerate (this study). They contain (locally) conglomerate beds with clasts of Mesozoic and Paleozoic formations up to 10 cm in diameter. Longwell (1949) and Brock and Engelder (1977) interpreted the Muddy Mountain thrust as having overridden an erosional land surface.

Brock and Engelder also established the existence of quartz-rich gouge lenses and dikes injected or faulted into the base of the Muddy Mountain thrust plate. These are similar to those found in the base of the Red Spring thrust plate, but better developed in the Keystone thrust sheet locally.

Overall the similarity between this thrust contact and the Red Spring thrust contact described earlier cannot be denied. The autochthon beneath the Contact thrust had been eroded to a deeper level locally; in places the Contact thrust

plate lies on rocks as old as the Triassic Moenkopi Formation (Carr 1978).

2) The Muddy Mountain plate was cut by the Arrowhead fault prior to emplacement of the Glendale thrust sheet. Longwell recognized the existence of the Muddy Mountain thrust plate and the Arrowhead fault in his early works (1921, 1922, 1928). However, he did not recognize the existence of the Glendale thrust plate as a separate, higher sheet until 1941 (Longwell 1949). This was cause for various interpretations of the Arrowhead fault in his many papers: 1921 - oblique slip; 1922 - normal slip, south-side-down; 1928, 1952 - left-lateral tear-fault during Muddy Mountain thrust emplacement; 1949 and 1962 - reverse slip, south-side-up, post-Muddy Mountain thrust, pre-Glendale thrust.

Longwell argued for reverse-slip displacement on the Arrowhead fault in 1949, when he recognized that the Glendale thrust was younger and structurally higher than the Muddy Mountain thrust. The arguments in favor of this interpretation were vague and unconvincing, as indicated by a different interpretation published in 1952. In 1961 he returned to the field to study the problem, and published a more detailed map in 1962, which caused him to return to his interpretation of 1949. More recent work by Temple (1977, 1979) verifies this hypothesis. Figure 19 is a sketch map after Longwell, 1949 and figure 20 is a sketch map of the same area after Longwell (1962) and Temple (1977).

In figure 19 it can be seen that Longwell mapped the

Figure 19. Sketch map of the Muddy Mountains, near the Arrowhead fault, after Longwell (1949). A = locality discussed in text, AF = Arrowhead fault, BA = Buffington anticline, GT = Glendale thrust, Ja = Jurassic Aztec Sandstone, MMT = Muddy Mountain thrust, ST = Summit thrust. Other letters denote ages of units.

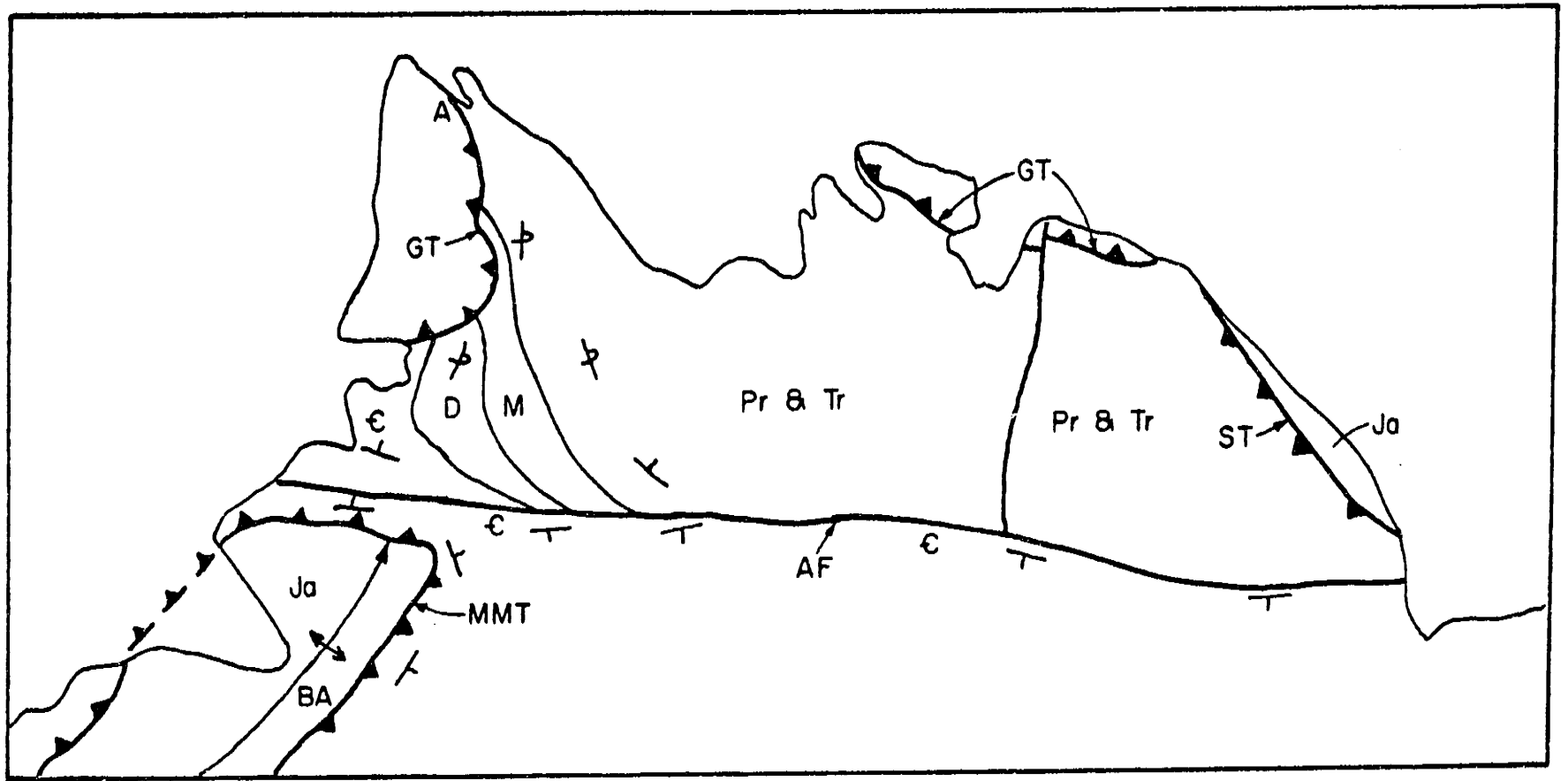
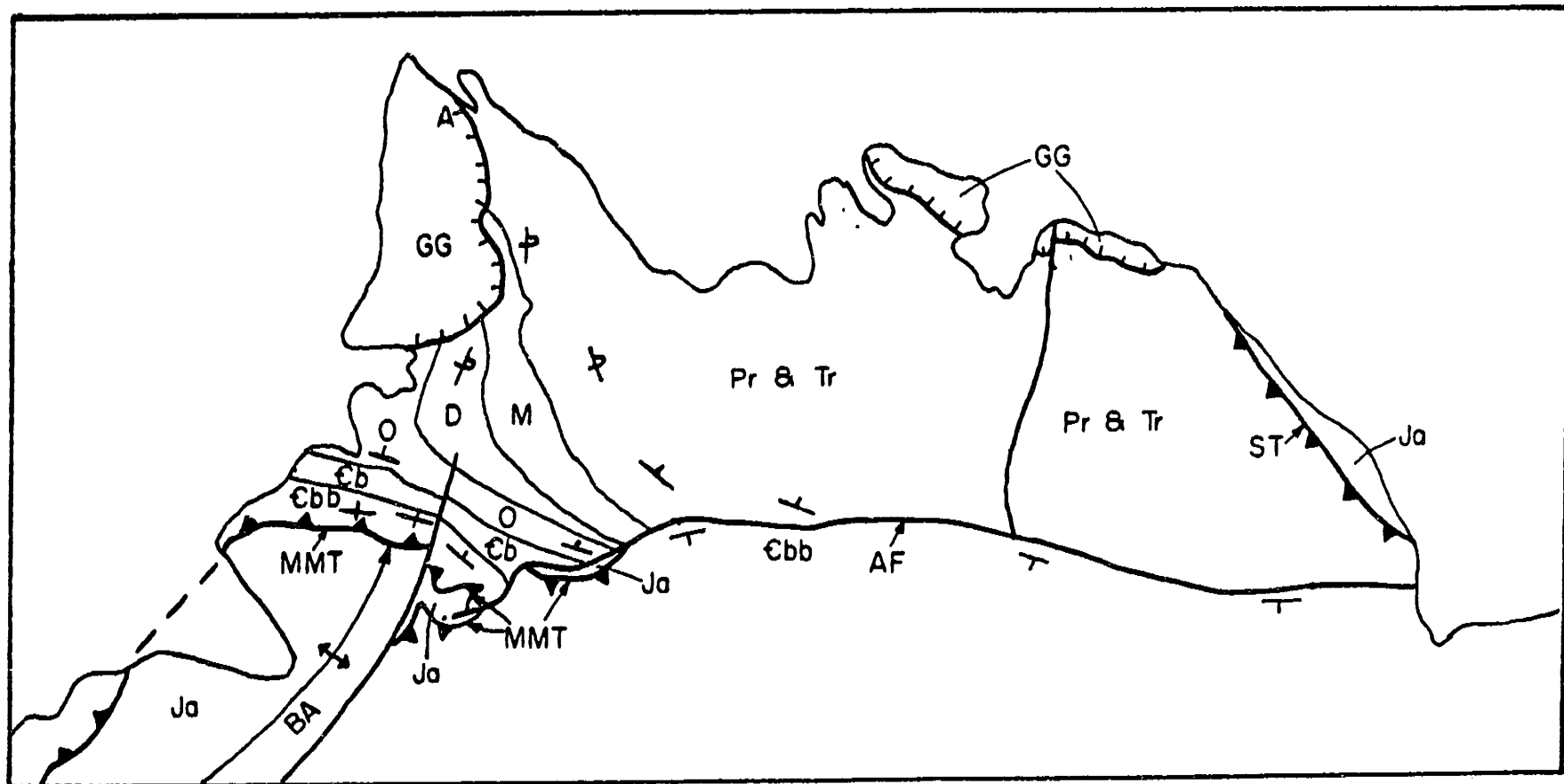


Figure 20. Sketch map of the Muddy Mountains near the Arrowhead fault, after Longwell 1962, and Temple 1977. Cb = Cambrian Buffington Formation (Nopah Formation equivalent), Cbb = Banded Mountain Member, GG = Glendale gravity slide (after Temple, 1977, an interpretation not followed by the author, or Longwell, 1962). Other letters have meanings as in figure 19.



Arrowhead fault as continuous to the west side of the range where it is covered by alluvium. Because of the continuity of the Arrowhead fault there was no direct tie between rocks to the north and south of it. However, more detailed work showed that the Arrowhead fault becomes sinuous, loses displacement and dies out westward into a monocline as shown by the attitudes on figure 20. At the point where the Arrowhead fault ends, a small window through the Muddy Mountain plate provides continuity between the north and south sides of the fault. The Arrowhead fault must have been a "scissors" type fault, with increasing displacement eastward. Temple (1977, 1979) interpretes this monocline as a drape fold, although it cannot be shown that the Arrowhead fault continues westward beneath the folded strata.

The Glendale thrust has apparently refolded the northern part of this monocline into an overturned syncline vergent to the east (see below) indicating that movement on the Arrowhead fault was prior to the emplacement of the Glendale plate. This period of high-angle faulting between periods of thrusting can be found throughout the length of the eastern Spring Mountains and in the Clark Mountains (see table 3). I suggest therefore that the stress field responsible for the early displacements on the Kokoweef, Cottonwood, La Madre, Turtlehead Mountain, Brownstone Basin and Box Canyon faults was also responsible for displacement on the Arrowhead fault. The reason for reverse slip displacement on the Arrowhead fault as opposed to normal (?) slip displacement on the others is unknown.

3) The Glendale thrust plate overrode and deformed rocks of the Muddy Mountain plate. Farther north than shown on figures 19 and 20, Longwell mapped a large recumbent syncline, the Weiser syncline, and several smaller thrusts, folds and faults, most of which are probably related to the Glendale thrust. What I interpret to be two of these structures are present in figures 19 and 20. Overturned beds beneath the large remnant of the Glendale thrust form a syncline which was probably folded at this time. The Summit thrust was probably a subsidiary thrust similar to the Willow Tank thrust farther north, which is interpreted by Longwell (1949) as having formed during the Glendale thrust event.

Temple (1977, 1979) interprets the Glendale thrust remnants as gravity slide masses, although he states that evidence for this is inconclusive. The only source terrain present for these, if they are gravity slide masses, is the uplifted Muddy Mountain thrust sheet. However, Temple (1977) writes that the lithology of Banded Mountain Member strata in the large western remnant of the Glendale sheet is dissimilar to lithologies in the same sequence from the Muddy Mountain plate.

I have visited the locality marked "A" on figures 19 and 20, where the basal contact of the remnant is exposed. It shows no thick zone of brecciation and internal deformation present at the base of many low-angle, gravity-driven (?) masses such as are present at La Madre Mountain, in the Sheep Range (Guth 1980, in prep.), and the Mormon Mountains (Wernicke, pers. commun, 1980) of Clark County or the Shadow Mountains of

California (Wilson 1966). However, Wernicke (pers. commun. 1980) has informed me that some of the remnants in the northernmost Muddy Mountains do display intense brecciation and may in fact be young gravity slide blocks or low-angle normal fault blocks.

I suggest that Longwell (1949) was correct, the Glendale thrust moved across the northern part of the Muddy Mountains inducing deformation in the rocks below. No detailed map has been published of the Paleozoic rocks south of the Arrowhead fault. However, Longwell (1949) has suggested that the Buffington anticline was formed during the Glendale thrust event. It is entirely conceivable that study of the south Muddy Mountains would show more remnants of the Glendale thrust plate atop the Muddy Mountain thrust plate.

Bohannon (pers. commun. Burchfiel 1979) considers that the Summit thrust of Longwell (1949) may be the equivalent of the Red Spring thrust. Too little data is presently available to evaluate this possibility.

The style of the Glendale thrust, overriding a deformed lower thrust sheet, is reminiscent of the similar relations along the Keystone thrust.

4) Structures related to the Glendale thrust involve rocks as young as Late Cretaceous. The Willow Tank thrust is interpreted by Longwell (1949) as a lower plate thrust caused by stress transmitted from the emplacement of the Glendale thrust sheet. The Willow Tank thrust placed Aztec Sandstone and early-Late Cretaceous Willow Tank Formation strata over

the Willow Tank Formation and Baseline Sandstone. The thrust fault is unconformably overlapped by the Overton Fanglomerate, possibly of Cretaceous age, but only known to be older than 23 m.y. (Armstrong 1963). Table 4 is a review of the age and lithologies of these formations, after Longwell (1949, 1952), Armstrong (1963) and Fleck (1967, 1970).

The Willow Tank Formation lies with slight angular unconformity on the Aztec Sandstone. The basal deposits are a cobble conglomerate containing Permian and Triassic detritus. The majority of the Willow Tank Formation is made of clays and tuffaceous sandstones, which have yielded early-Late Cretaceous fossils (Longwell 1949). Fleck (1970) dated a tuff layer which lies 50 to 80 feet above the base of the Willow Tank Formation. He reported K/Ar - biotite dates of 96.4 and 98.4 m.y. Longwell does not describe the upper contact of this formation.

The Baseline Sandstone overlies the Willow Tank Formation and can be divided into two members, a lower member composed mainly of fine- to medium-grained, whitish reworked Aztec Sandstone, and an upper member of interbedded conglomerate and sandstone, with conglomerate content increasing upward (Longwell 1949). Clasts in the conglomerates consist of Mesozoic and Paleozoic rocks as old as the Ordovician Eureka Quartzite (Longwell 1952). Fossils from the lower member, several hundred feet above the base of the section, indicate a pre-middle Late Cretaceous age. The closest occurrence of the Eureka Quartzite is in the Arrow Canyon Range.

Unconformably overlying the Willow Tank Formation,

Table 4

Overton Fanglomerate, Baseline Sandstone, Willow Tank Formation

<u>Unit</u>	<u>Thickness</u>	<u>Age</u>	<u>Description</u>
Overton Fanglomerate	900 m +	greater than 23 m.y.	coarse conglomerate on west, grading into sandstone and siltstone on east, Paleozoic and Mesozoic detritus
Baseline Sandstone, upper member	460 m	?	conglomerates and sandstones, coarsens upwards, Paleozoic and Mesozoic detritus
Baseline Sandstone, lower member	460-610 m	pre-middle Late Cretaceous (Longwell 1949)	fine to medium-grained white sandstone (reworked Aztec Sandstone) with some conglomerate with Ordovician Eureka Quartzite (Longwell 1952)
Willow Tank Formation, upper beds	90 m	early-Late Cretaceous (Longwell 1949) 96 m.y. (Fleck 1967, 1970)	grey to buff clays (often bentonitic) and tuffaceous sandstone
Willow Tank Formation, lower unit	less than 10 m	?	cobble conglomerate, Triassic and Permian detritus (Longwell, 1952)

Baseline and Aztec Sandstones is the Overton Fanglomerate. Coarse conglomerate dominates on the west, with blocks more than 7 m across common (Longwell 1949). Two large slabs of Permian limestone are also present, one of which is over 800 m in length. Eastward the fanglomerate grades into more distal facies, predominantly made of sand and silt size detritus.

Longwell (1949) suggested that the basal conglomerate of the Willow Tank Formation heralded the initial uplift related to the Glendale thrust. Pre-Silurian detritus was not deposited until the Baseline Sandstone was laid down however (Longwell 1952, Armstrong 1968). The presence of Eureka Quartzite clasts in the Baseline Sandstone is cause for some concern. Either a canyon through the Glendale uplift was present to allow transport of the quartzite from the vicinity of the Arrow Canyon Range or no Glendale uplift yet existed.

It is probably fortuitous that no pre-Silurian detritus is known from the Willow Tank Formation, as Cambrian strata were probably present at the surface, and were clearly contributing detritus to the Lavinia Wash Sequence (150±10 m.y. Carr 1978) and the Brownstone Basin Conglomerate (this study) in the Spring Mountains. If the Muddy Mountain thrust and Arrowhead fault do pre-date the Willow Tank Formation, then Cambrian strata were probably exposed locally and must have shed debris in another direction during deposition of the Willow Tank Formation. Unfortunately current knowledge does not allow evaluation of these hypotheses. The details of the

Willow Tank Formation, Baseline Sandstone and Overton Fanglomerate warrant further study.

The Overton Fanglomerate is interpreted as being syn- or post-tectonic (Longwell 1949, Fleck 1967, Armstrong 1968) relative to the youngest thrusting event. It was probably shed from the highland created by the Glendale thrust plate, although whether it was still moving, or its motion had ceased and it was only being eroded, is not known.

Longwell (1949) cites the presence of large blocks of Paleozoic carbonate rocks in and on the fanglomerate as evidence that the Glendale thrust overrode its own debris. Wernicke (pers. comm. 1980) indicates that some of these blocks are probably land or gravity slide masses. These could easily have been incorporated into the fanglomerate by landsliding events after the Glendale thrust had ceased to move.

The age of the Glendale thrust event appears similar to, but younger than the age of the Keystone thrust event in the Clark Mountains. Since the exact tectonic interpretation of the Willow Tank Formation, Baseline Sandstone and Overton Fanglomerate is not known, and since the age constraints on the thrusting are at two localities over 140 km apart, the age discrepancy is not seen as a serious problem.

5) If the previous correlation scheme is followed, there is no obvious equivalent of the Red Spring thrust in the Muddy Mountains or of the Glendale thrust in the Spring Mountains. This serious problem must be faced. The Red Spring-Contact thrust plate is known to have extended along strike

for at least 45 km in the Spring Mountains, and similar deformation is thought to have occurred in the Clark Mountains, it is surprising that no correlative structure is present in the Muddy Mountains.

Although the Glendale thrust is not known for such a great distance, it is present for at least 25 km along strike in the Muddy Mountains, and may be present in the Mormon Mountains (pers. commun, Wernicke 1979). It is unreasonable to interpret the Glendale thrust as the equivalent of the Dry Lake thrust, since lower plate strata of the Dry Lake thrust extend farther north than the southernmost remnant of the Glendale thrust.

On the basis of the evidence discussed above I have constructed a timing sequence of structural events in the Muddy Mountains, and have compared it with the sequence of events at La Madre Mountain (representative of the eastern Spring Mountains). Both the previous correlation and my new correlation are shown in table 5. It can easily be seen, on the basis of timing alone, that my correlations fit the available data better than the pre-existing correlation. Three important events cannot be matched using the previous scheme:

- 1) deposition of the Brownstone Basin Conglomerate,
- 2) the Glendale thrust event,
- 3) the Red Spring thrust event.

The deposition of the "molasse" of Brock and Engelder (1977) cannot be matched with an event at La Madre Mountain, but Secor (1963) found similar, though thinner, conglomerates

Table 5

Comparison of Correlations Between the Eastern Spring and Muddy Mountains

<u>Previous Correlation</u>		<u>New Correlation</u>
Muddy Mountains	La Madre Mountain	Muddy Mountains
? — — —————	1) deposition of the Brownstone Basin Conglomerate	1) deposition of "molasse" in Buffington Window
1) deposition of "molasse" in Buffington Window	? — ————— 2) Red Spring thrust event	2) Muddy Mountain thrust event
	? — ————— 3) high-angle faulting	3) high-angle faulting
2) Muddy Mountain thrust event	4) Keystone thrust event	4) Glendale thrust event and related sedimentation
3) high-angle faulting	5) high-angle faulting — — ?	
4) Glendale thrust event and related sedimentation	6) gravity sliding and oroclinal flexure	5) gravity sliding (?)
5) gravity sliding (?)		

below the Keystone thrust.

Using the correlation proposed here only one event cannot be matched: the second high-angle faulting event in the Spring Mountains does not appear to be present in the Muddy Mountains.

If this correlation is correct, then movement on the Red Spring thrust probably occurred prior to deposition of the Willow Tank Formation (96.4 and 96.8 m.y. Fleck 1970). Movement on the Keystone thrust would have to have occurred after this time, and before 23 m.y. (Armstrong 1963).

V Conclusions

The La Madre Mountain area has rocks which range in age from Middle Cambrian to Cretaceous (?) in three main structural units, the autochthon (or parautochthonous Bird Spring thrust plate, see figure 3), the Red Spring thrust plate and the Keystone thrust plate.

The two major thrust faults transported Paleozoic carbonate rocks eastward. The Keystone plate has been transported a minimum of approximately 19 km, and the Red Spring plate has moved a minimum of about 7 km, or a total minimum displacement of approximately 26 km. These figures were obtained from the geometry shown on section AA' of figure 14. Data from other areas indicates that the thrusting took place after 150 ± 10 m.y. ago (Carr 1978) and before about 90 m.y. ago (Clark Mountains, Burchfiel and Davis 1971, 1977, in prep.) or before 23 m.y. ago (Muddy Mountains, Armstrong 1963, Fleck 1970).

The Paleozoic carbonate rocks belong to a facies which is

transitional between cratonal and miogeosynclinal. Facies in the two thrust sheets are similar, indicating that they occupied similar depositional regions, but their original proximity to each other is not known. Tectonic transport may have been roughly parallel to some isopach lines and facies boundaries.

The autochthonous or parautochthonous rocks range in age from Permian to Tertiary (?). Pre-thrusting deposits are as young as the Early Jurassic Aztec Sandstone. Pre- and/or syn-thrusting deposits are Jurassic or Early Cretaceous (?) in age (Brownstone Basin Conglomerate). Mesozoic rocks are mainly terrigenous, clastic or eolian sedimentary rocks. Marine deposition ceased by Middle Triassic time. Post-thrusting deposits are limited to Quaternary alluvium, and Tertiary(?) landslide deposits which originally covered a minimum area of 7 km².

The following sequence of structural events can be recognized in the La Madre Mountain area:

- 1) emplacement of the Red Spring thrust plate over an erosional surface on the autochthonous rocks,
- 2) north to northwest trending high-angle normal(?) faulting of the Red Spring thrust plate and autochthon, forming northeast-tilted, fault-bounded blocks,
- 3) emplacement of the Keystone thrust plate above the tilted and eroded fault blocks,
- 4) renewed movement on the pre-existing high-angle faults of event 2,

5) deposition of the Tertiary (?) landslide breccia and Miocene dextral oroclinal flexure of the entire La Madre Mountain area from a north to a northeast trend by movement on the Las Vegas Shear Zone.

Both major thrusts are interpreted to have overridden erosional land surfaces on their frontal parts, although in the case of the Keystone thrust evidence for this comes from outside the La Madre Mountain area. The Red Spring thrust plate overrode an erosional surface on the Jurassic Aztec Sandstone at La Madre Mountain and overrode its own fore-thrust debris, the Brownstone Basin Conglomerate. High fluid pressure could not have developed on the Red Spring thrust on this part, because of the highly porous nature of the Aztec Sandstone and Brownstone Basin Conglomerate.

As indicated by Aztec Sandstone derived fault gouge lenses and injection dikes found along the Keystone thrust contact, the Keystone thrust plate overrode the Aztec Sandstone northwest of the Red Spring thrust plate, probably having cut a new ramp through the faulted lower plate rocks. This quartz-rich gouge (with minor carbonate and chert fragment content) is now found above Mississippian rocks of the Red Spring plate and below and in Cambrian rocks of the Keystone plate. The gouge has been transported a minimum of approximately 6.8 km (section BB', figure 14).

At its eastern end the Keystone thrust cut up section in the upper plate for more than 300 m, almost entirely removing the Bonanza King Formation. For most of its length at La Madre

Mountain and for several tens of kilometers to the south, the Keystone thrust is stratigraphically controlled at the surface, being near the silty unit of the Bonanza King Formation for most of its length.

A sequence of events similar to the one at La Madre Mountain occurred in the Potosi Mountain/Goodsprings area (Cameron 1977, Carr 1978) and in the Clark Mountains (Burchfiel and Davis 1971, 1977). A similar sequence is documented in the Muddy Mountains (Longwell 1949, 1962). On the basis of the similarity to the structural history in the Muddy Mountains I propose a new correlation of thrust plates to the north: The Keystone thrust is probably equivalent to the Glendale thrust of the Muddy Mountains (Longwell, 1949) and the Red Spring thrust is probably equivalent to the Muddy Mountain thrust. If this correlation is correct the movement on the Red Spring thrust was prior to 98.4 m.y. ago (Fleck 1970) and the movement on the Keystone thrust post-dated this time.

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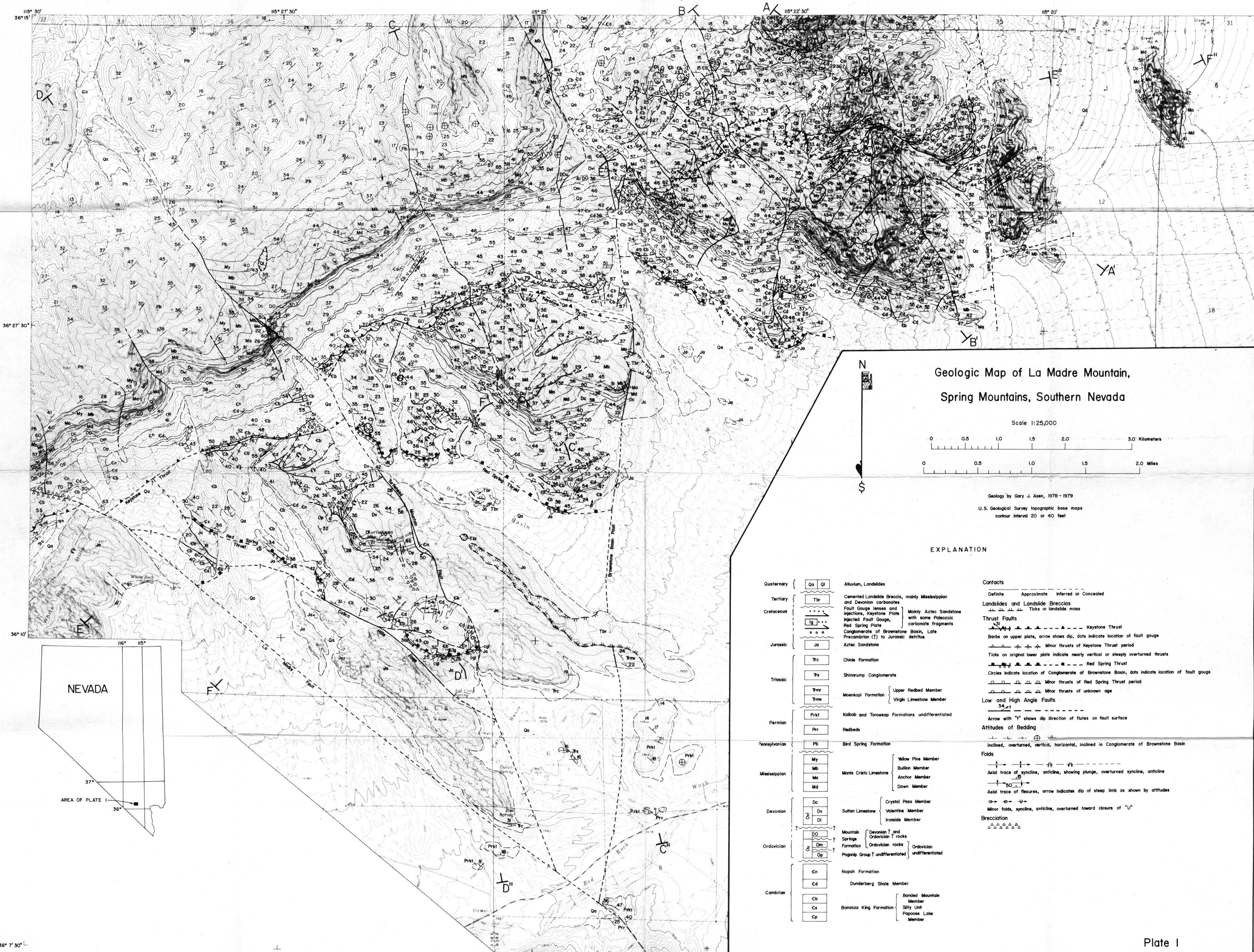
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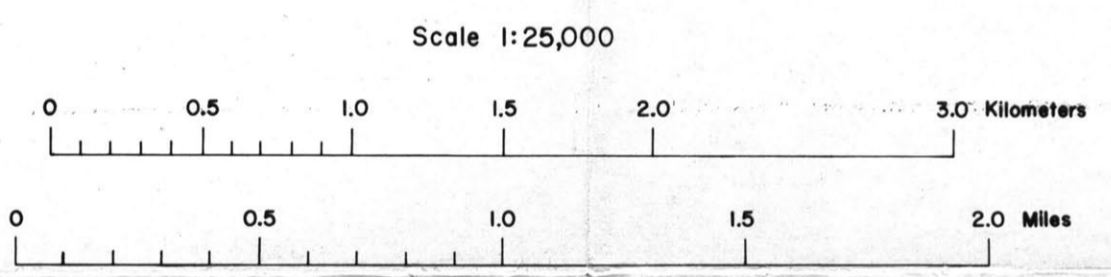
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**Geologic Map of La Madre Mountain,
Spring Mountains, Southern Nevada**



Geology by Gary J. Axen, 1978-1979
U.S. Geological Survey topographic base maps
contour interval 20 or 40 feet

EXPLANATION

Quaternary	Qa Ql	Alluvium, Landslides
Tertiary	Ttr	Cemented Landslide Breccia, mainly Mississippian and Devonian carbonates
Cretaceous	Tg	Fault gouge lenses and injections, Keystone Plate
	Ig	Mainly Aztec Sandstone with some Paleozoic carbonate fragments
Jurassic	Ja	Conglomerate of Brownstone Basin, Late Precambrian (?) to Jurassic detritus Aztec Sandstone
Triassic	Tc	Chinle Formation
	Ts	Shinarump Conglomerate
Permian	Tmr	Moenkopi Formation
	Tmw	Upper Redbed Member Virgin Limestone Member
Permian	Prkt	Kaibab and Toroweap Formations undifferentiated
	Prr	Redbeds
Mississippian	Pb	Bird Spring Formation
Mississippian	My	Yellow Pine Member
	Mb	Bullion Member
	Ma	Anchor Member
	Md	Down Member
Devonian	Dc	Sultan Limestone
	Dv	Crystal Pass Member
	Di	Volentine Member Ironsides Member
Ordovician	Do	Mountain Springs Formation
	Om	Devonian? and Ordovician? rocks
	Op	Ordovician rocks Pogonip Group? undifferentiated
Cambrian	Cn	Nopah Formation
	Cd	Dunderberg Shale Member
	Cb	Bonanza King Formation
	Cs	Banded Mountain Member
	Cp	Silly Unit Popoosa Lake Member

Contacts
 Definite Approximate Inferred or Concealed

Landslides and Landslide Breccias
 Ticks in landslide mass

Thrust Faults
 Keystone Thrust
 Bars on upper plate, arrow shows dip, dots indicate location of fault gouge
 Minor thrusts of Keystone Thrust period
 Ticks on original lower plate indicate nearly vertical or steeply overturned thrusts
 Red Spring Thrust
 Circles indicate location of Conglomerate of Brownstone Basin, dots indicate location of fault gouge
 Minor thrusts of Red Spring Thrust period
 Minor thrusts of unknown age

Low and High Angle Faults
 Arrow with "f" shows dip direction of flutes on fault surface

Attitudes of Bedding
 Inclined, overturned, vertical, horizontal, inclined in Conglomerate of Brownstone Basin

Folds
 Axial trace of syncline, anticline, showing plunge, overturned syncline, anticline
 Axial trace of flexures, arrow indicates dip of steep limb as shown by attitudes
 Minor folds, syncline, anticline, overturned toward closure of "U"

Brecciation
 Symbols for brecciated areas

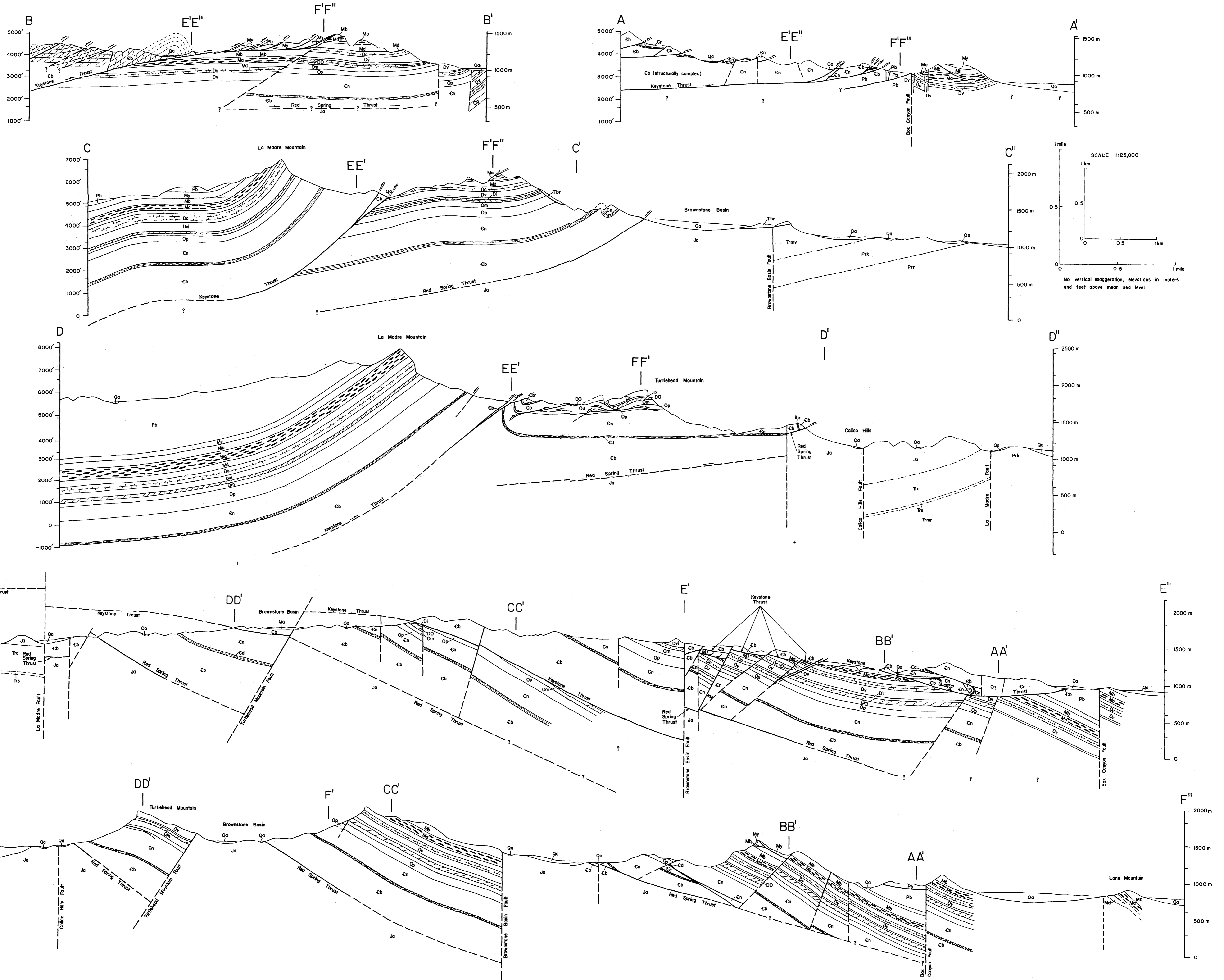
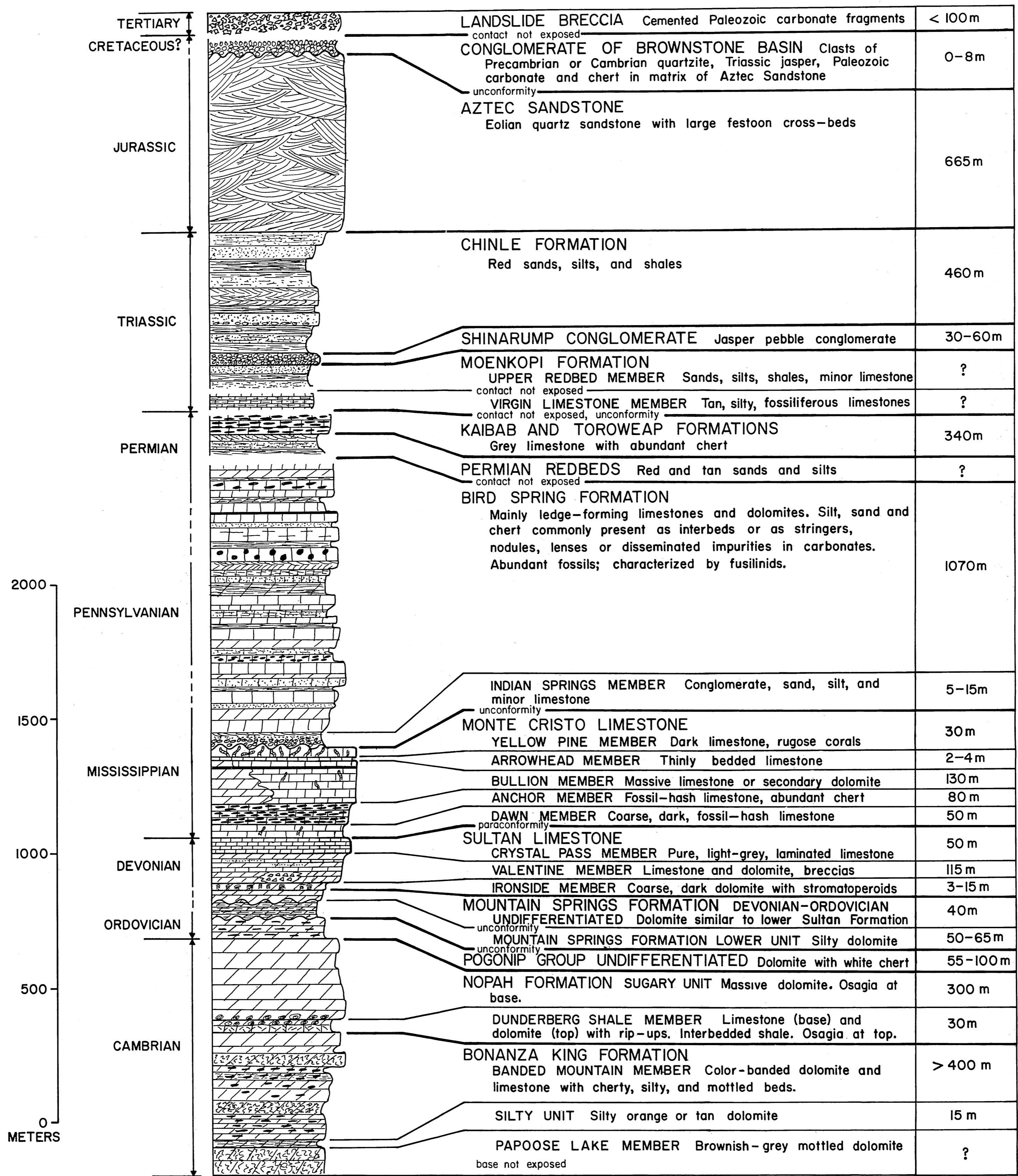


Plate 3 Stratigraphic Column, La Madre Mountain



Thicknesses are approximate. Some thin units are exaggerated. Some units with unexposed contacts are shown thinner than strata actually present. See text for more accurate thicknesses and discussion.