ranges. In addition, much of the geology is developed within carbonate rocks, which crop out well in desert regions.

The regionally averaged topographic pattern of the Basin and Range at the latitude of Las Vegas is one of high flanks, comprising the Sierra Nevada on the west, and the Colorado Plateau on the east, and two broad, low-lying areas on either side of a median high (Eaton and others, 1978). This pattern resembles that of the northern Basin and Range, but at smaller scale because the province here is half the width (Fig. 2). The median high is centered on the Spring Mountains, Sheep Range, and Las Vegas Range, whereas the lows include the Colorado River trough/Lake Mead area on the east and the Death Valley region on the west (Fig. 4). As discussed below, the two low-lying areas are highly extended, whereas the median high is less extended.

**Basement, Proterozoic Basin, and Miogeoclinal Wedge**

Precambrian Y (mostly ca. 1.7–1.4 Ga) crystalline basement in the region lies nonconformably beneath unmetamorphosed sediments of Precambrian Y (?), Precambrian Z, or Cambrian age (Fig. 3). Precambrian Y (?) and Z strata of the Pahrump Group (Fig. 3) are locally present in ranges west and southwest of the Spring Mountains between basement and regionally persistent Precambrian Z to Cambrian strata that form the base of the Cordilleran miogeoclinal in the region (Stewart, 1970, 1972). Although the lower portion of the Pahrump is probably Precambrian Y in age, the upper part appears to be in gradational contact with the Cordilleran miogeoclinal, and thus is probably Precambrian Z in age (Miller, 1987). The west-thickening Precambrian Z and Paleozoic miogeoclinal (Figs. 2 and 3) is overlain conformably or with mild angular unconformity by locally thick accumulations of Mesozoic strata (Fig. 3).

The most significant stratigraphic feature beneath the miogeoclinal strata is the northward pinchout of the Pahrump Group in the southern Death Valley region (Wright and others, 1974, 1981). South of the pinchout, as much as 3,000 m of Pahrump strata is present below the basal units of the miogeoclinal in the southern Black Mountains, Kingston Range, and Panamint Range (Fig. 4). Over a distance of less than 10 km, the basal miogeoclinal unconformity cuts downsection through the Pahrump Group and onto crystalline rocks.

Lithologically, the miogeoclinal is divisible into two main parts, including a Middle Cambrian and older clastic wedge and a Middle Cambrian and younger carbonate succession (Fig. 3). The clastic wedge thickens from less than 100 m on the craton to the east, where basal strata are Lower Cambrian, to more than 5,000 m in western areas, where most of the sequence lies below basal Cambrian beds. The Paleozoic sequence is entirely marine, except for some Permian strata that are partly nonmarine (Wright and others, 1981; Stone and Stevens, 1987). Westward thickening of the carbonate succession occurs in part by thickening of individual units and in part by the pinching in of Ordovician, Silurian, and Devonian strata beneath a major sub–Upper Devonian disconformity (Fig. 3). On the craton, Upper Devonian strata lie disconformably on Upper Cambrian. To the west, they lie on progressively younger strata until a fully developed, Ordovician, Silurian, and Devonian section is present. The youngest marine strata in the region are Triassic and are overlain in eastern areas by nonmarine clastics locally as young as Cretaceous and in western areas by lower Mesozoic volcanics (for example, Wright and others, 1981). In sections in the transition zone between craton and miogeoclinal, the highest Paleozoic strata present on the craton, including the Kaibab and Toroweap Formations, pinch out westward beneath the basal Mesozoic unconform-

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**Figure 2. Regional tectonic setting of the Las Vegas area Basin and Range, showing isopach trends of the Precambrian Z-Cambrian clastic wedge of the Cordilleran miogeoclinal, Paleozoic Anfier and Mesozoic Sevier orogenic fronts; and the position of the Mesozoic batholith belt (crosses). Note that the position of the study area of this report resides largely in the miogeoclinal prism and craton.**
In the Riverside Mountains a thrust fault in the footwall of the Riverside Mountains detachment fault places Proterozoic crystalline rocks over highly faulted and deformed Paleozoic and Mesozoic strata [Lyle, 1982a; b; see also Carr and Dickey, 1980]. This thrust fault is the structurally highest exposed thrust in this part of the MFTB. Mylonitic fabrics within the thrust zone contain a moderately well-developed NSE to N15°E lineation and locally well-developed S-C fabrics that indicate top-to-the-south shear (J. Spencer, unpublished data, 1987).

A segment of this thrust boundary, now displaced tens of kilometers to the northeast or east-northeast by detachment faulting, is exposed in the western Buckskin Mountains. The fault segment juxtaposes Proterozoic crystalline rocks to the north and west with highly slivered and sheared Paleozoic and Mesozoic metamorphic rocks to the south and east (Figures 3 and 4) [Frost, 1983; Reynolds and Spencer, 1989]. The fault is interpreted as a product of multiple deformations and is not simple thrust fault. Crystalline rocks to the north and we are part of an extensive terrane of crystalline rocks in the western Buckskin, eastern Whipple, and southern Bill Williams mountains that form much of the upper plate of the Whipple detachment fault. This crystalline rock terrane is not known to have been affected by significant Mesozoic deformative features [Davis et al., 1980; Frost, 1983] except near the deformed Mesozoic and Paleozoic strata [Reynolds and Spencer, 1989].
Figure 5. Generalized stratigraphic sections in the Frenchman and Spring Mountains areas.
Dome Rock, Big and Little Maria Mountains

Triassic (?) metasedimentary rocks—Tung Hill Mine, northern Dome Rock Mountains. Metasedimentary rocks consisting dominantly of quartz-mica schist, with lesser amounts of quartz-feldspar schist, yellowish micaceous mica schist, and metapelitic schist. Leucocratic metagreywacke, and quartzite are exhumed. Little Maria: grey-green schist, phyllite, anhydrite, and calcite rich metagraywacke.

Kalbach—Chert-ribbon calcite marbles, which contain abundant wollastonite at high grade. Chert tends to form small irregular globules in least deformed rock. Discontinuous dark grey layers are common.

Cocino—fine-grained, vitreous, hard, grey to white quartzite. In thin sections from Little Maria Mountains, small mica flakes are found growing along the grain boundaries and commonly found in the middle of strain-free quartz grains.

Hermits—calc-silicate schist

Supal—Boyer Gap; heterogeneous assemblage of banded calc-silicate schist, marbles, and quartzites. Big Maria: impure quartzites and carbonates at low grade and complex calc-silicate rocks at high grade, Little Maria: layers of alternating 2-5 cm thick beds of calcite and chert or quartzite. Now largely converted to wollastonite; crops out as a distinctive zebra-striped unit.

Cambrian—Mississippian carbonates—Boyer Gap area; banded grey and white micaceous marble near the base (Muny), massive, light tan weathering dolomite marble; white, chert-ribboned, calcite marble near the top (Redwall?).

Big Maria Mountains, from base: calcite marble (Muny?); thick brown weathering dolomite marble; white calcite marble, which is designated Redwall Marble (Upper Devonian and Mississippian). Rock is mass-transported?

Bright Angel—light foliated quartz-bicteiorite schist

Tapes—light tan to blue-grey weathering calcite foliated quartzite

Proterozoic—crystalline rocks

Figure 3. Paleozoic and lower Mesozoic stratigraphy of eastern (Pleomos Mountains) and western (Big and Little Maria mountains) Maria fold and thrust belt.

Unconformities and faulting—Late Cretaceous plutons. These rocks will be the focus of our field trip.

Early Miocene and probable Late Cretaceous or early Tertiary low-angle normal faults have reveroofed: structural levels from south to north or southwest to northeast. The deepest structural levels are exposed beneath the Miocene Whipple-Buckskin-Bullard detachment fault system at the eastern end of the belt. Significant Miocene normal faults in the northern part of the Big Maria, Dome Rock and Plomosa mountains apparently lose displacement southward [Spencer and Reynolds, 1989, 1991]. Large-scale tilting of uncertain magnitude accompanied movement on these faults, but the true nature of the movement remains uncertain. We will visit are largely unexposed internally and appear to form a raft separating regions of greater mid-Tertiary extension to the north, east and south [Sherman and Rosdal, 1991; Spencer and Reynolds, 1991]. The western end of the Maria belt has been disrupted by Late Miocene right-lateral faulting [Richard, 1993].

Purpose of trip—California

On this trip, we will examine faults and unconformities in the Cretaceous McCoy Mountains Formation and related rocks representing shallow paleodepth in the southern Pleomos Mountains and Livingston Hills and poly-deformed Paleozoic and Mesozoic metasedimentary rocks representing deeper parts of the orogen in the northern Dome Rock, Big Maria and Little Maria Mountains. Major problems to be addressed include the interaction of deformation and sedimentation at high structural levels in the southern part of the belt, style and kinematics of ductile deformation in the northern part of the belt, and the relationship between events documented in these two domains.

OVERVIEW OF ROCK UNITS
Dome Rock, Big and Little Maria Mountains

Aztecian to basal weathering quartzite
Triassic(?)* metamorphic rocks—Tung Hill Mine, northern Dome Rock Mountain.

metasedimentary rocks consisting dominantly of quartz-mica schist, with lesser amounts of quartz-phyllite, sericite, and carbonate and quartz are exposed. Little Maria: grey-green
mica, quartz, and carbonate rich schist. Kalbach—Chert-rich calccic marbles, which contain abundant wollastonite at high grade. Chert tends to form small irregular laths in least deformed rock. Discontinuous dark grey layers present in the schist. Coconino—fine-grained, vitreous, hard, grey to white quartzite. In thin sections from Little Maria, small mica flakes are found growing along the quartz grain boundaries and commonly found in the middle of strain-free quartz grains. Hermit—calc-silicate schist
Supai—Boyer Gap: heterogeneous assemblage of banded calc-silicate schists, marbles, and quartzites. Big Maria: impure carbonates and carbonates at high grade and complex calc-silicate rocks at high grade. Little Maria: layers of alternating 2-5 cm thick beds of calcite and chert or sillstone. Now largely converted to wollastonite; crops out as a distinctive zebra
sandstone unit.
Cambrian-Mississippian carbonates—Boyer Gap area: banded grey and white micaceous marble near the base (Muav), massive, light tan weathering dolomite marble; white, chert-banded, calccic marble near the top (Redwall?).
Big Maria Mountains, from base: calccic marble (Muav?); thick brown-weathering dolomite marble; white calcite marble, which is designated Redwall Marble (upper Devonian and Lower Mississippian, respectively). Bright Angel—lightly foliated quartz-biotite schist
Tepa—light tan to blue-gray weathering feldspathic quartzite
Proterozoic crystalline rocks

Figure 3. Paleozoic and lower Mesozoic stratigraphy of eastern (Plomosa Mountains) and western (Big and Little Maria Mountains) Maria fold and thrust belt.

Undeformed Late Cretaceous plutons These rocks will be the focus of our field trip.

Early Miocene and probable Late Cretaceous or early Tertiary low-angle normal faults have unroofed deeper structural levels from south to north or southwest to northeast. The deepest structural levels are exposed beneath the Miocene Whipple-Buckskin-Bullard detachment fault system at the eastern end of the belt. Significant Miocene normal faults in the northern part of the Big Maria, Rock Mountain and Plomosa mountains apparently lose displacement southward (Spencer and Reynolds, 1989, 1991). Large-scale tilting of uncertain magnitude accompanied movement on these faults, but the ranges we will visit are largely unextended internally and appear to form a "raft" separating regions of greater mid-Tertiary extension to the north, east and south (Sherrod and Tosdal, 1991; Spencer and Reynolds, 1991). The western end of the Maria belt has been disrupted by Late Miocene right-lateral faulting (Richardson, 1993). In order to facilitate discussion of Mesozoic tectonics, Figure 2 presents a palinspastic reconstruction of the Maria Belt in early Tertiary time.

Purpose of trip: Eastern California

On this trip, we will examine faults and unconformities in the Cretaceous McCoy Mountains Formation and related rocks representing shallow paleodepth in the southern Plomosa Mountains and Livingston Hills, and poly-deformed Paleozoic and Mesozoic metasedimentary rocks representing deeper parts of the orogen in the northern Dome Rock, Big Maria and Little Maria Mountains. Major problems to be addressed include the interaction of deformation and sedimentation at high structural levels in the southern part of the belt, style and kinematics of ductile deformation in the northern part of the belt, and the relationship between events documented in these two domains.

OVERVIEW OF ROCK UNITS
Figure 5. Map of pre-Tertiary outcrop area, showing Mesozoic structural levels. Contacts between units are not necessarily thrust faults and include later faults that juxtapose thrust plates and the axial traces of anticlines in asymmetric fold pairs; some areas in westernmost region are intruded post-tectonically. a = sub-Keystone system, autochthonous and paraautochthonous rocks, k = rocks above Keystone thrust system and below Wheeler Pass system, w = rocks above the Wheeler Pass system and below the Clery thrust, c = rocks above the Clery thrust and below the Marble Canyon thrust, m = rocks above the Marble Canyon thrust and the west-vergent White Top Mountain backfold/thrust system, b = rocks below the White Top Mountain structure and the Last Chance system, l = rocks above the Last Chance system, e = rocks above the East Sierran thrust system. Bold arrows show approximate line of restored section in Figure 6. Arrow on west-vergent structure in Grapevine Mountains shows sense of rotation required to realign it with other exposures of the structure. HBF, Hamblin Bay fault; NFZ, northeastern Death Valley–Furnace Creek fault zone.
Wilson Cliffs thrust to place Cambrian rocks above overturned Triassic rocks. Cretaceous (?) sandstone and conglomerate deposits lie below the Keystone plate just south of where it cuts out the Wilson Cliffs thrust (Figure 1-1). The sandstone unit consists of reworked Aztec sandstone and has beds of conglomerate with clasts derived exclusively from the Bonanza King Formation (McCl, Figure 1-4a). These sedimentary rocks clearly lie below the Keystone thrust, but their relation to the Wilson Cliffs plate is unclear because of poor exposure. Detailed mapping suggests, however, that the sandstone and conglomerate rest on an eroded remnant of the Wilson Cliffs thrust plate (Figure 1-4a). This interpretation leads to the conclusion that the Wilson Cliffs thrust plate was emplaced, deeply eroded, and perhaps largely removed by erosion just south of the La Madre fault before the
Formation in the hanging wall for great distances along and across strike. With a few exceptions, the thrust faults virtually everywhere occur within 75 m of a distinctive marker horizon at the base of the Banded Mountain Member. The Middle and Upper Cambrian Bonanza King Formation (for original definition, see ref. 14) is the basal unit of the thick Paleozoic miogeoclinal platform carbonate sequence of the southern Great Basin. Two members are commonly identified: the upper Banded Mountain Member and the lower Papoose Lake Member. The Banded Mountain Member generally consists of well-bedded dolostone with rare limestone in the region of Fig. 1; the Papoose Lake Member generally consists of undivided dolostone and limestone. The Banded Mountain Member averages -500 m in thickness where a complete section is exposed; the Papoose Lake Member varies between 175 and 450 m thick, where exposed (Fig. 2).

The Banded Mountain Member forms the hanging wall of the Mormon thrust fault for a distance of at least 40 km in the transport direction. The Mormon thrust fault is probably correlative with the North Buffalo thrust in the central Muddy Mountains, and the Red Spring and Contact thrusts in the central Spring Mountains. All of these correlative thrusts carry the Banded Mountain Member of the Bonanza King Formation in the hanging wall. The CRM thrust system carries the same unit in the hanging wall for at least 40 km across strike and at least 150 km along strike; it therefore has a decollement geometry.

Thrust faults in the KMG thrust system carry the Banded Mountain Member of the Bonanza King Formation in the hanging wall for 15 km across strike in the northern Clark Mountains, for 8-10 km across strike in the central Spring Mountains, and for at least 25 km across strike in the Muddy Mountains. The KMG thrust system carries the Banded Mountain Member in the hanging wall for nearly 200 km along strike, from the southern Mormon Mountains in the north, through the Muddy Mountains and Spring Mountains, to the Clark and Ivanpah Mountains of southeastern California. Therefore, the KMG thrust system also has a decollement geometry, by the criterion above.

The phrase 'in the hanging wall' is used to denote the upper plate immediately adjacent to the thrust fault. The hanging wall means the bottom surface of the plate of the thrust, and not volume of the upper plate.

Because the Banded Mountain Member forms the hanging wall for virtually all of the exposures of both thrust systems, it is clear that this unit contains the decollement horizon and exposed portions of the thrusts. To demonstrate that the decollement horizon formed within the Bonanza King Formation, preference to the underlying Middle and Lower Cambrian limestones, shales and siltstones, it must be shown that the Papoose Lake Member was present beneath the Banded Mountain Member in the allochthon before formation of the faults.

Complete sections of Cambrian strata are exposed in the autochthon in the Mormon Mountains, at Frenchman Mountain, at Sheep Mountain and in the Ivanpah Mountains (Fig. 1). All three of the sections contain a thick Papoose Lake Member. The Papoose Lake Member is also preserved in the higher allochthons west of the KMG thrust system. The Papoose Lake Member and underlying strata are extremely extensive, present everywhere the entire Cascade range is exposed both east and west of the two thrust systems. It follows that these beds were originally present beneath the Banded Mountain Member of both the KMG and CRM allochthons, and were left behind beneath the decollement during thrust faulting. This is supported by the absence of silvers of the Papoose Lake Member preserved beneath the thrusts.

It is possible that the decollement in the Banded Mountain Member is not a basal decollement, but rather for duplex structure at depth. There is no support for such a duplex: if one exists, it is nowhere internal or consistent set of balanced cross-sections. Without postulating such a structure. In addition, the CRM thrust system, overlying KMG thrust system (Fig. 1), GreenMountain–Lee Canyon thrust system and the beds of the Banded Mountain Member in the autochthon at virtually every exposure of the Papoose Lake Member, only as silvers, and lower units are not present. The simplest explanation is to postulate a master decollement at the base of the Banded Mountain Member.

We infer that the CRM and the KMG thrust systems formed at shallow levels on the basis of the general location of thrust deformation within the thrust sheets and the thrust debris and stream–channel conglomerates of both thrust systems. The absence of paleo-deposits...
clasts, all of the clast and matrix material at this level appears to be derived from the underlying, autochthonous Mesozoic stratigraphic section. However, the upper portion of the sequence, particularly near the section boundary, contains as much as 50 percent of subrounded clasts of carbonate rocks with diameters of up to 10 cm. The carbonate clasts were derived from a Cambrian to late Paleozoic sequence now present in the eastern Spring Mountains only in the Red Spring, Keystone, and higher thrust plates. The abrupt appearance and striking upward increase in carbonate clasts in conglomerate beneath the Red Spring thrust plate appear to herald the approach of the thrust plate as it moved across the land surface and over stream channels choked with detritus; detritus derived initially from the surrounding autochthonous Mesozoic terrane and then from the Paleozoic allochthon as well.

**RELATIONS BETWEEN THE RED SPRING AND KEYSTONE THRUST FAULTS**

Longwell (1960) proposed that torsional deformation leading to block faulting and downdropping of the front of the Keystone thrust plate (Red Spring thrust plate) was locally produced in the Spring Mountains by an interaction between eastward thrust faulting and concurrent right-lateral, strike-slip displacement along the northwest-trending Las Vegas shear zone. Subsequent geologic studies
Figure 3. Simplified reconstruction of the Clark Mountain thrust complex along the powerline road, Shadow Mountain to Ivanpah Valley.
is, at the time of this writing, equivocal. Arguments were given at stop 2-5 that the impressively ductile Striped Mountain syncline had formed beneath the Winters Pass plate prior to development of the Mescal thrust, one of the major thrust faults within the Mesquite Pass plate. Yet, some field relationships in the Pachalka Spring area can be interpreted as circumstantial evidence that the Pachalka thrust plate (= Winters Pass?) was not emplaced until the Cretaceous. We are uncomfortable with such a young age of thrusting for this highest thrust sheet in the complex. Hopefully, dioritic rocks intruded along the Pachalka thrust during late stages of displacement can be dated to resolve this question of timing.

Third Day

Introduction

Return to the northern part of the Clark Mountain thrust complex, north of Interstate 15. Having established the Mesozoic tectonic framework of the complex yesterday, we now focus on Mesozoic extensional modifications of it. We have recognized four examples of such modifications:

1) extensional faulting in the west-central Mescal Range (stop 2-7 and Fig. 13); eastern Kingston Range and at structurally high levels of the Mesquite Mountains (between the Kingston Range and Clark Mountains); this domain of southwest-directed extension (relative to lower-plate rocks) constitutes the southeastern breakaway margin of a major, probably composite, late Tertiary extensional province that extends as far to the west as the Sierra Nevada (Fig. 3).

Of the four examples of Cenozoic extension, only (4) appears at this time to have regional implications. The trace of a major west-dipping, low-angle normal fault, the Kingston Range detachment, is present in the northeastern Kingston Range (Burchfiel, Hodges, and Walker, in prep.). Most of the range consists of complexly faulted, east- and northeast-tilted Precambrian, Cambrian, and upper Cenozoic strata (Figs. 14, 15). The Kingston Range detachment (Fig. 3) separates a region to the east and south, including the Mesquite and Clark Mountains, that has been little affected by Cenozoic extension, from a region (as far to the west as the Sierra Nevada) that has been strongly affected by such extension. For this reason, the Kingston Range detachment forms the eastern breakaway zone for the extended regions to the west (Burchfiel and others, 1983). South of the Kingston Range, the continuous trace of the Kingston Range detachment is largely concealed under Precambrian sedimentary rocks.

Figure 14. Cross-section through the Mesquite Pass thrust plate, hill south of powerline road (cf. Fig. 9), illustrating involvement of basement crystalline rocks in the thrust belt. Geologic relationships are explained at stop 3-1. Rock units (oldest first): Precambrian gneisses (Pegn); Noonday Dolomite (Pen); Johnnie Formation (Pes); Sturley Quartzite (Pes); Quaternary alluvium (Qal).
Figure 5. Generalized geologic map of the Mescal Range, Striped Mountain, and Ivanpah Mountains in the southern part of the Clark Mountain thrust complex. The Ivanpah pluton lies in the core of a large east-overturned fold. Overturned Precambrian to Devonian rocks lie east and below the pluton, and upright Devonian to Permian rocks lie above the pluton to the west. A narrow exposure of the pluton is present in the eastern Mescal Range where it is overlain by Cretaceous sandstone (Fig. 6). Rock units are as follows: pg = Precambrian gneiss and intrusive rocks; Cs = Cambrian to Devonian sedimentary rocks; Cs = Cambrian sedimentary rocks; Ds = Devonian sedimentary rocks; MPS = Mississippian to Permian sedimentary rocks; Tr = Triassic to Jurassic sedimentary rocks; Kd = Cretaceous Delfonte volcanic rocks; Ji = Late Jurassic Ivanpah pluton; MI = Mesozoic intrusive rocks of unknown age; and Tc = Cenozoic conglomerate that lies above the breakaway, detachment fault in the Mescal Range. Double ticked lines are normal faults.

**DISCUSSION**

The data presented above allow us to better bracket the age of the contractual deformation within most of the Clark Mountain thrust complex and to place it in a regional context. Because the Clark Mountain thrust complex lies at the intersection of the Sevier fold and thrust belt and the Mesozoic magmatic arc and its associated structural features, the Clark Mountain area is an ideal region to compare timing of arc, thrust-belt, and foreland deformational events. The Pachalka thrust formed as a ductile thrust carrying plutonic rocks of the magmatic arc.
Figure 16. Map showing the distribution of major extensional fault zones and arc-type volcanic rocks extruded from 53 to 17 Ma and subdivided into the indicated time slices. Volcanic rocks compiled and modified from Christiansen and Yates (this volume). Alkaline rocks of 53 to 38 Ma are illustrated in the northern part of the Cordilleran to show the eastern limits of igneous activity. Location of the Rio Grande rift and "metamorphic core complexes" (medium red oblique lines) are also shown. Ticks on faults are on hanging wall side. Future location of San Andreas fault zone shown in gray. BM, Bare Mountain; BR, Bitterroot mylonite zone; C, Catalina Mountains; F, Funeral Mountains; GWC, Grand Wash Cliffs fault zone; K, Kingston Range; LC, Lewis and Clark line; LG, La Grange fault (Klamath Mountains); MR, Mineral Ridge; N, Newport fault; NC, northern Cascades; NWA, northern Wasatch fault; O, Okanogan Mountains; OC, Omenica crystalline zone; OM, Olympic Mountains (red; shows material accreted during this time interval); P, Pioneer Mountains; RM, Ruby Mountains; RR, Raft River/Albion Ranges; S, Shuswap; SA, Santa Rosa fault zone; SC, Santa Catalina; SD, Sevier Desert fault zone; SN, Snake Range; SR, Sheep Range; W, Whipple Mountains; WA, Wasatch fault; WM, Western Mojave; Y, Yerrington.
ently offset right laterally about 50 km (Fig. 5). The likelihood that this offset has an origin as a tear structure in the Keystone thrust plate (for example, Royse, 1983) or was controlled in some way by an abrupt change in trend of isopachs in the miogeoclinal seems remote in view of the similarities of the thrust system north and south of the shear zone. The strong control of facies and isopach trends on thrust geometry observed in most thrust belts suggests that major paleogeographic anomalies are usually associated with major transverse structures, with a change in both the character of the faulted sediments and the number and spacing of thrusts across them (for example, Price, 1981).

West of the synclinorium in the hanging wall of the Keystone, the Paleozoic section thickens by thickening within individual units and also by the appearance of the Middle Ordovician Eureka Quartzite, Upper Ordovician Ely Springs Dolomite, and Silurian strata below the sub-Devonian unconformity and of Middle and Lower Devonian strata above the unconformity (Figs. 3 and 6; Burchfiel and others, 1974). Within this region, there are a number of relatively small east-vergent folds and thrust faults that carry units as old as the Middle Cambrian Bonanza King Formation over rocks as young as the Carboniferous-Pennsylvanian Bird Spring Formation, such as the Lee Canyon thrust (Fig. 6a). These structures tend not to be as laterally persistent as the Keystone system. West of the synclinorium, the Bird Spring Formation thickens from about 600 to >2,000 m (Figs. 3 and 6; Burchfiel and others, 1974).

Wheeler Pass System. The next highest major thrust system is the Wheeler Pass system. It can be traced for nearly 120 km along strike in the Sheep Range, Las Vegas Range, and Spring Mountains, interrupted only by the Las Vegas Valley shear zone (Fig. 5; Longwell and others, 1965; Burchfiel, 1965; Guth, 1961). Unlike the Keystone system, the Wheeler Pass system is not consistently exposed within the Spring Mountains-Clark Mountains block (Fig. 5). In its northern exposures in the Spring Mountains, the thrust strike at high angle to the boundary between the Spring Mountains block and the highly extended area to the west (Fig. 7), projecting into the alluvium of Pahrump Valley (Figs. 4 and 5). Southwest of the Spring Mountains, in the highly extended Death Valley region, the thrust is present in a number of range blocks and is found as far west as the Panamint Range (Wernicke and others, 1988a, 1988b; Figs. 4 and 5). To the south, the thrust system reappears in the Clark Mountains block (Fig. 5).

At present erosion levels, the thrust usually carries Precambrian Z clasts over the Bird Spring Formation (Figs. 3 and 6). The thrust is probably in part a decollement in northern areas (for example, Guth, 1981; Burchfiel and others, 1974), but south of the Spring Mountains, it typically is not a hanging-wall decollement within miogeoclinal strata, as it cuts rapidly through the miogeoclinal section (for example, Burchfiel and Davis, 1971; Burchfiel and others, 1983; Wernicke and others, 1988b). At structurally deep levels, where hanging-wall basement overrides Precambrian Z clastics, the thrust has a decollement geometry (Burchfiel and Davis, 1971).

The Wheeler Pass system is the lowest thrust plate to contain exposures of the Precambrian Z clastic section and underlying basement and Pahrump strata (Fig. 6). It carries the thickest sections of these strata, which thicken rapidly westward from about 2,000 to 2,500 m immediately above the thrust to more than 5,000 m to the west (Figs. 3 and 6). Silurian strata pinch in just beneath the thrust in the Nopah Range area (Figs. 4 and 6), but farther north, the Silurian is present well to the east of the thrust plane (for example, Langenheim and others, 1962). Maximum thickness of Silurian strata are found only in higher thrust plates (Fig. 6a).

The features that distinguish the Wheeler Pass system include its structural style, position in the miogeoclinal, and the fact that it is the only thrust in the region that emplaces rocks as old as Precambrian Z on top of post-Mississippian strata, with the exception of portions of the Last Chance system (described below), which is clearly a structurally higher system. The stratigraphic throw of the Wheeler Pass system is consistently about 5,000 ft.

Higher Thrusts and Backfold. Above the Wheeler Pass system, recognize a belt of two east-vergent structures (Clary-Lemoligne and Marble Canyon-Schwaub Peak thrusts) and a third, structurally higher west-vergent structure (White Top Mountain and related west-
in the eastern foothills of the Kingston Range. These folds are on strike with similar folds in the Mesquite Mountains to the southeast that are in the hanging wall of the Mesozoic Winters Pass thrust. We suggest that these folds formed during an early episode of northeast-directed thrusting along the Winters Pass thrust. Because the older rocks were folded by Mesozoic deformation it is difficult to assess how much of their tilting within the upper plate of the Kingston Range detachment occurred during Cenozoic rotation. Upper Cenozoic strata rest unconformably on folded Cambrian rocks at one locality on the northeast slope of the Kingston Range in the footwall of the detachment. They dip 10 to 20 degrees northeastward, suggesting some Cenozoic rotation of the footwall rocks. It is not clear, however, whether this rotation is related to detachment faulting or to warping along the northeastern flank of the Mesquite Pass antiform (Fig. 9).

The Noonday Dolomite rests unconformably on crystalline metamorphic and igneous rocks in the footwall of the Kingston Range detachment with only thin (a few tens of meters) intervening local deposits that may be equivalent to the upper Precambrian Pahrump Group. However, the hanging wall contains a thick sequence (several kilometers) of Pahrump Group rocks below the Noonday Dolomite. The dolomite rests unconformably on rocks of the Pahrump Group and progressively rests toward the north on older Pahrump units until it lies across crystalline southwest-dipping, planar and listric normal faults and associated northeast-striking tear or transfer faults. Some of the normal faults have clearly been rotated into shallower dips. Many of the faults are strongly curved in plan view and, presumably, in cross section. This suggests that some of the hanging wall faults are spoon-shaped. Extensional duplexes can be seen locally in erosional windows. The matching of hanging-wall to footwall cutoffs of the northeast-dipping Noonday Dolomite indicates that the easternmost and lowest fault of the detachment complex has about 3 to 4 km of displacement (stop 3-6).

Figure 15. Cross-sections through the northeast Kingston Range and the northwest Mesquite Mountains that illustrate the shallow dip and upper plate structure of the Kingston Range detachment fault. The locations of sections AA' and BB' are shown on Figures 16 and 9 respectively. Unit designations not explained for previous figures are: Xm = Precambrian metamorphic rocks; Yp = Precambrian Pahrump Group; Znj = Precambrian Noonday Dolomite and Johnnie Formation. The patterned unit at A, section AA', is the Miocene Kingston pluton. The heavy dashed line near the bottom of section BB' is the Mesozoic Winters Pass thrust fault.
Fig. 0-6: Tectonic map of the Basin and Range province at the latitude of Las Vegas showing major Cenozoic fault systems. Areas of relatively minor Neogene tectonism bound two major extensional belts, the Death Valley extensional system to the west and the Las Vegas extensional system to the east. Tick-marked lines, low-angle normal faults; ball-and-bar symbol, high-angle normal faults; arrows, strike-slip faults; GF, Garlock fault; SDF, Southern Death Valley fault zone; HMF, Eunter Mountain fault; NFZ, Northern Death Valley-Furnace Creek fault zone; LVVSZ, Las Vegas Valley shear zone; LMFS, Lake Mead fault system. Note that left-lateral strike-slip faults tend to strike northeastward while right-lateral strike-slip faults strike northwestward [modified from Burchfiel and Davis, 1988 and Wernicke et al., 1988].

differs from structurally underlying thrusts in the Death Valley region in that it commonly is a decollement in both hanging wall and footwall, and has nearly twice the stratigraphic throw (generally 5000-6000 m). There are numerous windows into Carboniferous strata throughout the Last Chance Range-Inyo Mountains area that show that the thrust cuts gradually downsection within Precambrian Z strata to the west [Stewart et al., 1966; Nelson, 1981]. The transition from quartzite and siltstone facies to shale and carbonate facies of the Precambrian Z clastic wedge (Figure 0-3) occurs within the hanging wall of the thrust system [Corbett et al., 1988].

East Sierran thrust system and Sierran batholith. The eastern margin of the Sierra Nevada batholith and a coincident zone of thrust faults trend about N30°W across the western part of the region, cutting obliquely across the northeast-trending isopachs, facies lines and thrust faults developed in the miogeoclinal wedge. (Figure 0-4) [Dunne, 1986]. The East Sierran system was apparently localized by the thermal contrast between the batholith and cooler lithosphere to the east [e.g. Burchfiel and Davis, 1975]. It is younger than the higher thrusts developed in the miogeocline, because a suite of Early Jurassic alkalic plutons cuts the miogeoclinal thrusts, while younger plutons of the batholith are cut by strands of the East Sierran system [Dunne, 1986]. The hanging wall of the system seems to override progressively lower thrust plates southward, but the large proportion of plutonic rock in the hanging wall of the thrust system precludes identification of offset traces of the older thrusts. For a discussion of relative and absolute timing constraints on the thrust systems in the region, the reader is referred to Dunne et al. [1978], Burchfiel and Davis [1981], Dunne [1988], and Corbett et al. [1988].

Cenozoic Extensional Framework

Cenozoic extension in the Las Vegas region is dominated by two west-dipping normal fault systems, active principally in Neogene time (Figure...