B. C. BURCHFIEL *Department of Geology, Rice University, Houston, Texas 77001*
R. J. FLECK *U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025*
D. T. SECOR *Department of Geology, University of South Carolina, Columbia, South Carolina 29210*
R. R. VINCELETTE *Trend Exploration Limited, 600 Capitol Life Center, Denver, Colorado 80203*
G. A. DAVIS *Department of Geology, University of Southern California, Los Angeles, California 90007*

Geology of the Spring Mountains, Nevada

ABSTRACT

The northwest-trending Spring Mountains, Nevada, contain a 45-mi-wide (75-km) cross section of the eastern part of the North American Cordilleran orogenic belt and geosyncline. This cross section is probably the most southerly exposed section which exhibits structure and stratigraphy "typical" of the eastern part of the Cordillera.

Stratigraphically, the transition from Paleozoic craton to miogeosyncline is present from east to west across the Spring Mountains. The sedimentary succession through the middle Permian thickens from 8,800 ft (2,660 m) east of the Spring Mountains to approximately 30,000 ft (9,000 m) in the west. Thickening of individual formations accounts for 6,800 ft (2,070 m) of added section, addition of formations at unconformities accounts for 4,600 ft (1,400 m) of added section, and addition of a thick terrigenous late Precambrian sequence accounts for 9,800 ft (3,000 m) of added section.

Three major thrust plates are exposed in the Spring Mountains, each structurally higher plate containing a thicker sequence of Paleozoic rocks. The easternmost thrust is the Keystone thrust, except where the earlier Red Spring thrust plate is present below the Keystone as isolated remnants. The Keystone thrust appears to be a décollement thrust, but complications at depth suggest that additional thrust slices may be present below the thrust or several thousand feet of late Precambrian terrigenous rocks may be present above the thrust. The structurally higher Lee Canyon thrust plate probably contains at least 4,000 ft (1,200 m) of these terrigenous rocks at its base, and the Wheeler Pass thrust plate contains at least 11,000 ft (3,300 m) of these rocks. Pregeosynclinal basement could be involved in some of the higher thrust plates, particularly the Wheeler Pass plate, but depths of exposure are inadequate to determine its role.

Thrust faulting has produced a shortening of from 22 to 45 mi (36.6 to 75 km) in the geosynclinal rocks based on geometric constructions of cross sections at depth. This range probably represents a minimum figure. Some folding and thrusting occurred during the early Late Cretaceous, but data within the Spring Mountains only establish a much wider time bracket, post–Early Jurassic to pre–late Cenozoic for the easternmost thrust faults and post–Early Permian to pre–late Cenozoic for the westernmost thrusts.

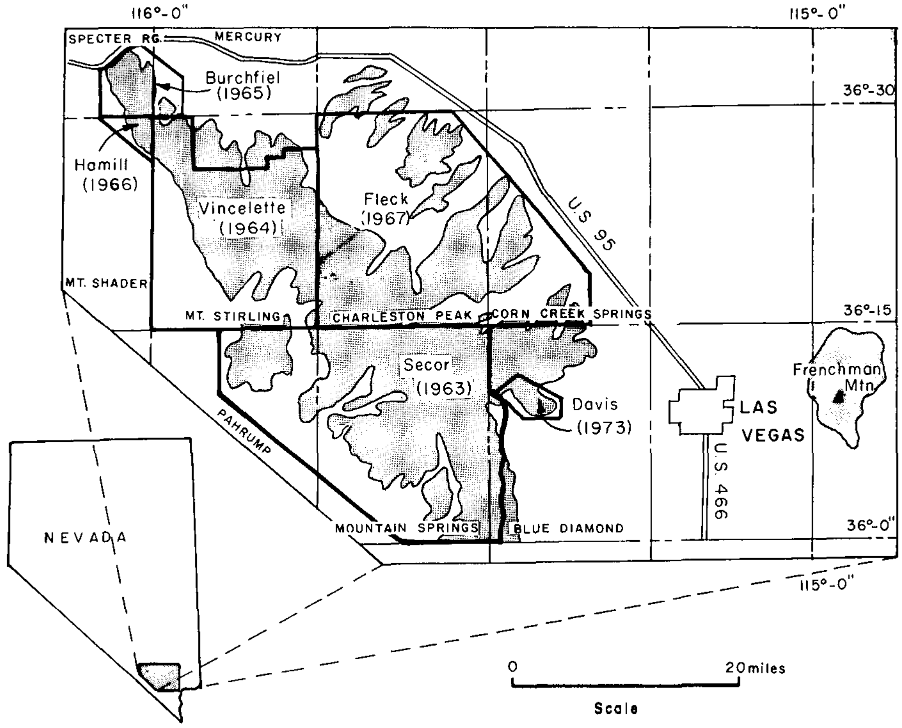

Figure 1. Location map of the Spring Mountains, Nevada, showing areas of mapping responsibility. Quadrangle names are shown for the Spring Mountains area.

INTRODUCTION

The Spring Mountains are located in southeastern Nevada, 10 mi west of Las Vegas (Fig. 1). Trending northwest more than 45 mi, they form a southern boundary for the general north or northeast-trending ranges farther north in Nevada. Because the northwest topographic trend is transverse to the north- or northeast-trending regional structural strike, the Spring Mountains offer a unique opportunity to study a wide cross section of continuously exposed pre-Tertiary rocks. Stratigraphically, the Spring Mountains contain Paleozoic rocks which show the transition from craton to miogeosyncline. Structurally, they contain rocks of the undeformed craton and of three major thrust plates belonging to the easternmost part of the North American Cordilleran orogenic belt.

The earliest geologic work in the Spring Mountains was by G. K. Gilbert (1875), who served as a geologic assistant for the Wheeler expeditions of 1871–1872. R. B. Rowe of the U.S. Geological Survey did extensive work in the central part of the Spring Mountains during the period 1900–1901, but he died before his results could be published. His field data were incorporated in the regional report of J. E. Spurr (1903). Rowe clearly recognized the fault along the east side of the Spring Mountains now referred to as the Keystone thrust.

In 1919, C. R. Longwell began systematic mapping in the region of southeastern Nevada. His work, together with that of Nolan (1929) and Glock (1929), led to the first regional geologic map of southeastern Nevada and of the Spring Mountains (Bowyer and others, 1958). Longwell's work forms the basis for most of our present understanding of the tectonics and

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stratigraphy in this part of the Cordilleran thrust belt. The present report summarizes the geology of most of the Spring Mountains compiled from work completed at various times from 1961 to the present (Fig. 1). The authors of this paper owe a great debt to Chester Longwell for assistance given, ranging from selection of map areas, field excursions, and discussions to personal inspiration.

GEOLOGY OF THE SPRING MOUNTAINS

The Spring Mountains contain geology typical of the eastern part of the Cordilleran orogenic belt which can be traced continuously from Canada to southern Nevada. Late Precambrian and Paleozoic rocks are characterized by a thin (approx. 8,800 ft or 2.6 km) cratonal sequence to the east which thickens northwestward (to approx. 30,000 ft or 9.0 km) in the Spring Mountains into the miogeosynclinal part of the Cordilleran geosyncline (Fig. 2). Mesozoic rocks are present only in the eastern part of the Spring Mountains, and their relations to Mesozoic geosynclinal development are not clear (Stanley and others, 1971; Burchfiel and Davis, 1972). Structures in the Spring Mountains are dominated by east-directed thrust faults along which thicker sequences of Paleozoic rocks have moved over thinner ones. At present levels of exposure, thrust plates carry only sedimentary rocks. These structural and stratigraphic characteristics are similar to those described from areas farther north along the eastern part of the Cordilleran orogenic belt.

Southward, however, the structural and stratigraphic relations change, such that the next exposed southeast cross section in the Mesquite and Clark Mountains, 30 mi farther south, contains Paleozoic sedimentary rocks characteristic of the craton and transitional between craton and miogeosyncline, and thrust plates that involve Precambrian crystalline basement rocks (Burchfiel and Davis, 1971, 1972). Regional relations suggest a divergence of structural and geosynclinal units (Burchfiel and Davis, 1972); thus, the Spring Mountains represent the southernmost example of "typical" Cordilleran tectonics.

Stratigraphy

No attempt is made here to describe all the stratigraphic units present in the Spring Mountains. Lithology, thickness, and facies changes are presented in Figure 2, and details of these sequences can be found in Burchfiel, 1964; Secor, 1963; Vincelette, 1964; Fleck, 1967, 1970, 1974; Gans, 1970; Longwell and others, 1965. The four representative stratigraphic columns presented on Figure 2 demonstrate the change from a cratonal sequence at Frenchman Mountain (25 mi east of the Spring Mountains; Fig. 1) to a geosynclinal sequence in the northwest Spring Mountains.

Stratigraphically, the oldest exposed parts of the most easterly and westerly sections, and by inference the two central sections, begin with a nonmarine and shallow marine sequence of terrigenous rocks. At Frenchman Mountain, these rocks are Early and early Middle Cambrian in age, approximately 1,000 ft (300 m) thick, and rest unconformably on Precambrian crystalline rocks. In the northwestern part of the Spring Mountains, the terrigenous rocks are more than 11,000 ft (3.3 km) thick and range from late Precambrian to early Middle Cambrian in age. South and southwest of the Spring Mountains, the thick late Precambrian terrigenous sequence rests unconformably on either crystalline basement or on an older sequence of unmetamorphosed to weakly metamorphosed late Precambrian sedimentary rocks (Pahrump Group) that rests unconformably on crystalline basement. Regional correlations by Stewart (1970) suggest that the upper part of the Tapeats Sandstone in some cratonal sequences correlates with the Zabriskie Quartzite of the geosynclinal sequence (for example, northwestern Spring Mountains section) and that the lower part of the Tapeats correlates with the uppermost part of the Wood Canyon Formation. The transition from the thin cratonal sequence to the thick geosynclinal sequence must occur beneath the Spring Mountains; the thick geosynclinal terrigenous sequence is first exposed in the Wheeler Pass thrust plate where it is already fully developed.

The upper part of the terrigenous sequence becomes calcareous and contains carbonate beds in lower Middle Cambrian rocks of the Bright Angel Shale, or its geosynclinal equivalent, the Carrara Formation, and grades upward into a thick sequence of shallow-water carbonate rocks that range in age from Middle Cambrian to Early Permian. Thin terrigenous units are present at several stratigraphic levels, and three can be followed from the cratonal into geosynclinal sequences: (1) the thin calcareous siltstone at the base of the Banded Mountain Member of the Bonanza King Formation, (2) the Dunderberg Shale Member of the Nopah Formation, and (3) the basal terrigenous rocks of the Bird Spring Formation. Three other prominent but thin terrigenous units are present in the geosynclinal sequence of the northern Spring Mountains, but are not present in the eastern Spring Mountains. Those three units are (1) Eureka Quartzite, (2) Ninemile Formation, and (3) a sandstone unit at the base of the Nevada Formation.

The carbonate formations can be followed through the Spring Mountains with little lithologic change: some are cut out by unconformities. Facies changes occur between the Spring Mountains and Frenchman Mountain, but the general characteristics of the formations are maintained. All the carbonate formations that have been studied suggest deposition in shallow marine or marginal marine environments (Gans, 1970).

Thickening of the carbonate sequence across the Spring Mountains takes place in two ways: (1) by thickening of individual formations and (2) by addition of formations at unconformities. Thickening is marked in the Bird Spring Formation and equivalents of Late Mississippian to middle Permian age which thicken from 1,600 ft (485 m) at Frenchman Mountain (Callville Limestone and Permian red beds) to more than 6,700 ft (2,000 m) in the central Spring Mountains. Some formations thicken by 50 to 60 percent (for example, Bonanza King Formation), whereas others show little if any thickening (for example, Monte Cristo Limestone and Sultan Limestone).

Addition of formations at unconformities accounts for approximately 4,600 ft (1,400 m) of thickening across the Spring Mountains. In the cratonal sequence at Frenchman Mountain, only one major unconformity is present in the Paleozoic carbonate sequence; the Middle Devonian Muddy Peak Limestone rests unconformably on the Upper Cambrian Nopah Formation. In the eastern part of the Spring Mountains above Red Rock Canyon, two and possibly three unconformities are present. One occurs between Lower and Upper Ordovician rocks (Goodwin Limestone and Mountain Springs Formation of Gans, 1970) which are here present below the Middle Devonian unconformity. A second unconformity is present below Middle Devonian rocks (Sultan Limestone) and is of regional extent. A third unconformity within unfossiliferous dolomites at the top of the Mountain Springs Formation is suspected but not proven (Gans, 1970). South along the Spring Mountains, the Ordovician and suspected Devonian rocks are cut out by the unconformities beneath Middle Devonian rocks, and the Middle Devonian Sultan Limestone rests on the Upper Cambrian Nopah Formation at Mountain Springs Pass. The trend of this wedge out of Ordovician and Devonian(?) rocks must be northeast across the structural trend (that is, west of Frenchman Mountain and north of Mountain Springs Pass).

Farther west, the Middle Ordovician Ninemile Formation, Antelope Valley Limestone, and Eureka Quartzite occur below the Upper Ordovician rocks, so that in the central part of the Spring Mountains, an unconformity is no longer recognized within Ordovician strata, and the Ordovician sequence is complete. Farther west, but still in the central Spring Mountains, the

Silurian Laketown Dolomite occurs beneath the Middle Devonian Sultan Limestone and thickens westward. Finally in the northwest Spring Mountains, Lower Devonian dolomite beds of the Nevada Formation are present beneath Middle Devonian rocks and thicken rapidly; farther west the unconformity within Devonian rocks is no longer recognized. Thus, in the northwest Spring Mountains, all formations seem conformable and range from late Precambrian to Mississippian and probably Late Permian in age.

Pre–Late Permian strata (that is, pre-Coconino Sandstone) on the craton are 7,700 ft (2,300 m) thick. Assuming that a thick section of Bird Spring Formation once overlay the rocks exposed in the northwest Spring Mountains, the total stratigraphic thickness of pre–Late Permian geosynclinal rocks may have been approximately 30,000 ft (9.0 km). Estimates of the contributions to westward thickening of the section are the following: (1) thickening of individual formations that carry through to the craton: 6,800 ft (2,070 m) or 32 percent; (2) addition of formations at unconformities: 4,600 ft (1,400 m) or 22 percent; and (3) addition of thick terrigenous late Precambrian sequence: 9,800 ft (3,000 m) or 46 percent. The Bird Spring Formation alone accounts for one-half of the total effect of formational thickening. Thus, excluding this formation, the main cause of geosynclinal thickening is the addition of the late Precambrian terrigenous wedge at the base.

Formations that overlie the Paleozoic carbonate sequence are largely terrigenous with marine carbonate rocks present only in Late Permian and Early Triassic units. These terrigenous formations range in age from Early Permian to Cretaceous(?) and are exposed only in the cratonal sequence at Frenchman Mountain and in the eastern part of the Spring Mountains (Figs. 2 and 3). The oldest of these terrigenous units is the lower Permian red beds which lie below the Kaibab and Toroweap Formations of Leonardian age. In the eastern Spring Mountains, they conformably overlie Lower Permian rocks of the Bird Spring Formation. Because the Bird Spring Formation in the central Spring Mountains contains fusulinids of Leonardian age, part or all of the red beds in the east may be equivalent to marine limestone units farther west. The red beds grade upward into the marine limestone and evaporite beds of the Toroweap and Kaibab Formations. The Kaibab and Toroweap Formations wedge out to the northwest and are not present in the central Spring Mountains where they are cut out by pre-Moenkopi erosion.

The Moenkopi Formation of Early Triassic age was deposited unconformably on older formations. Unlike the unconformity at the base of the Sultan Limestone, which from west to east truncates progressively older formations, the pre-Moenkopi unconformity truncates older formations from east to west. A basal detrital and conglomeratic unit overlies the unconformity and is overlain in turn by shallow-water marine limestone correlative with the Virgin Limestone member of the Moenkopi Formation. These rocks represent the last identified marine strata in the Spring Mountains area. A thin sequence of red beds forms the uppermost beds of the Moenkopi; they are the youngest rocks present in the allochthonous terrane of the Spring Mountains and are present only in the Keystone thrust plate. Rocks younger than Bird Spring Formation are absent above the Lee Canyon thrust fault. Detrital rocks of the Moenkopi in the cratonal sequence on Frenchman Mountain and below the Keystone thrust in the eastern Spring Mountain continue unbroken into the Lower Jurassic Aztec Sandstone. The uppermost part of the Moenkopi Formation and the Aztec Sandstone are not present west of the Keystone thrust fault.

Locally, channels filled by conglomerate with red sandstone matrix are present at the top of the Aztec and immediately below the Keystone and Red Spring Thrusts. Secor (1963) and Davis (1973) have interpreted these channel deposits of post-Aztec age and suggest that they may be as young as Cretaceous. In any case, these conglomerate units are the youngest rocks in the area and indicate that the Keystone and Red Spring thrust plates may have moved across erosional surfaces (see below).

Structure

Structure of the Spring Mountains north of Mountain Springs Summit is dominated by three thrust faults which trend north to northeast through the northwest-trending range (Fig. 4). Passing through the eastern part of the range is the Keystone thrust which forms the easternmost thrust of the Cordilleran orogen throughout most of the Spring Mountains as well as farther south. The Lee Canyon thrust cuts through the central part of the mountains, and the Wheeler Pass thrust cuts through the western part. Four thrusts of probably smaller magnitude are also present: (1) the Red Spring thrust which lies below the Keystone thrust northeast of Red Rock Canyon, (2) the Kyle Canyon thrust which crops out over a small area in the central Spring Mountains, (3) the Deer Creek thrust, and (4) the Macks Canyon thrust. The latter two faults crop out only in the north half of the range (Fig. 4).

Folds occur either as minor intrafolial or intraformational structures of limited lateral extent or as very large amplitude, long wave-length structures, involving most or all of the stratigraphic section in the area. The latter are commonly associated with thrust faults, which appear to postdate the folds (Fleck, 1970; Vincelette, 1964; Nolan, 1929). High-angle faults cut and are cut by thrust faults, suggesting at least two periods of high-angle faulting. The high-angle faults most commonly trend northwest, although north-trending faults are numerous locally.

The structural grain of the northeastern half of the Spring Mountains has been rotated by late Tertiary movement on the Las Vegas Valley shear zone (Longwell, 1960; Fleck, 1967), which lies in Las Vegas Valley immediately northeast of the Spring Mountains. Thrust faults, folds, and bedding that strike north in the southwestern part of the range arc northeast adjacent to Las Vegas Valley. This bending was interpreted by Longwell (1960) to be right-lateral drag along the south side of the shear zone.

Structure of the Autochthon. Autochthonous rocks crop out only on the eastern slope of the Spring Mountains where they form a homocline of Mesozoic strata that dips gently westward. In Red Rock Canyon, the Mesozoic rocks are overturned eastward below the Keystone thrust. This fold plunges below the thrust and is not exposed north or south of the Red Rock Canyon area. East of Mountain Springs Summit, near the southern boundary of Figure 3, a northwest-striking, high-angle fault, the Cottonwood fault (Hewett, 1931), juxtaposes Devonian and Mississippian rocks on the south and Jurassic Aztec Sandstone on the north. Rocks south of the fault are part of the Contact thrust plate (Hewett, 1931; Davis, 1973) which overrides Aztec Sandstone south of the area shown on Figure 3. Thus, rocks south of the Cottonwood fault are displaced downward several thousand feet relative to rocks north of the fault. The fault displaces the thrust vertically by only 200 ft (65 m), with the south side down, suggesting that most displacement on this fault was pre-Keystone in age. Other faults that cut both the autochthon and the Red Spring thrust farther north suggest similar age relations (see below).

Red Spring Thrust Plate. Longwell (1926) described the Red Spring thrust as a low-angle fault in the eastern Spring Mountains which carried Cambrian dolomite eastward over Jurassic Aztec Sandstone. The thrust was subsequently broken into at least four east-tilted fault blocks by north- or northwest-trending high-angle faults (Fig. 4). Later, probably following considerable erosion, the blocks were overridden by the Keystone thrust plate. Longwell later (1960) reinterpreted the Red Spring thrust plate as frontal parts of the Keystone thrust plate which were faulted, rotated, and overridden by the Keystone thrust plate. Mechanically, Longwell visualized a continuous eastward advance of the Keystone

Figure 3. Geologic Map of the Spring Mountains, Nevada.

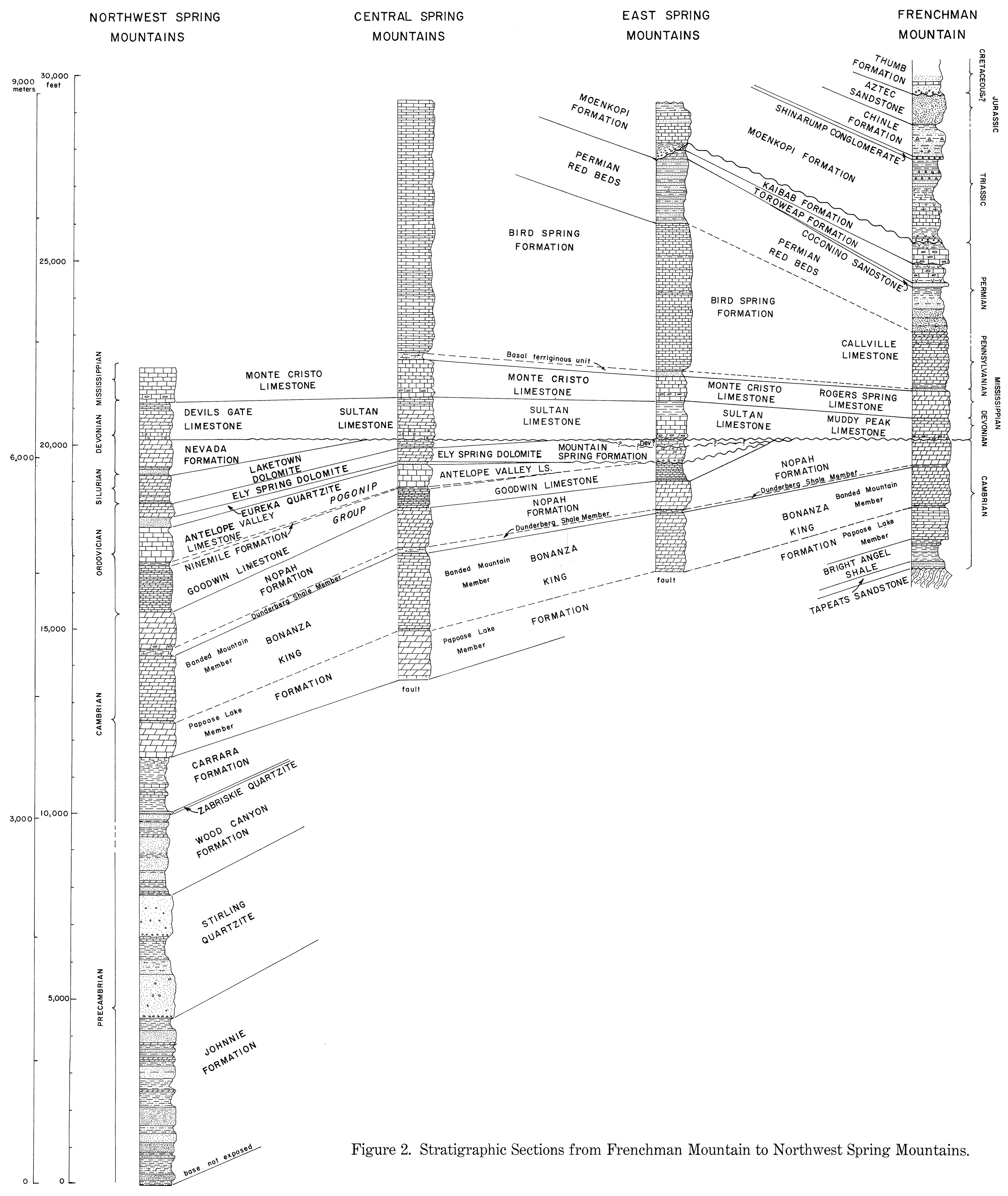

Figure 2. Stratigraphic Sections from Frenchman Mountain to Northwest Spring Mountains.

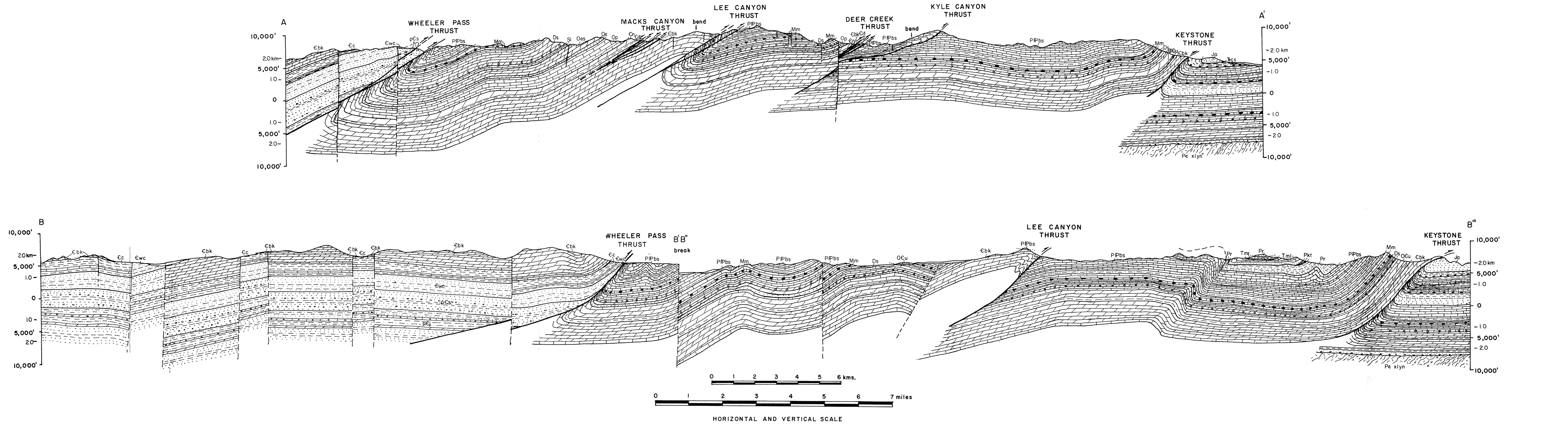

Figure 5. Geologic Sections, Spring Mountains, Nevada.

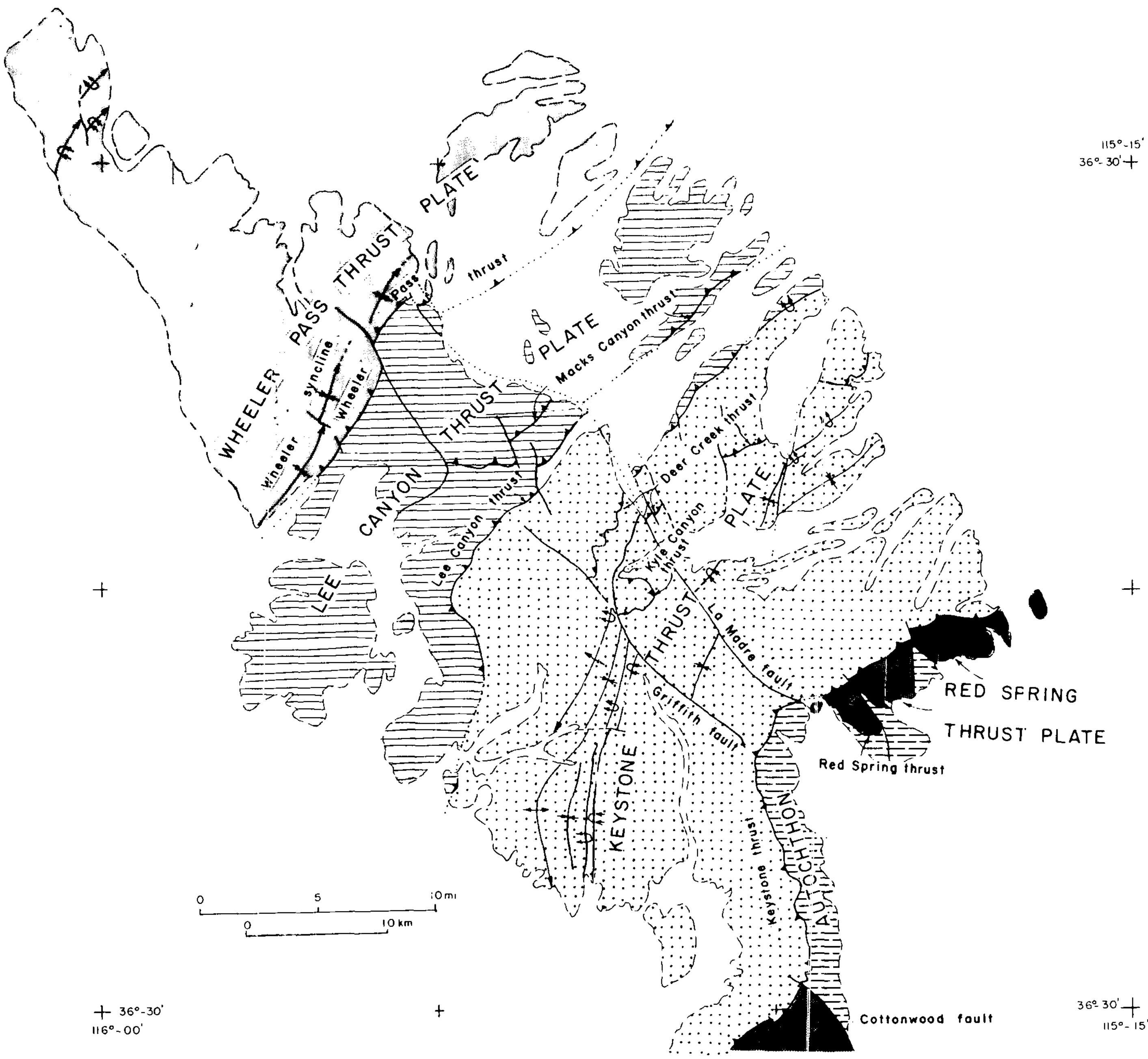

Figure 4. Generalized tectonic map, Spring Mountains, Nevada.

plate modified by synchronous strike-slip movement on the Las Vegas shear zone. Later work by Fleck (1967; 1970) and Anderson and others (1972) demonstrated a late Tertiary age for the Las Vegas shear zone. Recent work by Davis (1973) and Longwell (1973) have returned to Longwell's original interpretation of the Red Spring thrust. Only the westernmost fault blocks containing the Red Spring Thrust have been remapped and are shown on Figure 3.

Davis (1973) believes that rocks below the Keystone thrust and south of the Cottonwood fault, which belong to the Contact thrust plate of Hewett (1931), are correlative with the Red Spring thrust plate. He further interprets the Cottonwood fault as similar to faults that cut the Red Spring thrust. Thus he suggests that the Red Spring thrust plate once covered most of the Jurassic Aztec Sandstone shown on Figure 3, but it was uplifted on a horst between the La Madre and Cottonwood faults and was subsequently eroded prior to the thrusting of the Keystone thrust plate.

Longwell (1926) described discontinuous conglomerate lenses beneath the Red Spring thrust which he interpreted as surficial deposits overridden by the thrust plate. A restudy of these conglomerates by Davis (1973) reconfirms Longwell's interpretation; Davis (1973) believes that the conglomerates represent channel deposits cut into the Aztec Sandstone, indicating that the frontal parts of the Red Spring thrust moved across an erosion surface. The conglomerate beds contain rounded pebbles and cobbles of late Precambrian terrigenous rocks, Paleozoic carbonate rocks, and Mesozoic terrigenous rocks set in a matrix of red sand reworked from the Aztec Sandstone. Longwell (1973), however, has abandoned his original interpretation of the restricted surficial nature of the conglomerate beds. He now interprets them as basal remnants of a thicker, more extensive clastic sequence which has been overridden and largely obliterated by movement of the Red Spring thrust plate. Because of their importance, locations of the conglomerate beds are shown by small circles on Figure 3 (secs. 23, 24, and 36, T. 20 S., R. 58 E.).

Along the crest of the ridge on which the Red Spring thrust crops out and is centered on sec. 31, T. 20 S., R. 59 S., there is a long narrow outcrop of breccia composed of carbonate rocks which were derived from Cambrian to Mississippian formations. Originally mapped as a thrust klippe (Longwell and others, 1965), the breccia is interpreted by Davis (1973) as a landslide breccia. Small outcrops can be followed north where they seem to project below the north-dipping Red Spring thrust plate. Although the relation is obscured by alluvium, stream channels carrying debris eroded from advancing thrust plates and landslide material shed from these plates may have been buried beneath the Red Spring thrust plate as it advanced.

Keystone Thrust Plate. The Keystone thrust fault can be followed along the entire eastern face of the Spring Mountains, although its continuation east of sec. 14, T. 20 S., R. 58 E. has not been mapped since the work of Longwell and others (1965). Along the fault, the Cambrian Bonanza King Formation was thrust eastward over Jurassic Aztec Sandstone and remnants of the Red Spring and Contact plates. Along its trace, the thrust dips west approximately parallel to bedding in the Bonanza King Formation above and the Aztec Sandstone below. In Red Rock Canyon, the thrust is exposed at a deeper level and dips approximately 30° west, still approximately parallel to bedding in the Bonanza King Formation of the upper plate but cutting across bedding in overturned Mesozoic formations of the lower plate. Farther east, the thrust cuts across rocks of the Red Spring thrust plate which are locally thrown into an overturned syncline (secs. 22 and 23, T. 20 S., R. 58 E.); dips along the thrust contact vary from 16° north to near vertical.

At Red Rock Canyon, the thrust lies at the base of the Banded Mountain Member of the Bonanza King Formation, but southward, rocks at the base of the plate are folded, faulted, and brecciated on a small scale; how closely the thrust follows stratigraphic horizons in the Bonanza King is obscure. On a regional basis, the thrust fault is located near the boundary between the two members of the Bonanza King Formation (Fig. 2) for a distance of more than 35 mi (60 km), strongly suggesting stratigraphic control of the thrust.

Structure within the Keystone thrust plate consists of folds, high-angle faults, and thrust faults, which are variably developed in three blocks bounded by two northwest-striking faults. The southern block is bounded by alluvium on the south and by the Griffith fault on the north; the central block is bounded by the Griffith and La Madre faults, and the northern block is bounded by the La Madre fault on the south and alluvium on the north. At the eastern end of each block, the Paleozoic rocks dip homoclinally west or northwest at the base of the Keystone plate; within a few miles west of the thrust, however, each block develops a different structural style.

The southern block contains a complex syncline and anticline, both of which generally plunge south (Fig. 5, cross section). The syncline is outlined by a core of Permian red beds and Moenkopi Formation, which exhibit varying degrees of small-scale folding. The anticline, which has a core of Bird Spring Formation or, locally, Monte Cristo Limestone, is asymmetric with its eastern limb overturned to the east. Both the major syncline and locally the major anticline are cut by several northwest-trending, high-angle faults that may have acted as tear or adjustment faults. Secor (1963) has shown that many of the smaller folds are truncated by these faults and do not continue in the adjacent fault blocks. The form and number of folds change from block to block. Three blocks contain thrust faults, each confined to a single block; one thrust is east directed, another west directed, and a third contains a truncated klippe. Because of these changes in style, some high-angle faults were probably present during folding.

West of the axial traces of folds shown on Figure 3, there is a broad area underlain by unfolded Bird Spring Formation that dips 5° to 25° southwest. Westward, the dips steepen to 30° to 45° before passing below the Bonanza King Formation of the Lee Canyon thrust plate. Below the Lee Canyon thrust, there are two slices of upper Paleozoic carbonate rocks which were sheared from the Keystone plate. South of Trout Canyon, the southern slice contains mostly right-side-up Bird Spring Formation. The northern slice in the vicinity of Charleston Peak, however, contains overturned Bird Spring and Monte Cristo Formations which probably represent the overturned limb of a syncline below the Lee Canyon thrust, which was sheared off along its axial surface. Limestone beds in this slice are foliated and recrystallized mylonite near the Lee Canyon Thrust.

Structures and stratigraphic units can be followed directly from the southern block into the central block at the ends of the Griffith fault; but structurally, the main part of the central block is very different from that of the southern block. The only fold is a broad, open syncline in the southeastern part of the block, and no rocks younger than the Bird Spring Formation are present in its core. Northwest of this syncline, there are a series of east-directed thrust slices that are comparable to the overturned anticline of the southern block. The most important of these thrust faults is the Deer Creek thrust, which carried Cambrian dolomites over Bird Spring Formation. Shortening southwest of the Griffith fault is accommodated by folding. Both the upper and lower plates of the Deer Creek thrust are imbricated north of Kyle Canyon, repeating formations in several slices. The lowermost thrust of the lower plate which repeats the Bird Spring and locally the Monte Cristo Limestone has been named the Kyle Canyon thrust. Several of the small thrusts that repeat upper Paleozoic rocks above the Kyle Canyon thrust die out eastward into overturned folds, just as they do to the west. Thrusts in this area appear to die out upward as well as laterally; thus, lateral continuity of thrusts may be related in part to depth of exposure.

The northwestern part of the central block is cut by numerous high-angle faults, some of which are confined to rocks of the thrust plates. Other high-angle faults terminate small thrusts (such as west of Deer Creek campground) or fail to displace other thrusts. These relations suggest that some of these faults are tear (or adjustment) faults that date from the time of thrusting. At the northwest end of the central block, Cambrian rocks of the Lee Canyon thrust plate rest on Deer Creek thrust plate.

Northeast of the La Madre fault, the structural style of the northern block of the Keystone thrust plate is somewhat different from that of the central block. A large northeast-plunging syncline with an overturned western limb trends northeastward through the central part of the block. The core of the fold is outlined by Permian red beds and Triassic Moenkopi Formation and is locally folded on a small scale. A north-trending high-angle fault displaces the syncline, causing a right-handed separation.

The Deer Creek thrust is displaced by approximately 5,000 ft (150 m) of dip-slip movement on the La Madre fault. It crops out 1 mi southeast of the Hilltop campground in section 16, T. 19 S., R. 57 E. High-angle faults with large displacement truncate this short segment of the Deer Creek thrust near Angel Peak, and the thrust does not crop out for a distance of 3 mi to the northeast. The thrust reappears, however, in Lucky Strike Canyon. It can be followed from there to Las Vegas Valley. No structures related to the Deer Creek thrust are found between these exposures, although higher thrust plates, while displaced, crop out continuously across the block. Fleck (1974) concludes that evidence from these exposures and from others on the Lee Canyon thrust indicates that thrust displacement decreases upward on at least the smaller thrust faults and that deeper exposures in the Angel Peak area would reveal the Deer Creek thrust. This interpretation requires that crustal shortening related to the thrust faulting be accommodated by some other means, probably folding. The lateral transition of folds into thrust faults in this area (Fleck, 1970) supports this interpretation.

The Lee Canyon thrust plate has overridden the Deer Creek thrust plate; an overturned slice of Bird Spring Formation is present beneath it and represents the overturned limb of a syncline that was sheared along the axial surface. This relation is very similar to that present in the southern block of the Keystone thrust plate.

Total shortening in the northern block of the Keystone thrust plate is probably larger than in the other two blocks to the southwest. The northern block contains the Deer Creek thrust of the central block, a large overturned syncline and anticline similar to those in the south block, and several smaller folds and thrust slices. We suggest that the total shortening increases northeastward in the Keystone thrust plate, perhaps in part compensating for a decrease in displacement on the Lee Canyon thrust (see below).

Lee Canyon Thrust Plate. The Lee Canyon thrust fault is the middle of three major thrust faults that can be followed through the Spring Mountains. It can be traced from a small outcrop south of Trout Canyon (sec. 18, T. 21 S., R. 56 E.) to the west side of Charleston Peak, through Lee Canyon northeastward on the ridges south of the Lee Canyon road to Las Vegas Valley. Unlike the Keystone thrust, the Lee Canyon thrust cuts across significant thicknesses of strata. At Trout Canyon, the upper Bonanza Formation is exposed immediately above the thrust. Farther northeast, the thrust cuts through Ordovician, Silurian, Devonian, and Mississippian formations until (just before reaching Las Vegas Valley) it dies out into overturned folds in the Bird Spring Formation, demonstrating a decrease in displacement northeastward. Folding of the upper-plate rocks is common in the southern and northeastern parts of the Lee Canyon thrust plate; whereas in Lee Canyon, imbricate thrusts are more common.

The Macks Canyon thrust, here considered part of the Lee Canyon plate, can be traced from Clark Canyon through Macks Canyon (secs. 27 and 33, T. 18 S., R. 56 E.) and northeastward to the Las Vegas Valley along the ridge north of the Lee Canyon Road. At its west end in Clark Canyon, Bonanza King Formation is thrust over itself or over Nopah Formation. In its middle part, Cambrian and Ordovician rocks are imbricated; in its northeastern part, Mississippian and Pennsylvanian rocks are repeated. Thus, displacement on the Macks Canyon thrust is small and the fault is here considered a subsidiary thrust in the Lee Canyon thrust plate.

In upper Clark Canyon, the Macks Canyon thrust is cut by a curving high-angle fault that has west-side-down displacement. This fault is one of several intersecting high-angle faults of similar displacement that can be followed from 4 mi north of Wheeler Well (sec. 31, T. 17 S., R. 55 E.) southeast across Clark Canyon, then south across Wallace Canyon, and beneath a broad expanse of alluvium to the north side of the ridge north of Trout Canyon (sec. 26, T. 20 S., R. 55 E.). The down-dropped blocks probably contain the upper plate of the Macks Canyon thrust at depth, but because displacement on the Macks Canyon thrust just before intersecting the high-angle fault at Clark Canyon is less than a few hundred feet, it is possible that the thrust never extended much farther west.

North and west of the Macks Canyon thrust, progressively younger rocks are present in the Lee Canyon thrust plate because of a general northwestward-to-westward dip. Folding of these rocks is variable. In the southwestern part of the Lee Canyon plate (T. 20 S., west part of R. 54 E., east part of R. 55 E.), numerous small folds are present; many trend north, but others are more dome-shaped and have no obvious trend. In the western part of the plate, there is a syncline-anticline pair (secs. 17, 18, 19, T. 19 S., R. 55 E.), and the anticline is adjacent to the Wheeler Pass thrust. Small but unmapped thrusts probably complicate this atypical relation between folds and the Wheeler Pass thrust. Farther north, 2 mi southwest of Willow Spring (sec. 2, T. 18 S., R. 55 E.), a large overturned syncline is present beneath the Wheeler Pass thrust. To the northeast, across several miles of alluvium, an overturned slice of Bird Spring Formation is present below the projected but covered trace of the Wheeler Pass thrust. This slice probably represents the overturned limb of a syncline which was thrust along or near the axial surface of the fold, a relation suggested for similar slices below the Lee Canyon and Deer Creek thrust faults.

Wheeler Pass Thrust Plate. The Wheeler Pass thrust trends northeast across the west-central part of the Spring Mountains and carries a thick sequence of late Precambrian terrigenous rocks eastward over the Bird Spring Formation. The eastern trace of the thrust is covered by alluvium, but the fault undoubtedly passes between an overturned slice of Bird Spring Formation and rocks of the Cambrian Carrara Formation on Indian Ridge at the north end of the Mount Charleston quadrangle.

Beds of the Wood Canyon Formation or Stirling Quartzite lie immediately above the thrust and dip 25° to 45° west or northwest. Exposures near Wheeler Pass show that the dip of the thrust is steeper than bedding, cutting older strata at deeper levels. Rocks near the thrust are brecciated and contorted, but mylonitization was not detected. One small imbricate slice with an eastward overturned anticline above it is present near the base of the plate northeast of Wheeler Well (sec. 20, T. 18 S., R. 55 E.).

Within the Wheeler Pass thrust plate, structure is relatively simple. In its eastern part, the plate contains a north-plunging syncline (the Wheeler syncline); in its northwest part (north and west of the northwest corner of the Mount Stirling quadrangle), the plate contains a large northeast-plunging overturned syncline and locally an overturned anticline farther north. Rocks in the remainder of the plate dip at moderate angles to the north and northeast and are repeated by northwest- or north-striking, high-angle faults. Most of the northeastward or eastward dip of the beds and northeast plunge on the folds that occur in the western part of the plate were probably caused by east-northeast tilting of this part of the Spring Mountains during Cenozoic time.

Small-scale folding within the Wheeler Pass thrust plate is mostly confined to the well-stratified, thinly bedded terrigenous formations (that is, the Carrara and Johnnie Formations). The Carrara contains many small-scale folds near the southwest end of the Wheeler syncline. These folds are overturned eastward in the west flank of the syncline which is inconsistent with an origin as parasitic folds for the Wheeler syncline. Axial trends of these small folds have been rotated by the Wheeler syncline and are regarded as folds formed by intraformational slip during thrusting, but prior to the development of the Wheeler syncline.

Small folds are common in the middle and lower parts of the Johnnie Formation in the northwest part of the Spring Mountains. Folds generally increase in intensity downward and in proximity to the large overturned folds in the northwest part of the map area. Axial plane cleavage is better developed downward and to the northwest in the Johnnie Formation.

The projection of the Wheeler Pass thrust at depth in the northwest Spring Mountains is equivocal. Nolan (1929) believed the Wheeler Pass thrust flattened at depth and reappeared along the contact between the Johnnie Formation and the Stirling Quartzite as the Johnnie thrust. Subsequently, the Johnnie thrust played a large part in the interpretation of thrusting in southern Nevada (Longwell, 1945) and as recently as 1960, King described it as a classical example of a thrust fault which flattens at depth and follows stratigraphic units. Remapping of the area of the Johnnie thrust by several workers (Burchfiel, 1965; Hamill, 1966; Livingston, 1964; Vincelette, 1964) has not supported the existence of the Johnnie thrust.

Nolan's observations supporting the existence of the Johnnie thrust were (1) a white quartzite at the base of the Stirling Quartzite that he believed was a tectonic microbreccia formed along the thrust plane, and (2) that beds in the Stirling Quartzite above and beds in the Johnnie Formation below were truncated by this microbreccia. Vincelette (1964) demonstrated that the white quartzite is locally fractured but otherwise undeformed. The white quartzite is a basal member of the Stirling; at many localities, it makes a transitional sedimentary contact, locally unconformable with the Johnnie Formation. Furthermore, the intensity of deformation generally increases downward away from the Stirling-Johnnie contact, not toward it, as might be expected if this contact were a thrust fault. Locally, the contact shows evidence of displacement, but we regard this as differential movement between strongly contrasting lithologic units. Similar movement has been detected along the upper and lower contacts of the Eureka Quartzite.

If the Wheeler Pass thrust does flatten at depth, it must flatten below exposed parts of the Johnnie Formation. Even if it does flatten below the Johnnie, a simple décollement geometry cannot apply, because a reasonable projection of the thrust places the base of the Johnnie Formation in the Wheeler Pass thrust plate approximately 10,000 ft higher than corresponding rocks in the overridden Lee Canyon plate below. This relation suggests complications of thrust geometry at depth which is common for all thrust faults in the Spring Mountains and will be treated separately below.

The Wheeler syncline in the eastern part of the Wheeler Pass thrust plate does not appear to be the result of ramping produced above a riser on a décollement thrust, an interpretation which at first appears reasonable. The axial trace of the syncline converges with the trace of the Wheeler Pass thrust too rapidly to fit the geometry for a ramp origin (Fig. 3).

Large overturned folds in the Johnnie Formation in the northwestern part of the Wheeler Pass plate cannot now be related to any regional features. An overturned anticline is present in sec. 15, T. 16 S., R. 53 E., and is truncated obliquely by a high-angle fault that dips steeply west, so that only its normal west limb is exposed over much of the area west of this fault. Near the northwest corner of the map area, Cambrian dolomite is faulted against the late Precambrian terrigenous sequence along several intersecting faults. Some of these faults are low angle, dipping 30° north; others are nearly vertical. Relations tentatively suggest that the north block has moved down along the gently dipping normal faults that were parts of a single fault which was subsequently cut by later high-angle faults. The faulted contact between Cambrian dolomite and late Precambrian terrigenous rock probably represents the northwest boundary of the main part of the Spring Mountains block elevated during Cenozoic time.

Landslide Deposits. Within the Spring Mountains, there are large and small areas underlain by rocks which have been detached and moved downslope under the influence of gravity. Many of the smaller rock masses are thoroughly brecciated fragments, chaotically mixed. Most of the material in these masses was derived from one or more Paleozoic formations. These masses were probably emplaced as rock-fall avalanches or rock slides.

In most of the larger landslides, however, breccia is present only in the basal 50 to 100 ft of the deposit; the remainder of the deposit is unbrecciated and retains its coherence such that stratigraphic units can be traced through the deposits. Some of these landslide deposits, such as the composite landslide north of the mouth of Trout Canyon, reach large size. Here the landslide is made of several individual landslide blocks composed of Devonian through Permian formations bounded by brecciated rock at their basal contacts. These blocks are probably the erosional remnants of a sheet of landslide debris which was once more extensive and may have covered more than 20 sq mi. From their coherent character, we infer that these masses moved downslope rather slowly.

In all cases, the source of the landslide debris can be found upslope from its present position. None of the landslide masses are cut by either thrust faults or high-angle faults. Some masses, such as those at Trout Canyon, are being removed by the present drainage. Most of the deposits are found in topographically low areas of present basins or at the foot of the mountains, suggesting that they are related to topography not much different than that existing today, although most of the blocks are being buried by recent alluvium. With one exception, all evidence suggests a late Cenozoic age of emplacement for these masses. Only the landslide deposit east of the Red Spring thrust in the eastern Spring Mountains may be older. Davis (1973) has suggested that it may have been shed from the front of the Red Spring thrust plate and was later overridden by the thrust plate — such a relation would suggest a Mesozoic age for this landslide.

Geometry of Thrust Faults at Depth. Projecting the thrust faults of the Spring Mountains to depth in an attempt to construct their three-dimensional geometry encounters several difficulties and ambiguous relations that cannot now be resolved. However, some limits as to the range of possible interpretations can be presented. All interpretations presented here involve a geometry in which the thrust faults flatten with depth. This is a common interpretation for the eastern part of the Cordilleran thrust belt; it is supported by evidence from the Clark Mountain area 30 mi to the south (Burchfiel and Davis, 1971). The Clark Mountain thrust complex is the continuation of at least part of the thrust belt represented in Spring Mountains but exposed at a deeper level. The thrusts flatten at depth whether or not they are stratigraphically controlled (Burchfiel and Davis, 1971). Thus, this geometry is used as a basis for interpretation in the Spring Mountains.

The Red Spring thrust fault cannot be projected to depth, because it is truncated along its west side by the later Keystone thrust fault. This relation indicates that originally more westerly parts of the Red Spring thrust plate, not removed by pre-Keystone erosion, were incorporated into the frontal parts (that is, easterly parts) of the Keystone plate and transported at least far enough to the east so that post-Keystone erosion could remove evidence of their existence. Some problems in projecting the Keystone thrust fault to depth (see below) might be resolved, however, by inserting remnants of the Red Spring thrust plate below the fault.

The magnitude of displacement on the Red Spring thrust cannot be calculated because its geometry has been disrupted by pre-Keystone high-angle faults. A minimum estimate can be obtained, assuming the thrust originally dipped 30° and cut through a stratigraphic section with a minimum thickness of 10,000 ft (3,000 m). Using these assumptions, an estimate of 4 mi can be used as a minimum figure.

On a regional basis, the Keystone thrust fault appears stratigraphically controlled and can be reasonably projected as a fault that flattens at depth probably within or near the base of the Bonanza King Formation. Beneath the eastern part of both the southern and northern blocks of the Keystone plate, the thrust fault is projected to a depth of approximately 7,000 ft below sea level, which is close to the projected depth of the same stratigraphic level in the autochthonous rocks, making décollement geometry appear reasonable (Fig. 5). West of the large overturned syncline in these two blocks, the depth to the base of the Bonanza King rises to less than 4,000 ft below sea level beneath a broad anticline. This suggests that the fault is folded, cuts through older rock units in the plate, or contains several splay faults which die out upward below the anticline. If the thrust fault is warped, such as are thrusts in the Canadian Cordillera (Bally and others, 1966), other thin slices of Paleozoic rocks may be present above the décollement but below the Keystone thrust (Fig. 6a). Slices of this type are known from the Clark Mountain area 30 mi to the south (Burchfiel and Davis, 1971). An alternate interpretation is to change the geometry of the plate such that added stratigraphic units are present in the Keystone plate and above a décollement surface that dips gently westward (Fig. 6b). Older formations added at the base of the plate could include 3,000 ft (900 m) of the late Precambrian and Cambrian terrigenous sequence, and the eastern limb of the overturned anticline would represent a step in the upper plate where the thrust cuts across the base of the Bonanza King Formation to a lower stratigraphic level in the terrigenous sequence westward.

Configuration of the thrust below the central block presents additional problems, because the projected depth to the thrust, if it is at the base of the Bonanza King Formation, is nowhere more than 3,000 to 4,000 ft (900 to 1,200 m) below sea level (Fig. 5, A-A′). The corresponding stratigraphic level in the autochthon is at 7,000 ft (2,100 m), thus producing a disparity of nearly 3,000 to 4,000 ft (900 to 1,200 m) between the two positions. Possible solutions to this space problem are again the same as those presented for the north and south blocks of the Keystone plate, however, the eastern limit of the added slices or stratigraphic units would be several miles farther east in the central block, suggesting the La Madre and Griffith faults may extend to the base of the allochthonous units. Pre-Keystone high-angle faults that cut the Red Spring thrust might also cause complications in the geometry of the Keystone thrust at depth; however, the problem area is confined to the central block, suggesting a relation to the two bounding faults, the Griffith and La Madre faults. An alternate interpretation is that the central block has been elevated, relative to the blocks on either side, between the La Madre and Griffith faults. Displacements on the two faults increase westward, causing greater elevation in the central part of the block and resolving the space problem.

The Deer Creek thrust of the central and northern blocks can easily be projected into the lower part of the carbonate sequence because the same stratigraphic levels of the upper and lower plates are comparable at a point 3 mi west of the surface trace of the Deer Creek thrust (Fig. 5, sections A-A′). The Kyle Canyon thrust appears to be a high-level thrust slice below the Deer Creek thrust (Fig. 5, A-A′).

If the model involving thrust slices below the Keystone thrust is accepted, nearly the entire width of the Keystone plate would be allochthonous and the magnitude of eastward displacement would be approximately 14 mi (23 km) (Fig. 6a). If the model involving the addition of the terrigenous sequence at the base of the Keystone plate is accepted, the magnitude of eastward displacement is approximately 7 mi (11.6 km). Movement on the Deer Creek thrust adds approximately 3 mi (5 km) for the western part of the central and northern blocks.

The Lee Canyon thrust fault dips 30° to 40° west and cuts less steeply dipping bedding in the upper plate at an angle of 10° to 15°. At a depth of 2,000 to 4,000 ft (600 to 1,200 m) below the surface, the thrust must either change dip, if it follows the base of the Bonanza King Formation, or continue to dip westward and cut into older rocks such as the late Precambrian terrigenous sequence (Fig. 6). This latter case would require that 2,000 to 4,000 ft (600 to 1,200 m) of the terrigenous sequence be added to the Lee Canyon plate. In either case, folds in the Lee Canyon plate can be interpreted as originating from the overriding of ramp segments in the lower plate by the Lee Canyon plate (Fig. 6). From the geometry projected at depth, merger of the Lee Canyon and Keystone thrusts at depth can be inferred to occur 7 to 8 mi (11.6 to 13.3 km) west of the surface trace of the Lee Canyon thrust where stratigraphic levels in the two plates are at comparable elevations.

With either model proposed for the Lee Canyon thrust, the eastward displacement is approximately 4.5 mi (7.5 km) (Fleck, 1970). In addition, evidence presented above suggests that the Lee Canyon thrust is losing displacement eastward, and this

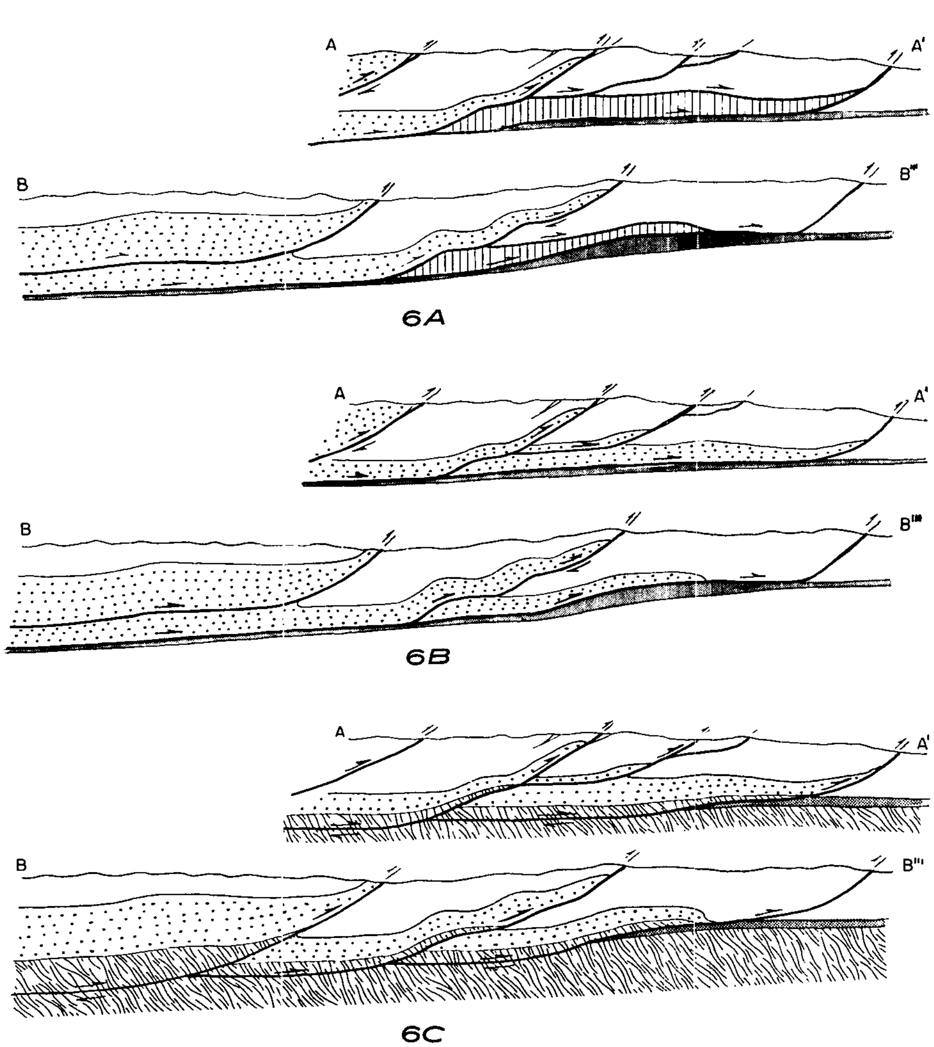

Figure 6. Interpretative cross sections from Figure 5. 6A. Space problem is solved by adding a thrust slice. 6B. Space problem is solved by adding late Precambrian terrigenous rocks to plates. 6C. Space problem is solved by adding Precambrian crystalline basement rocks to plates. Inclusion of crystalline basement in the Lee Canyon and Keystone thrust plates is to emphasize the non-décollement geometry which is possible. Note: high-angle faults have been removed, and topography is hypothetical. Dot pattern is late Precambrian terrigenous sequence, vertical line pattern is added thrust slice, gray pattern is autochthonous terrigenous sequence, and curved lines are Precambrian crystalline rocks.

may be the reason for the cross-cutting relations between the thrust and stratigraphic units in the upper plate (that is, as it loses displacement, the thrust trace more clearly expresses the ramp or cross-cutting character toward the point at which the thrust finally dies out).

The Macks Canyon thrust probably does not merge at depth with the Lee Canyon thrust in the central Spring Mountains. At its westernmost exposure, displacement on the thrust is small and it appears to be dying out within the upper part of the Bonanza King Formation. Farther northeast where it has larger displacement, the thrust may merge at depth with the Lee Canyon thrust.

A great disparity in the structural elevations of stratigraphic units on either side of the Wheeler Pass thrust is present. A difference of 10,000 ft (3,000 m) in elevation is present between the base of the Bonanza King Formation in the upper and lower plates (Fig. 5). If the thrust flattens into the late Precambrian terrigenous sequence at depth, it must flatten below the exposed parts of the Johnnie Formation. Because the Johnnie is near the base of the conformable geosynclinal sequence, only the Noonday Dolomite would be older and yet conformable (Stewart, 1970); the thrust might flatten into the basal part of the Johnnie. If that is the case, the thrust would flatten at a depth comparable to the base of the Bonanza King Formation in the lower plate, suggestng that at least 5,000 ft (1,500 m) and probably 7,000 to 8,000 ft (2,100 to 2,400 m) of strata of the lower plate extend beneath the entire exposed width of the Wheeler Pass thrust plate in the Spring Mountains. This geometry would require an eastward displacement of at least 20 mi (33 km) (Fig. 6b).

An alternative hypothesis is that Precambrian basement rocks are involved in the Wheeler Pass thrust (Fig. 6c). Work in the Clark Mountains has demonstrated that over distances of as much as 16 mi (26 km), some thrusts flatten at depth into older basement rocks (Burchfiel and Davis, 1971). If this is the case for the Wheeler Pass thrust, its geometry at depth is more difficult to determine, and the amount of displacement could be as small as 7 or 8 mi (11.6 to 13.3 km) or as large as 20 mi (33.3 km).

Assuming that thrusts in the Spring Mountains flatten at depth, the geometry of the thrust belt appears similar in style to that of other parts of the Cordilleran orogen (Armstrong, 1968; Bally and others, 1966). In general, a detached miogeosynclinal sequence seems to have moved eastward and imbricated as thrust faults westward into older stratigraphic units. It is uncertain where the thrust faults first cut into the late Precambrian terrigenous sequence; it may occur as far east as the Keystone thrust or as far west as the Wheeler Pass thrust.

Work in the Clark Mountains thrust complex has demonstrated that thrusts, even though they flatten at depth and involve only sedimentary rocks, are not stratigraphically controlled in detail (Burchfiel and Davis, 1971). Thrusts in some places cut subparallel to stratigraphic units but at other places cut across folds and formation contacts both downdip and parallel to strike. Thus, these thrusts are not décollement faults in a strict sense. Probably similar relations are present below the Spring Mountains, particularly in the Lee Canyon and Wheeler Pass thrust plates, and the geometry presented in Figure 6 must be viewed as an over-simplified construction.

Estimates of the magnitude of eastward displacement vary considerably, depending upon which model is used for the geometry of the thrust faults at depth. In the models presented here, the minimum figures range from 22 to 45 mi (36.6 to 75 km). The lower figure presented here is within the range (18 to 32 mi; 30 to 50 km) presented by Fleck (1970) based on arguments other than those presented here. The 45-mi (75-km) value is within the range (40 to 60 mi; 67 to 100 km) presented by Armstrong (1963) as average for the eastern thrust belt of the Cordilleran orogen. The figure could be even larger, however, as no estimate was made of additional displacement required because of (1) the geometry of eroded parts of the plates, (2) the western extent of the Wheeler Pass thrust plate, (3) a more extensive displacement of the Red Spring thrust plate than estimated above, and (4) the possible presence of additional thrust slices at depth that cannot be predicted from surface geology.

Age of Deformation. The age or ages of deformation in the Spring Mountains is not closely bracketed by stratigraphic units. The Keystone and Red Spring thrusts can be placed only in the interval Early Jurassic (post-Aztec) to pre–late Cenozoic (alluvial deposits). The age of the channel-fill deposits below the Keystone and Red Spring thrusts unfortunately is unknown.

Closer dating of the deformation comes from the Muddy Mountains 40 mi (67 km) to the northeast and from the Clark Mountains 30 mi (50 km) to the south. In the Muddy Mountains, the Willow Tank Formation and Baseline Sandstone overlie the Aztec Sandstone with slight angular unconformity. Fossils from the upper part of the Willow Tank yield early Late Cretaceous ages (Longwell, 1949), and ash beds in the lower part of the Willow Tank have yielded K/Ar ages of 98.4 and 96.4 m.y. or early Late Cretaceous (Fleck, 1970). Regional studies show that pre-Silurian strata were not exposed in southeastern Nevada until early Late Cretaceous time, since the earliest occurrence of detrital material from these rocks is in the Baseline Sandstone (Longwell, 1952; Armstrong, 1968). The younger Overton Fanglomerate appears to be syn- or post-tectonic, but its age is uncertain; it is Cretaceous(?) or Tertiary(?). Postassium-argon ages of approximately 23 m.y. from ash beds lying conformably above the Overton were determined by Armstrong (1963); thus the upper limit of deformation in this area can only be dated as Miocene.

In the Clark Mountain area to the south, thrust faults, including the continuation of the Keystone thrust, are intruded by plutons that yield radiometric dates between 84 to 94 m.y. (Adams and others, 1968). These relations are consistent with regional data presented by Armstrong (1968) that thrusting in the eastern part of the Cordilleran orogen from central Utah to southern Nevada was concluded before the end of the Cretaceous.

Recent work by Burchfiel and Davis (1971) has demonstrated that in the Clark Mountains, thrusting began as early as Late Triassic or Early Jurassic time in some of the thrust plates above the Keystone plate. Structures from this older episode (or episodes) project northward and perhaps continue into the central part of the western Spring Mountains. The time of inception of deformation in the central and western Spring Mountains thus remains uncertain.

SUMMARY

The Spring Mountains, Nevada, contain probably the most southern example of "typical" eastern Cordillera structure. Three major east-directed thrust plates move geosynclinal Paleozoic and late Precambrian sedimentary rocks eastward over cratonal equivalents. Too much uncertainty exists in the projection of thrust faults to depth to determine the involvement of older basement rocks, although the reconstructions suggest that these rocks may be present in the Wheeler Pass thrust plate. Thrusting in the Spring Mountains produced a minimum shortening estimated from the décollement model to be between 22 and 45 mi (36.6 to 75 km). Some deformation occurred during Late Cretaceous time, but recent work suggests that part of the deformation could be early or middle Mesozoic in age.

Stratigraphy across the Spring Mountains shows a transition from a Paleozoic cratonal sequence in the east to a geosynclinal sequence in the west. Addition of a thick section of late Precambrian terrigenous rocks at the base of the geosynclinal sequence accounts for nearly one-half of the thickening in the geosynclinal sequence. Where this section of terrigenous rocks first occurs beneath the Spring Mountains is unknown, but geometry of the thrust plates at depth suggests that they may occur in or below the Keystone thrust.

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