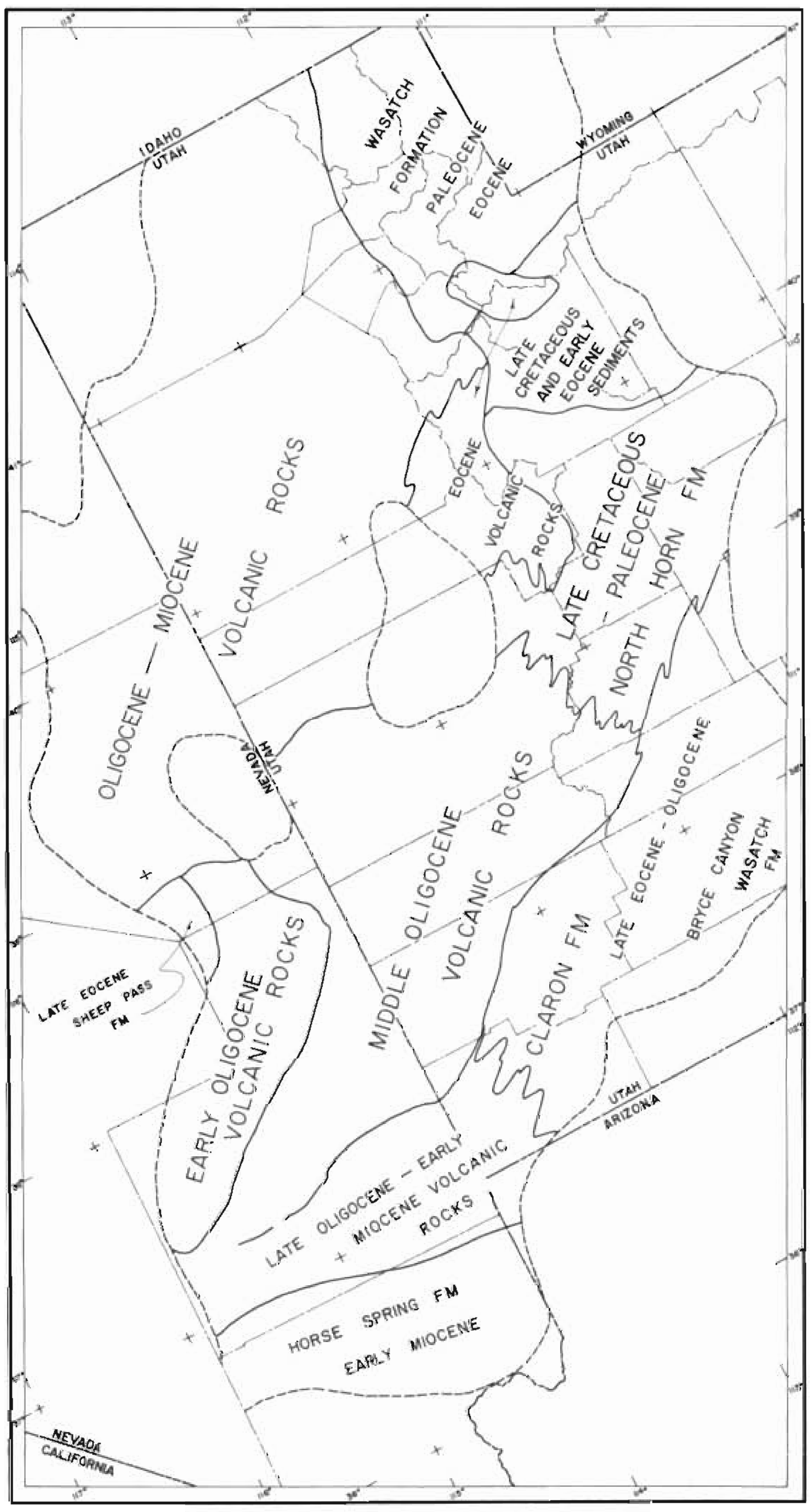

Figure 1. Map showing units overlying unconformity studied, Eastern Great Basin.

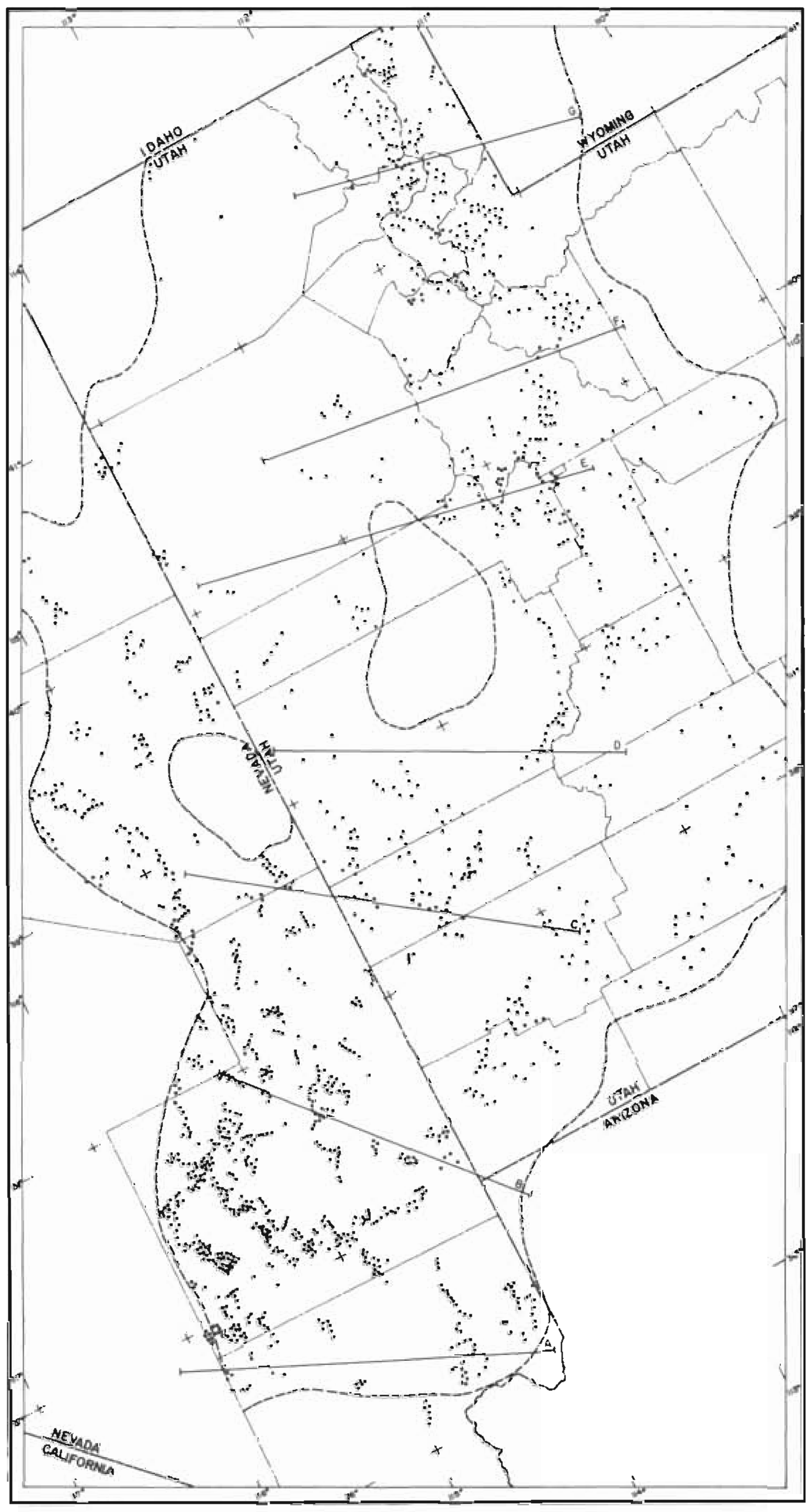

Figure 2. Localities from which Tertiary–Pre Tertiary contact information was taken (See explanation on Plate 1, figure 4).

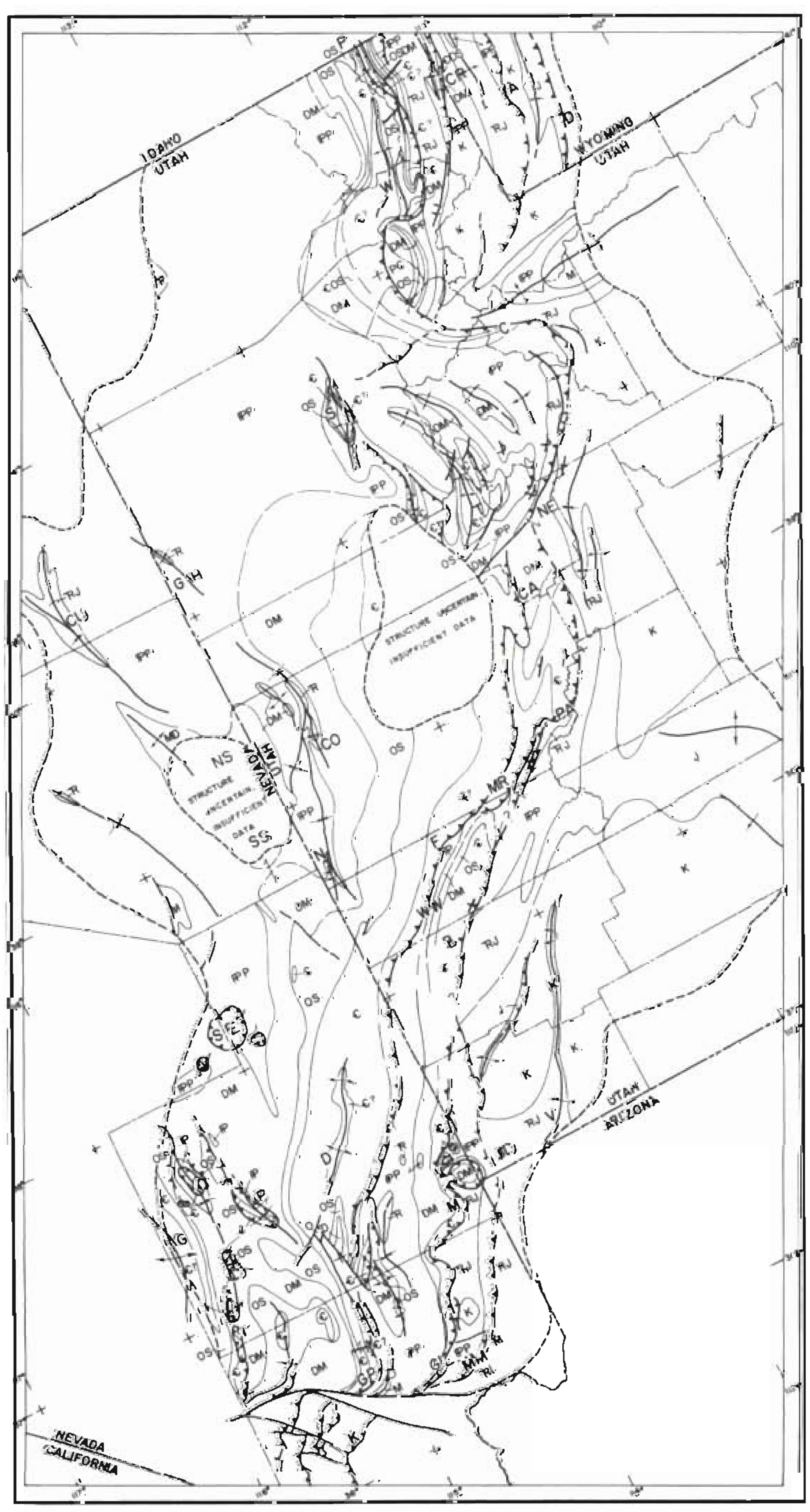

Figure 3. Paleogeologic map, Eastern Great Basin (See explanation on Plate 1, fig. 4).

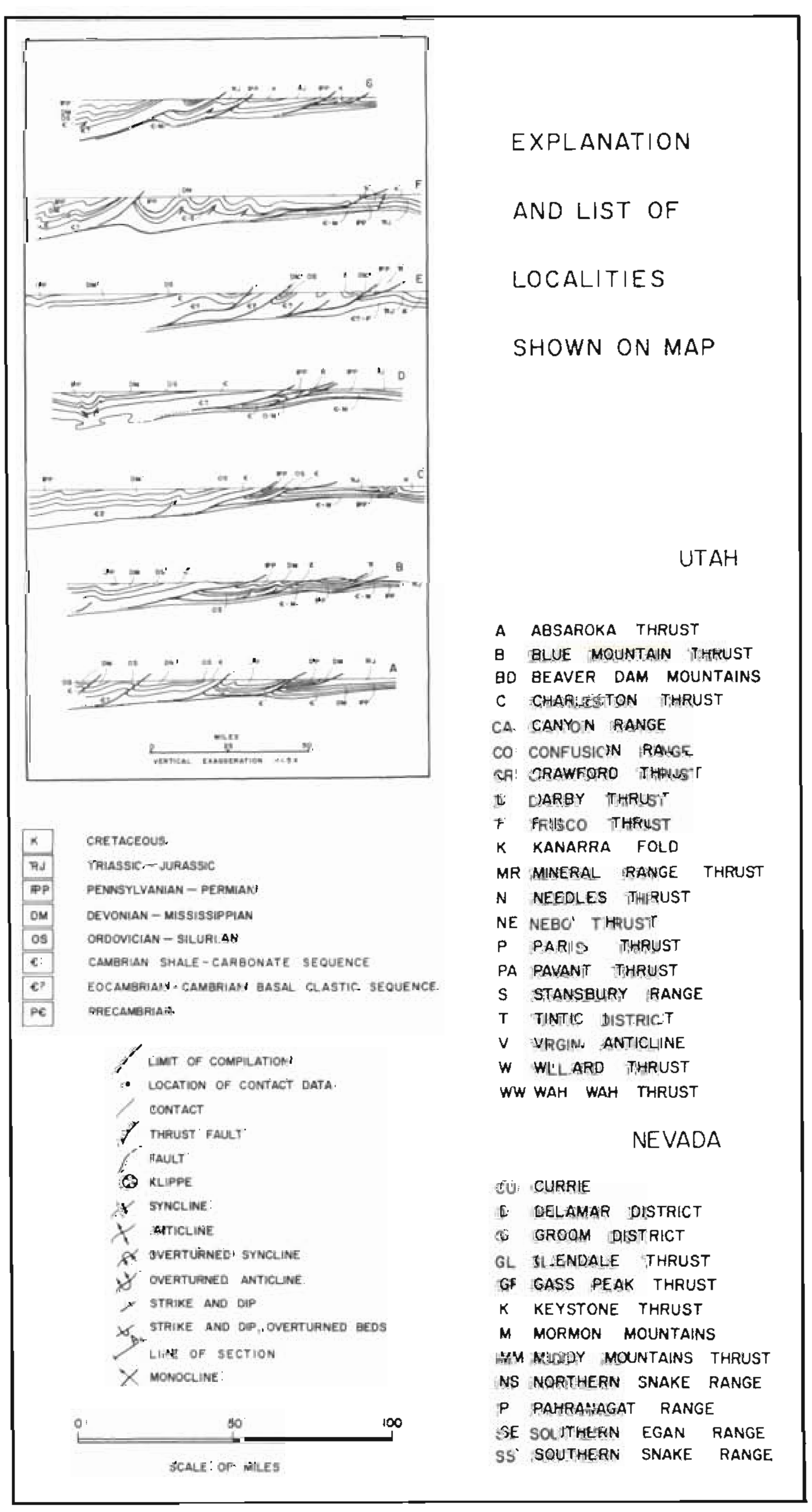

Figure 4. Paleogeologic cross sections, Eastern Great Basin.

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Sevier Orogenic Belt in Nevada and Utah

Abstract: In Nevada and Utah, sedimentation in the Cordilleran miogeosyncline began before the appearance of Cambrian fossils and continued without orogenic interruption through the Triassic. During the Jurassic, deformation and regional metamorphism occurred in the western part of the miogeosyncline, and the area of sediment accumulation shifted onto the Colorado Plateau.

A major source of clastic material appeared along the eastern margin of the Cordilleran miogeosyncline in Early Cretaceous time; this source supplied the sediments that filled the Cretaceous to Paleocene Rocky Mountain geosyncline. Clasts in the Cretaceous conglomerates show an inverted stratigraphy, reflecting successive exposure of older and older rocks in an evolving orogenic belt along the eastern side of the Cordilleran miogeosyncline. This source area was the Sevier orogenic belt, which had a history of deformation through most of the Cretaceous (Sevier orogeny). Décollement thrusts with displacements of tens of miles are the characteristic structures of the belt, but several large folds are also known. The largest thrusts are overlain unconformably by uppermost Cretaceous conglomerates.

Thrusting in the Sevier orogenic belt had virtually ceased by the time the Laramide orogeny began east of the Sevier belt in latest Cretaceous time. Laramide mountains were the result of uplift of great blocks of crystalline basement along nearly vertical, reverse, and steep thrust faults. The Uinta arch, which intersects the Sevier orogenic belt almost at a right angle, is the only one of these basement uplifts closely involved with the deformation of the Cordilleran miogeosyncline.

North-south-trending regional normal faulting of post-Oligocene age has broken up the orogenic belt so that it is not immediately recognizable on geologic maps. Arch ranges, intrusive domes, and gravity slides are additional complications of the Tertiary geology, but widespread Tertiary deposits, particularly Oligocene ignimbrites, make a paleogeologic reconstruction possible; thus, the Sevier orogenic belt can be viewed as it existed before the normal faulting.

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INTRODUCTION

The eastern Great Basin in eastern Nevada and western Utah is characterized by north-south-trending fault-block ranges composed of carbonate assemblage rocks of the Cordilleran geosyncline. The area under consideration is bounded on the west by the mid-Paleozoic Antler orogenic belt (Roberts and others, 1958), on the south by the Las Vegas shear zone (Longwell, 1960), and on the east by the Colorado Plateau. Although the Idaho boundary has been taken as an arbitrary northern limit, it should be emphasized that structures described in the Great Basin persist without significant modification northward into, and even past, central Idaho.

In order to understand the results of K-Ar dating studies of the region, a review of available knowledge of Great Basin geology was essential; the results of the K-Ar studies have been published elsewhere (Armstrong, 1963; 1966; Armstrong and Hansen, 1966). The only complete synthesis of Basin and Range geology (Nolan, 1943) has become a classic. Since the appearance of that report, a great amount of work has been done in the area, particularly as thesis projects. All Utah and approximately 80 percent of eastern Nevada have been mapped in enough detail to show the most significant structural features. Osmond (1960) discussed briefly the tectonic history of the Basin and Range province in Utah and Nevada; Misch (1960) discussed certain structural features of the eastern Great Basin; and Gilluly (1963) has reviewed the tectonic history of the western United States. No up-to-date detailed synthesis of the geology of the eastern Great Basin exists, however, and this led King (1959, p. 142) to say, after describing Longwell's discoveries in the Las Vegas region:

> To pursue details of the structures in other parts of the eastern Great Basin would probably only bewilder the reader without profit. Many folds and thrusts are known, but the larger pattern is for the most part undetermined. Not only have the fundamental structures been obscured over wide areas by Basin and Range structure, but many of the ranges have been little explored geologically.

It is the writer's opinion, however, that eventually we shall know more about the orogenic history of the Great Basin *because* of the faulting and volcanics, not in spite of them, for they provide exposures in the third dimension and key horizons for reconstructing the deformed orogen now exposed at varied structural levels.

The existence of thrust faults and folds of Mesozoic age along the eastern edge of the Cordilleran geosyncline is common knowledge (Eardley, 1962, 1963); the same area has been clearly recognized as a source of clastic material during the Cretaceous by Spieker (1946; 1949; 1956) and his students and by Harris (1959) who proposed the name, Sevier arch, for the clastic source. This paper is a review and analysis of the geology of this fold and thrust belt.

ACKNOWLEDGMENTS

I am indebted to the large number of geologists who contributed directly and indirectly to this project through their studies in the Great Basin. Without such previous work, this synthesis would be impossible. Kenneth F. Bick introduced me to the geology of the Great Basin in 1956. Pierre Biscaye and, later, Julia Armstrong assisted in the field studies during 1961. C. R. Longwell, Paul Williams, Robert Scott, T. B. Nolan, Keith Ketner, Harold Masursky, L. J. P. Muffler, J. C. Taylor, and Hoover Mackin provided hospitality and guidance in their respective field areas. During preparation of the original manuscript, John Rodgers, Edward Hansen, Keith Howard, Clark Burchfiel, D. H. Adair, Kenneth Pierce, and Pierre Biscaye provided helpful discussion. K. K. Turekian, John Rodgers, P. M. Orville, C. R. Longwell, R. J. Roberts, Peter Misch and D. H. Adair have read the present paper at various stages of preparation and provided helpful comments. Much of the drafting was done by Gary Audette. Field work was supported by National Science Foundation grant G14192. This research was done in major part while the writer was a National Science Foundation graduate fellow (1959–1962).

GEOLOGIC SETTING AND STRATIGRAPHIC HISTORY

Two principal parts of the Cordilleran geosyncline are recognized. The miogeosyncline in Nevada and Utah contains a thick section of Paleozoic rocks of the carbonate assemblage[1] (limestone, dolomite, clean sandstone, and little shale), and within, and west of the Antler

[1] "Carbonate assemblage" and "siliceous assemblage" are used for the contrasting geosynclinal facies as suggested by Silberling and Roberts (1962) and R. J. Roberts (1964, written commun.).

orogenic belt Paleozoic rocks of the siliceous assemblage (shale, dirty sandstone, chert, and volcanic rocks) of the eugeosyncline occur. East of the geosyncline in the central Wasatch Range and on the Colorado Plateau, rocks of the carbonate assemblage occur in a drastically thinned and incomplete Paleozoic section.

The relationships between the Paleozoic sections in the eugeosyncline, the miogeosyncline, and the adjacent shelf are obscured by major thrust faults with displacements of tens of miles. Eugeosynclinal rocks have been thrust over miogeosynclinal rocks in western and central Nevada, and miogeosynclinal rocks have been thrust over thin shelf facies in southeastern Nevada and western Utah. The present-day geographic distribution of the various rock assemblages, therefore, does not represent their distribution at the time of deposition.

Older Precambrian crystalline rocks that were metamorphosed approximately 1.5 b.y. ago underlie the shelf sections in Utah and southern Nevada and the miogeosynclinal rocks in the Death Valley, California, region. Within most of the geosyncline, however, no proven older Precambrian (> 1 b.y.) rocks are exposed. In the Uinta Mountains, Cottonwood Uplift, and Death Valley areas, thick sections of younger Precambrian sedimentary rocks unconformably overlie the older metamorphics and are in turn overlain unconformably by rocks of the Cordilleran geosyncline.

The Paleozoic history of areas west of a line extending south by southwest from northeastern Nevada was complex because two major Paleozoic orogenies occurred there (Roberts and others, 1958; Silberling and Roberts, 1962). In the miogeosyncline of eastern Nevada and western Utah, however, Eocambrian[2] through Triassic stratigraphic relations are relatively simple. Gentle truncation of units occurs, particularly along the eastern and western margins of the miogeosyncline, but only one distinctly angular unconformity is known (Stansbury anticline of Rigby, 1958), and this is only of local extent.

Deposition began in the Cordilleran miogeosyncline before the oldest Cambrian fossils appeared. Approximately one third of the stratigraphic section of the miogeosyncline is composed of a basal clastic sequence which includes Eocambrian, Lower, and Middle Cambrian quartzite and argillite and a widespread Eocambrian tillitic member. In southern Nevada and at scattered localities elsewhere, dolomite is present in this basal sequence. After Early Cambrian time, carbonate deposition became widespread. Middle and Upper Cambrian deposits are complexly intertonguing shale and carbonate rocks, more dolomitic toward the top. Lower Ordovician limestones with minor shale were succeeded in Middle Ordovician time by a distinctive, widespread, clean white quartz sand, which is absent only locally over the Tooele arch, a Cambrian and Ordovician positive element. Upper Ordovician, Silurian, and Lower Devonian deposits are almost exclusively dolomite, and Upper Devonian and later Paleozoic carbonates are predominantly limestone. Later Devonian sedimentation was more varied because of tectonic activity in and near the miogeosyncline. A gentle arch formed in east-central Nevada between Middle and Late Devonian time; the Stansbury anticline rose in north-central Utah during Late Devonian time. From very late Devonian time until later Pennsylvanian time, the Antler orogeny affected sedimentation in Nevada and western Utah; a widespread uppermost Devonian-Lower Mississippian shale was succeeded by Lower Mississippian limestone, which was locally removed as a consequence of Early Mississippian warping and erosion. During the rest of Mississippian and Pennsylvanian time, a clastic wedge composed of material derived from the Antler orogenic belt extended into the miogeosyncline from the west. Subsidence of the Oquirrh basin in north-central Utah began in Mississippian time and continued into Permian time. From Late Mississippian through Permian time, clastics shed from the rising basement uplifts of the Ancestral Rocky Mountains accumulated in the Oquirrh basin which was bounded on the north by an east-west-trending monoclinal flexure. During Pennsylvanian time, most of eastern Nevada was the site of limestone deposition; in the Oquirrh basin, more than 20,000 feet of alternating limestone and quartzite accumulated. Thick lower and middle Permian deposits—limestone with much quartz sand, sandstone, siltstone, dolomite, and some evaporite—accumulated in the Arcturus basin in east-central Nevada, and thick limestone deposits

[2] The term "Eocambrian" is used to emphasize that no significant time gap separates the sediments referred to from overlying fossiliferous Cambrian strata. Usage of this term is the same as in the Caledonide area of Norway where Eocambrian was first proposed by W. C. Brogger in 1900 (Holtedahl, 1960, p. 111–112).

accumulated in southern Nevada; in Utah, correlative strata consist of alternating quartzite and limestone with minor dolomite. Southeastward from the miogeosyncline, Permian marine strata intertongue with continental red beds.

Upper Permian deposits (Park City Group) are a widespread blanket of relatively uniform thickness and lithology (limestone and dolomite with minor chert and phosphate) over the entire region, including the Antler orogenic belt and much of the Colorado Plateau shelf. In the miogeosyncline, marine sedimentation continued without orogenic interruption into the Triassic over much of Nevada and Utah. Triassic (or earliest Jurassic) rocks were the last deposits of the Cordilleran miogeosyncline. In Middle Triassic time, marine waters withdrew from the eastern Great Basin in Nevada for the last time, marking the beginning of the orogenic chapter in the history of the region. The Triassic-Jurassic boundary probably lies within the widespread eolian sandstone (Navajo-Aztec-Nugget), which is the youngest pre-orogenic formation present in the eastern Great Basin west of the Mesozoic fold and thrust belt.

During the Jurassic, the region of thickest sediment accumulation shifted to central and eastern Utah, and the western part of the Cordilleran miogeosyncline became a source area (Stokes, 1960) in response to orogenic deformation taking place there. Continental clastic deposits of Upper Jurassic and lowermost Cretaceous age, derived from this western source, spread across the eastern edge of the Paleozoic miogeosyncline and the Colorado Plateau. In Early Cretaceous time, the eastern edge of the geosyncline became a source of clastic material, which accumulated during Cretaceous and Paleocene time in the Rocky Mountain geosyncline still farther east. At a few localities in eastern Nevada, continental Lower Cretaceous deposits are present, but over most of the region there is a great hiatus between deposits of the Cordilleran geosyncline and Tertiary deposits.

Tertiary strata of the eastern Great Basin and adjacent Colorado Plateau can be subdivided into three major groups. The oldest is composed of nonvolcanic continental sediments —scattered Eocene lacustrine deposits and undated conglomerates in Nevada and western Utah and Paleocene and Eocene fluviatile and lacustrine sediments that are well developed in central Utah and northward into Wyoming. The middle group consists of widespread intermediate to acidic volcanics, chiefly ignimbrites of latest Eocene, Oligocene, and early Miocene age. The youngest group, Miocene to Recent, is a heterogeneous collection of discontinuous clastic units, volcanic-rich sediments, volcanics (commonly basalts but also all other types), and lacustrine sediments, deposited during the development of the Basin and Range structure. Figure 1 is a correlation chart illustrating Tertiary stratigraphic relationships within, and adjacent to, the eastern Great Basin.

A more complete review of the Precambrian through Tertiary stratigraphic history, together with documentation not included in this paper, may be found in Armstrong (1968). Palinspastic isopach maps for all Paleozoic systems and three palinspastic paleostratigraphic profiles across the region are included in the review.

PRE-NORMAL FAULTING PALEOGEOLOGY—SEVIER OROGENIC BELT

Paleogeologic Map

The present-day structural pattern of the eastern Great Basin is dominated by the effects of Tertiary normal faulting. Geologic maps of the region cannot clearly portray the general features of the pre-Tertiary structures that are exposed in separated ranges. Each individual exposure displays the older structures in a different attitude or aspect, and irregularly distributed Tertiary volcanics and sediments do not make things clearer. If we remove the effects of normal faulting and Tertiary sedimentation, we can view in a simple manner the broad features of the pre-Tertiary structures. This can be done by a paleogeologic reconstruction, as described by Levorsen (1960). All later effects of sedimentation and deformation are erased and the resultant map portrays the geology as it was at the time the unconformity was buried. This technique is applied here to the eastern Great Basin to display the pre-normal faulting paleogeology.

Plate 1, figure 1 shows the units which overlie the unconformity used for the reconstruction (*see* also Fig. 1). The range in age of the unconformity is latest Cretaceous to earliest Miocene. This undoubtedly has a somewhat distorting effect on the resultant paleogeology, but it does not alter the fundamental geologic pattern. In all areas, the unconformity postdates the main Mesozoic deformation, although locally in cen-

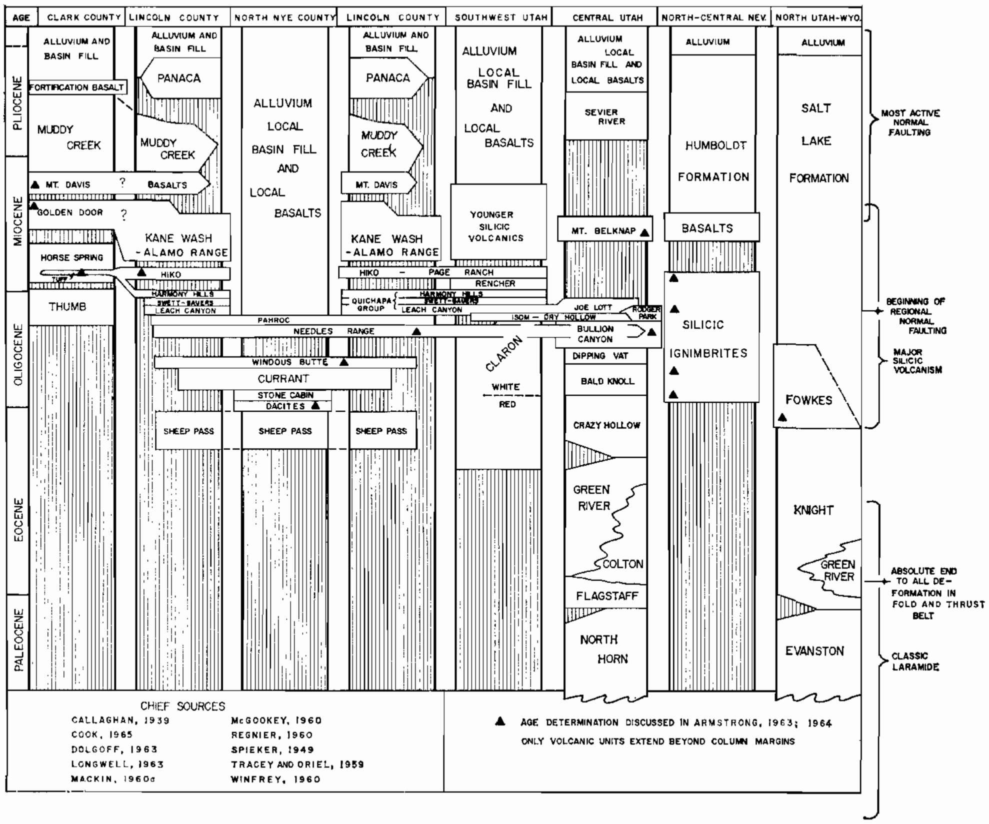

Figure 1. Eastern Great Basin Tertiary correlation chart.

tral Utah some minor folding and even thrusting may have occurred later than the unconformity. The unconformity, however, predates the major normal faulting. Early normal faulting may affect the pattern somewhat in eastern and southern Nevada but only to a relatively minor degree. The over-all structural pattern of the region was not significantly altered during the time spanned by the unconformity.

If the older structure is not enormously complex, the resultant paleogeologic map should display the broad features of the regional geology during early Tertiary time. Plate 1, figure 2 shows the distribution of points (~900) where information on rocks underlying the unconformity was recorded. The source maps consulted are given in Table 1. In addition to simple rock age information supplied by Tertiary–pre-Tertiary contacts, it is also often possible to construct paleo-strikes and dips by rotating the oldest Tertiary deposits (commonly ignimbrites) back to horizontal and determining the effect of the same rotation on the older rocks. In areas where a suitable unconformity is lacking, it is possible to put limits on the ages of rocks as those exposed in early Tertiary time must have been as young as, or younger than, those now present.

The normal faulting responsible for the present topography and much of the geologic complexity of the Great Basin occurred mostly during Miocene and Pliocene time. Pre-Miocene normal faults are known in many places in the region, but none approach the magnitude of displacement of the faults formed later. No example can be cited where rocks differing in age by several geologic periods were juxtaposed along pre-Miocene normal faults. Thrusting accounted for the major discontinuities present.

A significant structural feature of the region is the widespread near-conformity of the Paleozoic sediments and Tertiary volcanics. Over large areas, the angularity of the uncon-

TABLE 1. GEOLOGIC MAPS OF THE EASTERN GREAT BASIN AND VICINITY WHICH WERE USED FOR CONSTRUCTION OF THE PALEOGEOLOGIC MAP* (Pl. 1, fig. 3).

Nevada	
Clark County	Bowyer and others (1958)
Lincoln County	Kellogg (1963) Tschanz (1960) Tschanz and Pampeyan (1961)
White Pine County	Adair (1961) Bauer and others (1960) Douglass (1960) Drewes (1958; 1960)
	Fritz (1960) Langenheim and others (1960) Lloyd (1959) Nelson (1959) Playford (1962) Ward (1962) Whitebread and others (1962) Woodward (1964) Young, J. C. (1960)
Elko County	Harlow (1956) Nelson (1956) Schaeffer and Anderson (1960) Snelson (1955)
Utah	
State Geologic Map	
Northeast Quarter	Stokes and Madsen (1961)
Northwest Quarter	Stokes (1963)
Southwest Quarter	Hintze (1963)
Other Maps	Hintze (1962)
Wyoming	
State Geologic Map	Love and others (1955)
Other Data from	Cochran (1959) Schick (1959)

* A geologic map of Nevada (Webb and Wilson, 1962) is available but was not used for construction of Plate 1, figure 3. It includes data from the references in the table but in a more generalized form.

formity is less than 5 degrees; only locally is it distinctly angular. Cook (1965, p. 54–55) states:

> pre-volcanism deformation was sharply localized along axes that trend east of north, leaving between the narrow belts of deformation broad areas of undeformed Paleozoic rocks, the ignimbrites in many sections are essentially parallel to the underlying sedimentary rocks . . . the attitude of the volcanics in many places reflects the attitude of the subadjacent sedimentary rocks; locally . . . the angularity of the unconformity is great.

Mackin (1961, oral commun.) made the same observation, and the writer also agrees. The relationship is of importance in reconstructing the pre-normal faulting paleogeology of the region. The generalization does not apply to more westerly areas near and in the Antler orogenic belt.

The observed near-parallelism of Tertiary and pre-Tertiary rocks in the region establishes that low dips were characteristic of pre-Tertiary rocks during early Tertiary time. Extrapolation between scattered data, therefore, should be safe at least for distances of a few miles. The near-parallelism of units, however, is only a generalization. In many areas, sharp angular unconformities occur, and the paleogeologic reconstruction must maintain consistency with these relationships. The paleogeology becomes increasingly complex westward into central Nevada. The reconstruction is limited to the area from which suitable data are available and where the paleogeology appears to have been fairly straightforward.

The pre-normal faulting paleogeology is shown on Plate 1, figures 3 and 4. The map agrees with all the data collected, but in many areas alternate interpretations of the data are possible; this does not imply, however, that the major structural features are in doubt. The map portrays the geology as it would have been mapped shortly after the end of the Cretaceous. The degree of definition (resolving power) is slightly better than that represented by more detailed parts of the 1932 edition of the U. S. Geological Survey geologic map of the United States.

The general features of the paleogeology are immediately evident. The structural trends are generally north to northeast. On the east side of the map is a broad, virtually undeformed, foreland basin area filled by Cretaceous deposits. Two broad arches which lie nearly perpendicular to the regional trend occur in this foreland. The middle of the map is occupied by a fold-and-thrust belt with eastward overturning and thrusting. The region farther west displays a deceptively simple structural pattern, in which, over broad areas, only gently folded upper Paleozoic rocks are shown. In southern Nevada, the pattern is complicated by an uplift exposing lower Paleozoic and Eocambrian rocks and surrounded by klippen of Paleozoic rocks overlying middle and upper Paleozoic strata. This pattern is the summation of all the effects of Mesozoic and early Tertiary deformation in the region.

Foreland

East of the belt of folds and thrusts is a broad area that was slightly deformed during

Mesozoic time; later in the era, it was a basin in which orogenic debris from the area now occupied by the Great Basin accumulated. At the end of the Cretaceous and during early Tertiary time, broad arches formed in the foreland. These can be seen on the paleogeologic map as the Uinta arch in northern Utah and the Circle Cliffs upwarp in the southern part of the state.

Sevier Orogenic Belt

General statement. The Sevier arch was named by H. D. Harris (1959), who described it as a late Mesozoic positive area in western Utah and southeastern Nevada. The arch concept was based on paleogeology, and the arch was considered the source of the orogenic clastics shed to the east; thrusting was considered to be the climax of arching during late Cretaceous time. Harris (1959, p. 2646) says:

> There is no direct evidence of large-scale thrusting associated with the uplift of the Sevier arch. Deformation appears to have been generally limited to upwarping and development of major folds, some of which undoubtedly developed into belts of structural weakness that later became zones of thrusting.

The paleogeologic map of Plate 1, figure 3 is based on more than ten times the amount of data presented by Harris and does not support the concept of a simple late Mesozoic arch, for nowhere is an eastern limb evident. It shows that the exposure of old rocks in the area is indeed the result of thrusting, which was the deformation responsible for the clastics shed into the Rocky Mountain geosyncline during the latter half of the Mesozoic. It is suggested that "Sevier orogenic belt" is a better term for the belt of thrusts and folds originally described as the Sevier arch.

In several recent studies, paleogeographic arches or geanticlines have been discovered to be orogenic belts; for example, the Manhattan geanticline became the Antler orogenic belt (Roberts and others, 1958), and the Mesocordilleran geanticline was the site of Jurassic deformation (Misch, 1960; Armstrong and Hansen, 1966). It does not appear reasonable to expect enormous quantities of coarse clastics from simple arching. Orogenic deformation, including faulting, is necessary to account for the Mesozoic clastics.

In its earliest stages, the Sevier belt may well have been archlike. Permian isopachs offer the first faint suggestion of uplift along the locus of the belt. Further uplift in later Permian or early Triassic time may be indicated by the pre-Triassic unconformity in southern Nevada. The first conclusive evidence of orogenic deformation in the belt, however, is the appearance of lower Paleozoic clasts in early Colorado time in Utah and Nevada or as far back as the beginning of the Cretaceous in Idaho (F. C. Armstrong and Cressman, 1963, p. 10). The only possible source of these clasts is the Sevier belt. Lower Cretaceous and Upper Jurassic sediments could have been derived from anywhere in the eastern Great Basin, but they may also have come, at least in part, from the Sevier belt during earlier stages of its development. The Eocambrian rocks of the belt occur almost exclusively in the sole of major thrusts. Their appearance, in abundance, as clasts approximately at the end of Colorado time is evidence that thrust displacements of tens of miles existed by then.

The relative ages of folds and thrusts in the belt normally cannot be determined, but in the Canyon Range folding definitely postdates displacement on the major thrust (Christiansen, 1952). In other mountain belts, such as the Appalachians, folding postdates movement along regional bedding-plane thrusts (Rich, 1934; Pierce and Armstrong, 1964), for after folding such thrusts are unable to develop. Probably, therefore, most of the Sevier thrusting represents an earlier stage of deformation than the folding. Some folding was probably also contemporaneous with, if not caused by, thrusting (Rich, 1934; Cressman, 1964). On the major thrusts of the belt, a minimum of 25 miles of total displacement has occurred; such a displacement is approximately equal to the thickness of the crust and cannot be merely the climax of deformation in a tight fold. To summarize, thrusting was prolonged and of great magnitude in the Sevier belt. It was not merely the climax to earlier folding and arching. Figure 2 provides an index map for the following detailed discussion of the Sevier orogenic belt.

Southern Nevada-Southwestern Utah Sector. The structural geology of Clark County, Nevada, has been discussed by Longwell (1949; 1952; 1952a; 1960; 1962), and a county map has been published (Bowyer and others, 1958). The paleogeology retains all features of Longwell's interpretation of the area. Modification of the structural pattern by later Tertiary normal faults is relatively minor.

The major thrust in terms of stratigraphic displacement is the Gass Peak thrust which brings the Lower Cambrian and Eocambrian

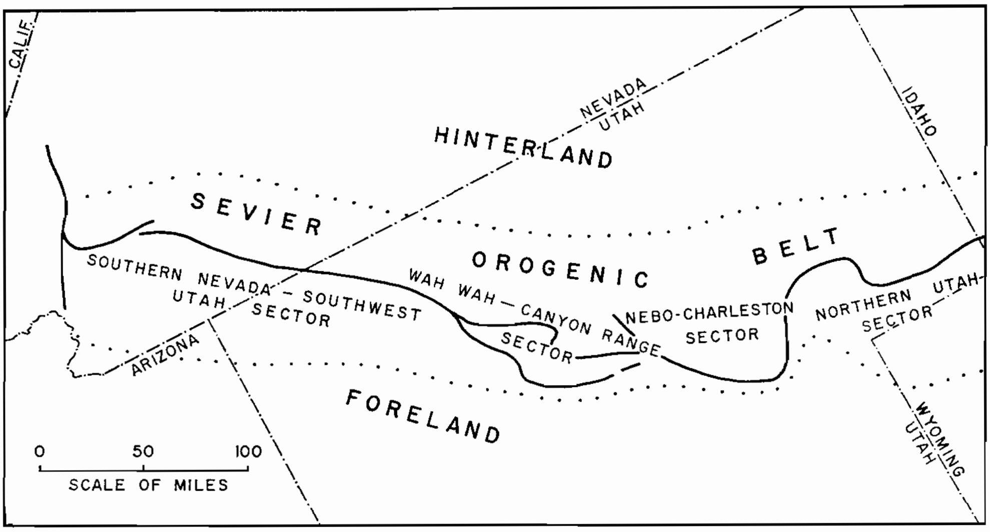

Figure 2. Index map for Sevier orogenic belt, Nevada and Utah.

quartzite over carbonates of the Pennsylvanian and Permian Bird Spring Formation. East of the major thrust is the Glendale thrust, which overrides the Muddy Mountain thrust; both thrusts apparently flatten out at depth in Cambrian shales and both override Jurassic sediments.

The absence of lower or middle Tertiary sediments prevents continuation of the paleogeology south of the Las Vegas shear zone, but similar thrusts appear there, although they are displaced approximately 25 miles to the west. The Wheeler Pass and Keystone thrusts would correspond to the Gass Peak and Glendale-Muddy Mountain thrusts, respectively.

The structural geology of southeastern Lincoln County has been discussed only in an abstract (Tschanz, 1960a), but a county map has been published (Tschanz and Pampeyan, 1961). In the Mormon Mountains in the southeast corner of the county, a thrust system, probably a continuation of the Glendale thrust, is present; the main thrust brings Cambrian over Mesozoic rocks which are locally imbricate. The structure as illustrated on the paleogeologic map undoubtedly is oversimplified; it represents one plausible interpretation consistent with the available data. The involute pattern of the thrust is probably due to topography.

Allochthonous blocks in the Beaver Dam Mountains have been interpreted as Tertiary gravity-slide blocks by Cook (1960) and Jones (1963) and thus are not features of the paleogeology.

To the east of the larger thrusts are two related structures: the Iron Springs Gap structure (Mackin, 1947; 1960a, p. 114–119) which is a thrusted anticline formed at the end of a décollement in the Carmel Formation, and the Virgin-Kanarra fold (Gregory and Williams, 1947; Threet, 1963, 1963a).

The westernmost thrust of the Sevier belt in Lincoln County places Lower Cambrian over Upper Paleozoic rocks. It has a greater stratigraphic displacement than the other thrusts in this sector and may have the greatest total displacement. There is a problem as to exactly how it connects with the similar thrust in Clark County. On the paleogeologic map, they are shown as the same thrust affected by later, but pre-middle Miocene, normal faulting. According to an alternative interpretation suggested by D. H. Adair (1962, oral commun.), the thrusts are *en echelon*, the Gass Peak dying out northward, the thrust in Lincoln County growing in the same direction, each compensating for the changing displacement on the other. In the first interpretation, certain Upper Paleozoic outcrops in Lincoln County are autochthonous relative to the major thrust; in the second, they are allochthonous.

Approximately 15 miles west of the trace of the major thrust in Lincoln County is an elongate exposure of Lower Cambrian and Eocambrian (Є?) quartzite. The quartzite-

Tertiary volcanic contact is well exposed near Delamar, a ghost town. Except for this anticline, the structure above the thrust is a gentle homocline from Cambrian to Mississippian and younger rocks of the hinterland. The upper plate of the major thrust extends for miles westward virtually undeformed in contrast to the imbricate belt to the east. The stratigraphic section of the upper plate must have been relatively competent. The Delmar anticline might be related to a step in the underlying thrust surface in the same manner that surficial anticlines are related to steps in such thrusts as the Cumberland Plateau thrust (Wilson and Stearns, 1958).

Wah Wah-Canyon Range Sector. Between the Wah Wah Mountains and the north end of the Canyon Range, there are many exposures of the Sevier belt, and structural continuity of the various isolated pieces of the major thrust of the belt may be demonstrated with reasonable assurance.

The upper plate of the major thrust can be traced with structural continuity from Lincoln County to the Wah Wah Range, but the actual thrust trace and the imbricate faults to the east are obscured by volcanics. Miller (1958; 1963) described the geology of the southern end of the Wah Wah Range and discussed the evidence for continuity of the upper plate of the major thrust which appears locally as the Wah Wah thrust, Frisco thrust (East, 1956; 1957), Mineral Range thrust (Liese, 1957), Pavant thrust (Maxey, 1946), and Canyon Range thrust (Christiansen, 1952). These thrusts have the Eocambrian-Lower Cambrian quartzites on their soles and override rocks ranging in age from Lower Cambrian to Jurassic, successively, toward the southeast. The southwest quarter of the geologic map of Utah (Hintze, 1963) shows that the Canyon Range allochthon overrides Paleozoic carbonates of the Pavant Range allochthon, thus demonstrating that the major thrust (the one which brings the Eocambrian-Lower Cambrian clastic sequence to the surface) bifurcates in this sector. A possible interpretation of this relationship is shown on the paleogeologic map.

East of the major thrusts lies the imbricate belt, but it is not well exposed and lacks the structural continuity of the major thrusts. Southeast of the Wah Wah thrust is the Blue Mountain thrust, a structural twin of the Glendale or Muddy Mountain thrusts to the southwest, on which Cambrian carbonates override Jurassic(?) sandstone. The section between the Blue Mountain and Wah Wah thrusts is complexly faulted, but all the faults are relatively minor. The over-all pattern is highly generalized on the paleogeologic map. In the Frisco area, the imbricate belt is complex and so confused by later volcanics, intrusives, and faults, that little generalization is possible at present. Southwest of the Pavant thrust, Crosby (1959) worked out an example of an overturned sheared-off limb of an anticline. The entire section from Cambrian to Triassic dips gently northwestward but is upside down! The major thrust overrides the overturned block, which is itself in thrust contact with underlying strata. The relationship of the overturned block to structural units southwest of it is uncertain.

The Sanpete-Sevier anticline east of the Canyon Range has been described by Gilliland (1963). Jurassic shale and other clastics protrude through Cretaceous sediments. Diapiric phenomena are reported to be partially responsible for the structure.

The Sevier Desert west and northwest of the Canyon Range is a large area where geologic data are unavailable. It has furnished a name, but little supporting evidence, for the Sevier orogenic belt.

Nebo-Charleston Sector. A fault of uncertain character separates the Canyon Range structural block from the Gilson Mountains and other areas to the north at the only locality where the relationships are not covered. Costain (1960) considered this fault, the Leamington fault, to be a thrust with a dip of approximately 30° N. It is also possible that the movement on the fault may be normal or, in part, strike-slip. Morris and Shepard (1964) considered it to be a strike-slip fault and offered a slightly different interpretation than that shown on the paleogeologic map for the area between it and the Tintic district to the north.

Between Mount Nebo and the vicinity of Salt Lake City is a distinctly different sector of the Sevier orogenic belt. The rocks involved in deformation are those of the Oquirrh basin. The differences in structural style and appearance of the map in this sector are believed to be due to the difference in response to deformation of the thick sediments of the Oquirrh basin and not to differences in age of deformation or applied stress.

The major thrust in this sector continues out of the Great Basin into the Southern Wasatch Mountains; at the southern end is the Nebo thrust (Eardley, 1934). Overturned Triassic and Upper Paleozoic rocks are thrust over Middle Jurassic shales at Mount Nebo. The Nebo thrust is connected beneath a covered area with the Charleston and Strawberry thrusts at the northern end of the Southern Wasatch block (Bissell, 1959; Crittenden, 1959). The Charleston thrust was recognized by Baker and others (1949) and has been described by Baker (1959) and Baker and Crittenden (1961). Along this fault, the thick Oquirrh basin section has been juxtaposed against the much thinner shelf section. At the sole of the thrust, Cambrian and Eocambrian quartzites are thrust over rocks as young as Middle Jurassic.

West of the thrust, there is a wide fold belt. In this belt are the Tintic and Stansbury folds with Eocambrian rocks exposed in their cores and several smaller folds such as the Bingham and Pole Canyon synclines. Several of the folds are overturned; a few have developed into thrusts. The Stansbury anticline (Rigby, 1958) is a reactivated older fold whose trend and location were predetermined by a buried Devonian anticline. The geology of the Tintic anticlines has been discussed by Morris (1957). At the northern end of the Oquirrh Range is the east-west-trending, north-dipping, North Oquirrh thrust (Roberts and Tooker, 1961).

The large folds are confined to the Oquirrh basin, but folding continues westward. Much of the hinterland in Utah is folded, but the folds are apparently of smaller magnitude as pre-Pennsylvanian rocks are not exposed in their cores.

The paleogeology becomes complex in the West Tintic (Groff, 1959) and Sheeprock (Cohenour, 1959) areas. On the Sheeprock thrust, which was first described by Loughlin (Butler and others, 1920, p. 436), Eocambrian quartzites are thrust over lower and middle Paleozoic rocks. The thrust rises in the section eastward and has always been considered a normal part of the belt of thrusts in Utah. Cohenour (1959) recognized an additional thrust dipping north and northeast, which he called the Pole Canyon thrust, the upper block of which was considered to have moved south and southwestward in contrast to eastward movement on the Sheeprock thrust. Figure 3 shows an alternative interpretation; the Pole Canyon and Sheeprock thrusts appear to be the same thrust with eastward movement. This interpretation would explain eastward overturning of the Eocambrian section below the Pole Canyon thrust. Total displacement on the Pole Canyon thrust is about 5 miles, which would easily account for the 2–3 miles of stratigraphic displacement on the Sheeprock thrust. The Government Creek fault of Cohenour (1959) may be a separate thrust west of the Sheeprock thrust. South and west of the Sheeprock area is an area left bare on the paleogeologic map (Pl. 1, fig. 3) because lack of exposure makes it impossible to determine what relationship the complex fold-and-thrust area has to the belt of relatively simple structure to the south.

Northern Utah Sector. No direct connection between the thrust belt in northern Utah and the Nebo-Charleston sector has been found. Autochthonous rocks of the Uinta arch extend to the edge of the Salt Lake basin; paleogeologic information in the basin and to the northwest is very limited. It is possible, however, to trace the Oquirrh Formation from central to northern Utah with only a few covered areas about 5 miles across; there is no evidence suggesting a major structural discontinuity between the two areas. Crittenden (1959; 1961) pointed out that the thrust sheets in the Nebo-Charleston and northern Utah sectors are parts of the same structural block, a conclusion supported by the similarity in age, direction, and amount of thrusting in both areas. Accordingly, the trace of the major thrust outlines a large re-entrant near Salt Lake City, connecting the Charleston with the Willard thrust. The fault surface is probably close to the base of the Eocambrian section. In all its present-day exposures, the Precambrian Farmington Canyon basement complex is autochthonous, or nearly so, when it is contrasted with the Willard thrust sheet.

In the Northern Wasatch Mountains, paleogeologic and structural information are abundant, and the interpretation shown on the map can be considered reasonably certain. Except for the Farmington Canyon complex and the immediately overlying Paleozoic strata between Salt Lake City and Ogden, all the Northern Wasatch Mountains are an immense allochthonous block.

The Willard and associated thrusts have been described by Eardley (1944). East of Ogden, a thick geosynclinal section, including 10,000 feet of Eocambrian, overlies (along the Willard thrust) a relatively thin shelf section with no Eocambrian. The thrust dips east and at one time was thought to have moved westward; this view is no longer generally accepted.

Drag features observable at Pineview Dam (including the gigantic *Z* fold) showing a down-dip (eastward) movement sense, and facies relationships requiring structural continuity between geosynclinal areas and the Willard block

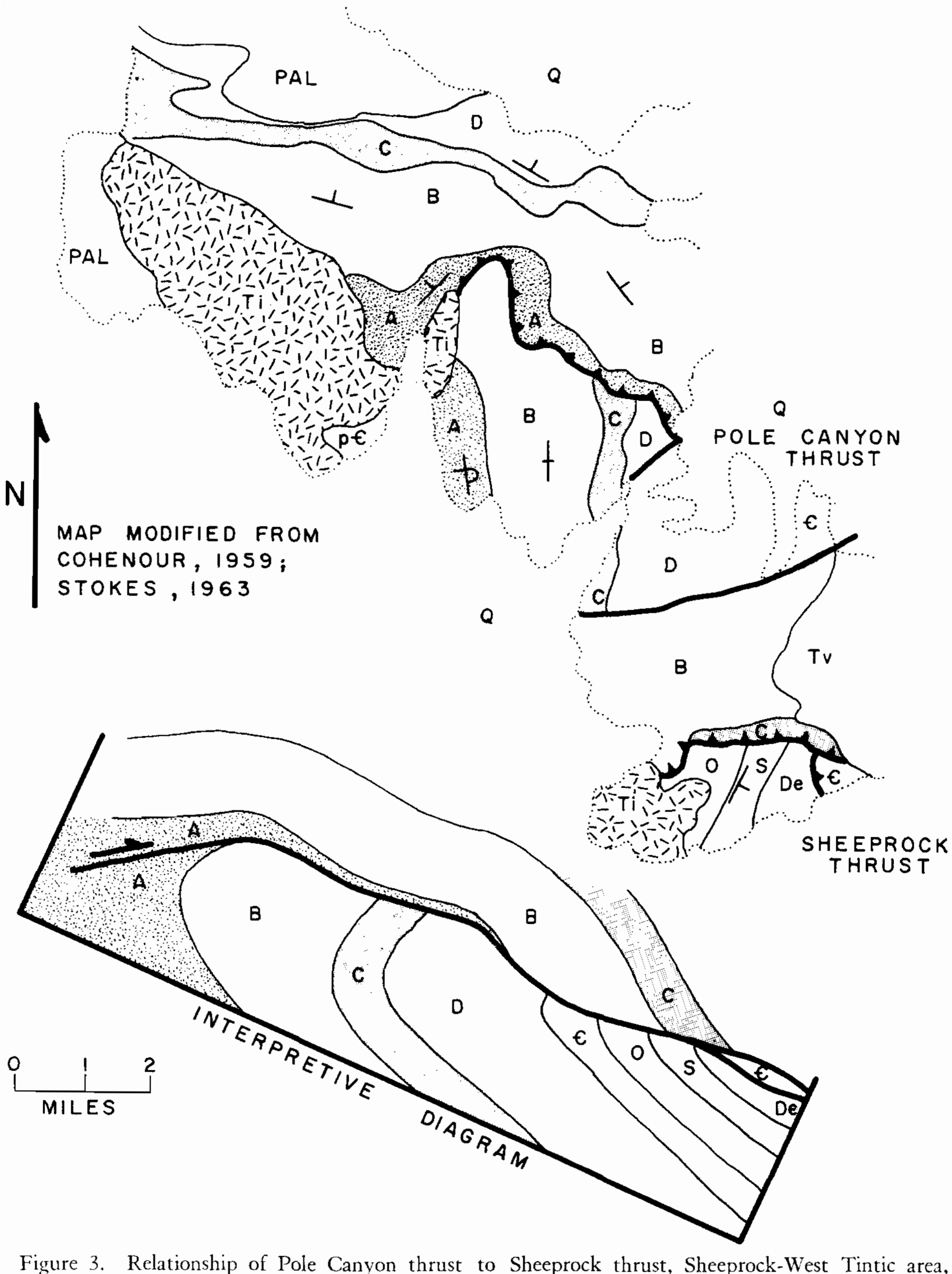

Figure 3. Relationship of Pole Canyon thrust to Sheeprock thrust, Sheeprock-West Tintic area, Utah. Pre-Lower Cambrian stratigraphic units are indicated by *A*, *B*, *C*, and *D* from bottom to top, respectively; undifferentiated Paleozoic rocks, by PAL; Cambrian rocks, by Є; Ordovician rocks, by *O;* Silurian rocks, by *S;* Devonian rocks, by De; Tertiary plutons, by Ti; Tertiary volcanic rocks, by Tv; and Quaternary sediments, by Q.

prove eastward movement. The thrust rises in the stratigraphic section to the east, which is consistent with eastward but not with westward movement. Indeed, no regional relationships support a western movement direction. Provable minimum displacement on the fault is 30 miles.

Structural continuity of the Willard block requires connection of the Willard thrust with the southern extension of the Paris thrust of Idaho. F. C. Armstrong and Cressman (1963, p. 18) did not accept this interpretation because of a presumed difference in age of the thrusts, but they were under the incorrect impression that the Willard is a Late Cretaceous or Paleocene thrust. They considered the Paris and Ogden-Taylor thrusts to be contemporaneous, and they also argued that the thrust near Woodruff Creek (west-dipping 30 miles east of Ogden) might be too insignificant to project 24 miles northward. The west-dipping fault at Woodruff Creek must have a *minimum* displacement of 30 miles. It *could not* die out before the Utah-Idaho boundary only 30 miles to the north. The Brigham Quartzite occurs on the sole of the thrust continuously from Paris, Idaho, to Woodruff Creek, Utah. In view of the lack of structural complexities between the two areas, it is reasonable to accept structural continuity between the Paris and Woodruff Creek and, hence, the Willard thrusts. The major thrust branches near the Idaho-Utah border, but this affects neither argument.

East of the major thrust is a series of thrusts that are part of the Idaho-Wyoming thrust belt. From west to east, these faults are the Crawford (Cambrian on Cretaceous), Absaroka (Upper Paleozoic on Cretaceous), and Darby (Jurassic on Cretaceous) thrusts. These thrusts appear to be successively younger eastward; each probably flattens out at depth into the same or successively higher stratigraphic horizons eastward. Rubey and Hubbert (1959) and F. C. Armstrong and Cressman (1963) discussed the evolution of the thrust belt north of Utah.

The Ogden and Taylor thrusts were described by Eardley (1944) as east-dipping with westward movement, in contrast to the eastward movement on the overlying Willard thrust (for a while all three thrusts were thought to have moved west, but later the interpretation of the Willard was changed). Westward movement requires a separate episode of thrusting and a more complex structural history for northern Utah. This interpretation still is accepted by some geologists (Eardley, 1962; 1963; F. C. Armstrong and Cressman, 1963, p. 18–19). From the map pattern, a reinterpretation appears possible (Fig. 4). The Ogden and Taylor thrusts rise stratigraphically eastward relative to both upper and lower plates; this is awkward for a west-moving thrust and suggests that these thrusts moved eastward just as the overlying Willard thrust did. No large difference in age is necessary, and a separate orogeny is not required. The smaller thrusts could be simply peel thrusts in essentially autochthonous rocks overridden by the Willard block. It is noteworthy that basement crystallines are involved in these minor thrusts. The present dip of the faults must be the result of folding and of later eastward tilting of the Northern Wasatch Mountains; this tilting is already proven by the present dip of the Willard fault.

Amount of Shortening in Sevier Orogenic Belt

Several attempts have been made to estimate the amounts of shortening associated with parts of the Sevier orogenic belt. Rubey (Rubey and Hubbert, 1959, p. 190) gave an estimate of shortening by thrusting of about 75 miles for the Idaho-Wyoming belt north of Utah that was based on structural considerations. Crittenden (1961) estimated 40 miles for apparent displacement of isopachs by the Willard and Charleston thrusts. Along the Charleston thrust, a minimum of 20 miles can be concluded from eastward displacement of the Tintic Quartzite over Jurassic strata. Hintze (1960) gave an estimate of 12 miles for shortening by folding and thrusting at Mount Nebo. In the description of the Nebo-Charleston sector, 5 miles of displacement on the Sheeprock–Pole Canyon thrust was estimated. Hintze (1960) reported 8–10 miles of shortening in the Needles Range, which may be considered part of the Sevier belt. A minimum displacement of 20 miles is required for the Muddy Mountain and Glendale thrusts in southern Nevada in order to explain observable structural relationships (Longwell, 1961, oral commun.), not to mention the larger Gass Peak thrust in the same area.

In both northern and southern Utah, the sole of the major thrust is Eocambrian or lower Cambrian quartzite. From observable overriding relations, a minimum displacement of 25 miles in southern Utah and 30 miles in northern Utah is evident on this fault alone, and to this must be added the displacement on the faults

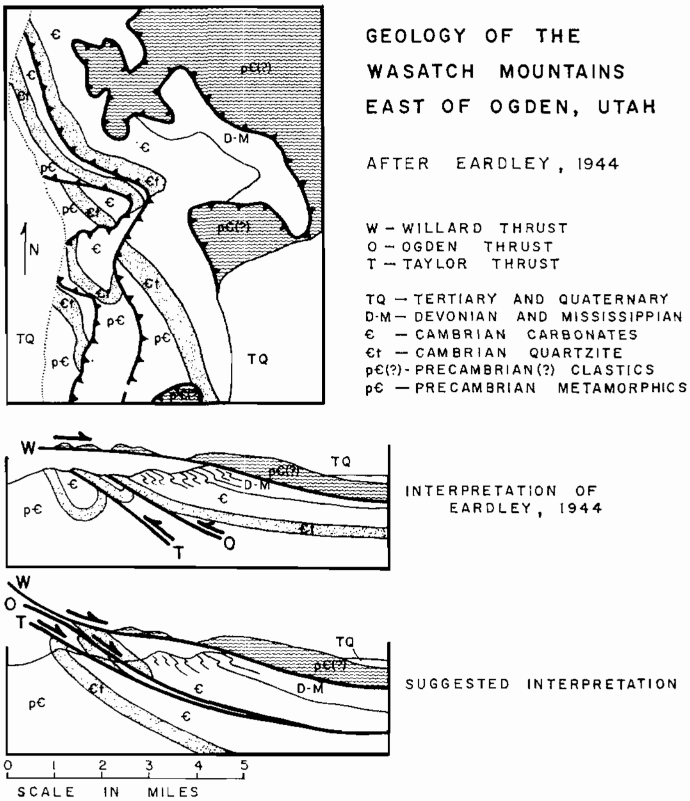

Figure 4. Reinterpretation of Taylor and Ogden thrusts.

farther east. The total displacement in the northern area must be greater than that estimated because the westernmost autochthonous and easternmost allochthonous sections are strikingly dissimilar. Additional intervening, now eroded, strata are required.

To summarize, it would seem that total shortening of 40 miles across the Sevier belt is a minimum value, and 60 miles is adequate to accommodate comfortably any of the estimates. In the Nebo-Charleston sector much of the shortening is taken up by the folds and thrusts west of the major thrust so that the major thrust in that area may have a relatively smaller displacement (as little as 10–20 miles).

Structural Continuity of Thrust Belt

Between Gass Peak and Canyon Range, the evidence points to structural continuity of the upper plate of the major thrust, with the possible exception of the area near the Lincoln-Clark County boundary. To the north, there appears to be a single major thrust from Mount Nebo to the Paris area in Idaho. The greatest uncertainty concerns the connection between the Nebo and Canyon Range areas.

The Leamington fault appears to mark a significant discontinuity in the upper plate of the major thrust of the Sevier belt; subsurface data may be required to understand the structural relations in this area.

The folds and thrusts east of the major thrust do not appear to be individually continuous. In places, structural complexities in this imbricate, highly deformed zone are unresolvable in the pre-normal faulting paleogeology, but the zone itself is continuous except where the thick sedimentary accumulation of the Oquirrh basin has been pushed eastward over the foreland.

In over-all view, the Sevier belt is a continuous entity from Nevada to Idaho; structural style, age of deformation, magnitude of shortening, and width of the highly deformed zone show no radical changes over a distance exceeding 500 miles. Admittedly, there are variations along strike, but these are explainable by variations in the sediment accumulations involved in the deformation.

Style and Localization of Thrusts

The thrusts of the Sevier belt appear to be décollement thrusts, like those of the eastern Canadian Rocky Mountains (O'Brien, 1960). The major thrust invariably appears to flatten out at depth in the Eocambrian quartzite-shale sequence (Pl. 1, fig. 4). There is no other way to explain the persistence along strike of the stratigraphic position of the thrust and the lack of apparent involvement of crystalline basement rocks in the major thrusts. If thrusts with displacements of 20 miles steepened westward, great uplifts of Precambrian would be inevitable. This sort of reasoning has led to similar conclusions for thrusts in Wyoming (Rubey and Hubbert, 1959, p. 187) and in southern Nevada (Longwell, 1950). The larger thrusts are restricted to the belt of rapid change of thickness of the entire geosynclinal prism. Under regional compression, the thick geosynclinal section of 30,000–40,000 feet of quartzite and carbonate with minor shale, has behaved with relative competence. The thinner section along the edge of the geosyncline has failed in one or more thrusts along which the geosynclinal strata are piled up on the transition zone. The shelf section was too thin to transmit stress and undergo significant deformation. The relatively broad transition zone in northern Utah and adjacent Wyoming resulted in a broader thrust-and-fold belt. A preexisting fold localized the Mesozoic Stansbury anticline. The Oquirrh basin was evidently less competent than other areas in the geosyncline, and, as a result, it experienced more intense folding and perhaps less shortening by thrusting than the rest of the belt during orogenic deformation.

The shaly zones in the Eocambrian and Cambrian clastic sequence provided the major zones of bedding-plane movement in the region; the major thrust rises from this level. Other important décollement zones are the Middle Cambrian shales, into which a number of the frontal thrusts apparently go downdip (Muddy Mountain, Glendale, Blue Mountain, Crawford), the various Mississippian shales, which are followed by important bedding-plane faults in the Southern Wasatch Mountains, and the Middle Jurassic shales and evaporites, into which several faults step up and flatten out (Blue Mountain, Pavant).

It is impossible to say definitely what happens to the décollement in the Eocambrian section as it continues westward from the Sevier thrust belt, for there is no direct evidence of its existence more than approximately 50 miles west of the trace of the major thrust. In northern Utah, the Taylor and Ogden thrusts have wedges of basement in their upper plates, but they are secondary thrusts about 30 miles west of the main fault trace. Along the Wasatch front near Santaquin, Utah, crystalline Precambrian rocks are shown on published maps in stratigraphic continuity with the upper plate of the Nebo thrust. If this is correct, then, the major thrust must be in crystalline rocks in that area. An alternative possibility is that the thrust is concealed as a bedding-plane fault along the mountain front.

In southern Nevada, the décollement can be observed 30 miles behind the frontal Wheeler Pass thrust as the Johnnie thrust described by Nolan (1929) and discussed by Burchfiel (1961, p. 129–131).

Eventually, the thrust must grade westward into mobile basement underlying the geosynclinal area. This concept returns to some degree to the idea Nolan (1929, p. 469–471) advanced to explain the Johnnie-Wheeler Pass thrust. Armstrong and Hansen (1966) proposed that a mobile basement underlay areas to the west of the thrust belt during the Mesozoic. During later stages of the deformation of the Sevier belt, particularly during some of the late postthrust folding, the basement within the fold and thrust belt may have become mobile enough to take part in the folding because of tectonic thickening of the overlying cover and the consequent rise in temperature of the basement. In earlier stages, apparently, the basement was relatively rigid, and deformation was confined to the sedimentary cover.

Hinterland

West of the Sevier orogenic belt on the paleogeologic map is a wide area of apparently simple structure that actually contains complex deformation of a different type than that in the Sevier belt. Most of the complexity lay deep below the surface in early Tertiary time, but fortunately, normal faulting has deeply exposed the region for geologic examination.

In the hinterland of southern Nevada, a major domal uplift is apparent in the Groom area. A number of exotic klippen occur near the dome; none has been mapped in detail, and little can be said about them. They contain lower and middle Paleozoic rocks and overlie middle and upper Paleozoic strata which are gently folded. D. H. Adair (1962, oral commun.) pointed out the close association of the apparent klippen with pre-normal faulting structural lows. They might be remnants of a large overthrust, but their chaotic character suggests that they are probably isolated blocks transported by gravity, most logically from the Groom dome. Similar blocks may occur west of the dome on the Nevada test site. Several thrust plates of upper Paleozoic rocks in the Southern Egan Range are shown by Tschanz (1960). These may be similar to the klippen in southern Nevada.

More work is needed to evaluate these klippen and their relationships. It should be stressed that later work may show the klippen, or some of them, to be nonexistent. Enough of the region is covered to allow a number of interpretations. The largest klippe in southern Lincoln County, the Pahranagat klippe, may be interpreted as a thrust-bound wedge without great transport, but the writer feels the klippe hypothesis is more likely on the present evidence.

East-central Nevada superficially appears to be a region of broad gentle folds. The angular unconformity between Paleozoic and Tertiary rocks in that region is small but increases westward. Cook (1965, p. 55) said, "the regional disconformity at the base of the volcanic sequence changes into an angular unconformity . . . in the central Egan Range, the Grant Range, the White Pine Mountains and the Pancake Range."

Many ranges in this area show a complex internal structure characterized by bedding-plane or near bedding-plane "shearing off" faults, i.e., faults where beds are consistently cut out instead of repeated (Misch, 1960). Misch (1960) discussed many examples of this type of structure; in a number of cases, he considered such faults to be parts of his regional décollement. In contrast to the complexity observed in many ranges, there are well-exposed ranges in the same area where the entire Paleozoic section can be observed intact without significant faulting. This contrast between simplicity and complexity of structure in the ranges was noted by Misch (1960) and is one of the remarkable features of the hinterland.

The near conformity of Tertiary volcanic strata with Upper Paleozoic strata in the same region containing this complex faulting has led some to conclude that most of the deformation is Tertiary (J. C. Young, 1960, p. 169–170). Much of the deformation may well be Tertiary and in some areas almost certainly is, but in the Snake Range "shearing off" faulting as well as folding and high-angle faulting predate Cretaceous plutons (Misch, 1960; Misch and Hazzard, 1962). There appears, therefore, to have been fairly intense deformation, at least locally, before the time represented by the paleogeologic reconstruction. The paleogeologic method would be unable to detect bedding-plane faults that did not juxtapose rocks of contrasting age or that did not reach the early Tertiary surface. Deformation actually appears to have been greater at depth than near the surface. Most of the "shearing off" faults occur in lower Paleozoic rocks, often in the Cambrian-Eocambrian part of the section (Misch, 1960).

From the available data, it seems necessary to conclude that in the hinterland of the Sevier belt, the surficial structure was fairly simple—mostly broad folds, with no complex tightly folded areas. Only upper Paleozoic and Mesozoic rocks were exposed at the surface, for nowhere do Oligocene volcanics lie on lower Paleozoic rocks. Even in Sacramento Pass between the central and southern Snake Ranges (in the blank area on Pl. 1, fig. 3), Oligocene volcanics lie on Pennsylvanian rocks disconformably. Much of the chaotic structure in that area is Tertiary (Misch, 1960). No major overthrusting involving telescoping of the Paleozoic section occurred in this region. Total shortening of the supercrustal rocks must have been relatively minor compared to that in the Sevier belt. In early Tertiary time, the complex structures of this part of the eastern Great Basin were deeply buried.

East of the Snake Range is the Confusion Range fold belt which is a narrow, deeply downfolded zone containing strata as young as Mesozoic. It is possible that this belt is the surface exposure of a zone sucked down between adjacent rising domal structures in a mobile basement. Alternatively, it could be a surficial structure formed by gravity-propelled gliding of upper Paleozoic rocks eastward off the rising Snake Range dome, possibly even in Tertiary time. In the Gold Hill area, the carefully worked out structural history of Nolan (1935) is in agreement with a simple paleogeology. In Eocene time, folded upper Paleozoic rocks were present at the surface. One fold was fairly tight and overturned to the east. The larger thrusts and most normal faults in the area are post-Eocene and, therefore, later than the time represented by the paleogeologic reconstruction.

A model for the deep-seated structure of the hinterland has been proposed by Armstrong and Hansen (1966). The present-day fault-block ranges expose different tectonic levels which may be interpreted as an *infrastructure*, a mobile deeply buried zone affected by regional metamorphism, and a *suprastructure*, an unmetamorphosed zone of broad open folds developed under a relatively thin cover. These two tectonic levels may grade into one another, but in most areas, they are separated by a zone of tectonic adjustment with disharmonic deformation and steep metamorphic gradients, an *Abscherungszone*.

The hinterland of the Sevier orogenic belt on the paleogeologic map exposes only the suprastructure—unmetamorphosed upper Paleozoic rocks, broadly folded but with little over-all shortening. Deeply buried in early Tertiary time but now exposed in areas such as the Snake Range, Ruby Mountains, and Raft River Range is the infrastructure—metamorphic rocks, in places, migmatites, with complex minor structures and large-scale recumbent folds. The transition between these two tectonic levels occurs in most areas in the upper part of the Eocambrian clastic section, but elsewhere, it rises into lower, and, in the Ruby Mountains area, even to middle Paleozoic rocks. This zone, in which adjustments were made for differential deformation of infrastructure and suprastructure, is the site of zones of intense shearing. In many areas, faults have been recognized in or closely related to this zone; they are the younger–on–older thrusts that characterize the hinterland. A note of caution is needed, however, because other structures also have been categorized as younger–on–older thrusts so that some confusion on this point is inevitable. Misch (1960) reviewed the occurrence of the structural complexities of the *Abscherungszone*, although in a somewhat different context than the tectonic framework proposed by Armstrong and Hansen (1966).

Both Misch (1960) and Armstrong and Hansen (1966) concluded that the orogeny which affected the hinterland was pre-Lower Cretaceous, making the structures distinctly older than the Sevier orogenic belt. Lower Cretaceous plutons which cut across both orogenic structures and metamorphosed Eocambrian-Lower Cambrian rocks are unequivocal evidence of this. The regional décollement of Misch (1960) cannot be related directly to the Sevier orogenic belt as has been proposed by Miller (1963), for it is too high stratigraphically and distinctly older. Moreover, it does not appear possible to the writer or to Misch to consider that the Sevier belt is the result of gravity gliding eastward from central Nevada, the only possible area of "tectonic denudation." Rather, I feel compelled to seek the locus of shortening displayed by the orogenic belt in crustal shortening and deformation at depth within and west of the Sevier belt. The Paleozoic blanket of the hinterland was already deformed and "nailed down" by cross-cutting Lower Cretaceous plutons; only a very contrived explanation could specify a locus of gliding to bring the Sevier belt out of Nevada by gravity.

An entirely analogous situation is provided by the Rocky Mountains in Canada. There, regional metamorphism, complex deformation, and emplacement of plutons of batholithic dimensions in the hinterland occurred before thrusting, with shortening exceeding 100 miles in the Rocky Mountains (White, 1959; Shaw, 1963; Gabrielse and Reesor, 1964). It appears necessary to invoke some sort of *Verschluckung* to explain the development of these later Mesozoic fold and thrust belts.

STRATIGRAPHIC EVIDENCE CONCERNING AGE OF DEFORMATION IN SEVIER OROGENIC BELT

Evidence for a Pre-Cretaceous Sevier Arch

It was in later Permian time, perhaps, that the orogeny began in the Sevier belt. Permian isopachs show a southwest-trending arch in southwestern Utah and adjacent Nevada that coincides with the belt of Mesozoic thrusting. Brill's maps (1963, p. 319) show that this arch affected the distribution of Leonardian strata but not the distribution of Wolfcampian strata. Data for later times are lacking, but possibly the arch is a precursor of later deformation in the area; it would be an ancestral Sevier arch.

Throughout the region, the basal contact of the Triassic is a disconformity above Permian strata. The time gap represented by the contact is somewhat greater in southern areas than in northern ones. In southern Nevada, erosional relief of more than 100 feet and coarse conglomerates are commonly found at the contact (Longwell, 1925; Secor, 1962). In the westernmost exposures, in the Spring Mountains, at least 1400 feet of Permian strata are missing below the disconformity, perhaps as a result of uplift and erosion on the ancestral Sevier arch.

Jurassic deposits, now occurring only in the easternmost part of the Sevier orogenic belt and on the Colorado Plateau shelf, are significant as sources of indirect information concerning events in the Great Basin. The shift of sediment sources during the Jurassic has been discussed by Wright and Dickey (1958, 1963, 1963a) and Stokes (1960, 1963a, 1963b). During Middle Jurassic time, the hinterland of the Sevier belt became a source of clastic sediment. In the southern Wasatch Mountains, Upper Jurassic and lowermost Cretaceous conglomerates occur conformably on both upper and lower plates of the major thrust of the Sevier belt (Bissell, 1959, p. 163; Stokes and Madsen, 1961), suggesting that uplift and deformation there began after the end of the Jurassic. In northern Utah, later Jurassic formations are truncated westward by erosion which preceded deposition of Lower Cretaceous Kelvin Conglomerate. In southern Idaho, movement on thrusts of the Sevier orogenic belt may have begun as early as the end of the Jurassic (F. C. Armstrong and Cressman, 1963, p. 8–16).

In summary, evidence for a pre-Cretaceous Sevier arch is suggestive but not conclusive. There is no evidence that extensive uplift or thrusting began in the belt before the end of the Jurassic; the story for the Cretaceous is an entirely different matter.

Cretaceous to Paleocene—Rocky Mountain Geosyncline

East of the Great Basin, an enormous accumulation of Cretaceous sediments provides a detailed record of the advances and retreats of the Cretaceous seas in response to eustatic changes, deformation, and repeated great floods of clastic materials from a westward source. Facies and thickness changes indicate a source west of the present outcrop areas.

The Sevier orogenic belt was the source of material that accumulated in the Cretaceous Rocky Mountain geosyncline (Fig. 5). This is proven by contemporaneity of deformation in the orogenic belt with sedimentation in the immediately adjacent area to the east, by the coarsening of clastics toward the orogenic belt, by the coarseness of clastics in the westernmost deposits (some clasts being too large for transport of more than a few miles), and by conclusive provenance studies. The Sevier orogenic belt is the only possible source for the large quantity of carbonate and quartzite clasts derived from lower Paleozoic and Eocambrian rocks of the Cordilleran geosyncline. The prenormal faulting paleogeology shows that rocks of the same age and facies were not exposed elsewhere in the Great Basin during Cretaceous time.

In central Utah, a relatively complete sequence of Cretaceous strata have been studied by Spieker (1946, 1949, 1956) and his students (Schoff, 1951; Hardy and Zeller, 1953). The Cretaceous of Utah recently was reviewed by Burger (1963). Early Cretaceous rocks are absent in most westernmost exposures of Cretaceous formations because of Early Cretaceous uplift and erosion; however, Early Cretaceous rocks are present only a few miles to the east. Numerous angular unconformities occur within the Cretaceous section along its western edge, indicating concurrent deformation and deposition. In central Utah, middle and upper Montana Price River Formation locally lies unconformably across major thrusts of the Sevier orogenic belt (Hintze, 1962). In southwestern Wyoming, a similar situation prevails in that upper Montana and Paleocene Evanston Formation lies unconformably across major thrust faults (Tracey and Oriel, 1959). In both areas, some deformation in the Sevier belt postdates the end of the Cretaceous.

The Cretaceous Rocky Mountain geosyncline deposits thicken gradually from east to west in Utah, reach a maximum near the westernmost exposures, and thin drastically toward the adjacent deformed belt. The greatest thickness of Lower Cretaceous deposits occurs in southern Idaho. The maximum thickness in any given east-west cross section decreases gradually from 15,000 feet in Idaho to a few hundred feet in southern Nevada. The Upper Cretaceous section is thick in central Utah, thins fairly rapidly southward toward southern Nevada, and thins slightly, and then thickens again northward into Idaho and Wyoming.

Review of information provided by clast provenance. The Sevier orogenic belt was the only possible source for the coarse lower Paleozoic clasts found in the Cretaceous deposits of the Rocky Mountain geosyncline. The sequential exposure of older and older units in the evolving orogenic belt resulted in an inverted stratigraphy of the lower Paleozoic clasts. The structures in the belt are large thrusts with a few folds; this type of deformation must have provided sources for the clastics.

The information available on clast composition is summarized in Figure 6. By the beginning of the Cretaceous, upper Paleozoic clastic sources were present within the orogenic belt so that at least locally the Mesozoic cover had

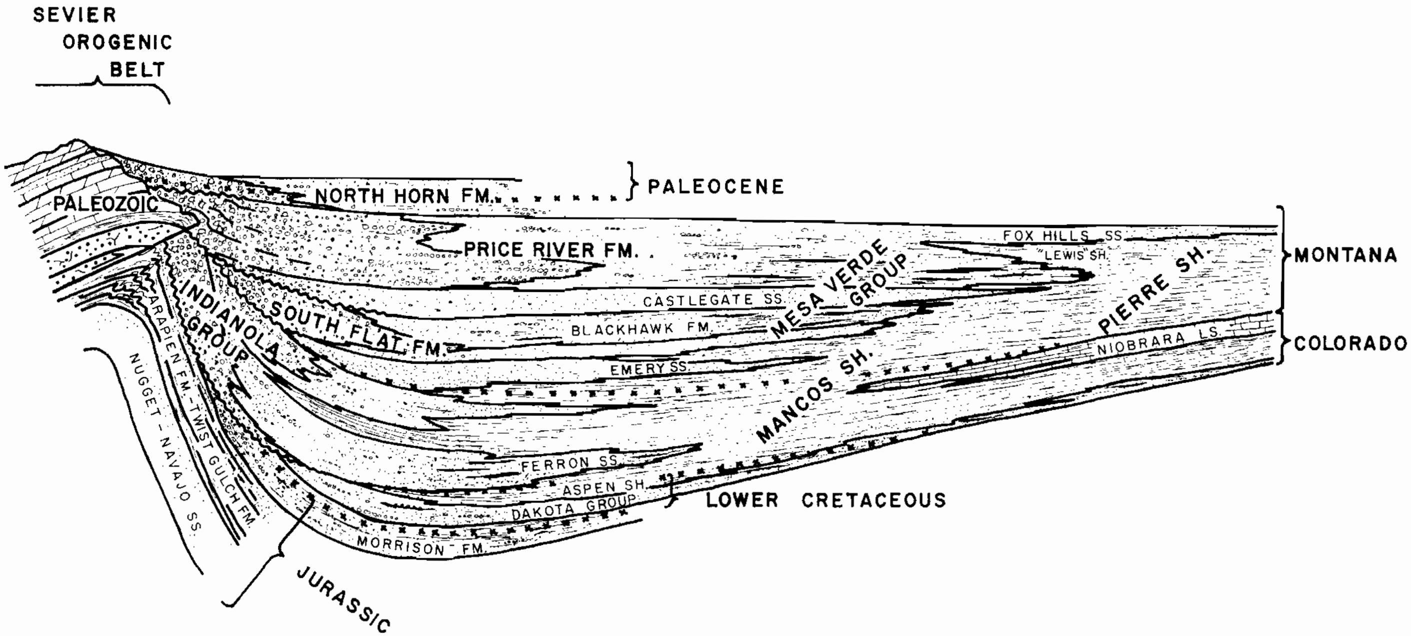

Figure 5. Diagrammatic section across Rocky Mountain geosyncline in central Utah. (Principal sources: Cobban and Reeside, 1952; Fisher and others, 1960; Spieker, 1949.)

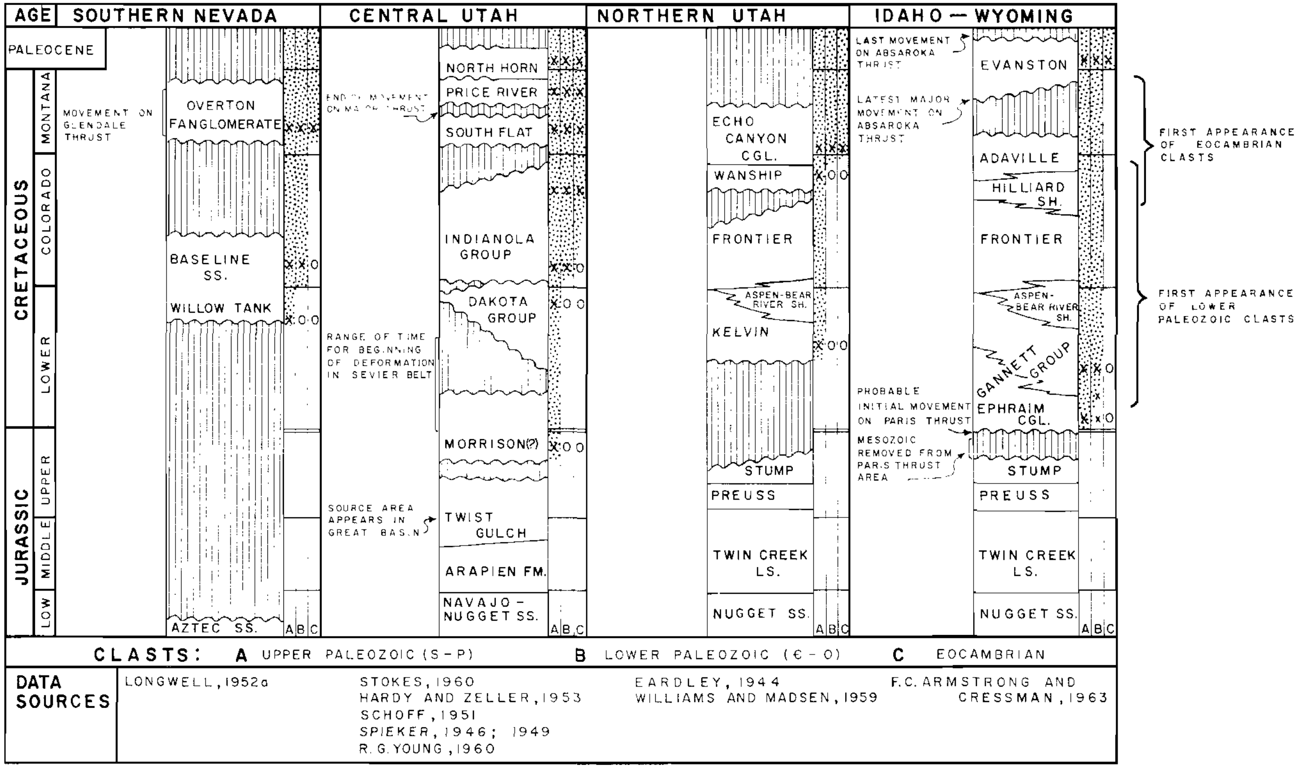

Figure 6. Jurassic to Paleocene correlation chart showing inverted stratigraphy of clasts in Rocky Mountain geosyncline.

been removed. Ordovician quartzites first appear in lower Colorado sediments in southern Nevada and in the Lower Cretaceous sediments in Idaho. The distinctive Eocambrian quartzites appear first in the upper part of the Indianola Group (Colorado) of central Utah, and they become widespread and abundant in Montana conglomerates from southern Nevada through Wyoming, at least as far north as the Teton area (Love, 1956). To a certain degree, the appearance of abundant Eocambrian clasts is almost coincident throughout the length of the Sevier orogenic belt. This would suggest that the evolutionary stages of the orogenic belt were similar over the entire region and that structures within the belt are of similar age and may be extrapolated and correlated along strike.

Problem of Canyon Range fanglomerate. In the Canyon Range of central Utah (Christiansen, 1952), more than 10,000 feet of red-matrix boulder conglomerates, conglomerates, and sandstones, with local lacustrine limestones, occur. These clastic rocks, situated 20 miles west of the westernmost standard Cretaceous sections of the central Utah plateaus, will be referred to as the Canyon Range fanglomerate. The fanglomerate lies with great angular unconformity across a major thrust, which places Eocambrian quartzites of the Cordilleran geosynclinal section over Cambrian and younger carbonates. The fanglomerate strata have been tilted to near vertical attitudes, and locally minor movement along the major thrust has placed the Eocambrian quartzites in thrust contact with them.

Many writers have considered this area significant for the dating of orogeny in central Utah, but the quoted relationships here are discordant with those elsewhere in the fold-and-thrust belt. This is due to Christiansen's (1952) assignment of the Canyon Range fanglomerate to the Indianola (?) conglomerate. He made the Indianola correlation strictly on the basis of lithologic similarity. No alternatives were discussed, but at the time regional information was much more limited, and nothing about the age assignment seemed unreasonable. The time has come for reassessment of the age of the Canyon Range fanglomerate.

Variegated siltstone, conglomerate, sandstone, and light-colored limestone that overlie the fanglomerate with a slight angular ($\sim 10°$) unconformity were considered North Horn(?) Formation, thus establishing a Cretaceous age for the fanglomerate, which was assigned to the Indianola(?), although fossil evidence or tracing of lateral continuity were lacking. The Canyon Range fanglomerate was also correlated with red conglomerates in the Snake Range of eastern Nevada, which are now known to be Tertiary (Armstrong, 1964, p. 73). This is typical of how misleading lithologic correlations among clastics in this region may be. Spieker (1949, 1956) emphasized that similar facies are repeated in formations of different age.

The writer suggests that the Canyon Range fanglomerate may be a lateral equivalent of the Paleocene and early Eocene Flagstaff Limestone of the Utah Plateaus. This correlation can be supported by evidence as strong as that supporting an Indianola (?) age, although either correlation may be proven to be correct when fossil evidence is found. The important point is that the age of the fanglomerate is not well known.

Nowhere do rocks known to be older than upper Montana lie unconformably across major thrusts; hence, in terms of structural position, the fanglomerate should be Price River or younger. The basal conglomerates of the Canyon Range fanglomerate are composed mostly of Eocambrian quartzite, some boulders exceeding eight feet in diameter. An obvious local source is present in the upper plate of the Canyon Range thrust. In the Indianola strata of the Gunnison Plateau (due east of the Canyon Range), the lower beds contain none of the distinctive Eocambrian quartzite, but higher in the section it appears in modest quantities (5–10 percent locally). Only the Price River and later conglomerates contain the Eocambrian quartzites in abundance. Clast composition, therefore, would allow, at best, correlation of the Canyon Range fanglomerate with upper Indianola, and a Price River or later age would be more likely.

Where proven, Indianola beds are as closely associated with major thrusts as the Canyon Range fanglomerate, the deformation is much greater. Northeast of Nephi, Indianola conglomerates underlie an angular (almost 90°) unconformity below Price River conglomerates. The slight angular unconformity between Christiansen's Indianola (?) and North Horn(?) formations in an area much farther within the Sevier orogenic belt is further evidence against the age he assigned to the older conglomerates.

On Long Ridge, northeast of the Canyon Range, Muessig (1951) recognized a facies equivalent of the Flagstaff lacustrine deposits of the High Plateaus to the east that was composed of red matrix conglomerates and sands. This correlation is established by fossil evidence and intertonguing with other Tertiary formations. Flagstaff age conglomerates exposed near Mills, Utah, only 10 miles from the Canyon Range, are virtually identical to conglomerates of the Canyon Range fanglomerate. Rock types and clast compositions match so closely that on lithologic criteria correlation of Flagstaff Formation with Canyon Range fanglomerate would be stronger than the Indianola-Canyon Range correlation. This is by no means proof, but it emphasizes the fact that facies can be matched in rocks of widely different age. The Indianola of the Gunnison Plateau certainly is similar to the Canyon Range fanglomerate, but it is not as perfect a match as the Flagstaff of Long Ridge. As to later deformation and structural position, the Flagstaff on Long Ridge is reported by Muessig (1951) to be locally tilted to an almost vertical attitude, just like the Canyon Range fanglomerate.

Thus, much doubt can be cast on the correlation of the Canyon Range fanglomerate with the Indianola Group of central Utah, and it is at least equally possible to argue for a Flagstaff age although any age between Indianola and Flagstaff eventually may be established. The post-thrusting clastics of the Canyon Range should not be considered evidence of a distinct episode of pre-Upper Cretaceous thrusting in Utah, unless fossil proof of a Colorado age is found.

Summary

The evidence provided by the clastic rocks, unconformities, and structural relationships can be used to arrive at a summary of the timing of deformation in the eastern Great Basin. A faint suggestion of uplift along the Sevier belt is found in lessened Permian deposition and pre-Triassic erosion along a NE-SW-trending belt in southwestern Utah and southern Nevada. By Late Jurassic time, deformation was well under way within the Great Basin, and the area was sufficiently elevated to be a clastic source. By the end of the Jurassic, fairly coarse conglomerates were being shed.

In the southern Wasatch Mountains, faulting began just after the end of the Jurassic. In this sector of the Sevier orogenic belt, as elsewhere, deformation probably began earlier farther west (Sheeprock thrust, folds in the Oquirrh basin). Movement on the major thrust may have begun as early as the end of the Jurassic in northern parts of the Sevier orogenic belt (F. C. Armstrong and Cressman, 1963, p. 8–16). During most of Early Cretaceous time, thrusting must have been going on in the Sevier orogenic belt. By early Colorado time, lower Paleozoic clasts were being shed from the entire belt. Later in Colorado time, Eocambrian rocks became significant sediment sources in central Utah, and by Montana time clasts of these rocks were supplied in abundance from the entire belt. The Eocambrian rocks within the fold and thrust belt occur only in the soles of major thrusts. For the area to have been a source of these rocks, thrusting must have been of large magnitude by the beginning of Montana time. F. C. Armstrong and Cressman (1963, p. 8–16) consider that much of the movement on the Paris thrust in Idaho occurred during Lower Cretaceous time. Movement on the major thrusts of the Sevier belt was probably approximately coincident with movement on the Paris thrust.

Major thrusting in the Sevier orogenic belt ceased before the end of Montana time, for the upper beds of Price River of equivalent strata lie unconformably across the large thrusts. Later deformation consisted mostly of folding, at times with local thrusting. This period of waning deformation lasted into the Paleocene. During the Eocene, the orogenic belt was quiet, and erosion actively reduced the relief inherited from the deformation.

Within the broad continuous pattern of deformation of the eastern Great Basin, some fine structure can be recognized. In southern Nevada, earlier deformation in the Sevier orogenic belt began in the west (Longwell, 1952a; Secor, 1962). In the imbricate belt of Idaho and Wyoming, a series of thrusts become younger eastward (Rubey and Hubbert, 1959; F. C. Armstrong and Cressman, 1963, p. 8–16). In Utah, it is possible, but not provable, that deformation likewise began in the west along the major thrusts. The clastic source evidence does indicate that the major thrusts were active during much of the deformation of the belt.

The clastics of the geosyncline in the Rocky Mountains can be subdivided into three great floods or complex tongues. The first was Upper Jurassic and Lower Cretaceous (Morrison, Dakota, Kelvin, Gannett). Diminished influx of clastics allowed the uppermost Lower Cretaceous shales (Aspen and equivalents) to spread over a wide area. The second clastic flood corresponds to the Indianola Group and Frontier Formation of Colorado age. This was followed by another time of widespread shale deposition in late Colorado time (Hilliard; part of Mancos). The flood of clastics in Montana time came with the final major deformation of the orogenic belt (Price River, South Flat, Echo Canyon, Mesaverde, Adaville). The retreat of the sea in latest Montana time after deposition of the "Lewis" Shale tongue above the Mesaverde Group in eastern Utah marked the end of the Rocky Mountain geosyncline.

The total volume of Cretaceous sediment eroded from the orogenic belt corresponds to a strip of material 25,000 feet thick and approximately 100 miles wide (estimated from isopachs of Weimer and Haun, 1960). More than half of this volume can be accounted for by thrusting of the geosynclinal section over the shelf with shortening corresponding to approximately 50 miles. The remainder would have to be derived from erosion of folds farther west and in the orogenic belt. Crudely, at least, the amount of sediment in the Cretaceous geosyncline equals that estimated on structural grounds to have been removed from the orogenic belt. Of the three major clastic floods, the second two are of greatest significance volumetrically. If amount of deformation and amount of debris could be correlated, then presumably most of the evolution of the Sevier belt took place in Late Cretaceous time. Such a correlation has not yet been established.

TERTIARY STRUCTURES

This discussion would be incomplete without mention of some of the Tertiary complications which have obscured the Sevier orogenic belt and its possible relation to them. The most evident structural development in the Tertiary was the breakup of the region by normal faults which are discussed in detail by Nolan (1943), Mackin (1960a), and Moore (1960). The major late Tertiary faults have a generally north-south trend and displacements commonly greater than 10,000 feet; some displacements exceed 30,000 feet. The origin of the normal faulting is a matter of debate. Thompson (1960) supported the concept of crustal stretching as the basic cause. Mackin (1960) has presented an eruptive-tectonic hypothesis that explains the faults as collapse features due to withdrawal of lateral support by eruption of 60,000 cubic miles of Tertiary volcanics. The time lag between volcanism and normal faulting presents this hypothesis with difficulties. It is too attractive an explanation to be rejected, however, and is probably an important part of the phenomenon, especially in areas like the Nevada Test Site where volcanism and faulting were synchronous. The regional pattern of the faulting and the timing anomaly support the crustal-stretching hypothesis. The regional faulting would have a deep tectonic control, and the volcanic eruptions would simply modify the pattern.

One strong suggestion in favor of over-all thinning of the crust in the Great Basin region is its present topographic altitude. It is, on the average, lower than surrounding areas. The Sierra Nevada on the west and the High Plateaus of Utah and the Wasatch Mountains on the east project far above the Great Basin region. Without crustal thinning, the region would probably now stand at altitudes of more than 10,000 feet as an Alpine chain undergoing deep dissection. Stretching has resulted in normal faulting, crustal thinning, and resulting lowering of average altitude. Consequently, structures that formed at shallow depths in the orogen have been preserved, and there is an unusual opportunity to observe here all depths of an orogenic belt simultaneously. The stretching of the crust in the Great Basin may be only part of a much larger tectonic system, the East Pacific Rise, that was described by Menard (1960). The strain appears to have taken the form of distributed faulting in contrast to rift valleys common elsewhere on oceanic rises or on the rise in Africa. Perhaps in the orogenic belt, even some tens of millions of years after deformation had ended, the crust would still be warmer and thereby weaker than elsewhere. That the lower crust and upper mantle under the Great Basin is relatively weak is shown by Crittenden's analysis (1963) of the isostatic rebound in the Bonneville basin which gave viscosities an order of magnitude smaller under the Great Basin than those found in Fennoscandia. Under "tension" (when the vertical principal stress exceeds the horizontal principal stresses in deeper parts of the crust), the softer zones of the crust would stretch like taffy, but shallow rocks would fail by faulting of the Basin and Range type. The Colorado Plateau was unaffected because it lacked a softened basement; thus, the weak basement hypothesis provides an explanation for the coincidence of the eastern margin of the Basin and Range province and the eastern edge of the Sevier orogenic belt.

Normal faulting is not the whole story, however. Several ranges, particularly those most elevated during the Tertiary, appear to have been arched and may not have faulted margins (Misch, 1960, p. 19–20; Snelson, 1957; Woodward, 1964; Felix, 1956). These ranges occur in the hinterland of the Sevier belt and contain rocks metamorphosed during the Mesozoic;

these rocks would have been warm and more plastic than the shallow rocks of the suprastructure. As a consequence, these ranges could have flexed during uplift, perhaps developing beneath horsts formed at shallower tectonic levels. Brittle deformation would characterize the suprastructural rocks; all suprastructure ranges appear to be simple fault blocks.

At a number of localities domal structures related to Tertiary plutons have formed (Mackin, 1960a; Blank, 1959; Cook, 1957; Wisser, 1960). Structural relief resulting from normal faulting, arching, and doming has resulted in gravity slides, some of large dimensions (Mackin, 1960a; Misch, 1960; Moores, 1963; Secor, 1962; Bissell, 1964; Cook, 1960; Jones, 1963; Armstrong, 1964). The structural style characteristic of these slides is pervasive brecciation. In addition to newly initiated faults, many older faults may have been reactivated during the Tertiary extension-gravity sliding regimen. The present complex geology represents the summation of Jurassic, Cretaceous, and Tertiary effects. With careful work, as many as five episodes of structural development have been worked out in some quadrangles (for example, Nolan, 1935).

NEVADAN, SEVIER, AND LARAMIDE OROGENIES

According to Wilmarth (1938), the Nevadian (Nevadan) revolution was a term applied to early Early Cretaceous and Late Jurassic diastrophic movements; the Laramide revolution was a mountain-building period in the Rocky Mountain region that began in Late Cretaceous time and ended in early Tertiary time. These terms, grounded in early conceptions of the nature of the orogenic record, are widely used today in the writing of Cordilleran geologists, and they have been so well established that new terms or concepts have not received acceptance. Although most recent reviews of regional geology in the west (King, 1959; Clark and Stearn, 1960) acknowledge an over-all continuity of orogeny in the Cordillera, the pictures presented indicate that confusion has not been eradicated. It is the universal practice to lump structures of the Sevier fold-and-thrust belt and the basement uplifts of the eastern Rocky Mountains under the term Laramide. Pre-Laramide orogenic activity in the Sevier belt is acknowledged, but the emphasis supplied by the two discrete names Nevadan and Laramide never allows a balanced picture to emerge. Attempts to extend, broaden, or blur the two concepts, or to refine subdivisions within and between Nevadan and Laramide have only perpetuated confusion.

Basically a revision of the nomenclature is required. At best, the most that can probably be achieved is to add another term to the collections, something to allow at least a mental divorce of fundamentally different concepts now blurred into one.

In the Rocky Mountains, characterized by basement uplifts, movement began close to the end of the Cretaceous. Keefer and Love (1963) reviewed the evidence in Wyoming. Uplift began in Maestrichtian time, was intense during Paleocene and early Eocene time, and had ceased by middle Eocene time. The orogenic movements here are Laramide in the classic sense, as the Laramie Range in southeastern Wyoming was affected.

In the Sevier orogenic belt, orogenic deformation began approximately at the beginning of the Cretaceous, and major thrusting ended in Campanian time. Campanian and Maestrichtian Price River Formation unconformably overlies the thrusts in Utah, and Maestrichtian (?) Evanston Formation overlies those in Wyoming. Relatively minor movements continued as late as Paleocene in both areas. Thus the common implication that the Cordilleran thrusts are Laramide structures is erroneous. The orogenic structures of the Sevier belt are distinctly different in age from classic Laramide, and moreover, they represent a drastically different sort of deformation and tectonic regimen. General considerations on the nature of orogeny in the Cordillera are impossible unless this fundamental distinction between the Sevier belt and eastern Rocky Mountains is clearly recognized. If Nevadan and Laramide are terms that will continue to be used by geologists, a new term, of equal rank, is necessary. The term Sevier orogeny is suggested for the deformation which produced the structures of the Sevier orogenic belt, largely during Cretaceous time. This orogeny lies in the middle of a period of geologic time (Fig. 7). If it is used in the sense of the definition, it should help clarify discussion of the regional history. A proper summary then is that the central Cordillera of the western United States was affected during the Mesozoic by at least the Nevadan, Sevier, and Laramide orogenies. These orogenies, along with the Paleozoic Antler and Sonoma orogenies, are the principal Cordilleran orogenies which have been significant in the development of the central Cordillera of the western United States. Even this statement is an embarrassing oversimplification.

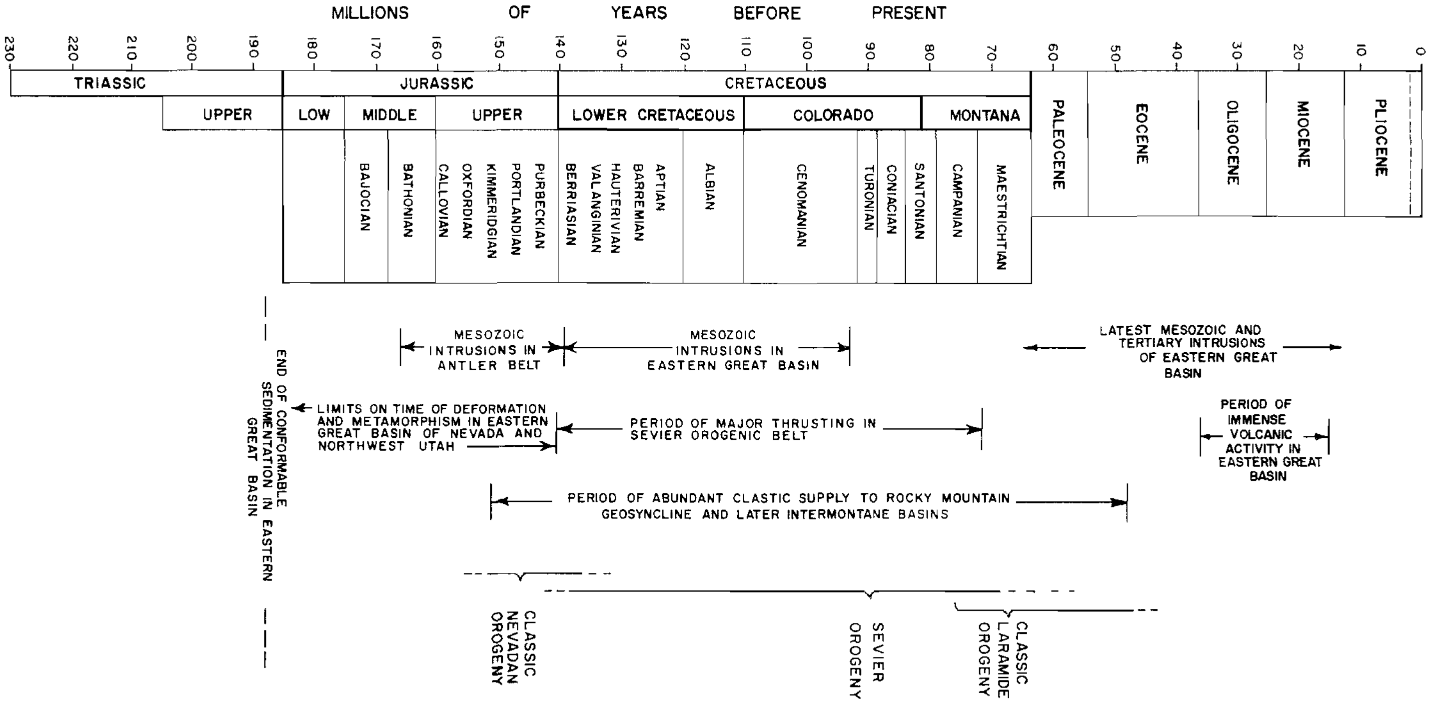

Figure 7. Geologic time scale. Tertiary time scale *after* Evernden and others (1964); 120 m.y. to Tertiary *from* work of Folinsbee and others (1960); and 230–120 m.y. *modified from* data given by Kulp (1961), Baadsgard and others (1961); and Armstrong (1964).

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