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STRUCTURE AND STRATIGRAPHY IN THE CENTRAL TOIYABE RANGE NEVADA

BY

W. D. MEANS

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STRUCTURE AND STRATIGRAPHY IN THE CENTRAL TOIYABE RANGE, NEVADA

BY

W. D. MEANS

ABSTRACT

A small area of autochthonous (?) lower Paleozoic rocks in the central Toiyabe Range has been mapped in detail. A Cambrian (?) sequence composed mainly of quartzite and schist is overlain by Ordovician (?) rocks the lithology of which varies laterally from dark slates and phyllites in the east to predominantly light-colored calcareous rocks in the west. Rocks of both facies are considered to be autochthonous. Allochthonous calcareous rocks, in part of Ordovician age, crop out in a narrow belt in the eastern foothills of the range.

On the scale of the area as a whole, the autochthonous rocks make up a northeast-dipping homocline divided medially by a west-dipping normal fault and truncated on the east by a thrust fault. On a smaller scale the rocks are complexly folded. A study of mesoscopic and macroscopic fold geometry indicates that the autochthonous rocks have been subjected to two major phases of deformation and that structures produced during the second phase of deformation are those which now dominate the mesoscopic fabric of the rocks. The first deformation, tentatively ascribed to the Antler orogeny, is supposed to have taken place under nonmetamorphic conditions and to have produced a large syncline overturned toward the east. The second deformation, accompanied by metamorphism and the widespread development of northeast-dipping axial plane cleavage, may have taken place during Jurassic time.

Granitic plutons intruded after the second phase of folding and several sets of faults are briefly described. Mineral assemblages in the metamorphic rocks are outlined in an appendix.

INTRODUCTION

THE AREA investigated lies about 25 miles south of Austin, Nevada, and extends across the Toiyabe Range from Smoky Valley on the east to Reese River Valley on the west (map 1, in pocket). In this part of the range the eastern slopes descend precipitously from maximum elevations just exceeding 11,000 feet to the margin of Smoky Valley at 6,500 feet and afford excellent exposures. Most of the mapping here was carried out on preprint copies of U. S. Geological Survey 15-minute quadrangles enlarged to a scale of 1:4800. The western slopes are less steep and less well exposed. This terrain and some areas east of the crestline were mapped at a scale of 1:16,000. Field work was done in the summers of 1957, 1958, and 1959.

The purpose of this study has been primarily to describe and interpret structures in the deformed, low-grade metamorphic rocks which make up much of the Toiyabe Range for about 40 miles south of Austin. Mapping was confined to a small area in the hope that detailed knowledge of the form of contacts, supplemented by statistical analysis of numerous attitudes of mesoscopic structures,[1] would help elucidate local structural history. While this hope has been realized to some extent, a number of important stratigraphic facts remain obscure. In particular, it is not

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The author is now in the Department of Geology at the University of Otago, Dunedin, New Zealand.

[1] "Mesoscopic structures" are those for which orientations are directly measurable in single exposures. Folds of this type are intermediate in size between larger and smaller structures designated "macroscopic" and "microscopic," respectively. (This definition is based on a discussion by Weiss, 1959*a*, p. 7.)

yet possible to make definite correlations between the rock units described here and the established formations of broadly similar lithology which have been mapped 15 miles to the south (Ferguson and Cathcart, 1954). Until further mapping provides a basis for these correlations, temporary and informal stratigraphic designations must be adopted. For purposes of this paper, groups of lithologically similar beds are designated "units" (with lithological prefixes, e.g., "blue marble unit"). Groups of apparently conformable units are designated "sequences" (with geographic prefixes, e.g., "Clear Creek sequence").[2]

ACKNOWLEDGMENTS

I am particularly indebted to Professor L. E. Weiss and Professor Charles Meyer of the University of California, Berkeley, who supervised this research and the preparation of a doctoral dissertation based on it (Means, 1960). Their advice and stimulating approach to problems substantially advanced the project. Weiss initially suggested the hypothesis, here adopted, that some of the fold patterns resulted from superposed deformation.

I also thank Professors C. M. Gilbert, F. J. Turner, and M. N. Christensen of the University of California for helpful discussions in the field and Professor W. B. N. Berry for fossil identification. The assistance of C. S. Grommé and V. C. LaMarche made field work especially pleasant and profitable during the summers of 1958 and 1959.

The manuscript was read critically during early stages in its preparation by Professors L. E. Weiss, W. S. Fyfe, and H. E. Hawkes of the University of California. I am grateful to them for numerous valuable comments.

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PREVIOUS WORK

The first geological investigation of the Toiyabe Range was undertaken by S. F. Emmons (1870) as part of the U. S. Geological Exploration of the 40th Parallel. Emmons' remarkable map of the entire range shows approximately the areas underlain by metamorphic, granitic, and volcanic rocks, and provided the basis for similar maps published by Spurr (1905) and Hill (1915). Attention is focused in these and more recent reports (White, 1939; Kral, 1951; Ross, 1953; Nye, 1958) on the geology of mines in the range. Detailed areal mapping commenced with studies by Ferguson and other members of the U. S. Geological Survey in the Tonopah quadrangle (Ferguson and Muller, 1949) and the included Round Mountain quadrangle (Ferguson and Cathcart, 1954). More recently parts of the Toiyabe and Toquima ranges have been mapped by Kay (1955), Crawford (1958), Lowell (1958), MacLachlan (in progress), and Hansen (in progress), of Columbia University; and by Nye (1958) and Powers (in progress), of the University of California, Berkeley. Areas investigated by these workers are shown in figure 1. Although much detailed information is now available on specific aspects of each area, the geology is so complex and the interests of the above-mentioned workers are so varied that no over-all picture of the structure or the stratigraphy of the range has yet emerged. No attempt will be made here

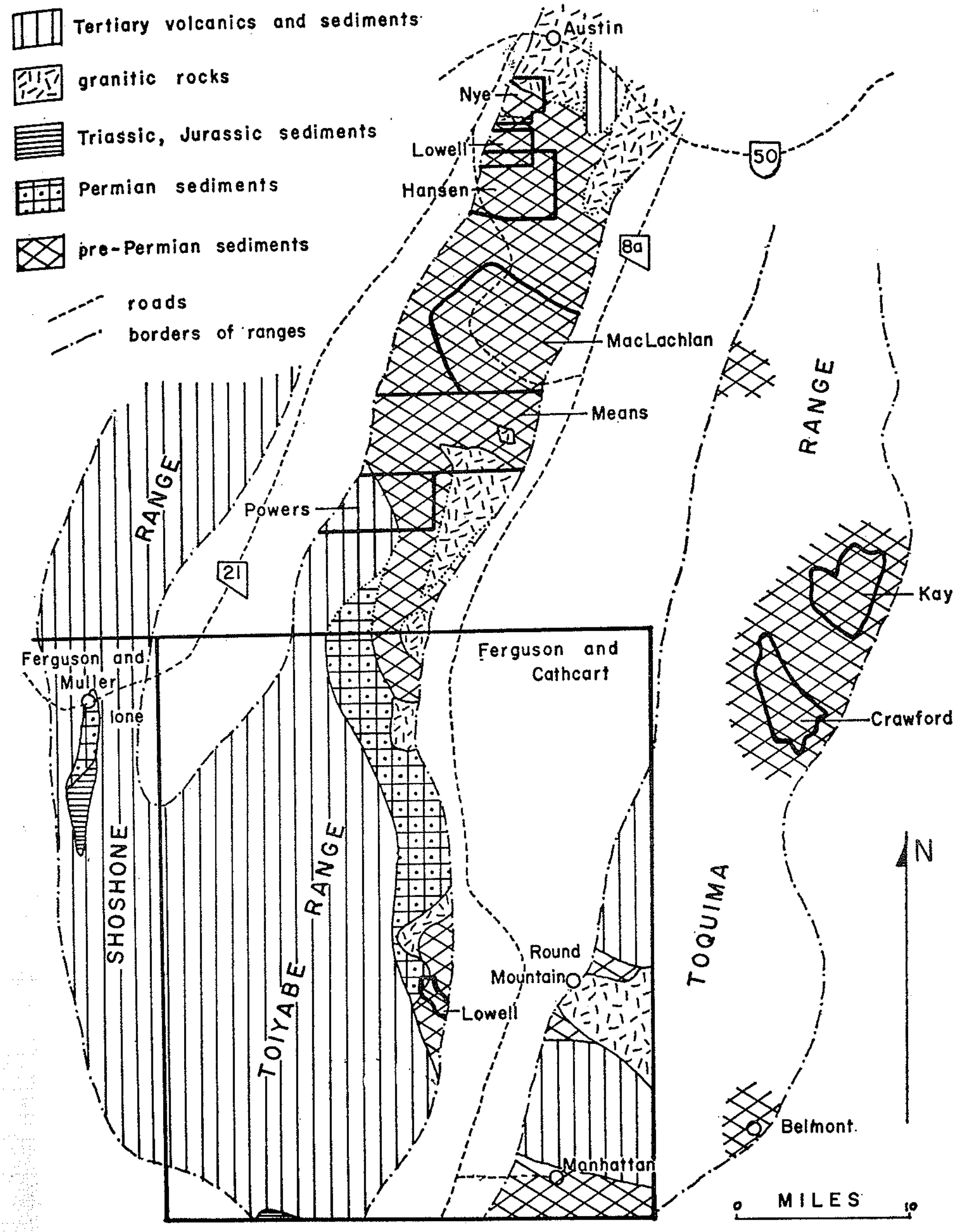

Fig. 1. Sketch map of the central Toiyabe Range and vicinity, showing areas recently investigated.

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[2] The terms "unit" and "sequence" have been used as informal equivalents of "member" and "formation." The boundaries between units or sequences have been placed at horizons across which marked lithological changes are observed, irrespective of whether these horizons are conformable contacts. The term "sequence" is used in a more specialized sense in descriptions of rocks from this region by Professor Marshall Kay and his students. Boundaries between sequences are drawn by them only at surfaces of tectonic unconformity (i.e., thrusts).

to provide such a synthesis. For summaries of the geology of central Nevada as a whole, the reader is referred to excellent papers by Nolan (1943) and Roberts *et al.* (1958).

STRATIGRAPHY

The metamorphic rocks of this area are conveniently divided into four sequences. Three of these are believed to be autochthonous and have been further divided into units. The distribution of rocks of each sequence and the succession of units making up the autochthonous sequences are shown in figures 2 and 3. Thicknesses indicated in figure 3 and in the text below were estimated from the field maps in localities where minimum distortion of thickness by folding could be expected. They may nevertheless depart considerably from original stratigraphic thicknesses.

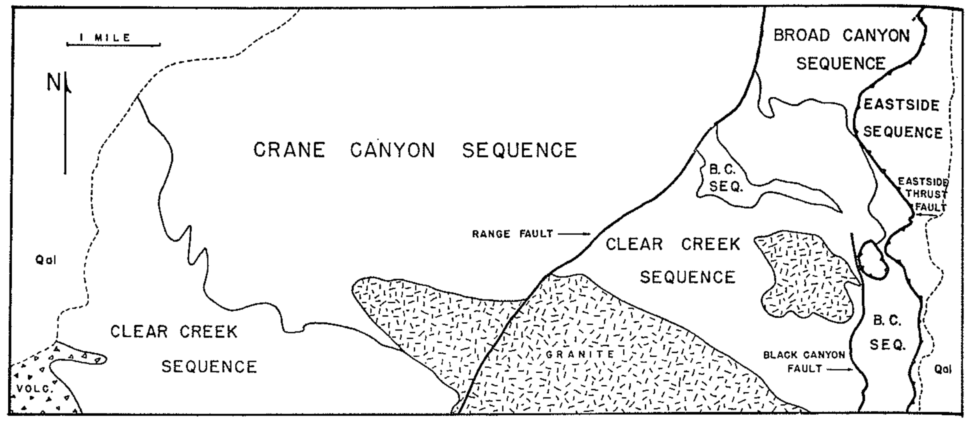

Fig. 2. Outline map of areas underlain by rocks of each of the four stratigraphic sequences.

Clear Creek Sequence

The oldest rocks in the area, referred to here as the Clear Creek sequence, are a series of beds exceeding 4,000 feet in thickness made up predominantly of quartzite, schist, and mudstone. In Clear Creek Canyon the sequence is represented by four units (pl. 1) which may be traced over much of the area. These are designated, from oldest to youngest: the quartzite-schist unit, the buff quartzite unit, the brown schist unit, and the blue marble unit.

Quartzite-schist unit.—The quartzite-schist unit consists predominantly of interbedded quartzite and schist or mudstone and makes up the entire Clear Creek sequence except for its upper 100–600 feet. East of the Aiken Creek pluton (map 1), quartzite and schist are present in about equal proportions, and quartzite beds are typically from 2 feet to 2 inches thick. West of the pluton, schist and mudstone make up about 80 per cent of the unit and quartzite beds are rarely more than 8 inches thick.

The quartzites are white to pale brown or gray. They may be massive or laminated by dark layers 1–2 mm thick and 1–10 mm apart. Cross-bedding is rare. Coarse clastic material is absent. Grain size is less than 0.5 mm. Microcline is typically present to the extent of 15–25 per cent.

The schists and mudstones are gray, brown, olive-brown, or purplish brown on fresh and weathered surfaces. Grain size in a typical schist is less than 0.2 mm. Schistosity is well developed on the east side of the range but faintly defined or absent on the west side. Bedding is characteristically obscure. In the schists it

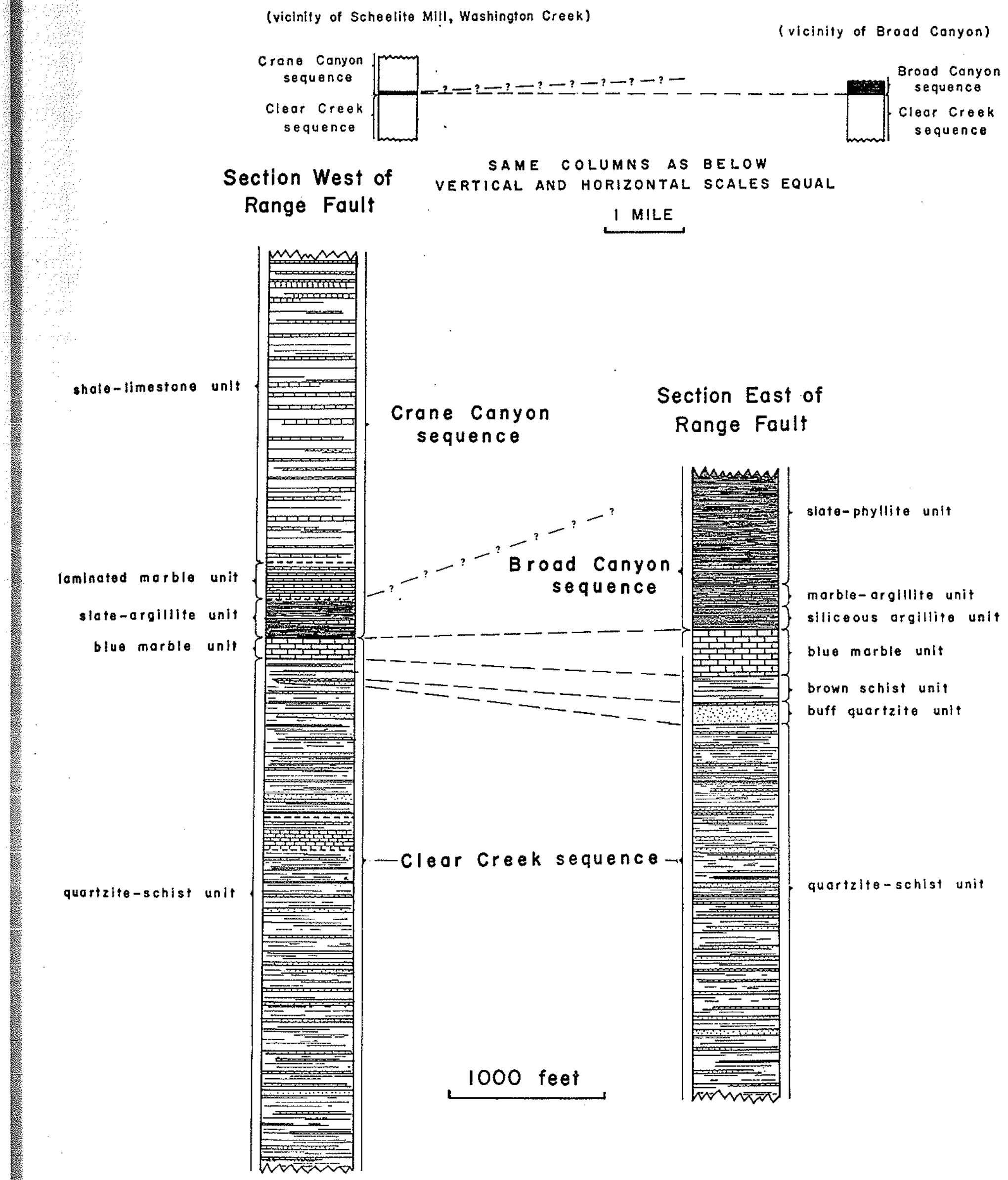

Fig. 3. Generalized stratigraphic columns. Contacts marked with dashed lines indicate units of very uncertain thickness.

may be defined by delicate laminae of contrasted lithologies oriented transverse to schistosity. In the mudstones it may be represented as well by a weakly developed bedding fissility.

Lithologies of subordinate importance in the quartzite-schist unit include blue-gray and yellow-brown marble and black to gray shale and slate. In Clear Creek Canyon, yellow-brown marble 10–40 feet thick occurs 10–70 feet below the top of the quartzite-schist unit. In the vicinity of the Vindicator pluton a greater thickness of thinly bedded blue-gray marble and subordinate amounts of dark slate are present (map 1). These rocks are intensely deformed and so poorly exposed that no estimate of their thickness can be made with confidence; 100–500 feet of beds may be represented. They occur approximately 1,000 feet below the top of the quartzite-schist unit.

Buff quartzite unit.—The buff quartzite unit conformably overlies the quartzite-schist unit and forms prominent cliffs in Clear Creek and Carseley Creek canyons. It ranges in thickness from 100 to 200 feet in eastern parts of the area to less than 50 feet west of the crestline, where it is generally absent. Except for its upper 5–40 feet, the unit consists of thick-bedded buff to white quartzite. This quartzite is more massive than many quartzites in the underlying unit, but is otherwise lithologically indistinguishable from them. The upper 5–40 feet of the unit is made up of pale yellow-brown, thinly bedded, quartz-rich marble which grades downward into the quartzite. The marble is invariably interbedded with brown-weathering siliceous layers one-fourth of an inch to one inch thick.

Brown schist unit.—The brown schist unit conformably overlies the buff quartzite unit and consists of 150–200 feet of brown or gray schist lithologically identical with that in the quartzite-schist unit. Gray siliceous or calcareous beds a few inches thick are commonly interbedded with the schist near the base of the unit.

Blue marble unit.—The blue marble unit conformably overlies the brown schist unit and includes 200–400 feet of beds consisting mainly of blue-gray marble. The color of the marble ranges from nearly white to dark gray according to its graphite content. Darker and lighter beds a few centimeters to a few millimeters thick commonly alternate. Typical grain sizes are 0.5 mm and 0.1 mm for the lighter and darker marbles, respectively, on the east side of the range. Grain size tends to be smaller in marbles on the west side of the range. Carbonate grains alone are visible in most specimens from this unit, but porphyroblasts of colorless chlorite or of black graphitic tremolite are locally abundant.

Several thin subunits may occur at the base of the blue marble unit; black slate, 2–40 feet thick, is regularly present, usually with 1–20 feet of brown to gray quartzite either above or below it. North of Clear Creek, brown-weathering buff marble, 2–8 feet thick, makes up a third subunit. The sequence in this area, from oldest to youngest, is: brown schist, brown quartzite, brown marble, black slate, blue marble. The total thickness of the three subunits here is 20 feet.

Broad Canyon Sequence

A sequence of dark slates, phyllites, and argillites which overlies the Clear Creek sequence east of the Range fault (map 1) is particularly well exposed in Broad Canyon and is designated the Broad Canyon sequence. Three units, representing about 1,000 feet of beds, are distinguished in the vicinity of Broad Canyon. These are, from oldest to youngest: the siliceous argillite unit, the marble-argillite unit, and the slate-phyllite unit. Rocks lithologically representative of each unit are found outside the immediate vicinity of Broad Canyon, but the contacts between them are not distinct, mappable horizons. Rocks of the Broad Canyon sequence in such areas have been mapped as undifferentiated.

Siliceous argillite unit.—The siliceous argillite unit consists of 100–200 feet of siliceous black argillite. Cleavage is poorly developed and bedding is obscure except in the lowermost few tens of feet of the unit, where thin marble interbeds may occur. Many argillite specimens from this unit contain enough disseminated calcite to effervesce readily on contact with dilute hydrochloric acid.

Marble-argillite unit.—The marble-argillite unit is 100–200 feet thick and consists of alternating beds of gray marble and dark argillite. The argillite is itself commonly calcareous. The beds are characteristically 1–2 inches thick. The marble-argillite unit conformably overlies the siliceous argillite unit.

Slate-phyllite unit.—The greater part of the Broad Canyon sequence is made up by a series of gray to black spotted slates and phyllites, designated the slate-phyllite unit. The contact between rocks of this unit and those of the marble-argillite unit is gradational and is therefore regarded as conformable. Slaty cleavage is well developed. Bedding is rarely visible.

Crane Canyon Sequence

The Crane Canyon sequence comprises those rocks west of the Range fault (map 1) which overlie the blue marble unit of the Clear Creek sequence. Dark argillite and slate make up the lower several hundred feet of the sequence and are overlain by a thick series of thinly bedded calcareous shales and impure limestones. Three units are recognized, from oldest to youngest: the slate-argillite unit, the laminated marble unit, and the shale-limestone unit. Together they include at least several thousand feet of beds. No more precise estimate of thickness is possible on account of intense small-scale folding and a lack of mappable horizons within the very thick shale-limestone unit.

Slate-argillite unit.—The slate-argillite unit includes up to 200 feet of dark gray to brown slate or argillite, locally interbedded with gray marble layers. Rocks of this unit are similar to rocks of the Broad Canyon sequence except in the following respects: (1) slaty cleavage is less well developed; (2) the slates and argillites are commonly paler in color; and (3) marble interbeds are generally thinner. A marble-rich layer of unusual thickness (up to 20 feet) occurs in the slate-argillite unit north of the scheelite mill in Washington Creek (map 1). This marble is similar to that making up the blue marble unit of the Clear Creek sequence except that it is more thinly bedded. Marble beds several inches to several feet thick alternate with dark argillaceous or siliceous layers 1–8 inches thick.

Laminated marble unit.—Conformably overlying the slate-argillite unit, the laminated marble unit consists of 100–350 feet of very regularly interbedded pale gray or brown marble and darker gray or brown siliceous shale, argillite, or phyllite. The siliceous beds stand out on weathered surfaces and impart a characteristic corrugated appearance to outcrops. Individual beds are typically from one-fourth of an inch to half an inch thick.

Shale-limestone unit.—Approximately 75 per cent of the shale-limestone unit is gray or pale yellow-brown impure limestone interbedded with calcareous or siliceous shale of the same colors. The beds are typically one-fourth of an inch to four inches thick. Limestone and shale beds are normally present in about equal proportions. Thinly bedded limestones or calcareous shales in which the beds are separated by dark phyllitic partings 1–2 mm thick are also abundant. Both bedding and cleavage are visible in typical outcrops of the limestone-shale unit. In many instances bedding has been transposed by folding into near-parallelism with cleavage.

Dark argillites and slates occur in subordinate amounts throughout the shale-limestone unit. They are abundant in the basal few hundred feet of the unit and in the vicinity of Broad Canyon.

Eastside Sequence

The Eastside sequence includes all rocks above the Eastside thrust (map 1). It has not been divided into units on account of complex structure, lithological homogeneity, and poor exposure. The dominant lithologies are strikingly similar to those of the Crane Canyon sequence. Pale brownish yellow and gray calcareous shales and interbedded shaly limestones predominate. As in the Crane Canyon sequence, these rock types are present in subequal proportions. The beds range in thickness from one-fourth of an inch to eight inches. Unlike the Crane Canyon sequence, the Eastside sequence contains virtually no dark slate or argillite. It does contain minor dark chert, in beds from one inch to four feet thick, associated with blue-gray limestone.

Stratigraphic Relations between Sequences

A conformable contact is observed in continuous exposures between the youngest beds of the Clear Creek sequence and the basal argillites of the Broad Canyon and Crane Canyon sequences. The Broad Canyon and Crane Canyon sequences are therefore at least in part stratigraphically equivalent. The writer favors the view that these sequences are in fact entirely equivalent and that lateral facies change accounts for the lithological contrast between them. This interpretation is based mainly on observation of gradational, and therefore conformable, contacts between all units of the Crane Canyon sequence. It receives some support from the occurrence of abundant dark slate and argillite interbedded in the shale-limestone unit near Broad Canyon. This is regarded as an area in which typical Broad Canyon lithologies are interfingering westward with typical Crane Canyon lithologies. In the writer's view, the Clear Creek and Broad Canyon–Crane Canyon sequences make up an entirely conformable section, and this is assumed to be autochthonous, for lack of evidence to the contrary.

Alternate interpretations of the lithological contrast between the Broad Canyon and Crane Canyon rocks would involve the assumption of a thrust fault or unconformity at the base of the laminated marble unit. An unconformity or fault is

indeed strongly suggested by the map pattern east of the scheelite mill in Washington Creek, where the base of the laminated marble unit truncates contacts in the underlying unit. Outcrops in this critical area, however, show no evidence of unconformity. The contacts between units are gradational. The map pattern is therefore considered to indicate no more than a complex pattern of sedimentation.

The Eastside sequence is regarded as allochthonous because it overlies a thrust fault for which there is abundant direct evidence, as outlined in a later section of this paper. The striking lithological similarity between the Eastside and Crane Canyon rocks suggests that they are of similar age and that the Eastside rocks may not have traveled far. The Eastside sequence may be para-autochthonous.

Age and Correlation of Sequences

A few fossils, including graptolites and brachiopod fragments, have been found in beds of the Eastside sequence.[3] The presence among them of the graptolite species *Diplograptus decoratus* indicates that the beds may be correlated with the Copenhagen formation or, less probably, with the upper part of the Antelope Valley limestone of the Pogonip Group (W. B. N. Berry, personal communication). The Eastside sequence is therefore at least in part of Ordovician age.

No fossils have been found in rocks of the three autochthonous sequences. Correlation of these with sections described elsewhere is based entirely on similarities in lithology, thickness, and sequence. Such a procedure is of doubtful value in this part of Nevada, where major facies changes in rocks younger than middle Cambrian are well known (see, for example, Roberts *et al.*, 1958). Nevertheless, several broad correlations with rocks north and south of the area mapped seem likely to be correct and are suggested below.

Lower Paleozoic rocks in the southern Toiyabe Range and adjacent parts of the Toquima Range (fig. 1) have recently been described by Ferguson and Cathcart (1954). They recognize two formations characterized as follows:

The Gold Hill formation consists essentially of quartzite and schist with subordinate siliceous slate and limestone. Estimated thicknesses are at least 5,000 feet in the Toquima Range and 3,000 feet in the Toiyabe Range. The formation is regarded as Cambrian, partly on the basis of a single trilobite found in the southern Toiyabe Range.

The Palmetto formation consists mainly of dark slate, but includes near its base at least 800 feet of schist (the Mayflower schist) which is overlain by at least 800 feet of gray limestone (the Zanzibar limestone). No fossils have been found in the schist or limestone, but slates of the Palmetto formation yield graptolites of middle Ordovician age. The total thickness of the Palmetto formation is estimated as 5,000 feet in the Toquima Range and 2,500 feet or more in the Toiyabe Range.

It appears probable that slates of the Broad Canyon sequence are equivalent to slates of the Palmetto formation and that at least the quartzite-schist unit of the Clear Creek sequence is equivalent to the Gold Hill formation. On this basis the Clear Creek and the Broad Canyon sequences are considered to be at least in part of Cambrian and Ordovician age, respectively. The Gold Hill–Palmetto

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[3] Fossil locality: at elevation approximately 7,500 feet, near top of ridge northeast of Carseley Creek; N. ½ sec. 11, T. 15 N., R. 43 E., Millet Ranch quadrangle.

boundary of Ferguson cannot yet be located in this area. It is tempting to correlate the brown schist and blue marble units with the Mayflower schist and Zanzibar limestone, respectively, and so place the Gold Hill–Palmetto boundary within the Clear Creek sequence. But these correlations are surely not justified, considering the distances involved and the fact that the brown schist is not a distinguishable unit over even the whole of the area described here.

It is notable that no rocks lithologically similar to the calcareous shales and impure limestones of the Crane Canyon and Eastside sequences have been described from the southern Toiyabe Cambro-Ordovician section, but similar rocks do occur to the north. Lowell (1958) reports the occurrence of Ordovician fossils in such rocks from a section about 15 miles north of Crane Canyon, between Dry Canyon and Indian Creek in the Toiyabe Range. Rocks of the Crane Canyon sequence are considered by the writer to be at least in part of Ordovician age for the following reasons: (1) their lithological similarity to fossiliferous Ordovician rocks near Dry Canyon, (2) their lithological similarity to fossiliferous Ordovician rocks of the Eastside sequence, and (3) their inferred equivalence to Ordovician (?) rocks of the Broad Canyon sequence.

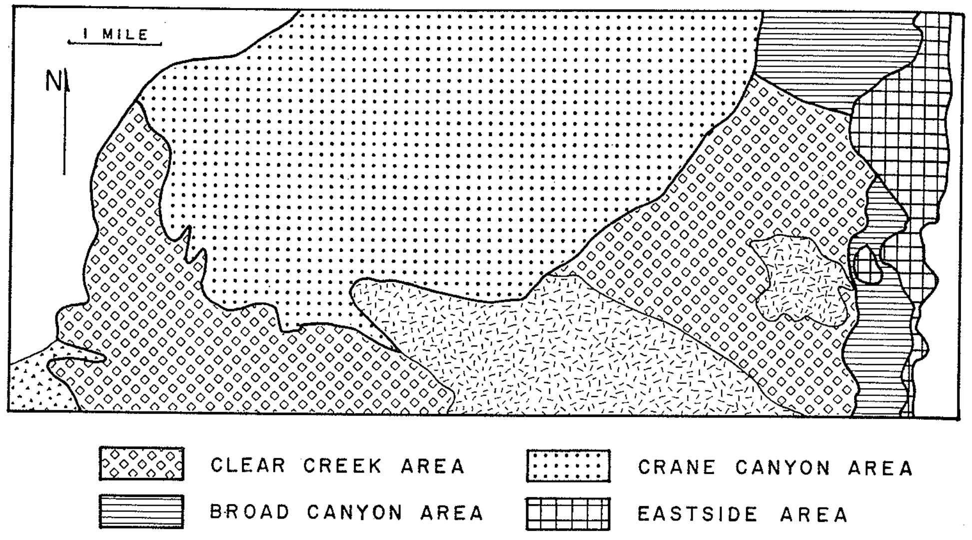

Fig. 4. Outline map of areas for each of which structural geometry is discussed separately.

STRUCTURE

Considered on the scale of the area as a whole, the autochthonous rocks make up a northeast-dipping homocline divided medially by a northwest-dipping normal fault and truncated on the east by a thrust fault. On a smaller scale the rocks are complexly folded. The axial planes of folds are similarly oriented throughout the area, but the orientation of fold axes varies considerably from place to place. The nature of this variation is described and interpreted below. Extensive use is made of statistical methods of structural analysis introduced by Sander (1930, 1948) and refined in more recent structural studies, particularly in the Scottish Highlands (see, for example, Weiss and McIntyre, 1957; Ramsay, 1958). The principles and procedures involved are discussed by Weiss (1959*a*).

The geometry of folds and associated structures is separately described and discussed for several large areas (fig. 4), each dominantly underlain by and named for one of the four stratigraphic sequences. Fold geometry in each area is described from two points of view: first, as it is expressed by stereographic projections of sets of measurements of mesoscopic structures; second, as it is expressed by the mapped pattern of stratigraphic units. The following mesoscopic structures are considered:

Bedding (S_1): Lithological layering of sedimentary origin, laterally continuous for long distances in proportion to its thickness and inclined to S-surfaces of metamorphic origin in the some outcrop.

Cleavage (S_2): Penetrative S-surfaces of metamorphic origin on which the rocks tend to break, defined by dimensional parallel preferred orientation of nonequant grains or aggregates of grains.

Fracture cleavage (S_3): S-surfaces of metamorphic origin, defined by axial surfaces of crenulations in S_2 in mica-rich rocks, nonpenetrative on the scale of a thin section.

Axes of small folds (L_1): Intersection of S_1 with the axial surfaces of folds in S_1.

Bedding-cleavage intersection (L_2): Intersection of S_1 with S_2.

Crenulations (L_3): Intersection of S_2 with S_3.

CLEAR CREEK AREA

MESOSCOPIC STRUCTURES

Numerous measurements were made of S_1, S_2, L_1, and L_2 in this area. S_2 is best developed east of the Range fault, particularly in the schists, slates, and phyllites. It is visible also in many outcrops of quartzite and marble, appearing as irregularly spaced planar fractures controlled by preferred orientation of small amounts of mica in the quartzites and by preferred orientation of mica and nonequant calcite grains in the marbles. West of the Range fault, S_2 is commonly not visible, even in the mica-rich rocks. Where S_2 is present, it invariably parallels the axial planes of folds in S_1.

Folds in S_1 are seen in many outcrops. They range in size from barely visible corrugations to folds spanning tens of feet (pls. 2, 3). Throughout this range of sizes the folds may be open or tightly appressed. The style of folds is correlated with lithology to a limited extent. Very tightly appressed folds occur mainly in the mica-rich rocks and in the marbles. Relatively open folds occur in all the rock types.

Geometry of S_1.—The Clear Creek area is subdivided into a number of small areas (A–L) each of which is relatively homogeneous (Weiss, 1959*a*, p. 7) with respect to S_1. In figure 5 (in pocket) contoured equal-area projections of poles to S_1 (πS_1 diagrams) are arranged within the areas from which the plotted measurements were collected. The pole to each πS_1 girdle is the statistically defined fold axis for that particular field and is designated β on the diagrams. Two important geometrical relationships are brought out by comparison of the diagrams:

1. Larger areas are homogeneous with respect to S_1 than those for which the projections have been made. These are areas A-B-C-D, G-H-I, and J-K-L.
2. The mean orientations of β for these three areas are approximately coplanar.

Geometry of L_1 *and* L_2.—With rare exceptions, L_1 and L_2 parallel one another where both are observed in the same outcrop. They are accordingly plotted together in the diagrams of figure 6 (in pocket). The following points are noted:

1. Areas A-B-C-D, G-H-I, and J-K-L are relatively homogeneous with respect to L_1 and L_2.
2. The orientation of L_1 and L_2 within each of these areas corresponds with the orientation of β for the same area as defined by the πS_1 girdles of figure 5.
3. The orientation of L_1 and L_2 in area E varies between the orientations characteristic of areas A-B-C-D and G-H-I.

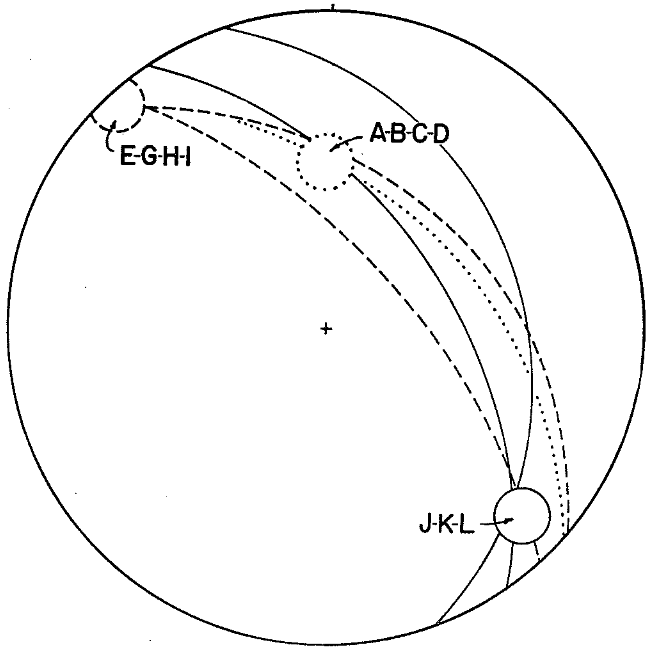

Fig. 8. Synoptic geometry in the Clear Creek area.

Geometry of S_2.—The geometry of S_2 is shown by πS_2 diagrams in figure 7 (in pocket) for each of the large areas A-B-C-D, E-G-H-I, and J-K-L. The following points are noted:

1. The mean orientation of S_2 is much the same in areas A-B-C-D, E-G-H-I, and J-K-L.
2. The poles to S_2 tend to be arranged in a weak girdle. In E-G-H-I and J-K-L the girdle parallels that in the corresponding πS_1 diagrams. In area A-B-C-D, S_2 is rarely observed; the diagram is based on so few measurements that the orientation of the girdle is not reliably defined.

Patterns of preferred orientation of S_1, S_2, and L_1–L_2 in the Clear Creek area are summarized in figure 8. The circles show the mean orientation of fold axes for each area as defined by poles to πS_1 girdles and the L_1–L_2 concentrations. The great circles correspond to maxima in the πS_2 diagrams and represent the most commonly observed orientations of cleavage in each area.

MACROSCOPIC STRUCTURES

The form and location of macroscopic folds east of the Range fault are shown in cross section A–A′ (map 1). Data collected near the trace of this section have been projected into it parallel to fold axes. The axes and axial planes of macroscopic folds parallel the axes and axial planes of associated mesoscopic folds, but their profiles are not necessarily similar in form. Closely appressed mesoscopic folds are equally common on the limbs of open or of closely appressed macroscopic folds.

The only large fold known in that part of the Clear Creek area west of the Range fault is defined by contacts mapped near the Vindicator pluton. In figure 9 these contacts are projected into a plane normal to the statistically defined fold axis for the area (trend N 7° E, plunge 38° N). Several mapped faults and the possible presence of a number of unmapped faults prevent figure 9 from being a true transverse profile of the fold. It seems probable, nevertheless, that the hinge of an anticline (north of Washington Creek) and the hinge of a broad syncline (between Washington and Cottonwood creeks) are represented and that the axial surfaces of these folds approximated the present orientation of S_2. The trace of S_2 on the plane of projection is shown by the dashed line in figure 9. A principal ambiguity in the interpretation of figure 9 is the pre-faulting position of segment A in relation to the rest of the fold. The form of the proposed anticline would be simplest if this segment came from the vicinity of A′.

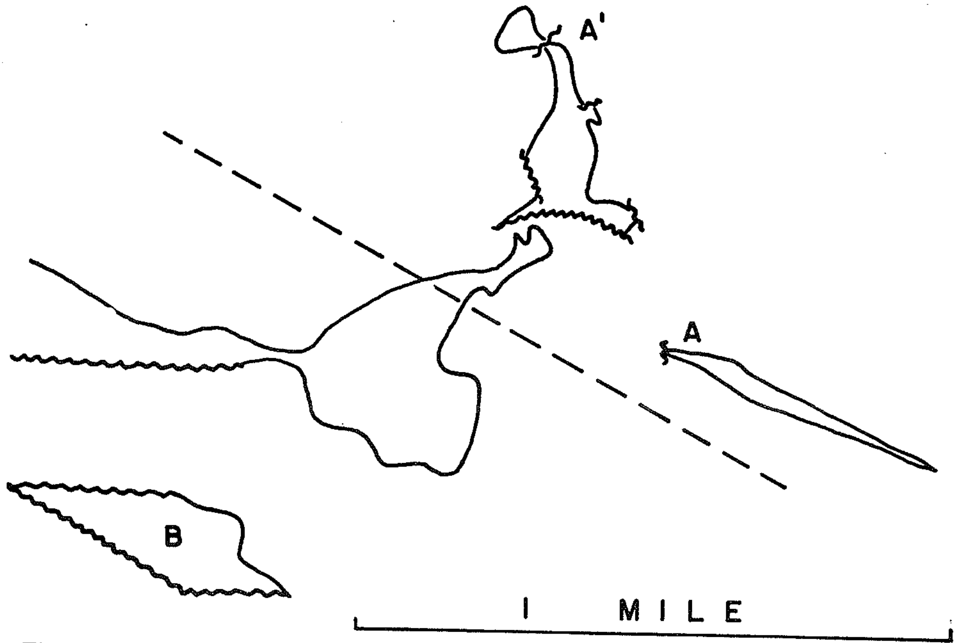

Fig. 9. Axial projection of contacts in vicinity of Vindicator pluton. Contacts known not to parallel fold axes (contacts with volcanic rocks, faults, or alluvium) are shown by scalloped lines. Dashed line shows orientation of trace of S_2 on plane of projection.

DISCUSSION

Origin of variation in fold-axis orientations.—The orientation of fold axes in rocks of the Clear Creek sequence varies from east to west in a continuous manner (fig. 8). There are several possible interpretations of this variation.

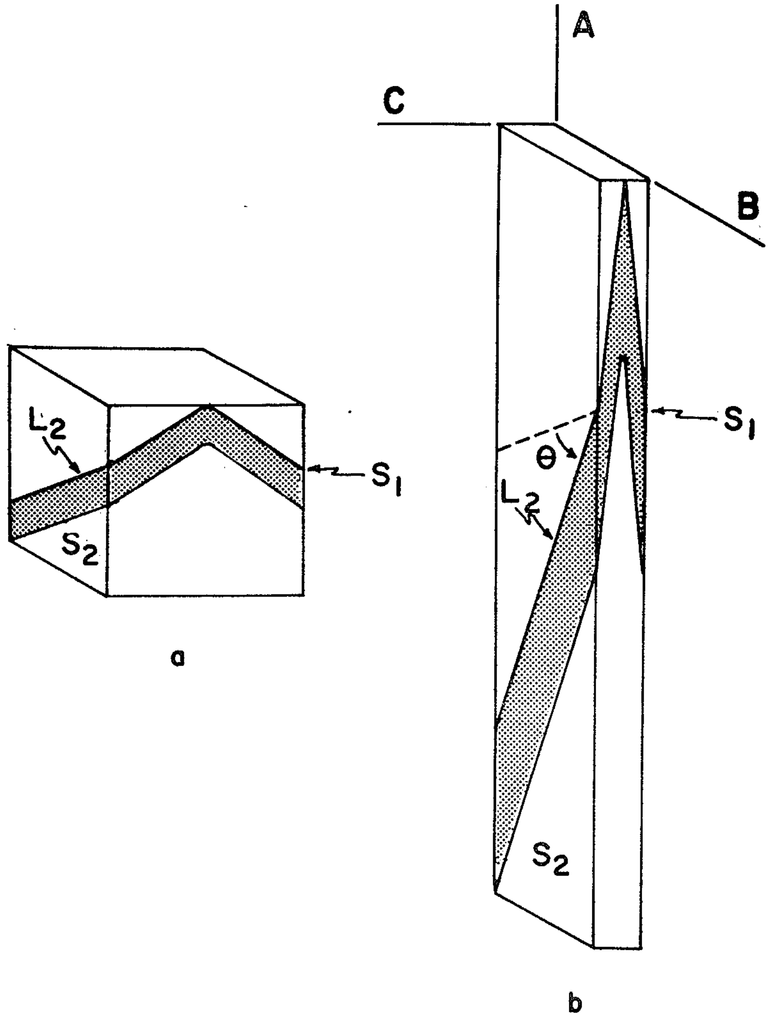

Fig. 10. Diagrammatic illustration of rotation of L_2 by flow in S_2: *a*, after early stage of folding and initial development of S_2; *b*, same volume of rock after 300 per cent extension parallel to A. L_2 has been rotated toward A through angle Θ. The figure is constructed for the simple case in which no strain occurs parallel to B.

I. Folds of the north-trending and southeast-trending sets were originally parallel. They attained their present orientations by being (*a*) differentially rotated by flow in S_2 or (*b*) differentially rotated by later folding.

II. Folds of the north-trending and southeast-trending sets were never parallel. They formed at an angle because they were superposed upon a fold of an earlier generation.

The mechanism of rotation suggested in I*a* is illustrated diagrammatically in figure 10. Fold axes in general orientations with respect to the A and B axes of strain tend to rotate toward A as folding progresses. Differential rotation could be produced by this means if the A and B axes of strain were differently oriented in different parts of the area or if the ratio of strains parallel to these axes varied

from place to place. Although fold axes may commonly be bent through small angles by this mechanism, an extremely inhomogeneous deformation would be required to bend them through nearly 90°, as observed in the Clear Creek area. Interpretation I*a* is therefore not satisfactory.

The geometry of S_2 is critical in considering interpretations I*b* and II. S_2 parallels the axial planes of folds. It maintains a similar orientation throughout

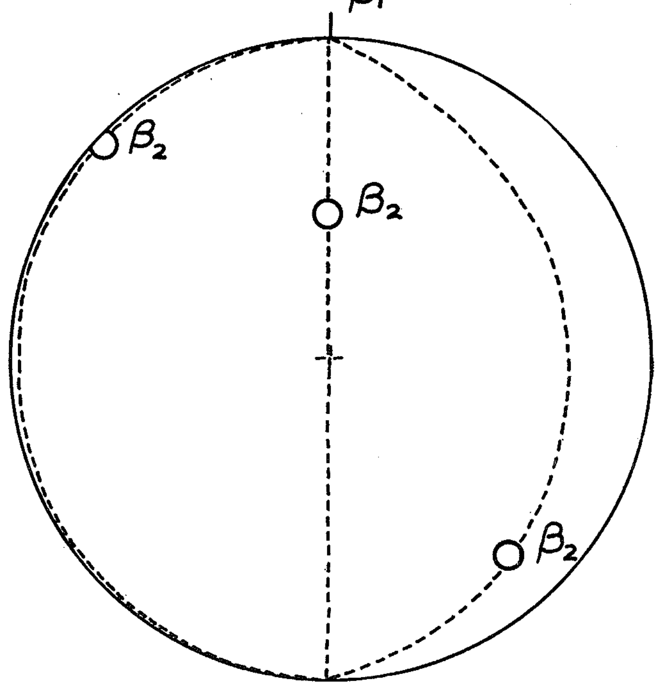

Fig. 11. Great circles represent attitudes of bedding on three parts of first-generation fold. Axes of first- and second-generation folds are represented by β_1 and β_2, respectively.

the Clear Creek area, dipping moderately to the northeast, irrespective of the orientation of fold axes within it. Interpretation I*b* may be rejected on the basis of this fact. Intense folding postdating S_2 has clearly not occurred. The uniform orientation of S_2 does, however, accord with interpretation II. Weiss (1959*b*) has shown that the axial planes of superposed folds may be expected to parallel one another throughout fields in which their axes are variously oriented. The Clear Creek area is considered to be a field of this type.

Character and age of the earlier structure.—Following the analysis of Weiss, possible orientations of fold axes must be limited by the attitude of beds in which they develop. Fields in which fold axes are uniformly oriented are likely to have been fields in which the attitude of bedding was uniform before folding. It follows from this that A-B-C-D, G-H-I, and J-K-L are areas within each of which the attitude of bedding was virtually uniform before the second generation of folds developed. By making a single assumption, one may determine this attitude of bedding for each area and construct a profile of the first-generation fold. The required assumption concerns the plunge of the first-generation fold. No evidence in this area indicates that rocks have been deformed more than twice. It is therefore assumed that the first-generation fold formed in subhorizontal beds and had a subhorizontal axis. Utilizing this assumption, one may estimate the trend of the fold from observations made in the field. It is observed (fig. 6) that the orientation of second-generation fold axes varies markedly in the Clear Creek area in an east-west direction but imperceptibly from north to south. It may be inferred that the attitude of bedding on the first-generation fold varied in a similar way. To a first approximation, therefore, the trend of the first-generation fold must have been northerly.

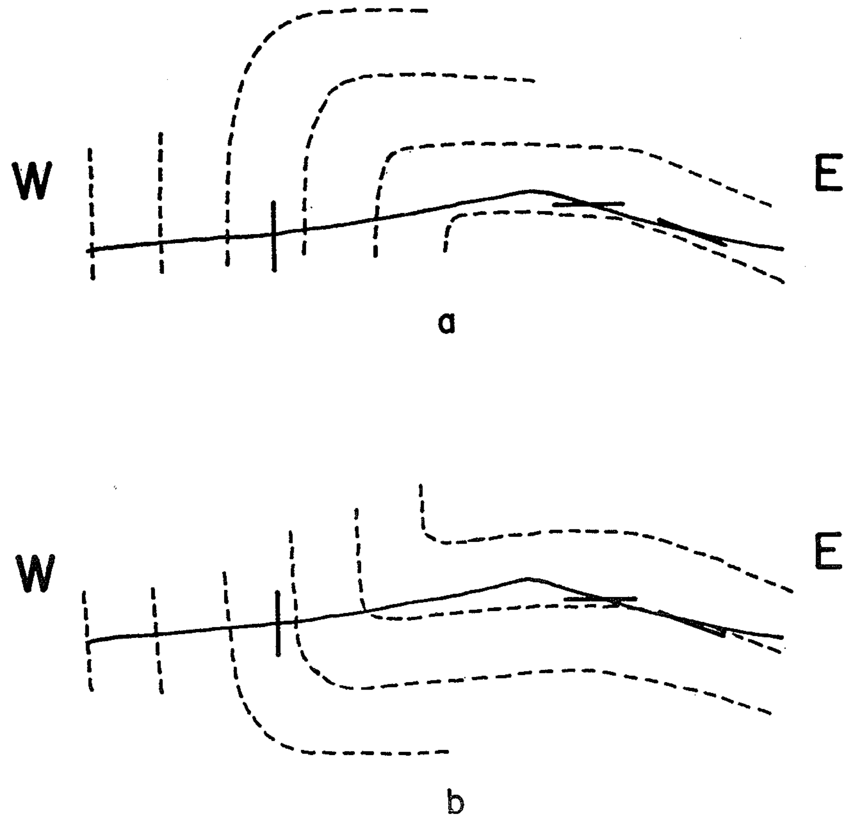

Fig. 12. Profiles of two possible first-generation folds. Short solid lines represent attitudes of bedding as determined in fig. 11. Long solid line is a generalized topographic profile of range.

The general attitude of bedding on the fold in areas A-B-C-D, G-H-I, and J-K-L may now be determined as shown in figure 11. The attitude sought for each area must be that represented by the unique great circle passing through β_1 and the β_2 point appropriate to the area. Bedding is thus found to have dipped steeply in area A-B-C-D, to have been subhorizontal in area G-H-I, and to have dipped gently eastward in area J-K-L. Two profiles sketched on the basis of these attitudes are shown in figure 12. Of these, the synclinal type of fold represented by profile *b* is considered more probable. During the second deformation the general attitude of bedding would presumably have been rotated toward S_2. Rotation of bedding toward S_2 on the west flank of the anticlinal structure would produce large-scale stratigraphic overturning, which is not observed.

The foregoing analysis of fold geometry in the Clear Creek area leads to the proposal that the earliest structure involving the Clear Creek rocks was a subhorizontal northerly-trending syncline overturned toward the east. This interpretation, though based entirely on structural data from the area, is compatible with present concepts of regional tectonic history which are based largely on stratigraphic evidence. The first major folding of lower Paleozoic rocks in central Nevada, during the Antler orogeny, is supposed to have been most intense along a belt which trends slightly east of north. The area described here lies directly in the center of this belt as it is shown diagrammatically by Roberts *et al.* (1958, p. 2825). Early folds in the autochthonous rocks of this area would probably have formed during the Antler orogeny and might well have had northerly trends. The easterly sense of overturn of the proposed syncline is in accord with the pattern of west-to-east thrusting associated with the Antler orogeny.

The idea that rocks in the Toiyabe Range have been subjected to important post-Antler deformation is not a new one. Ferguson and Cathcart (1954) proposed that in the southern Toiyabe Range, where Permian rocks occur, folds were produced initially during the Antler orogeny and subsequently during a Jurassic orogeny. Although detailed comparison of structural patterns in the central and southern Toiyabe Range has not been carried out, the writer tentatively regards the second generation of folds in the Clear Creek area as a product of Jurassic orogeny.

Broad Canyon Area

MESOSCOPIC STRUCTURES

The Broad Canyon area is made up of two separate areas designated M and N (figs. 6, 7). The following is concerned primarily with structures in area M. Little is know about the poorly exposed rocks in area N.

S_2 is the prominent surface in outcrops of slate and phyllite, the dominant lithologies in the Broad Canyon area. Delicate color bands are commonly visible on S_2 surfaces. These result from the intersection of S_1 with S_2. S_1 is a mesoscopically visible structure only where marble is interbedded with the slate or phyllite. A fracture cleavage, S_3, is commonly present and is expressed by delicate crenulations on S_2 surfaces. The crenulations, L_3, typically have wave lengths of several millimeters and amplitudes of a fraction of a millimeter. The fracture cleavage is in general so weakly developed that only with difficulty can the rocks be made to break parallel to it. An example of well-developed fracture cleavage is shown in plate 4. The consistent sense of offset across S_3 shown in the photomicrograph does not usually apply to fields the size of a hand specimen or larger.

Geometry of S_1 *and* S_2.—The πS_1 and πS_2 diagrams for area M (figs. 5, 7) do

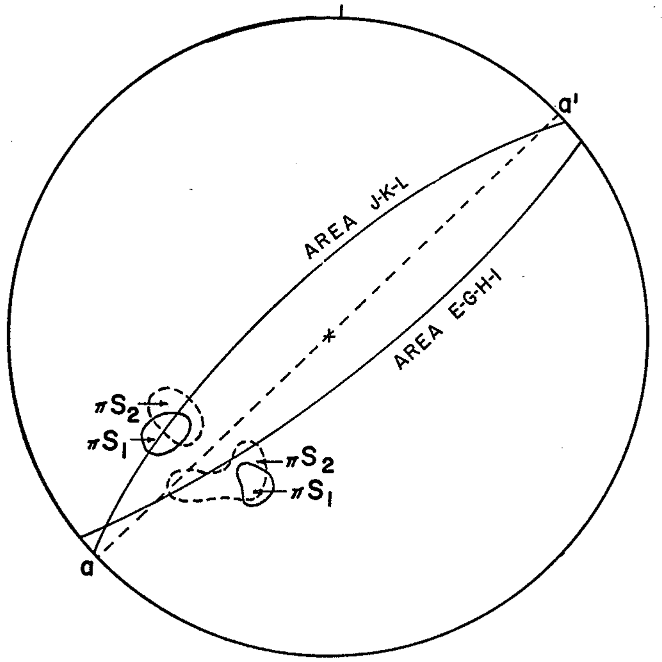

Fig. 13. Relations of πS_1 and πS_2 maxima from area M with πS_1 and πS_2 girdles from parts of Clear Creek area.

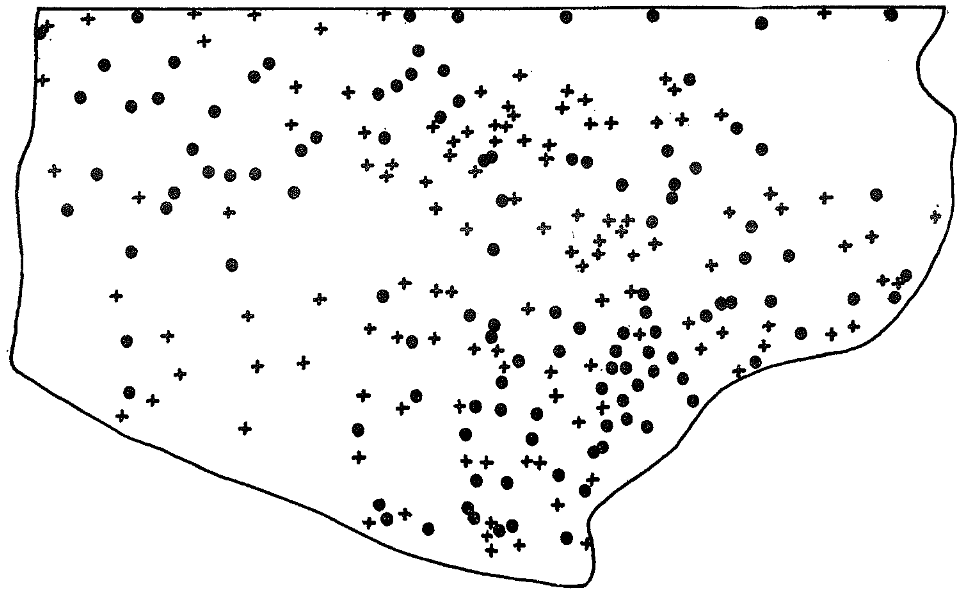

Fig. 14. Outline map of area M showing locations of S_1 and S_2 attitudes which plot left (circles) and right (crosses) of line *a–a'* in fig. 13.

not display girdles. Both diagrams have double maxima. These are shown superposed in figure 13, together with great circles corresponding to the πS_1 and πS_2 girdles of areas E-G-H-I and J-K-L in the Clear Creek area. The πS_1 and πS_2 points from area M fall into two groups (separated by line *a–a'*) which contains S_1 and S_2 attitudes commonly observed in areas E-G-H-I and J-K-L. Area M must be divisible into smaller areas within each of which attitudes of one sort or the other predominate. It is shown in figure 14 that these areas are too small to be defined by the data available.

Geometry of S_3 *and* L_3.—In figure 15, poles to S_3 are shown by crosses and the orientations of L_3 are shown by circles. Neither structure is uniformly oriented over the whole of area M. Even much smaller areas (for example, a few hundred feet by 50 feet) were found to be only slightly more homogeneous with respect to these structures.

Geometry of L_1 *and* L_2.—In contrast with their uniform orientation over large parts of the Clear Creek area, L_1 and L_2 in area M display a great variety of orientations within small areas. Easterly and northeasterly trends, rarely observed in the Clear Creek area, are common in area M.

In summary, area M is not particularly homogeneous with respect to any of the structural elements measured in it. The dimensions of many subareas which are homogeneous are of the order of tens of feet. The diagrams for S_2 and L_1–L_2 indicate that the geometry of strucutral elements in area N is similar to that in area M.

MACROSCOPIC STRUCTURES

Determination of the geometry of large folds in area M is more difficult than in areas to the south on account of the gradational nature of many contacts and a tendency for S_1 to parallel S_2 even in the hinges of folds. At location 1 (map 1, first ridge south of Broad Canyon) a paired anticline and syncline may be seen in three dimensions as they cross a ridge line. The anticline is better defined. Its axis trends S 33° E and is horizontal. A syncline at location 2 is probably the same as that at location 1. Its axis plunges 5° toward S 40° E. Assuming that these synclines are coaxial, the map indicates an average fold axis plunging 9° toward S 38° E for a distance of 1,200 feet. At location 3 an anticline may be traced for 1,750 feet. Its axis plunges 24° toward S 65° E. At location 4 the axis of a small rootless anticline plunges 4° toward S 43° E. The axes of these folds are plotted in figure 16.

The important features of macroscopic folds in area M are that they are tightly appressed toward an axial plane paralleling S_2, that they have subhorizontal axes, and that the orientation of these axes is therefore much more consistent than the orientation of axes of mesoscopic folds in the same field.

DISCUSSION

Both axes and axial planes of macroscopic folds in area M parallel those elements of the macroscopic folds in area J-K-L. This is consistent with the interpretation suggested above, that the observed folds have been superposed upon an earlier, subhorizontal, northerly-trending fold. L_1 and L_2, however, in contrast to their behavior in area J-K-L, scatter widely in the diagram for area M. Two possible

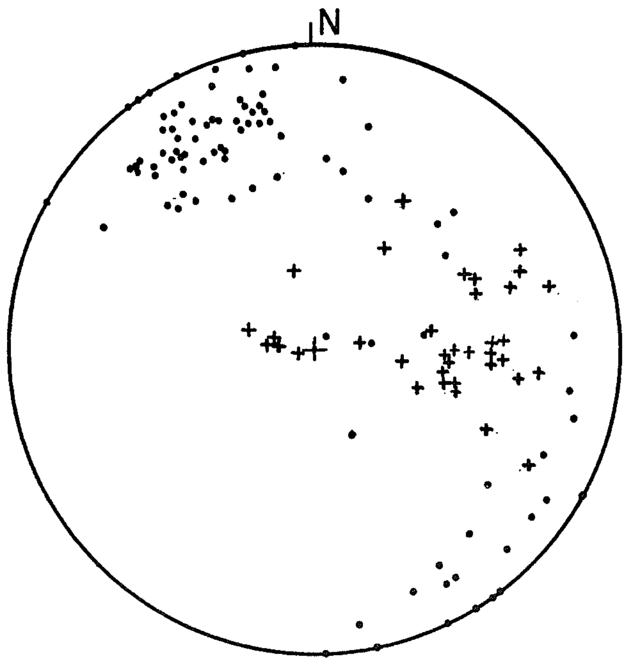

Fig. 15. Orientations of πS_3 (crosses) and L_2 (circles) in area M.

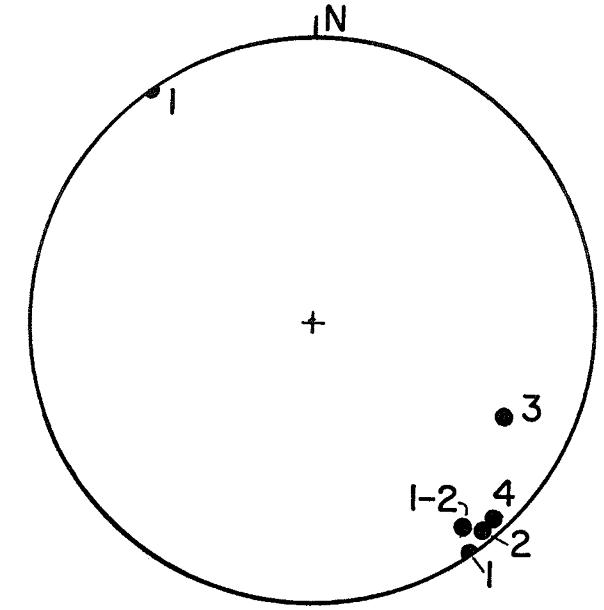

Fig. 16. Orientations of axes of macroscopic folds in area M. Numbers refer to locations within area M shown on map 1 (in pocket).

interpretations of this scatter are those considered above to account for variations in fold-axis orientations in the Clear Creek area: the variously oriented axes result either from differential rotation in S_2 of an originally rectilinear set of folds, or from superposed folding. The first interpretation is unlikely to be correct, for pronounced differential rotation would be required on a small scale in rocks in which subparallel macroscopic fold axes indicate no differential rotation on a large scale. Superposition is the preferred interpretation. In the Clear Creek area a very large original fold was implied by the hypothesis of superposition because second-generation fold axes varied in orientation only across distances of miles. In area M very small original folds are implied. The fact that the orientation of axes of macroscopic folds is uniform implies that, though the beds in area M were earlier folded on a small scale, the major stratigraphic units remained more or less planar until the second folding. Figure 17 shows diagrammatically how the structure in the Clear Creek and Broad Canyon sequences may have looked before the second deformation. Nothing can be determined regarding the probable orientation of the axes of the early small folds in the Broad Canyon sequence except that they lay parallel to the boundaries between major stratigraphic units. It is possible that these folds developed earlier than the large fold, perhaps even penecontemporaneously with deposition of the sediments.

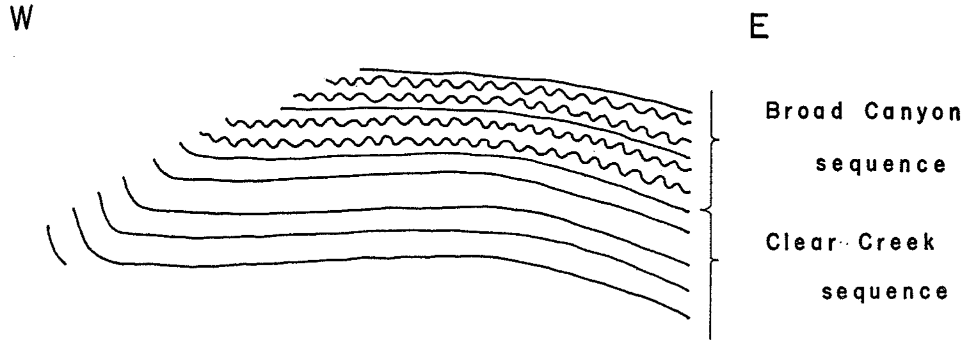

Fig. 17. Possible profile of first-generation fold in rocks of Clear Creek and Broad Canyon sequences.

The fracture cleavage is clearly younger than S_2 and therefore younger than the folds so far discussed in area M. A few broad warps in S_2 (about 2 feet in wave length, 2 inches in amplitude) with S_3 parallel to their axial planes have been observed. Similar warps on a larger scale may contribute to the variability of attitudes of S_1 and S_2 in this area. In the writer's view, movements associated with the development of S_3 produced only small-scale and local deformation.

CRANE CANYON AREA

MESOSCOPIC STRUCTURES

S_2 is better developed in rocks of the Crane Canyon area than in rocks of the Clear Creek sequence on the west side of the range. Mesoscopic folds may be relatively open or tightly appressed. All folds have axial planes parallel to S_2. Especially in the northeastern part of the Crane Canyon area, delicate crenulations,

L_3, are commonly developed on S_2 in the mica-rich beds. These parallel the intersection of S_2 with a fracture cleavage, S_3.

Geometry of S_2.—The Crane Canyon area has been divided into areas, O and P, within each of which the orientation of S_2 is statistically uniform (fig. 7). The pole to the great circle drawn through the πS_2 maxima for areas O and P plunges 40° toward N 10° W.

Geometry of L_1 *and* L_2.—As in rocks of the Broad Canyon sequence, L_1 and L_2 here scatter widely through the range of possible positions lying in S_2. A slight tendency for northerly plunges to be less common than the others is shown in the diagram for area P (fig. 6). The locations of northeast-plunging and northwest-plunging L_1–L_2 are shown in figure 18. There appears to be little pattern in their distribution on this scale.

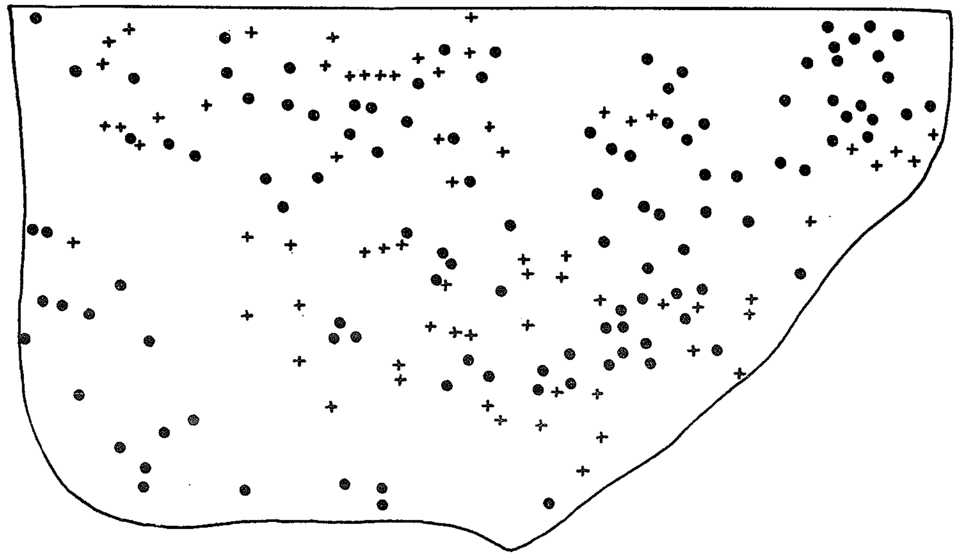

Fig. 18. Outline map of area P showing locations of northwest-plunging (crosses) and northeast-plunging (circles) attitudes of L_1–L_2.

Geometry of S_1.—πS_1 points in the diagram for area O (fig. 5) define a girdle which implies a northeast-plunging fold axis, similar in orientation to fold axes in the underlying Clear Creek rocks. Area P as a whole is inhomogeneous with respect to S_1, and homogeneous areas within it are too small to be defined by the available data.

Geometry of S_3.—A small number of measurements of S_3 indicates that it tends to strike in a northerly direction and to dip steeply east or west (fig. 19).

MACROSCOPIC STRUCTURES

No large folds of the type mapped in rocks of the Clear Creek and Broad Canyon sequences are known in rocks of the Crane Canyon sequence. Horizons mapped in the lower units of the sequence in general maintain a northwesterly or westerly strike, dip moderately northeast, and are not repeated. North and west of the western part of the Aiken Creek pluton there is some indication, in the form of the upper contact of the laminated marble unit, of gentle folding about a subhorizontal axis trending east. This folding may have accompanied intrusion of the pluton, and need not be considered indicative of similar folding throughout the Crane Canyon area. Mappable horizons are rare in the large area underlain by rocks of the shale-limestone unit. Those traced yielded no evidence of large folds.

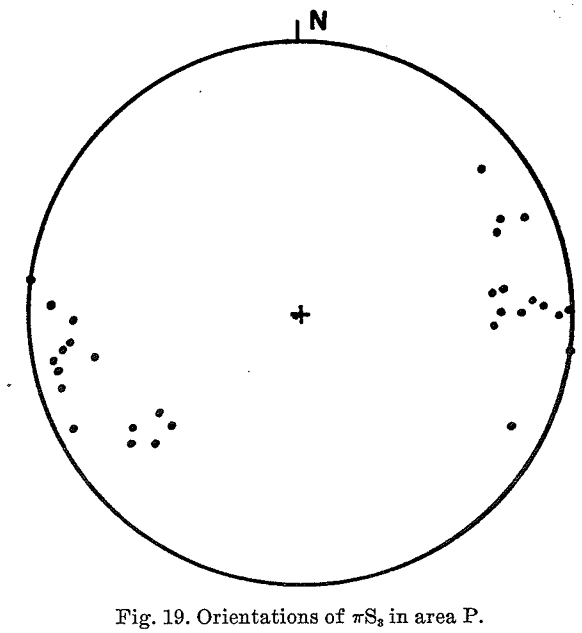

Fig. 19. Orientations of πS_3 in area P.

DISCUSSION

Although little is understood about structures in the Crane Canyon area, the data in hand do allow comment on the problem of the autochtonous or allochthonous character of the Crane Canyon sequence. On the basis of stratigraphic evidence, the entire sequence was considered to be autochthonous. The structural evidence is not inconsistent with this interpretation. The orientation of S_2 in area O parallels that observed throughout the Clear Creek and Broad Canyon areas. This is a good indication that the rocks of area O occupied their present position at least since the beginning of the latest period of folding. This must apply to the rocks of area P as well, for the change in orientation of S_2 from area O to area P is gradual.

The only structural information which might be interpreted as evidence for a thrust contact between the Crane Canyon and Clear Creek rocks is the contrast in the L_1–L_2 patterns. But a similar contrast exists in the L_1–L_2 patterns of the Broad Canyon and Clear Creek rocks, and there other structural evidence supports the interpretation of a conformable contact. In the writer's view, therefore, the scatter of L_1–L_2 orientations in the Crane Canyon rocks is best interpreted as resulting from superposition of the type proposed for the Board Canyon rocks.

An unusual structural feature of the Crane Canyon area is the broad north-

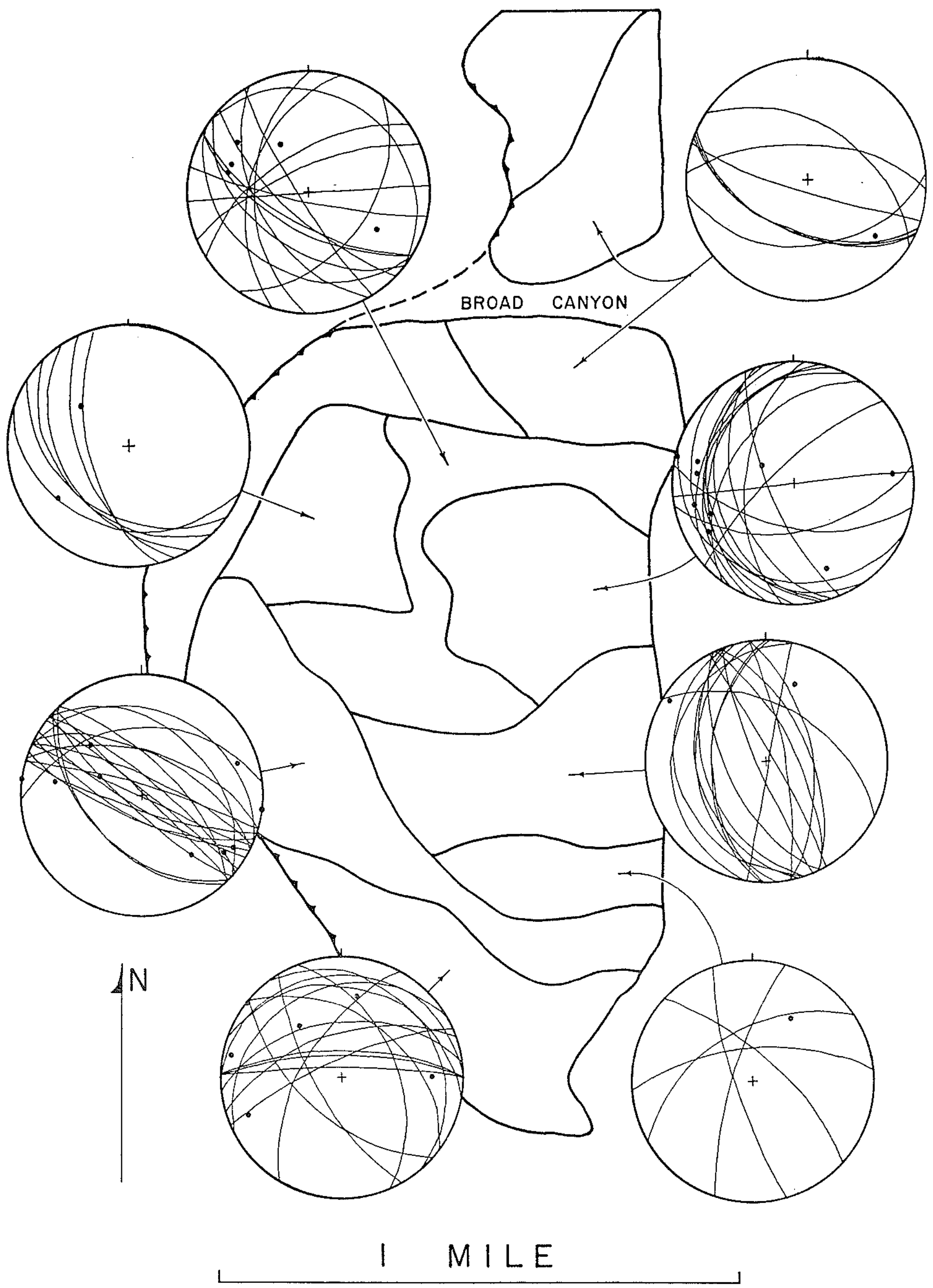

Fig. 20. S_1 diagrams for subdivisions of area Q. Each great circle is lower-hemisphere, equal-area stereographic projection of an attitude of S_1. Points are projections of L_1 and L_2.

trending warp in S_2 evident from comparison of the S_2 diagrams (fig. 7) for areas O and P. This fold may have originated in association with S_3, which parallels its axial plane. However, S_3 is not commonly observed near the boundary between areas O and P, where the orientation of S_2 changes most rapidly. A second possible interpretation is that the warp resulted from drag on the Range fault. This seems unlikely, because no bending is observed as S_2 approaches the fault from the east and because the hinge of the warp is miles west of the fault. The writer favors the idea that the warp results from the shouldering aside of rocks north of the pluton during intrusion.

EASTSIDE AREA

MESOSCOPIC STRUCTURES

Contacts between lithological units in the Eastside area can nowhere be traced far enough to provide reliable indicators of the structure. Information on fold geometry is therefore limited to what may be learned from the orientations of mesoscopic structures.

Geometry of S_1.—S_1 orientations in area Q indicate that fold axes are not uniformly oriented over the area as a whole (fig. 5). In figure 20, area Q has been divided into smaller areas. A uniform fold-axis orientation is suggested for some of these by the S_1 diagrams. The orientations indicated include westerly and southwesterly trends unknown in the autochthonous rocks.

Geometry of L_1 *and* L_2.—Area Q as a whole is inhomogeneous with respect to L_1 and L_2 (fig. 6). Even in areas which are somewhat homogeneous with respect to S_1, L_1–L_2 may bear no simple relation to the statistically defined macroscopic fold axis (fig. 20).

Geometry of S_2.—The orientation of S_2 is more variable in area Q than in areas of comparable size in the autochthonous rocks.

DISCUSSION

The data available are inadequate for an understanding of structure in this block. The foregoing diagrams are presented solely to demonstrate that even in rather small areas the elements S_1, S_2, and L_1–L_2 may be geometrically disordered and that they display no striking similarity in preferred orientations to the patterns established in rocks west of the fault. The rocks on the two sides of the fault have clearly had different deformational histories. This in turn implies that the "fault" was in fact a surface of movement and not simply an unconformity.

FAULTS

Range fault.—The prominent northwest-dipping normal fault, here designated the Range fault, is probably related to an unnamed east-dipping reverse fault mapped 10 miles to the south by Ferguson and Cathcart (1954). A line of saddles and valleys, similar to that which marks the fault's position in the area described here, may be traced between these localities on topographic maps.

Displacement on the fault in this area is unknown, but a net slip of at least several thousand feet is indicated. A strike slip component of movement not exceeding 1,400 feet is suggested by the 1,400-foot offset of the steeply dipping northern contact of the Aiken Creek pluton. An order-of-magnitude estimate of the net slip is obtained by projection of the base of the blue marble unit into the fault plane from both sides as follows: the distance from the top of the laminated marble unit to the base of the blue marble unit, measured normal to the general attitude of bedding, is determined in the sections I–I′ and II–II′ (map 1). It is assumed that the distance between the same horizons in the section III–III′ falls in this range of values, and possible intersections of the blue marble unit on the west side of the fault are obtained by projection. These intersections and that of the blue marble unit on the east side of the fault allow estimation of the net slip. If movement is assumed to have been entirely dip-slip, a net slip of 3,500–4,900 feet is indicated. If dip-slip and left-lateral movement were combined, the minimum possible net slip indicated is 2,800–4,000 feet.

Fig. 21. Projection of points evenly spaced along trace of Eastside thrust fault into an east-west vertical plane.

The Range fault is younger than the Aiken Creek pluton; the pluton postdates Jurassic (?) folding.

Black Canyon fault.—The Black Canyon fault is an east-dipping normal fault which extends for about a mile north and south of Black Canyon (map 1). Its dip may be estimated near the saddles south of Black Canyon and Carseley Creek as 30° and 50°, respectively. Displacement on the fault near Carseley Creek cannot exceed several tens of feet. Near the southern border of the area, juxtaposition of the brown schist unit with slates of the Broad Canyon sequence indicates a minimum vertical displacement on the fault of 200 feet. The Black Canyon fault is considered to have developed after intrusion of the granitic plutons and contemporaneously with smaller north-striking normal faults described below.

Other high-angle faults.—Smaller faults in the area may be divided into a group with northerly strikes and a group with northwesterly strikes. Normal faults predominate in each group.

Diabase dikes have been intruded along many of the northerly-striking faults and along parallel fractures on which there has been no appreciable movement. These fractures and the faults are probably of similar age and postdate emplacement of the plutons. Presumably they developed during the long period of Basin and Range faulting. A north-striking fault in the northeast corner of the area brought Tertiary (?) tuff against rocks of the Eastside sequence. Displacement on this and parallel faults concealed by alluvium raised the east front of the range with respect to the Smoky Valley block.

Three northwest-striking normal faults (near Carseley Creek, Clear Creek, and Broad Canyon) dip northeast and appear to have involved relative movement of the blocks not exceeding a few hundred feet. No diabase is associated with these faults. An undeformed dike of granite is intruded along the fault in Carseley Creek. The northwest-striking faults are considered to be younger than both periods of folding, but older than the plutons.

Eastside thrust fault.—The Eastside thrust fault extends for about four miles through foothills on the eastern side of the range. It disappears beneath alluvium immediately south of the area mapped, and is truncated half a mile north of Broad Canyon by a high-angle fault (map 1). In figure 21, points evenly spaced along the trace of the thrust fault are projected into a vertical plane normal to its average strike. The average dip indicated by the projection is about 18° E.

The fault plane or planes can nowhere be seen in outcrop. The structure is nevertheless known to be a fault rather than an unconformity for the following reasons: (1) calcite-cemented breccia is common in float along the fault trace; (2) contrasted structural geometry of rocks above and below the fault indicates that rocks above it have had a different, and probably more complex, deformational history.

The Eastside thrust fault is older than the north-striking faults, but its age relative to emplacement of the plutons is unknown. Lack of contact metamorphic effects in rocks of the Eastside sequence is taken as weak evidence that faulting postdated emplacement.

The data collected in this study fail to indicate the direction or amount of movement which has occurred on the Eastside thrust. No significant changes in orientations of mesoscopic structures in the autochthonous rocks are observed as the fault is approached. Possibly a more detailed structural investigation of the Eastside rocks, especially those near the fault, would yield information on the direction of movement.

IGNEOUS ROCKS

Granitic Rocks

Three bodies of granitic rock exposed in the area are referred to as the Carseley Creek, Aiken Creek, and Vindicator plutons (map 1). The contacts of these bodies are sharp, steeply dipping, and generally discordant. Small dikes, satellitic to the larger plutons, are injected into fractures paralleling S_2 in the surrounding metamorphic rocks. Intrusion of the plutons must therefore postdate the Jurassic (?) orogeny during which S_2 developed.

The means by which the plutons made room for themselves is unclear. No changes in orientation patterns of mesoscopic structures are observed as the contacts of the Carseley Creek pluton are approached. This suggests the operation of a passive mechanism of emplacement like stoping; yet no stoped blocks are observed apart from rare and small xenoliths immediately adjacent to contacts. Several larger bodies of metamorphic rock completely surrounded by granitic rock (south of C–C′, map 1) are considered to be roof pendants rather than stoped blocks because the mesoscopic structural fabric within them has not been rotated. Structural patterns north of the Aiken Creek pluton on the west side of the range provide some evidence for forcible intrusion there. No such evidence is found along the northern contact of the Aiken Creek pluton east of the Range fault. Abundant breccia found in float near the Vindicator pluton may have been produced during forcible intrusion; poor outcrop prevents detailed investigation of this area.

Each of the larger plutons consists principally of granitic rock of uniform aspect (main phase) into which are intruded numerous alaskite dikes (late phase). The dikes are especially abundant near the margins of the plutons and make up thick border zones locally. In a few localities alaskite is seen to grade into biotite-bearing rock of the main phase, but, much more commonly, rocks typical of the main and late phases are separated by sharp intrusive contacts. In figure 22 are plotted the relative proportions of quartz, microcline, and plagioclase in representative samples of the main and late phases of each pluton. The main phase of the Carseley Creek pluton ranges in composition from granite to adamellite, that of the Aiken Creek pluton from granodiorite to adamellite. Although the main phases of the two plutons are distinctly different, their late phases are similar in composition and fall close to the lowest part of the thermal valley in the system albite-orthoclase-silica at moderate to high water pressures. This convergence is interpreted to indicate that the granitic rocks crystallized from magma the composition of which changed, toward the lowest part of the thermal valley, as crystallization proceeded.

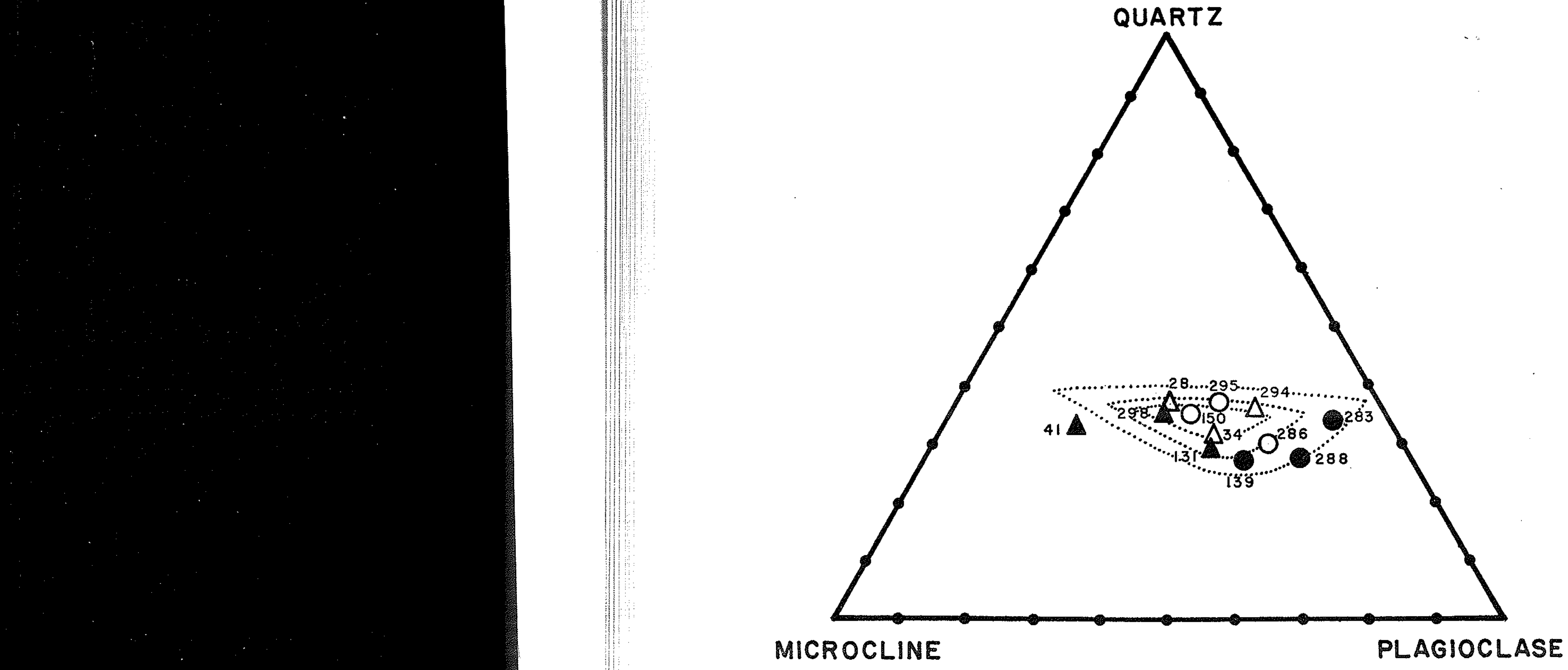

Fig. 22. Relative proportions of quartz, microcline, and plagioclase in the granitic rocks. Triangles represent Carseley Creek pluton; circles represent Aiken Creek pluton. Solid and open figures represent main and late phases of each pluton. Dotted lines are isotherms on liquidus in system albite-orthoclase-silica at $P_{H_2O} = 2000$ kg/cm² (after Tuttle and Bowen, 1958, p. 55).

Dike Rocks

Solidification of the granitic rocks was followed in turn by intrusion of felsites and basic dike rocks. Felsite dikes are observed only on the ridges on either side of Carseley Creek and are generally too small to have been mapped. An exceptional example is several tens of feet thick and may be traced for more than a mile (map 1). The felsite dikes characteristically strike east and dip steeply.

The basic dikes are far more numerous than the felsites, and occur throughout rocks east of the Range fault. Especially prominent examples occur in the Aiken Creek pluton and in a north-striking zone east of the Carseley Creek pluton (map 1). Most of these dikes are dark brown–weathering diabase. They range in thickness from 1 inch to 60 feet. Those shown on the map are more than 10 feet thick. They fill steeply dipping north-striking fractures on many of which faulting took place before intrusion. The basic dikes, like the north-striking faults, are probably of Tertiary age.

Volcanic Rocks

Volcanic rocks occur in the extreme northeast and southwest corners of the area. Those in the northeast corner are light-colored lithic tuffs. Those in the southwest are pale brown, orange, gray, or pinkish-weathering quartz latite. Phenocrysts of quartz, sanidine, and plagioclase are present in about equal proportions in the quartz latites, and together make up as much as 50 per cent of the rock. The plagioclase is An_{35} in a typical specimen; in many specimens it has been altered to clay minerals. The groundmass of the quartz latites consists of brown glass which may include numerous tiny crystals and crystal fragments of quartz and feldspar. Lithic fragments, mainly of gray shale and less than 1 cm in diameter, are visible in many specimens.

The outcrop pattern of the volcanic rocks north of Cottonwood Creek suggests that they dip gently westward, but evidence of their attitude in individual outcrops is difficult to find. Lensoid cavities, resulting perhaps from flattening of gas-filled openings, and faintly defined layers richer and poorer in lithic fragments suggest steep attitudes locally. In only one locality (at the southern edge of the alluvium along Cottonwood Creek) is the contact between volcanic and metamorphic rocks observed in continuous exposure. There it dips 60° E and is intrusive. The entire contact from this point to the southern border of the area mapped may be intrusive.

The volcanic rocks in the vicinity of Cottonwood Creek are probably part of the Pliocene (?) Toiyabe quartz latite (Ferguson and Cathcart, 1954) which covers much of the crest and western flank of the range in the Round Mountain quadrangle.

SUMMARY

Lower Paleozoic, metasedimentary rocks in a small area in the central Toiyabe Range have been mapped in detail. In this paper the grosser features of each unit shown on the map are described, but no attempt is made to provide a comprehensive account of the rocks from a stratigraphic point of view. The paper is concerned primarily with orientation patterns of folds and related structures in autochthonous rocks of the area and with interpretation of these patterns in terms of pre-Tertiary structural history. Routine mapping procedures have been supplemented by statistical analysis of the orientations of mesoscopic structures.

Metamorphic rocks of the area make up four thick successions of strata referred to here as the Clear Creek, Broad Canyon, Crane Canyon, and Eastside sequences. The Clear Creek sequence is regarded as autochthonous, and consists predominantly of Cambrian (?) quartzite and schist or mudstone. It is overlain on the east and west sides of the range by Ordovician (?) rocks of the Broad Canyon and Crane Canyon sequences, respectively. The Broad Canyon rocks are almost entirely dark slates, phyllites, and argillites. The Crane Canyon sequence contains abundant light-colored shales, slates, and limestones. In spite of the lithological contrast between them, the Broad Canyon and Crane Canyon sequences are both considered to be autochthonous. The only rocks in this area that are regarded as allochthonous are shales and limestones of the Eastside sequence which crop out in foothills along the east side of the range. They are separated from rocks to the west by a gently east-dipping thrust fault. The Eastside sequence is at least in part of Middle Ordovician age.

The structure of the autochthonous rocks is dominated by folds on many scales which developed during a period of intense deformation accompanied by regional metamorphism. The folds are associated with an extensively developed axial plane cleavage or schistosity. This surface is similarly oriented throughout the area underlain by autochthonous rocks. But fold axes within the same area display a great variety of orientations. Closer study of fold-axis orientations leads to the proposal that the observed folds in the autochthonous rocks were superposed upon an earlier generation of folds. It is further proposed that the earlier structure in rocks of this area was dominated by a large northerly-trending syncline overturned toward the east. This fold probably developed during a nonmetamorphic period of deformation tentatively correlated with the Antler orogeny. The metamorphic period of deformation which gave rise to the observed folds is regarded as Jurassic (?) in age.

Two sets of high-angle faults developed in these rocks after folding and metamorphism. An older set comprises northeast-dipping normal faults which predated intrusion of granitic plutons. A more extensively developed set includes north- and northeast-striking normal faults which postdated intrusion of the plutons. The north- and northeast-striking faults are probably of Tertiary age.

Igneous rocks in the area are very briefly described. These include granitic rocks, a variety of younger dike rocks, and Pliocene (?) volcanic rocks.

APPENDIX

Notes on the Mineralogy of the Metamorphic Rocks

The metamorphic rocks of this area are medium- to fine-grained quartz-bearing metasediments in which mineral assemblages characteristic of all three subfacies of the greenschist facies have developed. The grade of metamorphism increases eastward in the autochthonous rocks. Some rocks on the west side of the range and those of the Eastside sequence are virtually unmetamorphosed. Regional metamorphism occurred during the period of deformation in which S_2 was produced. Assemblages most commonly observed are listed in table 1. Intrusion of granitic plutons followed regional metamorphism and gave rise to very narrow zones of hornfelsic rocks which surround the plutons discontinuously. Assemblages produced or modified by contact metamorphism are present mainly in the impure calcareous rocks, and include idocrase, epidote, tremolite, wollastonite, sillimanite, and scheelite.

Optical and X-ray measurements indicate that the colorless chlorite in some of the regionally metamorphosed rocks is a clinochlore in which iron occupies about 5 per cent of the octahedral positions. This chlorite occurs together with biotite in a few specimens from Broad Canyon. No biotite accompanies the chlorite in rocks from the blue marble unit, but stratigraphically above and below this unit are rocks containing biotite. The apparently stable occurrence of chlorite in the biotite zone is undoubtedly due to its magnesian character (Fyfe *et al.*, 1958, p. 66).

Green chlorite in rocks from the west side of the range is considered to be a product of progressive metamorphism; that in rocks from the east side results largely from replacement of biotite and garnet.

Diopside in quartzo-feldspathic rocks from the east side of the range is iron-rich. From optical data alone, it appears to contain about 50 per cent of the hedenbergite end member. Its occurrence may reflect transition to conditions of the almandine amphibolite facies; or, alternatively, iron-rich diopsides may be stable under conditions of the greenschist facies.

TABLE 1

MINERAL ASSEMBLAGES IN THE METAMORPHIC ROCKS

Rocks	East side of Range	West side of Range
	QUARTZO-FELDSPATHIC	
Buff quartzite unit	Quartz–microcline–muscovite–biotite (diopside, tremolite, epidote, calcite, chlorite)	
Quartzite-schist and brown schist units	Quartz–microcline–muscovite–calcite (diopside, tremolite, epidote, biotite, garnet, green chlorite)	Quartz–microcline–muscovite (tremolite, epidote, biotite, calcite, green chlorite)
Siliceous argillite of Broad Canyon and Clear Creek sequences	Quartz–muscovite–graphite (tremolite, colorless chlorite, calcite)	
	PELITIC	
Schist and mudstone of Clear Creek sequence	Quartz–microcline–muscovite–biotite–green chlorite–garnet	Quartz–muscovite–green chlorite
Slates and phyllites of Broad Canyon sequence	Quartz–muscovite–biotite–colorless chlorite (graphite)	
	CALCAREOUS	
Marbles of Clear Creek sequence	Calcite–quartz–muscovite–colorless chlorite–graphite (dolomite, tremolite)	Calcite–quartz–muscovite–colorless chlorite–graphite
Calcareous rocks of Broad Canyon and lower Crane Canyon sequences	Calcite–quartz–muscovite–colorless chlorite–graphite (dolomite, tremolite)	Calcite–quartz–muscovite–colorless chlorite–graphite (biotite, tremolite)
Calcareous rocks of upper Crane Canyon sequence		Calcite–quartz–muscovite–fine clay minerals (graphite)
Eastside sequence	Calcite–quartz–muscovite–fine clay minerals (graphite)	

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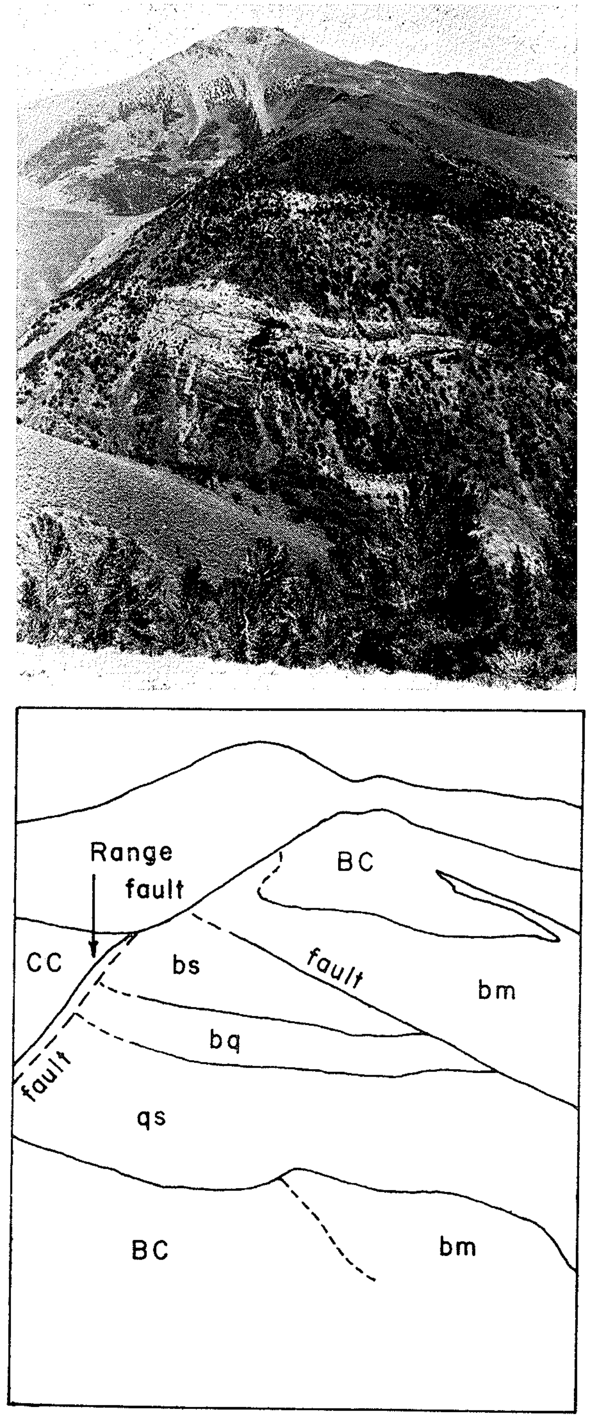
PLATES

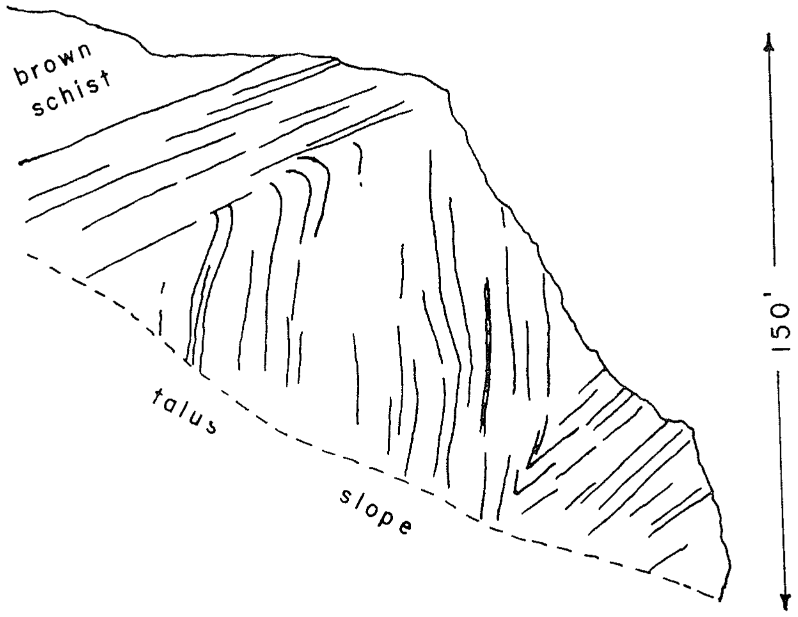


View north across upper part of Clear Creek Canyon. CC, rocks of Crane Canyon sequence; BC, rocks of Broad Canyon sequence; rocks of Clear Creek sequence: *bm*, blue marble unit; *bs*, brown schist unit; *bq*, buff quartzite unit; *qs*, quartzite-schist unit.

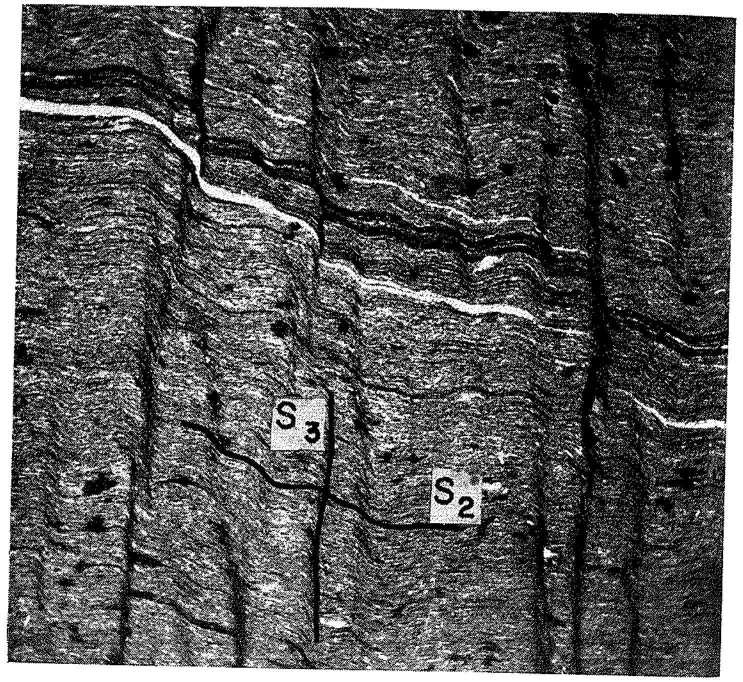
a. Small folds in upper part of buff quartzite unit, Clear Creek sequence. Viewed parallel to fold axis.

b. Folds in calcareous beds near top of brown schist unit, Clear Creek sequence, with S_2 in schist visible at lower right. View slightly inclined to fold axis.

a. Open folds in blue marble unit, Clear Creek sequence. View toward southeast, parallel to fold axis.



b. Large fold in buff quartzite unit, Clear Creek sequence. View toward southeast, parallel to fold axis. (Traced from photographs.)



Phyllite from Broad Canyon sequence cut normal to S_2 and S_3. Plane-polarized light. × 30.

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FIGURE 5

Fig. 5, 6, 7

Map 1