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# Synorogenic Quartz Sandstone in the Jurassic Mobile Belt of Western Nevada: Boyer Ranch Formation

## ABSTRACT

The province of Lower Mesozoic layered rocks in western Nevada contains a diversity of marine lithologies whose deposition continued locally as late as Middle Jurassic time. At places in the province, mature quartz sandstone constitutes all or part of the highest stratigraphic units in sections of non-volcanic rocks and is believed to record the last deposition of terrigenous sediments before complete effacement of the marine basin by widespread orogeny. The sandstone was deposited early in the orogenic episode and at least locally in troughs created by folding of subjacent rocks. The sands are anomalously mature with respect to co-deposited clastic components and to coarse detrital materials in nearly all earlier Mesozoic rocks of the province. The problems are the source of the quartz sand and the reasons the sand was deposited synorogenically.

The name, Boyer Ranch Formation, is formally proposed for a lithosome of homogeneous Jurassic quartz sandstone and basal conglomerate and limestone in the Dixie Valley region which is approximately in the northern third of the outcrop area of Jurassic quartz sandstone in western Nevada. The Boyer Ranch Formation contains up to 500 ft of sandstone, largely fine-grained calcareous quartz arenite, whose granulometric properties suggest eolian sorting, but whose bedding indicates quiet-water deposition. The sandstone lies above limestone and carbonate-pebble conglomerate with interstitial quartz sand.

The inferred early Mesozoic geographic and tectonic histories in the Dixie Valley region suggest that the sands of the Boyer Ranch Formation accumulated at the eastern shoreline of the Mesozoic basin in western Nevada in late Early or Middle Jurassic time. Until the onset of orogeny, the sands remained unlithified, probably owing to eolian saltation, and followed a generally westerly regression of the shoreline. Postulated strong wave action prevented seaward movement of the sand. The late Early Jurassic or Middle Jurassic (or both) orogeny created local troughs which the sea reinvaded and provided an irregularly configured and low-energy shoreline environment such that movement of the sand into the water was no longer impeded.

The sands may have evolved locally through the action of water and wind at the beach of the Early Mesozoic sea in western Nevada, or they may have been largely co-derived from a distant source with sands in Jurassic rocks of the eastern Cordillera and the Colorado Plateau.

## INTRODUCTION

The region of western Nevada shown in Figure 1 contains the southeastern portion of a broad province of lower Mesozoic rocks whose larger distribution is partly shown by Muller (1949) and Silberling and Roberts (1962). The province widely exposes deformed Triassic and Lower Jurassic terrigenous and volcanic sedimentary rocks and carbonate and volcanic rocks. Marine deposition was apparently continuous at places as late as Middle Jurassic time (Corvalan, 1962) before orogeny caused major, if not complete, withdrawal of the sea. Much of the region of Figure 1 contains sporadic exposures of quartz sandstone, which wholly or partly constitutes the highest stratigraphic units in sections of non-volcanic Jurassic rocks. We believe such quartz sandstones are lithostratigraphic correlatives which record the last non-volcanic Mesozoic sedimentation in west-central Nevada. It is uncertain, however, whether the sandstone exposures are remnants of a once continuous blanket. Deposition of the quartz sand was contemporaneous with the beginning of orogenic movements, and at least some sands accumulated in troughs created by folding of subjacent Mesozoic rocks.

The quartz sand is anomalously mature compared to co-deposited locally derived sediments and to the sand fractions of nearly all preceding Mesozoic clastic rocks. It would appear that

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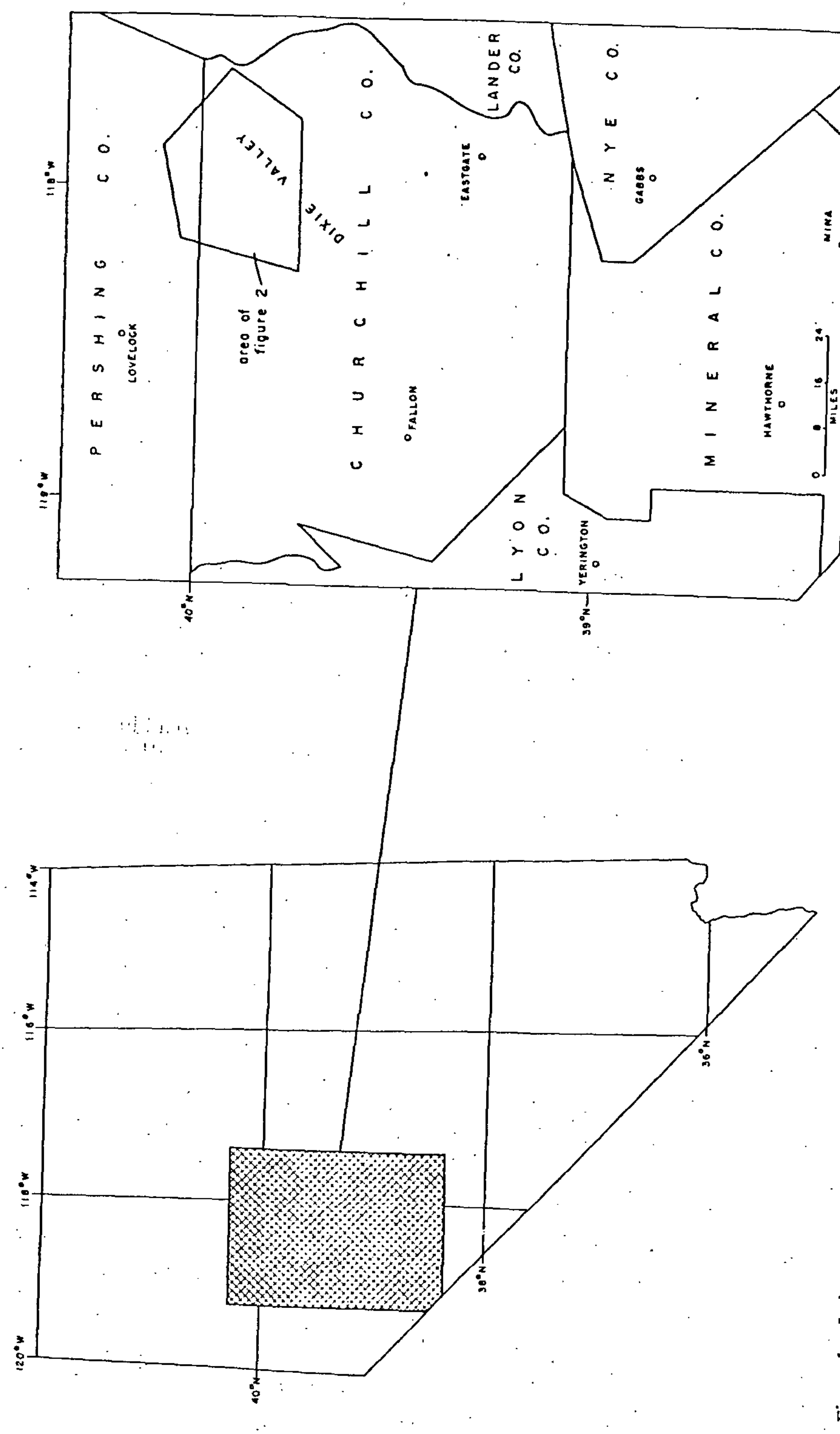

Figure 1. Index maps showing region of western Nevada in which Jurassic quartz sandstone is exposed and area of Figure 2 which contains rocks assigned to Boyer Ranch Formation.

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## ACKNOWLEDGMEN

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## BOYER RANCH F

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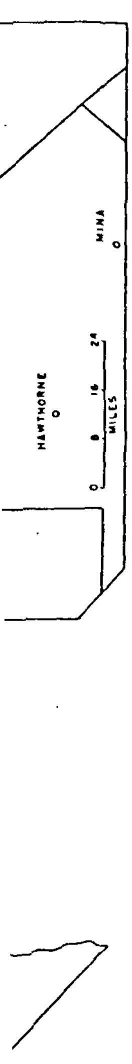


Figure 1. Index maps showing region of western Nevada in which Jurassic quartz sandstone is exposed and area of Figure 2 which contains rocks assigned to Boyer Ranch Formation.

e quartz sand matured in an environment ich was different from that in which it and jacent Mesozoic rocks were deposited. The jectives of our investigation are to determine e most likely source of the quartz sand and e reasons why a mature sediment should be posited under orogenic conditions.

The northern third of the belt of Jurassic artz sandstone in western Nevada (Figs. 1 d 2) contains a relatively homogeneous sand- ne unit, here designated the Boyer Ranch rmation. This paper focuses on the Boyer nch Formation with a view toward the eoenvironment and tectonic events which d to the deposition of the formation. The gin of Jurassic quartz sandstone at other ces in western Nevada will be compared in a er paper with the model set up here for the yer Ranch Formation, and in that paper, the urce of quartz sand will be explored in a re- onal context. In addition to its role in the oblem of the origin of mature sand deposited ring orogenic movements, the Boyer Ranch rmation is independently significant. It has gely controlled the heat transfer and em- cement of a large complex of gabbro and salt whose parent magma would have formed field of surface lavas if the Boyer Ranch rmation had not existed (Speed, 1968a). oreover, the Boyer Ranch Formation pro- des an important key to a better under- nding of the paleogeographic evolution and the sequence and times of tectonic events in e Dixie Valley–Carson Sink region of western vada.

## KNOWLEDGMENTS

We are indebted to B. M. Page and N. J. lberling of Stanford University and to L. L. ss of Northwestern University for valuable scussions in the field and for critical review of is paper. Further, we gratefully acknowledge e continuing interest in this study of R. E. llace, M. D. Crittenden Jr., and D. B. tlock of the U.S. Geological Survey. Mrs. Z. lva provided able assistance at the micro- ope. This study was supported in part by SF grant GA-1574 and in part by the U.S. ological Survey.

## OYER RANCH FORMATION

### rmation Characteristics

The name, Boyer Ranch *Formation*, is oposed here for quartz sandstone and associ- ed carbonate rocks and breccia which crop out in the northern Stillwater Range and the Clan Alpine Mountains of western Nevada. The rocks included in the Boyer Ranch Formation are the stratigraphically highest terrigenous rocks in sections of Mesozoic age in this region. The lithology of the formation is uniform except for lateral variability in thickness and composition of the basal member and differs markedly from subjacent lithologies. Figure 2 shows the location and extent of the Boyer Ranch Formation; the total area underlain by outcrops of the formation is roughly 8 sq mi, but a line which circumscribes the region of outcrop encloses about 640 sq mi. Thus, the exposures of the Boyer Ranch Formation are small and widely separated, and it is not certain that the rocks included in the formation were originally laterally contiguous. Nonetheless, the distinctive lithology of rocks included in the Boyer Ranch Formation and their contact relations with older Mesozoic sedimentary rocks and Middle Jurassic igneous rocks serve to identify the isolated exposures as lithostratigraphic correlatives.

Exposures of the Boyer Ranch Formation were first mapped in the northern Stillwater Range by Muller and others (1951) who included them variously in units assigned to the Paleozoic Havallah Formation, Jurassic diorite, or Tertiary volcanic rocks. South of lat 40° N. in the Stillwater Range, exposures of the Boyer Ranch Formation were identified as probable lithostratigraphic equivalents and were accurately mapped by Page (1965). Speed (1966, 1968b) presented aspects of the stratigraphy and structure of the formation.

The Boyer Ranch Formation contains basal units overlain by quartz sandstone. The more northeasterly exposures of the formation have 0 to 250 ft of basal dolomite conglomerate interbedded with quartz sandstone, whereas the basal deposits in southwesterly exposures are limestone and sandy limestone. The quartz sandstone is uniformly fine grained and evenly thin bedded, and the sand population is well rounded and well sorted. Detrital components are generally greater than 95 percent quartz. The maximum preserved thickness of the Boyer Formation is 500 ft.

The only organic components of the Boyer Ranch Formation are algal stromatolites. The age of the formation thus has not been determined paleontologically, but other lines of evidence presented below indicate a Jurassic age. The top of the Boyer Ranch Formation is exposed at places in the Stillwater Range where

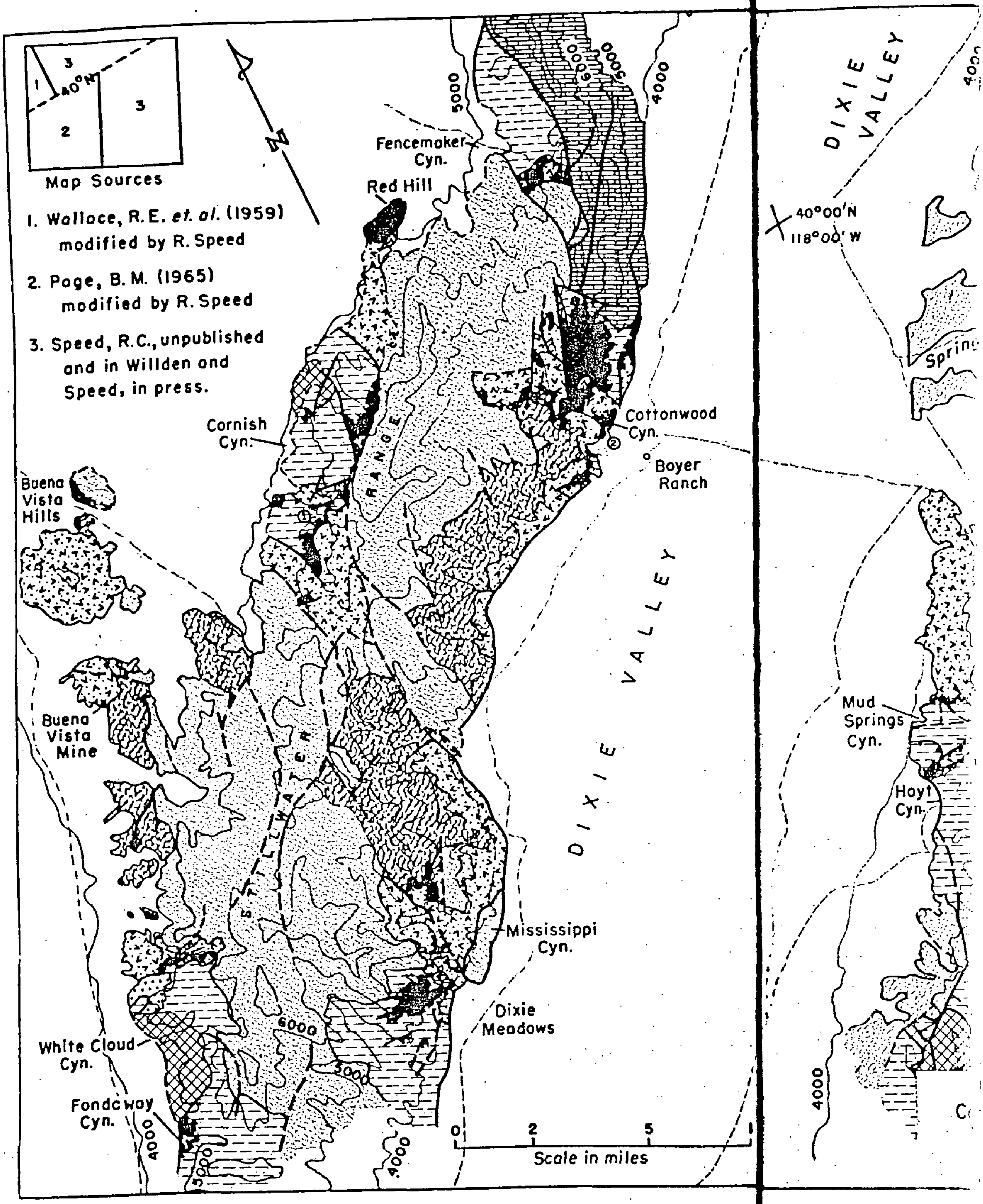
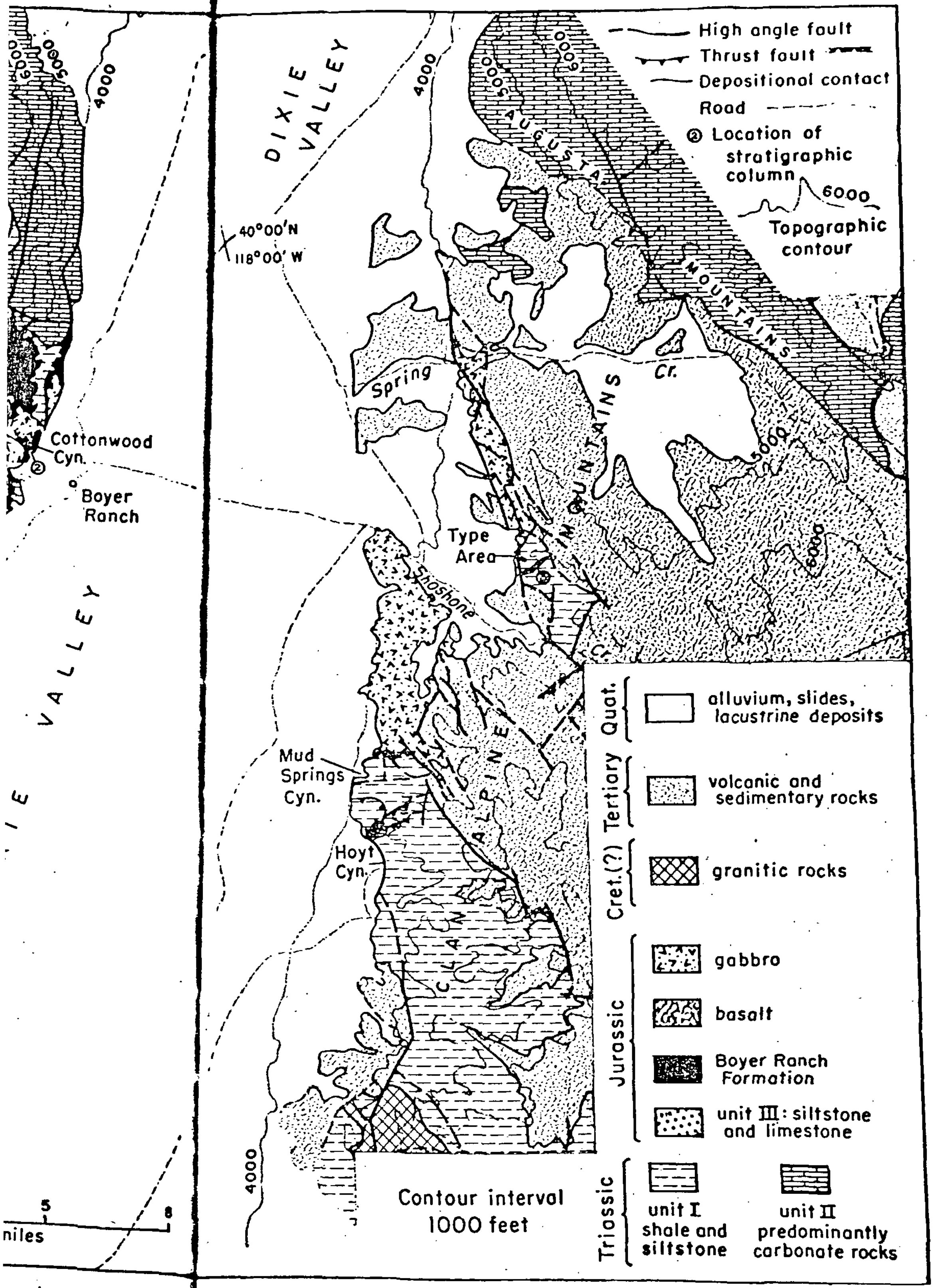


Figure 2. General geologic map of outcrop area of the Boyer Ranch Formation.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Boyer Ranch Formation
unit III: siltstone and limestone
Triassic
unit I shale and siltstone
unit II predominantly carbonate rocks

rmation.

quartz sandstone is conformably overlain by volcanic rocks which are believed to be part of a Middle Jurassic igneous complex. The Boyer Ranch Formation lies unconformably over rocks of Late Norian (late Late Triassic) or younger age at several places in the Clan Alpine Mountains and the Stillwater Range. Elsewhere, the formation is thrust over Late Triassic and Early Jurassic rocks.

The distinction between an unconformity and a thrust fault depends largely on the concordance of bedding in the Boyer Ranch Formation and its base. Where the bedding and basal surfaces are widely concordant, the contact is interpreted as an unconformity although at such contacts, bedding or its projection is locally discordant to steep walls of channels in the sub-Boyer Ranch surface. The occurrence of conglomerate-bearing clasts of underlying units at the base of the formation supports the interpretation of unconformable basal contacts. The Boyer Ranch Formation is strongly folded, but at many places the surface separating the Boyer Ranch Formation from subjacent rocks is not co-folded with bedding in the formation. That is, the basal surfaces are planar or broadly undulating, whereas the bedding is far more intricately deformed. Such contacts are thrust faults, an interpretation supported locally by brecciation in both plates and by the occurrence in the Boyer Ranch Formation of carbonate conglomerate structurally separated from the contact by homogeneous quartz sandstone. At some places, bedding in quartz sandstone in the Boyer Ranch Formation overlying thrust faults has been nearly obliterated, suggesting that the sandstone may not have been well lithified during thrusting. In the Stillwater Range south of 40° N., our interpretation of thrust *versus* depositional contact at the base of the Boyer Ranch Formation agrees in almost all cases with that of Page (1965).

The Boyer Ranch Formation is widely invaded by intrusive rocks of the Middle Jurassic igneous complex, and the formation occupies an annular region in plan about the elliptical igneous body (Fig. 2). In particular, most of the blocks of Boyer Ranch Formation which lie on thrust faults contact large masses of gabbro. The distribution of allochthonous Boyer Ranch Formation is believed to be largely due to the emplacement of the igneous complex which caused radial thrusting of the Boyer Ranch Formation onto the flanks of its depositional basin (Speed and Page, 1965; Speed, 1968a, 1968b). On the basis of this theory, displacements on the thrust faults are of the order of a few miles such that blocks of the Boy Ranch Formation have not been moved f from their sites of deposition. The displacem vectors are thought to emanate from a li source which would run from the Buena Vi Hills through northern Dixie Valley. The di tribution has been further complicated b Tertiary normal faulting.

## Regional Relationships

**General.** The distribution and phys relationships of the Boyer Ranch Formati relative to subjacent rocks suggest that it w deposited in a restricted area over which particular set of paleogeographic and tecto conditions existed. The occurrences of quar sandstone of age and physical attributes simi to those of the Boyer Ranch Formation at ce tain places to the south and southwest of Di Valley, however, indicate that such conditio obtained locally elsewhere in western Nevad

The pre-Tertiary rocks of the Dixie Vall region are almost entirely Triassic and Lo Jurassic sedimentary rocks and Jurassic ma igneous rocks (Fig. 2). The east side of Figur is within 35 miles of the easternmost se mentary rocks of the western Nevada Meso province at this latitude.[1] The present easte margin of Middle and Upper Triassic rocks regarded by Silberling and Roberts (1962) indicating approximately the maximum exte to which the Mesozoic sea transgressed ov the province from the west. Lower Juras deposits lie at least 40 miles west of the easter most Mesozoic rocks, and the distributions the Jurassic and uppermost Triassic (Upp Norian) rocks (Willden and Speed, in pr suggest that the shoreline moved west and b came more irregularly configured during th time interval. The marine basin was eradica probably in Middle Jurassic time by a regio orogeny whose initial movements were da as Toarcian (late Early Jurassic) near Mi (Fig. 1) by Ferguson and Muller (1949). T first movements occurred approximately at th same time in the Dixie Valley region, but with this region the phases and styles of deformati are areally variable.

**Pre-Boyer Ranch Formation Rocks.** Roc of the Dixie Valley region which are older th the Boyer Ranch Formation are divided i

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[1] The easternmost beds are in outlier of Tria conglomerate and limestone in the Hall Creek quadran of the Toiyabe Range; the deposits were recently d covered by J. H. Stewart of the U.S. Geological Surv The beds are equivalent to part of the Augusta sequen of unit II (J. R. MacMillan, oral commun., 1969).

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units[2] whose properties are summarized the following and whose distributions are n in Figure 2.

t I. TRIASSIC SHALE AND SILTSTONE. The Boyer Ranch terrain in both the Stillwater ge and Clan Alpine Mountains consists rly of a succession of Norian (upper Upper assic) rocks which are dominantly shale and tone. The exposed thickness of the succes- may be as great as 20,000 ft, and its base is where covered (Willden and Speed, in s).

n the western Stillwater Range south of Red Hill 2), Triassic shale and siltstone, which are commonly or phyllitic, are continuous with Lower Jurassic eous siltstone, shale, and silty limestone of unit III. the Clan Alpine Mountains, the Triassic section sists largely of shale and siltstone, but it contrasts correlative rocks in the Stillwater Range because upper 3000 ft contains about 40 percent limestone, and the upper 1700 ft is massive limestone and dolomite. Late Norian faunas of the *Rhabdoceras suessi* Zone of Silberling and Tozer (1968) occur within about 1200 ft of the eroded top of the section, but the uppermost rocks contain no age-indicative fossils. Because of their small area of exposure, the undated rocks are included with subjacent Triassic rocks in unit I on Figure 2. On Plate 1, however, they are differentiated in the type area. The lithologic similarity of the undated rocks to the subjacent Norian carbonate rocks may suggest the section is entirely Triassic (but it is possible that they may be partly correlative with Lower Jurassic rocks of unit III in the Stillwater Range). In the Clan Alpine Mountains, the stratigraphic relief of the section below the unconformity which underlies the Boyer Ranch Formation is about 1100 ft.

The east flank of the Stillwater Range and the northern part of the range between Boyer Ranch and Fencemaker Canyon (Fig. 2) contain no Jurassic sedimentary rocks like those on the west flank discussed above. In this region Late Triassic shale and siltstone are the youngest exposed sub-Boyer Ranch rocks with two exceptions. First, an erosion remnant of at least 100 ft of Upper Norian massive limestone like that in the uppermost Triassic (and Triassic) section in the Clan Alpine Mountains overlies Triassic shale about 7 miles north of Boyer Ranch. Second, the Boyer Ranch Formation near the mouth of Cottonwood Canyon near Boyer Ranch (Fig. 2) lies unconformably above a unit of very fine-grained sandstone and siltstone with abundant ripple marks and slump structures which has no counterpart elsewhere in the Stillwater Range. Lithologically similar rocks, however, occur with massive limestone near the top of the Triassic section in the Clan Alpine Mountains. The exceptions thus suggest that the Upper Triassic shale and siltstone of the northeastern Stillwater Range may have been overlain by an Upper Norian (and perhaps younger) carbonate-rich section like that of the Clan Alpine Mountains. This concept is supported by lateral variations in the lithology of the basal member of the Boyer Ranch Formation. In the northern Stillwater Range from Red Hill to Boyer Ranch and in the Clan Alpine Mountains, the basal member is chiefly carbonate-pebble conglomerate, whereas to the south and west in the Stillwater Range, the basal member is mostly limestone. The clasts in the conglomeratic facies are uniformly massive light- to dark-grey dolomite and limestone, which in the Clan Alpine Mountains were clearly derived from subjacent carbonate rocks. The similarity of composition and size distribution of the coarse components in the conglomerate across its outcrop belt (~20-miles wide), together with high clast angularity, argues for a homogeneous clast source which paralleled the belt of conglomerate.

Facies changes in the Triassic rocks of unit I thus occur in the uppermost few thousand feet of section of Late Norian age. A carbonate-rich section exists in the northern Clan Alpine Mountains and is inferred to have extended northwest across the Stillwater Range as far as Red Hill (Fig. 2). Southwest of this belt, uppermost Triassic rocks are chiefly siltstone and

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[2] Regional lithostratigraphic groupings of Mesozoic entary rocks in the region from Dixie Valley as north as Winnemucca were first presented by Muller 49) and Muller and others (1951), who differentiated rocks into two facies which were believed to be posed by the Tobin thrust. More recent studies cate that if the Tobin thrust exists, it is unlikely to e significantly redistributed Triassic rocks and that n exposed trace is confined to a small area at least 5 north of Figure 2 (Silberling and Roberts, 1962; J. Silberling, oral commun., 1968; R. C. Speed, ublished mapping in Stillwater Range). Triassic and assic rocks of the Stillwater Range and the Clan pine Mountains (south of Spring Creek) in Figure 2 re included by Muller (1949) in the lower Plate ces which has been redesignated the Winnemucca quence by Silberling and Roberts (1962). Triassic ks of the Augusta Mountains are part of the Upper te facies called the Augusta sequence by Silberling d Roberts (1962). The informal pre-Boyer Ranch rmation units presented in this paper and shown on gure 2 differ from previous groupings by the isolation Lower Jurassic rocks and of certain Upper Triassic e-grained clastic rocks from the Winnemucca sequence d by the lumping of the remainder of the Winnemucca ith the Augusta sequence. The assignment of Triassic ks to units I and II is based on differences in lithology, ickness, and age of youngest beds, but the stratigraphic bdivisions contrast as well in tectonic style. One of the ncepts employed by Muller (1949) for facies designa- on of Triassic rocks was intensity of folding, namely, at beds of the now-called Augusta sequence are slightly arped at best, whereas beds of the now-called Win- mucca sequence are structurally complex. Muller's iew finds little support in the Dixie Valley region, for the rocks in the Augusta and Winnemucca sequences assigned here to unit II are deformed rather similarly; moreover, their deformation contrasts markedly with that of the other Triassic rocks which are here grouped unit I.

shale like the rest of the Triassic section. The carbonate-rich facies was probably almost coextensive with the basal carbonate conglomerate of the Boyer Ranch Formation, and it was apparently the sole source of the pebbles in the conglomerate.

The large deformation of rocks in unit I prevents a clear reconstruction of the original distribution of Upper Norian facies; their present distribution suggests, however, that a Late Norian shoreline lay not far to the north and east of the inferred belt of carbonate rocks. The occurrence of robust shelly faunas and the relative coarseness of clastic interbeds in the carbonate rocks support the idea that this is a shoreward facies. Moreover, the increasing abundance of the massive carbonate rock toward the top of the carbonate facies of the Triassic section implies general shallowing of the sea with time, suggesting thereby a probable southwestward migration of the shoreline.

UNIT II. TRIASSIC ROCKS, PREDOMINANTLY LIMESTONE: Rocks included in unit II are chiefly Middle and Late Triassic carbonates which are as young as Middle Norian (Silberling and Roberts, 1962; N. J. Silberling, written commun., 1968). The time overlap between rocks of units I and II is not yet clearly defined, but it apparently spans much of the Early and Middle Norian stage. Rocks in the Augusta Mountains consist of at least 5000 ft of carbonate rocks overlain by perhaps 2000 ft of quartz sandstone with interbedded limestone, shale, and conglomerate of the Osobb Formation (Muller and others, 1951). In the northern Stillwater range, the Triassic section is of similar thickness and contains about 60 percent carbonate rocks and 40 percent shale, siltstone, and quartzite. Here, the Triassic rocks lie over metavolcanic rocks correlated with the Koipato Formation of Triassic and Permian age according to Silberling and Roberts (1962). Exposures of the Koipato Formation have been included in unit II in Figure 2.

Parts of units I and II are surely lithogenetic facies as advocated by Silberling and Roberts (1962, p. 21), but they are separated in this paper because of certain differences which may relate to the origin of the Boyer Ranch Formation. Rocks of unit I are substantially more pelitic and at least twice as thick as correlative rocks in unit II. Moreover, unit I contains thick deposits (for example, 6000 ft) of Triassic rocks which are continuous at least in part with Lower Jurassic rocks and which are younger than rocks of unit II. Perhaps most importantly, the phases and styles of folding in unit I differ from those of unit II.

UNIT III. JURASSIC SILTSTONE AND LIMESTONE: In the western Stillwater Range, Triassic shale and siltstone are continuous with Lower Jurassic marine sedimentary rocks which consist of a few hundred feet of calcareous siltstone, shale, and silty limestone. The youngest fossils obtained from these beds are Sinemurian or possibly, Toarcian (Page, 1965; Young, 1963; N. J. Silberling and R. E. Wallace, oral commun., 1963). A few miles north of the Buena Vista Hills in the Pershing Mining district of the Humboldt Range, N. J. Silberling has definitely identified Toarcian fossils in a section of about 300 ft of Lower Jurassic rocks (written commun., 1964).

Lower Jurassic siltstone and silty limestone occur only above the shale facies of Upper Norian rocks of unit I. This relation could imply that the margin of the present distribution approximates the Early Jurassic shoreline or that the carbonate facies of unit I is actually Jurassic in part. The Lower Jurassic fine-grained clastic rocks differ from subjacent Norian pelites by being far more calcareous and containing abundant thin limestone interbeds. Moreover, the rate at which Lower Jurassic deposits accumulated may have been two orders of magnitude higher than the Norian rate, provided Early Jurassic deposition was continuous. The latter points suggest a change of depositional environment from Norian to Early Jurassic time which was perhaps associated with westward migration of the more stable platform on which the massive beds of carbonate facies of unit I had been deposited.

Twenty miles west of the Stillwater Range in the West Humboldt Range, Lower Jurassic rocks are in far greater abundance than in the Stillwater Range. The total thickness of the Lower Jurassic section in the West Humboldt Range is uncertain, because the Mesozoic rocks there are in a pile of thrust nappes (R. C. Speed, unpublished mapping). The thickest continuous section of Lower Jurassic rocks, however, is around 1000 to 1200 ft. Provided the nappes are not far-travelled, it would appear that rocks in the West Humboldt Range indicate a Lower Jurassic thickness gradient with a strong westerly component. The youngest faunas obtained from these rocks are Toarcian. In the northern West Humboldt Range 5 miles east of Lovelock (Fig. 1), several hundred feet of gypsum and sandy limestone lie conformably above unfossiliferous calcareous siltstone which is lithologically identical with the rocks bearing Sinemurian and Toarcian fossils. Twenty-five miles southwest of Lovelock in the Mopung Hills, calcareous siltstone and limestone believed to be Lower Jurassic (Willden and Speed, in press) are overlain by gypsum, quartz sandstone, and limestone.

The structure of rocks in units I and III is complex; Triassic shale and siltstone and Lower Jurassic rocks are tightly co-folded about axes which plunge both in westerly and easterly

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tter points suggest a chang
it from Norian to Early Jur
associated with westward mi
platform on which the ma
of unit I had been deposited
the Stillwater Range in the We
r Jurassic rocks are in far grea
tillwater Range. The total thi
ic section in the West Humb
use the Mesozoic rocks there
pes (R. C. Speed, unpublis
t continuous section of Lo
is around 1000 to 1200 ft. Pr
it far-travelled, it would ap
umboldt Range indicate a Lo
nt with a strong westerly co
aunas obtained from these ro
rthern West Humboldt Ran
(Fig. 1), several hundred feet
stone lie conformably above
siltstone which is lithologica
bearing Sinemurian and Toarc
es southwest of Lovelock in th
s siltstone and limestone bel
Villden and Speed, in press)
uartz sandstone, and limest

rocks in units I and III
ale and siltstone and Low
ghtly co-folded about an
in westerly and easte

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ections (Willden and Speed; in press). The
iance in axis orientation is due to later
lding of broader wavelength whose axial
faces trace north-south. Unit I contains a
mber of thrust blocks which are interpreted
local slides during first folding. The deforma-
n began after deposition of unit III, hence,
Toarcian or later time.

Beds of unit II are relatively broadly folded
out northerly axes in the northern part of
gure 2; near the join with unit I, however,
d limbs are locally tightly appressed, and
ds are overturned (R. C. Speed and J. R.
cMillan, unpublished mapping). The con-
t between units I and II is a tectonic zone in
ich, at least in the Stillwater Range, rocks
unit I have ridden north over those of unit II.
e equivalent contact between units I and II
the northern Clan Alpine Mountains is con-
led by Tertiary deposits, but the contrast
structure across the 4-mi covered interval
gests a comparable relation to that in the
llwater Range. The displacement of unit I
r unit II is not great, however, because
glomerate wedges in the eastern Clan Alpine
untains indicate unit I has not moved far
th from likely pebble sources which lie to
e east. Broadly, the relations discussed above
est that fine-grained clastic sedimentary
ks (unit I) collected in a rapidly subsiding
in in Late Triassic time and then were up-
d, deformed, and transported to the north
r partly contemporaneous shelf facies (unit
early in the Jurassic orogeny.

The first folds in units I and III and the
ust surface which separates units I and III
m unit II in the Stillwater Range are de-
med together with beds of unit II in folds
ch have northerly axial traces. The early
s of units I and III thus formed before or
ing the overriding of unit II by units I and
In the Stillwater Range the Boyer Ranch
mation is truncated at one place by the
ust which brought unit I over unit II. The
osition of the Boyer Ranch Formation thus
eded thrusting of unit I and the second
e of folding. It is believed that the deposi-
n occurred during the early stages of first
ing of units I and III.

**egional Setting of the Boyer Ranch Forma-
n.** The distribution of outcrops of the
yer Ranch Formation is clearly not co-
nsive with the original distribution of the
n because the Boyer Ranch Formation is
cated on the north by the tectonic zone
ch separates units I and II and is covered on the east and west sides by Cenozoic deposits. Nonetheless, it seems clear that the Boyer Ranch Formation lies only above rocks of units I and III and is absent from terrain underlain by unit II. It is unlikely that the Boyer Ranch Formation is absent above unit II due to less probability for preservation there than over units I and III, because the deformation of rocks in unit II is far less than that in units I and III and because of the overriding of unit II by units I and III. Rather, the evidence suggests that the Boyer Ranch Formation was not deposited on unit II. Moreover, absence of Upper Norian and Lower Jurassic rocks in unit II in Figure 2 and in equivalent rocks to the north in the Mt. Tobin quadrangle (Muller and others, 1951) suggests that deposition in the Mesozoic basin where unit II was deposited may have ceased before Late Norian time. In contrast, the rocks subjacent to the Boyer Ranch Formation represent marine deposition through Norian time and, at least in part, through Early Jurassic time.

The Boyer Ranch Formation thus was deposited in an area which in slightly earlier time had likely been a shoreline environment. The erosional and angular unconformities below the Boyer Ranch Formation indicate that uplift and deformation occurred between the deposition of the Boyer Ranch Formation and that of subjacent beds.

The absence of the Boyer Ranch Formation from the West Humboldt Range, from 10 to 15 miles west of Figure 2, where Lower Jurassic rocks are overlain conformably by undated gypsum and sandy limestone suggests that the Boyer Ranch Formation was not deposited very far west of its present outcrop area. Indeed, these undated beds and Boyer Ranch Formation may be lateral equivalents. The correlation is supported by the association of quartz sandstone, gypsum, and limestone above Lower Jurassic rocks in the Mopung Hills, at the southern tip of the West Humboldt Range. Further, the gypsum deposits near Lovelock and those in the Mopung Hills are older than gabbroic rocks which are correlated with the Middle Jurassic igneous complex such that the gypsum beds and the Boyer Ranch Formation have similar minimum ages.

The gypsum beds imply some degree of reconfiguration of basin geometry after deposition of the Lower Jurassic rocks such that constrictions developed which impeded outflow of saline waters. If the constrictions had a tectonic origin, they may have been contemporaneous with the movements recorded by the basal unconformity and lithology of the lower member of the Boyer Ranch Formation. The present evidence broadly suggests that the gypsum beds may occupy the more offshore parts of the inherited, but somewhat reconfigured, Early Jurassic basin, whereas the Boyer Ranch Formation lies in the vicinity of the shoreline.

**Post-Boyer Ranch Formation Rocks.** The Boyer Ranch Formation is conformably overlain by up to 2000 ft of lava, tuff breccia, laminated tuff, and volcanic sandstone of basaltic and keratophyric composition. The volcanic rocks (Jurassic basalt of Fig. 2) occur only within the perimeter of the outcrop area of the Boyer Ranch Formation, and they contact no sedimentary unit other than the Boyer Ranch Formation. The relations indicate that deposition of the volcanic rocks and the Boyer Ranch Formation occurred in the same basin or series of basins.

Both the volcanic rocks and the Boyer Ranch Formation are intruded by gabbroic rocks whose compositional trends are similar to those of the volcanic rocks. The intrusive body is mushroom shaped and occupies about 450 sq km in plan. Part of the bottom of the igneous body is thought to be the erosion surface which underlies the Boyer Ranch Formation. The volcanic rocks cap the intrusion as well as the annular Boyer Ranch Formation. The geometric relations and compositional similarities of the volcanic and intrusive rocks indicate they are co-magmatic. The confinement of these relatively large masses of igneous rock to space on and within a single sedimentary unit, the Boyer Ranch Formation, argues for control of the distribution of the igneous materials by the particular properties of this sedimentary rock, a matter to be explored elsewhere.

Potassium-argon ages of a hornblende-biotite pair and an individual biotite from the gabbro are, respectively, 165–145 m.y. and 150 m.y. Assuming argon retention in the hornblende was superior to that of biotite (Hart, 1966) during Cretaceous and Tertiary thermal events in the Basin and Range, the age of the gabbro is most likely Middle Jurassic (Howarth, 1964). The age of the gabbro supplies a minimum age of Bathonian for the Boyer Ranch Formation. If the deposition of the volcanic rocks and Boyer Ranch Formation was continuous, the Boyer Ranch Formation cannot be much older than the gabbro.

Succeeding events in the vicinity of the Boyer Ranch Formation were the intrusion of widely separated granitic plutons, probably in Cretaceous or Tertiary time, and Tertiary volcanism and block faulting.

## Stratigraphy

No single section contains the depositional bottom and top of the Boyer Ranch Formation. Consequently, no adequate type section exists, and we have selected a type area for systematic description on the basis of the relative clarity with which the stratigraphy, structure, and basal contact relations can be interpreted. The type area, north of Shoshone Creek in the northern Clan Alpine Mountains, exposes the unconformable base of the Boyer Ranch Formation over a relatively large outcrop length. Unfortunately, the top of the formation is not preserved in the type area, but at other places where the depositional top is exposed, the large amount of intrusive rocks and extent of internal deformation and metamorphism obscure the Boyer Ranch stratigraphy.

The formation is named after the Boyer Ranch, a prominent landmark in northern Dixie Valley, which is near the center of the area of exposure of the formation. Excellent outcrops of the Boyer Ranch Formation occur two miles northwest of the Boyer Ranch at the mouth of Cottonwood Canyon which is accessible from the Dixie Valley Road.

The descriptive *stratigraphy* of the Boyer Ranch Formation is derived chiefly from three incomplete sections (Fig. 3), each of which is believed to have stratigraphic continuity. Together with observations at other points, these sections indicate that the Boyer Ranch Formation consists broadly of two members: a basal limestone or limestone and dolomite-pebble conglomerate with pebbly quartz sandstone and an upper homogeneous quartz sandstone. Macroscopic compositional and textural trends in the Boyer Ranch Formation are observable only in the basal member which is largely conglomerate in the northeastern half of the outcrop area and limestone in the southwestern half.

## Type Area

**General Geology.** The type area of the Boyer Ranch Formation covers about one-half square mile in the northern Clan Alpine Mountains, two miles due north of Shoshone Creek. A geologic map and cross sections of the type area are on Plate 1*. Mesozoic rocks in the type

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* See Plate Section for all plates.

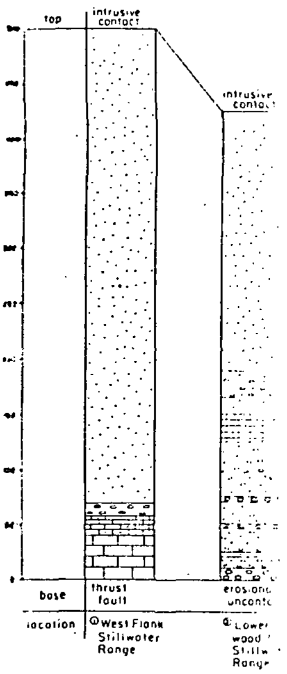

*Figure 3. Stratigraphic Secti*
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The Boyer Ranch Form
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lesozoic rocks, of which th
total of perhaps 20,000 ft
n the type area. The sub-
re discussed in the followin
nits in order of increasing
nconformity:

(a). *Massive dolomite and lim*
ck): chiefly medium grey fine-
e dolomite; almost entire secti
t 10 to 400 ft in block II (*see* l
assive, white, grey, and black li
una.

(b) *Limestone and sandstone*
n-bedded to massive, dark-gre
one and massive white and gre
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k of thin-bedded very fine-g
0 to 200 ft are red very fine
stone with current structure
rks; *Monotis subcircularis* thro

(c) *Limestone, shale, and silt*
ckness uncertain owing to in

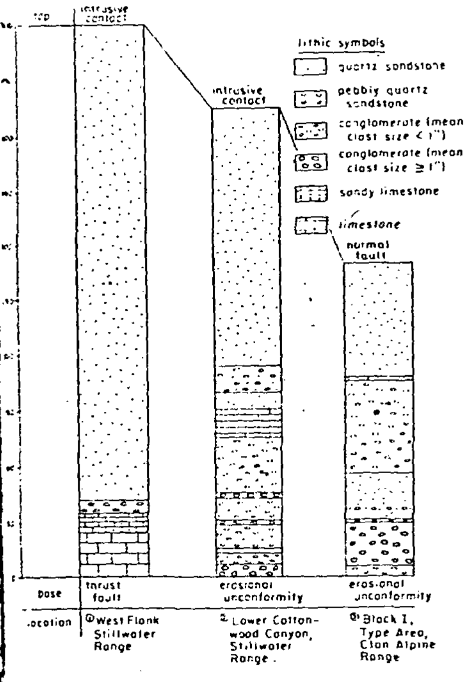


Figure 3. Stratigraphic Sections of Boyer Ranch mation section locations on Figure 2 and Plate 1.

crop out in a northerly trending block ch is largely in fault contact with ignimbrite d bedded tuff of probable Miocene age. The ology of the Clan Alpine Mountains and ighboring ranges is given by Willden and eed (in press).

The Boyer Ranch Formation in the type a is unconformably underlain by Lower esozoic rocks, of which the upper 3000 out of otal of perhaps 20,000 ft of section is exposed the type area. The sub-Boyer Ranch rocks discussed in the following, as three informal its in order of increasing distance below the conformity:

) *Massive dolomite and limestone* (400 to 1200 ft l): chiefly medium grey fine- to coarse-grained mas- dolomite; almost entire section at places is dolomite, 10 to 400 ft in block II (*see* later) is thick bedded to ive, white, grey, and black limestone; no diagnostic a.

) *Limestone and sandstone* (600 ft thick): largely bedded to massive, dark-grey to black cherty lime- and massive white and grey limestone, commonly in organic debris, sparse interbeds up to a few feet of thin-bedded very fine-grained sandstone; lower to 200 ft are red very fine-grained sandstone and one with current structures, slump folds, ripple ; *Monotis subcircularis* throughout unit.

) *Limestone, shale, and siltstone* (1500 ft thick): ess uncertain owing to internal faulting; about 40 to 50 percent thin-bedded to massive, black cherty limestone, percentage increasing toward top; units of homogeneous limestone from few inches to greater than 200 ft thick; 50 to 60 percent locally slaty, orange-weathering green shale and siltstone; minor current-bedded, ripple-marked calcareous sandstone and shelly, silty limestone; base is faulted; unit overlies thick (5000 ft) mudstone-shale-slate at Hoyt Canyon, 7 mi south-west; *Monotis subcircularis*, Hallorellititid brachiopods, *Septacardia sp.*

Unit (b) and the upper part of unit (c) are in the *Rhabdoceras suessi* Zone of the Upper Norian as established by Silberling and Tozer (1968), but the lower part of unit (c) lies in zone of *Steinmannites* beds of the Norian stage (N. J. Silberling, written commun., 1968). Unit (a), however, has no age-diagnostic fauna, and it could be Early Jurassic. The maximum possible age of the Boyer Ranch Formation in the type area is thus Upper Norian. Middle Jurassic gabbro and related igneous facies intrude and lie above the Boyer Ranch Formation. Thus, the minimum age of the Boyer Ranch Formation in the type area (and elsewhere) is Bathonian (late Middle Jurassic).

Unit (a) is largely massive gray dolomite, but bedded limestone of variable thickness occupies the basal part of the unit. The change from dolomite to limestone is gradational over an interval of about 3 ft, and the zone of transition is discordant to bedding in unit (a) (Pl. 1, map and section AA′). Although the three-dimensional configuration of the dolomite is not well known, a rough parallelism may exist between the base of the dolomite and the unconformity which underlies the Boyer Ranch Formation. The dolomite rock is broadly homogeneous, but it contains vestiges of bedding and organic material and has variable grain size. The attributes of the dolomite indicate that it is a product of replacement of limestone of unit (a) and that the source of magnesium was surface water rather than solutions from depth.

The configuration of the body of dolomite indicates that replacement occurred after warping and erosion of unit (a). The pebbles in the basal conglomerate of the Boyer Ranch Formation, though almost all dolomite, are texturally diverse and have distinct contacts with the carbonate matrix. The relations indicate that the conglomerate contains dolomite detritus rather than limestone clasts which were replaced *in situ*; thus, dolomitization preceded deposition of the Boyer Ranch Formation. The present investigation provides no further grounds for reconstruction of the paleogeography during dolomitization. Whatever the environment, it must have been widespread such that the Late Norian (and younger?) carbonate facies between the type area and Red Hill in the Stillwater Range were dolomitized. It is tempting, however, to suggest that precipitation of gypsum in waters to the southwest of the belt of calcareous deposits produced a Mg–Ca ratio sufficient for dolomitization of the adjacent carbonate rocks.

**Structure.** The Boyer Ranch Formation at the type area is exposed in three fault blocks which are delineated on Plate 1 as block I, II, and III.

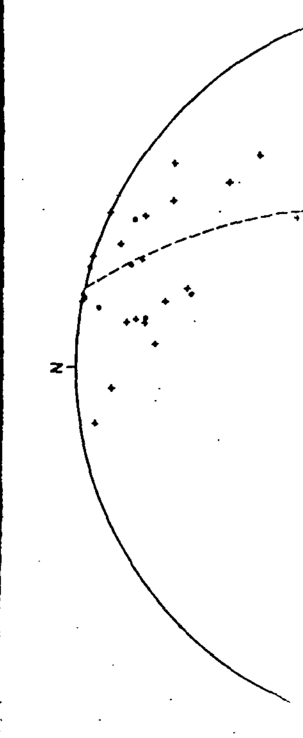
BLOCK I. The southern block is separated from block II by a normal fault which cuts the upper part of the Boyer Ranch Formation within block I. Block I largely consists of dolomite of unit (a) and limestone of unit (b) which are overlain by up to 400 ft of Boyer Ranch Formation. Near the east end of block I, a thrust fault brings the Boyer Ranch Formation and subjacent rocks over Triassic rocks of unit (c). A sheet of polymict breccia of gabbroic rocks lies over dolomite of the allochthonous unit (a) near the eastern edge of block I. The breccia is unlithified and unsorted; fragments are as large as 20 ft in maximum dimension and are highly angular. The breccia can only be dated as earlier than the Tertiary volcanic rocks. The breccia of block I may be a klippe of the thrust plate designated as block III in which similar gabbro breccia is widespread. If true, the block III thrust originally covered the entire type area. An alternative to the above hypothesis is that the breccia sheet of block I was a slide from pre-existing breccia in block III, but was not temporally related to the emplacement of the block III thrust.

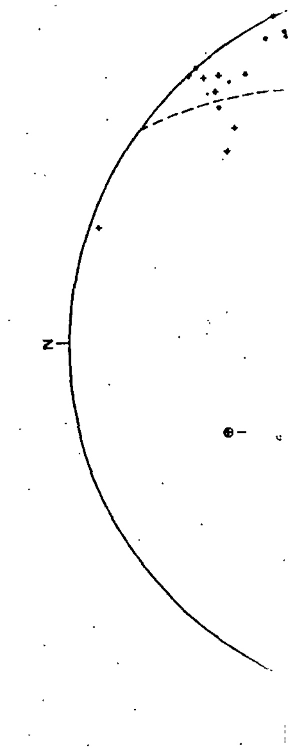
Beds in the allochthon of block I which contains the Boyer Ranch Formation mostly occupy the northerly limb of a macroscopic anticline (section BB′, Pl. 1) which is overturned to the north. Figure 4a shows the distribution of bedding poles for the Boyer Ranch Formation and subjacent rocks of units (a) and (b). The best fit[3] cylindrical axis for all the poles of Figure 4a plunges 32° N., 78° W. Exposures of the Boyer Ranch Formation in block I, however, occupy only a small interval on the fold profile such that the $\pi S_0$ distribution of Boyer Ranch poles falls far short of a great circle. The use of the above axis for the Boyer Ran Formation requires that the Boyer Ran Formation is folded coaxially with subjace rocks, an assumption which seems valid by th parallelism of bedding strikes on both sides the contact. The base of the Boyer Ran Formation in block I is thus implied to be eith an erosional unconformity or an angular un conformity without discordance of strike.

BLOCK II. The south side of block II is norma faulted against block I, and the northern margi of block II is the trace of the thrust whi separates the allochthonous rocks of block II from block II. Block II contains faulted se tions of sub-Boyer Ranch rocks which expo nearly all of units (a), (b), and (c). The Boye Ranch Formation is exposed only on the we side of block II where it is unconformable o beds of unit (a) with angles as great as 32 Bedding in the Boyer Ranch Formation an sub-Boyer Ranch rocks in block II is folde about axes which plunge 35° to 50° to th northwest. The axial surfaces are vertical inclined as much as 70° SW.

The westernmost fold of block II is an ove turned syncline in which the core is large occupied by the Boyer Ranch Formatio Figure 4b shows a $\pi S_0$ diagram for the Bo Ranch Formation and for beds of units (a) a (b) which are apparently folded in the sa syncline. The cylindrical axis which best f the totality of poles plunges 39°, N. 32 W best fits for the Boyer Ranch poles and poles of units (a) and (b) obtained separate however, are not coaxial. The difference orientation of the two axes, as well as the grea scatter of poles of the sub-Boyer Ranch ro than of the Boyer Ranch Formation, may explained by the existence of gentle folds in t sub-Boyer Ranch rocks of block II whose a differed from those of the later, more appres folds.

In the northwestern corner of block bedding attitudes indicate overturning *southwesterly directions, that is, opposite* the northeasterly overturning prevailing el where in block II. This area also contains mi folds and widespread breccia, both of wh are rare elsewhere in block II. The area anomalous structure adjoins block III and just below the southward projection of thrust which bases block III. The evidence th indicates reorientation of earlier structures brecciation of lower plate rocks which w near the thrust that transported Boyer Ra Formation and gabbro of block III. Bed attitudes in the area of reoriented struct





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[3] The fit was obtained by finding the orientation of the plane in spherical space which minimized the sum of squares of the normals between the plane and poles to bedding on a unit sphere. The projection of this plane on the equatorial plane is the best fit great circle through bedding poles on the equal area net.

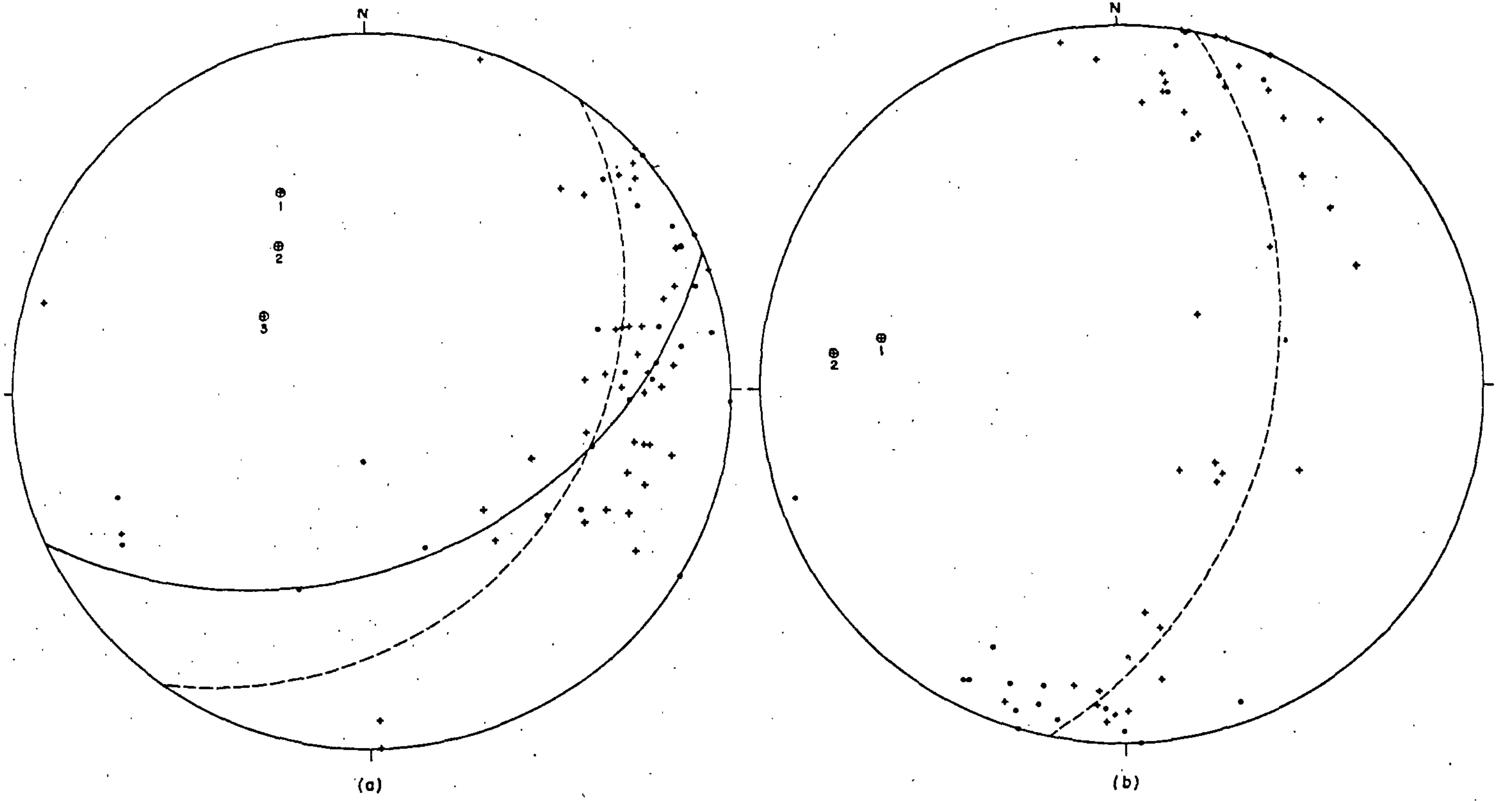

Figure 4. Equal area plots of poles to bedding of Boyer Ranch Formation (closed circles) and subjacent Triassic rocks (open crosses) in type area near Shoshone Creek, Clan Alpine Mountains. (a) Block II, westernmost syncline: full line is best fit great circle for poles of Boyer Ranch Formation and circled cross 1 is corresponding fold axis (N. 24 W., 39°); dashed line is best fit great circle for poles of sub-Boyer Ranch rocks and circled cross 3 is corresponding fold axis (N. 54 W., 60°); circled cross 2 is fold axis (N. 52 W., 50°) best fitting all points. (b) Block I: circled cross 1 is fold axis (N. 78° W., 32°) for all poles; circled cross 2 is a minor fold axis.

were not used in the axis computation of Figure 4b.

BLOCK III. Block III underlies the northern part of the type area; its boundary is a thrust fault with respect to which rocks of block II are autochthonous. The fault plane is a regular surface and thus is discordant to the folded beds of the lower plate. Where the thrust separates deformed quartz sandstone in the upper and lower plate, its trace cannot be clearly resolved such that it is shown on Plate 1 as an inferred contact. Block III contains quartz sandstone of the Boyer Ranch Formation overlain by facies of the Middle Jurassic igneous complex. In block III, bedding in the Boyer Ranch Formation is largely destroyed, and the quartz sandstone is extensively albitized.

As noted above, some reorientation of bedding in the lower plate apparently accompanied emplacement of the thrust plate. Overturning in the reoriented structures to the southwest implies motion of the upper plate in that direction. Speed (1963) found parallelism between foliation in gabbro and axial planes in folds in rocks underlying gabbro of the same igneous complex in the West Humboldt Range, 35 miles west of Shoshone Creek. Both fabrics were thought to have formed during the emplacement of the gabbroic complex which largely moved east to west in that area. Gabbro in block III of the type area has a mean foliation dip of 60° to N. 60 E., thus agreeing roughly with attitude of bedding in the lower plate rock of the northwestern part of block II. A southwesterly motion of the thrust plate of block III is implied.

**Unconformity.** The Boyer Ranch Formation depositionally overlies dolomite of unit (a) everywhere in blocks I and II, except at the north end of block II where it contacts the limestone of unit (a). The stratigraphic relief in the sub-Boyer Ranch rocks at the unconformity is 250 ft in block I and 750 ft in block II. The total variation in thickness of unit (a) in the type area is about 1100 ft, assuming that the base of unit (a) is correctly correlated in blocks I and II. The maximum apparent topographic relief on the unconformity is 250 ft. Over horizontal intervals of 100 ft or less, the unconformity is irregular; the most common channels at the top of the dolomite are about 5 ft wide and 1 to 2 ft deep.

In block II, bedding in the Boyer Ranch Formation and subjacent rocks is generally discordant (Fig. 5b); the maximum angular difference is 32°. The angularity of discordance varies gradually over distances of hundreds of feet, thus suggesting that the sub-Boyer Ranch rocks were broadly warped, rather than sharply inflected, before deposition of the Boyer Ranch Formation. As discussed above, there is no evident discordance along the nearly horizontal trace of the unconformity in block I though sub-Boyer Ranch beds could well have different dips from the Boyer Ranch Formation in directions perpendicular to the trace. A conceptual model of the type area at the beginning of Boyer Ranch deposition is a mildly dissected surface underlain by gently folded massive carbonate rocks.

**Conglomerate Member.** The lower member of the Boyer Ranch Formation in the type area consists of carbonate-pebble conglomerate and minor interbedded pebbly sandstone and homogeneous quartz sandstone. The range of composition and textures of the pebbles is such that all the clasts could have been derived solely from unit (a) of the subjacent section. The conglomerate matrix is quartz sand and carbonate cement. The thickness of the lower member varies markedly; the maximum is 250 ft, but along segments of the basal contact in both blocks I and II, the lower member is absent and the upper member directly overlies sub-Boyer Ranch rocks. Figure 5b shows the variation in thickness of the conglomerate member exposed in the syncline of western block II; the range of thickness is 0 to 40 ft. Maximum thickness occurs at the hinge of the syncline and the member thins around the interval of large curvature. About 2 ft of conglomerate exist on the upright limb, whereas conglomerate is absent from the overturned limb. This distribution indicates preferential accumulation of clasts along the hinge of the syncline. Superposed on this smooth thickness variation are irregularities due to filling of channels of a few feet in width on the dolomite surface.

In block I, the strike of the conglomerate member parallels the trend of the fold axis so that variation of conglomerate thickness with position in the syncline profile is unknown. Along strike, however, the conglomerate varies in thickness from 0 to 250 ft. Plate 1 and Fig. 5a show that the base of the conglomerate member in block I is far more irregular than the upper contact with the quartz sandstone member. Variations in conglomerate thickness in a direction parallel to the fold axis thus are due to topographic relief on the surface of the Triassic dolomite. The absence of the basal conglomerate along minor segments of the contact in both blocks I and II indicates that deposition of the conglomerate ceased before the lo

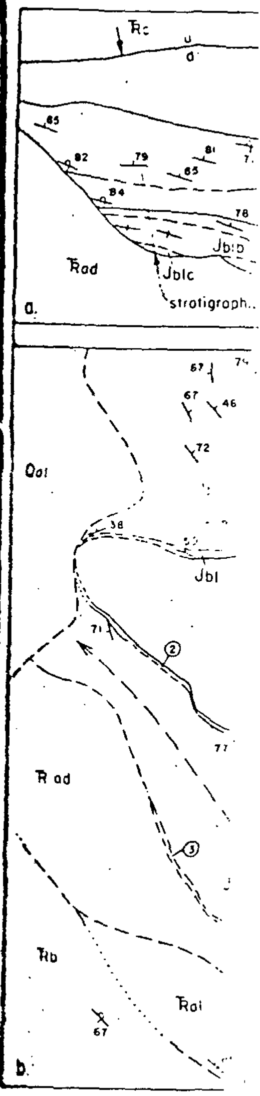

Figure 5. Large scale ge
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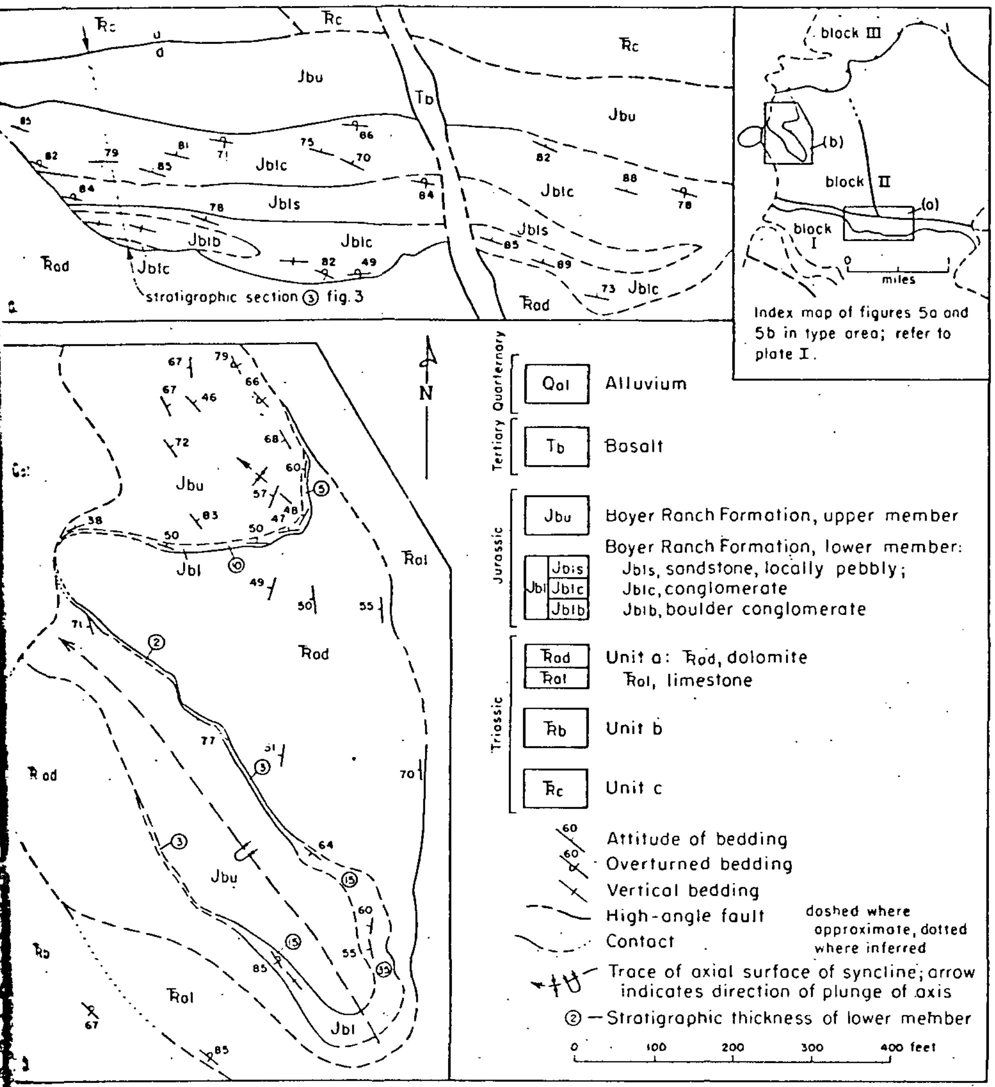

gure 5. Large scale geologic maps of parts of type area of Boyer Ranch Formation, (a) showing differentia- of lower member in block I and (b) showing variation of thickness of lower member with position relative to trace in block II.

lf was completely submerged. This relation plies that clasts of the conglomerate member not transported from persistent uplands djacent areas, but more likely were locally ved. We interpret the depressions in the onformity in block I as having been tribu- channels normal to a main trough which along a synclinal hinge that now trends N 78 W.

Clasts in the conglomerate member are en- ly of carbonate rocks. Greater than 80 per- of the clasts at all levels in the conglomer- are light-, medium-, or dark-gray dolomite. At stratigraphic levels within 100 ft of the quartz sandstone member, the clasts are at least 99 percent dolomite. Below that interval, however, 5 to 20 percent of the clasts are limestone.

The range of maximum dimension of carbonate clasts in basal conglomerate of the Boyer Ranch Formation is from ⅛ to 20 in. The rock is stratified by vertical changes of mean clast size which varies between ¼ and 4 in. The modal average grain size for the entire member is estimated to be ½ in. Roundness of clasts is largely between 3 and 5 on the scale of Krumbein (1941). Clasts which are less than roughly ½ in. in length have roundness values of about 4. Coarser fragments average about 5 and occasionally 6; very large boulders, however, are less round than clasts of the 1- to 6-in. range. Distinct lateral or vertical trends in roundness are absent. Clasts of length less than about 8 in. are discoidally shaped, whereas coarser particles are more spherical. Ratios of maximum to minimum dimension of clasts are in the range, 1 to 5; the average ratio in conglomerate beds varies from 1 ½ to 3, generally in inverse proportion to the average grain size. Discoid particles are well aligned in the bedding plane, and imbrication is rare. In general, the angularity of the clasts of the conglomerate member supports other evidence that the clasts were locally derived; moreover, it indicates that little reworking occurred near the site of deposition.

The conglomerate member is layered by variations in mean grain size of clasts, size sorting, shape alignment, and clast to matrix ratio. Submembers which are quasi homogeneous with respect to these criteria are between 2 and 25 ft thick and average about 10 ft thick. Some submembers in block I continue laterally over at least hundreds of feet, whereas others thin measureably within that distance. In particular, the coarsest boulder conglomerate in the lower member forms a tongue which wedges out 250 ft from the wall of the largest undulation in the basal unconformity (Fig. 5a).

Size sorting of clasts varies greatly between submembers. The sorting is best in thin layers of small clasts and is least in thick layers of coarse particles. Some intervals of coarse debris have bimodal size distributions where the edifice is supported by coarse clasts and the smaller clast population is restricted to sizes which could fit through the interstitial openings between the coarser particles. The degree of clast alignments is proportional to the extent of size sorting. Vertical changes in mean grain size and clast to matrix ratio are both abrupt and gradational. Small variations of these properties within some members provide excellent bedding on intervals of an inch to a few feet, averaging 5 to 10 in. Vertical trends through the member as a whole consist only of slightly poorer sorting and alignment in the lower part.

Besides the preferred orientation of their shortest axes normal to bedding (as defined by lithologic layering), the long axes of triaxial clasts are moderately well aligned in the bedding plane. The vector mean of long directions of clast populations at 24 places in block I is S. 87° W. plus and minus 21° (at 95 percent confidence). Ten values in block II have a mean direction of N. 34° W., plus and minus 45° (95 percent confidence). The directions were rectified with the fold axes given in Figure 4. The mean lineations are nearly parallel with the axes about which the conglomerate member is folded. It is not clear, however, whether the alignment is sedimentary or tectonic.

Conglomerate in the Boyer Ranch Formation is chiefly pebble supported, and quartz sand, dolomite cement, and minor clay fill the interstices. The conglomerate member also contains interbeds of homogeneous and pebbly quartz sandstone. The pebbly sandstone contains carbonate clasts of wide size and roundness range indicating a continuum between quartz sandstone and clast-supported conglomerate. Intermediate lithologies are simply mixtures of end members, however, and the carbonate clasts in pebbly sandstone are no more mature than those in conglomerate, and quartz sand is no coarser than in homogeneous quartz sandstone. In fact, the quartz sand in the conglomerate matrix, the sand in the quartz sandstone interbedded with the lower member, and the sands of the upper member have size and roundness distributions with similar limits (Table 2); thus, the sands of the upper and lower member were probably co-derived. The quartz sand is a highly mature sediment compared to the carbonate clasts in the lower member. Because the coarse components were clearly locally derived and because quartz sandstone is sparse in the underlying Triassic section, the quartz sand must have arrived from sources external to the local depositional system.

Good sorting and laterally continuous thi bedding in the dominantly finer grained conglomerate units, pebbly sandstone, and quart sandstone in the lower member indicate probable deposition in an aqueous medium. The absence of current bedding, pebble imbrication, and channeling which might be expected wher conglomerate lies above sandstone, indicate a fairly low-water-velocity environment. Th poorly sorted, massive, coarse-grained conglomerates, however, may have been deposite subaerially or, on the other hand, if they we deposited in water, velocities may not hav been sufficient to move clasts of this size onc they had fallen down local slopes to the present position.

Though sorting mechanisms were sufficie to separate fine carbonate clasts of differe mean grain size into planar beds a few inch thick, it is difficult to envision that the existen of massive homogeneous or pebbly sandsto beds in the conglomerate member is due sol to local sorting. The absence of size grad either vertically or laterally away from t trough wall among sand, granules, and pebb and the sporadically distributed carbon clasts of variable size and angularity float in sand-supported rock suggest that oth factors were operative in the origin of t sandstone interbeds. For example, the thick segment of the conglomerate member in blo I (Fig. 5a) contains a 25-foot-thick interbed quartz sandstone which extends without lith logic change across the exposure and co abruptly against the wall of the channel th filled by the lower member. The flux of carb ate debris from the trough wall must have b

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actually zero at the time of deposition of this quartz sandstone interbed. More generally, the distribution of sandstone in the conglomerate member may be due at least partly to the ratio of the influxes of the locally derived carbonate detritus and foreign quartz sand. The pebble flux thus was variable but, of course, nothing is known of the steadiness of the quartz sand flux. The supply of carbonate clasts was certainly dependent upon local topography, hence uplift. If the local uplifts were created by anticlinal folds, the carbonate influx must have been proportional to the rate of limb appression until the amount of sand deposited was sufficient to cover the anticlinal rises.

**Quartz Sandstone Member.** The upper member of the Boyer Ranch Formation consists largely of quartz sandstone and more sparsely of sandy limestone and dolomite. The member is up to 150 ft thick in block I and [illegible] ft in block II; in both blocks, the top is absent. The base of the upper member is gradational with the conglomerate member over 1 to 5 ft of pebbly sandstone. As mentioned above, quartz sand in the upper member is virtually identical with that in quartz sandstone interbeds and in the matrix between pebbles in the lower member. The boundary of the two members thus appears to mark a cessation of the influx of carbonate fragments. The lateral variability in thickness of the upper member is uncertain; lack of critical exposures prevents determination of the variation of thickness of quartz sandstone in syncline profile in blocks I and II.

Bedding in the quartz sandstone is defined by variations in sand/matrix ratio and by small changes in the mean size of the quartz sand. The most prominent beds are 1 to 8 in. thick, but many of these intervals contain subtle laminations 0.1 in. thick. Bedding surfaces are planar, and bed thicknesses are constant laterally over tens of feet. Ripple marks, inclined bedding, and other current features are absent. Further discussion of the petrology of the quartz sandstone is deferred to a later section.

**Sequence of Events.** The lower member of the Boyer Ranch Formation in the type area contains two co-deposited sets of clastic components which evolved under highly different sedimentary regimes. One set comprises clasts of carbonate rocks which were clearly derived from units now subjacent to the Boyer Ranch Formation. Properties of the lithic particles indicate small transport distances and little reworking at the site of deposition. The second component, fine-grained quartz sand, was not derived from or matured in the same sedimentary system that produced the lithic components, and the ultimate source of the sand was exotic. The sand, however, occurs throughout the lower member such that it must have been readily available when conditions for permanent deposition were created.

These conditions are believed to consist of local re-invasion of marine water, probably from the west, into troughs created by folding of a dissected subaerial surface. Deposition occurred in water whose current velocities were sufficient to provide size sorting of clasts less than an inch long, but which were not great enough to construct inclined bedding or other current features. Stratigraphic fluctuations in the ratio of lithic clasts to quartz sand suggest variations mainly in the influx of locally derived debris which, in turn, was probably related to variable rates of source uplift, or equivalently, limb appression. The transition from the lower to the upper member records the eradication of the source of carbonate debris by near submergence of local topography by Boyer Ranch sediments. The composition of the upper member thus indicates that mature quartz sand was then the only mobile clastic material. The duration of deposition of quartz sand is unknown; stratigraphic variations in the degree of folding of the upper member have not been recognized such that there is no indication that sand was deposited far into the stage of tight folding. Rather we postulate that as folding progressed, the marine waters were forced to withdraw, and the troughs in which the sand was depositing were obliterated.

### Other Localities Containing the Boyer Ranch Formation

**Hoyt Canyon, Clan Alpine Mountains.** Figure 6 shows geologic relations involving the Boyer Ranch Formation at a small area about 1 mi north of the mouth of Hoyt Canyon in the Clan Alpine Mountains. Here, the Boyer Ranch Formation depositionally overlies 100 to 150 ft of Triassic carbonate rocks which are thrust over a lower plate containing the same Triassic beds. The unconformity below the Boyer Ranch Formation is irregular on a scale of a few feet and is marked by a small angular discordance. The unconformity intersects stratigraphic levels in the Triassic section which are probably correlative with horizons in unit (b) in the type area.

The conglomerate and quartz sandstone near Hoyt Canyon are similar to those in the Boyer

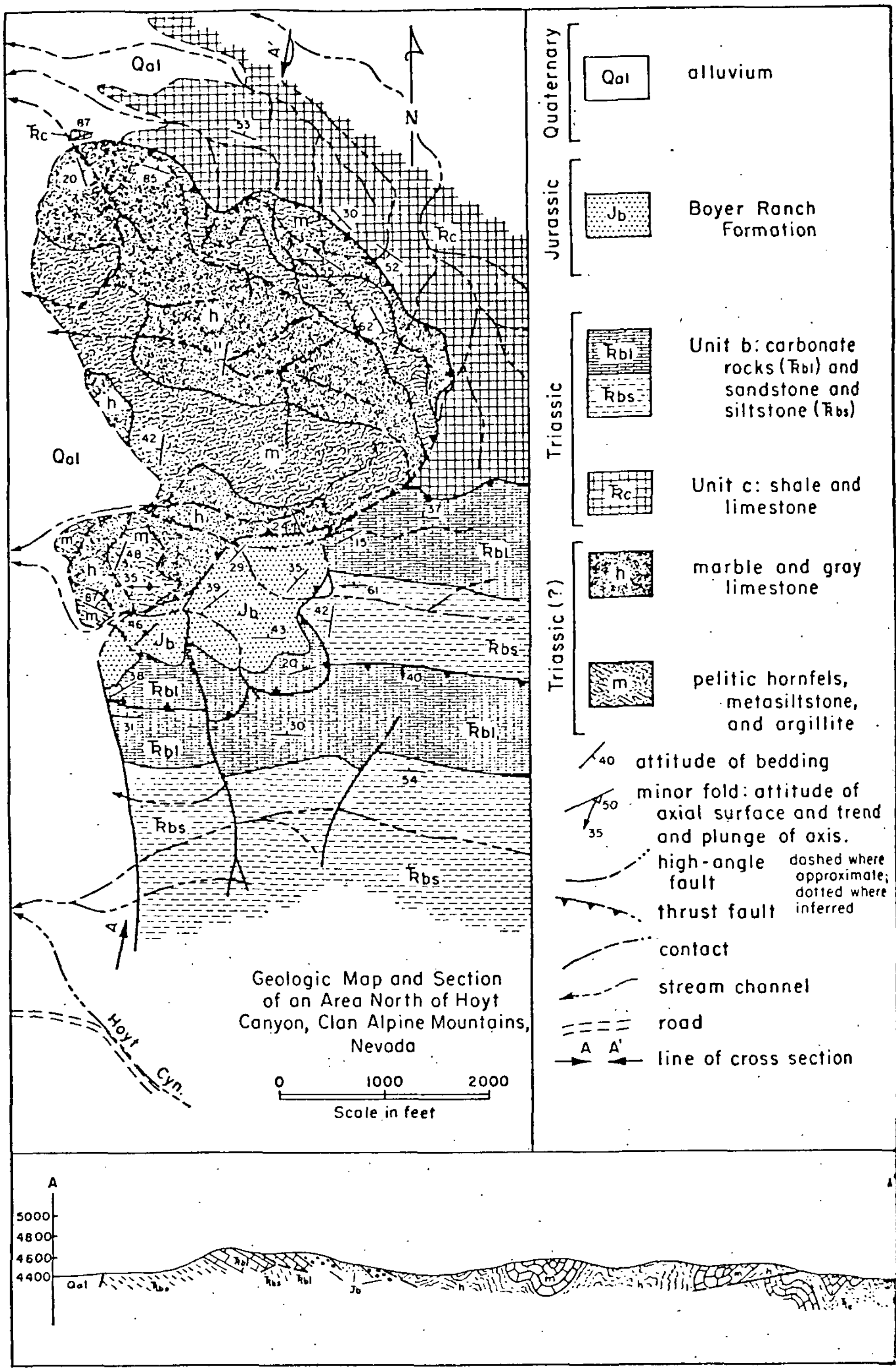

Figure 6. Geologic map and cross section of an area containing the Boyer Ranch Formation north of Ho Canyon, Clan Alpine Mountains.

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Ranch Formation of the type area. As shown in Figure 6, however, the quartz sandstone near Hoyt Canyon is overlain by deformed metasedimentary rocks consisting of intercalated limestone, marble, and siltstone (argillite and hornfels) in subunits from 200 to 300 ft thick. The age of the metasedimentary rocks was not determined faunally, but the lithologic similarity of these beds to Upper Norian strata of unit (c) in the type area of the Boyer Ranch Formation provides a strong correlation. Units (a), (b), and (c) also crop out widely in the vicinity of Hoyt Canyon though their thicknesses there are somewhat different from those in the vicinity of the type area. The metasedimentary rocks are folded about shallowly plunging westerly axes. The base of the metasedimentary section is discordant to the structures above it and must be a thrust which formed during or after folding.

A breccia layer separates the thrust plate from the quartz sandstone of the Boyer Ranch Formation. The upper part of the breccia contains only unstratified, unsorted angular fragments of the upper plate rocks in a calcitic matrix. Stratification improves down section in the breccia, and the base of the breccia is gradational with quartz sandstone. The breccia thus is included in the Boyer Ranch Formation. Figure 7 shows the lithologic succession in the Hoyt Canyon section.

The stratified breccia contains fragments of diverse lithologies. Most of the unit has a structural framework of angular clasts of metasiltstone and limestone and marble tectonite which were clearly derived from the superjacent thrust plate. The clasts are mildly size sorted, and their long dimensions are oriented in the plane of stratification. The matrix contains rounded quartz sand grains and carbonate cement and, at places, considerable pyrite. Stratification within a few stratigraphic intervals from 2 to 3 ft thick, is excellent due to dust-size sorting. These intervals contain a high percentage of quartz sand, and, at places, grade laterally into beds of homogeneous cross-bedded quartz sandstone which occupy channels within the breccia. Clasts of metasedimentary rocks are generally smaller and more rounded in the well-stratified intervals. Further, these intervals contain from 1- to 2-in.-diameter pebbles of a well-indurated feldspathic (20 to 35 percent) sandstone which are considerably better rounded than the co-deposited fragments of metasiltstone and marble. The probable source of the sandstone pebbles is the Upper Triassic Osobb Formation whose nearest present exposures are in the northernmost Clan Alpine Mountains 15 miles northeast of Hoyt Canyon, or Upper Triassic sandstones which are intercalated with siltstone and shale in the lower part of the exposed Triassic section in the central Clan Alpine Mountains (Willden and Speed, in press). Either source of sandstone pebbles requires transport from beyond the immediate vicinity, a hypothesis which is supported by the greater rounding of the sandstone clasts than of clasts of less durable rocks which were locally derived.

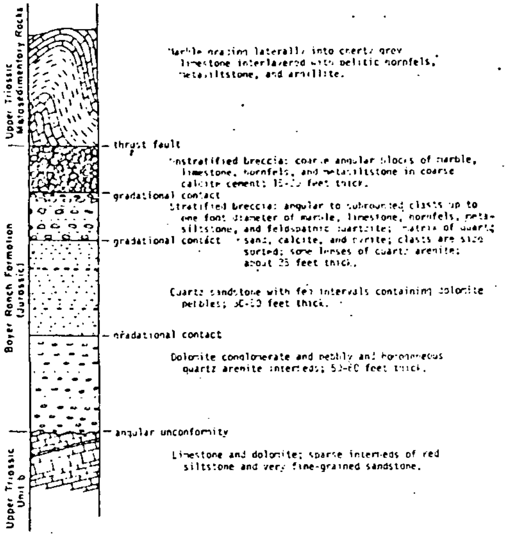

Figure 7. Diagrammatic lithic succession in Boyer Ranch Formation and relations with adjoining units 1 mile north of mouth of Hoyt Canyon, Clan Alpine Mountains.

Structural and stratigraphic relations near Hoyt Canyon indicate that a thrust plate of Triassic rocks moved laterally into a depositional basin of the Boyer Ranch Formation. The unsorted breccia directly under the thrust is interpreted as talus which fell from the prow of the upper plate and was, in turn, overridden by the upper plate. Debris from the thrust which was moved ahead of the postulated talus apron by running water, or possibly, waves, was laid down with grain maturity and perfection of stratification proportional to the distance from the front of the upper plate. The layers propagated laterally as the thrust plate moved over a surface underlain by its own debris. The channelling within the layered breccia indicates that at least part of its sedimentation was subaerial; the filling of the channels by quartz sandstone suggests the influx of quartz sand to the Boyer Ranch Formation was maintained during emplacement of the thrust plate. The absence of channelling or discordance at the contact of the quartz sandstone and the stratified breccia supports the concept that original deposition of the quartz sand and thrusting were not widely separated in time.

Metamorphism of the Triassic rocks of the upper plate clearly occurred before thrusting and deposition of the breccia at the top of the Boyer Ranch Formation. The only conceivable heat source is the Middle Jurassic gabbroic complex which is widely exposed three miles north of Hoyt Canyon. There, gabbro and subjacent Boyer Ranch Formation overlie with thrust contact Triassic hornfels and marble as well as unmetamorphosed equivalents of unit (c). The southern projection of the thrust would lie structurally above the present level of the Boyer Ranch Formation near Hoyt Canyon. It thus seems likely that the allochthonous metasedimentary rocks near Hoyt Canyon rode south to their present position. If the thrust was concurrent with deposition of quartz sand of the Boyer Ranch Formation, the intrusion of the gabbroic complex, at least in its early stages, must have occurred before completion of the deposition of the Boyer Ranch Formation.

**Cottonwood Canyon, Stillwater Range.** North and south of Cottonwood Canyon, the Boyer Ranch Formation overlies Upper Triassic slate with thrust contact. Here, the Boyer Ranch Formation is highly deformed and is widely invaded by gabbro so that it is difficult to reconstruct the stratigraphy in much of this area. In lower Cottonwood Canyon about 2 mi northwest of Boyer Ranch, however, the base of the Boyer Ranch Formation is exposed in a small window and is an erosional unconformity. The subjacent rocks discussed in an earlier section are very fine-grained sandstone and siltstone which are believed to be correlative with Upper Norian clastic rocks of the Clan Alpine Mountains. Because the rest of the Boyer Ranch Formation in the Cottonwood Canyon block is thrust over Triassic slate, it seems likely that the thrust fault must underlie the sub-Boyer Ranch unit in lower Cottonwood Canyon as well.

Section 2 of Figure 3 shows a stratigraphic section of the Boyer Ranch Formation at lower Cottonwood Canyon. The basal member is limestone and dolomite conglomerate whose bedding largely parallels that in the subjacent clastic unit. The contact undulates with amplitudes of a foot or less; the irregularities are interpreted as channels on the erosion surface filled by conglomerate. The basal conglomerate of the Boyer Ranch Formation at Cottonwood Canyon has a maximum thickness of 125 feet. Its granulometric attributes differ slightly from those of the conglomerate at the type area. The lowest ten feet contains coarse-grained (average 2 to 3-in. diameter) poorly sorted dolomite cobbles of considerably more spherical shape than elsewhere in the formation. The interstices contain quartz sand and calcite cement, and in several intervals in the conglomerate, the rock is a sand-supported structure with a few as 5 percent dolomite clasts. The upper part of the conglomerate is more uniformly composed of finer (diameter averages ½ to 1 in.) angular carbonate clasts, 50 to 100 percent of which are dolomite. The pebble content is from 40 to 60 percent of the rock which is generally a lower abundance than in the conglomerate at the type area. The conglomerate is overlain by 25 ft of partly silicified laminated massive-weathering limestone. The rest of the formation consists of about 275 ft of quartz sandstone, which has conspicuous thin planar beds from 1 to 2 in. thick.

Farther west in Cottonwood Canyon, 2 miles beyond the canyon mouth, the top of the quartz sandstone is exposed and is conformably overlain by well-bedded basaltic tuffs and lapilli tuffs of the mafic igneous complex. The stratigraphic interval between quartz sandstone in upper and lower Cottonwood Canyon is occupied by at least several thousand feet of gabbro.

**Northwestern Stillwater Range.** In the northwestern Stillwater Range (Fig. 2), rocks subjacent to the Boyer Ranch Formation are Triassic slaty siltstone and shale, and more sparsely, Lower Jurassic beds at least as young as Sinemurian which are co-deformed with the Triassic rocks. At Red Hill, the Boyer Ranch Formation and overlying gabbro are thrust over Triassic rocks. The stratigraphy of the Boyer Ranch Formation is uncertain owing to folding, but dolomite conglomerate includes in the upper plate suggests the prior existence of basal conglomerate like that at the type area. Quartz sandstone at Red Hill is the coarsest (up to 0.3 mm. mean size) in the Boyer Ranch Formation. South of Red Hill, for 1½ miles sporadic patches of quartz sandstone of the Boyer Ranch Formation are remnants of the roof of the igneous complex.

At Cornish Canyon (Fig. 2), an isolated body of Boyer Ranch Formation occurs in the core of a nearly recumbent macroscopic synform of Triassic slate. The fold is interpreted by the parallelism of the contact of Triassic rocks above and below the Boyer Ranch Formation with slaty cleavage and axial surfaces of minor anticlines in the Triassic rocks. The lithic units in the Boyer Ranch Formation here are fine-grained quartz sandstone, laminated sandy limestone which is locally a limestone breccia, and carbonate-pebble conglomerate with quartz sand matrix much like that of the lower member at the type area. The bedding in the units of the Boyer Ranch Formation largely parallels the contact with Triassic slate, and the formation has sparse minor folds which are coaxial with folds in the slate. The contact is most likely a folded angular unconformity. Provided the contact is correctly interpreted as being depositional, the Boyer Ranch Formation at Cornish Canyon was deposited after uplift, dissection, and removal of Lower Jurassic rocks and probably, a significant thickness of Triassic rocks, but before intense folding. This sequence of events is similar to that at the type area, and it places a maximum age of Sinemurian on the time of deposition of the Boyer Ranch Formation. As suggested earlier, the Lower Jurassic section in the Pershing mining district, 10 miles west of Cornish Canyon, contains rocks as young as Toarcian which appear to be co-deformed with units I and III of Figure 2. By extrapolation of this age to the west Stillwater area, the maximum age for the Boyer Ranch Formation would be Toarcian.

About four miles southwest of Cornish Canyon, an extensive block of homoclinal Boyer Ranch Formation lies with nearly planar contact above tightly folded and thrust-faulted Upper Triassic and Lower Jurassic rocks; in contrast to the structure at Cornish Canyon, the Boyer Ranch Formation here has not participated in the strong deformation which pervades subjacent rocks. Figure 3 shows a stratigraphic section in this block at location 1, Figure 2. The lowest unit here is massive locally stromatolitic limestone whose thickness varies between a few feet and 100 ft. Much of the limestone is monolithologic breccia of probable tectonic origin; together with the variable thickness of the limestone, the breccia suggests that the basal contact is a thrust fault, in agreement with the interpretation of Page (1965).

Locally, the massive limestone is overlain by laminated quartz sand-bearing limestone and limestone conglomerate with quartz sand matrix. The stratigraphic sequence of the basal units in the northwestern Stillwater belt is different from that at Cottonwood Canyon 5 miles east (Fig. 3). The carbonate conglomerate differs from that of the type area by having substantially higher roundness of the clasts, which suggests greater transport of the cobbles. The basal deposits are overlain by up to 500 ft of fine-grained quartz sandstone with a few thin interbeds of sandy limestone. Distinctive bedding is defined by variations of mean grain size over intervals of 0.1 to 40 in. but mostly 4 to 6 in.

The Boyer Ranch Formation from 3 to 5 miles southwest of Cornish Canyon is overlain by over a thousand feet of gabbro which is correlative with gabbro at Cottonwood Canyon and the type area. It would thus appear that in this area, Boyer Ranch Formation associated with gabbro was not co-deformed with subjacent Mesozoic rocks, whereas at Cornish Canyon where gabbro is absent, the Boyer Ranch Formation is infolded with Triassic rocks. The local absence and variations in thickness of the basal member and the widespread brecciation in the lower several hundred feet of the formation suggest that the base is a thrust fault even though the belt southwest of Cornish Canyon is anomalous among Boyer Ranch Formation sections in its apparent homoclinicity. Indeed, if the contact were not a thrust, strong folding of the Boyer Ranch rocks should be expected here. Using the attitude of foliation in the overlying gabbro in the manner employed at the type area and by Speed (1963), the motion of the thrust in the northwestern Stillwater belt was northerly; this is, significantly, the direction of overturning of folds in the sub-thrust rocks. The base of the sandstone apparently was a surface of near-perfect slip across which concomitant deformation in the upper and lower plates differed significantly.

Dixie Meadows. In the Stillwater Range one mile west of Dixie Meadows in Dixie Valley, the Boyer Ranch Formation lies with thrust contact above folded Upper Triassic siltstone and sandstone. The formation locally has up to 20 ft of basal limestone with ¼ in. thick alternating light and dark bands which are largely discordant to the basal thrust. Elsewhere, quartz sandstone directly contacts the Triassic siltstone, and both units are finely brecciated along much of the join. Quartz sandstone near Dixie Meadows is uniformly well bedded and fine grained. The thickness of the quartz sandstone near Dixie Meadows is uncertain because of the faulted bottom and internal folding of the unit. Bedding attitudes in the quartz sandstone indicate subhorizontal fold axes trending northwesterly and axial surfaces with probable steep northeasterly dips. The base of the formation, however, is at best broadly warped about a northerly axis.

In upper Mississippi Canyon, 5 miles north of Dixie Meadow, about 200 ft of metamorphosed quartz sandstone of the Boyer Ranch Formation lie between gabbro and basaltic rocks.

Up to a foot from the contact of the Boyer Ranch Formation and overlying volcanic rocks, quartz sandstone is massive and fine grained, but the upper foot of the unit is distinctly laminated. The laminae contain quartz detritus which varies in grain size from silt to fine sand. The fine-grained layers have considerable muscovite, whereas in the coarser ones, tourmaline, zircon, and apatite are more abundant than elsewhere in the formation. Basaltic rocks which lie over the quartz sandstone consist of flows and interlayered, bedded fine-grained breccia and tuff. Bedding attitudes in the two units are similar, and over a limited interval of fair exposure, the contact between the units parallels the bedding. The evidence at Mississippi Canyon indicates either continuity in deposition of Boyer Ranch Formation and basaltic rocks or a time break without intervening deformation or erosion. Considering that the Boyer Ranch Formation was deposited after the onset of crustal unrest, any hiatus must have been of short duration at best.

**Buena Vista Hills—Fondaway Canyon, Western Stillwater Range.** The southwesternmost exposures of the Boyer Ranch Formation occur near the mouth of Fondaway Canyon in the Stillwater Range (Fig. 2). There, Page (written commun., 1965) found quartz sandstone and limestone associated with Triassic slate and with rocks assigned a Lower Jurassic age by their lithologic similarity to dated rocks 5 miles north. The quartz sandstone at Fondaway Canyon is correlated with the Boyer Ranch Formation by lithology and stratigraphic position. Page (written commun., 1968) concluded that the Boyer Ranch Formation at Fondaway Canyon is infolded with, but less intensely deformed than the subjacent rocks; he interpreted the base of the Boyer Ranch Formation, however, as a thrust. Thus, thrusting of the Boyer Ranch Formation at Fondaway Canyon did not prevent the participation of the formation in part of the deformation of units I and III as it did at other places where the Boyer Ranch Formation is widely invaded by the gabbroic complex.

One mile north of White Cloud Canyon (Fig. 2), quartz sandstone is thrust over Upper Triassic and Lower Jurassic siltstone and limestone and is overlain by gabbro (Page, 1965; Young, 1963; Willden and Speed, in press). Conglomerate and limestone are absent from this occurrence of the Boyer Ranch Formation, although massive limestone in klippen which lie between White Cloud Canyon and the quartz sandstone exposures is probably Boyer Ranch limestone. The quartz sandstone body is as thick as 300 ft, but bedding is absent, and the stratigraphic thickness is uncertain. The quartz grains are highly intergrown, and the grain to matrix ratio is from 8.5 to 9, suggesting large tectonic compaction; the recrystallized matrix is albite-talc-chlorite-calcite. Though clearly metamorphosed, the range of original quartz grain sizes here appears similar to those elsewhere in the formation.

From the locality near White Cloud Canyon north as far as the Buena Vista Hills, quartz sandstone in scattered exposures lies above the intrusive facies of the igneous complex and below or interbedded with extrusive facies, a setting generally similar to that at Mississippi Canyon. The maximum exposed thickness in this interval is no more than 150 ft. Though metamorphosed, the original purity, grain size, and bedding of quartz sandstone in these exposures are judged to be similar to those properties of quartz sandstone of the type area. Boyer Ranch facies other than quartz sandstone have not been identified in this segment. As at Mississippi Canyon, the contact of quartz sandstone and volcanic rocks is conformable, channeling is absent, and the two units are co-deformed. Of particular interest here is the occurrence of quartz sand within the volcanic section.

The basal volcanic rocks are massive keratophyre which consist almost entirely of lineate very fine-grained lathy albite and sparse albite phenocrysts. Within the keratophyre section are many intervals of well-stratified volcanic sandstone and siltstone which contain clasts of keratophyre, feldspar grains, and variable quantities of well-sorted quartz sand. Conformably overlying the keratophyric rocks are up to 1500 ft of basaltic lava, tuff breccia, and volcanic sedimentary rocks in which quartz sand is rare.

Most of the quartz sand in the basal volcanic sedimentary rocks is in low concentration. It generally constitutes from 10 to 50 percent of the coarse laminations in association with lithic fragments, but it is absent from layers of silt and finer sized material. The lithic grains are mildly rounded and sorted and in apparent hydraulic equilibrium with th
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## Petrology of the Sandstones

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hydraulic equilibrium with the quartz sand. The relations suggest reworking and deposition of volcanic materials at the surface after each extrusion and addition of quartz sand from an outside source. An extreme of quartz sand concentration is a bed of homogeneous quartzite, as thick as four ft, which is intercalated with volcanic sedimentary rocks a mile southeast of the Buena Vista Mine (Nickle, 1968). The quartzite is now rather silicified, but relict quartz grains and bedding are resolvable. The layer can be traced laterally over at least a few hundred feet.

The bedding in the quartz-sand-bearing volcanic sedimentary rocks indicates they were deposited in a body of standing water rather than in a fluvial environment. The attainment of hydraulic equilibrium by the quartz and lithic components indicates some degree of local working and sorting under quiet conditions at the site of deposition. It is thus not clear whether quartz sand was still being supplied by a source external to the system or whether sand in the volcanic sedimentary rocks was reworked from the top of the Boyer Ranch Formation which may have been exposed elsewhere. As at Mississippi Canyon, however, the absence of channelling in the top of the Boyer Ranch Formation and the lack of discordance at the contact suggest that no significant time interval occurred between the deposition of the two units.

## Petrology of the Sandstones

**Mineral Assemblages.** About 120 specimens of sandstone and conglomerate of the Boyer Ranch Formation have been examined in thin section and by X-ray diffractometry. The areal and stratigraphic variability of the sandstones, however, has not been quantitatively investigated because of the widespread deformation and metamorphism. Rather, petrologic studies have been concentrated principally on specimens from the type area where the rocks have undergone minimal postdiagenetic changes. Table 2 contains the data on mineral assemblages and granulometry from 23 specimens of Boyer Ranch Formation together with 6 specimens of Navajo Sandstone which we include for a measure of calibration of the microscope measurements on the rocks of the Boyer Ranch Formation.

The abundance of sand-sized particles in sandstone of the Boyer Ranch Formation varies from about 40 to 75 percent. Of the sand population, quartz is at least 95 percent, and commonly 99 percent, regardless of sand/matrix ratio. The most frequent sand abundance is estimated to be from 65 to 70 percent. Microcline and plagioclase sand are generally a percent or less of total rock and have maximum abundance of about 3 percent. Up to 3 percent sand particles of chert and shale occur in some specimens, and sand-sized opaque grains are similarly abundant at some places. Blue-green tourmaline and zircon are consistently a few tenths of a percent of the sand.

The sand-grain content varies inversely with carbonate content in most specimens such that the principal lithic gradation is between calcareous quartz arenite (Williams and others, 1958, p. 293) and sandy limestone (or dolomite) in which the quartz sand grains are not self-supporting. Sand-sized particles of fine-grained carbonate, however, can be distinguished from carbonate cement in some rocks where the quartz sand grains are rarely touching. Due to carbonate recrystallization, the discontinuities between original carbonate matrix and sand have become largely indistinct, but the sandy limestones may well have been grain-supported quartz-carbonate sandstones.

In the type area, the matrix of sandstone and conglomerate is composed of variations of the assemblage, calcite-dolomite-kaolinite. More rarely, small amounts of white mica of 14Å clay can be detected. Dolomite and calcite occur as monomineralic matrix in some specimens, and they occur together and in combination with kaolinite in others. Kaolinite is generally aggregated in homogeneous very fine-grained irregular pods or lenses up to 0.1 mm in thickness which contact both quartz sand and matrix carbonate. The abundances of kaolinite reported in Table 2 are estimates based on both microscope counts and X-ray intensity; the latter would detect

TABLE 1. CHEMICAL COMPOSITIONS (WT. %) OF QUARTZ ARENITE AND METAMORPHOSED QUARTZ SANDSTONES FROM THE BOYER RANCH FORMATION

| | (1) | (2) |
|---|---|---|
| $SiO_2$ | 68.26 | 67.83 |
| $Al_2O_3$ | 1.88 | 10.40 |
| $Fe_2O_3$ | 0.37 | 0.20 |
| FeO | 0.13 | 0.28 |
| MgO | 0.27 | 13.31 |
| CaO | 15.08 | 1.12 |
| $Na_2O$ | 0.05 | 3.38 |
| $K_2O$ | 0.11 | 0.23 |
| $H_2O+$ | 0.73 | 1.07 |
| $H_2O-$ | 1.18 | 0.68 |
| $TiO_2$ | 0.06 | 0.40 |
| MnO | 0.02 | nil |
| $P_2O_5$ | 0.06 | 0.20 |
| $CO_2$ | 11.79 | 0.24 |
| Cl | 0.01 | 0.09 |
| F | 0.01 | 0.04 |
| Total | 100.90 | 99.47 |

(1) quartz arenite (quartz-calcite-kaolinite); type area, block II; specimen 5, table 2

(2) metamorphosed quartz arenite (quartz-talc-chlorite-albite); 2.5 miles N20°E from mouth of Hoyt Canyon, Clan Alpine Mountains

Analyst: Y. Chiba

TABLE 2. GRANULOMETRIC AND LITHOLOGIC DATA FOR SPECIMENS OF THE BOYER RANCH FORMATION AND THE NAVAJO SANDSTONE

| LOCATION* | | | | GRAIN SIZE DISTRIBUTION† (φ) | | | | | | | | | | | | | | | | | | | | MOMENTS‡ | | | | | SAND PERCENTAGES | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 | 2.25 | 2.5 | 2.75 | 3.0 | 3.25 | 3.5 | 3.75 | 4.0 | 4.25 | 4.5 | 4.75 | 5.0 | 5.25 | 5.5 | 1(φ) | [illegible] | [illegible] | 3 | 4 | % Quartz Sand | % Feldspar Sand | % Total Sand |
| *Boyer Ranch Formation (sandstone subunit)* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Type Area | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Block | I | 1 | % | | | | | 99.9 | 98.2 | 94.0 | 77.0 | 59.5 | 45.7 | 32.5 | 19.5 | 12.3 | 7.7 | 4.3 | 2.0 | 0.5 | | | | 3.01 | [illegible] | [illegible] | 0.63 | 2.99 | 46.1 | 0.8 | .. |
| | | | r | | | | | | 5.4 | | 5.3 | | 5.1 | | 5.0 | | | | | | | | | | | | | | | | |
| | I | 2 | % | | | | 98.9 | 97.5 | 93.5 | 88.3 | 82.2 | 74.2 | 62.5 | 50.0 | 37.2 | 24.2 | 15.0 | 8.7 | 4.5 | 2.3 | 1.0 | 0.2 | | 3.22 | [illegible] | [illegible] | −0.05 | 2.72 | 46.2 | 1.8 | 51.0 |
| | | | r | | | | 6.6 | | 6.3 | | 5.5 | | 4.8 | | 4.3 | | | | | | | | | | | | | | | | |
| Block | II | 3 | % | | | 99.4 | 98.3 | 96.0 | 93.0 | 88.0 | 82.0 | 72.0 | 57.5 | 44.0 | 31.0 | 17.8 | 10.7 | 6.4 | 3.5 | 1.5 | 0.8 | | | 3.12 | [illegible] | [illegible] | −0.10 | 2.98 | 71.5 | 2.5 | 74.0 |
| | | | r | | | | 5.8 | | 5.3 | | 4.9 | | 4.7 | | 4.5 | | | | | | | | | | | | | | | | |
| | II | 4 | % | | | | | 99.9 | 99.2 | 96.6 | 87.0 | 69.0 | 47.0 | 27.0 | 14.5 | 7.0 | 4.0 | 2.0 | 0.8 | 0.3 | | | | 3.06 | [illegible] | [illegible] | 0.63 | 3.83 | 55.8 | 0.2 | 59.0 |
| | | | | | | | | | | | 5.4 | | 5.0 | | 4.5 | | | | | | | | | | | | | | | | |
| | II | 5 | % | 99.8 | 97.0 | 93.0 | 83.0 | 76.0 | 69.5 | 55.0 | 40.0 | 28.3 | 18.5 | 10.0 | 4.3 | 2.0 | 0.6 | 0.1 | | | | | | 2.32 | [illegible] | [illegible] | 0.00 | 2.47 | 63.0 | .. | 65.0 |
| | II | 6 | % | | | | | 99.5 | 98.4 | 96.6 | 92.3 | 84.0 | 70.0 | 51.0 | 32.0 | 20.0 | 14.0 | 9.5 | 5.0 | 3.0 | 2.0 | | | 3.33 | [illegible] | [illegible] | 0.48 | 3.56 | 60.4 | 0.2 | 61.5 |
| | | | r | | | | | | 5.6 | | 5.2 | | 5.0 | | 4.8 | | | | | | | | | | | | | | | | |
| | II | 7 | % | | | | | | | 99.2 | 97.0 | 91.0 | 77.5 | 60.0 | 45.0 | 31.2 | 22.0 | 15.0 | 8.25 | 4.5 | 2.8 | 1.0 | | 3.51 | [illegible] | [illegible] | 0.58 | 2.98 | 57.5 | .. | 58.0 |
| | | | r | | | | | | | | 5.5 | | 5.3 | | 5.2 | | | | | | | | | | | | | | | | |
| | II | 8 | % | | | | | | 99.8 | 97.5 | 90.0 | 76.0 | 57.5 | 38.0 | 20.0 | 10.8 | 6.5 | 3.4 | 1.0 | | | | | 3.12 | [illegible] | [illegible] | 0.47 | 3.16 | 40.0 | 0.3 | .. |
| | | | r | | | | | | 5.7 | | 5.1 | | 4.6 | | 4.1 | | | | | | | | | | | | | | | | |
| | II | 9 | % | 99.6 | 95.8 | 89.6 | 74.8 | 61.0 | 52.0 | 44.5 | 37.5 | 30.0 | 22.0 | 15.8 | 9.8 | 6.2 | 4.5 | 3.7 | 2.3 | 0.2 | | | | 2.24 | [illegible] | [illegible] | 0.62 | 2.66 | 72.0 | .. | 72.0 |
| | | | r | | 6.5 | | 6.1 | | 5.4 | | 5.0 | | 4.8 | | 4.8 | | 4.8 | | | | | | | | | | | | | | |
| | II | 10 | % | | | | | | 99.9 | 99.4 | 97.8 | 95.0 | 85.0 | 71.5 | 56.0 | 36.2 | 22.2 | 14.1 | 7.0 | 3.3 | 1.7 | 0.5 | | 3.59 | [illegible] | [illegible] | 0.31 | 3.11 | 39.2 | 0.7 | 41.9 |
| | | | r | | | | | | 4.6 | | 4.9 | | 4.8 | | 4.3 | | | | | | | | | | | | | | | | |
| Block | III | 11 | % | | | | | | | 99.5 | 97.2 | 90.8 | 76.7 | 61.7 | 44.0 | 29.9 | 20.4 | 14.8 | 9.6 | 5.8 | 3.0 | 1.6 | 1.0 | 3.51 | [illegible] | [illegible] | 0.75 | 3.39 | 46.0 | 1.7 | 47.7 |
| | | | r | | | | | | | | 5.5 | | 4.9 | | 4.5 | | 4.3 | | | | | | | | | | | | | | |
| Cottonwood Canyon | | 12 | % | | | | | 99.8 | 97.8 | 94.2 | 85.0 | 67.5 | 46.0 | 29.0 | 13.7 | 5.7 | 2.7 | 1.8 | 1.0 | 0.3 | | | | 3.03 | [illegible] | [illegible] | 0.41 | 3.74 | 72.1 | .. | 72.7 |
| | | | r | | | | | | 5.9 | | 5.5 | | 5.3 | | 5.3 | | | | | | | | | | | | | | | | |
| Cottonwood Canyon | | 13 | % | | | | | 99.7 | 98.5 | 96.0 | 90.0 | 77.0 | 56.5 | 39.0 | 18.5 | 11.3 | 6.7 | 3.2 | 1.0 | | | | | 3.12 | [illegible] | [illegible] | 0.31 | 3.33 | 63.3 | 2.7 | 67.0 |
| | | | r | | | | | | 5.6 | | 4.8 | | 4.2 | | 3.9 | | 3.7 | | | | | | | | | | | | | | |
| Cottonwood Canyon | | 14 | % | | | 98.5 | 88.7 | 81.0 | 70.2 | 59.0 | 49.0 | 39.0 | 29.0 | 19.0 | 11.5 | 5.0 | 2.5 | 1.5 | 0.3 | | | | | 2.51 | [illegible] | [illegible] | 0.23 | 2.27 | 73.0 | .. | 73.0 |
| | | | r | | | | 5.8 | | 4.5 | | 4.2 | | 4.0 | | 3.8 | | 3.5 | | | | | | | | | | | | | | |
| Red Hill | | 15 | % | 98.0 | 85.2 | 73.0 | 58.0 | 47.4 | 34.0 | 21.0 | 12.7 | 8.0 | 5.7 | 2.7 | 0.8 | | | | | | | | | 1.75 | [illegible] | [illegible] | 0.52 | 2.73 | 66.0 | .. | 67.0 |
| | | | r | | 6.5 | | 5.3 | | 4.3 | | 3.7 | | 3.5 | | 3.2 | | | | | | | | | | | | | | | | |
| West Stillwater Range | | 16 | % | | | 99.2 | 97.6 | 95.4 | 88.0 | 78.5 | 66.0 | 50.0 | 27.5 | 14.0 | 7.3 | 3.5 | 1.7 | 0.3 | | | | | | 2.69 | [illegible] | [illegible] | −0.06 | 3.17 | 74.5 | 0.5 | 75.0 |
| West Stillwater Range | | 17 | % | | | 99.8 | 98.7 | 97.1 | 96.2 | 93.7 | 88.3 | 81.0 | 70.5 | 53.0 | 26.7 | 13.3 | 7.0 | 3.3 | 1.2 | 0.2 | | | | 3.21 | [illegible] | [illegible] | −0.55 | 4.03 | 58.3 | 0.8 | 59.1 |
| Dixie Meadows | | 18 | % | | | | 99.9 | 99.8 | 98.3 | 94.2 | 86.3 | 70.5 | 51.5 | 32.0 | 17.5 | 8.8 | 6.0 | 3.9 | 2.0 | 0.8 | 0.2 | | | 3.05 | [illegible] | [illegible] | 0.59 | 3.91 | 58.0 | .. | 59.0 |
| Boyer Ranch Formation (conglomerate subunit) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Type Area | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Block | I | 19 | % | | | | | | 99.8 | 99.0 | 96.7 | 90.8 | 78.5 | 59.5 | 42.2 | 25.0 | 13.7 | 7.8 | 4.5 | 2.8 | 1.5 | 0.5 | | 3.42 | [illegible] | [illegible] | 0.55 | 3.72 | 47.5 | .. | 48.5 |
| | I | 20 | % | | | | | | | 99.9 | 98.0 | 93.0 | 82.5 | 65.8 | 47.5 | 30.0 | 18.8 | 10.0 | 3.3 | 0.5 | | | | 3.50 | [illegible] | [illegible] | 0.20 | 2.56 | 22.4 | 0.9 | 27.0 |
| | II | 21 | % | | | | | | 99.5 | 97.5 | 95.0 | 88.3 | 72.3 | 55.0 | 39.2 | 26.2 | 14.5 | 5.8 | 2.0 | 0.5 | | | | 3.36 | [illegible] | [illegible] | 0.08 | 2.69 | 20.5 | .. | 21.0 |
| | II | 22 | % | | | | | 99.9 | 98.3 | 94.6 | 87.2 | 75.5 | 57.0 | 40.5 | 26.7 | 16.7 | 10.5 | 6.5 | 2.7 | 0.5 | | | | 3.18 | [illegible] | [illegible] | 0.36 | 2.90 | 36.9 | .. | .. |
| | | | r | | | | | | 6.0 | | 5.0 | | 4.4 | 4.3 | 4.1 | | | | | | | | | | | | | | | | |
| Red Hill | | 23 | % | | 99.0 | 97.2 | 91.0 | 82.5 | 73.5 | 63.3 | 52.0 | 42.5 | 32.0 | 20.0 | 12.0 | 7.0 | 3.5 | 2.0 | 1.5 | 0.5 | | | | 2.57 | [illegible] | [illegible] | 0.19 | 2.52 | 26.0 | .. | 28.0 |
| | | | r | | | | 6.1 | | 5.5 | | 4.9 | | 4.4 | | 3.9 | | | | | | | | | | | | | | | | |
| Navajo Sandstone | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Skull Creek W. Colorado | | 24 | % | | | | | 99.5 | 98.4 | 92.4 | 83.5 | 73.0 | 59.5 | 49.9 | 41.0 | 31.5 | 23.0 | 16.0 | 9.0 | 3.7 | 1.0 | 0.4 | | 3.33 | [illegible] | [illegible] | 0.25 | 2.19 | 72.8 | 1.5 | 74.[illegible] |
| | | | f | | | | | | 99.2 | 97.0 | 90.0 | 79.0 | 65.0 | 53.0 | 43.2 | 31.8 | 24.0 | 14.5 | 7.5 | 3.0 | 0.4 | | | 3.39 | [illegible] | [illegible] | 0.22 | 2.18 | | | |
| | | | w | | | | | 99.7 | 98.1 | 93.5 | 86.9 | 75.7 | 62.8 | 42.8 | 33.3 | 20.7 | 16.4 | 9.6 | 1.3 | 0.8 | | | | 3.23 | [illegible] | [illegible] | 0.20 | 2.47 | | | |
| | | | r | | | | | | 6.0 | | 5.6 | | 5.2 | | 4.7 | | | | | | | | | | | | | | | | |
| Skull Creek W. Colorado | | 25 | % | | 99.0 | 96.4 | 89.0 | 78.0 | 68.8 | 60.0 | 50.8 | 39.3 | 27.0 | 18.4 | 11.0 | 6.0 | 2.8 | 1.1 | | | | | | 2.49 | [illegible] | [illegible] | 0.15 | 2.26 | 68.5 | 2.1 | 70[illegible] |
| | | | f | | 99.8 | 99.0 | 96.4 | 88.8 | 75.5 | 66.0 | 57.6 | 46.0 | 33.0 | 21.4 | 12.0 | 6.0 | 2.7 | 1.0 | | | | | | 2.63 | [illegible] | [illegible] | 0.10 | 2.27 | | | |
| | | | w | | 99.5 | 98.8 | 97.0 | 90.8 | 81.3 | 69.3 | 59.0 | 44.3 | 33.2 | 21.8 | 16.2 | 10.4 | 8.4 | 5.0 | 1.3 | 0.3 | | | | 2.70 | [illegible] | [illegible] | 0.38 | 2.73 | | | |
| | | | r | | 7.2 | | 6.4 | | 6.2 | | 5.5 | | 5.0 | | | | | | | | | | | | | | | | | | |
| Diamond Mtn. Vernal, Utah | | 26 | % | | | | | 99.4 | 99.0 | 98.5 | 98.1 | 94.8 | 85.3 | 77.4 | 64.7 | 51.7 | 38.0 | 25.5 | 15.0 | 10.0 | 5.8 | 3.3 | 1.2 | 3.81 | [illegible] | [illegible] | 0.23 | 2.82 | 47.5 | .5 | 4[illegible] |
| | | | f | | | | | 99.6 | 99.2 | 99.0 | 98.8 | 97.0 | 90.8 | 81.0 | 69.0 | 54.0 | 40.0 | 24.5 | 14.0 | 8.0 | 3.5 | 1.7 | 0.2 | 3.83 | [illegible] | [illegible] | −0.04 | 3.17 | | | |
| | | | w | | 99.9 | 99.8 | 99.7 | 99.2 | 98.6 | 97.9 | 96.7 | 92.4 | 83.6 | 66.2 | 53.2 | 35.7 | 29.5 | 16.0 | 2.1 | 0.7 | | | | 3.56 | [illegible] | [illegible] | −0.32 | 3.02 | | | |
| | | | r | | | | | | | | 5.5 | | 5.3 | | 4.5 | | 4.2 | | 4.0 | | 4.0 | | | | | | | | | | |
| Diamond Mtn. Vernal, Utah | | 27 | % | | | 99.7 | 99.2 | 98.4 | 97.2 | 90.0 | 80.0 | 69.0 | 55.0 | 36.0 | 16.7 | 8.9 | 5.5 | 2.9 | 1.2 | | | | | 3.02 | [illegible] | [illegible] | 0.04 | 3.20 | 65.5 | 1.1 | 6[illegible] |
| | | | f | | | | 99.6 | 99.2 | 98.5 | 95.2 | 87.0 | 76.0 | 62.0 | 44.0 | 19.2 | 10.0 | 6.0 | 2.7 | 0.7 | | | | | 3.12 | [illegible] | [illegible] | −0.03 | 3.34 | | | |
| | | | w | | 99.9 | 99.3 | 97.8 | 94.4 | 90.0 | 79.9 | 61.1 | 37.2 | 25.7 | 9.8 | 4.0 | 1.3 | 1.0 | 0.3 | 0.2 | 0.1 | | | | 2.63 | [illegible] | [illegible] | −0.04 | 3.45 | | | |
| | | | r | | | | | | 6.2 | | 5.8 | | 5.1 | | 4.7 | | 4.7 | | 4.8 | | | | | | | | | | | | |
| Zion National Park, Utah | | 28 | % | | | | 98.0 | 94.0 | 87.0 | 79.6 | 69.4 | 52.0 | 38.8 | 28.6 | 17.0 | 10.0 | 4.5 | 1.7 | 0.2 | | | | | 2.82 | [illegible] | [illegible] | 0.07 | 2.50 | 55.6 | 7.2 | 6[illegible] |
| | | | f | | | | | 97.6 | 92.3 | 85.0 | 77.5 | 61.0 | 44.5 | 32.0 | 19.5 | 10.8 | 5.0 | 1.5 | 0.1 | | | | | 2.99 | [illegible] | [illegible] | 0.05 | 2.52 | | | |
| | | | w | | | 99.9 | 99.5 | 95.2 | 87.4 | 77.8 | 66.1 | 48.8 | 36.9 | 20.3 | 12.5 | 6.8 | 4.2 | 2.0 | 0.8 | 0.4 | | | | 2.77 | [illegible] | [illegible] | 0.34 | 3.00 | | | |
| | | | r | | | | 5.5 | | 4.8 | | 4.6 | | 4.1 | | 3.8 | | | | | | | | | | | | | | | | |
| Zion National Park, Utah | | 29 | % | | | | | 99.9 | 99.5 | 97.8 | 91.0 | 78.0 | 53.2 | 33.0 | 16.9 | 8.0 | 5.5 | 2.5 | | | | | | 3.08 | [illegible] | [illegible] | 0.50 | 3.36 | 61.9 | 6.2 | 6[illegible] |
| | | | f | | | | | | 99.9 | 99.2 | 96.8 | 85.5 | 66.0 | 41.0 | 19.5 | 10.0 | 6.0 | 2.0 | | | | | | 3.20 | [illegible] | [illegible] | 0.47 | 3.28 | | | |
| | | | w | | | 99.9 | 99.8 | 99.5 | 99.0 | 97.1 | 93.5 | 78.8 | 55.2 | 17.2 | 6.7 | 2.8 | 2.2 | 1.4 | 0.5 | 0.1 | | | | 3.00 | [illegible] | [illegible] | 0.34 | 6.06 | | | |
| | | | r | | | | | | 5.8 | | 5.2 | | 4.7 | | 4.2 | | | | | | | | | | | | | | | | |

TABLE 2—(*Continued*)

| | | MOMENTS‡ | | NTS‡ | | | SAND PERCENTAGES | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5.5 | 1(φ) | [illegible] | [illegible] | 3 | 4 | % Quartz Sand | % Feld-spar Sand | % Total Sand | LITHOLOGIC REMARKS§ |
| | | 3.01 | [illegible] | [illegible] | 0.63 | 2.99 | 46.1 | 0.8 | .. | Sandy limestone: about 2% shale particles and undetermined % carbonate sand; matrix entirely dolomite and calcite which locally merges with carbonate sand owing to partial recrystallization; quartz sand mostly concentrated in grain supported layers, but some floating sand. |
| 2 | | 3.22 | [illegible] | [illegible] | -0.05 | 2.72 | 46.2 | 1.8 | 51.0 | 3% chert and opaque sand, a few shale particles; dolomite cement 41%, kaolinite 8%. |
| | | 3.12 | [illegible] | [illegible] | -0.10 | 2.98 | 71.5 | 2.5 | 74.0 | Calcite cement 20%, 14 Å clay 6%. |
| | | 3.06 | [illegible] | [illegible] | 0.63 | 3.83 | 55.8 | 0.2 | 59.0 | Opaque sand 3%; calcite cement 30%, kaolinite 10%. |
| | | 2.32 | [illegible] | [illegible] | 0.00 | 2.47 | 63.0 | .. | 65.0 | 2% chert sand; calcite cement 30%, kaolinite 6%; trace very fine 10 Å mica in matrix, probably metamorphic; carbonate-quartz sand reaction. |
| | | 3.33 | [illegible] | [illegible] | 0.48 | 3.56 | 60.4 | 0.2 | 61.5 | Calcite and dolomite cement 29%, kaolinite 10%. |
| .0 | | 3.51 | [illegible] | [illegible] | 0.58 | 2.98 | 57.5 | .. | 58.0 | Few shale particles; dolomite cement 37%, kaolinite 5%. |
| | | 3.12 | [illegible] | [illegible] | 0.47 | 3.16 | 40.0 | 0.3 | .. | Microbreccia of dolomite clasts with interstitial quartz sand and dolomite cement; about 3% kaolinite. |
| | | 2.24 | [illegible] | [illegible] | 0.62 | 2.66 | 72.0 | .. | 72.0 | Matrix entirely microcrystalline quartz which has apparently replaced previous matrix; clear size break between sand and matrix quartz; no recrystallization of sand. |
| .5 | | 3.59 | [illegible] | [illegible] | 0.31 | 3.11 | 39.2 | 0.7 | 41.9 | Sandy *limestone*; chert and opaque sand 2%; sand largely floating in calcite and dolomite intergrowth with about 12% uniformly distributed kaolinite. |
| 1.6 | 1.0 | 3.51 | [illegible] | [illegible] | 0.75 | 3.39 | 46.0 | 1.7 | 47.7 | Quartz wacke; matrix largely kaolinite, no carbonate; traces of very fine-grained mica; partial silicification of matrix; quartz clay ratio is constant through specimen; sand floating. |
| | | 3.01 | [illegible] | [illegible] | 0.41 | 3.74 | 72.1 | .. | 72.7 | Dolomite cement 22% and mica about 5%. |
| | | 3.12 | [illegible] | [illegible] | 0.31 | 3.33 | 63.3 | 2.7 | 67.0 | Opaque sand 1%; chlorite, mica, and graphitic (?) material 33%. |
| | | 2.51 | [illegible] | [illegible] | 0.23 | 2.27 | 73.0 | .. | 73.0 | Calcite cement 15%, chlorite 9%. |
| | | 1.75 | [illegible] | [illegible] | 0.52 | 2.73 | 66.0 | .. | 67.0 | Few lithic (shale) sand grains; dolomite cement ~ 30%, locally replaced by silica; few % very fine-grained mica and kaolinite. |
| | | 2.69 | [illegible] | [illegible] | -0.06 | 3.17 | 74.5 | 0.5 | 75.0 | Albitized quartz arenite; matrix of albite plus chlorite 25%. |
| | | 3.21 | [illegible] | [illegible] | -0.55 | 4.03 | 58.3 | 0.8 | 59.1 | Albitized quartz arenite; matrix of talc-chlorite-albite 40%. |
| | | 3.05 | [illegible] | [illegible] | 0.59 | 3.91 | 58.0 | .. | 59.0 | Calcite cement 33%; chlorite plus mica 8%. |
| 0.5 | | 3.42 | [illegible] | [illegible] | 0.55 | 3.72 | 47.5 | .. | 48.8 | Pebbly quartz arenite, locally conglomerate; 35% angular dolomite clasts, maximum length 2 cm in quartz arenite; slightly layered in bands of sand framework and conglomerate framework; carbonate cement; quartz-carbonate replacement. |
| | | 3.50 | [illegible] | [illegible] | 0.20 | 2.56 | 22.4 | 0.9 | 27.0 | *Dolomite microbreccia and pebbly sandstone; dolomite clasts between 5.0 and 0.1 mm; quartz sand distributed through* rock but locally up to 50% of finer-grained layers; matrix is finely crystalline dolomite and patches of chalcedony; locally quartz replaced by dolomite; no quartz grain supported layers. |
| | | 3.36 | [illegible] | [illegible] | 0.08 | 2.69 | 20.5 | .. | 21.6 | Dolomite conglomerate; supported by *dolomite clasts* (55%) up to 1.5 cm in length; quartz distribution uniform; sand grains in cement of coarsely crystalline dolomite; partial replacement of quartz by dolomite. |
| | | 3.18 | [illegible] | [illegible] | 0.36 | 2.90 | 36.9 | .. | .. | Pebbly quartz-carbonate sandstone; about 35% clastic dolomite, particles in range 3/5 to 0.01 cm in length; about 3% chert sand; 25% carbonate cement. |
| | | 2.57 | [illegible] | [illegible] | 0.19 | 2.52 | 26.0 | .. | 28.0 | Dolomite conglomerate; 60% dolomite pebbles as long as 10 cm; interstitial quartz sand largely grain supported, cement is coarse dolomite; local silicification of dolomite clasts and matrix but little reaction of carbonate and quartz sand. |
| 0.4 | | 3.33<br>3.39<br>3.23 | [illegible] | [illegible] | 0.25<br>0.22<br>0.20 | 2.19<br>2.18<br>2.47 | 72.8 | 1.5 | 74.3 | Kaolinite, montmorillonite, mica, dolomite |
| | | 2.49<br>2.63<br>2.70 | [illegible] | [illegible] | 0.15<br>0.10<br>0.38 | 2.26<br>2.27<br>2.73 | 68.5 | 2.1 | 70.6 | Kaolinite |
| 3.3<br>1.7 | 1.2<br>0.2 | 3.61<br>3.83<br>3.56 | [illegible] | [illegible] | 0.23<br>-0.04<br>-0.32 | 2.82<br>3.17<br>3.02 | 47.5 | .5 | 48.0 | Kaolinite, montmorillonite, dolomite |
| | | 3.02<br>3.12<br>2.63 | [illegible] | [illegible] | 0.04<br>-0.03<br>-0.04 | 3.20<br>3.34<br>3.45 | 65.5 | 1.1 | 66.6 | Montmorillonite, kaolinite, mica |
| | | 2.82<br>2.99<br>2.77 | [illegible] | [illegible] | 0.07<br>0.05<br>0.34 | 2.50<br>2.52<br>3.00 | 55.6 | 7.2 | 62.8 | |
| | | 3.08<br>3.20<br>3.00 | [illegible] | [illegible] | 0.50<br>0.47<br>0.34 | 3.36<br>3.28<br>6.06 | 61.9 | 6.2 | 68.1 | |

* Specimens from type area located by number on Plate 1.

† % = percentage by number,
r = roundness on scale of 10 *in Krumbein and Sloss (1963)*,
f = equivalent weight % from number frequency by transformation of Friedman (1958),
w = weight percentage by screen analysis,
$\phi = -ln_2 d$ where $d$ is long dimension in mm.

‡ Equations used in moment calculations

1 (mean) $\overline{Y} = 10^{-2} \sum_{i=1}^{k} f_i Y_i$,

2 (std. deviation) $s = [10^{-2} \sum_{i=1}^{k} f_i (Y_i - \overline{Y})^2]^{1/2}$,

3 (skewness) $\alpha_3 = 10^{-2} \sum_{i=1}^{k} f_i (Y_i - \overline{Y})^3 / s^3$,

4 (kurtosis) $\alpha_4 = 10^{-2} \sum_{i=1}^{k} f_i (Y_i - \overline{Y})^4 / s^4$,

where $f_i$ = % of sample in ith size class interval,
$Y_i$ = midpoint of ith size class interval,
$i$ = 1, 2, 3, ..., $k$ for $k$ classes.

§ Lithology is quartz sandstone except where noted.

visually irresolvable clay disseminated in carbonate cement.

Table 1 gives a chemical analysis of quartz arenite from the type area (Table 2). The mineral assemblage of this specimen is quartz-calcite-kaolinite. Recalculating the chemical analysis on the basis of ideal compositions of the modal minerals and eliminating components in small abundance (FeO, $Fe_2O_3$, MgO, alkalis), 4.9 percent kaolinite by volume is obtained and compares favorably with a 6 percent estimate by other means. This procedure gives 68 percent quartz and 28 percent calcite compared to 65 percent quartz + chert sand and 30 percent calcite from thin section count.

The abundance of kaolinite in largely unaltered sandstones from the type area is mostly 5 to 10 percent and almost entirely in the range 0 to 15 percent. Specimen 11 from block III, however, is anomalous in containing about 50 percent kaolinite; the quartz grains are uniformly distributed in clay, and the rock is clearly a non-sand supported quartz wacke. Even though kaolinite is the predominant mineral in specimen 11, a large grain-size discontinuity exists between clay particles and the smallest sand grains.

At most localities other than the type area, rocks of the Boyer Ranch Formation have undergone post-diagenetic changes due to deformation and metasomatism during heating by the gabbroic complex. Partial recrystallization of quartz sand grains is proportional to the tightness of folding of the Boyer Ranch Formation. The deformed rocks also contain fine irregular blebs of quartz which have replaced carbonate in the groundmass. At some places, recrystallization has proceeded to the degree that the rocks are quartzites, but more commonly, it has only slightly altered the primary sand-size distribution.

Apart from ostensibly isochemical recrystallization by redistribution of quartz, metasomatism of the groundmass is widespread in the Boyer Ranch Formation. The degree of chemical change is roughly proportional to proximity to contacts with the gabbroic complex. The most frequent mineral assemblage in metasomatized rocks is quartz-talc-albite-chlorite, but quartz-talc-albite and quartz-albite-chlorite also occur. The large change in composition is demonstrated by comparison of analyses in Table 1. Talc-chlorite-albite occur as extremely fine intergrowths in the quartz sandstone matrix where they have replaced kaolinite and carbonate. Moreover, the ragged edges of some quartz grains suggest that quartz too is replaced by the metamorphic assemblage. In most rocks, however, the replacement of quartz sand has not progressed to the degree that the original granulometry of the quartz sand has been significantly changed. Metasomatic albite is generally in fine intergrowths or veinlets of irregular grains smaller than 10 microns which are invariably associated with talc or chlorite. Detrital plagioclase is clearly distinguished by its similarity in size and roundness to quartz sand grains.

In summary, silicate sand in both sandstone and conglomerate of the Boyer Ranch Formation is almost entirely quartz; feldspar and chert are notably sparse. Rare shale fragments in sandstones corroborate the evidence supplied by co-deposition of carbonate clasts and qua sand in the conglomerate that quartz sand w not matured in the local environment fro which the lithic components were derived. Th majority of sandstones are grain supported, ho in rocks with total sand content below abo 55 percent, the silicate grains are eith uniformly distributed throughout a structu framework of carbonate or clay, or both, more rarely, the quartz sand is concentrated laminations which alternate with clay carbonate-rich layers. The majority of sandstones thus is homogeneous calcareous quar arenite, but minor variants exist in the fiel of quartz wacke and sandy limestone. The da of Table 2 indicate that the mean grain sizes the variants are among the finest of the formation.

The original amount of carbonate sand no indistinguishable from the matrix in rocks call sandy limestone is uncertain. The occurren of occasional definable carbonate sand grains i these rocks and of pebbly quartz calcarenite the conglomerate member of the Boyer Ran Formation suggests that sandy limestone m have been grain-supported quartz-carbona sandstones.

The existence of quartz wacke indicates th at least locally kaolinite was a clastic compone co-deposited with quartz sand. Though quar sand in quartz wacke is very fine-grained, it as well sorted as sands in coarser quartz arenite There is no evidence that the quartz sand fra tion occurring with abundant clay is any le mature than sand with sparse clay. It would appear that a low-velocity environment wa able to transfer a finer quartz fraction to place where mud was depositing. The source of th kaolinite is puzzling because subjacent Trias pelites are illite-quartz-chlorite rocks.

Granulometry. Grain size and roundn distributions of quartz sand in various sampl of the Boyer Ranch Formation are given i Table 2.

Because the sandstones are highly indurated, s distributions were obtained by measuring long dimensions ($d$) in thin section; number frequency of size grad in intervals of $\phi/4$ where $\phi = -\log_2 d(mm)$ are compiled Table 2. The number of points counted was 300 to 80 Granulometric properties of sandstones are usually calculated from mass frequencies of size grades as determined by screen analysis, and screen and microsco distributions are not directly comparable. We attem to provide a qualitative calibration of size data from th Boyer Ranch Formation by assessing the difference values of various parameters obtained by microscope an screen analyses for six specimens of Navajo Sandston which contain sands whose granulometric attributes a

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like those of the Boyer Ranch Formation. The tics of the distributions are given by calculation of nts 1 to 4 (1 = mean grain size, 2 = standard tion, 3 = skewness, and 4 = kurtosis); the equa- employed are in the explanation of Table 2.

undness distribution of sand in the Boyer Ranch ation was estimated by reference to the chart of bein and Sloss (1963); the data are given in Table the mean roundness for grains in size intervals of The number of grains differs in each size class such the uncertainty in mean value is not a constant. bsence of roundness data for some specimens in 2 indicates that the roundness distribution was ficantly changed by postdepositional reactions.

specimens of Navajo Sandstone obtained from tions given in Table 2 were screened according to dures recommended by Krumbein and Pettijohn ). Moments 1 to 4 for both microscope and screen ibutions of these specimens are in Table 2. The size of the screen distributions of Navajo Sand- lies between 0.08 and 0.16 mm; this range includes mean grain sizes of Navajo Sandstone studied by ch (1950), Gregory (1950), and Cadigan (1961). specimens thus are fine-grained quartz arenites. The ard deviations of screen distributions of Navajo stones in Table 2 are in the range $0.38\phi$ to $0.77\phi$; rding to the sorting classification for medium- to fine-grained sandstones of Friedman (1962a), these rs indicate the specimens are well sorted to moder- well sorted. Moreover, they fall within the sorting of $0.35\phi$ to $0.80\phi$ that Friedman (1962a) found for dunes, the environment ascribed by most authori- for deposition of much of the Navajo Sandstone example, Gregory, 1950; Kiersch, 1950; Stokes, ).

Cadigan (1961) gave percentile values (2, 5, 16, 50, 95, 98) for size distributions of various sands from zoic formations of the Colorado plateau. We have ulated moments 1 and 2 for plots of Cadigan's data probability paper using equations in Table 2. Figure shows plots of mean *versus* standard deviation for igan's sands which include seven Navajo Sandstone ples together with our six Navajo Sandstone samples. Navajo Sandstone data cluster closely and show that Navajo sands are the best sorted of those measured. re 8b is an enlargement of the area in *Figure 8a* oc- ed by the Navajo Sandstone points; it shows further points for mean *versus* standard deviation as obtained microscope analysis of our Navajo Sandstone samples. microscope values lie within 0.2 to $0.3\phi$ units of valent screen values, and most of the screen values slightly coarser grained and better sorted than the croscope ones. The comparison in Figure 8b indicates the difference is small for values of first and second ments calculated from size distributions based on and number frequencies for sands of the Navajo .

ttempts were made to improve the correspondence moments calculated for the two distributions by use empirical linear transformations of Friedman (1958, b). Microscope sizes ($x$) were converted to equiva- sieve sizes ($y$) with the relation $y = 0.9027\,x +$ 15, and moments of the converted distribution were calculated. Alternatively, regression equations for moments 1 and 2 between microscope and sieve analyses obtained by Friedman (1962b) with correlation coefficients of 0.99 and 0.79, respectively, were employed to transform our number frequency moments to equivalent mass frequency moments. Figure 8b shows that neither method of moment transformation significantly improves the fits.

Of the six Navajo Sandstone samples, four have small positive skewness, one closely approaches a normal distribution, and one has a small negative skewness. The skewness values lie almost within Friedman's (1961) allowable range for dune sand ($\geq -0.28$). The average deviation of skewness of the microscope distribution from that of the screen distribution is 0.21, and the maximum deviation is 0.55. Figure 9 shows the plot of skewness *versus* mean for our Navajo samples for both screen and microscope distribution. The two point sets are nearly coextensive and lie in a field which Friedman (1961) showed to be occupied at least in large part by dune sands.

In summary, values for moments 1, 2, and 3 of both screen and microscope distributions of six samples of Navajo Sandstone do not differ strongly, and plots of mean size–standard deviation are in the same region as the points from the Navajo Sandstone distributions of Cadigan (1961). Moreover, values of these moments support the widely held view that the Navajo Sandstone is largely eolian.

The means ($\bar{y}$) of the microscope distributions of specimens of Boyer Ranch Formation in Table 2 are in the range $1.75 \leq \bar{y}(\phi) \leq 3.6$ or $0.3 \geq \bar{y}\ (\mathrm{mm}) \geq 0.08$. Of 23 specimens, 20 have means finer than $2.5\phi$ (0.18 mm). Most of the sand populations thus are fine grained to very fine grained. Medium-grained sands are less abundant, and specimen 15, Table 2, is believed to contain the coarsest sand in the Boyer Ranch Formation observed in the field.

The standard deviations ($s$) of the microscope distributions are in the range, $0.49 \leq s(\phi) \leq 0.79$ except for one value of 0.93. Application of Friedman's (1958, 1962b) conversions from microscope to equivalent screen distributions gives consistently lower values of standard deviation by up to $0.1\phi$, but generally less than $0.06\phi$. Because the transformations increase deviation between microscope and screen moments in some analyses of Navajo Sandstone, we have used raw moments from number frequencies in the following. Figure 8b plots mean size *versus* standard deviation for samples of the Boyer Ranch Formation. The Boyer Ranch Formation data cluster, except for two points, in a field which is virtually coextensive with Navajo Sandstone points from Table 2 and from Cadigan (1961). The correspondence

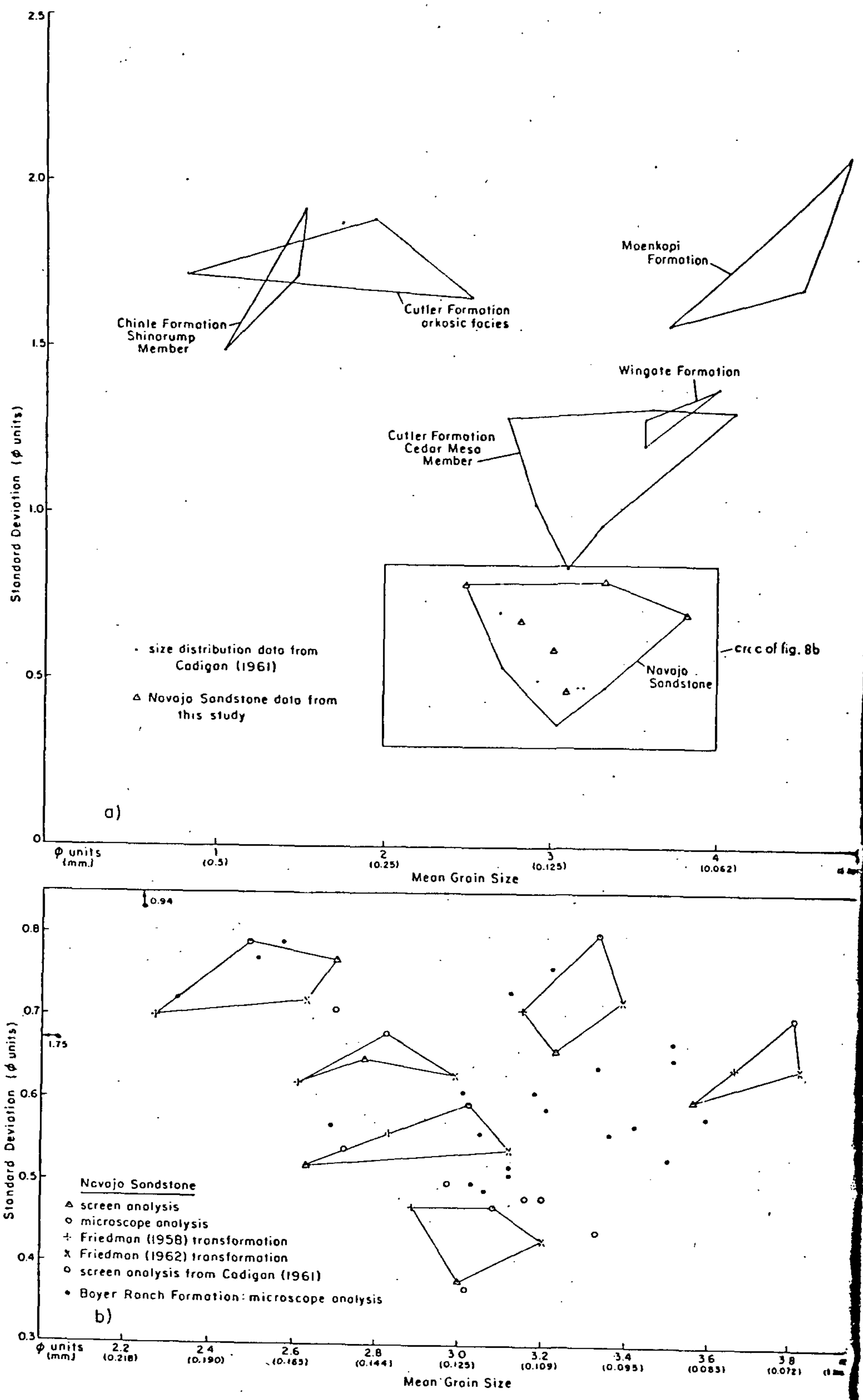

Figure 8.

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**Figure 8.** Plots of first (
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oments 1 and 2 of Navajo and Boyer ch sands obtained by microscope analysis ates that the distributions must be similar ast in the central regions. The correspon- e would suggest further that the deviation een number and mass distribution mo- ts for the Boyer Ranch sands should be ll, like that of the Navajo sands. Thus, nents from different data under such con- nts can be qualitatively compared, at least a first approximation. The values of *s* in le 2 suggest that the Boyer Ranch sands moderately well sorted according to the ification of Friedman (1962a).

kewness values of the microscope distri- ons of the Boyer Ranch Formation are stly small and positive; the maximum is 5. Four negative skewness values are in le 2, but three of them are $\geq -0.1$ and are ually normal. The specimen with skewness $-0.55$ is distinguished by being far more amorphosed than others; its matrix is pletely replaced by talc-chlorite-albite, and tial replacement of sand grains is strongly pect. Ostensibly, the fine quartz particles uld likely have been replaced completely h that the metamorphism may have pro- ed increasingly negatively skewed distri- tions.

Figure 9 indicates that points of mean *versus* wness for samples of the Boyer Ranch mation and the Navajo Sandstone occupy ilar fields. The closeness of the screen and croscope values for the Navajo sands in gure 9 suggests that the field of microscope ues for the Boyer Ranch Formation may well proximate that representing screen analyses. e correspondence of Boyer Ranch and Nava- sands in Figures 8b and 9 indicate that the alyzed sand distributions are similar in both e central regions and the tails.

A final granulometric measure to be discussed the roundness distribution of the Boyer nch sands which are in Table 2. The round- ss value of both Boyer Ranch and Navajo nds were estimated by the same operator by mparison with charts of Krumbein and Sloss 1963). The roundness values are averages for ains in $\phi/2$ intervals. The results show increasing roundness with grain size as is apparently true for most sand populations (Pettijohn, 1957). The roundness distributions of the Boyer Ranch and Navajo sands are generally similar.

Judged by its sorting (standard deviation), roundness distributions, and quartz/feldspar ratio, sandstone of the Boyer Ranch Formation is at least as mature as the Navajo Sandstone which, in turn, is among the most mature of the sandstones of the Colorado Plateau. The similarity of the size distributions (Figs. 8 and 9) of the samples of the two formations suggest, moreover, that the sands of the Boyer Ranch Formation and Navajo Sandstone matured under similar paleoenvironments since differences in the distribution moments are believed to reflect differences in the dynamic conditions under which sands approach equilibrium (Friedman, 1967; Folk, 1966). The widely held view (Gregory, 1950; Kiersh, 1950; Stokes, 1963) that the Navajo Sandstone largely consists of dune accumulations is supported by comparison of our values of Navajo sand moments with those of modern sands from Friedman (1961, 1962a). Though the moments by themselves do not allow a unique interpretation that the Navajo Sandstone is a dune accumulate, they tend to eliminate a beach as an origin—the most likely competitor for conditions under which quartz sands would evolve. Moiola and Weiser (1968) separated coastal and inland dune sands by plots of graphical measures of mean *versus* skewness; all comparable plots from the raw distributions of Table 2 fall into their field of inland dune sands.

The inference from the granulometry of the sands of the Boyer Ranch Formation is that they reached their relatively mature state under dune-forming conditions, like sands of the Navajo Sandstone. However, the restricted distribution of the formation, the prevalent plane-parallel thin bedding, and the absence of current structures are surely not reflective of a lithified dune field. We thus suggest that the final disposition of the Boyer Ranch sands was governed by different agents from those under which the sands had originally evolved.

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Figure 8. Plots of first (mean grain size) and second central (standard deviation of sorting coefficient) mo- ents for size distributions of Navajo and other Colorado Plateau sands and Boyer Ranch Formation. (a) Moments alculated from screen data from Cadigan (1961) and moments for screen analyses of Navajo Sandstone in Table 2. (b) Enlargement of part of Figure 8 (a) showing difference in plots for microscope and screen analyses and micro- ope-to-screen transformations of Friedman (1958, 1962) for Navajo Sandstone samples; lines tie points for each ample; compare with field of points from microscope analyses of Boyer Ranch Formation.

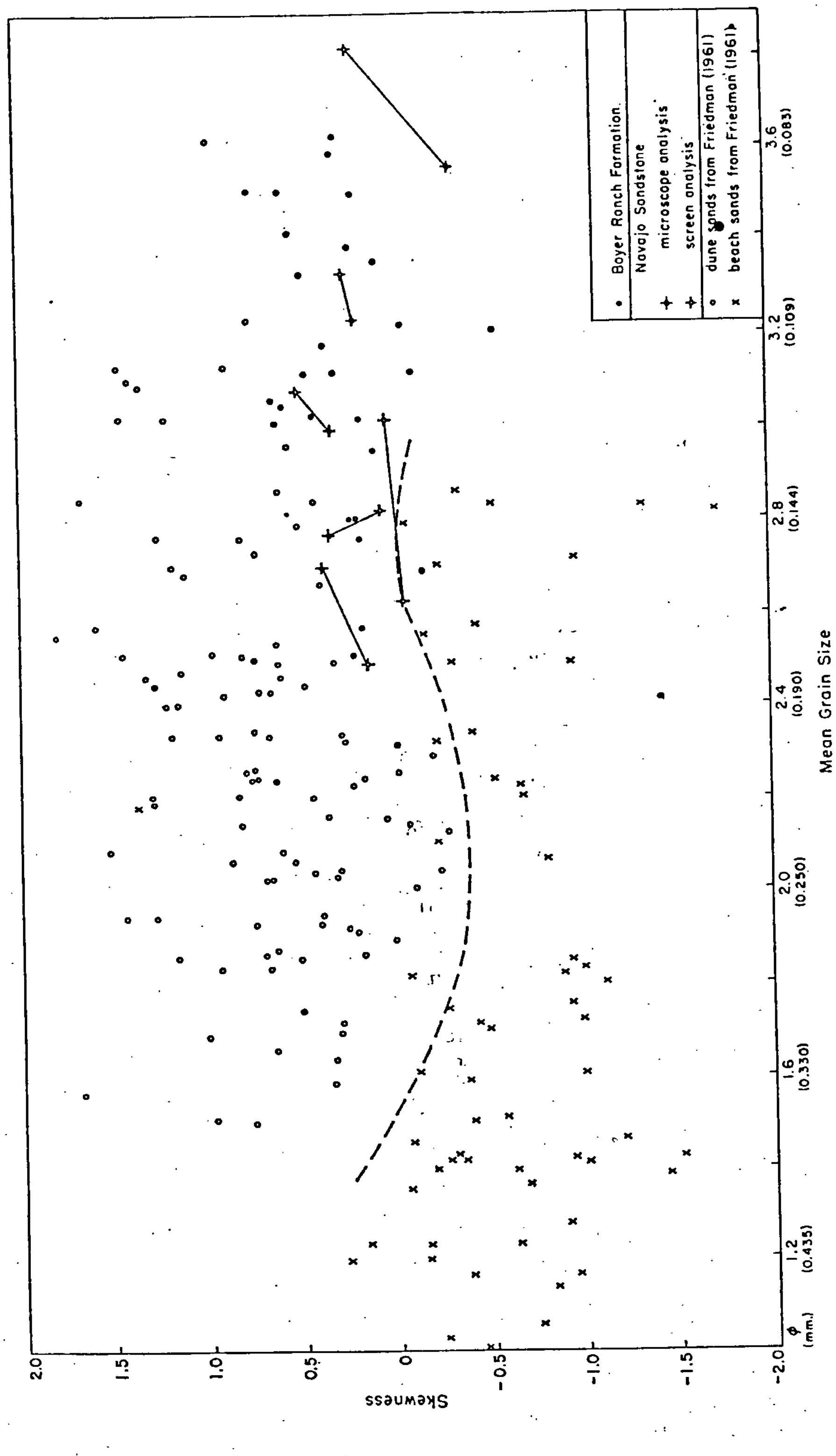

Figure 9. Plot of first moment (mean size) *versus* skewness function for size distributions of Boyer Ranch Formation (microscope analysis) and Navajo Sandstone (screen and microscope analyses) from Table 2 of this study and for recent dune and beach sands from data of Friedman (1961). Solid lines tie screen and microscope values for Navajo Sandstone samples. Dashed line is approximate field boundary of dune and beach sands of Friedman (1961).

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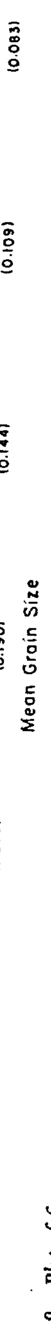

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## MMARY AND ORIGIN OF THE YER RANCH FORMATION

The rocks which have been included in the yer Ranch Formation are chiefly fine-grained l-sorted quartz sandstone of granulometric racteristics similar to those of Navajo Sand- ne. The sandstones of the Boyer Ranch mation are spatially uniform at least to the olution allowed by metamorphism and formation such that they contain no indica- n of the lithologic variability of subjacent ks. *In contrast,* coarse materials, chiefly bonate granules and pebbles, in the lower mber vary in abundance with proximity massive carbonate rocks in subjacent sections. e lithic assemblage of the Boyer Ranch mation is unique in the Mesozoic column the Dixie Valley–Carson Sink region of stern Nevada except for the existence of artz sandstone and carbonate conglomerate some intervals in the Upper Triassic Osobb rmation in Unit II in the southern Augusta ountains.

It is uncertain whether the present exposures the Boyer Ranch Formation are remnants of once-continuous sheet or, at the other treme, whether the formation was deposited a series of discrete troughs. In the Clan Alpine Mountains at least, some evidence suggests that single depositional basin existed, its eastern gin was irregular. Near Hoyt Canyon the movement of allochthonous Triassic rocks into he Boyer Ranch basin ostensibly during eposition of quartz sand argues for non- niform topography. More specifically, the ost likely source of the allochthon is within a w miles north of its present position such that topographic high may have separated sites of eposition of the Boyer Ranch Formation near Hoyt Canyon and the type area. The accumulation of basal conglomerate in the trough of a yncline in the type area, moreover, is suggestive of an irregular area of deposition.

It is inferred that the original extent of the Boyer Ranch Formation was not far greater than its present distribution. The outcrops of of the Boyer Ranch Formation are apparently restricted to an area underlain by a Mesozoic terrane (units I and III) whose stratigraphic and structural attributes differ from those of the Mesozoic terrane (unit II) to the north and east. The tectonic evolution of the subjacent rocks is believed to have played a key role in the origin of the Boyer Ranch Formation such that the absence of the formation from areas underlain by unit II suggests that conditions there were not appropriate for deposition of the Boyer Ranch Formation. Further, if the Boyer Ranch Formation is correctly correlated with the gypsum-carbonate deposits in the West Humboldt Range, the Boyer Ranch Formation could not have extended far to the west of its outcrop area. South of the area of Figure 2, quartz sandstone believed to be correlative with the Boyer Ranch Formation occurs in units dominated by other lithologies; though the available clastic components during deposition of these units were more variable than in the Boyer Ranch basin, the tectonic history of preceding rocks was largely similar.

The maximum age of the Boyer Ranch Formation is late Late Triassic as indicated by the age of the youngest dated rocks in sections on which the Boyer Ranch Formation lies unconformably. A more accurate maximum age is the time of uplift and erosion when the basal unconformity was created. In western part of its outcrop area, the Boyer Ranch Formation was deposited after partial erosion of Early Jurassic marine rocks which are at least as young as Sinemurian; by extrapolation over 10 miles, they are as young as Toarcian (late Early Jurassic). A minimum age in the Bathonian stage (late Middle Jurassic) for the Boyer Ranch Formation is supplied by the gabbroic complex whose radiometric ages indicate it is Middle Jurassic. The probable continuity of deposition between the Boyer Ranch Formation and conformably overlying volcanic rocks which are co-magmatic with the gabbro implies that the Boyer Ranch Formation is Bajocian or Bathonian. If continuity is not assumed, the age of the formation is most likely within the interval, Toarcian to Bathonian.

The stratigraphic position of the Boyer Ranch Formation indicates that the formation records the last deposition of terrigenous materials in the Dixie Valley region before withdrawal of the Mesozoic sea due to orogenic uplift. The superjacent volcanic rocks, which are probably marine in part, are co-extensive and co-deformed with the Boyer Ranch Formation; the volcanic rocks thus inherited or more probably, appropriated the Boyer Ranch depositional basin before the basin was finally destroyed tectonically.

The bedding in the Boyer Ranch Formation is indicative of deposition in a low-velocity aqueous medium. The existence of slightly earlier marine deposits below the Boyer Ranch Formation and the proximity of probably contemporaneous marine deposits to the west in the West Humboldt Range suggest the water was most likely marine. The co-deposition of quartz sand with highly immature clastic components of clearly local derivation and the paucity of current structures in the Boyer Ranch Formation indicate the quartz sand did not mature under the conditions in which it was deposited. The occurrence of pebbly sandstone near the bottom of the basal conglomerate indicates that at least some sand was present at the onset of deposition of the Boyer Ranch Formation. Relations between the upper and lower member imply that the quartz sand largely entered the basin from outside sources, ostensibly from the shoreward side of the basin, during deposition of the formation.

The sand must have evolved as a mature sediment in a different environment and must then have been transported as such to the depositional basin of the Boyer Ranch Formation. The quartz sand distribution moments are remarkably similar to those of Navajo Sandstone, and plots of moments believed to be sensitive to the dynamics under which sand populations evolve suggest that our samples of Boyer Ranch and Navajo sands may have been dune sands. This environment is widely agreed upon for Navajo Sandstone (for example, Kiersch, 1950; Gregory, 1950; Stokes, 1963), and the correspondence for the Navajo strengthens the genetic interpretation of the Boyer Ranch sand. Thus, it would seem that sand which matured in a dune-producing environment reached a state of final deposition in fairly quiet water. The possibilities are that the Boyer Ranch sand either was largely transported from a Jurassic dune field to the site of deposition or was derived from an older sandstone which is a dune accumulate.

In the following paragraphs, we attempt to outline a conceptual model of events leading to the present nature of the Boyer Ranch Formation. The youngest rocks in the terrane which underlies the Boyer Ranch Formation are interpreted as near-shore marine deposits. They most likely record a southwestward or westward regression of the shoreline across the Boyer Ranch outcrop area from latest Norian through Toarcian time; alternatively, it is possible that the shoreline maintained a steady position to the north and east of that area well into the Early Jurassic. Uplift, warping, and further westward regression of the sea followed the deposition of these rocks and allowed the creation of a dissected erosion surface on the terrane on which the Boyer Ranch Formation was to be deposited. The surface is envisioned to have been littered with coarse debris wh
underlain by massive carbonate rocks and
have been overlain at least locally by conc
trations of quartz sand. Continued fold
produced synclinal downwarps of suffici
amplitude to invite the sea which lay to t
west to re-invade part of its former basin.
the seaward half of the transgressed zone, ba
algal limestone was deposited, whereas in t
shoreward part where underlying rocks a
massive carbonate, coarse debris collect
principally along trough hinges. Quartz sa
accumulated concomitantly with the pebb
in the shoreward zone, but was not deposit
on the seaward side until the limestone depo
tion was near completion. The stratigrap
of the Boyer Ranch Formation, however, i
dicates that the sand must have continued
be supplied from sources outside the Boy
Ranch basin during its deposition. It is en
sioned that to the west, farther offshore, t
partially reconfigured, and perhaps constricte
marine basin was the site of precipitation
gypsum and limestone.

The Boyer Ranch basin was then the locus
invasion of basaltic magma which intruded t
Boyer Ranch deposits and extruded over ther
The intrusion grew by pushing the Boy
Ranch Formation and volcanic rocks lateral
out toward the basin flanks. Concurrently, t
Mesozoic rocks (unit I and III) subjacent
the Boyer Ranch Formation were continuin
to fold about east-west axes and to ride nort
over older and partly contemporaneous Mes
zoic facies of shelf affinities (unit II). The enti
Mesozoic terrane of the Dixie Valley regio
was later folded with a northerly axial trace i
Middle Jurassic or later time.

The Boyer Ranch Formation thus records
coincidence of tectonic basining and influx o
mature quartz sand, a sediment usually de
posited under conditions of high tecton
stability. It is possible these co-events wer
fortuitous, but we propose that instability w
instrumental in the deposition of quartz san
of the Boyer Ranch Formation. Briefly, we en
vision a field of quartz sand dunes confine
east of the generally regressive Mesozoic shor
line at least in Late Norian and Early Juras
time. The dune field may have been compos
exclusively of sand generated by wave actio
in the vicinity of the shoreline. Alternativel
the dunes may have largely contained transien
sands which migrated along the shoreline fro
a distant source which also yielded the sands i
synchronous deposits in the eastern Cordiller

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probably the Navajo
wave action at the sho
to further westward
The sands thus remai
continued subaerial
eolian saltation. When
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in units I and III,
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The absence of str
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**Cadigan, R. A.**, 1961.
grain-size distrib
rado Plateau sedi
v. 69, p. 121–14
**Corvalán, J. I.**, 1962.
raphy of the Wes
Nevada: unpub.
Stanford, Califo
**Ferguson, H. G.**, and
tural geology of
quadrangles, Ne
Paper 216, 55 p.
**Folk, R. L.**, 1966,
ters: Sedimentol
**Friedman, G. M.**,
size distribution
sedimentary pe
ology, v. 66, p.
—— 1961, Distincti
river sands from
Jour. Sed. Petro
—— 1962a, On so
the lognormalit
of sandstones: J
—— 1962b, Compa
sieving and thi
petrological st
32, p. 15–25.
—— 1967, Dynami
rameters comp
tion of beach
Petrology, v. 3
**Gregory, H. E.**, 19
the Zion Par
U.S. Geol. Su
**Hart, S. R.**, 1966,
determination
Trans., v. 47,
**Howarth, M. K.**,
Soc. London
**Kiersch, G. A.**,
other features

bly the Navajo Sandstone. The strong action at the shoreline produced a barrier ther westward movement of the sands. nds thus remained unlithified owing to nued subaerial exposure and probable saltation. When irregular tectonic down- s of sufficient amplitude to invite local vasion of the sea from the west developed nits I and III, the sands found sinks of t water in which they became trapped. absence of strong wave action in the hs and the probable irregular shoreline ed easy migration of sand particles down- in the troughs to a position of maximum itational equilibrium. The principal activation for motion of particles may have been tidal oscillations. West of the area of deposition of the Boyer Ranch Formation, positions may have been too far offshore to have received much sand, and it is here that we envision the concurrent precipitation of gypsum and limestone. The Mesozoic terrane (unit II) north and east of the Boyer Ranch Formation outcrop area did not apparently undergo early folding contemporaneous with that in the terrane subjacent to the Boyer Formation. Sinks for sand were thus absent from terrane of unit II, and the postulated superjacent dune field remained subaerial and unlithified.

## REFERENCES CITED

**gan, R. A.**, 1961, Geologic interpretation of grain-size distribution measurements of Colorado Plateau sedimentary rocks: Jour. Geology, v. 69, p. 121–145.

**nalin, J. I.**, 1962, Early Mesozoic biostratigraphy of the Westgate area, Churchill County, Nevada: unpub. Ph.D. thesis, Stanford Univ., Stanford, California.*

**guson, H. G., and Muller, S. W.**, 1949, Structural geology of the Hawthorne and Tomapah quadrangles, Nevada: U.S. Geol. Survey Prof. Paper 216, 55 p.

**R. L.**, 1966, A review of grain-size parameters: Sedimentology, v. 6, p. 73–95.

**dman, G. M.**, 1958, Determination of sieve-size distribution from thin section data for sedimentary petrological studies: Jour. Geology, v. 66, p. 394–416.

—1961, Distinction between dune, beach, and river sands from their textural characteristics: Jour. Sed. Petrology, v. 31, p. 514–529.

—1962a, On sorting, sorting coefficients, and the lognormality of the grain size distribution of sandstones: Jour. Geology, v. 70, p. 737–753.

—1962b, Comparison of moment measures for sieving and thin section data in sedimentary petrological studies: Jour. Sed. Petrology, v. 32, p. 15–25.

—1967, Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands: Jour. Sed. Petrology, v. 37, p. 327–354.

**egory, H. E.**, 1950, Geology and geography of the Zion Park Region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.

**rt, S. R.**, 1966, Current status of radioactive age determination methods: Am. Geophys. Union Trans., v. 47, p. 280–286.

**warth, M. K.**, 1964, The Jurassic period: Geol. Soc. London Quart. Jour., v. 120s, p. 203–207.

**ersch, G. A.**, 1950, Small-scale structures and other features of Navajo sandstone, northern part of San Raphael Swell, Utah: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 923–942.

**Krumbein, W. C.**, 1941, Measurement and geological significance of shape and roundness of sedimentary particles: Jour. Sed. Petrology, v. 11, p. 64–72.

**Krumbein, W. C., and Pettijohn, F. J.**, 1938, Manual of sedimentary petrography: New York, Appleton Century Inc., 493 p.

**Krumbein, W. C., and Sloss, L. L.**, 1963, Stratigraphy and sedimentation: San Francisco and London, W. H. Freeman, 660 p.

**Moiola, R. J., and Weiser, D.**, 1968, Textural parameters: An evaluation: Jour. Sed. Petrology, v. 38, p. 45–53.

**Muller, S. W.**, 1949, Sedimentary facies and geologic structures in the Basin and Range province: Geol. Soc. America Mem. 39, p. 49–54.

**Muller, S. W., Ferguson, H. J., and Roberts, R. J.**, 1951, Geology of the Mount Tobin quadrangle, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-7.

**Nickle, N. L.**, 1968, Geology of the southern part of the Buena Vista Hills, Churchill County, Nevada: unpubl. M.S. thesis, Univ. California, Los Angeles, California.*

**Page, B. M.**, 1965, Preliminary geologic map of a part of the Stillwater Range, Churchill County, Nevada: Nevada Bur. Mines Map 28.

**Pettijohn, F. J.**, 1957, Sedimentary rocks (2nd ed.): New York, Harper Bros., 526 p.

**Silberling, N. J., and Roberts, R. J.**, 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geol. Soc. America Spec. Paper 72, 58 p.

**Silberling, N. J., and Tozer, E. T.**, 1968, Biostratigraphic classifications of the marine Triassic in North America: Geol. Soc. America Spec. Paper 110, 63 p.

**Speed, R. C.**, 1963, Layered picrite-anorthositic gabbro, West Humboldt Range, Nevada: Mineralog. Soc. America Spec. Paper 1, p. 69–77.

**Speed, R. C.**, 1966, Paleotectonic significance of a new mid-Mesozoic formation, west central Nevada: Geol. Soc. America Spec. Paper 87, p. 231.

—— 1968a, Mechanics of emplacement of a gabbroic lopolith, northwestern Nevada: Geol. Soc. America Spec. Paper 101, p. 208–209.

—— 1968b, Time and geometry of Mesozoic orogeny, Dixie Valley-Carson Sink region, Nevada: Geol. Soc. America Spec. Paper 101, p. 336–337.

**Speed, R. C., and Page, B. M.**, 1965, Association of gabbro complex and Mesozoic thrusts, west-central Nevada: Geol. Soc. America Spec. Paper 82, p. 278.

**Stokes, W. L.**, 1963, Triassic and Jurassic formations of southwestern Utah: Guidebook to the Geology of southwestern Utah, In mountain Assoc. Petroleum Geologists, 60–65.

**Wallace, R. E., Silberling, N. J., Irwin, W. P.,** Tatlock, D. B., 1959, Preliminary geol map of the Buffalo Mountain quadrang Nevada: U.S. Geol. Survey Min. Inv. F Studies Map MF-220.

**Willden, R., and Speed, R. C.**, in press: Geol and mineral deposits of Churchill Coun Nevada: Nevada Bur. Mines Bull.

**Williams, H., Turner, F. J., and Gilbert, C. M** 1958, Petrography: San Francisco, W. H Freeman, 406 p.

**Young, C.**, 1963, Geology north of White Clo Canyon, Stillwater Range, Nevada: unpub M.S. thesis, Stanford Univ., Stanford, Ca fornia.*

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C. McA. POWELL

# Intrusive Sa
# Siamo Slate

Sandstone dykes up t
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of very low metamorp
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## INTRODUCTION

Clastic dykes hav
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observed clastic dyk
1890, p. 439). Most
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origin is reported t
penecontemporaneo
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