Title of article: Carbonate breccia (Rauhwacke) nappes of the Carson Sink region, Nevada

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Appendix A. Description of Nonbreccia Unit

Al. **Marble.** Marble constitutes perhaps 75 percent or more of the nonbreccia, and the most abundant rock types in the marble subunit are homogeneous and layered marble. Homogeneous marble consists of smoothly bounded calcite grains that range in diameter from 1 to 5 mm and form a xenomorphic granoblastic texture. Such rocks may contain a few percent quartz and albite in equant grains and patches of plumose chalcedony that has apparently replaced calcite. The chalcedony is length slow, however, suggesting it has replaced evaporite minerals rather than calcite (Folk and Pittman, 1971). Calc-silicate minerals are absent. In layered marble, marble of the homogeneous type alternates with thin layers, 5 to 10 mm thick, of finer grained gray quartzose calcite marble. In the gray interlayers, calcite grains average 0.6 mm in diameter, and quartz exists as discrete equant grains constituting 10 to 20 percent of such layers. Sparse albite grains are of the same size as quartz. Pyrite is prevalent along calcite grain boundaries in the fine-grained layers, and opaque dust exists within and between calcite grains. The joins of the fine and coarse layers are relatively regular; the grain size change is abruptly gradational, and there is no clear replacement relationship.

The marble is thus variable in terms of grain size and composition, implying that layering in the marble is a relict primary feature and that the marble was initially a sediment with quartz and feldspar sand-bearing layers. At a few places, thin layers of calcarenite and dark crystalline limestone (Fig. 5) occur in marble and are parallel to the fine-grained marble layers. The petrography of the calcarenite and crystalline limestone is like that in subunits in which these rocks are the dominant lithology (Table 2), and the existence of such interbeds in the marble supports the idea that layering in the marble is
relict bedding. Calcite grain shapes locally define a megascopic foliation that is parallel to axial planes of isoclinal folds of lithic layers.

A2. **Crystalline limestone.** The crystalline limestone subunit is composed of variably recrystallized dark gray limestone and scattered thin interbeds of calcarenite and calcirudite. The prevalent rock type of this subunit consists of intersutured calcite grains of highly variable size in the range 0.007 to 0.5 mm in diameter and scattered porphyroblasts as long as 1.5 mm. Quartz and albite occur as silt and fine-grained sand-sized grains to a few percent abundance. Opaque dust occurs as films along grain boundaries. Extensive interpenetration of calcite grains and the existence of porphyroblasts provide evidence that such rocks are recrystallized, but the highly irregular grain shapes and variable grain sizes suggest incomplete reorganization during recrystallization. The absence of relict textures of depositional constituents in much of the crystalline limestone implies that initial particle sizes were probably small. Foliation defined by preferred elongation of coarser calcite grains occurs locally in crystalline limestone. At places, thin beds of quartzose calcarenite and calcirudite can be recognized in the crystalline limestone. Calcarenite is identified by sugary, even-grained texture of calcite grains about 0.2 mm in diameter, quartz content as high as 20 percent, and relict cross-lamination. Calcirudite is composed of recrystallized rounded particles up to 0.5 mm diameter that could have been pellets or ooids, thin lithic carbonate slivers, and blocky clasts of dark limestone as much as 2 cm in diameter.

The crystalline limestone subunit probably represents successions of initially fine-grained bituminous limestone with intervals of thin-bedded deposits of sand and coarser carbonate particles. Distinctions between crystalline limestone and marble are in grain size, color, and texture; calcite grain boundaries in crystalline limestone are highly serrated compared to the smooth-walled cal-
cite grains in marble. Rocks of the marble and crystalline limestone subunits contrast strongly in degree of apparent recrystallization.

A3. **Micrite.** Very fine grained dark limestone and interbedded calcarenite and calcirudite occur at and near the base of the Muttlebury Formation for 2 km along strike at section E and in a small body 0.5 km north of section A (Fig. 4). The limestone is thin-bedded, dark gray micrite containing silt-sized quartz in laminae and scattered grains. The micrite is widely recrystallized to microsparite and sparite, and calcite grain sizes range from 10 to 100 μm. Maximum thickness of a micrite subunit is about 4 m.

Cross-laminated calcarenite occurs in beds as thick as 10 cm in the micrite subunit and is lithologically like that of the calcarenite subunit. Calcirudite consists of angular micrite clasts, carbonate mudchips, ooids, pellets, and sparse skeletal debris interpreted as fragments of probable bivalves in a matrix of fine-grained calcite and sand-sized quartz. Calcirudite occurs in thin beds and has good alignment of elongate particles parallel to bedding. I interpret the calcirudite beds to be sedimentary breccia consisting of intraclasts and other particles generated in a probable littoral environment. The micrite subunit thus reflects fluctuations of depositional environments from lagoonal or subtidal regimes in which carbonate mud was deposited and higher flow conditions in which calcarenite and calcirudite beds were laid down.

A4. **Primary Calcarenite.** The primary calcarenite subunit consists of thin-bedded light-colored limestone that contains relatively uniformly fine-grained calcite and quartz (as much as 20 percent) grains. Both calcite and quartz grains have diameters in the range 0.1 to 0.2 mm. Such rocks occupy bodies that are homogeneous, as much as 10 m thick, and as long as hundreds of meters on strike. The bedding is defined by subtle variations in grain size and quartz abundance, and at places, calcarenite contains low-angle cross-laminations. The
calcite grains form a granoblastic texture in which no matrix or cement can be recognized. It seems unlikely that grain growth could have produced the texture, because calcite grains are smooth and uniformly sized, and, moreover, they are similar in size to the associated quartz. The texture is more suggestive of compaction and slight recrystallization of the original calcite grains. A preferred elongation direction of calcite grains, observed in some thin sections of calcarenite, is parallel to bedding, but such alignment is difficult to recognize megascopically. The primary calcarenite subunit is interpreted as an accumulation of fine-grained calcite-quartz sand that has been compacted and strained.

A5. Gypsum. Thirty meters of gypsum and interbedded calcarenite overlie breccia in an isolated klippe correlated with the Muttleybre nappe (Fig. 38 and section B, Fig. 4). The top of the subunit is erosional. The gypsum subunit contains three types of interbedded rocks: Laminated calcitic gypsum, thin-bedded to massive gypsum, and thin-bedded calcarenite. The laminated rocks consist of alternations, 0.25 to 10 mm thick, of calcite-rich and calcite-poor gypsum. Carbonate-rich layers have about 25 percent calcite in isolated grains 0.1 to 0.2 mm in diameter and a few percent quartz and white mica in grains of the same size. Gypsum in such layers is in crystals 0.1 to 0.5 mm in diameter that have a granoblastic texture. The calcite-poor layers contain coarse (10 mm) euhedral gypsum in a finer grained (1 to 5 mm) gypsum mosaic. Thicker-bedded gypsum is homogeneous and texturally similar to that in the carbonate-poor laminae. Beds are commonly thicker than 2 cm; not exceptionally, they are several meters thick. Gypsum beds are isoclinally folded. An axial plane foliation is indicated most strikingly by the alignment of coarse euhedral gypsum crystals; the finer grains in the granoblastic mosaic are foliated as well, but their elongations are less pronounced.
Calcarenite in the gypsum subunit is in 1- to 3-cm-thick beds that occur singly within gypsum or in sets of tens of beds with minor intercalated gypsum. Calcite grains are 0.07 to 0.2 mm in diameter and are well sorted. At places, calcarenite beds contain low-angle cross-laminations. Quartz grains are commonly 5 to 10 percent of the rock, exceptionally zero to 50 percent. The calcarenite is uniformly granular, and no matrix or cement is recognized. The grain shapes define a foliation in adjacent gypsum. Because of its uniform fine-grained granular texture and the existence of good size sorting, and especially cross-bedding, I interpret the calcarenite to have been deposits of calcite-quartz sand. It seems clear, moreover, that the calcite-quartz grains in laminae with gypsum represent the same sand population because of similarities in size and quartz-calcite ratio.

A6. Subunit Interrelations: Marble occurs throughout the Muttlebury Formation and has no recognized preferred concentration among the basal, interior, or upper zones of nonbreccia. The crystalline limestone and micrite subunits, however, are chiefly in the basal zone. Primary calcarenite occurs in all zones, but there is a higher proportion of primary calcarenite relative to marble in the interior zone compared to the other zones. Gypsum occurs in a single body without contact with other nonbreccia, and it is not clear whether gypsum is in the interior or upper zone (section 3, Fig. 4). Contacts among marble, crystalline limestone, and primary calcarenite are sharp and concordant to layering, implying such rocks were initially part of depositional succession. The contact relations indicate, moreover, that rocks of the three subunits are not gradational facies, and that their textural differences are not the result of different degrees of recrystallization of a single carbonate parent.

Rocks of the micrite subunit are isolated from other nonbreccia subunits and crop out only at the north and south ends of the outcrop area of the Muttlebury Formation. Tight folds of bedding exist in the micrite subunit.
The subparallelism of limbs and axial planes of such folds to the local plane attitude of formation boundaries indicate they are probably intranappe folds. Thus, it is likely that micrite has a deformation history similar to other nonbreccia subunits. Further, lithologic comparison of rocks of the micrite and crystalline limestone subunits suggests that the crystalline limestone subunit is a more recrystallized equivalent of the micrite subunit. Thin-bedded calcarenite is similar in both subunits, and the clast sizes and shapes have morphologic similarities in calcirudites in both subunits. In calcirudite of the crystalline limestone subunit, however, recrystallization has made difficult the identification of ooids, pellets, and mudchips by internal structures. Support for correlation of the crystalline limestone and micrite subunits derives from their distribution. Crystalline limestone occurs only within the contact metamorphic aureole of a Cretaceous granodiorite (Fig. 2), the aureole being identified by metamorphism of the pelitic terrane. Micrite, however, occurs in the Murtlebury Formation only outside the aureole where pelite of adjacents are not hornfels. Thus, crystalline limestone is a product of thermal recrystallization during Cretaceous time.

The gypsum subunit (Section B, Fig. 4) is separated from marble of the basal zone by 7 to 10 m of breccia. Relations discussed in Appendix B indicate that both the gypsum and marble are older than the breccia and that, at least in part, the breccia is of intraformational origin. Such time relations are supported by the existence of isoclinal first folds and axial plane foliation in both gypsum and marble at section B (Fig. 4) and absence of these structures in the intervening breccia. Assuming all the breccia at section B is of intraformational origin, gypsum was presumably in contact with nonbreccia below it before generation of the breccia. The relations allow the gypsum beds to have been in original depositional continuity with other nonbreccia rocks, perhaps rocks precursor to the marble. Moreover, gypsum and marble at section B both
have isoclinal first folds, and open later folds, suggesting that gypsum and marble could have undergone similar deformation histories. Geometric proof of concurrent deformation is difficult, however, because rocks of the gypsum unit are exposed only on a small mine face and as large, disoriented, mined blocks.
Appendix B. Description of the Breccia Unit

Bl. Polymict Breccia. Breccia commonly contains lithic clasts of two types (Fig. 6), and less commonly, of one, three, and four types, as indicated in Figure 4. Thus, breccia is predominantly polymict, and marble and primary calcarenite are the prevalent clast pair. Polymict breccia is mostly unsorted and unstratified, and contains marble clasts that are characteristically two to five times coarser than clasts of other rocks. More rarely, polymict breccias contain uniform-sized clasts of a few centimeters diameter and have preferred orientation of nonequant fragments. Lithic fragments have sharp, angular boundaries. The degree of recrystallization, internal fracturing, and veining in various clast lithologies is like that in equivalent nonbreccia rocks.

A thin zone of monomict breccia commonly separates polymict breccia from nonbreccia, and the contacts of such breccia subunits are gradational. Polymict breccia, however, directly contacts all or part of some nonbreccia bodies, and in particular, the top of the basal nonbreccia zone has rare intervening monomict breccia. The top of the basal nonbreccia is broadly a smooth surface with local undulations as high as 10 cm. In the vicinity of a few sharp undulations, lithic clasts can be related to local nonbreccia sources. In such cases, displacement is small (<10 cm) and approximately normal to the contact, and the clasts are little rotated. In general, however, the lithic fragments in polymict breccia cannot be related to nonbreccia sources, and pairs of adjacent fragments generally have no relation in terms of lithic type or matching boundaries. Pre-breccia structures within equant lithic fragments are disoriented.

The interstices between lithic fragments in breccia are occupied by calcite quartz sand. The granulometric properties of the sand are nearly constant throughout the breccia and independent of the proximity of lithic fragments and
of the types and proportions of lithic clasts present. Moreover, the amount of quartz in the interstitial sand is independent of whether adjacent lithic fragments are quartzose or quartz-free. There is no evidence that calcite-quartz sand has been derived from the walls of nearby lithic fragments as might be indicated by hackly edges or reaction rims of sugary calcite around such fragments.

Pores between calcite-quartz sand grains and lithic clasts are rimmed or filled by drusy calcite spar. The centers of some pores contain clusters of 7A clay, abundant very fine-grained pyrite, and occasional spherical vacuoles that are central to the clay clusters.

8. Monomict Breccia. Monomict breccia occurs widely but in minor volume along parts of the margins of some nonbreccia bodies. Zones of monomict breccia are rarely thicker than 3 m. Monomict breccia grades out to polymict breccia by increased mixing with other lithic clasts and generally decreasing average size and preferred orientation of the clasts in the monomict zone. Calcite-quartz sand interstitial to monomict breccia fragments is like that of polymict breccia, and pore spaces are largely filled by sparry calcite cement and occasional clay clusters.

Coarse monomict marble breccia (Fig. 5) forms partial sheaths around most marble nonbreccia except above marble of the basal nonbreccia zone. Monomict marble breccia is particularly strongly developed at tapered ends of nonbreccia masses in the interior zone (Fig. 4). Such breccia is clearly derived by local fragmentation of nonbreccia.

Bodies of primary calcarenite nonbreccia are commonly enveloped by a sheath 5 to 50 cm thick of slightly dislodged primary calcarenite fragments whose bedding is subparallel with beds in the adjacent nonbreccia. Fractures between the clasts are filled with calcite-quartz sand, giving a brick and mortar appearance
to the sheath. Fractures persist toward the interior of the nonbreccia but with minute displacement and no sand filling. Away from the nonbreccia body, primary calcarenite fragments are increasingly separated and disoriented, and the monomict breccia grades out to polymict breccia or to massive or bedded pebbly secondary calcarenite. The gradations give the impression that during brecciation there was outward displacement of calcarenite fragments from a non-breccia body as fractures propagated inward. Beyond a meter or so from the non-breccia source, fragments entered an environment in which further displacement was unrelated to the fragment source. It is noteworthy that smaller bodies of calcarenite nonbreccia are thoroughly fractured, and the size of the fractured segments is much like that of primary calcarenite clasts throughout the breccia unit.

B3. Secondary Calcarenite. Polymict and monomict breccias grade vertically or laterally with increasing ratios of sand to lithic fragments to pebbly secondary calcarenite with floating lithic clasts and to pebble-free secondary calcarenite (Fig. 4). Bodies of secondary calcarenite are lensoid and elongate parallel to formation boundaries. They seem to have no preferred distribution within the breccia unit. Secondary calcarenite like polymict breccia is variably massive and stratified. The next section discusses sorting and stratification in the breccia unit as a whole.

Calcite sand grains in secondary calcarenite, like those in breccia interstices, have generally smooth boundaries, although intergrowths between grains occur in some specimens. Such grains have no preferred shape orientation. Pore space is generally between 10 and 20 percent and is occupied by drusy calcite and clusters of 7Å clay and pyrite, as in the breccias.

At most places, distinction between primary and secondary calcarenite is clear. Primary calcarenite is always well-bedded, generally has fine laminations,
and contains no lithic clasts. Its calcite grains are tightly compacted, there is no pore space or recognizable cement, and a microscopic foliation commonly exists. Primary calcarenite has isoclinal minor folds. Secondary calcarenite is commonly massive or poorly bedded and contains lithic clasts, most frequently of primary calcarenite, within strike lengths of few meters. Secondary calcarenite has pore space, no foliation, and its interstitial pyrite generally weathers to yield a yellowish hue that does not exist in the nearly colorless primary calcarenite. Minor folds in stratified secondary calcarenite are commonly open except at a few places such as near section C (Fig. 4) where tight, post-brecia folds exist (Fig. 3).

B4. Stratification. Approximately one-third of the breccia unit contains stratification delineated by variations in lithic clast size, in the ratio of lithic fragments to sand, and in grain size and ratio of quartz to calcite in the sand. Stratified rocks are highly local, and the general structure of the breccia unit is that of an irregular network of massive clastic debris containing gradational lenticular and irregular domains of subtly-stratified to well-stratified rocks.

Stratified breccia is defined by thin layers of granule-sized particles alternating with layers of slightly coarser fragments whose mean sizes are \(<3\) cm, by alternations of breccia and pebbly calcarenite, and by the preferred orientation of nonequant clasts. Breccia with mean clast size \(>5\) cm is rarely stratified. There is no recognized difference in roundness of lithic fragments in stratified and massive breccia. Domains of stratified breccia are irregular in shape and are difficult to delineate owing to gradational boundaries. Stratification becomes progressively ill-defined through a distance of 0.1 to 2 m as stratified breccia grades to massive breccia or secondary calcarenite. Thicknesses of stratified breccia zones vary from centimeters to several meters.
Zones of stratified secondary calcarenite vary from a few millimeters to several meters thick, and their strike lengths are perhaps 10 times their thickness. Stratification is manifested by thin layers of secondary calcarenite with few lithic clasts alternating with thicker layers of pebbly calcarenite. Moreover, lamination in secondary calcarenite results from subtle changes in mean sand size and covariant quartz/calcite ratio. Graded laminae are recognized at places, as are low-angle tangential cross laminae. The cross laminae indicate tops toward the Relay thrust.

All of the stratification features described are coplanar at a given location in the breccia unit and, in general, they parallel the local formation boundaries. Thus, the formation is broadly a deformed tabular body with locally concordant internal layering in the breccia unit, even though as a whole, the formation is an irregular mixture of diverse lithologies. The stratification by particle size, composition, and orientation in the breccia unit can be confidently interpreted as bedding resulting from transport by a fluid.

B5. Occurrence of Pelite Clasts. Pelite clasts in the breccia unit are of two distinctive types, Triassic pelite and Jurassic-Triassic pelite (Table 1). Triassic pelite clasts occur in breccia only within a meter or so of the formation top, or equivalently, the Relay nappe, which is entirely Triassic pelite. The pelite clasts are angular and range in maximum dimension from 0.1 to 10 cm; exceptionally, they are 30 cm. They are generally sparse and isolated from one another, and are not commonly progressively concentrated toward the formation top. Carbonate lithic fragments and sand-sized calcite-quartz in the zone of Triassic pelite clasts are like those elsewhere in the breccia unit. Breccia bearing clasts of Triassic pelite is generally polymict and has a framework of lithic fragments; at places, however, vague stratification by clast size and orientation occurs in such breccia. Where observed, the thrust contact between
the breccia unit of the Murtlebury Formation and Relay nappe is nongradational, and Triassic pelite above the thrust is not brecciated, or at least not fractured any more intensely than pelite far above. The Relay thrust does not demonstrably cut across clasts or stratification in subjacent breccia of the Murtlebury Formation. Thus, for much of their contact, the breccia unit and the Relay nappe have equivocal time relations.

A high concentration of Triassic pelite clasts occurs at section A (Fig. 4) in a hemispherical zone of about 5 m radius. The equatorial plane of the hemisphere is the formation top. The zone lies above polymict carbonate breccia and lenses of late calcarenite that have cross beds indicating tops toward the Relay thrust. The carbonate breccia grades up to pelite clast breccia with progressive change in the ratio of the two clast types. The pelite clasts are poorly sorted, as long as 30 cm, and are clustered, rather than uniformly mixed with carbonate clasts. At the top of the hemispherical zone, the rock is a coarse pelite-clast breccia with calcite-quartz sand together with fine pelite fragments in the matrix. The pelite-clast breccia grades laterally to carbonate breccia. The zone of pelite breccia is overlain by brecciated Triassic pelite that is lithologically homogeneous and exhibits little internal translation or rotation of fragments. Such breccia in turn grades to continuous pelite. The contact between the breccia unit and the Relay nappe is gradational at section A (Fig. 4), and the pelite and carbonate breccias there are younger than the Relay thrust.

Jurassic-Triassic (J-Ts) pelite clasts, easily distinguished by their calcareous and graphitic compositions from Triassic pelite clasts, with but two exceptions occur in the lower meter or so of the breccia unit where breccia is at the base of the Murtlebury Formation. Examples of basal breccia containing J-Ts clasts are a kilometer north of section C and just northwest of section E (Fig. 4). The J-Ts fragments are angular, 10 cm or less in maximum dimension,
and generally isolated from each other. The basal contact of such breccia is
sharp, and individual JRs clasts cannot be related to specific sources in the
subjacent rocks. The important relation, however, is that exotic clasts of
pelite lithologically identical to rocks of the adjacent nappes are scattered
in layers both at the top and bottom of the M futiley Formation, where the
breccia unit occurs at the boundaries between formation.

The two exceptions to the restricted occurrence of Jurassic-Triassic
pelite clasts in the basal breccia are at section C and near section E. At
section C, about two dozen small JRs clasts are scattered through breccia of
marble and secondary calcarenite clasts over an outcrop area of 100 sq m. Five
to ten meters of nonbreccia lie between the breccia containing the pelite clasts
and continuous Jurassic-Triassic pelite below the Wildhorse thrust. The gran-
ulometry and lithology of these clasts are identical to those elsewhere in the
basal zone. The second exception is 0.25 km northwest of section E; there, the
Jurassic-Triassic pelite consists of a long (200 m), thin (3 m) unbroken strand
of laminated mudstone and silty limestone enclosed by homogeneous marble of the
nonbreccia unit. The trend of the pelite strand and its bedding are generally
parallel to the isoclinally folded layering of nearby layered marble and the
trend of the upper zone of nonbreccia. Contacts of the pelite and marble are
sharp, and there is no evidence of brecciation. Rocks of the pelite strand
have little or no megascopic recrystallization, and limestone in the strand
contrasts strongly in grain size with the marble in which the strand is enveloped.

86. Relations of Gypsum and Breccia. Gypsum at section B (Fig. 4) lies
above intercalated polymict and monomict breccia and locally stratified secondary
calcarenite. The contact between gypsum and breccia, sparingly exposed, is gra-
dational over less than a meter. Interbedded gypsum and calcarenite grade down
to breccia of unoriented angular calcarenite clasts through an intermediate
zone of fragmented calcarenite beds with progressively lower proportions of intercalated gypsum and increasing disorientation of clasts. The relations indicate that the calcarenite breccia just below the gypsum is derived from the gypsum subunit by solution withdrawal of gypsum and concomitant fragmentation of calcarenite interbeds. Such time relations are supported by the existence of isoclinal folds in the gypsum but their apparent absence in subjacent breccia. Open folds of bedding in the breccia are probably of the same folds as those of foliation and axial planes in the gypsum.