Sedimentology of the Pennsylvanian and Permian Strathearn Formation, Northern Carlin Trend, Nevada

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With a section on

Microfossil controls on age of the Strathearn Formation

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ABSTRACT

Two framework-supported, poorly bedded conglomerate units of the middle Upper Pennsylvanian and middle Lower Permian Strathearn Formation belonging to the overlap assemblage of the Antler orogen are prominent in the northern Carlin trend. These horizons stratigraphically and temporally bracket thrust emplacement of a major allochthonous thrust plate of mainly quartzarenite of the Ordovician Vinini Formation. Lithologic and shape-ratio data from approximately 4,200 pebbles and cobbles at 17 sites as well as biostratigraphic data in the Strathearn, and their geologic implications, are included in this report. Conodont biofacies throughout the Strathearn Formation are normal marine and suggest middle shelf or deeper depositional environments. The conglomerate units roughly are similar in that they contain only chert and quartzarenite pebbles, but they differ in compositional proportions of the two lithologies. The relative proportion of quartzarenite pebbles increases sixfold in the middle Lower Permian upper conglomerate unit versus its content in the middle Upper Pennsylvanian lower unit, whereas chert pebbles predominate in both units. Various roundness categories of chert pebbles in both conglomerate units of the Strathearn show that the equant pebble class (B/A) = 1 clearly is represented strongly even in the subangular category, the lowest roundness categories for the pebbles. Thus, development of equant pebbles cannot be ascribed totally to a rounding process during predeposition transport. The equant character of many pebbles might, in part, be an original feature inherited from pre-erosion rock fractures and (or) bedding that control overall form of the fragments prior to their release to the transport environment. The allochthon of the Coyote thrust has been thrust above the lower conglomerate unit of the Strathearn during a regionally extensive contractional event in the late Paleozoic. The middle Lower Permian upper conglomerate unit, highest unit recognized in the Strathearn Formation, as well as similarly-aged dolomitic siltstone, onlap directly onto quartzarenite that comprises the allochthon of the Coyote thrust. The conglomerate units thus represent submarine fanglomerates whose quartz grains and quartzarenite fragments of variable roundness and shape were derived from a sedimentologically restored largely southeastward advancing late Paleozoic

allochthonous lobe of mostly quartzarenite of the Ordovician Vinini Formation. Chert fragments in the conglomerates probably were derived mostly from Devonian Slaven Chert, including a widespread thick mélange unit of the Slaven in the footwall of the Coyote thrust. Some chert pebbles may have been derived from the Ordovician Vinini Formation.

INTRODUCTION

Regional studies in the Beaver Peak (BP) area of the Tuscarora Mountains, Nev., near the northern Carlin trend of Au deposits (fig. 1) have shown that the Upper Pennsylvanian and Lower Permian Strathearn Formation overlap assemblage contains two major conglomerate horizons. These horizons stratigraphically and temporally bracket thrust emplacement of a major allochthonous thrust plate of mainly quartzarenite of the Ordovician Vinini Formation (Theodore and others, 1998; 2000a; 2001). Our lithologic and shape-ratio study of clasts from 17 well-exposed sites of these two conglomerate horizons is designed to resolve the sedimentology of the petrotectonic environment prevailing during final stages of late Paleozoic regional contractional deformation in northeastern Nevada. To achieve this purpose, three fundamental questions must be addressed: (1) Are there notable differences in lithologic composition in the two conglomerate horizons? (2) What do these differences imply with respect to their depositional and petrotectonic environments? (3) Are size and shape ratios of cobbles and pebbles in the conglomerates statistically different? This investigation in the Tuscarora Mountains is one of the ancillary topical investigations currently (2001) supported by the Western Region Gold Project of the U.S. Geological Survey (USGS), and the investigation supports ongoing mineral-assessment tasks of regional geologic and geochemical studies in the Humboldt River Drainage Basin Project of the USGS, also currently underway. Lithologic and shape-ratio data from approximately 4,200 pebbles and cobbles in the Strathearn Formation, as well as their geologic implications, are included in this report.

GEOLOGIC FRAMEWORK OF THE BEAVER PEAK AREA, TUSCARORA MOUNTAINS

Recent geologic investigations in the BP area—undertaken as part of geologic and geochemical study of the Santa Renia Fields and BP quadrangles (fig. 2)—established the presence of a remarkably intact lower Paleozoic stratigraphic sequence of siliceous rocks in the upper plate of the Roberts Mountains thrust (RMT) (Theodore and others, 1998; Theodore, 1999; Theodore and others, 2000a). The allochthon of the RMT in this area also contains a number of well-exposed relations of its units with the Strathearn Formation that belongs to the overlap assemblage (Roberts, 1964)—these relations have profound implications with regards to late Paleozoic tectonism in the region. The upper plate of the RMT initially was emplaced during the middle Paleozoic Antler orogeny (see also, Roberts and others, 1958; Sandberg and others, 1982; Saucier, 1997; Cluer, 1999; Trexler and Giles, 2000). Prior to recently completed investigations in the Tuscarora Mountains, (1) the Antler orogeny was envisaged as having been completed by the Late Pennsylvanian (Roberts and others, 1958; Roberts, 1964; Dickinson, 2001), and (2) the next succeeding contractional tectonism to affect the Antler orogen is inferred to have been the Late Permian and (or) Early Triassic Sonoma orogeny (Silberling and Roberts, 1962). However, on-going studies in the Tuscarora Mountains (Theodore and others, 1998, 2000a, 2001) and in the Shoshone Range (J.K. Cluer, written commun., 2000) strongly suggest that during the middle Late Pennsylvanian to middle Early Permian a regional east- to southeast-directed thrusting event reactivated significant parts of the RMT allochthon.

Previously, late Paleozoic deformation of the Antler orogen has been referred to as the Humboldt orogeny (Ketner, 1977), and the Humboldt orogeny was envisioned mainly as including late Paleozoic epeirogenic uplift, as well as depression of a number of basins widespread throughout the Cordillera (Snyder and others, 2000). Both uplift and depression owe their origins primarily to development of the Ancestral Rockies (Dickinson, 2001). In addition, the aforementioned shortening during the late Paleozoic may have occurred along a reactivated low-angle duplex whose sole is the RMT (J.K. Cluer, written commun., 2000). Regardless, well-documented shortening described herein involving the Strathearn Formation requires significant modification of earlier concepts of regional tectonism in this part of the Great Basin (Cashman and others, 2000, 2001). The Strathearn is equivalent in age to the upper parts of the Pennsylvanian and Permian Oquirrh Group in west-central Utah (Roberts and others, 1965), as well as the Pennsylvanian and Permian Antler Peak Limestone of the overlap assemblage at Battle Mountain, Nev. (Roberts, 1964).

The area we have selected for detailed examination of the Strathearn Formation includes the majority of tectonostratigraphic packages relevant to Paleozoic tectonism in the region. The lower plate of the RMT in the area crops out only near the Capstone-Bootstrap and Tara Au mines as well as in and near the open pit of the Dee Mine (fig. 2). As pointed out by Saucier (1997), largely carbonate rocks of the lower plate of the RMT regionally are cut in a number of places by thrust faults and also folded, probably during the Antler orogeny, thereby indicating that some lower plate rocks are themselves allochthonous (see also, McFarlane and Trexler, 1997; McFarlane, 1997, 2000; Dewitt, 2001). The widely exposed siliceous package of rocks in the upper plate of the RMT in the area includes Upper Ordovician Vinini Formation of Merriam and Anderson (1942; see also, Finney and Perry, 1991; Finney and others, 2000), Silurian and Devonian Elder Sandstone of Gilluly and Gates (1965), and Devonian Slaven Chert of Gilluly and Gates (1965). The Vinini Formation, Elder Sandstone, and Slaven Chert all are well exposed south of BP where stratigraphic relations among the formations have been revealed by sharply incised deep canyons (fig. 2). As mapped in this part of the Tuscarora Mountains, strata of the three formations generally are devoid of altered basaltic rock (greenstone), a fact previously noted as well by Dubé (1987, 1988) in the Lake Mountain area of the upper plate of the RMT approximately 10 km northeast of BP. Nonetheless, extremely sparse < 1–m-thick sequences of Ordovician submarine voclaniclastic rocks are present near the Dee Mine (fig. 2). In contrast, the Ordovician Valmy Formation at Battle Mountain contains submarine pillow basalt, basaltic tuff, and gabbro that crop out extensively throughout much of a 1.5 km^2 area (Theodore, 2000). The absence of widespread submarine volcanic rocks in lower Paleozoic rocks in the BP area probably is indicative of a lack of synsedimentary rifting. Uppermost strata of the Elder Sandstone regionally are as young as early Early Devonian (Noble, 2000). The Elder Sandstone at its base locally contains discontinuous, approximately 10–m-thick sequences of well-bedded knobby black and blue-green chert that probably are correlative with the Cherry Spring chert unit of Noble and others (1997), a unit exposed in the Adobe Range, approximately 50 km to the east (fig. 1).

Although upper Paleozoic rocks are quite extensive in the region (fig. 3), they record a geologic history that is just beginning to be unraveled because of complex relations among previously unrecognized important unconformities as well as late Paleozoic thrust faults. Siliceous upper plate rocks of the RMT are overlain unconformably—locally in several places with an angular discordance of about 30 degrees—by a variety of rocks all belonging to the Strathearn Formation that comprises the overlap assemblage of the Antler orogen at BP (fig. 4). Certainly, the late Paleozoic geology of the region is much more complex than suggested by figure 3. However, because of the structurally and stratigraphically discontinuous nature of outcrops assigned to the Strathearn in the general area of BP, the overall stratigraphic section assembled for the formation has been composited primarily from two areas. One section is at BP (Beaver Peak section) where the lowermost rocks of the formation are middle Late Pennsylvanian, and the other is from the western section, approximately 3 km southwest of

BP (fig. 4), where stratigraphically high conglomeratic strata of the Strathearn apparently are younger than middle Early Permian at their base. At the latter locality, the conglomeratic strata are present depositionally on quartzarenite of the Ordovician Vinini Formation (Theodore and others, 2001).

The regional extent of the Strathearn recently has been broadened into the area from its type section in Carlin Canyon (Dott, 1955; Cashman and others, 2000, 2001) approximately 20 km to the southeast (fig. 1). However, rocks of the Strathearn Formation in the greater BP area, on the basis of a number of well-constrained conodont and fuslinid biostratigraphic determinations (Theodore and others, 1998; see also section below entitled “Microfossil Controls on Age of the Strathearn Formation”), are equivalent in age to the lower unit (Cashman and others, 2001) of the Strathearn Formation at Carlin Canyon. In the Carlin area, the lower Strathearn unit is latest Missourian through early Asselian (Late Pennsylvanian through early Early Permian); the upper unit is confined entirely to the early Early Permian (latest Asselian through middle Sakmarian) (J.H. Trexler, Jr., written commun., 2001). In addition, the Strathearn Formation also crops out extensively in the Snake Mountains approximately 100 km to the northeast where its undeformed basal strata rest unconformably on deformed sequences of rock in the upper plate of the RMT (McFarlane, 1997).

Structural relations of the Strathearn Formation present in the area have wide-reaching tectonic implications. Locally, basal strata of the lower unit of the Strathearn Formation—in places commonly chert-pebble conglomerate—are Late Pennsylvanian in age, whereas in other places the upper unit of the Strathearn displays basal dolomitic siltstone strata that may be as young as middle Early Permian. However, prominent sequences of another chert- and quartzarenite-pebble conglomerate also comprise some of the stratigraphically highest outcrops in the upper unit of the Strathearn Formation. This latter chert- and quartzarenite-pebble conglomerate is well exposed on a high ridge approximately 3 km southwest of BP (fig. 4)—this ridge as well as BP itself were referred to previously as Dalton Peaks by the Clarence King-led 40th Parallel Surveys (Emmons, 1877) and the ridge southwest of BP also is referred to informally as Coyote ridge (Steve Moore, oral commun., 2001). The Strathearn Formation includes biofacies indicative of a normal marine depositional setting throughout its exposed stratigraphic sequences (fig. 4; see below). The Strathearn Formation is roughly age equivalent to the Pennsylvanian and Permian Antler Peak Limestone, middle unit of the overlap assemblage present in the classic Antler orogenic relations at Battle Mountain (fig. 1) (Roberts, 1964). Dubé (1987) previously assigned similar appearing rocks in the nearby Lake Mountain area to the Pennsylvanian and Permian Antler Peak

Limestone, and rocks near the mouth of Coyote Creek, approximately 1.6 km east-northeast of the southeast corner of the BP quadrangle, also belong to the Strathearn Formation (F.R. Hladky and P.R. Lewis, unpub. data, 2001).

The Strathearn Formation essentially is composed of two major units—one of the units, middle Late Pennsylvanian near its base, is structurally below the Coyote thrust and the other rests depositionally on rocks in the upper plate of the Coyote thrust (fig. 4). Areal distribution of the two units is shown schematically in figure 4. The upper unit of the Strathearn, apparently as young as middle Early Permian, also laps across a leading edge of the thrust. These two units are assigned to the same formation on the basis of well-exposed lithologic relations on a ridgeline close to a profile designated the Western Section that is southwest of BP (fig. 4). The quartzarenite in the upper plate of the Coyote thrust, assigned to the Ordovician on the basis of age-diagnostic graptolites (Theodore and others, 2001), probably is roughly equivalent to quartzarenite in the upper unit of the Vinini Formation in the Roberts Mountains (Finney and Perry, 1991; Finney and others, 2000). However, quartzarenite in the upper plate of the Coyote thrust apparently belongs to graptolite Zone 11 (lower Caradocian) of Berry (1960) whereas quartzarenite of the upper unit of the Vinini in the Roberts Mountains belongs to Zone 13 (middle Caradocian)—the Carodocian is the early Late Ordovician Epoch. Ordovician quartzarenite also is present structurally above Upper Devonian rocks near Beaver Creek, approximately 5 km northeast of BP (Dubé, 1987; T.G. Theodore, unpub. data, 2001).

As will be described below, geologic relations together with paleontological data apparently constrain emplacement of the upper plate of the Coyote thrust to a relatively narrow time interval between late Virgilian (Late Pennsylvanian) to latest Sakmarian-earliest Artinskian (middle Early Permian) (see section below entitled “Microfossil Controls on the Age of the Strathearn Formation”). Various parts of the Strathearn must have been involved structurally with a nearby belt of lower Paleozoic rocks that were advancing towards the southeast (present day coordinates) in a largely shallow marine environment. The Strathearn Formation at BP was deposited along a marine environment somewhat beyond the frontal lobe of late Paleozoic thrust faults associated with emplacement of the master Coyote thrust (figs. 2, 4). The latter may form a duplex with the Little Jack thrust. Thus, the lower Paleozoic rocks, in places, overrode their own detritus. Where rocks of the Strathearn Formation are well exposed close to the Coyote thrust near the north edge of figure 2, they have been severely brecciated or tectonized and show fabrics locally including strongly lineated surfaces, and, in places, rods. Presence of these overlap rocks throughout much of the northern part of the area is critical from a structural standpoint because of the excellent marker and time-stratigraphic horizons that they provide. In the Carlin Canyon area, Cashman and others (2000, 2001) have documented a Late Pennsylvanian to Early Permian northwest-southeast shortening that is temporally equivalent to the similarly oriented trend of thrusting near BP.

Jurassic (?) dikes are present in two localities southeast of the Boulder Creek fault and a number of similar dikes crop out in the general area of the Dee, Rossi, and Ren Mines (fig. 2) where the informally named Arturo dike at the Dee Mine has yielded a 162 Ma $^{40}Ar/^{39}Ar$ age (see Theodore and others (1998) for specifics). The two poorly exposed dikes southeast of the Boulder Creek fault intrude conglomeratic strata of the lower unit of the Strathearn Formation. These intensely altered alkali granite and monzonite dikes contain narrow seams of yellow limonite (jarosite?)$\pm$Fe–oxide mineral(s) as well as relatively abundant white mica. All of these dikes apparently are younger than the thrust faults described above on the basis of the pre-Jurassic age constraints on the thrust faults. On the basis of the structural relations described below, evidence for major Mesozoic shortening is not present in the area.

Tertiary rocks and Tertiary and Quaternary unconsolidated deposits are present mostly in the western part of the area (fig. 2). Miocene rhyolite flows and minor intrusive rhyolite that are approximately 15 Ma crop out in approximately 16–km^2 near the west-central edge of the area. The Miocene Carlin Formation of Regnier (1960), moreover, crops out widely in the western part of the area, from which air-fall tuff yielded 14.4– to about 15.0–Ma ages by the $^{40}Ar/^{39}Ar$ method (Fleck and others, 1998).

Geometry and structural relations of faults in the area conform with a number of regionally extensive geologic phenomena. For example, faults of the Coyote thrust system generally strike east-west and dip at shallow angles to the north (fig. 2) and are probably correlative with the Lander thrust in the Shoshone Range (fig. 1) (J.K. Cluer, written commun., 2000). The generally east-west strike of the Coyote thrust system parallels the east-northeast trend of the Proterozoic continental margin (S. Ludington, written commun., 2000; see also, Theodore, 2000, fig. 5). The basal or master surface of the Coyote thrust probably bends to the northeast around the northwest flank of BP as required by presence of isolated fault blocks of quartzarenite in the upper plate of the Coyote thrust throughout the southwest quadrant of the BP quadrangle (fig. 2; see also, Theodore and others, 2001). The imbricate Little Jack thrust probably is slightly older and structurally lower than the Coyote thrust because the Coyote thrust apparently cuts the Little Jack thrust north of the Dee Mine (fig. 2). Further, Late Devonian (Theodore and others, 2001) mélange fabric in the Slaven Chert overprints soft sediment deformation in the unit and may owe its origins to early contractional tectonism of the Antler orogen during the Late Devonian, if onset of shortening along the RMT first occurred during this time (see also, Murphy and others, 1984; Theodore, 2000).

Because geologic relations of the Strathearn Formation profoundly impact late Paleozoic tectonisim in the region, this report describes in detail those geologic relations as well as clast morphologies and modal clast compositions at 17 representative sites through two well-exposed sequences of largely siliciclastic conglomerate of the Strathearn.

PENNSYLVANIAN AND PERMIAN STRATHEARN FORMATION

Geologic relations

Chert-pebble conglomerate and interbedded limestone, as well as a relatively thick sequence of dolomitic siltstone and some shale near BP (fig. 4), make up part of the late Paleozoic overlap assemblage of the Antler orogeny—they are assigned to the Upper Pennsylvanian and Lower Permian Strathearn Formation of Dott (1955), specifically equivalent to the upper member (Cashman and others, 2001) of the Strathearn in the type section at Carlin Canyon. Although Snyder (1989) and some later reconnaissance investigators during the early 1990s recognized that chert-pebble conglomerate in the northern part of the SRF quadrangle belonged to the overlap assemblage (R.J. Roberts and R.J. Madrid, oral communs. 1996), many other geologists continued to believe that these rocks were an integral part of lower Paleozoic sequences because the strata generally were not shown separately on the regional geologic map of Coats (1987). For this reason, accurate paleontological evidence bearing on age of the Strathearn Formation is of singular importance for an understanding of the structural evolution of the area.

Microfossil controls on the age of the Strathearn Formation

By Anita G. Harris and Calvin H. Stevens

Our previous study (Theodore and others, 1998) showed that conodonts and fusulinids appeared to be among the most effective widespread Late Paleozoic paleontological age indicators in various sedimentary carbonate rocks of northeastern Nevada. Usage of these two crucial types of fossils allowed us to define the overall stratigraphic succession of spatially disconnected parts of Strathearn Formation. Results of additional conodont and fusulinid analyses are briefly described below. All available biostratigraphic data for the Strathearn Formation in the area, including previous data from Theodore and others (1998), are summarized in table 1.

Conodonts near the base of the Strathearn Formation (fig. 4, loc. 6) are late Middle Pennsylvanian to middle Early Permian in age (table 1 and Theodore and others, 1998). Fusulinids from the same locality, however, tightly restrict the age to the late Missourian. A biostratigraphically diagnostic conodont collection, however, was recovered from near the top of BP (table 1 and fig. 4, loc. 13) and yielded specimens of both *Mesogondolella bisselli* and *Sweetognathus whitei* that nicely restrict the age of the collection to the latest Sakmarian or earliest Artinskian (middle Early Permian). The collection is dominated by mesogondolellids suggesting a normal-marine, middle shelf or deeper water depositional setting. Nearby collections of long-ranging Late Pennsylvanian to Early Permian conodonts (table 1 and fig. 4, locs. 10 and 11) were recovered from beds about 200 m stratigraphically below those that produced the middle Early Permian conodonts. These stratigraphically lower collections are representative of a streptognathodid-hindeodid biofacies also suggesting normal-marine, middle shelf or possibly deeper water depositional conditions.

Fusulinids are present in samples 00TT-040, -041, -042, -063, and –064 collected near the contact between lower conglomerate and overlaying limestone and dolostone. Sample 00TT042, same as loc. 10 on figure 4 (see also, fig. 12) contains two different forms:

(1) *Pseudofusulinella utahensis* Thompson

(2) *Triticites* sp. of the *T. pinguis* Dunbar and Skinner group lowest Permian at Ferguson Mountain, according to Slade (1961), and it also is found in rocks assigned a late Missourian age (Theodore and others, 1998). The rocks considered Permian by Slade, however, probably now would be placed in the highest Carboniferous.

The *T. pinguis* types are present in the Keeler Canyon Formation in eastern California in the highest Gzhelian and lowest Asselian (Stevens and others, in press), essentially on the Upper Carboniferous–Permian boundary.

The lack of *Schwagerina* in the thin section may be due to the paucity of fusulinids in the section, but its absence and the presence of dominantly Upper Carboniferous species in the sample tend to suggest an age of Upper Carboniferous rather than of Permian.

On the basis of criteria of the modern coarse sedimentation model by Young and others (2000), the generally poorly sorted nature of Strathearn conglomerates, presence of a coarse-grained matrix, and absence of intraunit erosion surfaces suggest to us that deposition may have occurred by high-density debris flows.

Some limestone lenses in the Strathearn Formation host phenomenal concentrations of fusulinids in a zone of outcrop-scale carbonate sand, the upper and lower contacts of which grade into surrounding bioclastic sands that contain abundant fragments of echinoderm spines, crinoids, brachiopods, and the colonial rugose coral *Durhamina*. The latter is quite rare in Pennsylvanian sequences in the western United States. The presence of *Triticites newelli* Burma and *Pseudofusinella* cf. *P. utahensis* Thompson (fig. 6) near the base of the formation at locality 6 (fig. 4) suggests a late Missourian age (middle Late Pennsylvanian) for lowermost strata of the Strathearn that are structurally below the Coyote thrust and its upper plate rocks of Ordovician Vinini quartzarenite. Overall depositional environment of the limestone lenses are that of a shallow shoal, and, when compared to the middle shelf environments determined for most of the overlying sequence of the Strathearn Formation, suggests a progressive deepening or drowning with time.

The conodont- and fusulinid-bearing samples examined from the Strathearn Formation at BP—many samples are from critical localities near the base as well as the uppermost exposed parts of the of the formation—restrict its age to middle Late Pennsylvanian to middle Early Permian.

Stratigraphy

The lower unit of the Strathearn Formation at BP unconformably rests mostly on the Devonian mélange unit of the Slaven Chert in the upper plate of the RMT—the upper contact of the lower unit throughout much of the area is the Coyote thrust. Some of the lower unit also is depositional on the well-bedded chert unit of the Slaven (fig. 2). The upper unit of the Strathearn forms an unconformable succession on top of Ordovician quartzarenite in the upper plate of the Coyote thrust (figs. 4, 7). Thus, overall stratigraphic succession of the Strathearn necessarily is composite, because of the two major units that compose the formation as well as the discontinuous nature of many exposures. The succession is represented primarily by two sequences of rock that are present (1) at BP, and (2) approximately 3 km southwest of BP (figs. 4, 8). The latter, termed the western sequence, includes both upper and lower units of the Strathearn—a tectonic wedge of Ordovician quartzarenite separates the two units—whereas the BP section apparently includes a sequence of the formation that belongs entirely below the Coyote thrust; that is, the sequence comprises a succession of strata that belongs to the lower unit. The lower unit near BP typically includes chert-pebble conglomerate near its base as well as interbedded limestone. In fact, the thickest sequence of the Strathearn Formation crops out on the western slopes of BP where it includes a basal chert-pebble conglomerate, as much as 80 m thick, overlain by limestone as much as 100 m thick, and then a 200–m-thick sequence of buff to drab orange-buff, calcareous and (or) dolomitic siltstone interbedded with dolostone (see below). Fossil control of the stratigraphic succession near BP is provided by a profusion of middle Late Pennsylvanian fusulinids near the base of the sandy micrite (fig. 8)—present along almost its entire strike length—and presence of middle Early Permian conodonts near the top of BP (table 1; fig. 5).

Dolomitic siltstone facies in the upper part of the Strathearn Formation near BP contain low temperature silica that partly fills voids in otherwise fresh-appearing rocks. Buff-weathering, dark-gray dolomitic siltstone locally includes 10 to 15 volume percent angular K–feldspar grains, angular quartz fragments, well-developed rhombs of dolomite, and less abundant detrital white mica. The dolomite rhombs include two populations. Large subhedral rhombs in the 50 to 100 μm sizes are present in a matrix of dolomite in the 5– to 20–μm-size range. Dolomitization occurred probably in the Permian and was caused by hypersaline Mg brines (A. K. Armstrong, written commun., 2001). An ultimate detrital source may have been (1) an uplifted pre-Late Pennsylvanian granitic terrane or (2) reworked material from uplifted parts of the Silurian and Devonian Elder Sandstone in Roberts Mountains allochthon. Near the Ren Mine (fig. 2), the Elder Sandstone contains abundant detrital grains of white mica and some K–feldspar.

Basal parts of the Strathearn Formation vary in both age and lithology depending upon the overall tectonostratigraphic succession, and which unit, lower or upper, is present. In places, laminated calcareous siltstone rests directly on deformed Devonian chert mélange unit of the Slaven Chert (fig. 9; see also, fig. 13). However, chert-pebble conglomerate is a much more common basal lithology of the formation near BP and it typically forms steep cliffs (figs. 10, 11) that expose well-preserved relations between conglomerate and overlying carbonate units (fig. 12) as well as numerous surfaces suitable for point counting (figs. 14, 15). However, conglomerate near the base of the Strathearn Formation near BP also is quite discontinuous along strike as the conglomerate, in places, pinches out completely and, elsewhere, swells dramatically as apparent channels of mostly chert-pebble conglomerate are preserved (fig. 9). Although the overwhelming bulk of the lower conglomerate is quite siliceous, local lenses of sandy micrite or limestone—here we follow the definition of Dunham (1962) that defines limestone as containing more than 50 volume percent calcite—are present near the upper parts of the conglomerate, generally within 1 m of the contact with overlying sandy micrite (fig. 12*A*). Where well preserved, however, the actual transition between sandy micrite and conglomerate is quite sharp, and is marked by some interdigitation across roughly 50 cm between drab brown conglomerate, containing an abundant calcareous matrix, and gray sandy micrite (fig. 12*B*).

The western sequence of the Strathearn Formation (figs. 4, 8) that we investigated in detail is structurally much more complex than the BP sequence and it manifests several highly critical geologic relations of the Strathearn—these include (1) deposition of the upper conglomerate and some calcareous siltstone onto a substrate made up of quartzarenite of the Vinini Formation in the upper plate of the Coyote thrust (fig. 4; see also, Theodore and others, 2001); (2) onlapping of the Strathearn across the leading edge of the Coyote thrust; (3) a number of key fossiliferous localities whose ages affirm the mapped succession of the middle Late Pennsylvanian and middle Early Permian Strathearn; and (4) a 30–degree angular discordance of lower conglomerate of the Strathearn with underlying Devonian chert mélange. Moreover, in a number of localities somewhat farther to the northwest, lower conglomerate of the Strathearn has unequivocally been overthrust by quartzarenite in the upper plate of the Coyote thrust (Theodore and others, 2001). These geologic relations fully confirm that structural emplacement of the Coyote thrust must have been accomplished sometime during a relatively narrow time interval of approximately 30 m.y. between middle Late Pennsylvanian and middle Early Permian—the overall time span for deposition of the Strathearn in the area (fig. 8).

In addition, a narrow exposure of the Strathearn Formation near Hill 8026, approximately 3.5 km northwest of BP (fig. 4, loc. 6; close-up of locality shown in fig. 16), contains an approximately 1.5–m-thick, highly fossiliferous limestone lens in a sequence of largely chert-pebble conglomerate no more than 5 m above the base of the unit (table 1, loc. 6). This conglomerate also contains small amounts of quartzarenite fragments to be described more fully below. At locality 6, contact between generally flat-lying lower conglomerate of the Strathearn and underlying mélange unit locally forms a well-exposed, vertical buttress unconformity (fig. 17*A*, *B*). In addition, prominent horizontal slickensides—trend S. 45° E. (fig. 17*C*)—on many exposures of conglomerate at this locality suggest some slip may have occurred between nearby siltstone of Strathearn and conglomerate during overriding of the structurally higher Coyote allochthon or possibly even by a weakly-developed broad warping in the area, possibly during the Mesozoic, that is manifested by a broad open fold in the Strathearn near the southern part of the area (fig. 4). Additional views of nearby sites 7 and 8 are shown in figure 18.

The upper conglomerate recognized in the Strathearn Formation is largely confined to a 0.5–km-wide area of outcrop approximately 3 km southwest of BP (fig. 4). Exposures of the upper conglomerate are exceptionally well preserved on a number of joint surfaces (figs. 19–21).

Thus, the Strathearn Formation in the greater BP area (fig. 4) is marked by two prominent horizons of conglomerate: (1) a lower conglomerate that is in the footwall of the Coyote thrust, and (2) an upper conglomerate that depositionally laps directly on Ordovician quartzarenite in the hangingwall of the Coyote thrust (fig. 8). This Ordovician quartzarenite is therefore both above and below late Paleozoic rock.

FIELD PROCEDURE

Field study of the conglomerates of the Strathearn Formation focused specifically on the systematic visual determination and measurement of several features of the included pebbles that provide a foundation for conventional statistical analysis of clastic rocks that uses composition, roundness, size, and shape of clasts (Greensmith, 1978; Griffits, 1967; Howard, 1993; Krumbein, 1941). Resultant statistical analysis of the counted pebbles yields important conclusions about depositional environment and petrotectonic relations of the conglomerates.

During previous geologic mapping and related geochemical investigations, all outcrops of the Strathearn Formation were ranked as to suitability for pebble counting. Eight sample sites were selected in the lower conglomerate of the Strathearn, and nine in the upper conglomerate. Each site was selected on the basis of several requirements including: (1) predominant cliff morphology of the outcrop to enhance observations of geologic relations; (2) presence of a quasi-planar exposed surface no less than 1 m^2 in area oriented across traces of bedding in conglomerate; (3) a clean surface outcrop that was not masked or obscured by a covering of lichens or dense desert varnish; and (4) no less than 30 volume percent pebbles in the outcrop.

Selected outcrop surfaces were outlined by red tape; all pebbles counted inside the framed areas were classified first by composition, then roundness, and then measured directly to calculate their shape and size. Pebble counting was performed using the "ribbon or area method" that is most appropriate for determining pebble percentages (Howard, 1993; see also, Dickerman, 1999), as opposed to a visual characterization technique (see also, Latulippe and others, 2001). Ribbons were bordered by a weighted string that was draped sequentially every 5 cm across the selected surfaces. Typical counted outcrops bordered by red tape are shown in figures 17*A*, 18*B*, and 19*A*. Pebble lithologic compositions, roundness, shape, and sizes were determined in the field by visual identification and direct measurement. A total of 4,209 pebbles were examined at 17 separate sites in conglomerate where anywhere from 98 to as many as 326 pebbles per site were measured—lengths of long (A) versus short (B) pebble axes were measured to ± 1 mm. All of the raw counting data and their log values (base 10) are presented in Appendix A.

Composition of pebbles provided a definition of clast proportions diagnostic of the upper and lower conglomerates, helped to establish the makeup of the source, and allowed restoration of the petrotectonic environment of deposition. Both lower and upper conglomerates are polymictic and contain more than one fragmental pebble type. Pebbles in both units, however, contain two major pebble types, chert and quartzarenite. This binary composition division allowed calculation of proportions (percentage), and quantitative relations of the two different pebble types at each site—it demonstrated, as well, that many chert pebbles were derived primarily from the chert mélange unit of the Slaven Chert whose fragments are quite distinctive. Quartzarenite pebbles in both conglomerate units were derived from Vinini

Formation in the upper plate of the Coyote thrust, and, therefore, pebble sources for both Strathearn conglomerate units should be similar (fig. 4).

At the outset of this investigation of conglomerates of the Strathearn Formation, we hoped to find either fragments of Paleozoic igneous rocks or any possible indications of late Paleozoic process(es) of epigenetic mineralization. No pebbles of calcareous autochthonous rocks from the lower plate of the RMT were recognized in the two conglomerate horizons of the Strathearn Formation. Further, no prominent signs of mineralization are present either in pebbles or in cement of the examined conglomerates with the exception of negligible amounts of disseminated pyrite and intense veining by low-temperature silica in the form of cross-fiber-textured chalcedony in sparse numbers of chert pebbles accompanied locally by pyrobitumen. We did not find any other indication of mineralization or igneous activity that must predate late Paleozoic deposition of the Strathearn Formation. The low temperature silica found may be associated with minor exhalative processes of syngenetic mineralization on the Devonian seafloor represented by Slaven Chert.

Roundness of pebbles was determined visually during pebble counting. Roundness is a measure of sharpness of corners and edges of pebbles, and it is considered to be independent of pebble shape (Krumbein, 1941; Greensmith, 1978; Barrett, 1980). By applying a broad roundness classification format during the investigation, pebbles were field classified according to a three-fold scheme, namely: subangular, subrounded, and rounded. At first, an “angular” classification of pebbles also was applied, but close inspection of corners and edges of these pebbles showed that all of them actually are rounded to some extent. Examples of different roundness are shown in photographs of selected sites of the lower and upper conglomerates of the Strathearn Formation (figs. 15, 20).

Size of pebbles was used to distinguish among pebble samples (1) of different composition and different roundness, (2) at different sites, and (3) generally between each of the two conglomerate units. Variation of pebble size was a significant indicator of pebble sorting. Size was estimated by using the length of the major axis (A) of the pebble. Maximum individual pebble outlines were measured to ±1 mm at the lower axial limit of 4 mm (rarely 3 mm) and at an approximate upper axial limit of 250 mm.

Shape is a quantitative indicator calculated on the basis of measurements of individual pebbles. According to Krumbein (1941), shape is a measure of the ratio of the surface area of a particle to its volume. This definition implies an inherent ability to extract clasts from their surrounding soft friable sediment in order to measure all three axes of clasts for a further calculation of their volumes. Because our measurements were performed on planar exposed surfaces of highly lithified conglomerate, pebbles could not be removed for three-dimensional measurements. In addition, pebble shapes typically are calculated as ratio of short (B) to long (A) axes (B/A) measured on a plane that cuts the pebbles. Such “planar” ratios were used as the shape indicator in this study.

GEOLOGIC AND LITHOLOGIC DESCRIPTION OF STUDIED SITES OF STRATHEARN FORMATION

Outcrop-scale and microscopic-scale observations of the two stratigraphically different conglomerate units of the Strathearn Formation reveal a number of significant contrasts between the units.

Lower conglomerate

Locations where pebbles were counted and measured are situated near two topographically high promontories of the lower conglomerate unit of Strathearn Formation that are herein referred to as an eastern Beaver Peak Area and a Northwestern Area (fig. 4). The first area (sites 1 to 4, fig. 4) is situated on the northwestern slope of Beaver Peak, and the second (sites 5 to 8, fig. 4) is 2.6 km to the west of the first and is separated from the former by a wide expanse of chert mélange unit of the Slaven Chert and quartzarenite of the Vinini Formation. Lower conglomerate in both areas, however, is depositionally in contact with underlying chert mélange. Quartzarenite is typically bounded by faults.

Stratigraphy of the Strathearn Formation in the Beaver Peak Area is shown schematically in section (fig. 8). Lower conglomerate, as much as 80 m in thickness, lies on an eroded rugged surface of Slaven Chert and is conformably overlain by thin-layered sandy micrite, as much as 100 m thick. The upper part of the exposed sequence includes a calcareous siltstone unit approximately 200 m in thickness. Contact of lower conglomerate with overlying carbonate rocks is well exposed on a long prominent cliff scarp on a much more extensive steep slope that extends from the bottom of the east fork of Toro Canyon to near the top of Beaver Peak; dips indicate generally flat-lying bedding attitudes (figs. 10, 11). The lower conglomerate also contains small limestone lenses immediately below its upper contact (fig. 12). However, stratigraphic thickness of the lower conglomerate unit changes dramatically along strike as the unit locally pinches out completely and then reappears sharply again farther to the north between underlying Devonian mélange and the overlying micrite unit of Strathearn Formation. These relations are present on the steep northwestern slope of Beaver Peak.

At least three individual channels filled by conglomerate were determined to be present below the micrite unit along the exposed slope (fig. 9). These channels are 200 to 600 m wide and are eroded anywhere from 30 to 80 m deep into underlying mélange. The channels may indicate location of meanders of a Late Pennsylvanian paleo-marine channel system. Farther to the south, the basal lower conglomerate wedges out completely and is replaced by laminated calcareous siltstone that directly overlaps eroded Devonian mélange (fig. 13). Each of two areally restricted conglomerate lenses in the northern part of the area was examined and pebbles were counted, respectively site nos. 3 and 4 from north to south. The largest and southernmost conglomerate lens includes site nos. 1 and 2 (figs. 4, 9). A preponderance of subangular and subrounded pebbles is clear in both general and detailed photographic views of the sites (figs. 14, 15).

The Northwest Area comprises a single outcrop of the lower conglomerate of the Strathearn Formation, approximately 300 x 200 m in area (figs. 4, and 16 to 18). Lower conglomerate at this outcrop lies against a sinuous non-faulted approximately vertical surface of mélange; conglomerate also contains a number of joint surfaces that contain well-developed slickensides (fig. 17*C*). Nonetheless, overall visual appearance of lower conglomerate at this site is quite similar to that in the Beaver Peak Area (sites 1–4, fig. 4).

Microscopic study of thin sections of lower conglomerate revealed three main features (fig. 22):

(1) Matrix makes up 30 to 50 volume percent of the rock, averaging 44 percent (table 2)—it mainly consists of sandy material of subrounded and subangular monocrystalline quartz grains as much as 0.3 mm in diameter.

(2) Clay minerals are a binding component of the matrix—they form elongated and irregular micro-scale aggregations, as much as 1.5 mm long.

(3) Chert pebbles and small quartz grains as well as clay-mineral aggregations do not show any sign of diagenetic or post-lithification hydrothermal recrystallization.

Upper conglomerate

The upper conglomerate of the Strathearn Formation is exposed at two nearby areas in the southern part of the greater Beaver Peak area (fig. 4). Sites 9 and 10 are located in the southern lens (700 x 120 m) of upper conglomerate that is bounded by curved latitudinal faults and surrounded by (1) underlying siltstone of the Strathearn Formation and by (2) the mélange unit. The northern exposure is larger, approximately 800 x 700 m, and includes seven sample sites (sites 11 to 17). The upper conglomerate at the northern exposure conformably overlies siliceous siltstone of Strathearn Formation and onlaps Ordovician Vinini quartzarenite in the upper plate of the Coyote thrust (figs. 4, 8). Framework pebbles in the upper conglomerate also are either chert or quartzarenite and average about 45 volume percent coarse-grained sandy matrix. However, the upper conglomerate is better sorted than the lower one (as demonstrated by smaller standard deviations of pebble length of both chert and quartzarenite, tables 5 and 7) and thus visually distinctive from it. In addition, pebble roundness is better developed, primarily because subrounded and rounded pebbles are prevalent. Finally, relatively higher percentages of white quartzarenite pebbles are present in the upper conglomerate versus the lower one (figs. 19–21).

The upper conglomerate shows the following characteristics under the microscope:

(1) Clasts of differing composition, size, and roundness are contiguous with one another without any interfragmental cementing clay minerals—cement is not present in such samples (fig. 23).

(2) Quartzarenite pebbles are composed of well-rounded and well-sorted monocrystalline quartz grains without any sign of recrystallization (fig. 24*A*). Some individual sandy chert pebbles are present and include silt-sized, well-rounded, and unaltered quartz grains set in a microcrystalline or cherty siliceous matrix (fig. 24*B*).

(3) Fibrous chalcedonic quartz and several generations of microcrystalline quartz veinlets are present within some chert pebbles (fig. 24*C*). These veinlets terminate at the pebble boundaries—they may represent some circulation of hydrothermal fluids related either to Devonian diagenesis of siliceous sediment or exhalative processes on the Devonian seafloor.

(4) In some samples, inter-clast space is filled by opaque mineral(s), probably Fe–oxide minerals (fig. 25*A*), and by quartz (fig. 25*B*–*D*). Wedge-like quartz offshoots penetrate the surface of chert fragments. Small quartz grains in the cement bordering pebbles are regenerated forming irregular star-shaped grains, in places aggregated into coherent veinlets (fig. 26*A*,

B). This alteration might be related to diagenesis, a quite weak hydrothermal injection using porous pathways through the cement—the latter possibly may be related to a deformation event. Small rounded monocrystalline quartz grains within quartzarenite pebbles have not been affected by recrystallization and neocrystallization (fig. 26*A*).

The major features typical of the upper conglomerate unit thus include: (1) predominant roundness of framework pebbles; (2) lack of clay-minerals as cement; and (3) presence of a quartz filling of inter-pebble space that is accompanied by quartz micro-crystals that show some signs of regeneration and recrystallization. These features distinguish the upper conglomerate from the lower one.

ANALYSIS OF PEBBLE COMPOSITION AND ROUNDNESS

Pebble composition and roundness were determined at a number of sites (1) to characterize further the two conglomerate units of the Strathearn Formation, and (2) to develop a base upon which an expanded statistical analysis could be conducted using the above-measured quantitative data of pebble size and shape. Eventually, such combination of a number of measured parameters of the conglomerates enhances the overall analysis by providing additional perspectives that contribute to an overall sedimentologic understanding of the Strathearn.

Comparative pebble compositions

Chert pebbles dominate the framework pebbles in the lower conglomerate—the lower conglomerate contains 96 percent chert pebbles from a total of 2,315 pebbles counted (table 2, fig. 27). Quartzarenite pebbles that are irregularly distributed in various framework sites represent the remaining 4 percent. Less than 10 quartzarenite pebbles (1 to 3 percent) were counted at sites 2, 5, and 8 (fig. 4), and quartzarenite pebbles are completely absent in three others (sites 4, 6, and 7). Quartzarenite forms comparable subsets of 35 and 27 counted pebbles (16 and 10 percent respectively) at sites 1 and 3. The overall sparse content of quartzarenite pebbles in the lower conglomerate unit is quite clear on a general percentage plot (fig. 27*A*). This is a feature typical of the lower conglomerate unit whose framework pebbles have fragments of Devonian Slaven Chert, either bedded or mélange, as their major source. The generally sparse and irregular distribution of quartzarenite pebbles in framework sites throughout the lower conglomerate unit probably represents either their relatively distant transportation under unstable conditions or source regions that are generally sparse in quartzarenite—such conditions may correspond to initial stages of the Strathearn basin development over northeastern Nevada (see below).

In contrast with the lower unit, the upper conglomerate unit of the Strathearn Formation contains a considerable amount of quartzarenite pebbles, averaging 24 percent of the total 1,894 pebbles counted (table 3, fig. 27). Quartzarenite pebbles are present at every site examined in various proportions that range from 20 to 75 counts. The lowest percent of quartzarenite pebbles is present at sites 10 and 17 of the upper conglomerate unit (5 and 9 percent respectively, fig. 27*A*), but these minima are higher than the total 4 percent of quartzarenite pebbles detected in the lower conglomerate unit. With the exception of these two sites, the proportion of chert and quartzarenite pebbles at the other upper conglomerate sites is comparable, though chert pebbles generally are more abundant than quartzarenite. The difference in overall distribution of chert and quartzarenite pebbles between the lower and upper conglomerate units becomes obvious when these data are plotted (fig. 27*A*).

Comparative pebble roundness

Separation of chert and quartzarenite pebbles of lower and upper conglomerates into three categories of roundness—subangular, subrounded, and rounded—is shown in tables 2 and 3 and plotted on figures 27*B*–*D*, and 28.

The lower conglomerate unit is characterized by predominance of subangular and subrounded chert pebbles (average 46 and 51 percent respectively of the total number of chert pebbles) and of quartzarenite pebbles (average 29 and 54 percent respectively). A plot of roundness frequencies in different localities (fig. 28*A*) shows that the percentage of subangular and subrounded chert pebble populations is roughly comparable in the lower conglomerate—they range between approximately 35 and 60 percent. Rounded chert pebbles, however, are rare in the lower conglomerate unit (average 3 percent) and rounded quartzarenite pebbles are minor (average 17 percent; table 2, fig. 27*D*). The relative proportions of subrounded chert and quartzarenite pebbles are quite comparable in sites 1, 2, 3 and 5 where quartzarenite pebbles are noticeably present (fig. 28*C*). Subangular chert pebbles are more abundant than subangular quartzarenite pebbles at all sites of the lower conglomerate unit (fig. 27*B* and

28). As a rule, rounded chert pebbles are subordinate to rounded quartzarenite pebbles (fig. 27*D*). However, these latter relations should be considered only as possible because of the small number of rounded chert pebbles encountered (70 counts, table 2) and also because of the small number of quartzarenite pebbles in both the subrounded counts (44) and rounded counts (14).

The upper conglomerate unit is distinguished from the lower one by differing proportions of pebble roundness (table 3). The upper unit is characterized by a preponderance of subrounded and rounded categories for both chert pebbles (average 45 and 33 percent respectively) and quartzarenite pebbles (average 28 and 70 percent respectively). Frequency plots at each site (fig. 28*A*, right side) show that percentages of subangular, subrounded, and rounded chert pebbles in the upper conglomerate unit are roughly comparable. On the contrary, subangular quartzarenite pebbles are rare in the upper unit (average 2 percent)—a large proportion (50 to 91 percent) of quartzarenite pebbles, however, belong to the rounded category (fig. 29*B*). Nonetheless, in 14 of 17 sites examined in both conglomerate units, the relative proportions of subrounded category of chert and quartzarenite pebbles are in close agreement (fig. 28*C*). However, the proportion of subrounded quartzarenite pebbles in the lower conglomerate unit is much more varied than that in the upper conglomerate. In addition, abundance differences between subangular chert and subangular quartzarenite pebbles in the lower conglomerate unit are greater than comparable differences in the upper one (fig. 27*B*). However, these differences are subordinate to differences between the two conglomerate units in the rounded category of pebbles (fig. 27*D*). Any conclusions concerning subangular quartzarenite pebbles should be considered tentative because of the generally small number of subangular quartzarenite pebbles at most sites and their complete absence at four sites (table 3).

Our analysis of these data on pebble composition and roundness revealed the following common features:

(1) The lower and upper conglomerate units roughly are similar in that they both include only chert and quartzarenite pebbles, but they differ in compositional proportions of the two pebble types. The relative proportion of quartzarenite pebbles in the upper conglomerate unit is six times that in the lower unit, whereas chert pebbles predominate in both units.

(2) In comparison with the lower conglomerate unit, pebble roundness in the upper conglomerate unit is substantially greater, especially in quartzarenite pebbles, than the lower conglomerate unit.

(3) With respect to major roundness categories, the sites examined in the two conglomerate units show generally similar intraunit results for each of the two compositional varieties of pebble, but quite different results when lower and upper conglomerate units are compared. Generally, gradations among the various roundness categories we examined apparently are not present in pebble populations of either conglomerate unit. This suggests not only different ages of deposition of the two units relative to each other, a relation that has been established structurally and stratigraphically (figs. 4, 8), but also a change of geologic conditions in source region(s) and (or) in depositional environments.

ANALYSIS OF PEBBLE SIZE AND SHAPE

Pebble size (A) and shape (B/A) of clasts are typical quantitative measures used in the study of conglomerates (Greensmith, 1978; Howard, 1993; Dickerman, 1999). An enhancement in the present study to what many other previous investigators have attempted elsewhere is our involvement of pebble size and shape in statistical analysis along with pebble composition and roundness qualitative data.

Appendix A contains data obtained from quantitative pebble measurements of the lower and upper conglomerate units of the Strathearn Formation in the northern Carlin trend area. This table also includes calculated ratios (B/A) that are used to characterize pebble shapes (ratio of short axis “B” to long axis “A” of a pebble). Appendix A also contains logarithms to the base 10 of B and A. The data are grouped by site for each of 17 sites: sites 1 to 8 are in the lower conglomerate unit, and sites 9 to 17 in the upper one (fig. 4). Shapes of most water-worn gravel clasts have been shown to be approximately ellipsoidal (Koster and others, 1980). We further recognize the necessity of triaxial measurements of pebbles to fully describe the size of an individual pebble (see also, Krumbein, 1941; Barrett, 1980; Howard, 1992, 1993). However, we are precluded from obtaining such three dimensional data in this study because of well-developed lithification of the conglomerate units as described above.

At the outset, it is extremely important to emphasize that a preliminary overview of the quantitative data obtained shows that scatter plots of either short axis or long axis measurements alone mainly result in apparently diffuse clouds of points that are difficult to interpret. They are difficult to reconcile among the various pebble sets and subsets of the two conglomerate units, as well as their various pebble compositions and roundness categories. However, as will be described fully below, some significant geologic trends that vary areally can be extracted from the data by treating different pebble sets and (or) subsets as groups.

Basic descriptive statistics of the B (short axis) and A (long axis) (in logarithms) as well as (B/A) for the main data sets and subsets are shown in table 4 for the lower conglomerate unit, and in table 5 for the upper conglomerate. The statistics reported in these tables include number of pebbles in a particular data set or subset, measured or calculated minimum–maximum limits, as well as means, standard deviations, and medians. The following data sets and subsets have been prepared and are characterized statistically in the above-listed tables: (1) a total chert-pebble subset from each conglomerate unit; (2) a total quartzarenite-pebble subset from each conglomerate unit; (3) subsets of the three different pebble-roundness categories—subangular, subrounded, and rounded—for each of the two different pebble compositions chert and quartzarenite; (4) compositional subsets for chert and quartzarenite pebbles for each site. More detailed subdivision by pebble roundness in various pebble-composition subsets from each site was not attempted because, in many cases, the number of pebbles appeared to be less than that requisite for valid statistical comparisons. It appears that the detail to which we have taken our analysis provides satisfactory statistical comparisons of the measured data with the previously described qualitative data.

After a number of trial experiments, the median of pebble long axis (A), mean of B/A ratio, and the means and standard deviations of A and B, were chosen as the most useful statistics to reveal major characteristics and main relations among the various pebble sets and subsets.

Tests of group differences

Histograms of logA mostly show approximate lognormal distributions of this size measure size in all sets and subsets of the two conglomerate units, including various subsets defined on the basis of pebble composition and pebble roundness (figs. 29–31). However, histograms of logA of lower conglomerate quartzarenite pebbles of variable roundness categories (figs. 31*A*, *C*) do not demonstrate well-developed lognornal distributions because of the small numbers of samples in the subsets. Further, histograms of all subsets from the lower conglomerate unit show distributions that are weakly skewed positively, whereas all subsets from the upper conglomerate are not. Because of the small numbers of samples, histograms for subangular pebbles of quartzarenite from the upper conglomerate (fig. 32*B*, n = 9) and for rounded pebbles of quartzarenite from the lower conglomerate (fig. 32*E*, n = 14) were not prepared. Nonetheless, those demonstrated lognormal distributions of logA provide a statistically valid foundation for comparisons of medians of A among the various pebble sets and subsets (tables 4 and 5).

Two sets of samples usually will have different means (even when the data were properly transformed)—the question is whether the difference in means is more than can be expected by chance alone. Our goal here was to determine whether there were significant differences between the sizes and shapes of types and locations of pebbles. A well known statistical procedure called analysis of variance is ideally suited for these questions because it provides for the decomposition of the total variation into parts which can be assigned to separate sources contributing to the total variation (Griffiths, 1967). Here, for example, we hypothesize that the sizes in logarithms (A) of pebbles are the same for chert and quartzarenite and we use analysis of variance to test the hypothesis (table 6a). Total variation of the measured size of 4,209 pebbles was partitioned to that between pebble types (chert and quartzarenite) and within pebble types (called error) in Table 6a. If the mean sizes of chert and quartzarenite vary more than the variation of sizes within pebble type, then the F ratio will be large—the associated probability tells how likely a difference of that size could occur by chance if there were no difference between the groups. In the long "A" axis case of pebble type, the probability is 0.000 (table 6a) so we conclude that the sizes of chert and quartzarenite pebbles are significantly different. The shapes of pebble composition types as measured by B/A are also significantly different (table 6b). To avoid mixing these statistically different kinds of pebbles in further analyses, we analyze the groups separately below.

In Tables 4 and 5, the mean size (A) of chert pebbles is larger in the lower conglomerate than in the upper conglomerate—the difference is significant (table 6c). Similarly, quartzarenite pebbles are significantly larger in the lower conglomerate (tables 4, 5, and 6d). Chert pebbles are significantly more circular in shape in the upper conglomerate (tables 4, 5, and 6e). The same is not true for quartzarenite pebbles—their pebble shapes (B/A) in the lower and upper conglomerate are not significantly different (table 6f).

Comparison of pebble length

The 2,345 measured chert pebbles from the lower conglomerate unit have a median length 20.0 mm (table 4). However, quartzarenite pebbles in the lower conglomerate, although represented by only 81 pebbles, have a much larger median length of 25.2 mm. In addition, median pebble length does not rise in correspondence with an increase of pebble roundness in the chert subset (18.8; 21.0; and 20.8 mm, respectively analogous to subangular, subrounded, and rounded pebble categories) but does rise in the quartzarenite subset (16.9; 26.7; and 40.6 mm, respectively). This trend is perhaps related to the rock-fracture susceptibility and hardness in relation to a distance of pebble transportation. For instance, during erosion, breakdown of bedded chert commonly produces more small angular fragments than quartzarenite, which subsequently rounds more easily than chert under equivalent conditions of erosion (Greensmith, 1978). Large homogenous blocks of rocks generally become more resistant to fragmentation in the course of their rounding along a paleo-river stream. Certainly, spacing of joints and any other planar structural surfaces in bedrock also would influence fragment size and morphology at the outset of the process of erosion.

Spatial distribution of pebble size at various sites examined from the lower conglomerate unit is shown on a schematic map of exposures of Strathearn Formation in the Beaver Peak and Northwestern areas (fig. 32). In both areas, sample sites are located approximately along longitudinal trends about 330 and 100 m long, respectively. Analysis of variance of the sizes among sites in the lower conglomerates demonstrates that the sites are significantly different (table 5g). The distribution of median pebble size in stratigraphically similar basal conglomerate beds is well ordered showing a regular increase northward. Estimated medians are the antilogarithms of the means of the logA in Table 5. The spatial trend is expressed by contours of median pebble size (A) that suggest a probable pebble-source region to the north consistent with previous paleotectonic reconstructions (Theodore and others, 1998; Theodore and others, 2000). In addition, visual examination of pebble size in lower conglomerate of the Strathearn Formation that crops out well west of the study area in the SRF quadrangle suggests that pebble size also decreases dramatically to the west.

Major relations among pebble sizes in the lower conglomerate are preserved in the upper unit as well: median pebble length clearly is larger in the quartzarenite subset compared to the chert subset, 15.1 versus 18.9 mm (table 5). Further, within these two subsets median pebble size rises in association with an increase of roundness: respectively 15.0, 15.0, and 15.3 mm for subangular, subrounded, and rounded chert pebbles, as well as a corresponding 16.0, 16.0, and 20.3 mm for quartzarenite pebbles. These data also show that median sizes in the upper conglomerate unit are much more uniform than in lower conglomerate. Because of this, areal trends of various pebble-size distributions were not detected in this unit. The upper conglomerate unit apparently was deposited after a period of minor drowning or foundering—represented by the intervening calcareous siltstone between the two units—of marine channels preserved in a generally middle shelf or deeper environment (see also, Theodore and others, 1998). Thus, from a facies model reconstruction, the upper conglomerate unit should represent a sedimentary facies more distal from its source than the lower conglomerate unit. Certainly, multicyclic reworking, from conglomerates, even from some "upstream" equivalents, that are older than the Strathearn Formation and that are present in Mississippian and Pennsylvanian overlap rocks in the region (fig. 3) might be a possible process involved in the genesis of the two conglomerates in the Strathearn (J.H. Trexler, Jr., written commun., 2001). However, some remarkably well-exposed relations at the unconformity between the upper conglomerate unit and its underlying quartzarenite shows quartzarenite fragments actually breaking away from an immediately subjacent unfragmented source. Such relations appear to provide some evidence that reworking from older conglomerates may not have been an important process in the sedimentary evolution of the conglomerates of the Strathearn at BP.

Some considerations on pebble shape

Pebble shape is defined as the ratio (B/A) calculated from axial measurements of pebbles; the observed ratio ranges from 0.1 to 1.0. Histograms of shape show similar distributions in all sets and subsets of the two conglomerate units, including subsets subdivided by pebble composition and various roundness categories (figs. 33–35). The bimodal nature of each of these histograms suggests that at least two populations are present—a prominent mode at class interval (B/A) = 1 is clearly present in each histogram. The peak (B/A) = 1 is absolutely clear on histograms for shape for the entire pebble population of the lower conglomerate, as well as its chert and quartzarenite components (fig. 33*A*, *C*). A similar peak is prominent on corresponding histograms of the upper conglomerate (fig. 33*B*, *D*). Comparable distributions are present in chert subsets of various pebble-roundness categories (fig. 34). Histograms for shapes of quartzarenite pebbles also show similar distributions (fig. 35), but the number of quartzarenite pebbles in some categories is so small that histograms were not prepared.

Examination of various roundness categories of chert pebbles in both conglomerate units shows that the equant pebble class (B/A) = 1 clearly is represented strongly even in the subangular category, the lowest roundness categories for the pebbles (fig. 34*A*, *B*). Thus, development of equant pebbles cannot be totally ascribed to a rounding process during predeposition transport. The equant character of many pebbles might, in part, be an original feature inherited from pre-erosion rock fractures and (or) bedding that control overall form (Barrett, 1980) of the fragments prior to their release to the transport environment.

Another possible explanation of the bimodal distribution of pebble shapes might be operator errors. In some cases, measurement of shapes of small items tends toward circular shapes due to the difficulty of distinguishing the minor axis from the major axis. In these cases, we would expect to see shapes (B/A) becoming more circular as sizes become smaller. These data show no such trend, so we conclude that operator error did not cause the bimodal distributions of shapes. The reason for the bimodal distribution is not evident to us.

Plots of mean (B/A) versus median pebble length in mm (fig. 36) for individual sites of both conglomerate units reveal possible spatial trends of these two variables in both the Beaver Peak area and the Northwestern area for one of the conglomerate units. Distribution of sites in the upper unit (fig. 36*B*) apparently does not show any regular trends. In contrast, the diagram of the lower unit (fig. 36*A*) reveals similar trends in distribution of quartzarenite pebble subsets at Beaver Peak area and of chert-pebble subsets at Northwestern area. These trends are outlined by wide arrows that show a regular increase of mean (B/A) values—that is, an increase in the tendency for the pebbles to achieve an equant form—that also corresponds with a decrease of median pebble size. Geographically, the arrows are oriented southward, in present-day coordinates, probably coincident with the washdown direction that indicates a paleotectonic source region of the pebbles somewhere to the north of the studied areas (see also, fig. 32). In addition to the relevance of these relations for paleobasin facies analysis, they reveal an additional correlative opposing tendency wherein mean (B/A) increases toward distal parts of the basin and median pebble length decreases toward distal parts of the basin. However, this relation, to some unknown extent, may include some operator bias introduced during clast measurement. Tumbler experiments on 0.25– to 0.50–mm size fractions of quartz grains show an increase of smaller shape-ratio (B/A) values with time suggesting that grain-parallel fractures may be important in final determination of overall shape ratios in detrital environments (Osborne and others, 1993). Thus, our determination of an increase of mean (B/A) values toward distal parts of the basin for pebbles in the Strathearn Formation is compatible with an increase in duration of abrasive transport of the pebbles prior to deposition.

DISCUSSION AND CONCLUSIONS

The two framework-supported, poorly bedded conglomerate units of the Strathearn Formation in the northern Carlin trend, in places deposited in well-defined channels recognized in the lower conglomerate unit, represent submarine fanglomerates whose monocrystalline quartz grains in the matrix and quartzarenite fragments of variable roundness and shape were derived from a largely southeastward advancing allochthonous lobe of mostly quartzarenite of the Ordovician Vinini Formation. No channels were recognized in the upper conglomerate unit possibly because of the limited areal extent of the unit. The upper conglomerate unit crops out in an area of approximately 0.25 km^2 (fig. 4). Conodont biofacies throughout the Strathearn Formation are normal marine and suggest middle shelf or deeper depositional environments (table 1).

Various roundness categories of chert pebbles in both conglomerate units of the Strathearn Formation show that the equant pebble class (B/A) = 1 clearly is represented strongly even in the subangular category, the lowest roundness categories for the pebbles. Thus, development of equant pebbles cannot be ascribed totally to a rounding process during predeposition transport. The equant character of many pebbles might, in part, be an original feature inherited from pre-erosion rock fractures and (or) bedding that control overall form (Barrett, 1980) of the fragments prior to their release to the transport environment.

As noted above, the lower and upper conglomerate units roughly are similar in that they contain only chert and quartzarenite pebbles, but they differ in compositional proportions of these two lithologies. The relative proportion of quartzarenite pebbles increases sixfold in the upper conglomerate unit versus its content in the lower unit, whereas chert pebbles predominate in both units. The middle Early Permian upper conglomerate unit, highest unit recognized in the Strathearn Formation, as well as similarly-aged dolomitic siltstone, onlap directly onto quartzarenite that comprises the allochthon of the Coyote thrust. Chert fragments in the conglomerates probably were derived mostly from Devonian Slaven Chert, including a widespread thick mélange unit of the Slaven in the footwall of the Coyote thrust. However, we have no radiolarian data from chert pebbles in either lower or upper conglomerate units of the Strathearn. Some chert pebbles may have been derived from the Ordovician Vinini

Formation. Thus, thorough analysis of pebble roundness, size, and composition of more than 4,000 pebbles from the Strathearn Formation contributed significantly to our understanding of the sedimentologic evolution of this critical unit during an accompanying regionally extensive contractional event in the late Paleozoic.

Paleo-environmental indicators from conodont biofacies determinations (table 1), as well as clast composition, roundness, and shape-ratio values are all compatible with the lower and upper conglomerate units of the Late Pennsylvanian and middle Early Permian Strathearn having mixed source areas within the allochthon of the RMT. Further, widespread geologic evidence in the greater BP area indicates that the allochthon of the RMT was reactivated sometime following initial deposition of the middle Late Pennsylvanian lower conglomerate unit of the Strathearn Formation (fig. 37). We suggest that contractional reactivation largely was completed by middle Early Permian, on the basis of the youngest conodont ages (table 1) that we have obtained from the Strathearn Formation.

Globally, the late Paleozoic, specifically during the Late Pennsylvanian and the Early Permian, marked an important time in the geodynamic evolution of the Earth. During this time interval, North America, as an element of the Laurussian continental mass, formed part of the Pangean supercontinent—the general area of present-day northern Nevada was near the equator (Golonka and Ford, 2000; see also, Fluteau and others, 2001). Regardless of the specifics concerning overall configuration of Pangea (Fluteau and others, 2001), general consensus appears to place present-day northern Nevada approximately at latitude 2–3°N during the Late Pennsylvanian. The marine environment that we have documented in Late Pennsylvanian and Early Permian rocks of the Strathearn must represent an encroachment of shallow epicontinental seas from the eastern margin of Panthalassa onto the North American continent. As noted above (see also, table 1), the lower unit of the Strathearn—that part of the formation below the Coyote thrust—appears to represent a progressive drowning or deepening with time of a largely middle shelf environment, an observation which is compatible with global climatic data. On the basis of mean global temperature curves, the Mississippian and Pennsylvanian apparently were a relatively cool period of time during which sea level changes were quite frequent (Postma, 2001). Ross and Ross (1988) recognize about 60 Carboniferous and Permian transgressive-regressive sequences in strata present on stable cratonic shelves. Although much remains to be resolved concerning specifics of late Paleozoic tectonism and its interactions with global eustatic events in the region, Early Permian thrust faults elsewhere in the western Cordillera have been reported in east-central California (Stevens and Stone, 1988). Such contractional reactivation, including that in the greater BP area, probably occurred in conjunction with extensive late Paleozoic tectonism in western North America. Such tectonism is currently best ascribed to the Ouachita tectonic assembly or collision along what is now the southern margin of North America in conjunction with development of the Ancestral Rockies (Golonka and Ford, 2000; see also, Dickinson, 2001).

Much of the late Paleozoic tectonism in northern Nevada heretofore was envisaged to be extensional and (or) epeirogenic (Ketner, 1977). Thus, low-angle thrusting during the late Paleozoic at BP apparently contributed toward exhumation of the allochthon of the Coyote thrust that, in turn, provided a source region for much of the quartzarenite detritus deposited preferentially in the upper parts of the Strathearn Formation. Such a tectono-sedimentary conceptual model is similar to that proposed for development of fan-delta wedges in northeast Spain along the margin of the Ebro basin adjacent to the Catalan Coast Ranges (Lopez-Blanco and others, 2000), and the coarse clastics associated with the Antler foreland basin (Harbaugh and Dickinson, 1981). We cannot evaluate how much, if any, subsidence of the Strathearn basin is a result of downflexure of the underlying supracrustal rocks due to structural load from the advancing late Paleozoic thrust sheets (see also, Price, 1973). In the northern part of the area, siliceous allochthonous rocks above the sole of the Coyote thrust apparently are as much as 1,500 m thick (Theodore and others, 2001).

Regionally in the general area of BP, contractional deformation dating from the late Paleozoic involves reactivation of rocks previously emplaced along the RMT—this deformation affects rocks of the Strathearn Formation. We further suggest that late Paleozoic thrust faults in the area most likely represent episodic Ancestral Rockies-age shortening and uplift that may have been associated with docking of the Ouachita orogenic belt (Oldow and others, 1989; Ye and others, 1996; Geslin, 1998; Dickinson, 2001; see also, Saucier, 1997; Cluer, 1999). Viele and Thomas (1989) note that geologic structures related to the Ouachita belt extend onto the craton. However, as further pointed out by Viele and Thomas (1989), a number of problems—including tectonic syntheses requiring presence of rift-related early Paleozoic sedimentary rocks—still require solution before all tectonic elements in the Ouachita belt are understood fully. In addition, the latest contractional tectonism in the Ouachita belt is believed to have ended by Late Pennsylvanian (Viele and Thomas, 1989) whereas we suggest that thrusting may have continued to middle Early Permian at BP. Nonetheless, problems inherent throughout northern Nevada in unraveling late Paleozoic geologic events are well exemplified by the investigations of Moore and others (2000) in the southern Shoshone Range.

A number of thrust faults have been recognized in other places in Nevada that may date from the late Paleozoic. As described above, the Coyote thrust may be correlative with the Lander thrust in the Shoshone Range. Somewhat farther to the west in the Edna Mountains (fig. 1), Erickson and Marsh (1974) documented clearly the presence of deformation of Late Pennsylvanian or Early Permian age. Folded strata involving the Middle Pennsylvanian Battle Formation, the Late Pennsylvanian Highway Limestone, and the Pennsylvanian and Permian Antler Peak Limestone make up the upper plate of the Iron Point thrust (Erickson and Marsh, 1974). This deformation must have occurred prior to deposition of the Middle and (or) Late(?) Permian Edna Mountain Formation in the area. Elsewhere throughout Nevada during the late Paleozoic, protracted shortening and uplift were marked by multiple unconformities of regional extent suggesting active tectonism all through this period of time (Snyder and others, 2000).

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Table 1. Description of selected conodont samples from the Beaver Peak area, Nevada.

[Conodont samples collected by T.G. Theodore; conodont analyses by A.G. Harris. Map locality numbers keyed to figure 4. CAI, conodont color alteration index]

CONODONTS							
MAP LOC. NO. (FIELD NO.; USGS COLLN. NO.)	**LATITUDE N./ LONGITUDE W. 7.5 MIN. QUADRANGLE**	**STRATIGRAPHIC UNIT AND LITHOLOGY**	**CONODONT FAUNA**	**AGE**	**CAI**	**CONODONT BIOFACIES AND DEPOSITIONAL ENVIRONMENT**	**SAMPLE WEIGHT AND COMPOSITION OF HEAVY-MINERAL CONCENTRATE (HMC)**
6 (97TT-51; **33385-PC**)	41°05'15"/ 116°17'25" Beaver Peak, Elko County	Strathearn Formation. Approximately 1–m-thick bed near base of chert-pebble conglomerate sequence resting on Devonian chert melange unit of Slaven Chert. Thin section contains abundant fusulinids.	*Streptognathodus* sp. 10 Pa and 3 Pb elements (small juveniles, subadults, and a few adults) (figs. 5A, B) 19 indet. bar, blade, and platform fragments	Desmoinesian-Sakmarian (late Middle Pennsylvanian-early Permian); fusulinids from same locality indicate a late Missourian age (early Late Pennsylvanian).	1.5–2	Indeterminate (too few generically identifiable conodonts); normal-marine depositional setting.	1.5 kg of rock processed (80 g +20 and 74 g 20-200 mesh insoluble residue). HMC: chiefly anhedral and euhedral barite and lesser ferroan dolomite and composite ferruginous flakes.
7 (97TT-52)	41°05'11" 116°17'21" Beaver Peak, Elko County	Strathearn Formation. Buff-weathering dolomitic siltstone containing angular fragments of quartz and abundant Kfeldspar.	1 indet. bar or blade fragment	Ordovician-Triassic.	1.5 or 2	Indeterminate (too few conodonts).	0.5 kg of rock processed (380 g +20 and 30 g 20-200 mesh insoluble residue). HMC: composition not recorded.
10 (97TT-63; **33386-PC**)	41°04'58"/ 116°15'25" Beaver peak, Elko County	Strathearn Formation. Buff-gray micrite, approximately 10–15 m thick, above basal chert-pebble conglomerate. Thin section contains abundant fusulinids.	*Hindeodus minutus* (Ellison)? 4 Pa, 2 Pb, 1 Sa, and 1 Sc elements (figs. 5E-G) *Streptognathodus* sp. 12 Pa and 1 M elements (fig. 5D) 19 indet. bar, blade, and platform fragments	Late Pennsylvanian-middle Early Permian.	2	Streptognathodid-hindeodid biofacies; at least middle shelf or deeper water depositional setting.	1.2 kg of rock processed (20 g +20 and 28 g 20-200 mesh insoluble residue). HMC: chiefly phosphatic brachiopod fragments and composite ferruginous flakes and grains, and minor ichthyoliths.
11 (97TT-64; **33387-PC**)	41°05'11"/ 116°15'21" Beaver Peak, Elko County	Strathearn Formation. Same stratigraphic position as 97TT-63 but approximately 30 m thick at this locality. Buff-gray micrite with calcareous mud lumps and shell fragments.	*Streptognathodus* sp. indet. 4 juvenile Pa elements 1 unassigned Sc element 17 indet. bar, blade, and platform fragments	Late Pennsylvanian-middle Early Permian.	1.5	Indeterminate (too few conodonts); the conodonts indicate a normal-marine depositional setting.	1.6 kg of rock processed (15 g +20 and 77 g 20-200 mesh insoluble residue). HMC: chiefly phosphatic brachiopod fragments and composite dolomitic ferruginous grains.

13 (97TT-67; **33388-PC**)	41°04'40"/ 116°15'12" Beaver Peak, Elko County	Strathearn Formation. Silty to sandy sparry limestone near top of Beaver Peak and approximately 200 m stratigraphically above samples 97TT-63 to –65.	*Mesogondolella bisselli* (Clark and Behnken) 2 Pa elements (figs. 5H-J) *Mesogondolella* sp. indet. 25 Pa element fragments *Streptognathodus* sp. indet. 6 Pa element fragments *Sweetognathus whitei* (Rhodes) 4 Pa element fragments (figs. 5K-N) 1 unassigned M element 30 indet. bar, blade, and platform fragments	latest Sakmarian-earliest Artinskian (late Wolfcampian; middle Early Permian).	2.5	Mesogondolellid; normal-marine, middle shelf or deeper water depositional setting.	1.8 kg of rock processed (100 g +20 and 82 g 20-200 mesh insoluble residue). HMC: chiefly weathered pyrite euhedra, phosphatized bioclasts, phosphatic brachiopod fragments, and minor composite ferruginous grains and ichthyoliths.
14 (97TT-80)	41°04'02"/ 116°16'35" Beaver Peak, Elko County	Strathearn Formation. Drab light-gray to buff 2–m-thick sequence of silty limestone including abundant angular fragments of monocrystalline quartz.	3 indet. bar fragments	Silurian-Triassic.	1–1.5	Indeterminate (too few conodonts).	2.2 kg of rock processed (1.46 kg +20 and 52 g 20-200 mesh insoluble residue). HMC: composition not recorded.
15 (97TT-82; **33389-PC**)	41°03'27"/ 116°17'31" Beaver Peak, Elko County	Strathearn Formation. Dolomitic siltstone.	*Streptognathodus* sp. indet. 1 juvenile Pa element fragment	late Morrowan-earliest Artinskian, most probably no older than Missourian (Middle Pennsylvanian-middle Early Permian, most probably no older than middle Late Pennsylvanian).	1.5–2	Indeterminate (too few conodonts).	2.7 kg of rock processed (180 g +20 and 132 g 20-200 mesh insoluble residue). HMC: chiefly barite and lesser ferruginous barite and baritized composite grains and minor dolomite.
16 (97TT-83; **33390-PC**)	41°03'27"/ 116°17'20" Beaver Peak, Elko County	Strathearn Formation. Dolomitic siltstone including some rounded monocrystalline quartz sand grains. Sparry matrix partly replaced by barite.	*Polygnathus* sp. indet. 1 incomplete Pa element of Middle-Late Devonian morphotype (upper surface mostly covered by adventitious quartz grains) 1 juvenile Pa element fragment of Carboniferous-Permian morphotype 4 indet. bar, blade, and platform fragments	late Paleozoic (Late Mississippian-Early Permian) with redeposited Middle-Late Devonian conodonts.	1.5–2	Indeterminate (too few conodonts).	2.7 kg of rock processed (120 g +20 and 363 g 20-200 mesh insoluble residue). HMC: chiefly baritized composite grains and minor dolomite.
17 (97TT-84; **33391-PC**)	41°03'34"/ 116°17'34" Beaver Peak, Elko County	Strathearn Formation. Sparry dolomitic siltstone rests unconformably above tectonically emplaced quartzarenite of Vinini Formation.	*Streptognathodus* sp. indet. 16 Pa element fragments (chiefly juveniles and subadults) (fig. 5C) 1 digyrate Sa element fragment 11 indet. bar, blade, and platform fragments	late Morrowan-Sakmarian, probably Missourian-Sakmarian (probably Late Pennsylvanian-early Early Permian).	1.5–2	Postmortem transport from or within the streptognathodid biofacies suggesting middle shelf or deeper water depositional setting.	4.2 kg of rock processed (300 g +20 and 337 g 20-200 mesh insoluble residue). HMC: chiefly barite and lesser phosphatic composite grains and minor dolomite.
18 (97TT-85)	41°03'39"/ 116°17'21" Beaver Peak, Elko County	Strathearn Formation. Flaggy, brown-gray dolomitic siltstone.	**BARREN.**				3.0 kg of rock processed (2.5 kg +20 and 24 g 20-200 mesh insoluble residue). HMC: chiefly barite, rock fragments and minor ferruginous rock fragments and composite ferruginous flakes.

27 (99TT003)	41°04'31"/ 116°17'07" Beaver Peak, Elko County	Strathearn Formation of Dott (1955); Pennsylvanian or Permian. Poorly exposed buff-weathering, calcareous siltstone, possibly dolomitic. Nearby exposed sequence of rocks includes 1- to 2-m-thick brown to dark-gray siltstone. interbedded with black, well-bedded chert.	**NO CONODONTS OR OTHER MINERALIZED FOSSILS WERE FOUND.**				1.3 kg of rock processed (1.2 kg +20 and 23 g 20-200 mesh insoluble residue). Heavy-mineral concentrate: chiefly ferruginous and nonferruginous dolomitic composite siltstone grains.
28 (99TT004 **33455-PC**)	41°04'31"/ 116°17'07" Beaver Peak, Elko County	Strathearn Formation of Dott (1955); Pennsylvanian or Permian. Same loc. as 99TT003. Brownish-gray, yellow-ochre-weathering, laminated, calcareous, possibly dolomitic siltstone. Sampled interval is 2- to 3-m thick and about 6 m topographically below 99TT003.	1 incomplete juvenile Pa element *Streptognathodus* sp. indet.	Middle Pennsylvanian-early Early Permian	1.5	Indet. (too few conodonts).	2.42 kg of rock processed (2.2 g +20 and 47 g 20-200 mesh insoluble residue). Heavy-mineral concentrate: chiefly ferruginous quartz grains, weathered pyrite euhedra.

Table 2. Summary data of pebble composition and roundness in lower conglomerate of Pennsylvanian and Permian Strathearn Formation, greater Beaver Peak area, Nev.

[**N**, set of counts; **n** and **m**, subsets of counts]

SITE No.	Mat-rix %	N	CHERT								QUARTZARENITE							
			TOTAL		INCLUDING						TOTAL		INCLUDING					
					Subangular		Subrounded		Rounded				Subangular		Subrounded		Rounded	
			n	% of N	n_1	% of n	n_2	% of n	n_3	% of n	m	% of N	m_1	% of m	m_2	% of m	m_3	% of m
1	50	225	190	84	112	59	71	37	7	4	35	16	18	51	15	43	2	6
2	45	210	203	97	102	50	89	44	12	6	7	3	2	29	3	43	2	29
3	50	306	279	90	94	34	165	59	20	7	27	10	1	4	17	63	9	33
4	50	314	314	100	112	36	186	59	16	5	0	0	0	0	0	0	0	0
5	50	301	292	97	160	55	131	44.7	1	0.3	9	3	2	22	6	67	1	1
6	30	326	326	100	165	50.4	159	49	2	0.6	0	0	0	0	0	0	0	0
7	35	307	307	100	145	46	156	52	6	2	0	0	0	0	0	0	0	0
8	40	326	323	99	135	42	182	56	6	2	3	1	0	0	3	100	0	0
Total	**44**	**2315**	**2234**	**96**	**1025**	**46**	**1139**	**51**	**70**	**3**	**81**	**4**	**23**	**29**	**44**	**54**	**14**	**17**

Table 3. Summary data of pebble composition and roundness in upper conglomerate of Pennsylvanian and Permian Strathearn Formation, greater Beaver Peak area, Nev.

[**N**, set of counts; **n** and **m**, subsets of counts]

SITE No.	**Mat-rix %**	**N**	**CHERT**								**QUARTZARENITE**							
			TOTAL		**INCLUDING**						**TOTAL**		**INCLUDING**					
					Subangular		**Subrounded**		**Rounded**				**Subangular**		**Subrounded**		**Rounded**	
			n	**% of N**	**n_1**	**% of n**	**n_2**	**% of n**	**n_3**	**% of n**	**m**	**% of N**	**m_1**	**% of m**	**m_2**	**% of m**	**m_3**	**% of m**
9	35	98	55	56	17	31	28	51	10	18	43	44	3	7	17	40	23	53
10	30	370	350	95	65	19	174	50	111	32	20	5	1	5	9	45	10	50
11	50	144	76	52	15	20	36	48	24	32	68	48	0	0	16	23	53	77
12	50	254	186	73	34	18	76	41	76	41	68	27	0	0	15	22	53	78
13	40	266	223	84	44	20	102	46	77	35	43	16	0	0	8	19	35	81
14	50	188	113	60	21	19	49	43	43	38	75	40	1	1	24	32	50	67
15	70	146	92	63	25	27	41	45	26	28	54	37	3	6	21	39	30	55
16	50	183	129	70	45	35	37	29	47	36	54	30	1	2	15	28	38	70
17	30	245	223	91	47	21	113	51	63	28	22	9	0	0	2	9	20	91
Total	**45**	**1894**	**1447**	**76**	**313**	**22**	**656**	**45**	**477**	**33**	**447**	**24**	**9**	**2**	**127**	**28**	**312**	**70**

Table 4. Summary statistics of pebble major (A) and minor (B) axes (logarithms), and shape measurements of lower conglomerate clasts of Pennsylvanian and Permian Strathearn Formation, greater Beaver Peak area, Nev.

Site No. and pebble type	**Number**	**B (log_{10} mm)**				**A (log_{10} mm)**					**B/A**		
		min.	**max.**	Mean	Std. Dev.	min.	max.	Mean	Std. Dev	Median A	min.	Mean	Std. Dev.
All Sites Chert	2234	0.477	2.204	1.088	0.244	0.602	2.398	1.300	0.245	20.0	0.111	0.651	0.212
Subangular	1025	0.477	1.903	1.051	0.224	0.602	2.176	1.273	0.232	18.8	0.111	0.638	0.214
Subrounded	1139	0.602	2,204	1.119	0.252	0.699	2.398	1.323	0.251	21.0	0.184	0.659	0.207
Rounded	70	0.602	2.033	1.129	0.312	0.602	2.114	1.319	0.301	20.8	0.206	0.696	0.250
All Sites Quartzarenite	81	0.699	1.903	1.248	0.298	0.778	2.114	1.401	0.312	25.2	0.333	0.732	0.203
Subangular	23	0.845	1.544	1.079	0.196	0.845	1.544	1.228	0.227	16.9	0.350	0.746	0.229
Subrounded	44	0.699	1.903	1.263	0.295	0.778	2.079	1.426	0.307	26.7	0.333	0.715	0.198
Rounded	14	1.000	1.903	1.479	0.288	1.000	2.114	1.608	0.314	40.6	0.500	0.763	0.183
Site 1 Chert	190	0.602	1.845	0.974	0.226	0.699	2.114	1.187	0.219	15.4	0.167	0.666	0.253
Quartzarenite	35	0.778	1.477	1.065	5.354	0.778	1.602	1.190	0.202	15.5	0.350	0.783	0.219
Site 2 Chert	203	0.602	1.699	1.038	0.228	0.602	2.041	1.239	0.254	17.3	0.235	0.681	0.255
Quartzarenite	7	1.000	1.903	1.282	0.293	1.146	1.903	1.416	0.285	26.1	0.400	0.771	0.242
Site 3 Chert	279	0.699	2.204	1.195	0.289	0.845	2.398	1.397	0.292	25.0	0.184	0.663	0.204
Quartzarenite	27	1.176	1.903	1.471	0.225	1.230	2.114	1.644	0.235	44.1	0.333	0.695	0.181
Site 4 Chert only	314	0.477	2.000	1.090	0.236	0.778	2.041	1.335	0.226	21.6	0.111	0.603	0.199
Site 5 Chert	292	0.699	1.602	1.043	0.201	0.778	1.813	1.231	0.203	17.0	0.260	0.677	0.195
Quartzarenite	9	0.699	1.778	1.117	.0.365	1.000	1.903	1.349	0.322	22.3	0.400	0.600	0.136
Site 6 Chert only	326	0.699	1.845	1.064	0.192	0.778	2.114	1.261	0.194	18.2	0.200	0.667	0.198
Site 7 Chert only	307	0.699	1.903	1.036	0.232	0.778	1.964	1.253	0.228	17.9	0.208	0.640	0.201
Site 8 Chert	323	0.699	2.079	1.205	0.247	0.845	2.301	1.432	0.237	27.0	0.175	0.627	0.201
Quartzarenite	3	1.603	1.740	1.680	0.071	1.699	1.903	1.793	0.103	62.1	0.688	0.774	0.076

Table 5. Summary statistics of pebble major (A) and minor (B) axes (logarithms), and shape measurements of upper conglomerate clasts of Pennsylvanian and Permian Strathearn Formation, greater Beaver Peak area, Nev.

Site No. and pebble type	**Number**	**B (log_{10} mm)**				**A (log_{10} mm)**					**B/A**		
		min.	**max.**	Mean	Std. Dev.	min.	max.	Mean	Std. Dev.	Median A	min.	Mean	Std. Dev.
All Sites Chert	1447	0.602	1.778	1.020	0.196	0.699	2.114	1.179	0.213	15.1	0.125	0.742	0.248
Subangular	314	0.602	1.699	0.999	0.193	0.699	1.778	1.176	0.204	15.0	0.125	0.717	0.252
Subrounded	656	0.602	1.613	1.004	0.182	0.699	2.114	1.176	0.198	15.0	0.133	0.718	0.242
Rounded	477	0.699	1.778	1.055	0.213	0.699	2.000	1.184	0.237	15.3	0.186	0.791	0.246
All Sites Quartzarenite	477	0.477	1.845	1.117	0.230	0.602	1.954	1.277	0.239	18.9	0.231	0.738	0.245
Subangular	9	0.699	1.204	0.902	0.180	1.000	1.477	1.203	0.169	16.0	0.233	0.521	0.135
Subrounded	125	0.477	1.653	1.017	0.200	0.602	1.653	1.204	0.227	16.0	0.233	0.693	0.243
Rounded	313	0.699	1.845	1.163	0.227	0.699	1.954	1.308	0.239	20.3	0.231	0.762	0.243
Site 9 Chert	55	0.699	1.544	1.043	0.192	0.954	1.845	1.231	0.195	17.0	0.250	0.697	0.253
Quartzarenite	43	0.699	1.398	1.054	0.185	0.903	1.699	1.275	0.223	18.8	0.333	0.639	0.232
Site 10 Chert	350	0.602	1.602	1.034	0.194	0.699	1.845	1.208	0.174	16.1	0.125	0.723	0.261
Quartzarenite	20	0.477	1.398	0.943	0.223	0.602	1.477	1.104	0.232	12.7	0.233	0.754	0.283

Table 5. Continued.

Site No. and pebble type		Number	B (log_{10} mm)				A (log_{10} mm)					B/A		
			min.	**max.**	Mean	Std. Dev.	min.	max.	Mean	Std. Dev.	Median A	min.	Mean	Std. Dev.
Site 11	Chert	76	0.699	1.602	1.087	0.184	0.778	1.602	1.220	0.198	16.6	0.357	0.777	0.239
	Quartzarenite	68	0.778	1.544	1.145	0.183	0.903	1.699	1.258	0.198	18.1	0.280	0.809	0.231
Site 12	Chert	186	0.699	1.699	1.094	0.202	0.699	1.756	1.211	0.214	16.3	0.267	0.803	0.231
	Quartzarenite	68	0.778	1.544	1.199	0.167	0.778	1.740	1.336	0.199	21.7	0.278	0.768	0.230
Site 13	Chert	223	0.602	1.778	0.952	0.207	0.699	1.903	1.055	0.243	11.4	0.267	0.829	0.229
	Quartzarenite	43	0.778	1.845	1.292	0.257	0.778	1.845	1.424	0.267	26.6	0.358	0.775	0.231
Site 14	Chert	113	0.602	1.653	1.016	0.196	0.778	2.000	1.161	0.204	14.5	0.280	0.753	0.226
	Quartzarenite	75	0.699	1.663	1.100	0.248	0.699	1.845	1.210	0.258	16.2	0.389	0.806	0.210
Site 15	Chert	92	0.699	1.602	1.047	0.188	0.845	1.778	1.214	0.191	16.4	0.294	0.716	0.219
	Quartzarenite	54	0.699	1.568	1.136	0.232	0.845	1.699	1.273	0.255	18.8	0.350	0.768	0.228
Site 16	Chert	129	0.699	1.613	0.959	0.169	0.845	2.114	1.206	0.215	16.1	0.188	0.612	0.243
	Quartzarenite	54	0.602	1.398	0.959	0.189	0.602	1.954	1.267	0.268	18.5	0.231	0.540	0.243
Site 17	Chert	223	0.699	1.602	1.003	0.176	0.699	1.778	1.181	0.210	15.2	0.250	0.710	0.243
	Quartzarenite	22	0.699	1.505	1.108	0.223	0.903	1.505	1.279	0.188	19.0	0.375	0.706	0.221

Table 6. Analysis of variance of parameters of chert and quartzarenite pebbles from Pennsylvanian and Permian Strathearn Formation, greater Beaver Peak area, Nev.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F ratio	Probability
(a) Long "A" axis of chert and quartzaernite pebbles					
Pebble type	1	0.875	0.875	14.92	0.000
Error	4207	246.9	0.059		
(b) Shape B/A of chert and quartzaernite pebbles					
Pebble type	1	1.180	1.180	21.94	0.000
Error	4207	226.2	0.054		
(c) Long "A" axis of chert pebbles from upper and lower units of conglomerate					
Unit	1	12.89	12.89	237.4	0.000
Error	3679	199.7	0.054		
(d) Long "A" axis of quartzaernite pebbles from upper and lower units of conglomerate					
Unit	1	1.061	1.061	16.79	0.000
Error	526	33.26	0.063		
(e) Shape "B/A" of chert pebbles from upper and lower units of conglomerate					
Unit	1	7.259	7.259	141.4	0.000
Error	3679	188.9	0.051		
(f) Shape "B/A" of quartzaernite pebbles from upper and lower units of conglomerate					
Unit	1	0.002	0.002	0.036	0.849
Error	526	30.08	0.0057		
(g) Long "A" axis of chert pebbles among sites from lower conglomerate unit					
Sites	7	14.37	2.053	38.10	0.000
Error	2226	119.9	0.054		