Neoproterozoic Conglomerate and Breccia in the Formation of Leaton Gulch, Grouse Peak, northern Lost River Range, Idaho: Relation to Beaverhead Impact Structure

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ABSTRACT

A unique area of pods and lenses of complex breccia overlain unconformably by boulder conglomerate, south of Challis, Idaho is interpreted to be part of the record of the Neoproterozoic Beaverhead Impact Event. On Grouse Peak at the north end of the Lost River Range (Pahsimeroi Mountains), the formation of Leaton Gulch (Neoproterozoic to Ordovician) contains two stratigraphic units. The thick lower part (OZll) is hundreds of meters thick, and contains phyllitic quartz arenite. The strata are cut by zones of complex breccia and contain local areas of tight disharmonic folds. In thin section, the breccia contains mylonitic seams, possible pseudotachylite, and planar deformation features that cross grain boundaries. The upper part of the formation of Leaton Gulch (OZlu) is over 30 m thick. The basal bed is a massive boulder conglomerate that contains clasts of OZll. The conglomerate is overlain by latest Neoproterozoic and earliest Cambrian marine sandstone and siltstone that contains trace fossils. Individual sand grains in OZlu contain planar deformation features.

We present two possible interpretations that link these rocks with the Beaverhead Impact Event. The first holds that the basal conglomerate of OZlu was shed from a fault scarp that formed on the edge of an outer-ring crater of the 75 to 150 km diameter Beaverhead Impact Structure, within a few million years of the early Neoproterozoic event. The second interpretation is that the conglomerate represents an incised valley fill deposit of locally-derived impact-deformed clasts, but deposited in latest Neoproterozoic time (~600 Ma) hundreds of millions of years after the impact event. The latter interpretation is suggested by the available geochronology, which suggests that the event occurred about 850-900 Ma. In either case further manifestations of the Beaverhead Event should exist in Neoproterozoic strata and crust of eastern Idaho.

INTRODUCTION: BEAVERHEAD IMPACT STRUCTURE

The Beaverhead Impact Structure is one of only eight known bolide impacts with craters over 50 km in diameter. Direct evidence for the structure is found in at Island Butte in the southern Beaverhead Mountains, Montana (Fig. 1), where shatter cones and shocked grains are found in Mesoproterozoic sandstone, and underlying Archean gneiss contains pseudotachylite dikes and pods (Hargraves et al., 1990; 1994; Fiske et al., 1994). Ruppel (1998) mapped the host rocks for the shattercones as Mesoproterozoic Gunsight Formation, the uppermost member of the Lemhi Group (Fig. 2). Skipp and Link (1992) had earlier suggested the host strata were Wilbert Formation, of latest Neoproterozoic and Cambrian age.

U-Pb and $^{40}Ar/^{39}Ar$ data on shattercone-bearing Archean gneiss and suspected impact breccia indicate that the age of the impact is 875-900 00 Ma (Kellogg et al., 1999). This age supports Ruppel's assignment of the host rocks to the Gunsight Formation. It also has implications for our interpretation of the rocks on Grouse Peak, which we will discuss later.

Regional geophysical anomalies, including a 40 x 60 km inferred upper mantle gravity high and a 75 km diameter ring of aeromagnetic highs, centered in the northern Lost River Range, south of Challis, Idaho (Fig. 1) are interpreted as related to the Beaverhead Impact (McCafferty, 1992; McCafferty et al., 1993; McCafferty, 1995). The gravity high is interpreted as caused by a mafic intrusion in the upper mantle that formed immediately after the impact. The magnetic highs are interpreted as caused by Tertiary intrusions emplaced into a reactivated ring feature. McCafferty (1995) proposed that the Beaverhead Impact structure was dismembered by Cretaceous thrust faults and that the shatter cone-bearing rocks in the southern Beaverhead Mountains

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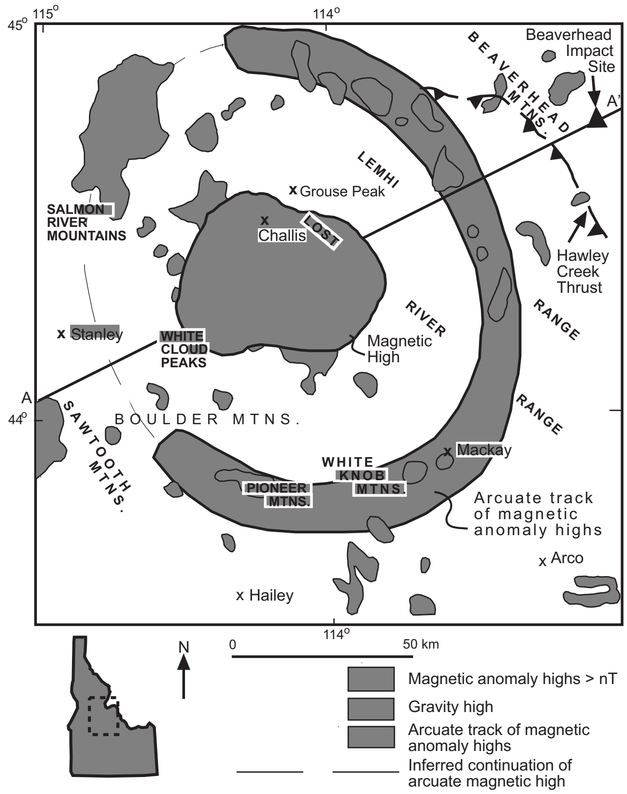

Figure 1. Location map of east-central Idaho showing the Grouse Peak site, Beaverhead Impact site, mid-crustal magnetic and gravity anomalies, and the Hawley Creek thrust fault (after McCafferty, 1995). Cross section A-A' is shown in Figure 16.

are the northeast-thrusted eastern part of the central crater whose root is expressed in the geophysical anomalies (Fig. 1, 16).

This study describes unusual conglomerates and tectonic breccias of the Ordovician to Neoproterozoic formation of Leaton Gulch (Fig. 2) located on Grouse Peak of the northernmost Lost River Range (Fig. 3). We interpret these features as related to the Beaverhead impact (Carr et al., 1996). Except for the shattercones in the Beaverhead Mountains and the sedimentary breccia described here, no other upper crustal manifestations of the Beaverhead impact have been reported.

REGIONAL GEOLOGY

East-central Idaho is part of the Sevier orogenic belt (Fig. 1) and contains regional thrust faults of late Cretaceous age; pre-Cretaceous upper crustal rocks are all allochthonous (Skipp, 1987; Rodgers and Janecke, 1992; Link and Janecke, this volume). The northern Lost River Range (Pahsimeroi Mountains) contain a southeast-dipping Mesoproterozoic to Carboniferous sequence in the hanging wall of the Hawley Creek thrust system (McIntyre and Hobbs, 1987; Mapel et al., 1965; Janecke, 1993; 1995).

Much of east-central Idaho was blanketed by Eocene Challis Volcanic Group and extensively faulted by pre-, syn-, and post-Challis faults and extensional folds (Moye et al., 1988; Fisher and Johnson, 1995; Janecke, 1994; 1995; Janecke et al., 1998). The Challis area was deformed by normal and strike-slip faults related to the Twin Peak Cauldron complex and northeast-striking Trans-Challis fault zone (Fisher et al., 1992; Worl et al., 1995; Janecke and Snee, 1993; Janecke et al., 1997). Uplift along these faults exposes the pre-Tertiary rocks.

Table 1. Sedimentary petrology data from Grouse Peak rocks. 500 point counts were made per slide by J. Carr. Stratigraphic position of samples is shown on Figure 4. OZll and clasts in OZlu are slightly higher in polycrystalline quartz than sands of OZlu.

	Qmu	*Qp*	*F*	*D*
OZlu sandstone				
45PL95	98	1.6	-	-
40PL95	96.6	3.3	-	-
39PL95	97.6	1.6	0.6	-
42PL95	98.6	1.0	0.3	-
OZlu conglomerate				
43PL95 (matrix)	95.6	4	0.3	-
44PL95 (clast)	98	2	-	-
41PL95 (clast)	95.3	4.3	-	0.3
46PL95 (clast)	92.6	7	-	0.3
OZll sandstone				
47PL95	94	6	-	-
48PL95	94	5.6	0.3	-
49PL95	94.3	5.6	0.3	-

The Lost River Range is at the north edge of the Basin and Range province. It occupies the footwall of the Lost River fault along the west side of the range, and the hanging wall of the Lemhi

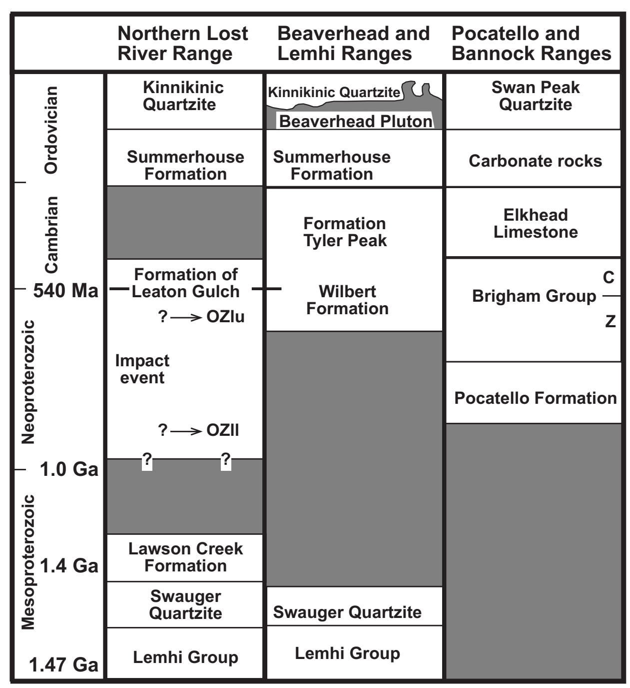

Figure 2. Correlation chart for Proterozoic and lower Paleozoic rocks of east-central Idaho showing age uncertainty for the formation of Leaton Gulch and Beaverhead Impact Event (modified from Skipp and Link, 1992).

fault to the east (Crone et al., 1987; Crone and Haller, 1991; Janecke, 1993; 1994; 1995). Numerous north-northwest-striking faults cut the range (McIntyre and Hobbs, 1987; Fisher et al., 1992; Wilson and Skipp, 1994). The normal faults have Holocene displacement and the area is seismically active.

FORMATION OF LEATON GULCH

The rocks exposed at Grouse Peak of the northernmost Lost River Range (Fig. 1, 2) are included in the "interbedded quartzite, dolomite and argillite of Leaton Gulch and Pennal Gulch" of Neoproterozoic to Ordovician age, (McIntyre and Hobbs, 1987). Complex structure, discontinuous exposure and the limited scope of their project prevented McIntyre and Hobbs from defining an internal stratigraphy. They noted the presence of "several zones of very coarse conglomerate or intraformational breccia" and the presence of "ripple marks, flute casts, and worm trails".

The formation of Leaton Gulch overlies the feldspathic Mesoproterozoic (Middle Proterozoic) Lawson Creek Formation (Hobbs, 1990; Hobbs and Cookro, 1995) and is unconformably overlain by quartz arenite of the Ordovician Kinnikinic Quartzite (Fig. 2). McIntyre and Hobbs (1987) suggested correlation of the Leaton Gulch beds with the Wilbert (Neoproterozoic) and Summerhouse (Lower Ordovician) Formations or with the Middle Cambrian formation of Tyler Peak (Ruppel, 1975; McCandless, 1982).

GEOLOGIC RELATIONS ON GROUSE PEAK

The formation of Leaton Gulch generally dips eastward on Grouse Peak, but is locally tightly folded (Fig. 3). It is unconformably overlain by rocks of the Eocene Challis Volcanic Group, including the tuff of Challis Creek and intermediate and mafic lava flows. Several down-to-the east normal faults repeat the section.

Lower Formation of Leaton Gulch (OZll)

We divide the formation of Leaton Gulch on Grouse Peak into two stratigraphic units (Fig. 4). The lower part (OZll in Fig. 2, 3, and 4) makes up the bulk of the formation. Based on outcrop width (McIntyre and Hobbs, 1987), this lower part is hundreds of meters thick. It crops out over an area 10 x 15 km. In general, the rocks have a steeply west-dipping cleavage. We have only examined the exposures shown on the map of Figure 4, and have not studied the entire area of outcrop.

The upper few hundred meters of OZll contains fine- to medium-grained, medium bedded, locally cross-bedded, purple to light pink, phyllitic quartz arenite. In thin section OZll sandstone contains over 90% monocrystalline quartz grains and 5 to 6 percent polycrystalline quartz (Table 1; Fig. 5).

Several linear and pod-shaped zones of lower formation of Leaton Gulch strata in the Leaton Gulch area (Fig. 3) are intensely brecciated (Fig. 6, Locality C). Clasts are up to 2 m in diameter,

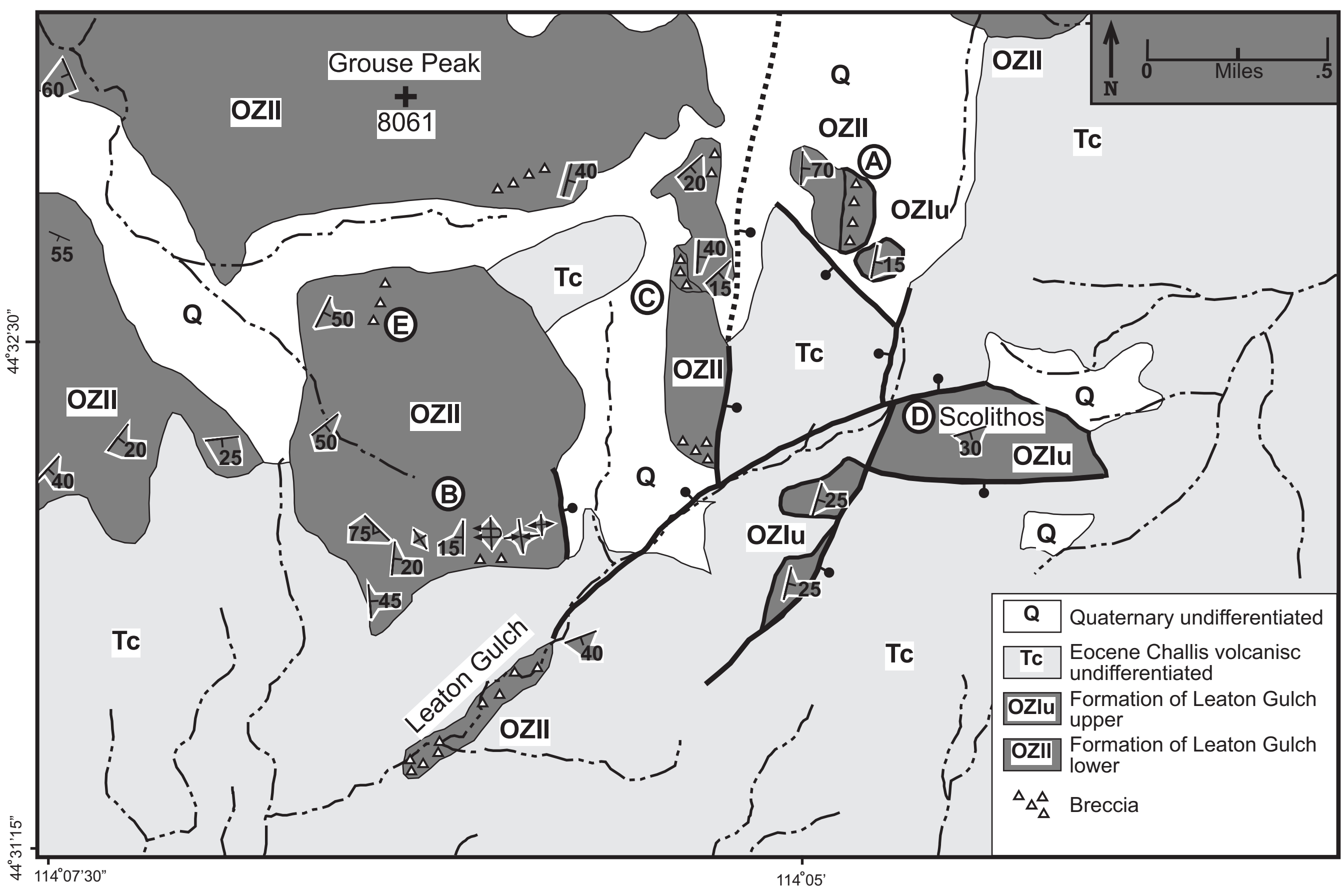

Figure 3. Geologic map of Grouse Peak area, northern Lost River Range (Pahsimeroi Mountains). Initial relations were described by Rob Hargraves. Further mapping by Idaho State University Field Camp, June, 1996. Stratigraphic column of Figure 4 is through the contact between OZll and OZlu at Locality A. Breccia localities B, C, and E in OZll are described in text.

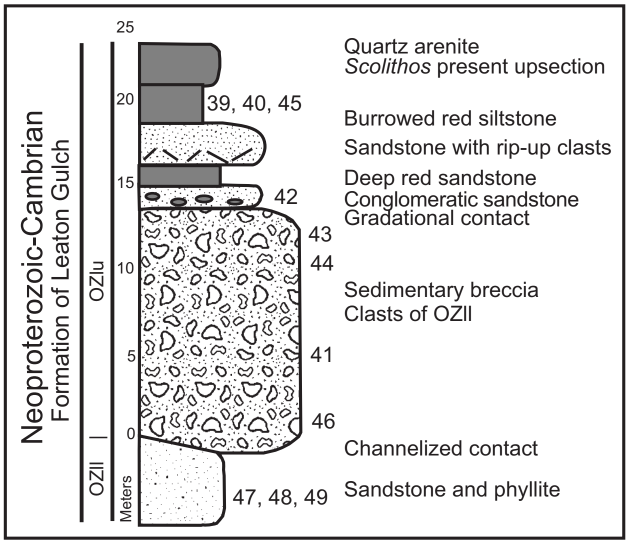

Figure 4. Stratigraphic column of the informal formation of Leaton Gulch at Locality A of Figure 3, east of Grouse Peak. Base of massive conglomerate represents unconformable contact between the lower part of the formation (OZll) and the upper part (OZlu). Stratigraphic position of samples from Table 1 is shown.

both angular and rounded, and locally severely iron-stained. At Locality B, OZll contains tight, disharmonic folds (Fig. 7), with brecciated cores (Fig. 8).

Upper Formation of Leaton Gulch (OZlu)

The upper part of the formation of Leaton Gulch (OZlu) unconformably overlies OZll on a channelized contact (Fig. 9), and consists of an upward-fining conglomerate to siltstone succession (see stratigraphic column, Fig. 4). The unit lacks outcrop scale folds, and generally lacks cleavage.

The base of OZlu is massive boulder conglomerate (Fig. 9, at locality A on Figure 3) with clasts up to 50 cm in diameter, in channels that cut down into OZll phyllitic quartzite. The channeled surface has a relief of 2 m. The conglomerate is 14 m thick, light-pink in color, and contains angular to sub-rounded quartz arenite clasts that are petrologically identical to the underlying OZll unit.

The conglomerate is gradationally overlain by 1 m of dark pink to orange, poorly-sorted conglomeratic sandstone with white to maroon subrounded clasts up to 1 cm in diameter (Fig. 10). Above this is a red fine-grained arkosic sandstone (1 m) overlain by intraformational conglomeratic sandstone with mudstone rip-up clasts (2 m). This grades into a 2 meter-thick red siltstone which contains bedding-parallel trace fossils (*Planolites*? up to 1 cm in diameter). This siltstone is overlain by tens of meters of medium-grained quartz arenite. At locality D, a fault-bounded block of this upper quartz arenite contains *Skolithos*.

The OZlu unit contains quartz arenites, with over 95% monocrystalline quartz and less than 5% polycrystalline quartz (Table 1; Fig. 5). Thin sections of clasts in OZlu basal conglomerate contain several percent polycrystalline quartz, and in general resemble OZll sands. Figure 5 reveals that neither of the Leaton Gulch units clearly match the sandstone petrography of the Cambrian and Neoproterozoic Wilbert Formation nor the Mesoproterozoic Gunsight and Swauger Formations of the southern Lemhi and Beaverhead Mountains (Skipp and Link, 1992). However, the Leaton Gulch units lack feldspar, which is a distinguishing characteristic of the Middle Proterozoic rocks. The distinction is not clear, however, based on limited sample size.

BRECCIAS AND PLANAR DEFORMATION FEATURES

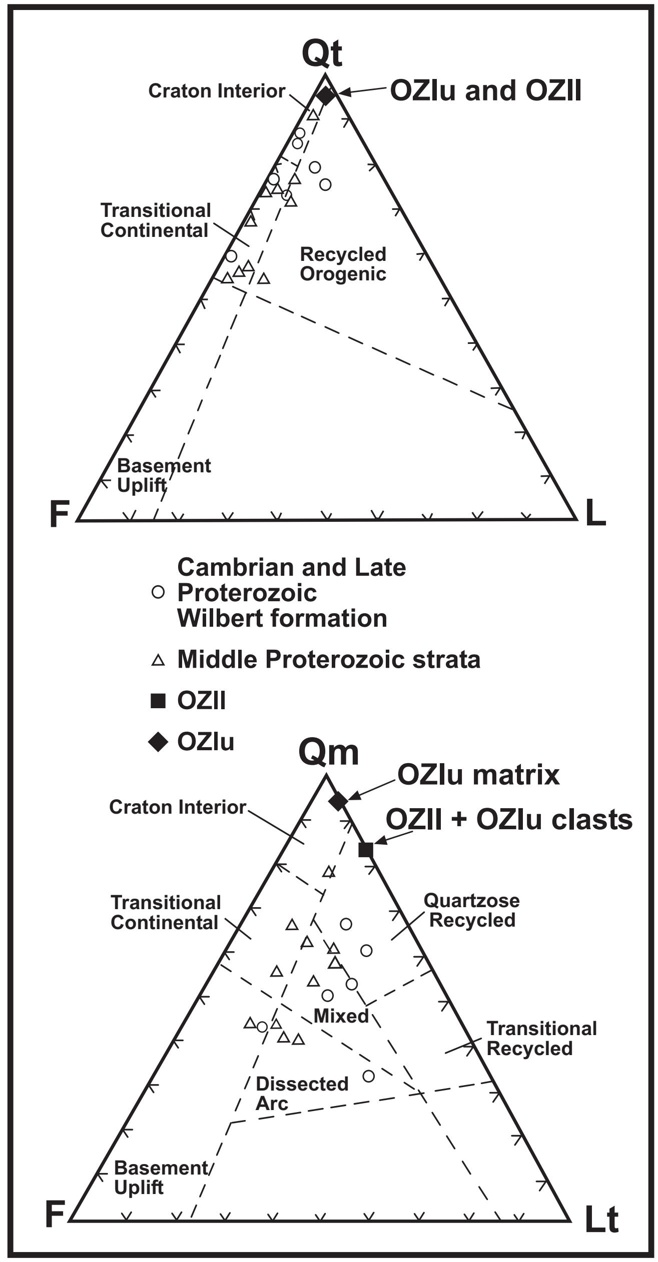

Figure 5. Ternary diagrams to illustrate composition of sandstones from the Grouse Peak area (data lumped from Table 1) compared to Middle Proterozoic Gunsight and Swauger Formations and Neoproterozoic-Cambrian Wilbert Formation from the southern Beaverhead and Lemhi Mountains. Modified from Skipp and Link (1992, their Figure 4).

Figure 6. Heterolithic breccia from OZll at Locality C on (Fig. 3). Clasts are both angular and rounded, up to 1 m in diameter, and include some clasts of angular breccia.

Figure 8. Breccia in core of fold at right side of Figure 7. Note person (John Preacher) sitting in middle view for scale. Clasts are up to 2 m in diameter. Thin sections of breccia matrix with flattened quartz domains (Figures 11 12, 15) are from this location.

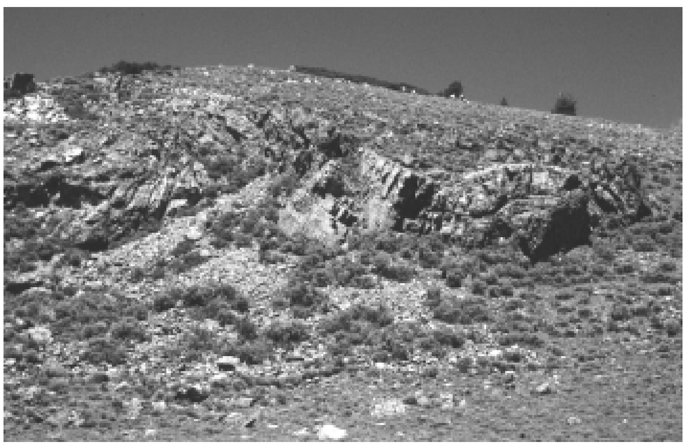

Figure 7. Outcrop-scale disharmonic folds in OZll at Locality B (Fig. 3). Breccia shown in Figure 8 is in core of anticline at right side of view.

Figure 9. Basal contact of OZlu conglomerate on scoured surface of OZll at Location A, east of Grouse Peak.

Brittle Breccias

Brittle breccia within OZll, with granulated and recrystallized quartz matrix, is exposed in lower Leaton Gulch (south of Locality B). Angular clasts of quartzite up to 40 cm in diameter are surrounded by an annealed quartz matrix, which is finely comminuted and recrystallized. Quartz grains are highly strained. These breccias likely formed along the northeast-striking fault zone in Leaton Gulch.

"Ductile" Breccia

Within OZll, "ductile" breccia (angular fragments in a ductile matrix) is found at Localities B, C, and E on Figure 3. Breccia at Locality B, in the core of a tight upright anticline (breccia shown in Fig. 8, folds in Fig. 7), contains angular pieces of the adjacent quartzite up to 20 cm in diameter. Thin sections of the matrix contain heterolithologic clasts (quartzite, gneiss, and schist) up to 1 cm in diameter, locally surrounded by a glassy mylonitic matrix (Fig. 11). Some areas have an amorphous, stringy texture, with some isotropic sub-grains, that forms an indistinct halo around surrounding grains (Fig. 12), a texture reminiscent of pseudotachylite.

Planar Deformation Features

Quartz grains in thin sections from these three localities of breccia contain two types of planar deformation features. The first type includes distinct planes manifested as multiple parallel lineations that cover about 80% of the length of a quartz grain (c.f. Fig. 13, 14). The lamellae are sub-perpendicular to the extinction angle. Some of the grains have subsequently been deformed so that lineations are somewhat kinked. These lamellae occur in monocrystalline quartz grains that exhibit undulose extinction, but are not present in polycrystalline quartz grains.

The second type of planar deformation feature is an alignment of parallel planes of tiny fluid inclusions (Fig. 15). In some grains, the fluid inclusion trains form two sets about 30 degrees apart. In some grains the lamellae go through grain boundaries, indicating the lamellae were imposed during or after lithification (Fig. 15).

Textures in Clasts and Matrix of Basal OZlu

In the sand matrix between clasts in the basal boulder conglomerate of OZlu, quartz contains rare to abundant planar sets of deformation lamellae and rare to moderately abundant trains

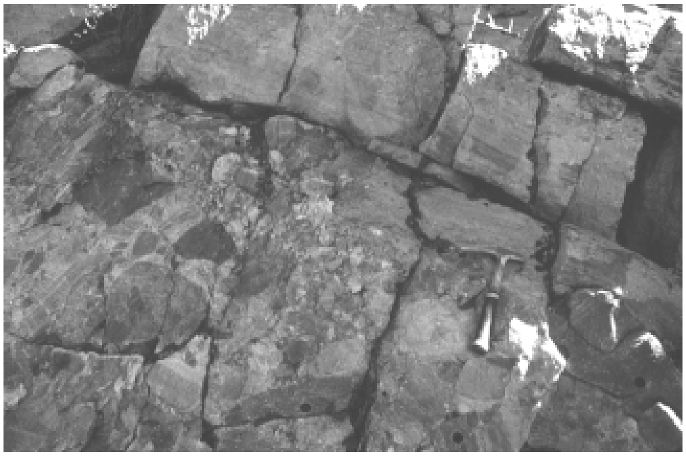

Figure 10. Upper contact of basal conglomerate of OZlu, Location A, east of Grouse Peak. Note pebbles and rip-up silt clasts in overlying parallel laminated coarse-grained sandstone.

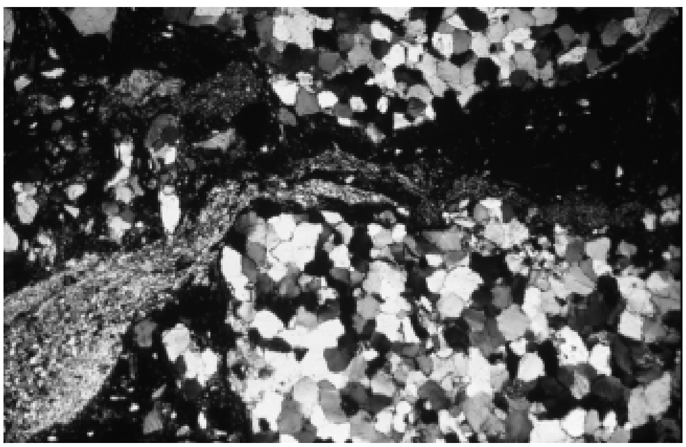

Figure 11 Mylonitic texture in breccia containing flattened quartz domains from OZll at Locality B (Sample 58PL95). Crossed polars. Field of view is ~2 mm.

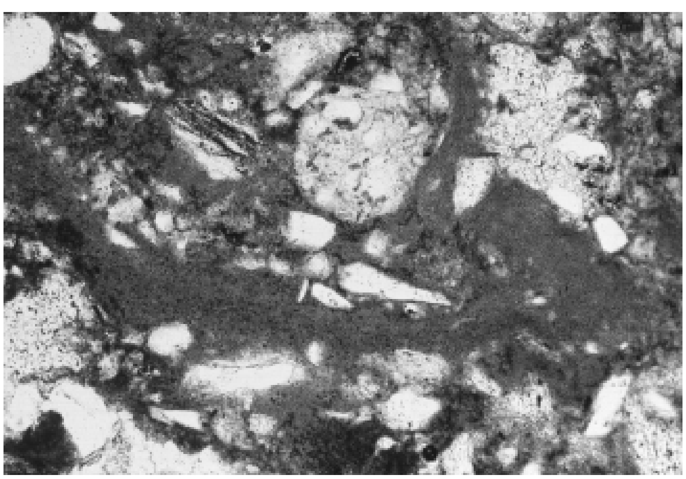

Figure 12. Possible pseudotachylite texture in matrix of breccia from OZll at Locality B (same thin section as Fig. 11, Sample 58PL95). Note diffuse area of isotropic, hazy, possible melt glass through middle of view. Plane light. Field of view is ~2 mm.

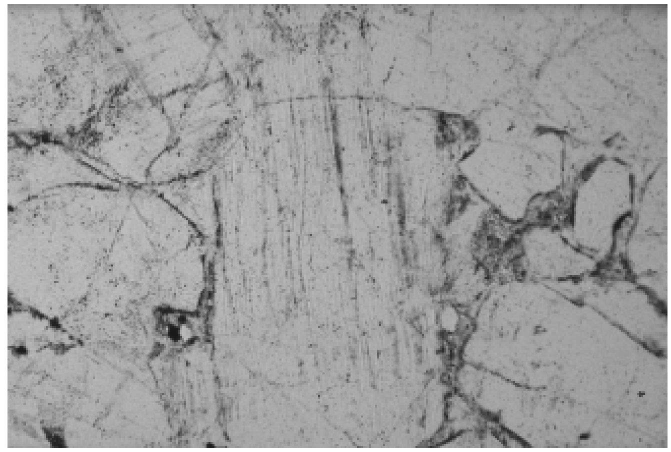

Figure 13. Thin section of sample 41PL95, a clast in basal conglomerate of OZlu, Locality A. Note slightly kinked planar deformation features that cross grain boundaries in coarse-grained quartz. Field of view is ~1 mm.

Figure 14. Thin section from sample 43PL95, matrix in coarse sand from basal conglomerate of OZlu, Locality A . Note that planar deformation features do not cross grain boundaries. Field of view is ~1 mm.

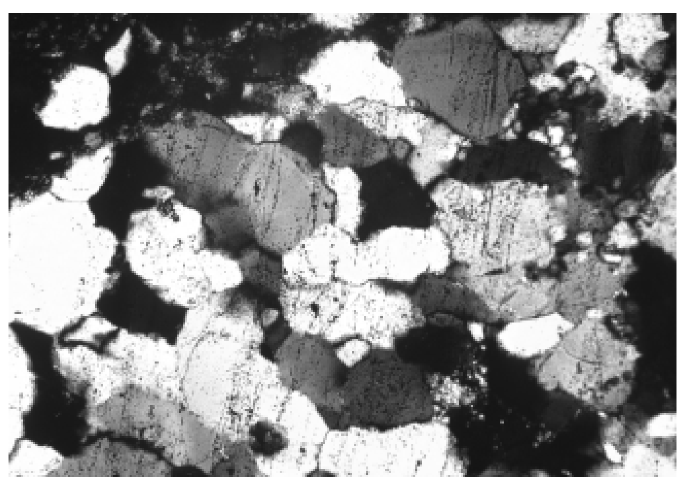

Figure 15. Thin section from breccia in core of fold at Locality B (Fig. 7 and 8, Sample 57PL95). Note the planar deformation features cross fine-sand grain boundaries. Field of view is ~2 mm.

of fluid inclusions. In the sand matrix of the conglomerate, the features do not cross grain boundaries (Fig. 14). However, in some clasts the features are observed to cross grain boundaries (Fig. 13), similar to relations in underlying OZll.

INTERPRETATION

The upper formation of Leaton Gulch east of Grouse Peak contains a basal conglomerate (OZlu) channeled into the lower part of the formation (OZll). To our knowledge, such coarse-grained conglomerates are unique in the Leaton Gulch unit. We interpret this conglomerate to represent an event-bed, either the stratigraphic record of the Beaverhead Impact or an incised valley-fill deposit containing material eroded from a proximal area deformed by the impact.

Although the definitive determination of whether planar deformation features in general are shock-related or caused by strain of longer duration is controversial, the features we describe in sand grains in OZlu and in lithified sandstone of OZll are comparable to photographs of demonstrated shock features formed during bolide impact (Alexopoulos et al., 1988). Further, the breccia pods within the OZll unit on Grouse Peak are unusual, complex, and difficult to explain by fault-related origin alone.

Thus we tie several disparate pieces of anomalous geology together and propose that they are all manifestations of the extraordinary tectono-magmatic events produced by the Beaverhead Bolide Impact. We suggest that the lamellae observed in quartz grains in the OZll unit formed due to shock and/or subsequent rapid strain-rate and normal faulting. The complex breccias with flattened quartz domains within OZll likely also formed at this time, though they have had multiple opportunities to be reactivated during Phanerozoic deformation.

Following McCafferty (1995), we infer that the impact event created outer- and inner-ring craters bounded by normal faults (Fig. 16). Although Grouse Peak is 100 km from the shattercone locality of the southern Beaverhead Mountains, an outer-ring scarp at Grouse Peak is possible if the original crater diameter was over 100 km in diameter (Hargraves et al., 1994). Such ringed structural zones are observed from the end-Cretaceous Chicxulub impact at distances of 85-98 km (Snyder et al., 1998). The Island Butte shattercone site would record the eastern edge of the inner-ring crater (McCafferty, 1995).

One interpretation is that the basal massive conglomerate of OZlu is a debris-flow or talus cone deposit, composed of clasts of OZll, and derived from this proximal fault scarp. Some lithified clasts of OZll, containing planar deformation features that cross grain boundaries, were eroded and deposited in the basal conglomerate of OZlu. Sand grains eroded from OZll, that contain deformation lamellae, were also deposited in OZlu. A second interpretation is that the conglomerate represents an incised valley fill deposit (c.f. Levy et al., 1994), composed of locally-derived (OZll) clasts and sand grains, but deposited significantly later than the Beaverhead event.

The most likely age for the OZlu conglomerate is latest Neoproterozoic (Ediacaran, ~600 Ma). The conglomerate is gradationally overlain by shallow subaqueous sands. Mudrocks, six m above the conglomerate, contain Cambrian trace fossils, suggesting the conglomerate was deposited, at the oldest, close to 600 Ma, i.e., latest Neoproterozoic or Ediacaran time.

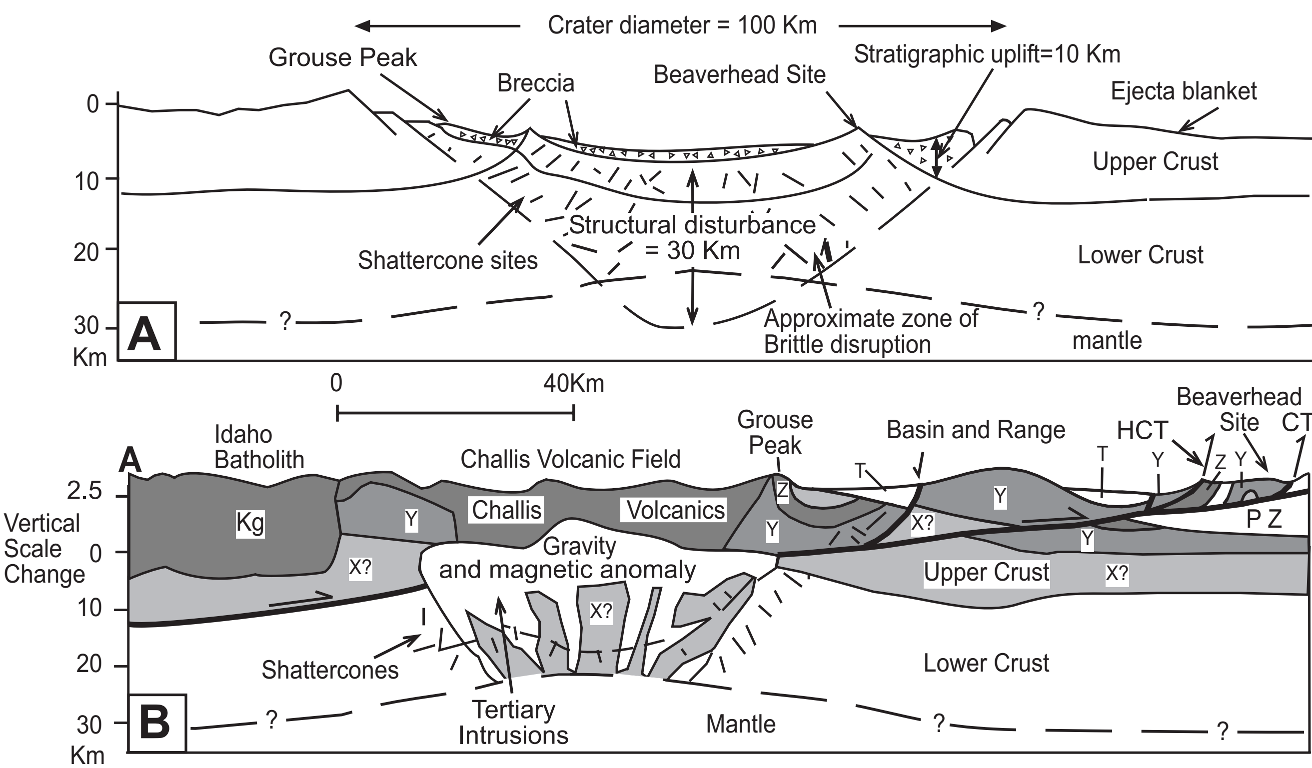

Figure 16. Proposed cross section of east-central Idaho through Beaverhead Impact structure. Upper diagram, (A) shows original locations of Grouse Peak and Beaverhead site. Lower diagram (B) shows modern locations, after eastward translation of rocks by Cretaceous thrusting. Location of southwest-northeast section along line A-A' is shown on Figure 1. Modified from (McCafferty, 1995).

IMPLICATIONS, TESTS, AND CAVEATS

Reconstruction of a dismembered Neoproterozoic meteor impact crater in an area affected by multiple superposed deformational events is chancy business. Although none of the data, except the shattercones and pseudotachylite in the southern Beaverhead Mountains, require the impact scenario, the synthesis suggested here makes a plausible, and testable, connection between observed relations. Fundamentally, if the Beaverhead Impact was as large as modeled by Hargraves et al. (1990), it will be manifested in several types of geologic and geophysical anomalies. Strata deposited immediately after the impact should contain shocked quartz grains, and probably trace-element geochemical anomalies. Phanerozoic geology of the area would be affected by the presence of the dense mid-crustal intrusion produced during the impact. Detailed geochemical and petrographic studies of Neoproterozoic strata (Pocatello Formation and Brigham Group), that might record the event, have not been made.

The apparent size of the Beaverhead crater is impressive. The palinspastic distance between the Beaverhead site and Grouse Peak is near 100 km (Fig. 16). If the features we observe are shock-related, rapid strain must have affected an area 100 km in diameter. One would not expect shock features over such a wide distance (R. Hargraves, written communication, 1998).

Recent geochronologic data (Kellogg et al., 1999) suggests that the age of the impact is 850 to 900 Ma, and the proximity of the OZlu conglomerate to Cambrian trace fossils suggests it is at the most 600 Ma. Thus, our second hypothesis for the origin of the conglomerate, that it represents an incised valley-fill deposit that accumulated above a lithified and scoured surface appears most reasonable at this time.

Our interpretation of the clasts in the OZlu unit as being lithified pieces of OZll requires enough time, and burial depth, for lithification. The prediction is that the contact represents a major unconformity, which should be recognized regionally within the formation of Leaton Gulch. Further work is necessary, to determine if the unconformity and conglomerate are present at more than one place.

We present these observations and interpretations in the hope that further study will provide better constraints on the still-cryptic timing and geologic manifestations of the Beaverhead Bolide Impact, one of the largest known impact events in Earth History.

ACKNOWLEDGMENTS

Rob Hargraves first introduced us to the Grouse Peak area, and many of these ideas started with him. All who know Rob are touched by his broad-thinking insight and his love of geology. The exquisitely illustrated study of McCafferty (1995) provided the framework within which our study of a detailed area can fit. The work was supported by the U.S. Geological Survey, Branch of Central Mineral Resources. We thank reviewers Sharon Lewis and especially Karen Lund, who provided excellent, constructive comments. Jim Riesterer and Vita Taube provided quality drafting support.

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Aerial view of folded Paleozoic rocks along the Continental Divide in the southern Beaverhead Range. Photograph by Glenn Embree.