54th Annual Institute on Lake Superior Geology

FIELD TRIP 5

THE SUDBURY IMPACT LAYER AT THE McCLURE SITE

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Matrix supported breccia containing clasts of chert in mixed glass-clastic matrix

Introduction

Note: As this guidebook is being prepared a substantial road construction project is underway to realign County Road 510 through the area of interest. Specifically, the road is being moved several hundred feet to the west of the location shown in Figures 2 and 3 and will connect to a new bridge being constructed over the Dead River. The descriptions and outcrop locations shown in this guide are those that existed through late 2007. When the field trip is conducted in May of 2008 the outcrop and access situation may be somewhat altered.

The outcrops to the west of 510 are nearly all on land owned by Marquette County and are publicly accessible. Please observe private property boundaries to the far west and south of this area. The outcrops east of 510 are on private property to which the owners have granted access for scientific examination and reasonable sampling for research purposes.

A set of outcrops near County Road 510, about 5 miles northwest of Marquette, Michigan (Figure 5.1) provides a complete section through the layer of debris deposited as a result of the giant impact at Sudbury, Ontario, which occurred about 500 km to the east at 1850 Ma . The Sudbury layer here is a breccia and sandstone unit about 40 m thick, which lies on banded iron-formation and is overlain by pyritic black slate. Outcrops include: 1) the basal contact of the layer that consists of large rip-up clasts of the underlying iron-formation; 2) exposures of matrix-supported breccias in which most large fragments are chert, but many smaller fragments are impact glasses; 3) an upper massive sandstone with minor chert clasts and glass particles; and 4) the upper contact with black slate. The McClure site is the best-exposed section of the Sudbury layer currently known in Michigan and also is the thickest. In addition it is the closest exposure to the impact site at Sudbury. Because there are no preserved rocks of 1850 Ma age between here and Sudbury, the McClure site contains the most proximal ejecta that is likely to be found.

General geology

The McClure site is in the Dead River Basin, a structural outlier of Paleoproterozoic strata surrounded by Neoarchean crystalline rocks. The strata consist entirely of various informal units of the Michigamme Formation. The Sudbury layer at McClure was mapped as a chert conglomerate by W.P. Puffett (1974) who provided a detailed outcrop map of the immediate site as well as a 1:24,000 scale map of the Negaunee Quadrangle on which the layer was shown as a map unit. The unit was extended further west into the adjacent Negaunee SW quadrangle by Clark and others (1975).

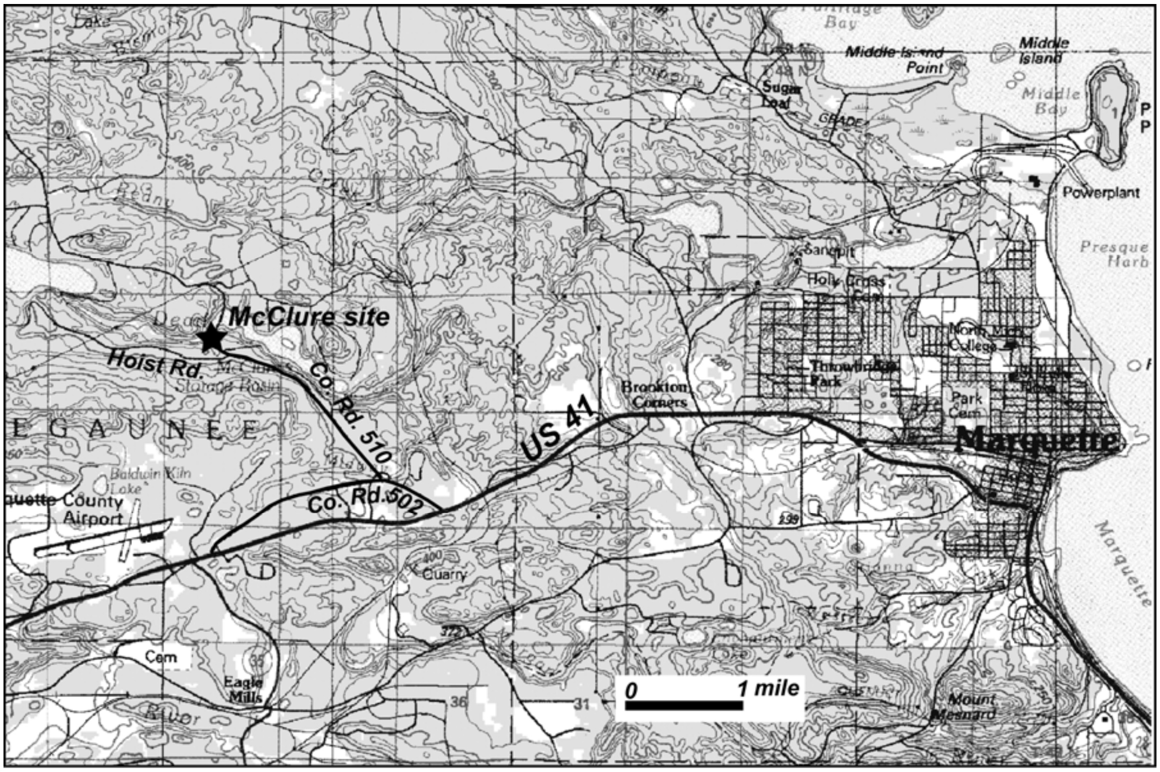

Figure 5.1. Map showing location of the McClure site.

The Sudbury layer at McClure lies within a north-facing monoclinal succession of sedimentary rocks, all informal members of the Michigamme Formation, a part of the Baraga Group, which lies unconformably on Neoarchean granitic rock (Figure 5.2). The Michigamme Formation consists of a basal unit of quartzite and conglomerate, probably equivalent to the Goodrich Quartzite of the Marquette Range. The unit is about 60 meters thick and grades upward into a 150-200 meter-thick unit of impure quartzite and argillite. A 60 meter-thick unit of banded chert-hematite-goethite iron-formation overlies the impure quartzite and is the unit on which the Sudbury impact layer was deposited. Overlying the Sudbury layer with an apparent gradational contact is pyritic black slate. Thus the Sudbury layer at the McClure site lies about 250-300 meters above the base of the Baraga Group. This field trip will examine a set of outcrops that exposes a cross section of the impact layer as well as the upper and lower contacts with the adjacent stratigraphic units (Figure 5.3).

Description of the Sudbury impact layer

The rock layer here referred to as the Sudbury impact layer has been studied and described for nearly a century, but only in 2006 was it documented to be an impact-related unit. The most complete previous description was by Puffett (1974) who mapped and described the unit as a chert conglomerate containing many fragments of volcanic rocks. He interpreted it to have originated "during a period of volcanism in which thick tuff deposits accumulated, then was disturbed by landslides or other gravity-activated mechanisms that dumped material into the site of deposition." Puffet clearly recognized the essentially instantaneous deposition of this massive, graded unit and the unusual mixture of volcanic fragments, chert clasts, and quartz sand grains, and called upon a reasonable combination of terrestrial geologic processes to have formed it.

As an historic note, my former colleague, Willard Puffet, showed these outcrops to me in September 1967 on one of my first days of employment with the USGS in the Marquette Field Office. He asked if I could help explain these unusual features. Fortunately, he didn't give me a deadline.

Our current interpretation of the nature and origin of the Sudbury layer at the McClure site is based on examination of the outcrops and standard thin section petrography of a suite of samples collected at a regular interval across the unit. The definitive microscopic evidence for a link between the breccia bed at McClure and a major impact is the documentation of shock metamorphic features within it. A small percentage of the quartz grains within the breccia matrix contain relict planar deformation features (pdf's) indicative of the extreme pressures generated instantaneously during a hypervelocity impact (Figure 5.4 A,B). There are no terrestrial processes capable of generating pressures remotely within the range needed to form these distinctive features. Figure 4 illustrates two examples of quartz grains with two sets of relict pdf's. These planar features were originally lamellae of impact-generated glass resulting from breakdown of the quartz lattice along preferred crystallographic planes by extreme shock pressures. Over time the glass has recrystallized to quartz, but has left behind planes rich in inclusions, relict pdf's, that mark the original shock lamellae.

At the McClure locality the identification of true pdf's is complicated by the occurrence of extraordinarily abundant Bohm lamellae, features produced by terrestrial deformation (sometimes referred to as metamorphic deformation lamellae). Apparently the temperature and pressure of deformation was optimum for development of these lamellae. Like pdf's they occur as parallel lamellae within quartz grains (Figure 5.4 C,D) and can be difficult to distinguish with certainty from pdf's. The most characteristic Bohm lamellae are thin planar features in which the quartz lattice has been slightly distorted so that the lamellae have extinction angles that vary by a few degrees from the host grain (seen best in Figure 5.4 C). Bohm lamellae are commonly somewhat curviplanar in contrast to unvaryingly planar pdf's, and also commonly develop at approximately right angles to boundaries between individual crystallographic domains within strained quartz grains (also seen well in Figure 5.4 C). Bohm lamellae are also common in quartz grains in the underlying quartzite and greywacke so seem clearly to have developed *in situ* during deformation of the host rocks and are not related to the Sudbury impact.

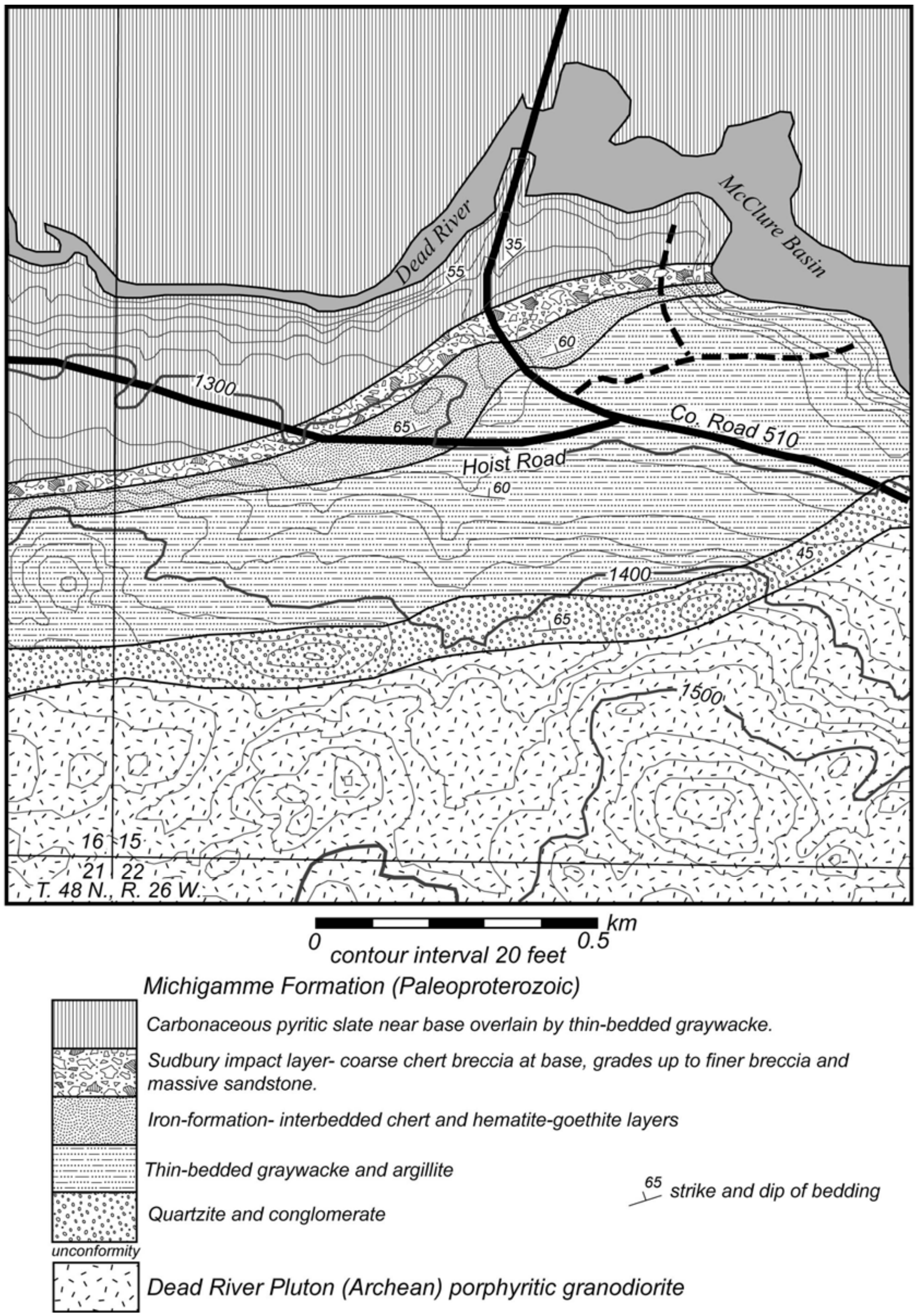

Figure 5.2. Geologic map of the area near the McClure site. Modified from Puffett (1974).

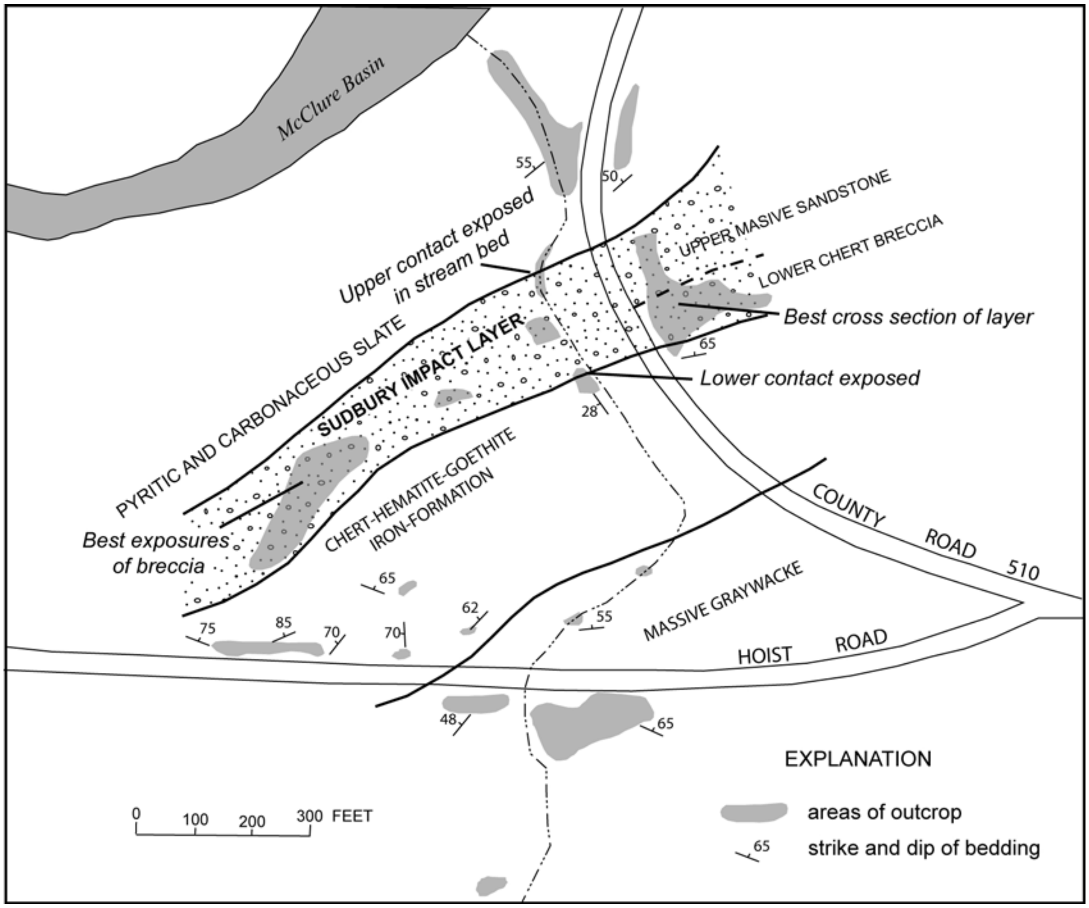

Figure 5.3. Detailed map of the McClure site. Modified from Puffett (1974). Note that the location of County Road 510 is that prior to relocation in 2007-08. The new road is not shown.

A cross section of the unit and modal compositions are shown in Figure 5.5. The most distinctive feature of the layer is the coarse chert breccia that makes up approximately the lower half of the unit. The breccia grades upward both in size and abundance of clasts, mostly chert. The basal unit is a framework of chert slabs up to a meter long surrounded by a matrix largely of clastic material and subordinate altered glass particles (Fig 5.6A). This grades up into matrix supported breccia (Figure 5.6 B,C,D,E) in which accretionary lapilli occur sparsely (Figure 5.6C). Clasts generally show little or no preferred orientation, but locally (Figure 5.6D) are well aligned. Most large clasts are chert, at least partly derived from the underlying iron-formation, but some phases have abundant exotic fragments, apparently volcanic rocks (Figure 5.6D). In some outcrops, many chert clasts have an alteration rim (Figure 5.6E) suggesting reaction between the clast and matrix. As shown by Figure 5, the breccia matrix has relatively constant composition expressed as the percentage of clastic quartz sand grains, altered glass particles, and fine groundmass. Glass particles account for 35-40% of the matrix. The glass particles are now mostly chlorite (Figure 5.7 A, B, C, E) in which relict vesicles are common. Many vesicles are flattened indicating considerable post-depositional distortion. Some particles have a complex intermixing of compositions (Figure 5.7A), possibly a result of immiscible melts. Other rock types, such as the quartzite clast in Figure 5.7F, are rare. The groundmass in the breccia matrix is aphanitic, apparently of felsic composition, and clouded with uniformly distributed opaque grains. Its nature is not clear at this point in our studies.

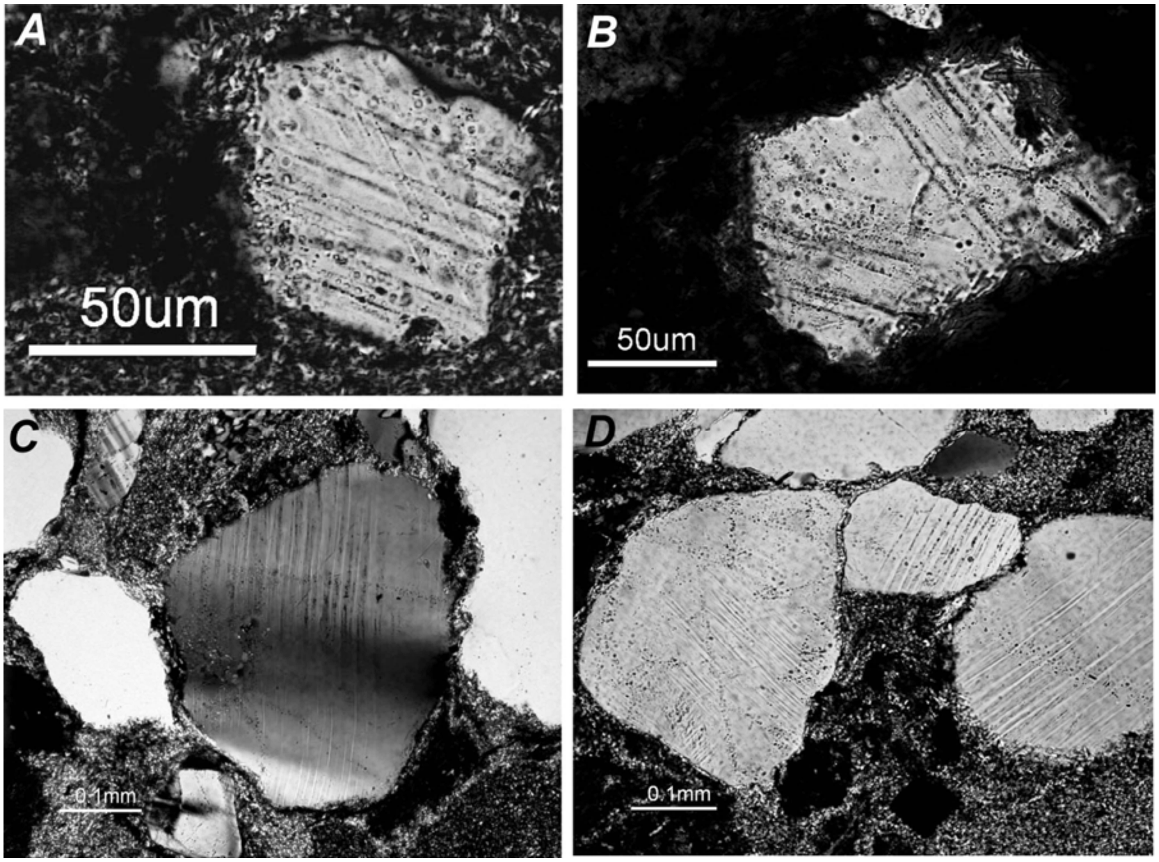

Figure 5.4. A and B- quartz grains with two intersection sets of relict planar deformation features expressed by abundant fine inclusions. These are definitive indicators of intense shock pressures. C and D- Quartz grains containing Bohm lamellae showing slight variations in extinction angles from host grains, curvilinear nature, and right angle intersections with boundaries of deformation zones in strained grains (best seen in C).

The upper part of the layer, beginning about 25 meters above the base, is a massive dark gray to black impure sandstone. Angular chert pebbles are sparse and much less abundant than in the underlying breccia. Glass particles are common but less abundant than in the breccia and average about 20% of the rock (Figure 5.7D). Rounded to subangular quartz grains are more abundant than in the underlying breccia and make up roughly 35% of the sandstone. The groundmass also differs from that of the breccia and appears to be fine clastic particles with a wide range of grain size in contrast to the very uniform groundmass of the breccia. The contact between the lower breccia and upper sandstone appears to be gradational over several meters.

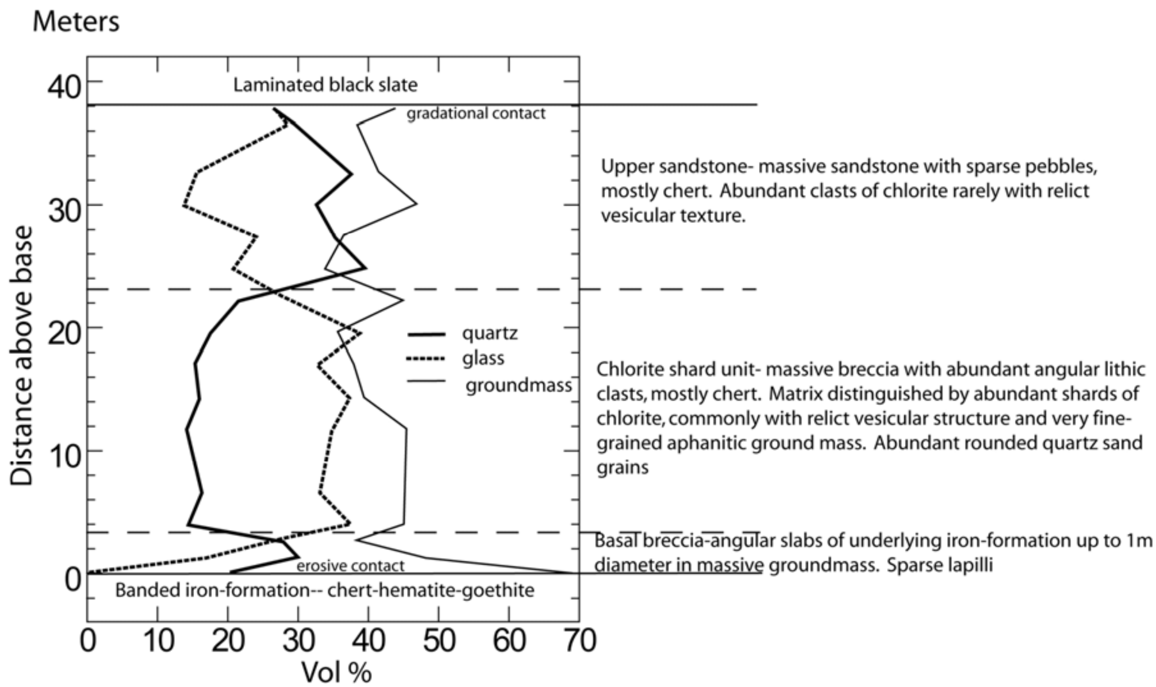

Figure 5. 5. Cross section of the Sudbury impact layer at McClure showing variations in the modal composition of the matrix of the lower breccia and the upper sandstone.

The upper contact of the Sudbury layer with overlying black slate can be seen in very small exposures in the bed of the intermittent stream that is subparallel to Co. Rd. 510. When the stream is flowing, these outcrops are largely below the shallow water. The contact appears to be gradational over a meter or two in which fine-grained sandstone gives way to laminated carbonaceous slate.

Interpretation

Several features of the Sudbury impact layer at the McClure site provide clues to the processes responsible for its deposition:
1) Shock metamorphic features provide verification that it contains ejecta from a major extraterrestrial impact. Independent age constraints place the time of deposition within a roughly 40 million year time window that includes the 1850 Ma Sudbury event. No other major impact events of that age are known in the region, so a link to the Sudbury impact is deemed very likely.
2) The massive, graded and poorly sorted nature of the deposit and complete lack of internal bedding or laminations suggest the entire 40 m thickness records a single depositional event.
3) The high energy deposition indicated for the Sudbury layer is in sharp contrast to the very low energy environments indicated for the underlying even-bedded iron-formation and overlying laminated black slate. So deposition appears to be a unique instantaneous event. Both the underlying and overlying units were deposited in a marine setting with water depths greater than the depth of wave action.
4) The abundance of rounded quartz and chert sand grains throughout the unit indicates that, in addition to material ejecta from the crater at Sudbury, the unit contains a substantial component

of material that was acquired by erosion of surficial materials that existed between Sudbury and the McClure site.
5) The abundance of altered particles of glass, a very high percentage of which are highly vesicular and of mafic composition, and have complex delicate shapes suggests that the particles were not derived by erosion of older volcanic rocks, which would have produced a variety of textures and compositions, but rather formed from solidification of highly gas-charged impact-generated melts and acquired their present shapes *in situ*.
6) The very coarse breccia at the base of the unit, consisting of meter-scale slabs of the underlying iron-formation, indicates that the onset of deposition was a very high-energy event.

Although studies of the Sudbury layer here are still in the early stages, a preliminary interpretation is presented based on current observations. Deposition began in relatively deep quiet water on a substrate of banded iron-formation. The basal beds are a result of highly energetic disruption of the iron-formation and may have been produced either by erosion caused by a fast-moving mass of ejecta or by seismic disruption of the surface sediments moments before the arrival of ejecta. The seismic shock wave generated by the impact would have arrived here within a minute or two after the impact, whereas the first ejecta may have arrived a few minutes later. Spaces between iron-formation slabs are filled with a mixture of clastic grains, particles of altered glass, and sparse accretionary lapilli indicating that the ejecta arrived while there was open space between the slabs.

The remainder of the unit at McClure may record deposition from a single turbidity flow. Numerous numeric models of giant impacts have been published in recent years and all predict a rapid expansion of an ejecta cloud or ejecta curtain consisting of solid rock, impact melt, and vapor. Horizontal velocities of thousands of kilometers per hour are predicted. As this high velocity mass returns to the Earth's surface, it continues to move at high velocities as a ground surge. This surging mass is capable of eroding and transporting surficial material and eventually incorporating it into hybrid deposits consisting both of ejecta and the eroded surficial materials. The mixture of ejecta material at McClure with quartz and chert sand and larger rock fragments, largely chert derived from the nearby iron-formation, suggests that a ground surge played a significant role in its formation. A less certain aspect of the interpretation is how a ground surge would have interacted with the ocean water that covered the area at the time. Did the surge ride atop the water column and eventually sink through it as it lost velocity, or did the entire water column become part of the surge. If the basal breccia is a result of erosion by the surge, then the water column must have been incorporated into the surge. If the breccia is a result of seismic disruption and later infiltration by ejecta an ocean-overriding mechanism is possible.

Much additional work is required to understand the intriguing features so well exposed at the McClure locality.

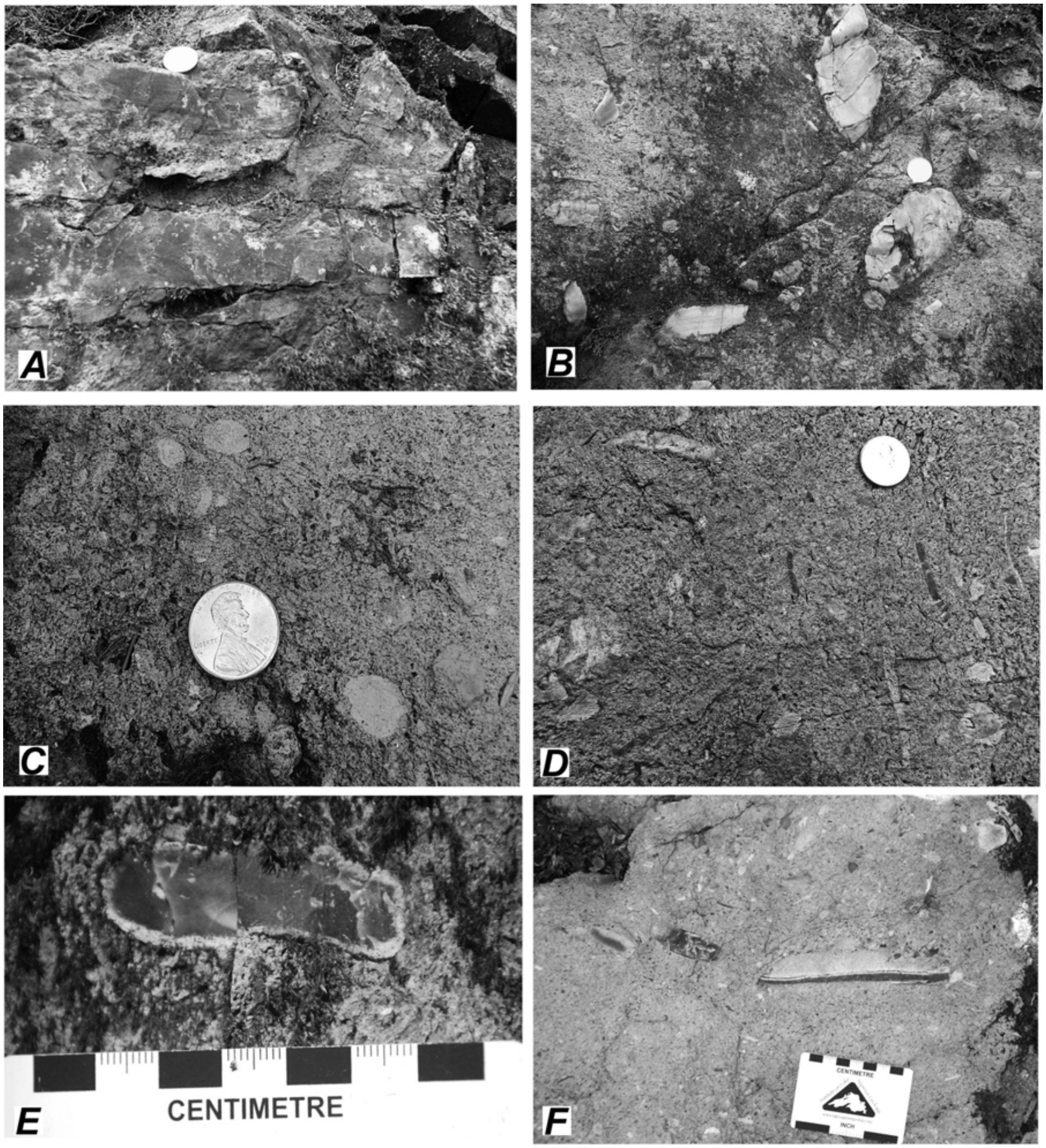

Figure 5.6. A- Coarse breccia at base of Sudbury layer containing meter-scale slabs of the inderlying iron formation.
B- Typical lower breccia containing chert fragments supported in a matrix of sand-sized quartz grains and fragments of altered glass.
C- Accretion lapilli in matrix of lower breccia.
D- Elongated chert fragments showing preferred orientation.
E- Chert fragment in lower breccia showing alteration rim.
F- Lower breccia with an unusually high abundance of exotic (non-chert fragments.
Coin is US penny in A-D.

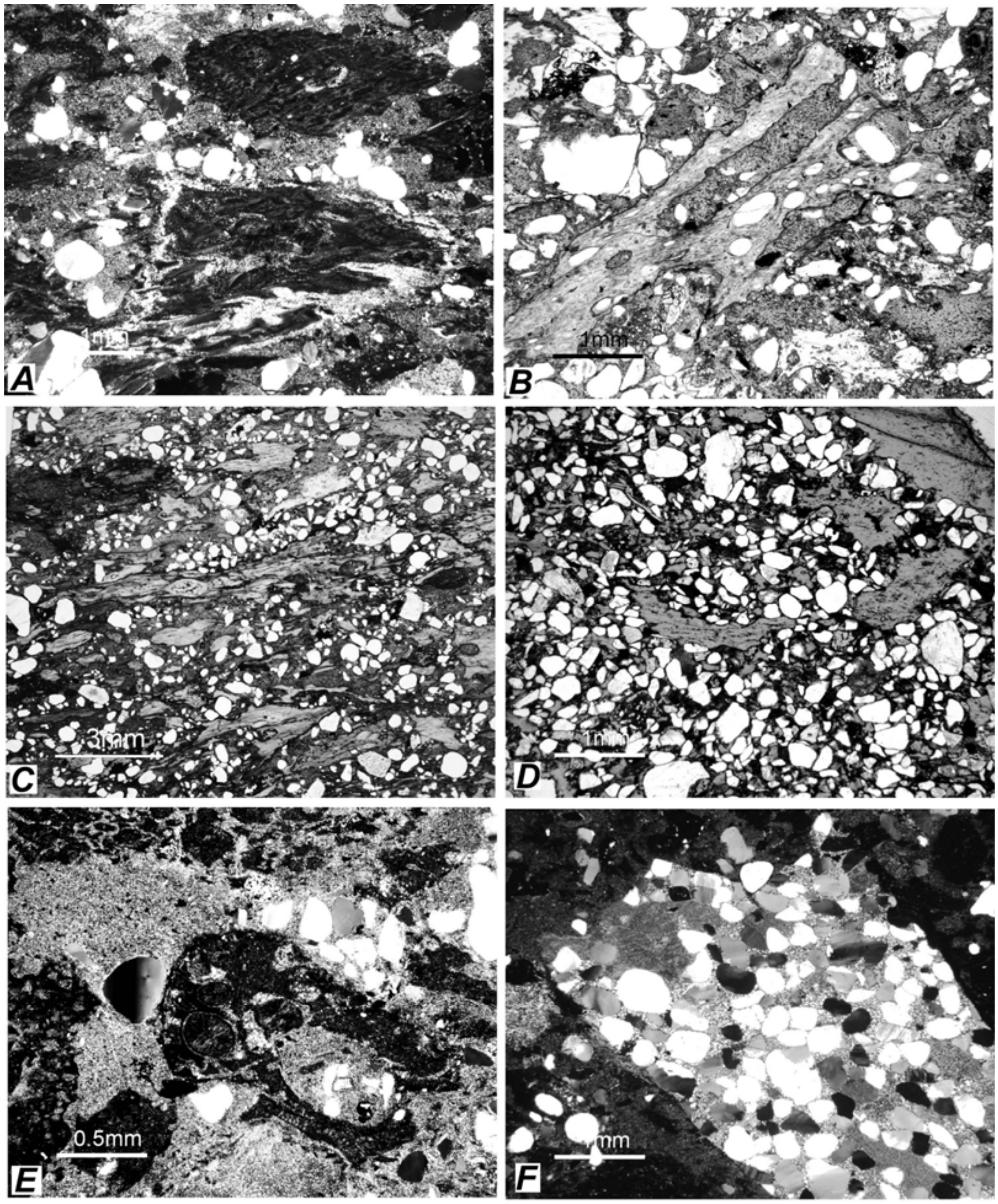

Figure 5.7. Photomicrographs of samples from the McClure site.
A-Complex glass particle from lower breccia with two distinct compositions, possible immiscible melts.
B- Complex fiamme of highly vesicular glass, now largely chlorite (trending upper right to lower left).
C- Lower breccia matrix with numerous flattened particles of vesicular glass, now largely chlorite.
D- Upper sandstone with numerous particles of altered glass, now largely chlorite;
E- Vesicular glass particle in lower breccia and aphanitic matrix.
F- Grain of quartzite in matrix of lower breccia.
Note the abundance of rounded quartz grains in all samples.

References

Clark, L.D., Cannon, W.F., and Klasner, J.S., 1975, Bedrock geologic map of the Negaunee SW Quadrangle, Marquette County, Michigan: U.S. Geological Survey Geological Quadrangle Map GQ-1226, scale 1:24,000.

Puffett, W.P., 1974, Geology of the Negaunee Quadrangle, Marquette County, Michigan: U.S. Geological Survey Professional Paper 788, 53 p.