THE TERMINAL CRETACEOUS MANSON IMPACT STRUCTURE OF IOWA AND ITS POSSIBLE INFLUENCE ON K/T EVENTS IN THE WESTERN INTERIOR OF NORTH AMERICA

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The Manson Impact Structure of northern Iowa is the largest well-preserved impact structure in the United States (35 km diameter). Its $^{40}Ar/^{39}Ar$ age of 65.4 $\pm$0.4 Ma (Kunk and others, 1993) is indistinguishable from the age of the Cretaceous-Tertiary (K/T) boundary. Although multiple impact events now seem likely to have occurred at or near the end of the Cretaceous, including the probable giant structure at Chicxulub, Yucatan (Hildenbrand and others, 1991), the Manson structure is of special interest because of its geographic proximity to documented K/T boundary sections in the Western Interior of North America. Manson is considered a likely source for some of the impact ejecta identified in the iridium-enriched impact layer of the K/T boundary layer in the Western Interior (Shoemaker and Izett, 1992). The maximum sizes of shocked quartz grains in K/T boundary layers worldwide generally decrease with increasing distance from Manson. A recent drilling program in the Manson structure, cosponsored by the U.S. Geological Survey and the Iowa Geological Survey Bureau, has identified a variety of impact-related rock types (Anderson and others, in press) and refined our understanding of the general internal structure of the feature (for a synthesis of previous studies, see Hartung and Anderson, 1988). Three major structural terranes are identified: 1) a broad "central peak" of Precambrian basement rocks uplifted 6-7 km; 2) an outer "terrace terrane" of complex downdropped blocks, including Cretaceous stratigraphic units structurally preserved far to the east of their present-day erosional margins across the Dakotas; and 3) an intermediate "crater moat." An overturned ejecta flap of stratigraphically inverted Proterozoic and Phanerozoic blocks and clasts is identified in one drill core from the terrace terrane, in a region downdropped at least 600 m relative to the crater margin. Crater modeling indicates that faulting within the terrace terrane and uplift of the central peak would have occurred within seconds to minutes after impact. Impact-related rocks include two general types of breccias: 1) crystalline clast breccias (CCB), dominated by clasts of Precambrian basement lithologies (gneiss, granite, minor mafics) that incorporate clasts of accretionary melt-rock material (some with isotropic domains of apparently largely unaltered glass) and minor Proterozoic sedimentary rocks; and 2) sedimentary clast breccias (SCB), dominated by clasts of Phanerozoic shales and carbonates. CCBs were identified as blanketing the crystalline basement rocks of the central peak and display contrasting matrix lithologies, including 1) a lower interval with a sandy argillaceous matrix, and 2) an overlying unit with an altered melt-rock matrix displaying regions of flow-banding (interpreted as the impact melt layer). Clasts and grains within the CCBs show abundant planar deformation features (PDFs), especially quartz with multiple sets of shock lamellae, features unique to impact events. Some clasts are partially to completely melted, and many are modified by early postimpact hydrothermal alteration (Crossey and McCarville, 1993). The CCBs overlie relatively intact large blocks of Precambrian basement rocks on the central peak, which incorporate pods or dikes of CCB and display thin pseudotachylite (frictional melt) veins generated along fracture offsets.

Mineral crystals in these basement rocks also display abundant PDFs. By contrast, the SCBs are known to blanket all three structural terranes in the crater. The most abundant SCB contains only scattered rare clasts of Precambrian basement lithologies, and melt-rock clasts are rare to absent. These breccias, however, contain a disproportionately high percentage of Cretaceous shale, mudstone, and sandstone clasts, including contorted large blocks up to 75 m in diameter. Isolated, well-preserved Cretaceous foraminifer tests are scattered to common in SCB matrix. A layer of SCB was deposited across the central peak and is preserved in a central depression where it locally incorporated clasts of impact melt-rock into its base.

The disproportionate dominance of Cretaceous lithologies in the SCBs, when compared to the total volume of crustal material excavated during transient cratering, suggests that much of the contained Cretaceous blocks and other materials were derived by sedimentary mass transport from the crater margin, not by ejecta fallback. Unstable scarps probably existed around the crater margin immediately following excavation of the transient crater and as unstable footwall scarps associated with the episode of normal block faulting during formation of the terrace terrane area. The upper strata of these scarps was dominated by Cretaceous sediments (an estimated 300 m of Cenomanian through Maastrichtian strata) and, along with the ejecta blanket, presumably served as the source for the bulk of the SCB material. These Cretaceous blocks, clasts, and matrix provide a record of Cretaceous deposits now largely eroded from the eastern margin area of the Western Interior. The presence of Paleozoic and rare Proterozoic and melt-rock lithologies identify the ejecta component of the SCB, incorporated chaotically with the mass of transported Cretaceous material during emplacement. Therefore, the SCB was likely transported from the crater rim by gravitationally driven mass wasting, coincident with and immediately following large-scale fault movements associated with the formation of the terrace terrane and the uplift of the central peak. This emplacement of the SCB included the transport of material, in thickness known to exceed 200 m, up to 15 km or more laterally, to cover all regions including the center of the Manson structure.

The scale of movement associated with emplacement of the SCB is hard to comprehend, and whether gravity-driven landslide alone was sufficient to accomplish the task. The scale of the emplacement raises an intriguing question: Was the Manson site dry land at the time of impact or was the site covered by a shallow seaway at that time? Some workers (e.g., Feldman, 1972) have raised the possibility that the Western Interior seaway did not completely withdraw at the end of the Cretaceous, noting that the eastward-thinning Hell Creek-Ludlow nonmarine package is sandwiched between marine units below (Pierre-Fox Hills) and above (Cannonball), similar to other Cretaceous nonmarine wedges (e.g., Two Medicine-Judith River). If the trend of Hell Creek thinning is extrapolated eastward beyond the present-day erosional edge, the Western Interior seaway may have remained in the eastern Dakotas and western Iowa at the time of the K/T boundary. If the Manson impact occurred in a shallow sea, tsunami-like currents may have swept back into the crater following impact, possibly transporting enormous amounts of material.

What effects might be predicted to have occurred at the end of the Cretaceous in the Western Interior as a result of the nearby Manson impact? First, about 2.2×10^{21} Joules (Anderson and Hartung, 1992) would have been released on the basis of a tentative scaling of known blast zones to a Manson-size impact; the effects of the atmospheric shock wave generated from the Manson blast would have been dramatic. Second, all combustible material within about 200 km of Manson would have been ignited, standing vegetation completely devastated out to a distance of approximately 600 km. Third, the force of the blast was sufficient to kill most exposed terrestrial animals in its wake as far as 1000 km and the shock wave could have knocked human-sized animals off their feet as far away as 1300 km. These distances intersect various K-T boundary sections in the Western Interior, including areas in south-central North Dakota (650-750 km), eastern Wyoming (including Teapot Dome) (800-950 km), southwest North Dakota (including the Bowman area) (850 km), the Raton Basin (1050-1100 km), and the type area of the Hell Creek Formation (1100 km). Fourth, significant amounts of ejecta were generated from the Manson impact, with estimates ranging from 600 to 1200 km^3 (Anderson and Hartung, 1992; Roddy and Shoemaker, 1993), about 15 percent of which would have been injected above the tropopause. The impacting body (comet or asteroid) completely vaporized on impact, providing a source of extraterrestrial material, likely to be iridium-enriched. Therefore, the Manson impact probably contributed ejecta (including large amounts of shocked quartz) and extraterrestrial material to the K/T boundary sections in the Western Interior and elsewhere in the world (Anderson and Hartung, 1992).

Although the Manson structure is significantly smaller than the current estimates of the size of the Chicxulub structure, the Manson impact remains one of the most remarkable events in the Cretaceous history of the North American Western Interior and may have had a truly significant effect on the biosphere. Many new details concerning the Manson structure will be emerging in the near future as a consortium of researchers continues to study the newly drilled core materials.

Anderson, R.R., and Hartung, J.B., 1992, The Manson Impact Structure: Its contribution to impact materials observed at the Cretaceous-Tertiary boundary: Proceedings Lunar and Planetary Science, v. 22, p. 101-110.

Anderson, R.R., Hartung, J.B, Witzke, B.J., Shoemaker, E.M., and Roddy, D.J., in press, Preliminary results of U.S. Geological and Iowa D.N.R. Geological Survey Bureau Manson Core Drilling Project, *in* Dressler, B., ed., Proceedings of the Sudbury 1992 Conference on Large Meteorite Impacts and Planetary Evolution: Geological Society of America Special Paper.

Crossey, L.J., and McCarville, P., 1993, Post-impact alteration of the Manson Impact Structure [abs.]: Lunar and Planetary Science Conference, v. 24, p. 351-352.

Feldman, R.M., 1972, Stratigraphy and paleoecology of the Fox Hills Formation (Upper Cretaceous) of North Dakota: North Dakota Geological Survey, Bulletin 61, 65 p.

Hartung, J.B., and Anderson, R.R., 1988, A compilation of information and data on the Manson Impact Structure: Lunar and Planetary Institute, Technical Report 88-08, 32 p.

Hildenbrand, A.R., Penfield, G.T., Kring, D.A., Pilkington, M., Camargo, A.Z., Jacobsen, S.B., and Boynton, W.V., 1991, Chicxulub crater: A possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico: Geology, v. 19, p. 867-871.

Kunk, M.J., Snee, L.W., French, B.M., Harlan, S.S., and McGee, J.J., 1993, Preliminary $^{40}Ar/^{39}Ar$ age spectrum and laser probe dating of the M-1 core of the Manson Impact Structure, Iowa [abs.]: Lunar and Planetary Science Conference, v. 24, p. 835-836.

Roddy, D.J., and Shoemaker, E.M., 1993, The Manson impact crater: Estimation of the energy of formation, possible size of the impacting asteroid or comet, and ejecta volume and mass [abs.]: Lunar and Planetary Science Conference, v. 24, p. 1211-1212.

Shoemaker, E.M., and Izett, G.A., 1992, Stratigraphic evidence from western North America for multiple impacts at the K/T boundary [abs.]: Lunar and Planetary Science Conference, v. 23, p. 1293-1294.