SEPM RESEARCH CONFERENCE REPORT:
THE SEDIMENTARY RECORD OF METEORITE IMPACTS
May 21-23, 2005, Springfield, Missouri

An SEPM-sponsored Research Conference on the Sedimentary Record of Meteorite Impacts was held May 21-23, 2005, in Springfield, Missouri. The conference featured talks and posters on the sedimentary aspects of impact structures around the world, a field trip to the Weaubleau-Osceola structure, and an optional field trip to the well known Decaturville and Crooked Creek impact structures. The aim of the conference was to bring together scientific specialists from different disciplines to address the sedimentary record of meteorite impacts using multidisciplinary approaches. The meeting was organized by Kevin Evans, Wright Horton, Mark Thompson, and John Warme. More than 60 participants, representing eight or more countries, attended the meeting. About ten of the attendees were graduate students. A day of oral and poster presentations was followed by an evening workshop to look at cored material, a one-day field trip to the Weaubleau-Osceola structure, and an optional day trip to the Decaturville and Crooked Creek impact structures. The integration of oral and poster presentations with field trips served as the basis for lively discussions among the various scientific specialists focused on the theme of the conference. The Abstracts with Program volume (Evans et al., 2005a) is online at http://geosciences.smsu.edu/geology/SEPMRC/conference.html.

The conference encompassed all aspects of the sedimentary record of meteorite impacts, including impact-generated and impact-modified sediments; proximal and distal deposits; processes such as ballistic sedimentation, atmospheric blowout, and tsunamis; the effects of reworking and alteration, and criteria for distinguishing impact-related deposits. The format promoted communication on these topics across a wide range of scientific specialties, including stratigraphy, sedimentology, petrology, mineralogy, geochemistry, paleontology, geophysics, hydrogeology, economic geology, and numerical modeling. Worldwide examples illustrated the importance of meteorite impacts as agents of sedimentation and sediment modification that vary according to geologic settings, ranging from marine to non-marine. Impact structures and deposits that they generate are hosts for hydrocarbons and ore deposits, and they influence water quality and availability. By preserving a record of ancient meteorite impacts, rocks and sediments provide insight into the distribution of these resources as well as modern risks for life and civilization.

ORAL PRESENTATIONS

Keynote addresses by Jay Melosh (University of Arizona) and Bevan French (Smithsonian Institution) provided a comprehensive background and stimulating perspectives for later discussions. Melosh reviewed the mechanics of meteorite impact ejection and sedimentation, beginning with a historical perspective on the recognition of impact craters and cratering processes. He highlighted scientific milestones such as Charles Gifford's (1924) impact-explosion analogy, the recognition of kinetic energy as the important factor in impact cratering, reinterpretation of "crypto-volcanic" structures as impacts, Robert Dietz's recognition of shatter cones as the first shock metamorphic feature diagnostic of impact, and distinctions between simple, complex, and multi-ring craters that provide insights into cratering processes such as the

transformation of central peaks into peak rings. Cratering studies, including numerical modeling, owe a lot to nuclear explosion technology as well as NASA simulations to assess potential meteorite-impact hazards on spacecraft. Melosh's discussion of impact processes from a numerical modeling perspective included the mechanics of ejection, melt volume as a function of crater size, ballistic sedimentation, how planetary atmospheres winnow and modify ejecta deposition, and "atmospheric blowout" as a mechanism for distributing far-traveled ejecta and tektites.

Bevan French spoke on the growing recognition of meteorite impacts as a normal geological process. He also started with a historical perspective, noting the importance of NASA support for meteorite impact studies in the 1960s, including Eugene Shoemaker's (1963) discovery of coesite as the first reliable indicator of extreme high pressures in near surface rocks, and Donald McIntire's (1968) discovery of shock-induced planar deformation features in quartz at Clearwater Lake in Quebec. Many impact deposits and craters have been found by "ordinary geologists doing ordinary geology." This pattern is exemplified by the Alvarez et al. (1980) discovery of a global iridium anomaly at the K/T boundary and delineation of the Chicxulub structure by geophysical surveys that were originally conducted for petroleum exploration. The research emphasis in recent years has been shifting away from finding craters and more toward understanding impact cratering as a normal geological process.

Oral presentations for the remainder of the conference discussed impact-related sedimentary processes and materials, planetary impacts, distal ejecta and tsunami deposits, ejecta as stratigraphic markers, marine impacts, and scientific drilling. Gordon Osinski gave a presentation on ejecta sedimentation processes. He cited the Bunte Breccia in the Ries crater (Germany) as a good example of ballistic sedimentation that incorporated secondary ejecta from the target as it was emplaced during the excavation stage. After a temporal hiatus, suevite was emplaced over the Bunte Breccia as a ground-hugging, relatively low velocity, melt-rich flow similar to a pyroclastic flow. Osinski gave another talk on processes and products of meteorite impacts into sedimentary rocks based on his doctoral thesis. Impacts into sedimentary rocks differ from those in crystalline rocks, because the targets are layered, porous, and contain volatiles. The apparent shortage of melt in sedimentary-target impacts is commonly attributed to explosivity due to volatiles, but Osinski presented evidence that it is at least partly due to a misinterpretation of textures associated with carbonate melts.

Jere Lipps discussed ideas for using impacts as probes for astrobiological targets in the interior of icy solar system bodies. He also suggested that Europa and Ganymede are the most interesting candidates for astrobiology.

Distal impact deposits were addressed in a series of talks. Gary Byerly's study of the petrology and sedimentology of Middle Archean impact spherule beds in the Barberton Greenstone belt (South Africa) demonstrates the importance of nickel spinels, formed in the original impact melt-quench process, as evidence for impact, because they persist for a long time in the sedimentary record. Arthur Banet discussed evidence for distal ejecta in drill cores that may help to constrain the age of the Avak structure in Alaska. Carl Campbell reported microtektites at the base of a coquina zone in the Clayton Formation at the K-T boundary in southeastern Missouri, and suggested that boudin-like changes in thickness of the zone may represent tsunami scours. Peter

Schultz discussed at least 7 different age layers of glass, interpreted to be impact glass, within Miocene to Holocene Pampean sediments of Argentina and their importance for regional stratigraphic correlations. Shaobin Liu described chemical distinctions between late Eocene microtektites of the North American strewn field, believed to have originated from the Chesapeake Bay impact, and similar-age clinopyroxene(cpx)-bearing microtektites attributed to the Popigai impact. The geographic distribution of the North American tektite strewn field covers about 2% of the Earth, whereas the cpx-bearing microtektites associated with Popigai cover the whole earth. Marie-Agnes Courty discussed the evidence and formative processes of deposits that she and her coauthors attribute to an impact event about 4,000 years ago.

Presentations on known or suspected impact structures along the 38th parallel in Missouri were of special interest for the field trips. George Davis reviewed evidence pertaining to the age and origin of the Weaubleau-Osceola structure (suspected impact structure) as well as Crooked Creek and Decaturville impact structures. Kevin Evans discussed evidence suggesting that the Weaubleau-Osceola structure and "Weaubleau breccia" may have formed by a marine impact. Jim Miller discussed fossil constraints on the age and depositional environment of breccias in the Weaubleau-Osceola structure. Shannon Dulin presented paleomagnetic studies of shallow-water carbonates from the Weaubleau-Osceola structure and from the Late Devonian Alamo breccia.

Several talks on marine impacts stimulated comparisons and discussions of the effects of differences in size, water depth, and target composition. Wright Horton discussed the character, distribution, and evidence for the origin of suevitic breccias, impact-modified sediments, and allogenic sediment-clast breccias in the late Eocene Chesapeake Bay impact structure (Virginia). David King attributed the horseshoe shape of the Late Cretaceous Wetumpka impact structure (Alabama) to collapse of a weakened rim on the southeast side due to increasing depth of target crystalline basement in that direction. The interpretation of crater-fill deposits at Wetumpka suggests an early fallback sequence followed shortly by the violent return of seawater, an interval of stasis when seawater was excluded by the crater rim, and a later surge of seawater following collapse of the crater rim. John Warme presented some hypotheses to explain enigmas of the Late Devonian, marine Alamo breccia (Nevada and Utah), such as the small crater size relative to the huge area and volume, and asymmetric geographic distribution of impact-related facies. Henning Dypvik discussed soot deposits in the Late Jurassic Mjølnir impact structure, which suggest that the heat of impact may have ignited the floor of the Barents Sea before the return of seawater! Frank Kyte presented the late Pliocene Eltanin impact as the only known example of a kilometer-sized asteroid that impacted a deep (5 km) ocean basin. The seafloor was severely disturbed, with erosion and redeposition, with no indication that the impactor penetrated the seafloor and formed a crater. The Eltanin deposit is the most meteorite-rich locality on earth.

Christian Koeberl spoke on recent drilling in the Bosumtwi impact crater (Ghana) by the International Continental Scientific Drilling Program (ICDP). The Bosumtwi impact crater is the largest young impact crater on Earth (11 km in diameter, about 1 million years old) and thus is exceptionally well preserved. It is the source of the Ivory Coast tektites, one of the four known tektite strewn fields on Earth. The crater is now filled by Lake Bosumtwi, where 2004 drilling recovered sediment cores that contain a paleoclimate record of the last million years and rock cores of impactites that are now under investigation.

POSTER SESSION

Poster presentations, which began informally the evening before the talks, provided a wonderful backdrop for discussions at the conference. Proximal impactites and sedimentary processes were addressed in posters on the Gardnos structure in Norway (Kalleson et al.), the Albion formation in Belize (King and Petruny), and the Lockne crater in Sweden (Ormö and Lindstrom). Fission-track dating of apatite from the Kentland crater (Indiana) was presented by Weber et al. An exhibit of drill cores from the Mjølnir impact crater by Dypvik et al. was a highlight.

Distal impact deposits and sedimentary processes were represented by posters on a Late Triassic ejecta layer in SW England (Amor et al.), a layer from the Late Cretaceous Fox Hills Formation in South Dakota (Jannette and Terry), glasses in loess of the Argentine Pampas (Harris and Schultz), and the Western Desert of Egypt (Haldemann et al.).

The late Eocene, shallow-marine Chesapeake Bay impact structure was represented by posters on different aspects, including investigations of the structure by geophysical surveys and drilling (Powars et al.), hydrogeology (Sanford et al.), shock-induced minerals (Jackson et al.), distal ejecta in Georgia (Harris et al.), and impact taphonomy of dinocysts (Edwards et al.). Impact taphonomy of microfossils received attention in another poster by Self-Trail and Jutson, who compared the preservation of calcareous nannofossils from the Chesapeake Bay and Silverpit (North Sea) structures. A poster by Conway and Haszeltine presented evidence that the Silverpit structure is unique among structures in the southern North Sea basin, although the impact origin remains controversial. Frisk et al. presented a unique post-impact Ordovician ecosystem in the marine Tvaren impact crater in Sweden. The Weaubleau-Osceola structure was represented by posters on the gravity and magnetic surveys (Mickus et al.) and drilling results (Davis).

CORE WORKSHOP

The SMSU-MoDOT Vista 1 core and a collection of fauna associated with the "Weaubleau breccia" were placed on display at Southwest Missouri State University. The core consists of more than 75 m of breccia that includes several facies, ranging from a moderately well-sorted polymict, matrix-supported carbonate breccia near the top to a crystalline-basement breccia from 69 m to total depth. Discussions over the core provided background for the field trip to the Weaubleau-Osceola structure the following day.

FIELD TRIPS

A field trip guidebook to the geology of the Weaubleau-Osceola structure and Decaturville and Crooked Creek impact structures (Evans et al., 2005b) is available online at http://geosciences.smsu.edu/geology/SEPMRC/sepmrc_guidebook.pdf.

The Weaubleau-Osceola structure is a proposed impact candidate that has not been fully documented. The Sunday field trip to this structure progressed from undeformed strata on Missouri Highway 82 to progressively more deformed (faulted, folded, and fractured) strata at the Ash Grove Aggregates quarry. Active quarrying operations have removed some classic

recumbent folds but exposed other blocks of displaced rock. The Burlington and Keokuk limestones (undivided) were the focus of post-deformation, pre-Pennsylvanian karstification.

A stop along Missouri Highway 13 was a highlight of this field trip. Eight meters of breccia exposed along the highway are correlative with the uppermost part of core recovered from in SMSU-MoDOT Vista 1 borehole. The polymict breccia includes a diverse mixed-age fauna of Early Ordovician and Early to medial Mississippian conodonts, and abundant Mississippian crinoids and blastoids. Clasts vary from angular green siltstone clasts, derived from the Early Mississippian (Kinderhookian) Northview Formation and angular chert clasts of Early Ordovician age.

Other exposures along Highway 13 cut through undeformed Pennsylvanian sandstone and sandy chert breccia demonstrated that deformation clearly pre-dated deposition of these units. Following brief but picturesque stops at the confluence of the Osage and Sac rivers and an overview of the proposed "ground-zero" area, an unscheduled stop on the southern margin of the main outcrop belt of the "Weaubleau breccia" highlighted the variability of this informal stratigraphic unit.

The optional Monday field trip was attended by 40 participants. A brief overview of the Decaturville impact structure addressed aspects related to the reported overturned flap at this structure. Tamara Goldin, a graduate student working with Jay Melosh, indicated that modeling shows similar features can develop on the margins of central uplifts during their collapse.

At the second stop, a 100-m-long road cut on Missouri Highway 5 exposes folded and thrust-faulted Lower Ordovician dolomite, shale, sandstone, and overlying polymict breccia. Discussions focused on the kinematics and timing of folding and faulting in this crater moat setting. The field trip then continued on to Crooked Creek.

Stops at Crooked Creek included an overview of the structure, brecciation of rock units in the crater moat, faulting and deformation associated with the margins of the central uplift, and development of shatter cones in the center of the structure.

Field trips generally provide an opportunity to discuss pertinent issues among specialists, further the education of non-specialists, and foster a social environment for developing working relationships among colleagues. The SEPM Research Conference on "Sedimentary Record of Meteorite Impacts" provided this opportunity. A forthcoming call for papers and future joint publication of a special volume with the Geological Society of America will give participants the opportunity to extend their meeting presentations to the larger scientific community.

PARTICIPANTS

[In the interest of preventing unsolicited email, addresses have not been included in this list. Participants can refer to previous SEPM Research Conference messages for the list of addresses.]

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