IMPACT CRATERS ON MARS AND EARTH: IMPLICATIONS BY ANALOGY. T. Kenkmann[1] and F. Schönian[1], [1]Institut für Mineralogie, Museum für Naturkunde, Humboldt-Universität Berlin, Invalidenstrasse 43, D-10115 Berlin, Germany, thomas.kenkmann@museum.hu-berlin.de.

Introduction: This paper reports on recent investigations on terrestrial impact structures, which may have relevance for understanding Martian impact craters and the role of volatiles during their formation. It focuses on the properties of the ejecta blankets of the Chicxulub and Ries crater. Implications by analogy between Earth and Mars craters support the view that the formation of fluidized ejecta blankets can be linked to the presence of subsurface volatile reservoirs (water or ice) [1, 2]. The role of atmospheric effects [3] for the deposition of ejecta blankets on Earth is currently not clear.

Chicxulub crater, Mexico (180 km Ø): Recently new evidence was found for a widespread preservation of the Chicxulub ejecta blanket at distances ranging from 2.9-3.9 crater radii S of the crater on the Yucatan peninsula [4-6]. Mapping of the ejecta blanket revealed that it filled a pre-existing karstified paleorelief. Ejecta diamictites are largely composed of material derived by erosion of the subsurface (limestone, marl, clay). Crater derived material is of subordinate quantity but it includes shocked quartz grains, crystalline basement and altered melt clasts. The northern part of the ejecta that is nearer to the crater displays a chaotic fabric and complex grain size distribution. At distances >3.5 crater radii from the impact center internal shear planes become a predominant sedimentological feature within the ejecta blanket. Subhorizontal shear surfaces are particularly frequent at the base of the ejecta and around obstacles. Flow directions inferred from striations and grooves on polished shear planes indicate a radial flow pattern with remarkable deviations around obstacles like paleokarst hills. The abundance of locally eroded clays that lubricate shear planes within the ejecta point towards the important role of these lithologies for the development of the flow and its large runout efficiency. Although it is inhibited to infer the primary morphology of the ejecta blanket, the flow can be reconstructed with the help of flow indicators.

The observations indicate that the ejecta flow was non-cohesive and turbulent up to 3.5 crater radii from the impact center (320 km distance). At larger distances it evolved to a cohesive debris flow, may be by detrainment of volatiles. Localization of flow along decameter long discrete shear planes indicates (1) that perturbation by secondary impacts is impeded at this distance, and (2) that the flow strain rate is strongly reduced, because the fault lengths inversely dependent on strain rate magnitude [7].

Implication for Mars: The large runout distance of the Chicxulub ejecta up to 5 crater radii [8] makes it comparable to Martian MLE craters. Since a dense atmosphere and the presence of water are evident for Chicxulub this may also hold for Mars with fluidized ejecta blankets. The transition from a less-cohesive, turbulent flow to a cohesive and localized flow of the ejecta blanket suggests (1) a decreasing amount of water by detrainment (2) and a decreasing flow rate with increasing distance from the crater center. As a consequence, the formation of ramparts could be due to an imbrication and stacking of thin sheets bounded by shear planes within the ejecta blanket. The bulk geometry of the ramparts is then constrained by the resistance to frictional sliding on basal and internal shear planes, and by the bulk rheology of the ejecta and the flow rate.

Ries crater, Germany (26 km Ø): The pre-impact stratigraphy of the Ries crater is composed of ~650 m of partly water-saturated and subhorizontally layered sediments (limestones, sandstones, shales) underlain by crystalline basement rocks (gneisses, granites, amphibolites). The ejecta blanket of the Ries crater is composed of clastic polymict breccias (Bunte breccia) that extents up to 4 crater radii from the impact center as a continuous ejecta blanket of decreasing thickness. Its constituents are mainly sedimentary rocks, with 5-10% of crystalline rocks. The ratio of primary crater ejecta to local substrate components decreases with increasing radial range [9]. Local and crater derived material are thoroughly mixed on all scales and devoid linear structural elements. It is interpreted as a “cold”, non-cohesive impact formation [10]. Internal shear planes within the preserved ejecta blanket as observed at Chicxulub are not recorded. In addition to the Bunte Breccia ejecta blanket occurs a suevitic ejecta breccia with a bulk volume of 5-10% of that of the Bunte Breccia. Suevite occurs in 10-25 m thick patchy layers outside the crater and extends up to about 2 crater radii. The contact to the Bunte Breccia is very sharp. Sharp contacts of the Bunte breccia ejecta blanket also occur to the underlying rocks, even if the substrate is formed by unconsolidated sands [11]. Striations on contact surfaces revealed a radial flow. Obstacles of the pre-existing paleorelief caused deflections by up to

30°. None of the contacts observed represents the land surface prior to the impact, because of the lack of a weathering horizon. Recent investigations have shown that the uppermost target layers beneath the ejecta blanket around the crater are mechanically decoupled along incompetent, fluid bearing beds [12]. Decoupling was caused by near-surface spallation. Spallation and subsequent dragging by the ejecta curtain and/or the ejecta blanket flow also induced subsequent outward shearing.

Implications for Mars: Thin-skin delamination of rocks beneath a continuous ejecta blanket is favored in targets with flat lying sediments of large competence contrasts and differences in fluid saturation. The outward directed detachment of thin thrust sheets can lead to buckling of layers or can cause fault-propagation folding above the tip of the thin thrust sheet. The morphological expression in remote sensing studies would be the presence of concentrical ridges that can be traced through the deposits of continuous ejecta blanket. Such features may occur in some of Martian craters ejecta blankets. In opposite, the presence of concentrical furrows within the fluidized ejecta blanket around Mars craters may indicate yielding and subsequent break off of thin layers as a consequence of radial extension and outward flow on weak, fluid-rich layers. If the Ries crater really bears analogies to Martian craters one should find indications for two types of ejecta deposits resting with sharp contact onto each other, namely a volumetrically dominant lower ejecta blanket (corresponding to the Bunte breccia) and an upper, patchy ejecta layer, which is volumetrically of subordinate importance (corresponding to the suevite).

Inverted-sombrero type craters: Target rocks of terrestrial impact craters often display a layered structure with a twofold rheology. A mechanically weak, water saturated and/or unconsolidated sedimentary upper part rests on a much stronger crystalline basement. These craters display geometries of an inverted sombrero with a wider and shallower outer crater that is formed within the sediments and an inner nested crater that is formed within the crystalline basement. Examples for these types of craters are (1) the marine Lockne crater, Sweden, with an inner nested crater of 7 km diameter and an outer crater of 13 km diameter [13, 14], (2) the Ries crater, Germany, with an inner crater of 12 km diameter (inner ring) and an outer crater of 24-26 km diameter [15], and (3) the shallow marine Chesapeake Bay impact crater with a deep inner crater basin of 38 km diameter and an outer crater of 85 km diameter [16, 17].

Implication for Mars: Many craters on Mars show unusually wide outer terrace zones for which the misleading term "peripheral peak ring" was introduced [18]. The ratio crater rim/outer terrace zone is 1.2-1.5 [18] and exceeds common terrace widths [19]. In analogy to inverted-sombrero-type craters on Earth, this flat outer zone may represent a shallower outer crater formed in soft, maybe fluid-saturated sediments of the uppermost part of the crust that were more easily stripped away during the impact.

Acknowledgement: T. K. would like to thank the organizers of the Workshop for their kind invitation and generous travel support.

References: [1] Barlow, N. G. (2005) *Large Meteorite Impacts III*. Kenkmann, T., Hörz, F. and Deutsch, A. (eds.) *GSA Spec. Pap. 384*, 433-442. [2] Mouginis-Mark, P.J. (1978) *Nature 272*, 691-694. [3] Barnouin-Jha, O.S. and Schultz, P.H. (1998) *JGR 103*, 25739-25756. [4] Schönian, F., Stöffler, D., Kenkmann, T. and Wittmann, A. (2004) *LPS XXXV, Abstract #1848.* [5] Schönian, F., Kenkmann, T. and Stöffler, D. (2003) *LPS XXXIV, Abstract #4128*. [6] Schönian, F., Tagle, R., Stöffler, D. and Kenkmann, T. (2005) *LPS XXXVI, Abstract #2389*. [7] Melosh, H. J. (2005). *Impact Tectonics*. Koeberl, C. and Henkel, H. (eds.) 55-80. [8] Pope, K. O. et al. (2005) *Large Meteorite Impacts III*. Kenkmann, T., Hörz, F. and Deutsch, A. (eds.) *GSA Spec. Pap. 384*, 171-190. [9] Hörz, F., Ostertag, R., and Rainey, D.A. (1983) *Rev. Geophys. Space Phys. 21*, 1667-1725. [10] Stöffler, D. (1975) *Fortschr. Miner., 52*, 385-387. [11] Hörz F., Gall H., Hüttner, R. and Oberbeck, V.R. (1977) *Impact and Explosion Cratering*. Roddy, D.J, Pepin R.O., and Merill R.B. (eds.), p. 425-448. [12] Kenkmann T. and Ivanov B. A. (2005) *LPS XXXVI, Abstract #1039.* [13] Ormö, J. and Lindström, M. (2000) *Geol. Mag. 137*, 67-80.[14] Lindström, M. et al. (2005). *Impact Tectonics*. Koeberl, C. and Henkel, H. (eds.) 357-388. [15] Pohl, J., Stöffler, D., Gall, H., and Ernstson, K. (1977). *Impact and explosion cratering* Roddy, D.J, Pepin R.O., and Merill R.B. (eds.), p. 343-404. [16] Powars, D.S. and Bruce, T.S. (1999) *USGS Prof. Paper 1612*, 82 pp. [17] Poag, W., Koeberl, C. and Reimold, W.U. (2004) *The Chesapeake Bay Crater*, 522 pp., Springer. [18] Nycz J.C. and Hildebrand (2005) *LPS XXXVI, Abstract #2167*. [19] Pearce, S.J. and Melosh H.J. (1986) *Geophy. Res. Lett. 13*, 1419-1422.