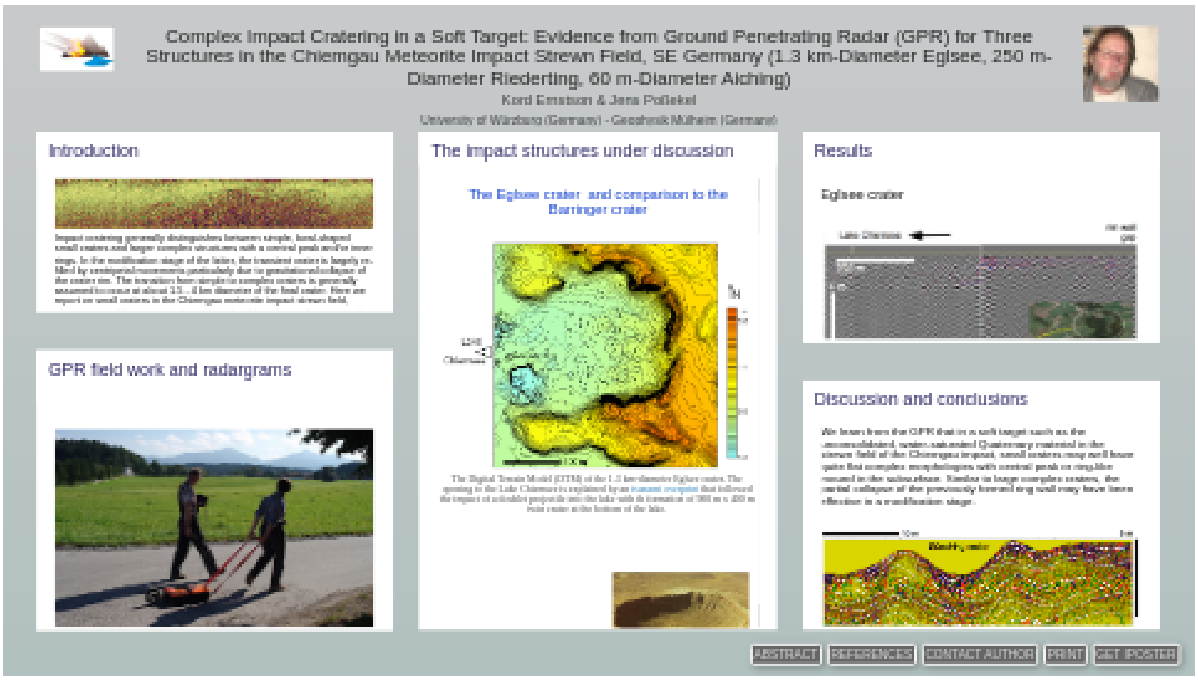
Complex Impact Cratering in a Soft Target: Evidence from Ground Penetrating Radar (GPR) for Three Structures in the Chiemgau Meteorite Impact Strewn Field, SE Germany (1.3 km-Diameter Eglsee, 250 m-Diameter Riederting, 60 m-Diameter Aiching)



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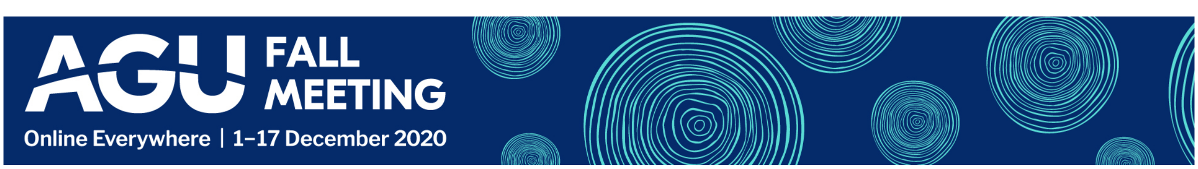
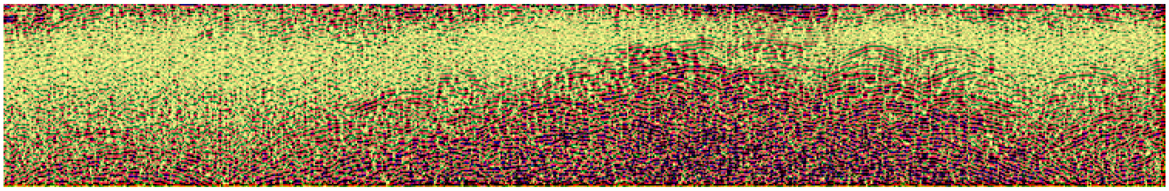
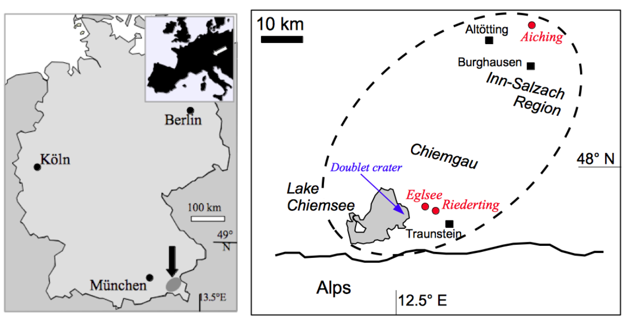


INTRODUCTION



Impact cratering generally distinguishes between simple, bowl-shaped small craters and larger complex structures with a central peak and/or inner rings. In the modification stage of the latter, the transient crater is largely re-filled by centripetal movements particularly due to gravitational collapse of the crater rim. The transition from simple to complex craters is generally assumed to occur at about 1.5 - 4 km diameter of the final crater. Here we report on small craters in the Chiemgau meteorite impact strewn field, where in a modification stage the primary bowl has changed into a complex crater with internal peak or ring morphology seen on GPR profiles through the crater center.

The Chiemgau meteorite impact (http://www.chiemgau-impact.com/)strewn field



Location map for the GPR measurements over the three craters (red circles) within the roughly elliptically encircled Chiemgau meteorite impact strewn field.

The Tüttensee meteorite impact crater. (http://www.chiemgau-impact.com/?s=t%C3%BCttensee) 600 m rim crest diameter.

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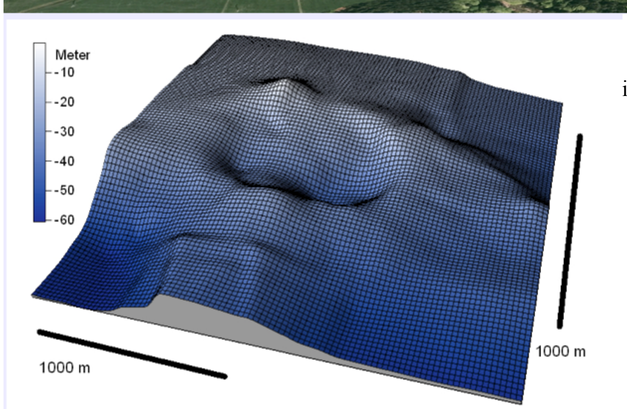
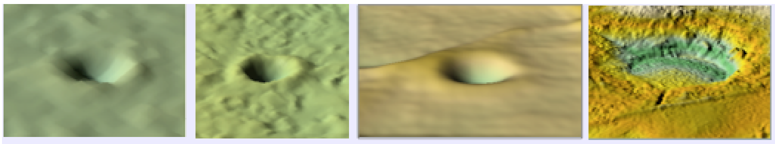


The doublet meteorite impact crater (http://www.chiemgau-impact.com/2013/01/chiemgau-impact-the-dual-crater-at-the-bottom-of-lake-chiemsee-nice-counterparts/) at the bottom of Lake Chiemsee. From echo sounder measurements.

Geologically, the craters occur in Pleistocene moraine and fluvio-glacial sediments. The craters and surrounding areas are featuring heavy deformations of the Quaternary cobbles and boulders, impact melt rocks and various glasses, strong shock-metamorphic effects, and geophys-ical (gravity, geomagnetic, sediment echo sounder) anomalies. Impact ejecta deposits in a catastrophic mixture contain polymictic breccias, shocked rocks, melt rocks and artifacts from Bronze Age/Celtic era people. The impact is substantiated by the abundant occurrence of metallic, glass and carbonaceous spherules, accretionary lapilli, microtektites and of strange, probably meteoritic matter in the form of iron silicides like gupeiite, xifengite, hapkeite, naquite and linzhite, various carbides like, e.g., moissanite SiC and khamrabaevite (Ti,V,Fe)C, and calcium-aluminum-rich inclusions (CAI), minerals krotite and dicalcium dialuminate. Physical and archeological dating confines the impact event to have happened most probably between 900 and 300 B.C. The impactor is suggested to have been a roughly 1,000 m sized low-density disintegrated, loosely bound asteroid or a disintegrated comet in order to account for the extensive strewn field.



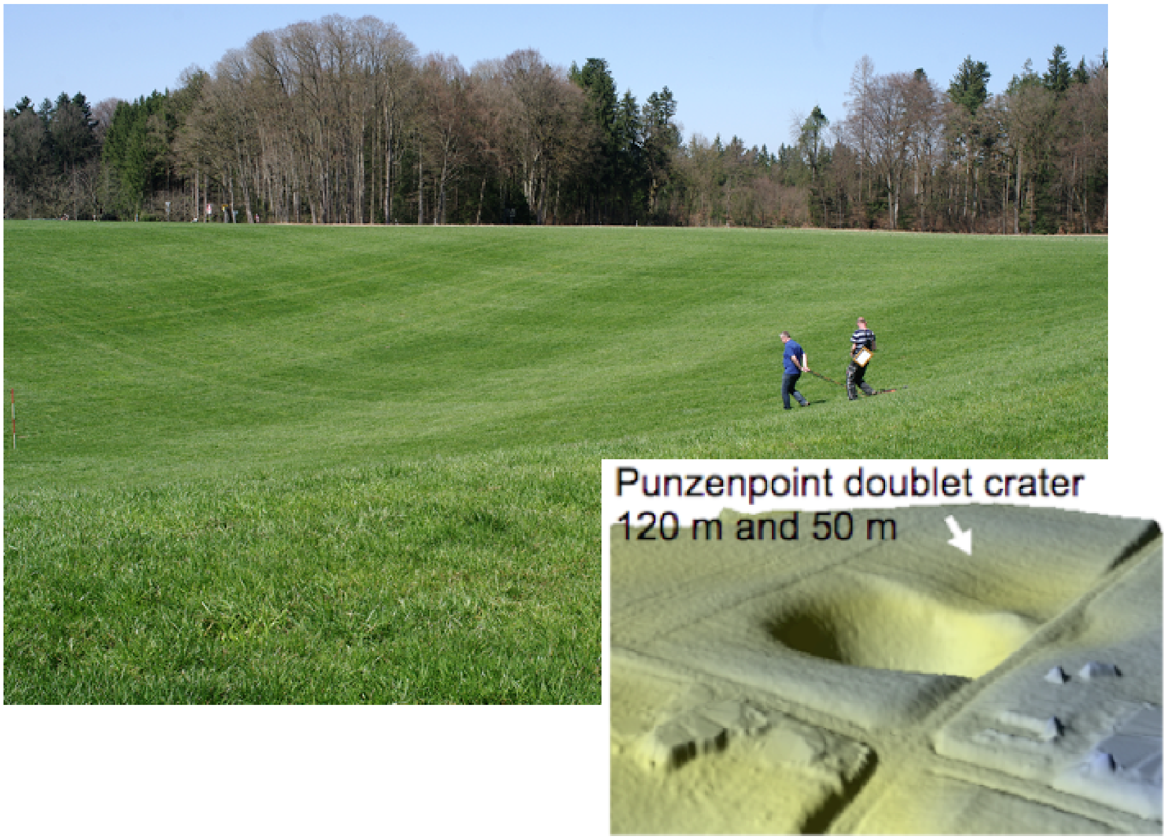
(http://www.impact-structures.com/2017/01/the-digital-terrain-model-dtm-and-meteorite-craters/)

Smaller craters in the Chiemgau impact strewn field: Mitterhauserweg (9 m rim crest diameter) Einsiedleiche (15 m), Engelsberg (45 m), Windschnur (80 m) . Surface plots from Digital Terrain Model (DTM). (http://www.impact-structures.com/2017/01/the-digital-terrain-model-dtm-and-meteorite-craters/)

References. - Ernstson, K. (2010) Journal of Siberian Federal University Engineering & Technologies 1/3, 72-103. Ernstson, K. et al. (2013) Proc. (Yushkin Memorial Seminar - 2013), 369-371, Syktyvkar. Ernstson, K. et al. (2011). Medit. Archaeology and Archaeometry 12/2, 249-259. Liritzis, I. et al. (2011): Medit. Archaeology and Archaeometry 10/4,17-33. Rappenglück, B. et al. (2010) Antiquity 84, 428-439. Hiltl, M., et al. (2011) - 42nd LPSC, Abstract #1391. Neumair, A., Ernstson. K. (2011) - AGU Fall Meeting 2011, Abstract & Poster ID GP11A-1023. Ernstson, K., Neumair, A. (2011) - AGU Fall Meeting 2011, Abstract & Poster ID NS23A-1555. Shumilova, T. G. et. al (2012) - 43rd LPSC, Abstract & Poster #1430. Isaenko, S. I. et al. 2012) - Abstracts Eur. Min. Conf. Vol. 1, EMC 2012-217. Rappenglück, M.A. et al. (2013) 76th Annual Meteoritical Society Meeting, Abstract #5055. Bauer, F. et al. (2013) - 76th Annual Meteoritical Society Meeting, Meteoritics & Planetary Science, Abstract #5056. Neumair, A., Ernstson, K. (2013) 76th Annual Meteoritical Society Meeting, Abstract #5057. Ernstson, K., et al. (2014) - 45th LPSC, Abstract #1200. Rappenglück, M A., et al. (2014) Yushkin Memorial Seminar - 2014), 106-107, Syktyvkar. Ernstson, K. (2016) - 47th LPSC, Abstract #1263.

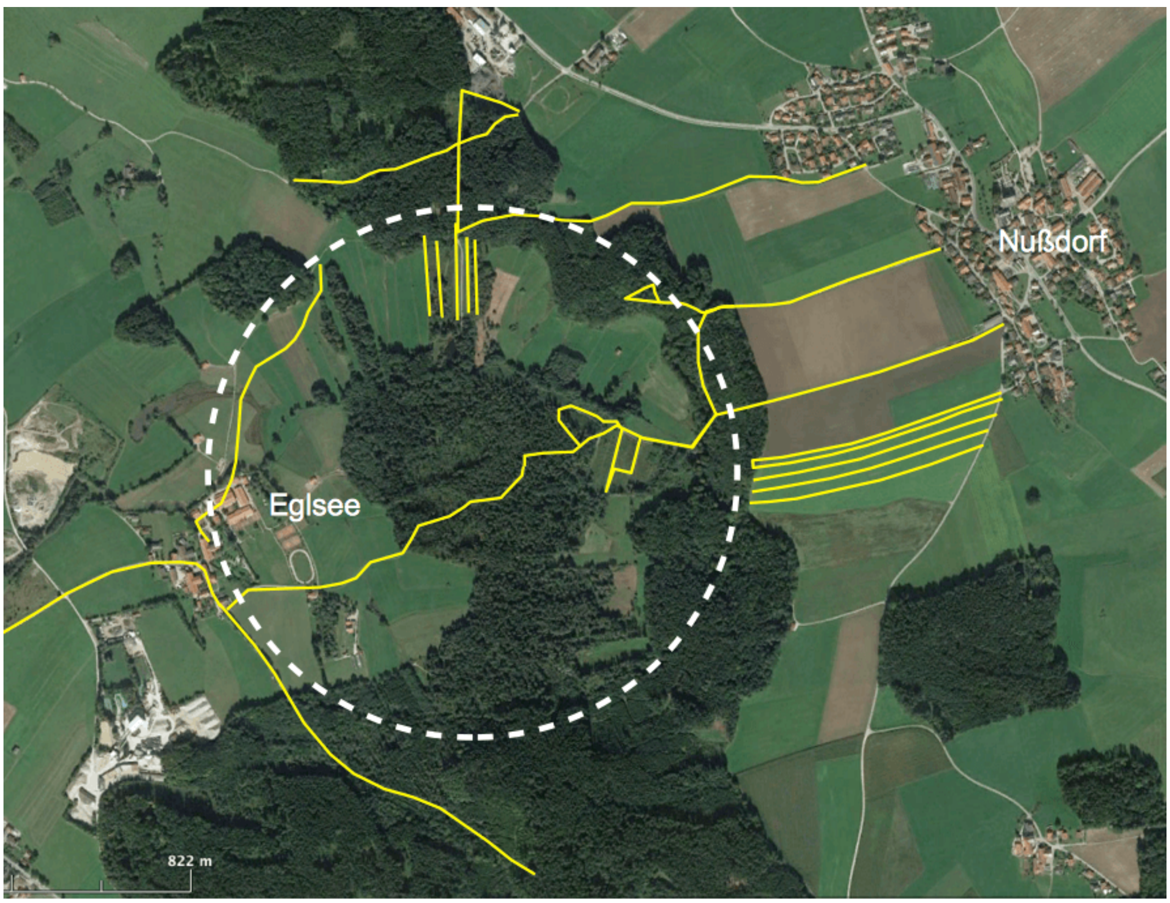
GPR FIELD WORK AND RADARGRAMS

The 300 MHz antenna VIY - Transient Technologies in the Eglsee crater.

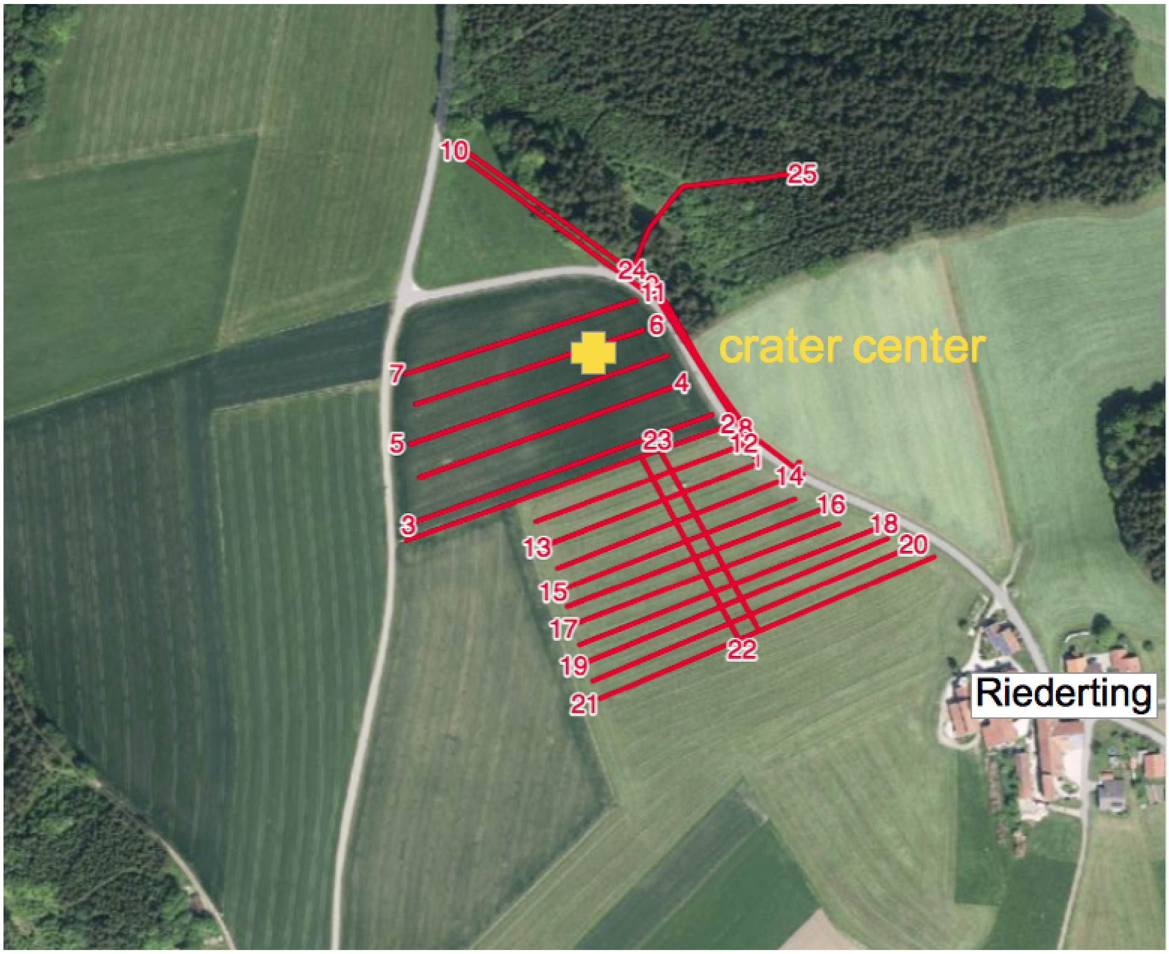


GSSI 200 MHz antenna in the 70 m-diameter Purkering crater

GSSI 400 MHz antenna operating at the Lake Chiemsee shore.



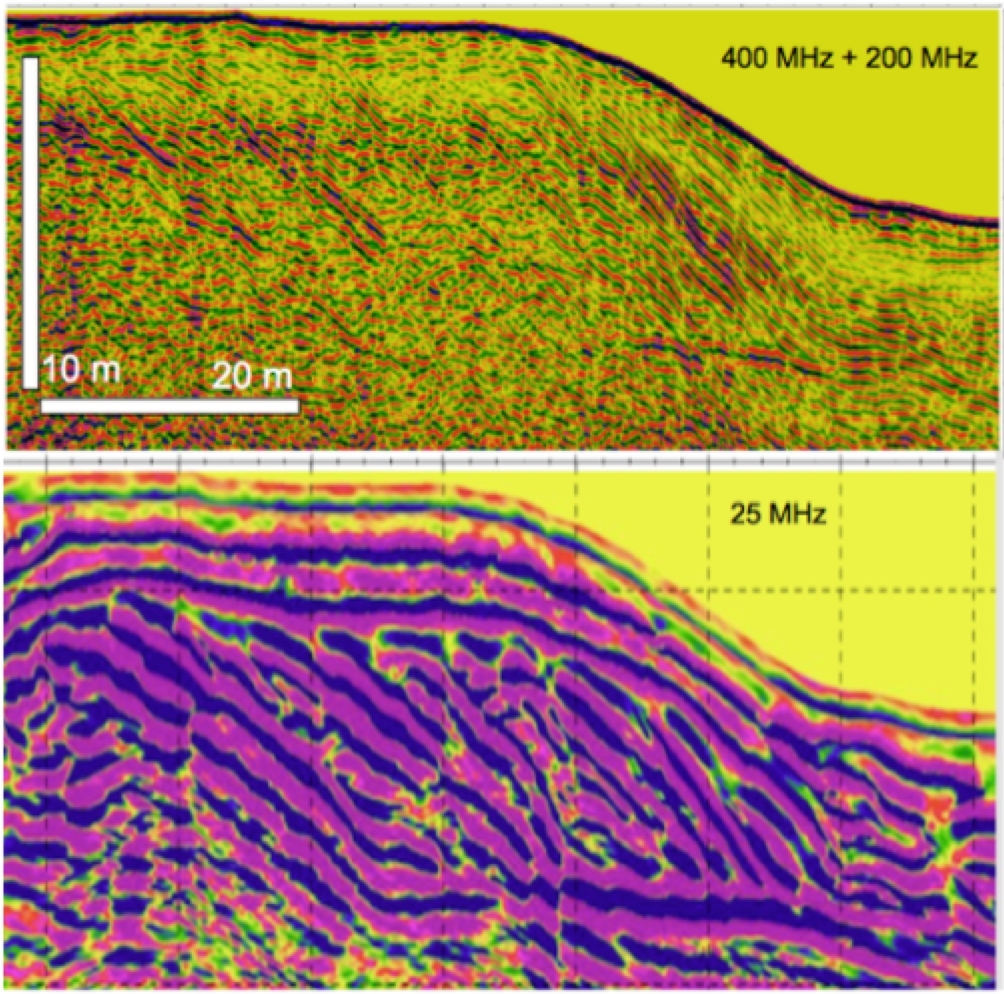
Location map for the Eglsee crater GPR profiles.



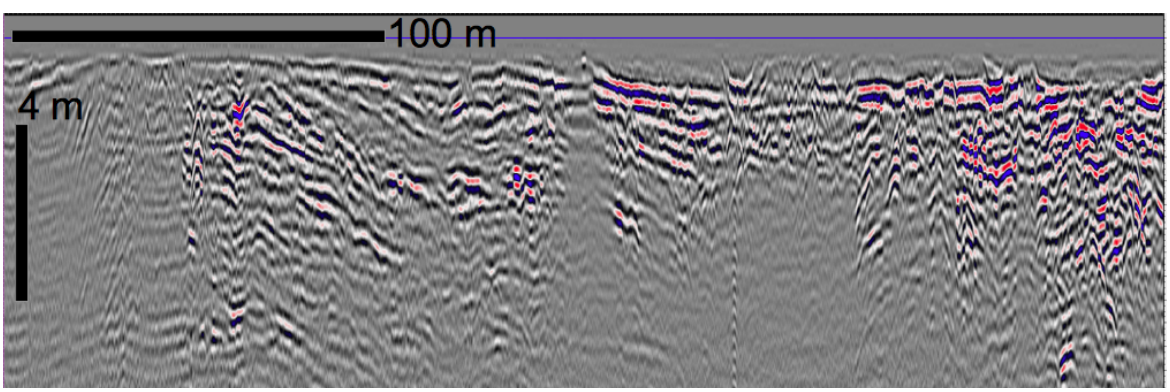
Location map for the Riederting crater GPR profiles.

Location map for the Aiching semi crater GPR profiles.

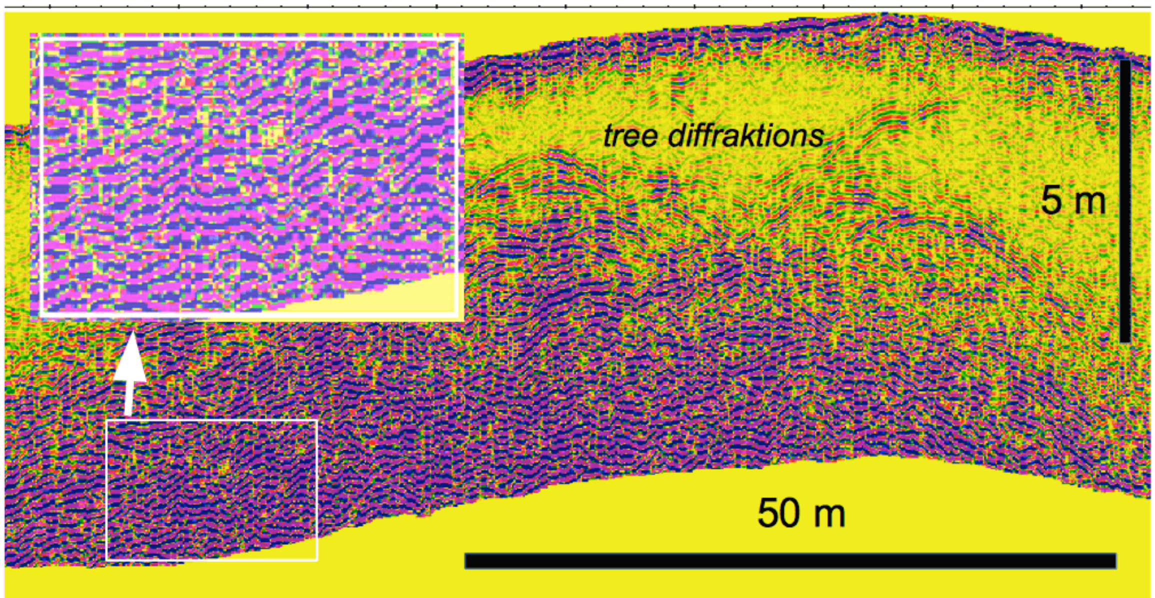
Radargrams



Rim wall of the Lake Tüttensee 600 m-diameter crater. The same GPR profile with three different frequencies. Above: Radargram from the data overlay of 400 MHz and 200 MHz. Below: The very low frequency emphasizes especially the main structures.



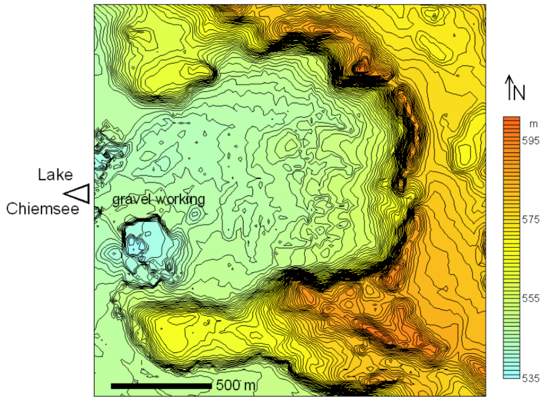
Eglsee crater, raw data section of the 3 km long diametric W - E profile; 300 MHz.



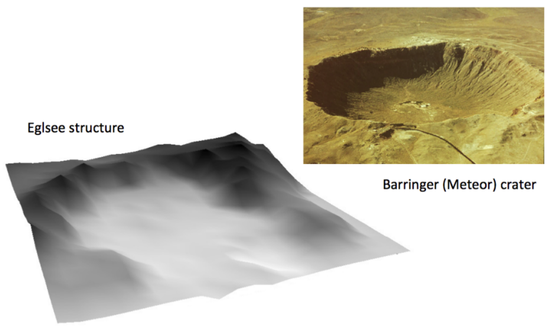
Riederting crater: 300 MHz radargramm (segment) crossing the crater rim. Note the complex cross bedding within the wall structure.

THE IMPACT STRUCTURES UNDER DISCUSSION

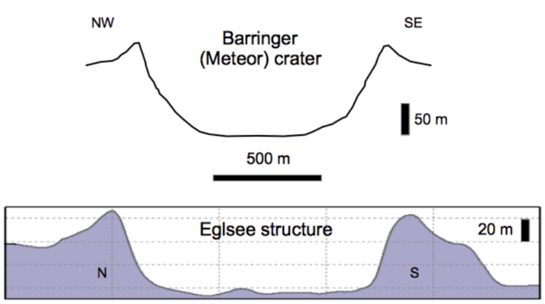
The Eglsee crater and comparison to the Barringer crater



The Digital Terrain Model (DTM) of the 1.3 km-diameter Eglsee crater. The opening to the Lake Chiemsee is explained by an tsunami overprint (http://www.chiemgau-impact.com/2015/11/a-cross-bedded-diamictite-evidence-of-a-big-lake-chiemsee-tsunami-in-the-chiemgau-meteorite-impact-event-strengthened/) that followed the impact of a doublet projectile into the lake with th formation of 900 m x 400 m twin crater at the bottom of the lake.

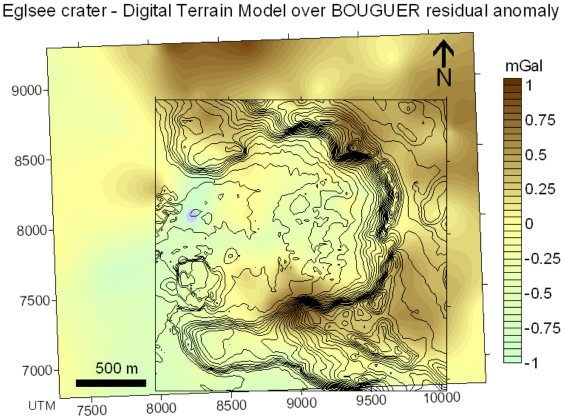


The DTM shaded relief of the Eglsee crater in comparison to the Barringer meteorite crater. Same size.

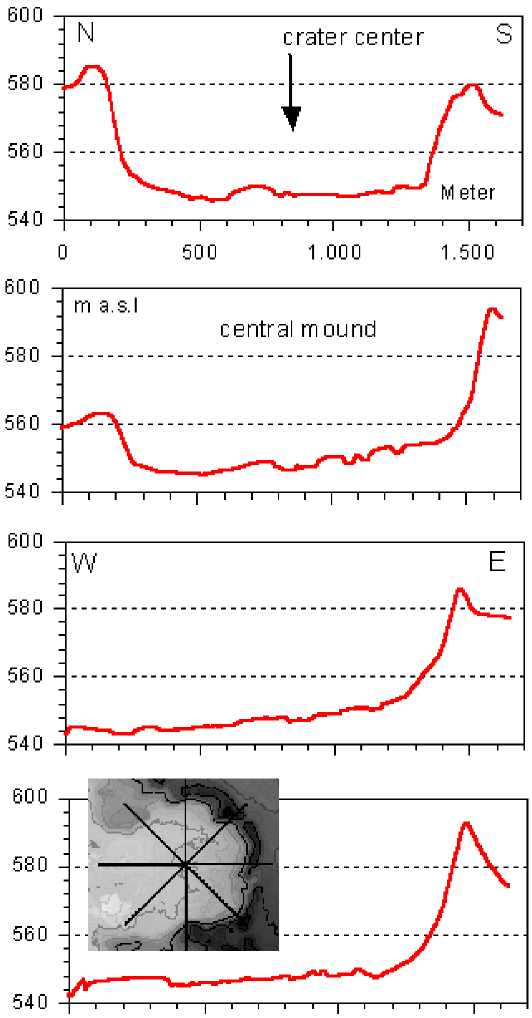


Cross sections of the Eglsee and Barringer craters

Eglsee crater - Digital Terrain Model over BOUGUER residual anomaly

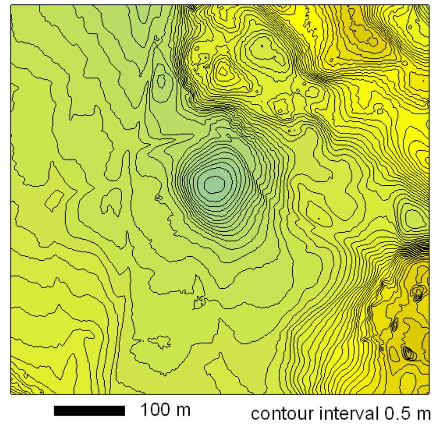


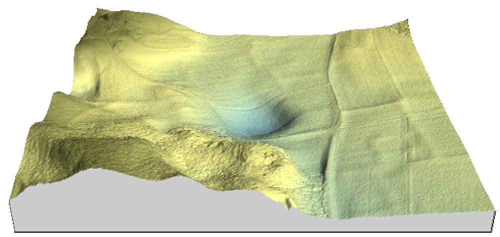
The Digital Terrain Model over the Bouguer gravity residual map.



The 250 m-diameter Riederting crater

Photo of the Riederting structure: the crater bowl with an inner ring (after some image processing).

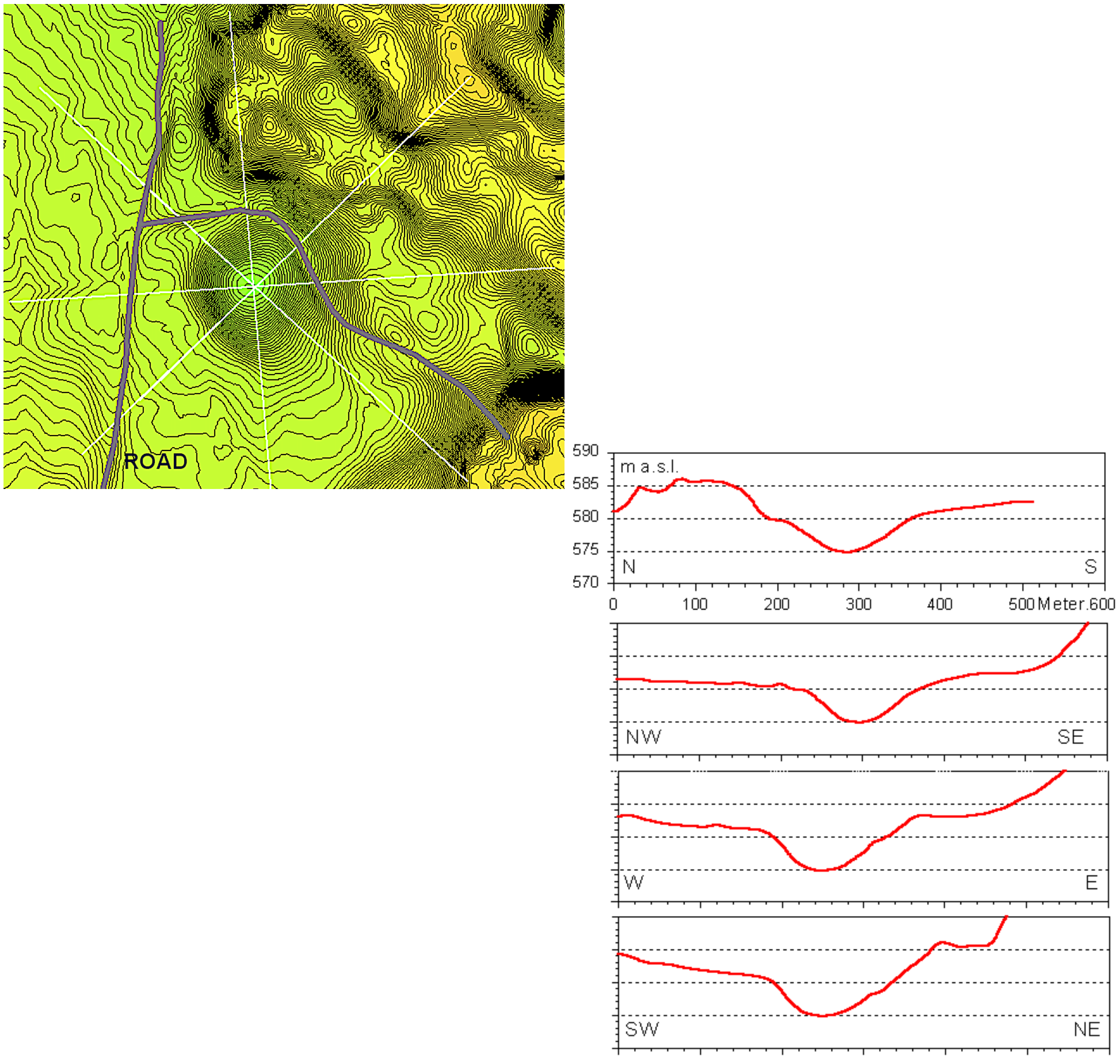




Digital Terrain Model DTM, topigraphic map, contour interval 0.5 m.

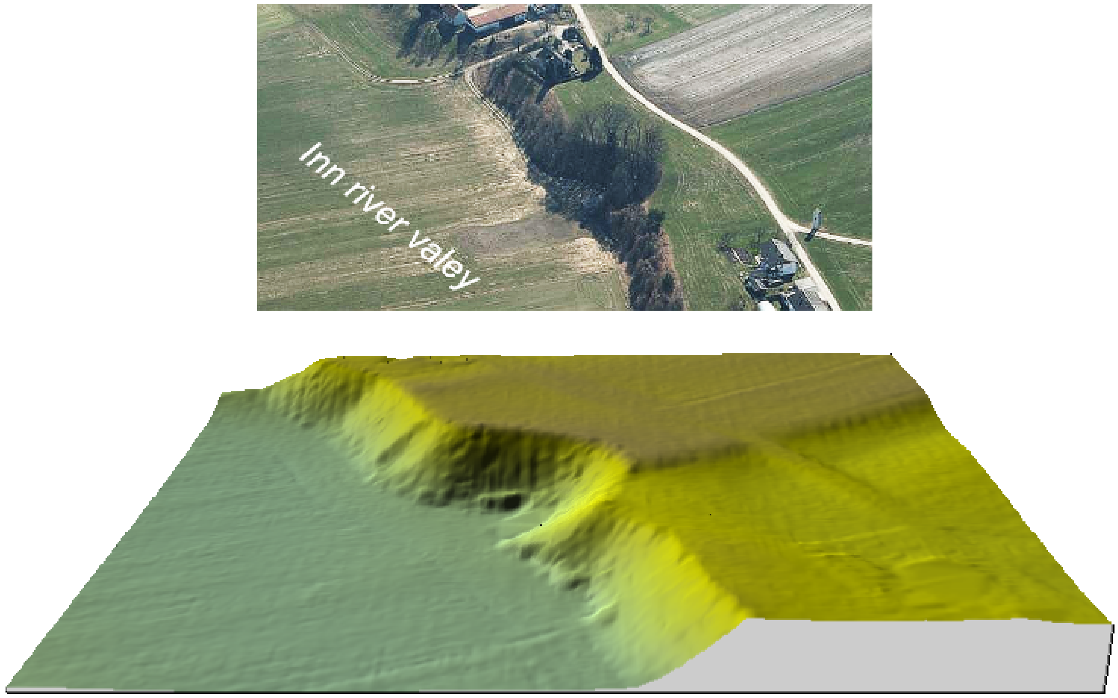
DTM, surface

DTM topography, countour interval 0.2 m, diametric profiles (next figure).

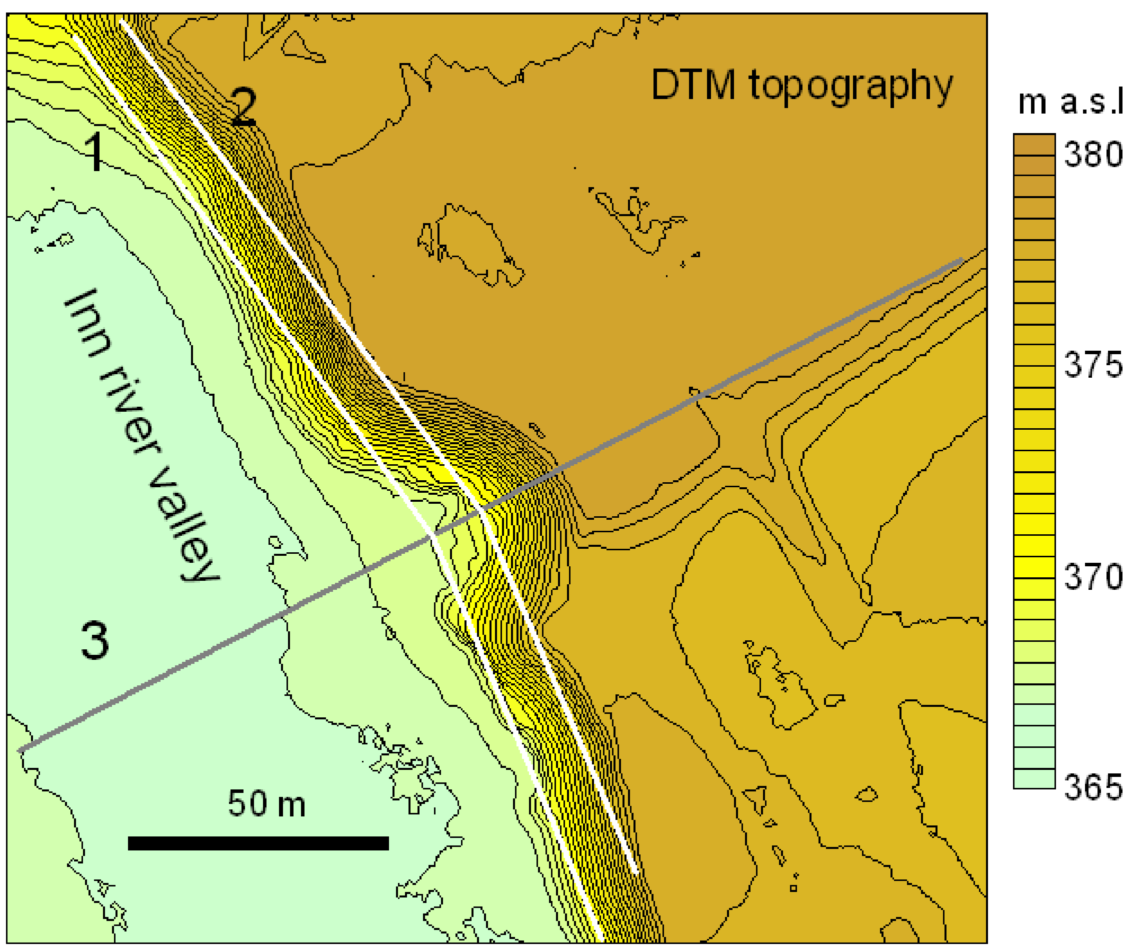


DTM, diametric toppographic profiles.

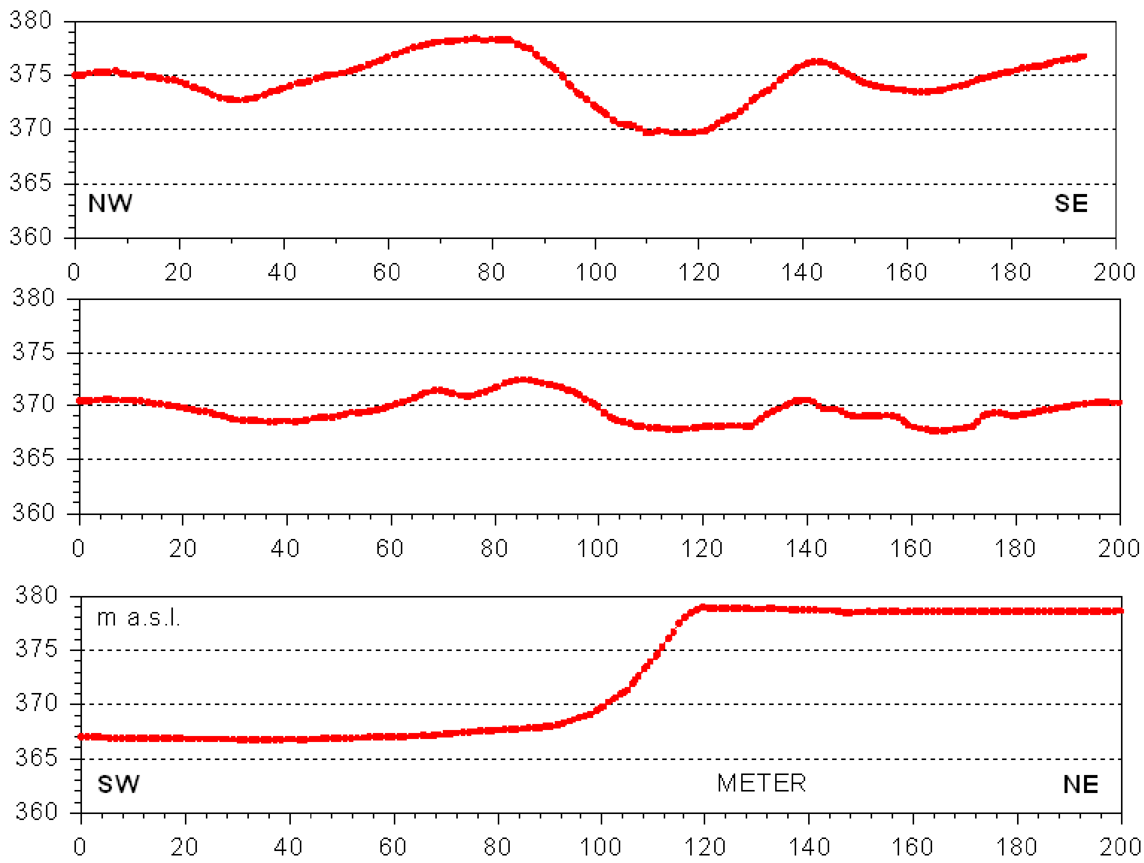
The Aiching 50 m-diameter semi crater



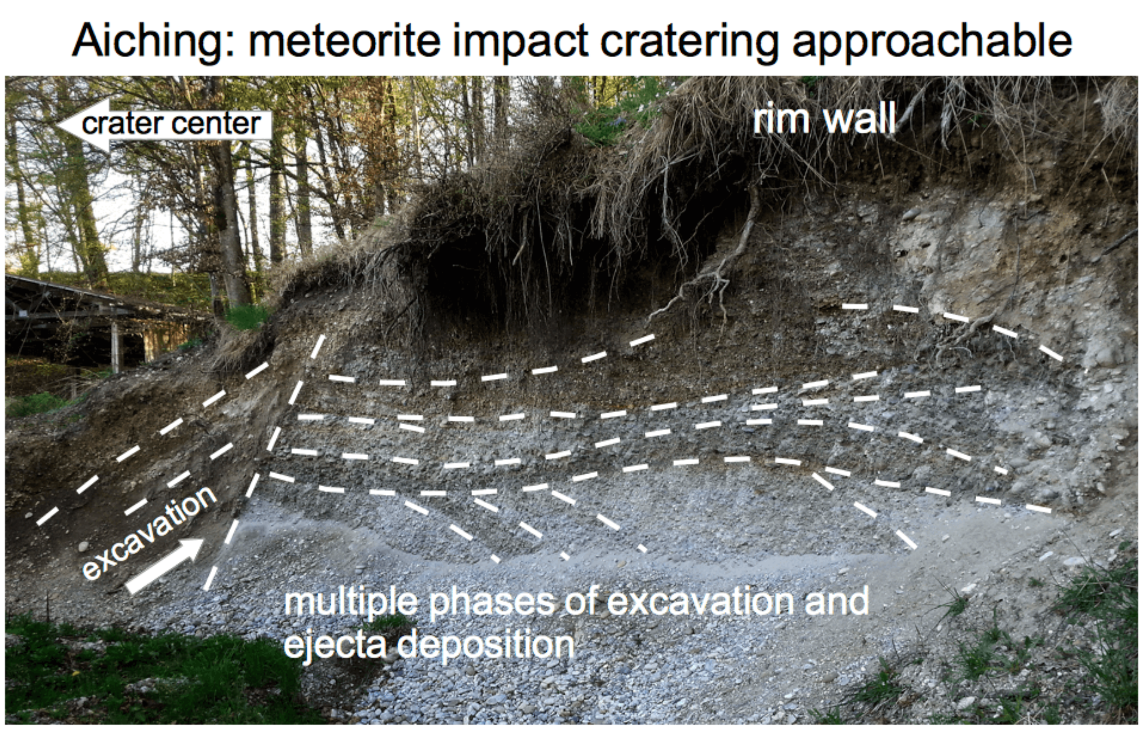
The Aiching semi crater, punched into the embankment of the Inn river. Upper: Aerial photograph in winter time. Lower: Digital Terrain Model (DGM 1) as 3D surface image.



The DTM semi crater topography; contour intervall 0.5 m, and the location for the topographic profiles below.



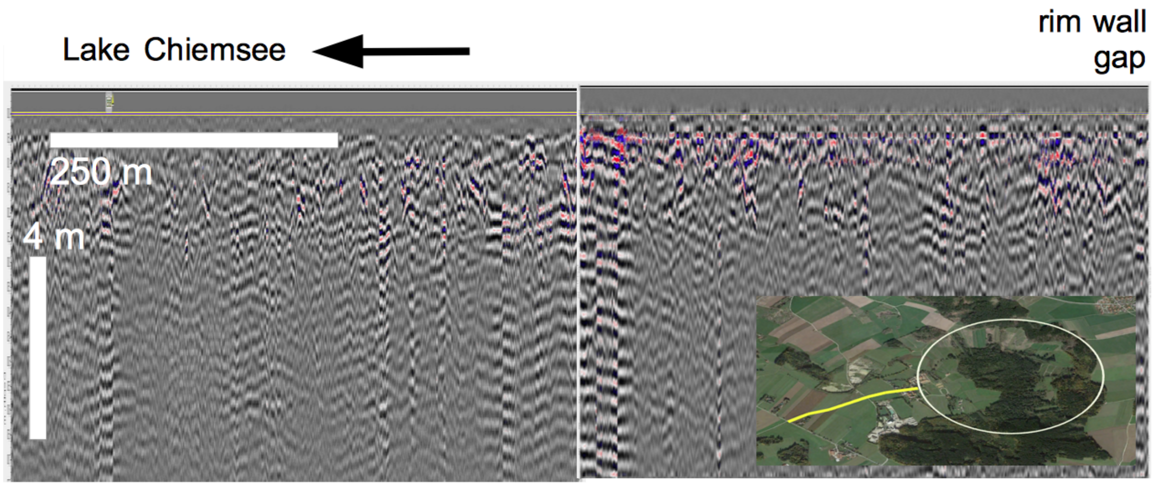
DTM topographic profiles for the Aiching semi crater. Note the wavy run along the embankmant profiles enlarging the impact-affected underground to nearly 200 m diameter. A rim wall on top of the crater (profile 3) is only faintly developed possibly due to farmers' leveling.



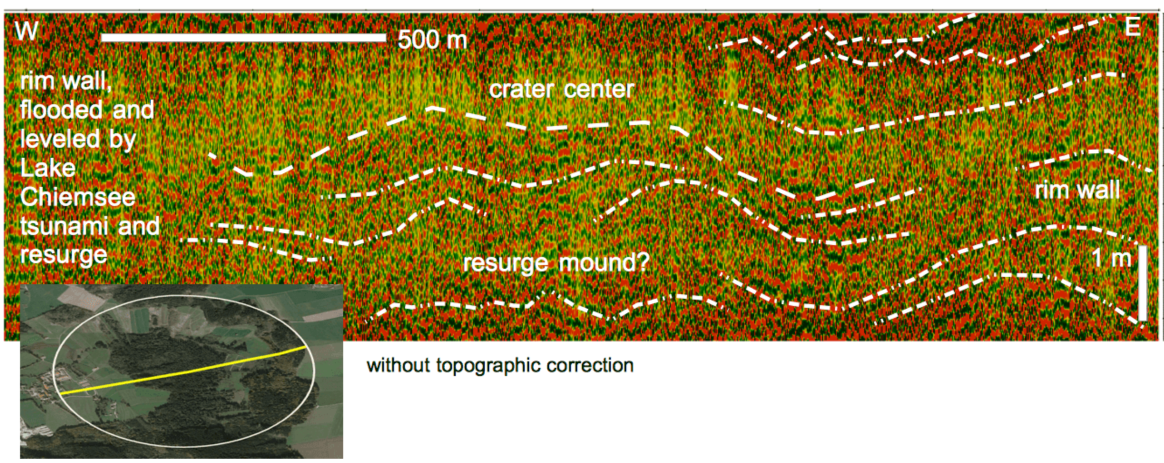
One of the very rare opportunities to observe an impact crater in a section through its crater rim. A comparison with the GPR profiles above the crater floor, which is not directly accessible, is revealing. (http://www.chiemgau-impact.com/2017/08/meteorite-craters-impact-approachable/)

RESULTS

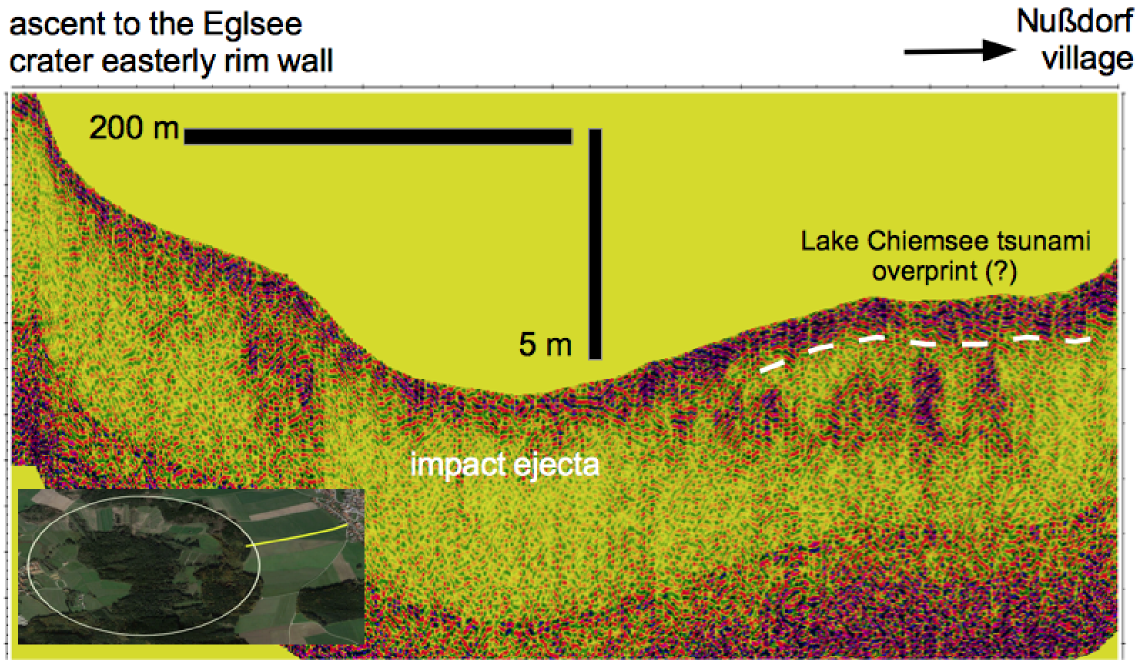
Eglsee crater



300 MHz raw data; most westerly section of the 3 km diameter profile across the 1.3 km-diameter crater passing the rim wall gap. Note the wavy deformation of the ground with roughly 100 m wavelengths.



300 MHz profile across the interior of the Eglsee crater showing a pronounced "camel humps" central mound. The relationship with the formation of an inner ring in the modification stage of large complex craters is evident.



300 MHz profile crossing the ejecta blanket of the Eglsee crater with significant partly wavy underground structures.The level of mixture with the deposits of the Lake Chiemsee tsunami, which must have followed the deposition of the ejecta blanket, must be left to assumptions.

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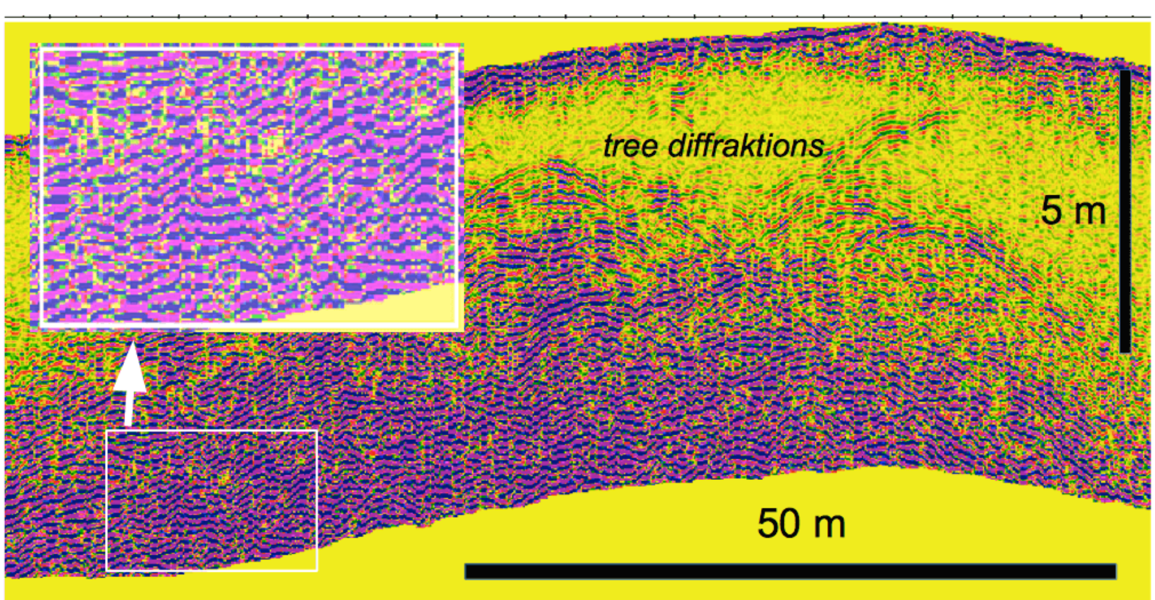
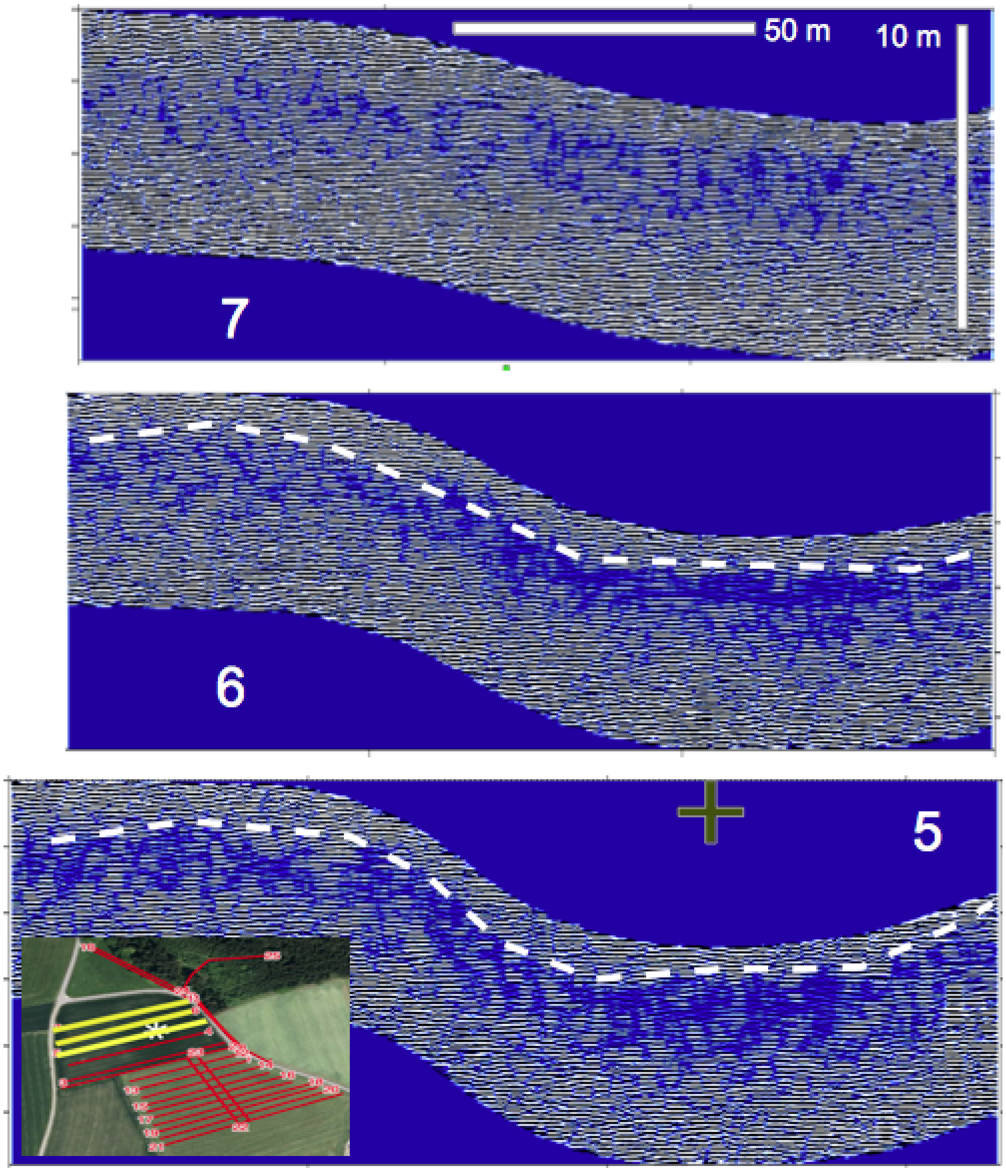
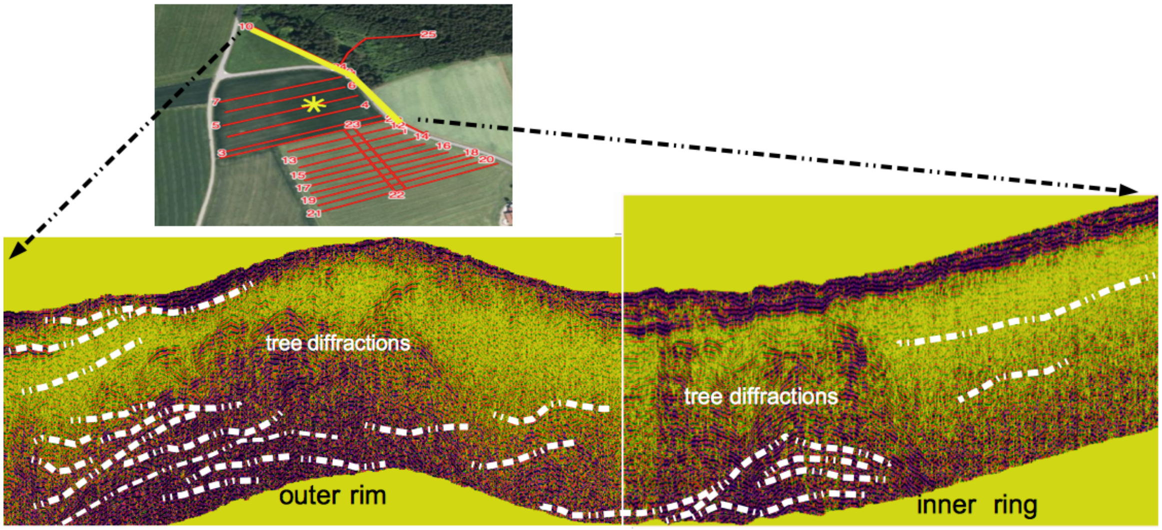
Riederting crater



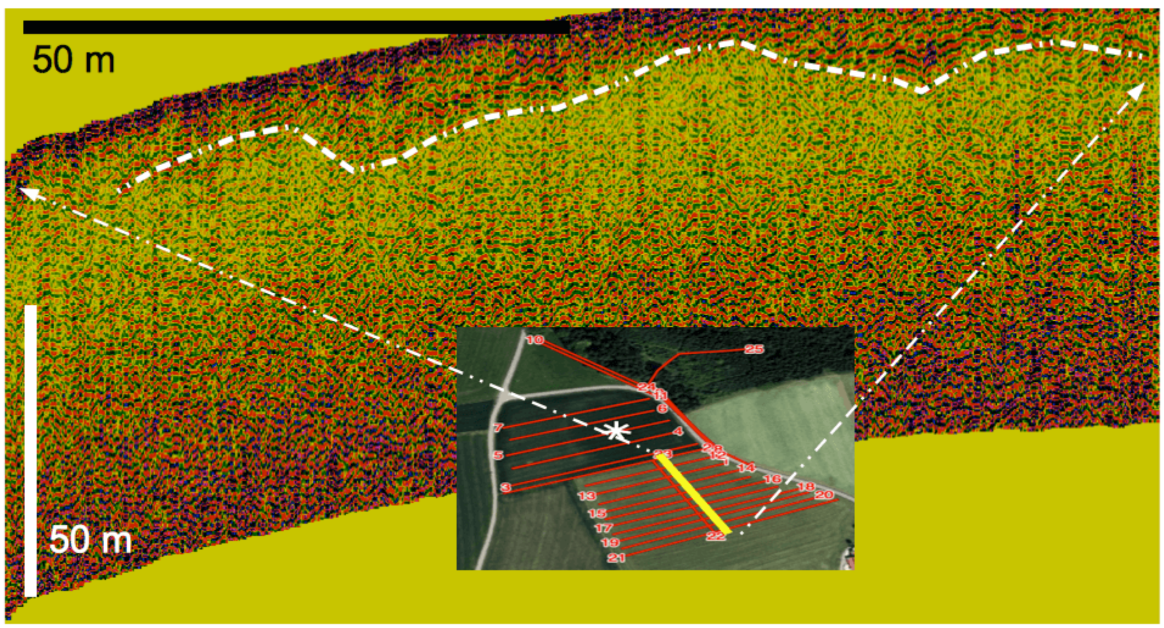
300 MHz radargram of a rim wall section revealing complex cross bedding of the sedimentary target. Strong cross bedding is observed throughout the crater, although it is not always clear whether this conspicuous structure was created during impact cratering or was included in the impact process as a pre-existent cross-bedded sediment package.



300 MHz profiles crossing the Riederting central bowl. Special low-pass filtering of the raw data revealing impact-affected facies and distinct pseudo-tectonics with intense step faulting.



300 MHz profile along the northeastern rim zone of the crater and internal structures. Interpretation difficulties due to superimposition of tree diffractions.



300 MHz profile away from the crater rim shows strongly undulating structures of the subsurface

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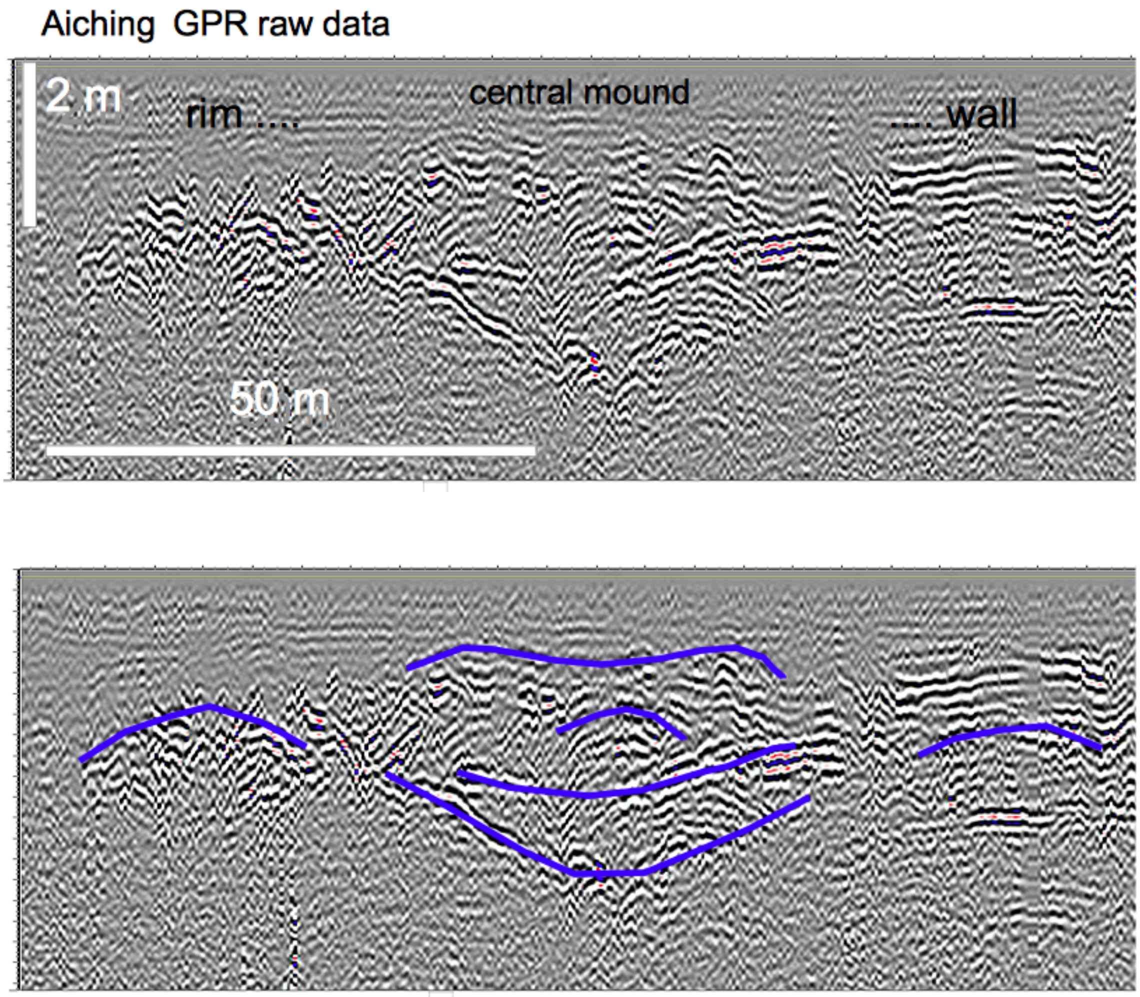
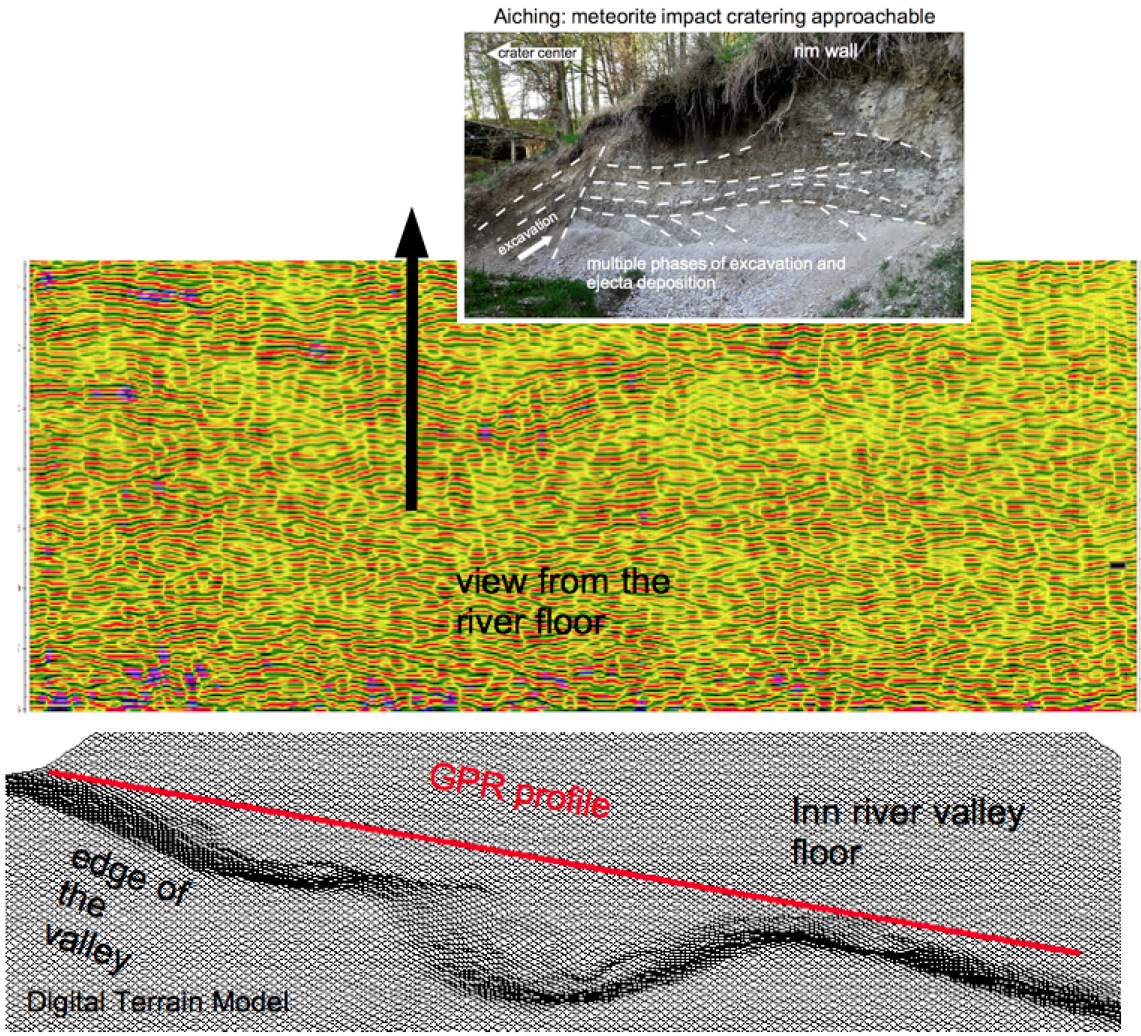
Aiching semi crater



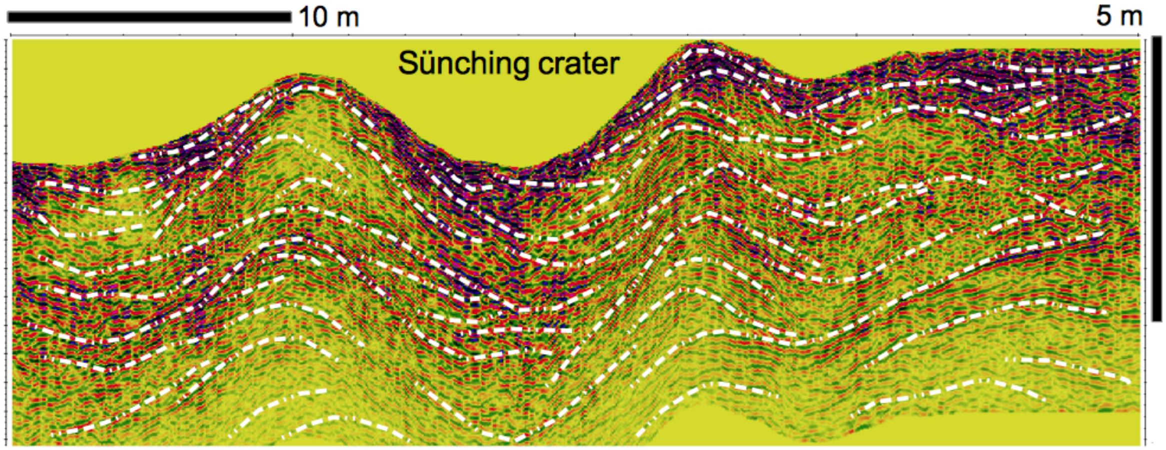
Raw date (300 MHz) of the profile across the assumed center of the semi crater located in the Inn river leveled valley floor (see image below). Lower radargramm traces the main structures. Like in the Eglsee crater we see a "camel humps" central mound over a "dromedary hump".



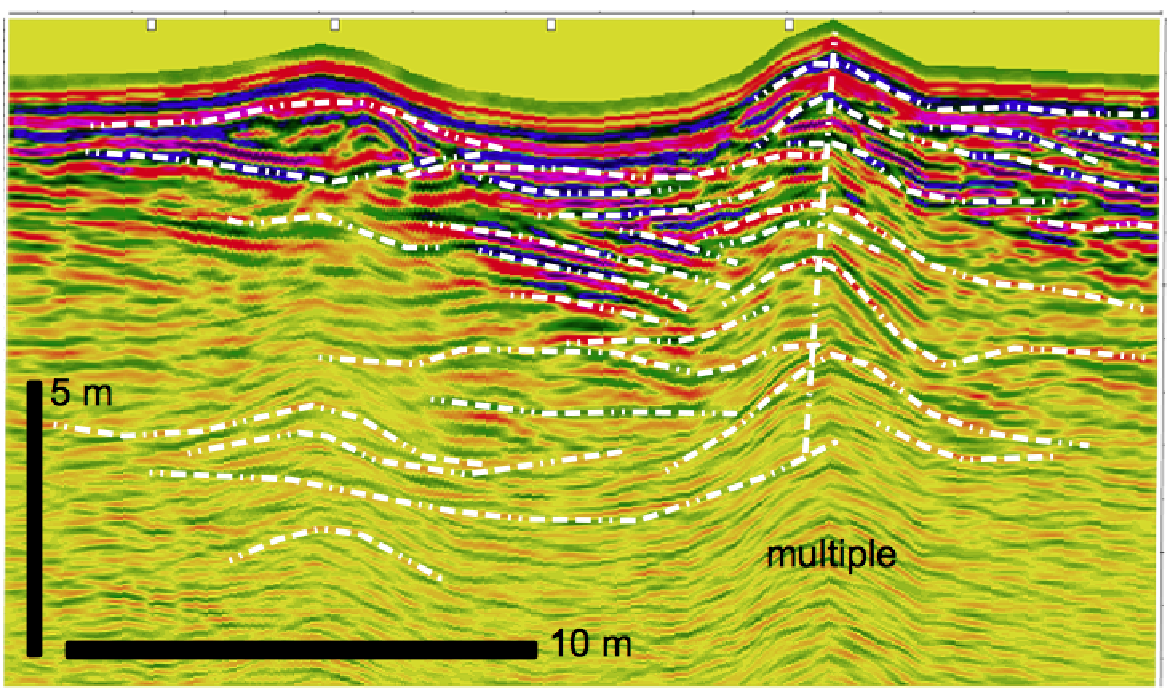
The GPR radargramm of the buried crater mirrors the general geological complex structure seen in the outcrop of thew rim wall.

DISCUSSION AND CONCLUSIONS

We learn from the GPR that in a soft target such as the unconsolidated, water-saturated Quaternary material in the strewn field of the Chiemgau impact, small craters may well have quite flat complex morphologies with central peak or ring-like mound in the subsurface. Similar to large complex craters, the partial collapse of the previously formed ring wall may have been effective in a modification stage.

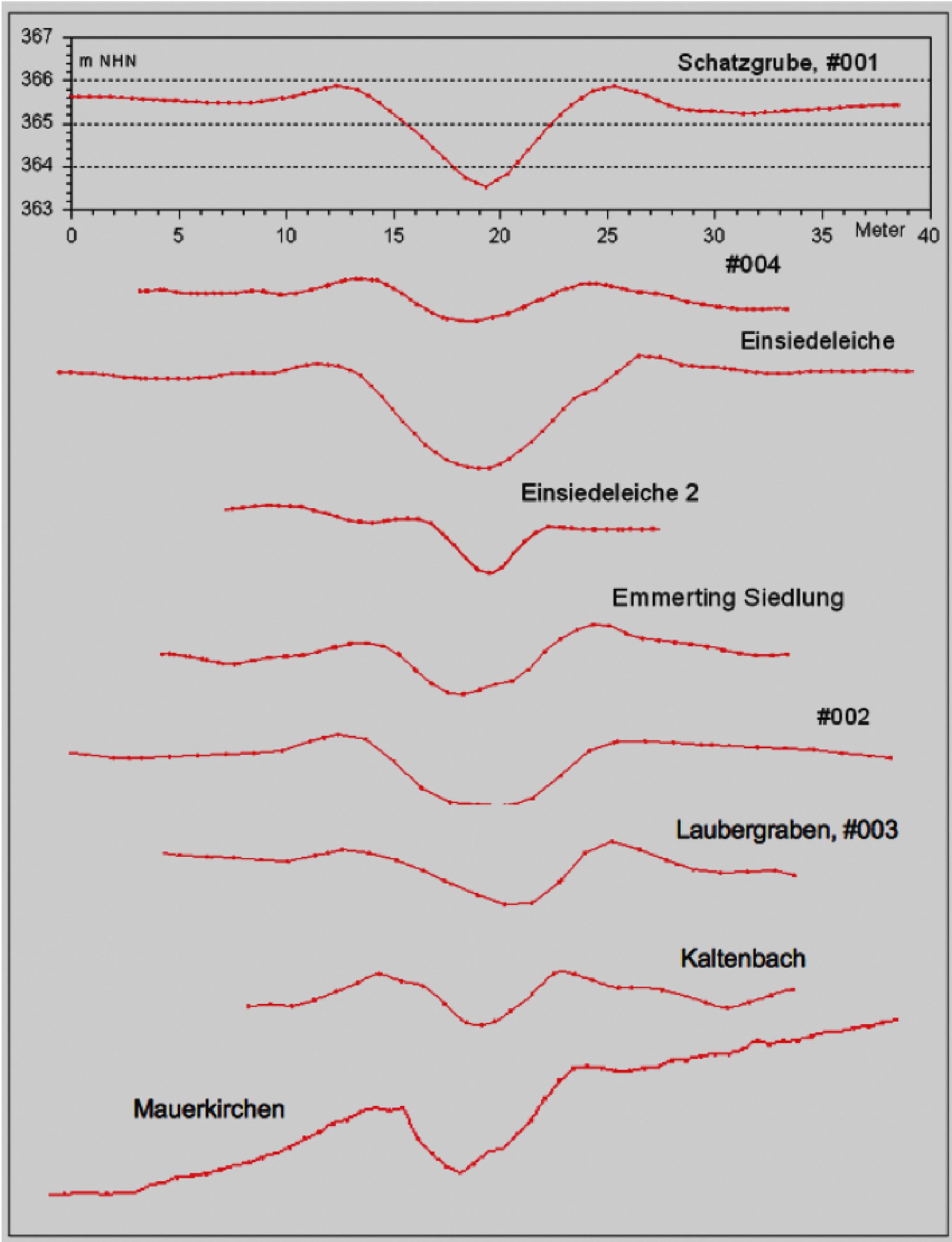


Sünching crater (individual crater outside the crater strewn field ellipse). One of the small craters showing similar wavy morphology and internat structure. The remarkable lateral displacements of bulges and indentations producing cross bedding proves a complex chronological sequence of cratering like in the larger craters discussed before.

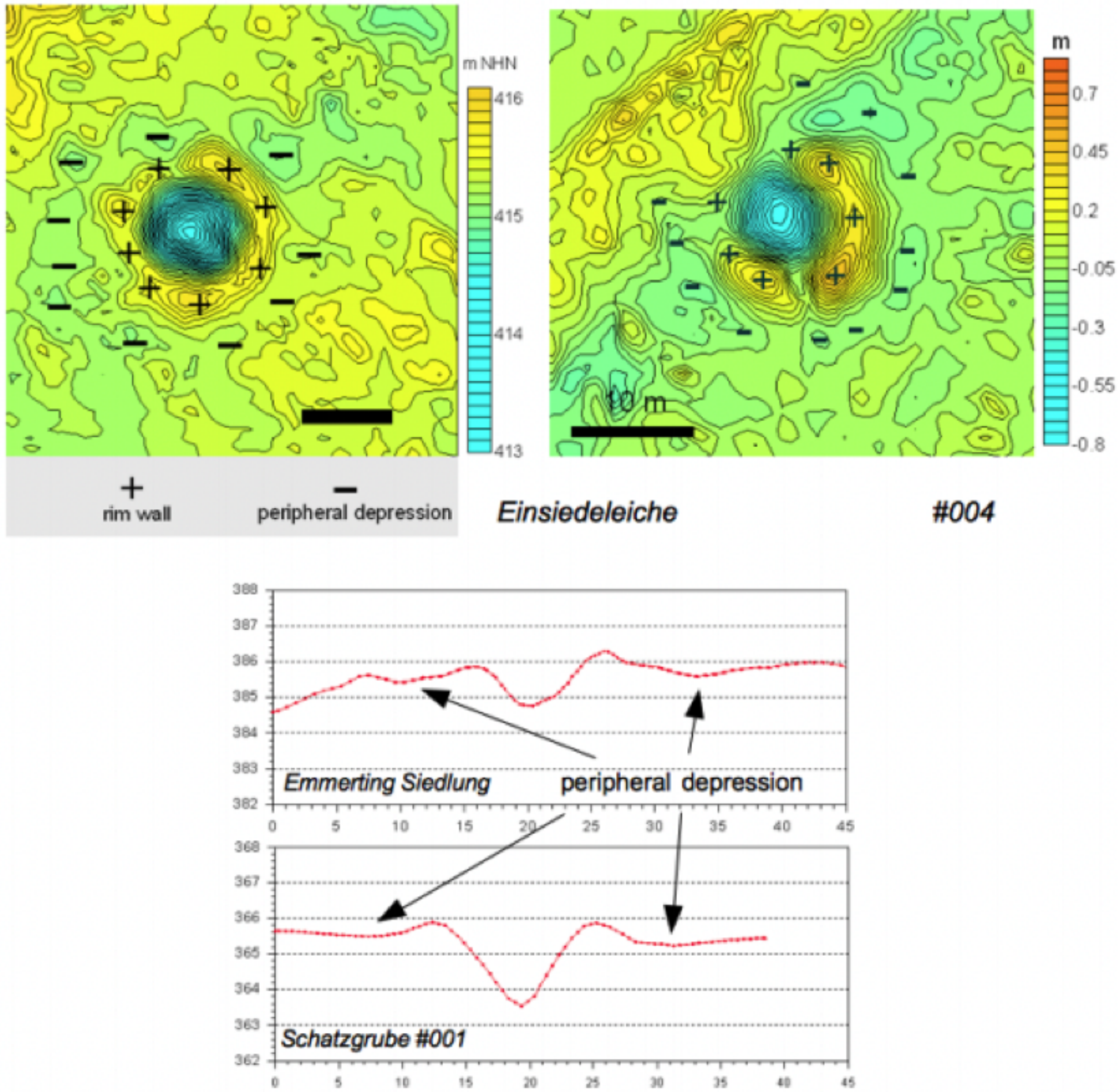


The Emmerting (004#) crater in the northern part of the strewn field ellipse structurally resembling the equally sized Sünching crater. 25 MHz (plus modulated 200 MHz) antenna (RTG).

The similarity of the two craters of approximately the same size with their complex internal deformations underlines an obviously very similar impact process in the area of the crater strewn field. This is especially underlined by the fact that a large proportion of craters of all sizes in which no GPR measurements have been made so far, also outside the crater walls, show a more or less strongly pronounced concentric wavy morphology, as the examples of the following images convey.



DTM diametric profiles of craters in the Chiemgau impact strewn field showing periphal depresions.



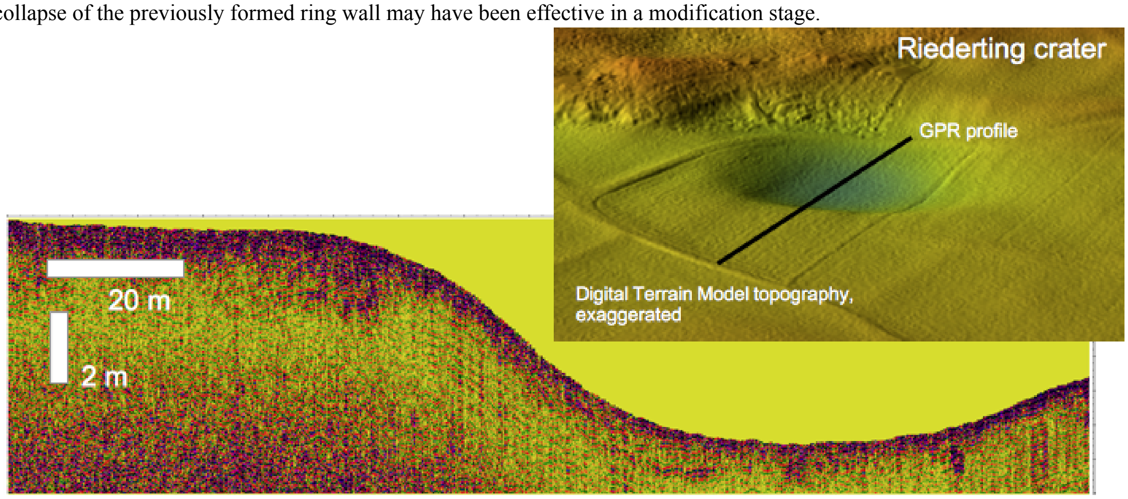
The annular depression of the Einsiedleiche crater .

Stacking of 20 small craters from a limitedly selected forest area (1 square kilometer) and cross sections from DTM data. A wavy enclosing is indicated.

The here presented results of the GPR measurements over meteorite impact craters of various size in the young soft target of the Chiemgau impact strewn field exemplify the enormous potential of this high-resolution geophysical tool of underground exploration, which may lead to a much better understanding of impact cratering processes even on remote planetary bodies.

ABSTRACT

Impact cratering generally distinguishes between simple, bowl-shaped small craters and larger complex structures with a central peak and/or inner rings. In the modification stage of the latter, the transient crater is largely re-filled by centripetal movements particularly due to gravitational collapse of the crater rim. The transition from simple to complex craters is generally assumed to occur at about 1.5 - 4 km diameter of the final crater. Here we report on small craters, where in a modification stage the primary bowl has changed into a complex crater with internal peak or ring morphology seen on GPR profiles through the crater center. The Eglsee crater, which has a comparable size as the famous Barringer (Meteor) crater, belongs to the Chiemgau impact event (900-600 B.C.) and has a depth-to-diameter ration of roughly 1:70 comparable to much larger complex impact structures (like e.g. the Ries crater). The Eglsee crater complex nature of formation is underlined by GPR that reveals a buried ring-like mound below the otherwise flat crater interior. The nearby Riederting crater has a diameter of 250 m and, with a maximum depth of 5 m, is comparably shallow as the Eglsee crater and other complex craters. GPR through the flat basin shows a complexly sculptured wavy layering with a central depression several meters deep, which is surrounded by a steplike inner rim wall of roughly 60 m diameter. With a diameter of 60 m and a depth of about 10 m, the Aiching semi crater has indeed the typical bowl shape of a simple meteorite crater. The GPR on the flat crater floor however shows a very complex, wave-like layer structure and a central mound with a diameter of about 30 m, which reaches up to about 2 m below the crater floor in the center. We conclude from the GPR that in a soft target such as the unconsolidated, water-saturated Quaternary material in the strewn field of the Chiemgau impact, small craters may well have quite flat complex morphologies with central peak or ring-like mound in the subsurface. Similar to large complex craters, the partial collapse of the previously formed ring wall may have been effective in a modification stage.



(https://agu.confex.com/data/abstract/agu/fm20/1/3/Paper_677731_abstract_647260_0.png)

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References. - Ernstson, K. (2010) Journal of Siberian Federal University Engineering & Technologies 1/3, 72-103. Ernstson, K. et al. (2013) Proc. (Yushkin Memorial Seminar - 2013), 369-371, Syktyvkar. Ernstson, K. et al. (2011). Medit. Archaeology and Archaeometry 12/2, 249-259. Liritzis, I. et al. (2011): Medit. Archaeology and Archaeometry 10/4,17-33. Rappenglück, B. et al. (2010) Antiquity 84, 428-439. Hiltl, M., et al. (2011) - 42nd LPSC, Abstract #1391. Neumair, A., Ernstson. K. (2011) - AGU Fall Meeting 2011, Abstract & Poster ID GP11A-1023. Ernstson, K., Neumair, A. (2011) - AGU Fall Meeting 2011, Abstract & Poster ID NS23A-1555. Shumilova, T. G. et. al (2012) - 43rd LPSC, Abstract & Poster #1430. Isaenko, S. I. et al. 2012) - Abstracts Eur. Min. Conf. Vol. 1, EMC 2012-217. Rappenglück, M.A. et al. (2013) 76th Annual Meteoritical Society Meeting, Abstract #5055. Bauer, F. et al. (2013) - 76th Annual Meteoritical Society Meeting, Meteoritics & Planetary Science, Abstract #5056. Neumair, A., Ernstson, K. (2013) 76th Annual Meteoritical Society Meeting, Abstract #5057. Ernstson, K., et al. (2014) - 45th LPSC, Abstract #1200. Rappenglück, M A., et al. (2014) Yushkin Memorial Seminar - 2014), 106-107, Syktyvkar. Ernstson, K. (2016) - 47th LPSC, Abstract #1263.