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SSMP-Excursion to the Ries and Steinheim meteorite impact craters, Germany

14 – 16 October 2005

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Introduction

The Ries and Steinheim twin impact craters (24 and 3.8 km diameter) were formed in the Miocene, 14.3 ± 0.2 Ma ago (Buchner et al., 2003). These two craters are the best preserved of the very few impact craters in central Europe. Chemical evidence (El Goresy and Chao, 1976) suggests that the impacting meteoroid had a chondritic composition, and its size is considered to be roughly 1/20th of the crater diameter. This means that the main meteoroid producing the Ries crater had a diameter of ca. 1 km. This meteoroid possibly had a smaller satellite („Moon“), ca. 100–200 m in diameter, which produced the Steinheim impact crater (see for example asteroid 243 Ida and its small satellite).

Melt fragments (moldavite tektites) and debris ejecta from the impact site are found as moldavites (tektites) in Saxony, The Czech Republic and Austria (e.g., Lange, 1996; Stöffler et al., 2002) and as rocky debris in the Graupensandrinne of southern Germany (e.g., Buchner et al., 2003), and even in the Swiss Molasse basin near St. Gallen (Hofmann, 1973; Krayss, 2004), where Malm limestone blocks with shatter cones were found. The aim of the excursion to the Ries was to provide an overview of the rocks affected by the Ries and Steinheim impacts and to study the influence of impact events on landscape and culture.

Friday, 14. October 2005

(Bern – Winterthur – Nördlingen)

After crossing the fog-covered Swiss Molasse basin, the fog made place to the sun and a slightly hazy late fall landscape. We arrived at the first outcrop around 13:30 h, starting with lunch.

Outcrops visited

1. Iggenhausen 48° 43.50'N 10° 22.78'E

Small quarry, ~0.5 km E of Iggenhausen, geologically located ~9 km outside the impact crater rim. A small hill of bare limestone consists of a coherent, but impact-tectonically outward thrust, intensely shattered Malm limestone sequence which locally shows karstic pockets filled with ochre-coloured clay (siderolithic Bolus clay). This quarry represents the typical, naturally disaggregated limestone („Gries“) used over centuries for building graded roads. The large limestone block can be regarded as a single large clast within the "Bunte Brekzie" layer (variegated breccia, nearly

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unmetamorphosed, dominantly sedimentary impact ejecta), but the contacts to other lithologies of the breccia are presently hidden.

2. Seelbronn 48° 44.15'N 10° 28.15'E

Suevite quarry of the Schwenk Zement KG, Ulm (permission and helmet required). Active suevite (impact breccia containing a significant component of melt) quarry exploited as cement additive. The suevite contains abundant vesicular melt bombs ("Flädle") and shock-metamorphosed clasts mainly derived from the crystalline basement. This quarry is presently one of the freshest outcrop of suevite, where the cowpat-shaped glassy melt fragments are still preserved. Apart from the melt fragments, abundant shocked crystalline basement as well as sedimentary cover fragments are recognizable.

Fig. 1 Suevite wall in Aumühle quarry displaying wall-hardened trunc-shaped degassing pipes in suevite, showing both positive and negative shapes. Note the orientation perpendicular to the surface of the top of the suevite blanket. Hand in the top right for scale.

3. Altenbürg (suevite in contact with Malm) 48° 48.83'N 10° 25.87'E

Abandoned suevite quarry declared as bio- and geotope. The suevite from this quarry was mainly used to build the St. Georg church of Nördlingen with its tower "Daniel". Because suevite occcurs in sharp contact with a coherent sequence of Malm limestone the situation was originally interpreted as a volcanic diatreme crosscutting limestone. Since the recognition of suevite as impact-derived material the limestone block is considered allochthonous, too. Near the contact of suevite to Malm limestone the weathered suevite shows deposition of caliche veins and -coatings.

4. Nördlingen (St. Georg church)

The tower of the St. Georg church, called "Daniel", is accessible to the public and contains an apartment occupied by the guard who lives there for several days in a row. The tower (and the main body of the church) constructed 1427–1540 consist of suevite blocks mainly from the now abandoned Altenbürg quarry. The balcony fence at the top of the accessible tower was rebuilt using artificial "suevite" consisting of basalt and limestone clasts in a cement-sand matrix. Also the weather exposed wall parts of the tower outside are partially replaced with this fake "suevite" which, at first glance, is easily confused with the true suevite. Real blocks of suevite allow the study of this classic impactite in all variations. There is a stunning view from the tower all around the Ries crater.

Saturday, 15. October 2005

5. Meyers Keller in Nördlingen 48° 50.48'N 10° 29.6'E

A small rock wall located behind the restaurant "Meyers Keller" provides one of the best outcrops of shocked crystalline basement of the so-called inner ring of the Ries impact basin. The main lithologies are gneisses, amphibolites and minor granites. All rocks are strongly altered to clay minerals (with textures preserved). Nearby outcrops of post-impact lacustrine limestones demonstrate that this outcrop is located very close to the paleosurface.

6. Nördlingen (Rieskratermuseum)

Opening hours 10:00–12:00h and 14:00–16:00h. The museum hosts a systematic collection of the most important meteorite types, an original rock piece collected during the Apollo Moon missions, an excellent regional collection describing the different rock types formed by the Ries impact, and a lot of well-presented geological information about the Ries area. Different exhibition parts explain the dynamic crater-forming process and give reference to other terrestrial and extraterrestrial impact craters. A short video gives an impression of the landscape of the Ries area before the impact and shows the sequence of catastrophic events during the impact and the subsequent geologic evolution and landscape shaping until the present.

7. Wengenhausen (carbonates overlaying crystalline breccia) 48° 54.67'N 10° 27.77'E

Small quarry (classified as geotope). The outcrop consists, in its lower part, of shattered crystalline (probably large crystalline "scholle") and is, in the upper part, covered by a softer horizon of what is considered as weathered suevite. The top of the outcrop is formed by weathering-resistant freshwater limestone (post-impact Ries lake deposit). The crystalline rocks comprise migmatic biotite gneisses, granitic dikes, and a lamprophyre dike (kersantite). Shatter cones were recognized in the granitic material, and are locally well recognizable in the lamprophyre. Whereas the suevite is strongly weathered, the transition to the limestone section is characterized by the decrease in crystalline clasts. In some parts the limestone shows bedding, contains abundant 1–2 mm-sized gastropod shells, cm-sized algal filaments, and <5 cm-sized plant imprints.

8. Büschelberg near Hainsfarth 48° 57.28'N 10° 38.0'E

Abandoned limestone quarry now used as football ground. Outcrop of post-impact lake sediment deposits. Walls (up to 8 m in height) of the outcrop display spectacular bioherms (reefs) mainly made up of the green alga *Cladophorites*. Cyanobacterial mats and algal filaments are locally well recognizable. Typical for the lower part of the wall are also backwatering pockets of softer material which contain abundant 1–2 mm-sized gastropod sands, locally also rich in ostracods. This outcrop is well described by Arp (1995).

9. Aumühle near Oettingen 48° 58.23'N 10° 37.76'E

Quarry belongs to Märker Zement GmbH, Harburg (permission and helmet required). Active suevite quarry exploited as cement additive. Spectacular contact features between "Bunte Brekzie" (below) and suevite (top). In places this contact is very steep indicating that the surface of the Bunte Brekzie was very rough when the suevite fell on it (just minutes after the impact), or that suevite deposition was associated with significant erosion. The suevite contains abundant melt bombs (mainly derived from crystalline basement rocks). Similar to thick lava flows, the suevite locally shows columnar jointing and abundant spectacular degassing pipes. As the pipe rims are hardened due to interaction with vapor, or possibly late infill of soil and organic material, the pipes can be recognized as positive or negative forms (Fig. 1). In the top part of the sequence, cowpad-shaped melt fragments are weathering out of the suevite matrix and their three-dimensional shape can be studied. The suevite contains abundant shocked and partially molten crystalline basement fragments, including amphibolites and garnet-bearing metapelites. Fractures in the suevite are filled with plastic brown (organic-rich) smectitic clay.

10. Gundelsheim 48° 54.5'N 10° 50.0'E

Active quarry belonging to Gundelsheimer Marmorwerke GmbH & CoKG, Gundelsheim (permission and helmet required). The exploited limestone is used for the production of slabs for the building industry. It is famous among fossil hunters for its well-preserved ammonites and belemnites. Locally, the limestone is dissected by karstic pockets commonly filled with Bolus clay. To exploit the limestone, the overlying "Bunte Brekzie" layer, the base surge material produced by the impact, has to be removed. In contact to the "Bunte Brekzie", the nearly flat, slightly undulating limestone surface is polished and shows abundant striations. This striations formed due to the scratching of harder material pushed over the limestone, away from the impact side. Similar to glacial striation, shear sense determination is locally possible. Outcrops like this one provided arguments for the assumption of a local glacier, a theory which was later abandoned. The "Bunte Brekzie" contains mainly unmetamorphosed clays (mainly of Keuper and Dogger origin) and non- to moderatly shattered limestone blocks but also coal fragments and few crystalline blocks.

Sunday, 16. October 2005

11. Wallerstein castle rock (sublacustrine spring mound) 48° 53.34'N 10° 28.50'E

A former quarry exploiting post-impact sublacustrine spring mound "travertine" deposits is found in the garden of the Wallerstein castle of Fürst Moritz zu Oettingen-Wallerstein. The protected outcrop is open to the public. A small footpath leads to the top of the hill opening a splendid view to the Ries basin (theoretically). The slighly foggy weather hampered the view to the neighbouring villages. A detailed description of geochemistry is given by Pache et al. (2001). Limestone fabrics produced by different organisms (cyanobacterial stromatolites, green algae) are well visible on the limestone walls.

12. Unterwilflingen 48° 54.89'N 10° 26.77'E

The eastern parts of this quarry consist of impact-shocked and transported crystalline basement comprising garnet-biotite-gneisses, cordierite-bearing gneisses, amphibolites and granitoid rocks. Locally thin (centimetric) suevite veins are visible. In the central part of the quarry this crystalline material is covered with a backfall suevite containing large shattered crystalline blocks and abundant, flow-oriented glass bombs ("Flädle"). In contrast to the black color of fresh glass in other outcrops, it is altered to whitish soft material here, pointing to a complete replacement of the glass by secondary minerals (probably clays and other sheet silicates, and zeolites). Bunte Brekzie prevails at the west side of the quarry, containing well-recognizable fragments of white, coarse-grained Triassic Stubensandstein, and red Keuper marl. An obviously strongly shocked white, friable aplitic clast (approx. 15×10×10 cm) from the suevite was investigated to check for the presence of high-pressure minerals. The X-ray diffraction pattern of the fraction <2 µm, after treatment with HF (1:4, coesite is more resistant to HF than quartz) overnight, is nearly pure coesite (Fig. 2), the high-pressure SiO_2 polymorph which formed due to the extreme pressure conditions reached during the meteorite impact.

13. Burgstall 48° 40.50'N 10° 4.15'E

After a drive via Heidenheim we reached the southern rim of the Steinheim crater. The outer allochthonous limestone ring is exposed at the Burgstall locality (hill with former quarry at base). The hill provides a panoramic view over the Steinheim impact basin with central uplift, ring basin and outer ring wall. A geologic plate explains the general geologic situation and depicts a cross-section through the Steinheim impact crater. The Burgstall hill consists of a sliver of Malm limestone thrust away from the impact centre over younger sedimentary rocks. This Malm limestone is internally broken up. Due to shock friction the limestone may have been partially transformed to CaO which subsequently, under the the

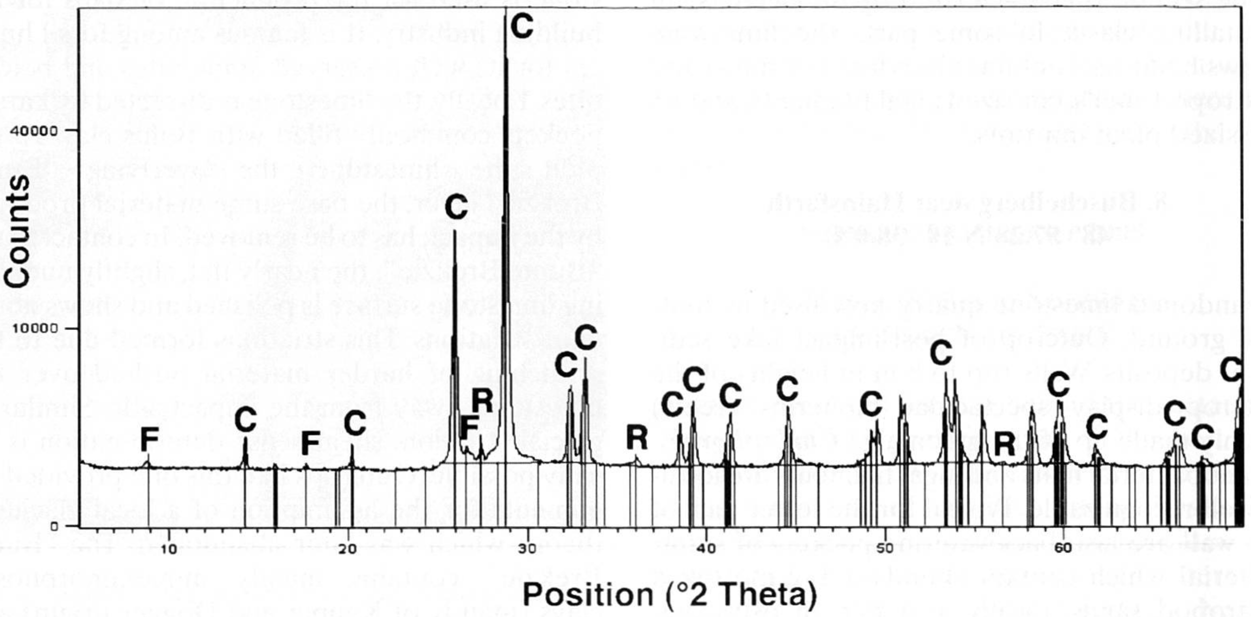

Fig. 2 X-ray diffractogram of HF-treated fraction <2 µm of white crystalline clast in suevite, collected during the excursion at Unterwilflingen/Ries. In addition to dominant coesite (C), minor rutile (R) and a fluoride (F) precipitated due to HF treatment are present.

influence of meteoric water and CO_2, reacted back to form $CaCO_3$, cementing the porous limestone breccia.

14. Pharion'sche Sandgrube near Steinheim (fossiliferous sands) 48° 41.1'N 10° 3.63'E

The classic locality (quarry) yielded abundant mammal, reptile, insect and plant fossils, and is now protected and fenced. A small area located above the main quarry is presently open for fossil hunters. The deposits are dated at 13–14 Ma, thus formed in a crater lake just after the crater formation by meteorite impact at 14.3 Ma. The association of fossils points to warmer climatic conditions with annual average temperature of ca. 15°C. All participants had the possibility to collect fossil fresh water gastropods of the *Gyraulus* species (planorbis). See Tütken et al. (2006) for recent work on Steinheim and the use of isotopes to reconstruct a former ecosystem.

15. Short visit to the Meteor Crater Museum

in Steinheim, with good samples of shatter cones, which cannot presently be collected at Steinheim due to a lack of exposures.

Back to Bern with stop in Winterthur. Arrival time 20:00.

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