Repolust Cave (Austria) revisited: Provenance studies of the chert finds

Fundrevision der Repolusthöhle (Österreich): Herkunftsbestimmungen der Hornsteinfunde

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Abstract - In the course of a revision of the Repolust Cave site an analysis of the lithic finds was carried out. The lithic find complex consisting of quartz and chert artefacts is the most substantial Palaeolithic assemblage in the Eastern Alpine region. One distinctive raw material, a variety of tabular chert, is known to occur regularly at Styrian Neolithic sites. Due to great visual similarities, this raw material was thought to originate from the well known Baiersdorf chert source in Lower Bavaria. At the same time, a chert source with a similar kind of tabular chert, macroscopically indistinguishable from the Baiersdorf chert, was recognized at the Rein basin north of Graz. For the purpose of distinguishing these chert sources, a project was set up to identify the provenance of the chert through the application of natural scientific methods. Due to the geological setting of the raw material sources, their clear distinction was possible using LA-ICPMS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry). In view of the great similarity of the two tabular chert varieties to the Repolust Cave chert, the obtained research results were then applied to that assemblage. Ultimately, it was possible to identify the origin of the Repolust Cave chert finds as the Rein basin chert outcrop.

Zusammenfassung - *Im Zuge einer Neuaufnahme des Fundmaterials aus der Repolusthöhle wurden die lithischen Funde neu bearbeitet. Diese bestehen aus Quarz- und Hornstein und stellen das umfangreichste paläolithische Inventar des ostalpinen Raumes dar. Von anderen steirischen Fundstellen war seit Längerem ein charakteristisches Rohmaterial in Form eines Plattenhornsteins bekannt, welcher aufgrund großer optischer Ähnlichkeit zunächst der bekannten Niederbayerischen Lagerstätte von Baiersdorf zugeordnet wurde. Da jedoch auch in der Steiermark, im Becken von Rein nördlich von Graz, eine Lagerstätte nachgewiesen werden konnte, die ein optisch identisches Rohmaterial liefert, wurde ein Projekt zur Abgrenzung der beiden Vorkommen auf naturwissenschaftlichem Wege unternommen. Aufgrund der besonderen geologischen Lagerstättenverhältnisse war eine eindeutige Trennung durch die Anwendung geochemischer Analysen mittels LA-ICPMS (Laser Ablation-Induktiv gekoppelte Plasma-Massenspektrometrie) möglich. Die Beobachtung einer großen optischen Ähnlichkeit der Hornsteine aus der Repolusthöhle mit diesem Plattenhornstein führte zur praktischen Anwendung der Untersuchungsergebnisse auf diese Funde. Es gelang der eindeutige Nachweis der Herkunft der Hornsteingeräte der Repolusthöhle aus dem Reiner Becken.*

Keywords - **Repolust Cave, Middle Palaeolithic, stone tools, raw material procurement, chert source provenance studies, LA-ICPMS analysis**
Repolusthöhle, Mittelpaläolithikum, Steingeräte, Rohmaterialversorgung, Herkunftsbestimmung von Hornstein Lagerstätten, LA-ICPMS Analyse

Introduction

Palaeolithic finds are known from only a few localities in Styria, Austria. Due to adverse conditions of preservation due to glacial processes, these are exclusively cave sites like the Drachenhöhle close to Mixnitz (Dragon Cave; Kyrle 1931), Badlhöhle (Badl Cave; Kusch 1996), Tunnelhöhle (Tunnel Cave; Fuchs & Ringer 1995; Derndarsky 2009), Tropfsteinhöhle (Dripstone Cave; Fuchs 1989), Lurgrotte (Derndarsky 2006; Fladerer et al. 2006) and the caves of the Peggauer Wand (Peggauer Wall). Rare finds of artefact indicate a local Late Middle Palaeolithic (Neanderthal) population.

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At the Repolust Cave site, the remains of hunter-gatherer occupations dating to the Middle Palaeolithic period have been preserved. The site is well known for its evidence for the earliest traces of human activities in the region during the last Ice Age. Several excavation campaigns have produced the most substantial Palaeolithic find complex known from an Eastern Alpine cave site.

In the course of a critical review of the find complex from the Repolust Cave in Styria, Austria, a large number of chert tools produced from a raw material of unknown provenance was recovered. The identification of the possible source of these lithic artefacts became the focal point of detailed mineralogical and geochemical investigations.

The Repolust Cave chert finds visually correspond to a specific chert variety known from previous studies (Brandl 2009) in connection with lithic assemblages in Styria (mostly from Neolithic sites). This raw material, a grey-white, non-transparent tabular chert type, has been defined as the "lithic index fossil" for most of the Styrian sites.

Only two chert sources within a particularly small catchment area (330 km^2) produce a material showing a similar appearance, Baiersdorf in Lower Bavaria (Germany), and Rein in Styria (Austria). Extensive survey activity relating to Styrian chert sources produced no evidence of further chert deposits in the Western Styrian Neogene Basin (Brandl 2009).

At first sight, a distinction between the chert varieties from Rein and Baiersdorf is impossible. Since the deposit in Rein was unrecognized for a long time, many chert finds from Styria in an archaeological context were thought to originate from the Baiersdorf source (Einwögerer 1999).

The main research objective of this study was to link the chert artefacts from the cave site to one of the two possible raw material sources. In order to achieve this two main research questions were addressed: (1) the first research question concerns the possibility of clearly distinguishing the Rein and Baiersdorf chert raw materials. Chert samples from both deposits were analyzed mineralogically and geochemically in order to create a fingerprint of the chert sources (Postl et al. 2008a; Postl et al. 2008b; Brandl et al. 2010). (2) The second research question investigates the possibility of assigning the Repolust Cave finds clearly to one of the two characterized chert deposits.

Research history

The cave was discovered in 1910 by a miner called "Repolust" and has been named after him. After the finding of Pleistocene mammal remains and lithic artefacts in the course of a test excavation in the year 1947 carried out by the Bundesdenkmalamt (Austrian Federal Office for the Care of Monuments), Maria Mottl started a systematic excavation of the Repolust Cave on behalf of the Joanneum Graz in September 1948. This first campaign lasted until January 1949 and a second campaign took place in August 1950. After that field season, the sediments of the horizontal passage had been removed for the most part, the investigations seemed complete and the results were published (Mottl 1951).

A two day excavation campaign in 1952 subsequently showed that the bedrock in the rear section of the cave had not been reached during the first field seasons. In October 1954, the excavations were taken up again by the Joanneum and, with interruptions, continued until July 1955. Karl Murban was the initiator of that activity and the field director was Hermann Bock. At the far end of the horizontal passage, the shaft was dug out to the bedrock at 9.5 m depth. Once the campaign was finished, the results were released immediately (Mottl & Murban 1955).

Following several episodes of illegal digging in the 1970s, the deep shaft of the Repolust Cave was backfilled again. Between 1981 and 1985, Harald Temmel started short excavation campaigns to recover mammal bones from the redeposited shaft spoil and from two sondages in the untouched deepest part of the cave. He found numerous indications for dating the fauna of the shaft to the Middle Pleistocene and presented the results in his thesis (Temmel 1996). In 1998, Gerald Fuchs, Jörg Fürnholzer and Florian Fladerer carried out the first critical revision pertaining to the stratigraphic record of the Repolust Cave with a major examination of the original excavation reports, the identification of sediment samples, the dating of fossil bones by means of the Uranium/Thorium-method

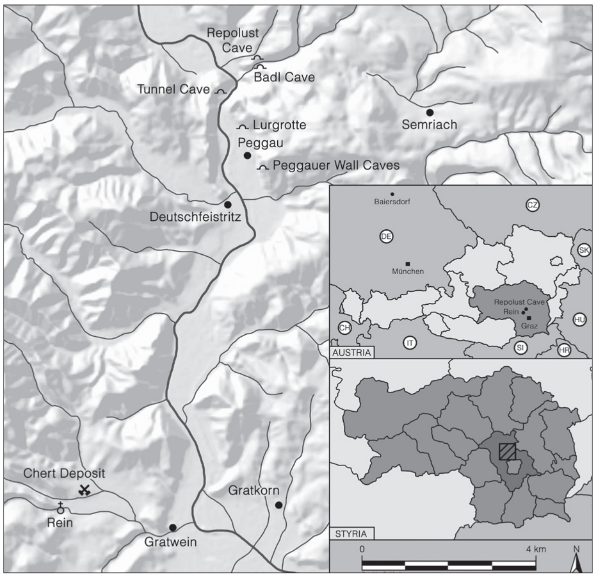

Fig. 1. Detailed plan with the position of the chert deposit near Rein and selected cave sites between Gratkorn and Semriach, in addition general maps of Austria (with the chert deposit of Baiersdorf) and Styria (graphic: D. Modl).

Abb. 1. *Detaillierte Karte mit der Position der Hornsteinlagerstätte bei Rein und ausgewählten Höhlenfundstellen zwischen Gratkorn und Semriach, zusätzlich Überblickskarten von Österreich (mit der Hornsteinlagerstätte von Baiersdorf) und der Steiermark (Grafik: D. Modl).*

Fig. 2. Repolust Cave, entrance (photo: D. Modl).
Abb. 2. *Repolusthöhle, Eingangsbereich (Foto: D. Modl).*

and by associated palaeontological investigations (Fuchs et al. 1998).

In November 2010, a three days long excavation was carried out by Michael Brandl and Daniel Modl (present authors). The goal of that teamwork was a multi-disciplinary investigation of the last in situ remains in the Repolust Cave.

The setting of the Repolust Cave

Erosion processes formed the Repolust Cave within the solid Schöckelkalk-limestone formation of the Central Styrian Karst. The Repolust Cave (Austrian cave cadastre number: 2837/1) is located at the very south-east rim of the Inner Alpine region, in the Middle Mur Valley, on the northern side of the so called "Badlgraben" near Peggau (Fig. 1). The entrance of the Repolust Cave is exposed to the southeast and lies about 520 m above sea level. A rock pillar separates the two openings in the cave entrance (Fig. 2), 120 m above the bottom of the valley. A ca. 30 m long horizontal passage with an average width and height of 3-4 m (Fig. 3) leads to a 9.5 m deep shaft, which is now backfilled, and to an 8 m high chimney with dripping water activity.

Fig. 3. Repolust Cave, horizontal passage (photo: D. Modl).
Abb. 3. *Repolusthöhle, Horizontalgang (Foto: D. Modl).*

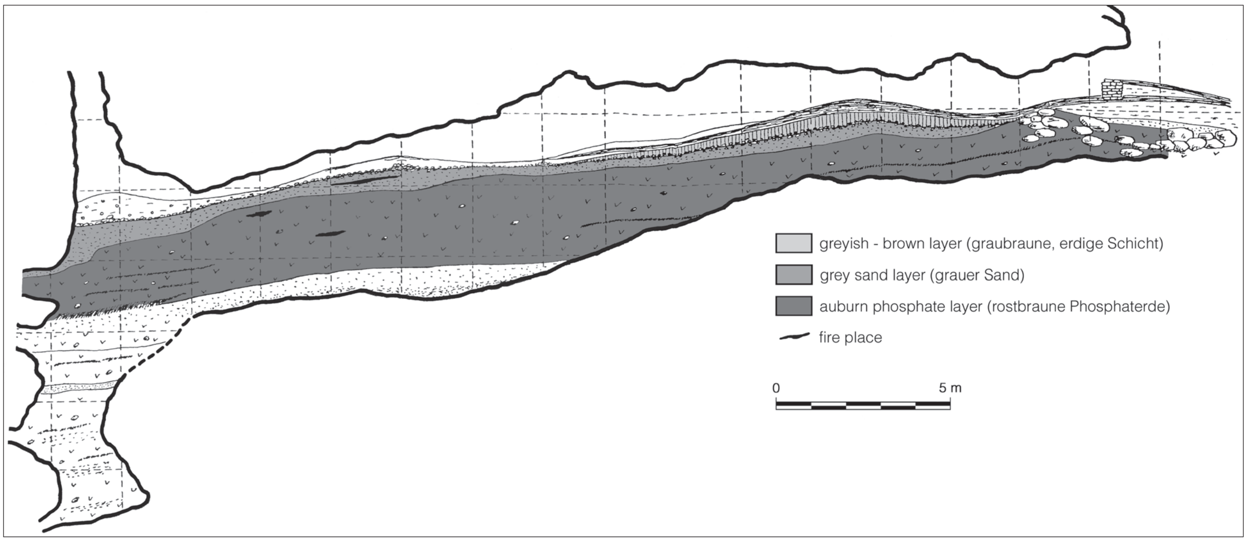

Fig. 4. Repolust Cave, cross-section plan with the three main layers (greyish - brown layer, grey sand layer, auburn phosphate layer (graphic: Mottl & Murban 1955, master plan, adapted by D. Modl).

Abb. 4. Repolusthöhle, Profilplan mit den drei Hauptfundschichten (graubraune, erdige Schicht, grauer Sand, rostbraune Phosphaterde) (Grafik: Mottl & Murban 1955, Übersichtskarte, angepasst von D. Modl).

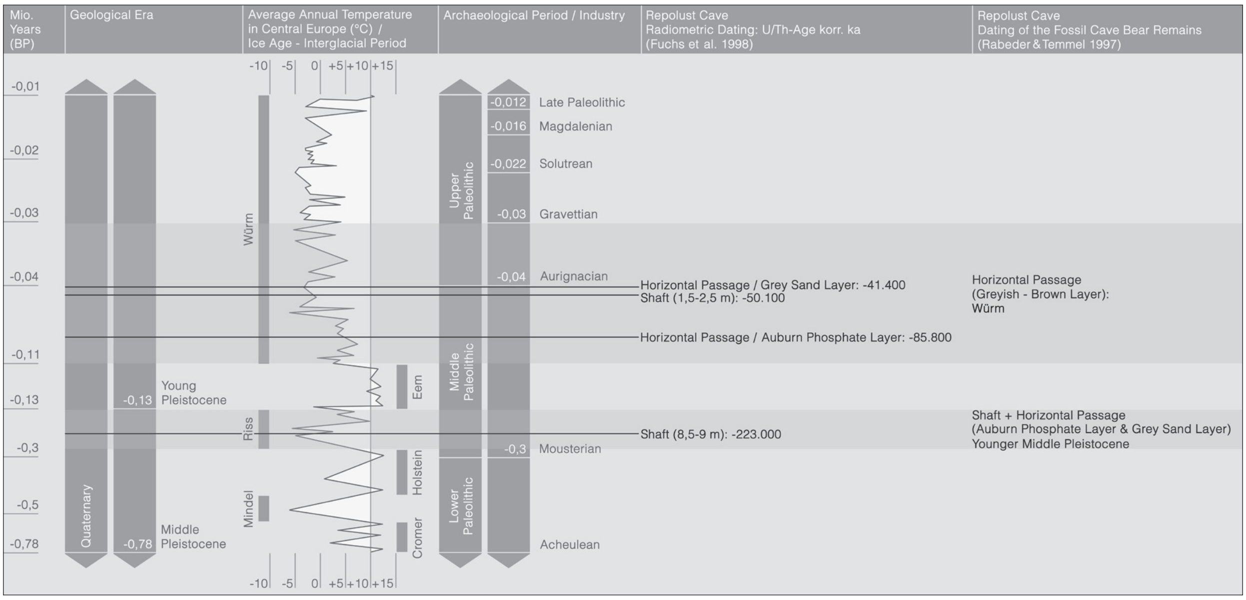

Fig. 5. Overview of the geologic eras, the climate variations and archaeological periods of the last 800 000 years in Central Europe with the results of the present U/Th-dates (Fuchs et al. 1998) and the paleontological investigations (Rabeder & Temmel 1997) from the Repolust Cave (graphic: D. Modl).

Abb. 5. *Überblick über die geologischen Zeitalter, klimatischen Veränderungen und archäologischen Perioden der letzten 800 000 Jahre in Zentraleuropa, mit den Resultaten der neuesten U/Th - Datierungen (Fuchs et al. 1998) und den paläontologischen Untersuchungen (Rabeder & Temmel 1997) der Repolusthöhle (Grafik: D. Modl).*

Sample No.	Inv. No.	archaeo-logical layer	bone	U/Th-age (ka) uncorr.	U/Th-age (ka) corr.
Uh 1266	76.143 A	auburn phosphate soil	astragalus	93.2 ± 2.7	85.8 ± 2.8
Uh 1267	76.260	grey sand layer	ulna	41.7 ± 1.7	41.4 ± 1.7

Fig. 6. Chronometric data (adapted from Fuchs et al. 1998, tab. 6 and 7, by M. Brandl).

Abb. 6. *Chronologische Daten (aus Fuchs et al. 1998, tab. 6 und 7, adaptiert von M. Brandl).*

Stratigraphical and chronological aspects

In the horizontal passage of the cave, three layers containing cultural and faunal remains are of special interest. These are (in their correct stratigraphical order) a "greyish-brown layer" limited to the middle part of the cave, the so called "grey sand layer" and the "auburn phosphate layer" (Fig. 4). The last two occur over the entire length of the horizontal passage. In both the "grey sand layer" and the "auburn phosphate layer" charcoal accumulations have been detected and interpreted as fireplaces, unrecognized indicators for

Fig. 7. Repolust Cave, choice of various chert tools (with lateral retouching, serrated pieces, scrapers; photo: D. Modl).
Abb. 7. *Repolusthöhle, Auswahl verschiedener Hornsteingeräte (mit Kantenretuschen, gezähnte Stücke und Schaber; Foto: D. Modl).*

various settlement horizons at the time of the excavation (Hofmann 1951).

The boreo-alpine faunal remains are considered most informative until now. According to Gernot Rabeder and Harald Temmel (Rabeder & Temmel 1997), the sediments from the deep shaft and the material of the "grey sand layer" as well as the "auburn phosphate layer", both in the horizontal passage, can be associated with the appearance of *Ursus deningeri* in the younger Middle Pleistocene. The higher positioned greyish-brown layer, however, contained rare remains of *Ursus spelaeus*, corresponding to the Würm period (Fig. 5).

These assumptions are based on the tooth morphology of the *Ursidae*, but unfortunately nearly all dental samples used for the analysis were collected from the previously excavated and displaced material of the deep shaft. The results must be treated with caution for that reason. Even though uranium/thorium-analyses, carried out on six fossil bones of both cave bear populations, supported these first assumptions, they posed new questions at the same time (Fuchs et al. 1998). Samples from the upper level of the shaft and from the layers in the horizontal passage are dated between 41.4 ± 1.7 ka and 85.8 ± 2.8 ka BP, corresponding to the Early and Middle Würm period respectively (Fig. 6). Due to methodological problems in using uranium/thorium for dating bones, these results must also be regarded critically.

The lithic finds

Altogether, the Repolust Cave find complex comprises almost 1700 lithics, 1058 of them quartz and quartzite and 629 of them chert. Regarding chronological questions, the lithic finds cannot make a significant contribution. In an initial overview, the lithic industry was classified as Tayacian or alternatively Clactonian (Mottl 1975), subsequent analyses would point rather to an undifferentiated Middle Palaeolithic assemblage. The lithics recovered in the horizontal passage were retrieved from the "grey sand layer" and the "auburn phosphate layer", however their spatial distribution within those two main layers can no longer be reconstructed. The artefacts can be divided into manuports, flakes, debris, cores and a group of tools mainly showing lateral retouching (Fig. 7). Whilst the quartz and quartzite raw material most likely originates from gravel bars of the Mur river, the provenance of the chert remained unknown (Mottl 1975). In order to solve this problem, mineralogical and geochemical investigations were carried out on a statistically significant number of Repolust Cave chert artefacts.

Analytical Techniques

Mineralogical investigations have been carried out at the Department of Mineralogy (now Department of Geosciences) at the Universalmuseum Joanneum at Graz. In a first step, polished sections and thin sections (0.03 mm) of selected chert samples have been produced. The mineral content was determined applying X-ray diffractometry, in some cases additional IR-spectra have been produced. From each of the two sources 11 samples were analyzed. X-Ray Diffraction (XRD) is a technique for analyzing a wide range of crystalline materials. This method allows the detection of crystalline mineral components in small amounts. A Siemens X-Ray-D 500 and a Bruker AXS D8 diffractometer were used for the investigations of the chert samples.

Secondary electron images displaying the surface of the samples were obtained by a JEOL JSM 6310 scanning electron microscope (SEM). The electrons interact with the atoms of the sample producing signals that contain information about the surface topography, material composition and further properties of the sample. Altogether, 22 samples from Rein and Baiersdorf were coated with gold and analyzed for characteristic mineralogical and textural properties.

Geochemical investigations were carried out using a laser ablation unit coupled to an inductively coupled plasma mass spectrometer (LA-ICPMS) at the University of Graz, Institute of Chemistry – Analytical Chemistry. The Laser ablation unit is a New Wave UP-213 (Fremont, CA, USA), and the ICPMS unit is an Agilent 7500ce ICPMS (Waldbronn, Germany). Material was ablated by using a 213 nm laser pulsed at 5 Hz, 40 µm spot size and 80% laser power which corresponds to an energy of ~7 J/cm2. Helium 5.0 at 1.0 l/min flow was used as carrier gas for the LA and data was acquired in time resolved analysis mode. The standard glass NIST610 was routinely analyzed for standardization and drift correction. The standard glasses NIST612 and BCR-2 were analyzed as unknowns and allowing for their reproduction within 10% relative error. Silicon (m/z 29) was used for internal standard correction. Concentrations were calculated from raw data with Glitter data reduction software (v 4.41, Macquarie, Australia). The sample from the Rein source comprised 28 micro flakes, while 22 pieces were analyzed from the Baiersdorf locality. All samples measured 2x2 mm on average.

Raw material from Rein and Baiersdorf

In order to comprehend better the background of this research, a brief characterization of the raw material deposits is presented below (see Fig. 8).

Rein

The chert deposits of Rein is located in a basin 12 km northwest of the Styrian capital of Graz, west of the River Mur. The Rein Basin is surrounded by rolling hills which make the area a perfectly enclosed settlement territory. The chert source is situated on a shallow ridge sloping north-south towards the bottom of the basin. The mining area apparently covers a three hectare area of land on the lower southern part of the slope.

Geological setting

Palaeozoic limestones, dolomites, sandstones and schists form the basis of the Rein deposit. Above the the bedrock lies a sequence assigned to the Badenian, consisting of Eggenberg breccia, red earths (laterites) and a formation referred to as "Reiner Schichten" (Rein Layers). These form a sub-unit of the Stallhofen Formation which covers large areas within the Western Styrian Neogene Basin. Both the Rein Layers and the Stallhofen Formation date back to the Badenian, the main difference lies in the occurrence of limestone banks within the Rein layers. These are composed of freshwater marls and limestones, bluish and light clays, sands, freshwater breccia and sporadic intercalated coal seams. Locally restricted tuff- and bentonite horizons are imbedded in those layers. Sandy-gravelly fluvial sediments known as "Eckwirtschotter" (Eckwirt gravels) and locally restricted Pleistocene loamy components (Flügel 1975; Ebner & Gräf 1979) overlay the Rein Layers.

Linked to the Rein Layers occur tabular and, much more rarely, nodular cherts occur. A first description of chert finds from the Rein basin is given by Peters (1853)

Chert source	Baiersdorf	Rein
Location/ Geological unit	Franconian Alb, Paintener Wanne	Styrian Neogene-Basin, Rein Basin
Geological stage	Upper jurassic Thitonian/Malm ζ	Neogene, Miocene Lower Badenian
Period in Ma	150.8 - 145.5	16 - 13.3
Stratigraphy:		
Basis	Massenkalke, Kelheim facies Loamy "Albüber-deckung"	Limnic units (Badenian) "Rein Layers"
Upper part	On top: Package of weathered laminated cherts in loamy matrix, ("Sandwich-plates")	Linked to these layers: Tabular chert within lacustrine carbonates in the upper parts of the Rein Layers.
		Chert occurrence: Rein Basin at an elevation up to 440 m
Petrology	Silicified marine sediments	Silicified freshwater carbonates

Fig. 8. Comparison of the geological settings of Baiersdorf and Rein (graphic: M. Brandl).

Abb. 8. *Gegenüberstellung der geologischen Situation von Baiersdorf und Rein (Grafik: M. Brandl).*

and Hatle (1885). Alker (1979) analyzed nodular as well as tabular chert. The chert nodules are described as originating from deeper parts of the Rein layers (bentonite-Niveau I) by Ebner & Gräf (1979), whilst the tabular variety occurs within the higher parts unattached to the bentonite.

The genesis of the chert is closely related to the lacustrine limestones in the upper parts of the Rein Layers. Chert occurs within the entire Rein Basin up to an elevation of 440 m. Mineralogically, the chert from Rein is silicified freshwater limestone (Alker 1979). Alker derives the silica from former glassy tuffs transformed into bentonite. Hence, the source of the silica is related to the 14-17 Ma old Styrian volcanism (e.g. Gleichenberger Kogel).

Sample descriptions

The plate thickness of the Rein chert samples ranged between 7 and 22 mm. The colour variation is from whitish-brown to beige-grey, rarely with bluish-grey tones. Cream colours and beige tones dominated the sample selection. Some samples show natural banded stripes or present a speckled-mottled appearance. In most cases, a yellowish-white cortex ranging from 0.5 to several mm in thickness occurs at both sides of the plates. Sometimes the cortex covers the plates entirely. The cortical surfaces are developed in different ways. One of the two cortex surfaces is markedly rougher in terms of tactile sensation. Most likely, this is the original underside of the plate. The surface of the cortex has a predominantly brownish appearance. For the Rein material, Brandl (2009) distinguishes four material quality grades (Rein I–IV) and three cortex types (1a, 1b and 2) on the basis of texture, granularity and the degree of silification (tested with hydrochloric acid).

In the literature, a rich fossil content is described from the Rein basin (Peters 1853; Gobanz 1854; Unger 1858; Penecke 1891; Wenz 1923-30; Kubart 1924; Hiden & Rottenmanner 2007). Within the lacustrine limestones and marls occur rocky banks consisting of gastropods shells (*Planorbis mantelli*) occur (Fig. 9a). Moreover, bulrush and reeds remains are commonly found in these contexts.

With regard to micro fossils, in thin sections and on back scattered electron (BSE) pictures various species of smooth-skinned freshwater ostracods were found in the Rein chert, mostly located close to the natural surface or in rock parts of poorer quality (Fig. 9c, g).

Baiersdorf

The region around Kelheim/Regensburg known as the "Altmühl-Alb" is an important area for chert quarrying in southern Germany. One of four quarrying sites within this raw material cluster is the deposit of tabular chert at the site of Baiersdorf.

The Baiersdorf chert source is situated on a shallow ridge between the villages of Baiersdorf and Keilsdorf, about 25 km west-southwest of Regensburg in Lower Bavaria. The mostly tabular chert occurs in one of the Upper Jurassic basins in the southern Franconian Alb, the so called Paintener Wanne. The supposed prehistoric mining district covers the entire upper part of the ridge, some 35 hectares in all.

This basin is one of numerous geological structures in the region, covering an area of approximately 6 km^2 around the eponymous town of Painten, 20 km west of Regensburg. It is mostly wooded country on a plateau cut by small streams with an elevation of about 500 m above sea level. The southern border is characterized by a steep slope, descending abruptly 150 m to the narrow valley of the Altmühl.

Geological setting

The Franconian Alb is one of the major geographical features of Southern Germany. It is more or less the continuation of the Swiss and French Jura Massifs, running for about 400 km between the Schwarzwald (Black Forest) in the southwest and the Frankenwald region around Bayreuth in the northeast. The region is characterized by a landscape of scarp and valley, with locally steep cliffs of limestone.

A local terminology is used in the region with reference to the geological stratigraphy. In place of the international standard division Lower, Middle and Upper Jurassic (Geyer & Gwinner 1984), this period is divided into "Schwarzer" (Black), "Brauner" (Brown) and "Weißer" (White) Jura. These epochs are further subdivided into five stages numbered form α (alpha) to ζ (zeta), which in some cases are again divided into numbers. In order to indicate the age of a formation, the epoch names Lias, Dogger and Malm are used.

The base of the geological stratigraphy in the Paintener Wanne is formed by Massenkalken of the Kelheim facies. On top of this formation follows a loamy unit called "Albüberdeckung" (Neogene). In the upper parts of the Albüberdeckung, packages of weathered laminated cherts occur in a loamy matrix. According to the local terminology, these so called "sandwich-plates" were formed in Malm ζ, which correlates with the Upper Jurassic stage of the Thitonian (Moser 1978; Binsteiner 1987, 1989, 1990, 2001, 2005). Besides the well known tabular varieties, chert nodules also occur within the Baiersdorf deposit (Binsteiner 2005).

Sample descriptions

The chert samples originating from the Baiersdorf source attain thicknesses ranging between 12 and 25 mm. The variation of colour ranges from cream coloured-beige to light brown and grey. Irregularly banded stripes and speckled colour sequences are common features of this raw material. The whitish-light brown cortex covers both sides of the plates and can reach several mm in thickness. The difference between the upper and lower faces is more significant than in the Rein samples. The rough (under-) side shows porous, partly warty shaped areas. The upper

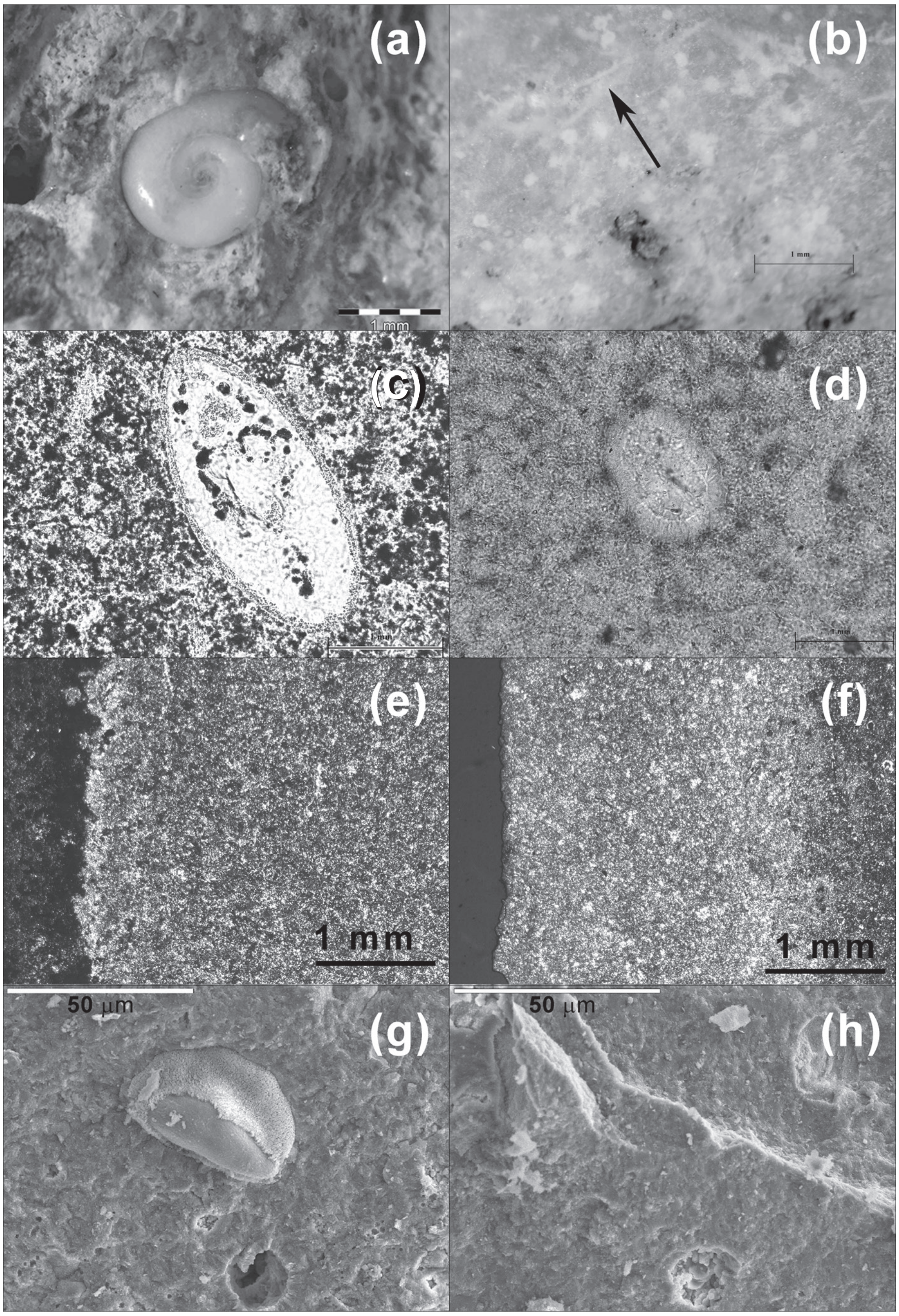

Fig. 9. (a) *Planorbis* sp. in silicified limestone from Rein (reflected light microscopy, photo: W. Postl); (b) reflected light microscopy, arrow points at one specimen (photo: M. Brandl); (c) Freshwater ostracode in Rein chert (transmitted light microscopy, photo: W. Postl); (d) Marine detritus in Baiersdorf chert (transmitted light microscopy, photo: W. Postl); (e) Thin section of Rein chert (photo: W. Postl); (f) Thin section of Baiersdorf chert (photo: W. Postl); (g) Freshwater ostracode in Rein chert (SEM picture by C. Hauzenberger, bar: 50 µm); (h) Marine detritus and cavities in Baiersdorf chert (SEM picture by C. Hauzenberger, bar: 50 µm).

Abb. 9. *(a)* Planorbis *sp. in verkieseltem Süßwasserkalk aus Rein (Auflichtmikroskopie, Foto: W. Postl); (b) Spicula in Baiersdorfer Hornstein (Auflichtmikroskopie, Pfeil weist auf ein Exemplar, Foto: M. Brandl); (c) Süßwasserostracode in Reiner Hornstein (Durchlichtmikroskopie, Foto: W. Postl); (d) Mariner Detritus in Baiersdorfer Hornstein (Durchlichtmikroskopie, Foto: W. Postl); (e) Dünnschliff von Reiner Hornstein (Foto: W. Postl); (f) Dünnschliff von Baiersdorfer Hornstein (Foto: W. Postl); (g) Süßwasserostracode in Reiner Hornstein (REM - Aufnahme von C. Hauzenberger, Balkenlänge: 50 µm); (h) Mariner Detritus und Hohlräume in Baiersdorfer Hornstein (REM - Aufnahme von C. Hauzenberger, Balkenlänge: 50 µm).*

faces are predominantly auburn coloured. Two samples were of nodular appearance with a diameter up to 40 mm.

Only few unidentifiable remains of marine organisms with grain sizes ranging from 5 to 20 µm and marine detritus were detected in the Baiersdorf chert (Fig. 9h, d). The only detectable inclusions are residues of shells and echinodermata, and in rare cases spicula (Fig. 9b).

It is well known from previous studies, that this tabular chert is very poor in fossil remains (Binsteiner 2005). Fossil inclusions within Baiersdorf cherts only occur regularly close to the cortex region. The core material only very rarely shows fossil contents.

Chert samples from the Repolust Cave

Sample descriptions

Altogether, 78 lithics from the Repolust Cave find assemblage were analyzed. None of the artefacts investigated during this study showed diagnostic fossil inclusions.

A comparison of the samples from the raw material sources and the chert artefacts from the Repolust Cave reveal certain differences. The Repolust finds are markedly darker and contain more brownish colour components. Additionally, recent artefact morphological analysis revealed that most of the artefacts have been produced from nodular chert.

The chert deposits in Rein and Baiersdorf typically contain tabular chert, however, the occurrence of chert nodules is known from each of the sources (Alker 1979; Binsteiner 2005).

Alteration of chert artefacts

More than a third of all Repolust Cave artefacts show a condition we term "chert pest" (chert plague). Most likely due to depositional conditions in the cave sediments, the pieces superficially show a compact surface structure, but are tangibly too light for typical chert. In the case of fractures at the edges of these artefacts, it is obvious that the rock structure has been transformed (weathered?) into a chalk-like state, scratchable with the fingernail. Mineralogically, it is still quartz. This corresponds to previous observations concerning the patination of flint (Schmalz 1960; Rottländer 1989).

There are several phenomena described as weathering or patination effects on chert and flint, like gloss patination, white patina, stain patina, or desert varnish (Howard 2002). Luedtke (1992, 98) describes two different types of weathering, chemical and mechanical, which are closely interrelated. The most common type of mechanical weathering is frost fracturing. Chemical weathering occurs by the precipitation of soluble materials from the surface regions of the chert. Rottländer (1975) focuses on the two main types of chemical patination regularly occurring with microcrystalline quartz varieties: white and glossy patination.

In the case of glossy patination, the entire rock surface is covered by a translucent gloss as result of silica deposition. The silica comes from the chert itself, dissolved from projections on the surface and redeposited in low areas, uniformly coating the chert (Rottländer 1975; Luedtke 1992).

For white patination, Rottländer (1975) states:

"Alkaline solutions with a pH-value above 10.0 result in white patination. These vigorously acting solvents attack the surface of chert starting at boundaries of grains at the size of only a few mymeter in magnitude. From those microfissures, a solvent penetrates into the material producing etched holes during the process of the patination. Intensity and rate of the patination is directly linked to the microstructure of the raw material."

Basically, research results point in the direction that silica is removed from the surface of cherts buried in alkaline environments (Luedtke 1992).

In the case of the Repolust Cave finds, we have to consider a combination of both glossy and white patination. It is not clear, if and how they are interrelated, or if those phenomena occurred independently. This seems rather unlikely due to the fact that artefacts showing a strong glossy effect on the surface are often more porous in their inner parts than others. This was observed for objects showing edge damage caused during the excavations. Presence of moisture additionally triggers chemical reactions that promote patination on chert surfaces (Burronia et al. 2002). This is certainly true for parts of the Repolust Cave due to dripstone activity. Some researchers emphasize the direct link between patination in general and environmental influences, e.g. lichens (Ackerman 1964; Rottländer 1983; Burronia et al. 2002).

Results

Mineralogical characterization of chert sources from Rein and Baiersdorf

Macroscopically, both materials are ver similar (Fig. 10). For the most part, their colouration, tactile feel, fracture characteristics and knapping properties are nearly identical. Slight differences can only be detected in the texture of the cortex and the edge appearance of the chert plates. Ordinarily, in the Baiersdorf chert the cortex is coarser and yellower than the cortex of the Rein chert. Additionally, the edges of the plates from Baiersdorf are sharp and splintery, while the edges of Rein are often rounded and covered in cortex.

Sections showing clearly defined layers of different coloration were documented for both sample series (Fig. 9e, f). Nevertheless, both reflected and transmitted light microscopy investigations showed basically no potential for a differentiation between the two raw materials according to these optical divergences. Surface appearance, porosity and overall characteristics are too similar to make results conclusive. Only in the case of fossil inclusions is a clear discrimination possible (Fig. 9a-d, e, f).

The X-ray diffraction analysis showed only quartz in both the Rein and the Baiersdorf samples. A few of the Baiersdorf samples contain a small amount of calcite in the cortex region. Nevertheless, this observation is not suitable for a differentiation. The components of Moganite, Tridymite and Opal-CT are below the detection limit.

Furthermore, the IR spectroscopy revealed that amorphous phases (Opal-A) also lie below the

Fig. 10. Macroscopic comparison of chert from Rein (left) and Baiersdorf (right) (photo: W. Postl).

Abb. 10. *Makroskopischer Vergleich zwischen Hornstein von Rein (links) und Baiersdorf (rechts) (Foto: W. Postl).*

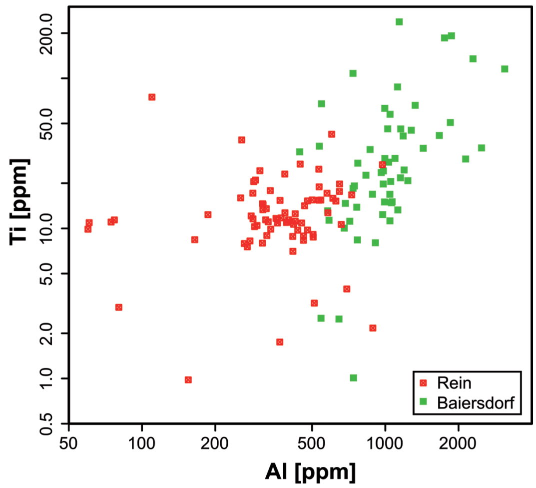

Fig. 11. Ti - Al plot of Rein and Baiersdorf chert samples.

Abb. 11. *Ti - Al Plot von Reiner und Baiersdorfer Hornsteinproben.*

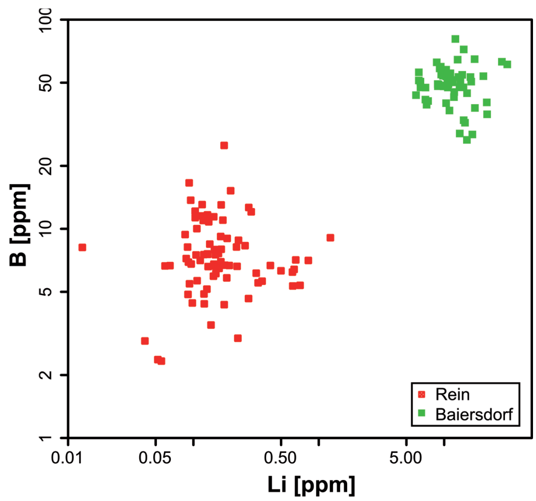

Fig. 12. Li - B plot of Rein and Baiersdorf chert samples.

Abb. 12. *Li - B Plot von Reiner und Baiersdorfer Hornsteinproben .*

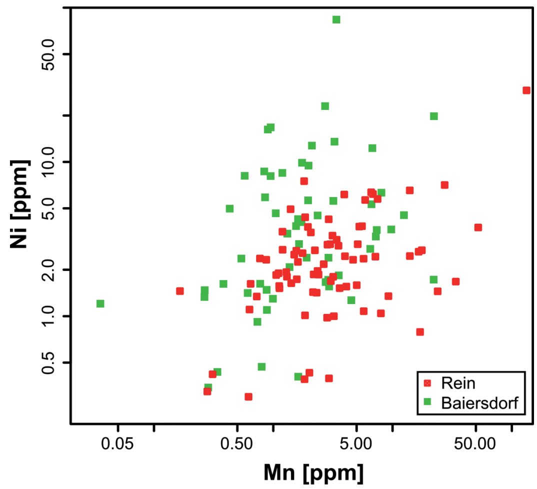

Fig. 13. Ni - Mn plot of Rein and Baiersdorf chert samples

Abb. 13. *Ni - Mn Plot von Reiner und Baiersdorfer Hornsteinproben.*

Figures 11 -16: graphics: C. Hauzenberger.

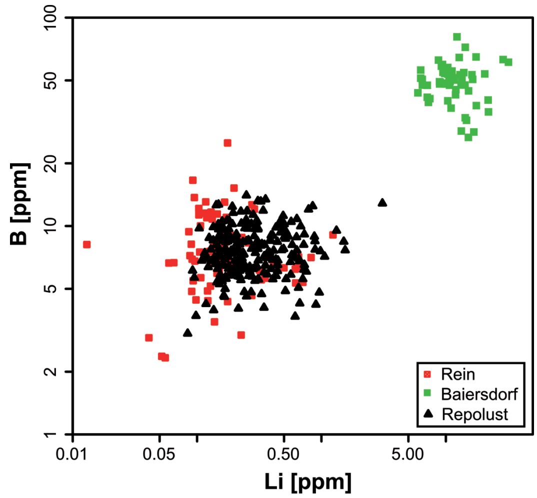

Fig. 14. Li - B plot of Rein and Baiersdorf chert samples together with samples from the Repolust Cave.

Abb. 14. *Li - B Plot von Rein und Baiersdorfer Hornsteinproben zusammen mit Proben der Repolusthöhle.*

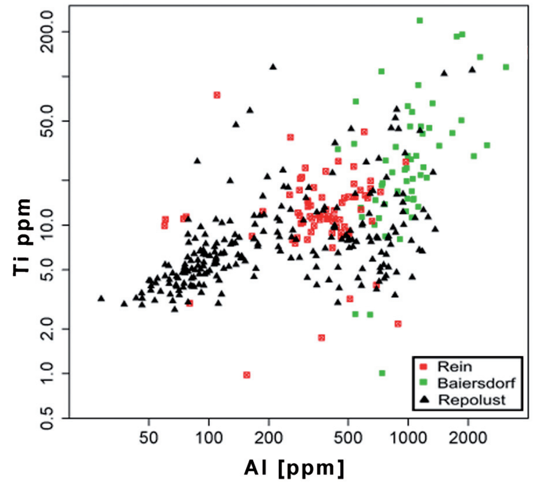

Fig. 15. Ti - Al plot of Rein and Baiersdorf chert samples together with samples from the Repolust Cave.

Abb. 15. *Ti - Al Plot von Reiner und Baiersdorfer Hornsteinproben zusammen mit Proben der Repolusthöhle.*

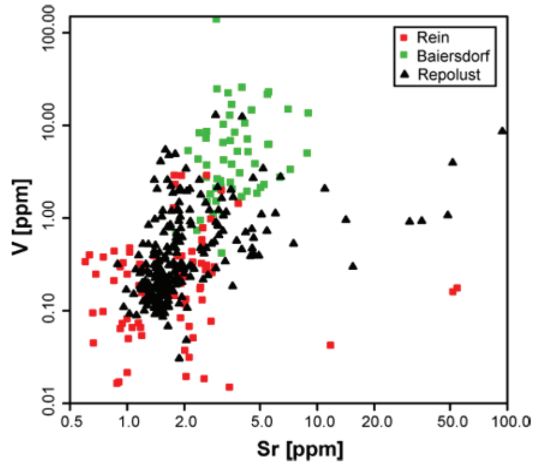

Fig. 16. Sr - V plot of Rein and Baiersdorf chert samples together with samples from the Repolust Cave.

Abb. 16. *Sr - V Plot von Reiner und Baiersdorfer Hornsteinproben zusammen mit Proben der Repolusthöhle.*

analytical limit as well. The analytical results from SEM investigations confirm the results from XRD and IR spectroscopy. All samples consist of micro crystalline quartz in a micro granular pattern. The Baiersdorf cherts probably show a slightly larger grain size and partly a slight gradation.

Visual properties, XRD, IR spectroscopy and SEM results thus did not allow a clear distinction of the Baiersdorf and the Rein samples. Since the employed mineralogical methods did not deliver significant results, subsequent analysis mainly focussed on a geochemical approach.

Geochemical analysis of the raw material sources

Geochemical parameters like lithium, boron and to a lesser extent Al, Ti, V, Sr, Rb, Cu, Zn were found to be useful in distinguishing samples from Rein and Baiersdorf. To a certain degree, their distinction is possible using the elements Ti and Al (Fig. 11), a clear discrimination is given by the elements Li and B (Fig. 12). The trace elements V, Sr, Rb, Cu, and Zn also allow a separation between the two deposits. However, these elements occur partly at very low concentrations (< 1 mg/kg), which is close to the detection limit of the applied method.

The low lithium and boron contents in the samples from Rein can be explained by the lacustrine origin of the cherts compared to the marine origin of the Baiersdorf chert deposit. Sea water contains about 0.17 mg/kg Li and 4.5 mg/kg B while fresh water has 0.003 mg/kg Li und 0.01 mg/kg B (Taylor & McLennan 1985). Thus the deposited cherts inherited these significant differences in Li and B concentrations. The measured Li and B contents differ between the samples from Rein and Baiersdorf by one order of magnitude.

In contrast, the elements Fe, Mn, Cr and Ni turned out to be unusable for any discrimination (Fig. 13). The content of these elements vary with the colour of the chert. Brownish and black areas are enriched in these elements, independent of the origin of the chert samples (also see Rottländer 1975; Andersen & Whitlow 1983).

Application to the chert finds from the Repolust Cave

78 artefacts from the Repolust Cave from the collection stored in the Universalmuseum Joanneum were sampled by W. Postl and M. Brandl and analyzed by LA-ICPMS. As shown above, a distinction of the deposits at Rein and Baiersdorf can be achieved using the lithium (Li) and boron (B) content. The data collected from the Repolust Cave cherts clearly overlap the cluster produced from samples from the Rein Basin (Fig. 14). The samples from the Repolust Cave show slightly higher Li-values compared to the raw material samples from Rein on average.

In addition to Li and B, Ti, Al, Sr and V have been used for a further classification of the archaeological objects. Titanum and aluminium did not turn out to be distinctive in the case of the Repolust Cave finds. All three clusters overlap insignificantly (Fig. 15). A better determination can be achieved looking at the Sr and V contents. These elements show a higher agreement of the Repolust cherts with the Rein data (Fig. 16).The Rein cluster demonstrates a low ratio average for both Sr and V contents. Baiersdorf cherts generally contain much higher V contents than the Rein samples. The Sr-concentrations are slightly higher at the Baiersdorf source. The bulk of the data gained from the Repolust Cave samples coincides with the main cluster from Rein. Some outliers have considerably higher values than both Rein and Baiersdorf.

Discussion

Due to the geographic proximity of the Repolust Cave and the Rein source we hypothesized a provenance of the Repolust Cave cherts from the Rein deposit. The general appearance of the Repolust Cave finds clearly matched that of the Rein samples. Even though an origin from the Baiersdorf source seemed rather unlikely, these data were incorporated into the comparative study in order to verify and monitor the results. The main research question was, if possible, to prove or disprove the assumption, that the Repolust Cave finds originated from the Rein basin, but represented the use of the rarer nodular components from that deposit. Since the microscopical, petrographical and mineralogical methods of analysis did not deliver significant results for differentiating the Rein and Baiersdorf chert sources, we decided to apply a geochemical approach.

Chert source provenance studies using trace element analysis techniques are an especially difficult undertaking due to the usually heterogeneous nature of the samples and low element concentrations (Speakman et al. 2002). In order to create a geochemical fingerprint of chert raw material that is useful in sourcing archaeological artefacts, it must be generally implicid that the analyzed material was not heavily altered by weathering effects (Tykot 2004; Hughes et al. 2010).

Although there is a wide range of interdisciplinary approaches in chert sourcing (e.g. Wright 1967; Aspinall & Feather 1972; Reed 1990; Pooltona et al. 1995; Gratuze 1999; Gratuze et al. 2001; Pillay 2001; Thacker & Ellwood 2002; Tykot 2003; Tykot 2004; Cinta Pinzaru et al. 2008; Parish 2009), the main focus in this research field is presently concentrated on three geochemical techniques. These are Neutron Activation Analysis (NAA; Julig 1995; Glascock et al. 2008), X-Ray Fluorescence (XRF; Rafferty et al. 2007; Hughes et al. 2010), and laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS; Speakman & Neff 2005). All three techniques quantify the specific elemental composition contained in rock material. In the case of chert analysis, the main objective is on the detection of rare earth elements (REE; see Murray et al. 1990; Murray et al. 1991; Murray et al. 1992) and trace elements (Bush 1976; Parish 2009).

Only few chert sourcing approaches applying LA-ICPMS have been conducted so far (Delage 1997; Roll et al. 2005; Morgenstein 2006; Evans et al. 2007; Speakman et al. 2007). These pilot studies – as is often the case – did not explore the entire range of possibilities provided by the tequnique so as to maintain a narrow range of focus in order to determine the efficacy of the method (Tykot 2004, 64). In most cases, only small numbers of samples were analyzed and definitive geochemical source specific patterns in terms of trace element compositions could not be established (Roll et al. 2005; Morgenstein 2006; Hughes et al. 2010). Other than a few clear-cut clusters, the microfacial heterogeneity of samples within the sources was detected in most cases (Evans et al. 2007). The heterogeneity of samples within a specific source on the one hand and the similarity of samples from sources within a certain catchment area on the other hand are the main challenges to differentiation approaches using trace element analysis. Analysing only a small amount of samples increases these problems due to the lack of relevant statistical evaluation.

As demonstrated by the previous studies applying LA-ICPMS, the main problems occurred due to the small number of samples analyzed and the generally similar geological genesis of the cherts compared in provenance studies. This is due to the marine origin of the majority of chert and flint (McBride 1979). In our present study, the two sources under discussion showed distinct geochemical parameters and were analyzed together with archaeological samples under the same conditions. The investigation of a statistically significant amount of samples demonstrated the relative homogeneity of the raw materials. We avoided sampling artefacts obviously affected by the described "chert pest".

The Baiersdorf chert source is of marine origin, whereas the Rein source is a lacustrine formation. The two geological settings are reflected by the high divergence in the Li and B content of the cherts, clearly distinguishing the samples. Based on our geochemical results, we can now conclude that the initial assertion – that the Repolust Cave cherts originate from the Styrian raw material source – is strongly supported by the Li and B content of the chert material. The possibility of an origin from a different, not yet identified source seems unlikely due to the agreement of other trace element concentrations like Sr and V in the Rein samples and the Repolust Cave cherts. Tendentially, the Repolust Cave cherts show higher Li and Sr values than the Rein cluster. An explanation may be found in the natural range of the collected raw material samples or in geochemical processes that took place during the course of deposition in the cave and somewhat influenced the composition of the artefacts (Luedtke 1992; Howard 2002; Burronia et al. 2002; Hughes et al. 2010).

In the course of extensive survey activity relating to Styrian chert sources, the possibility of chert occurrences in the Western Styrian Neogene Basin has been subject to thorough investigations. The surveys covered the entire catchment area and produced no evidence of further chert outcrops (Brandl 2009). This needs to be set into perspective due to the slight possibility that once accessible deposits vanished without leaving a trace during long time periods. At the state of the art, we assume that the Rein Basin chert source is the only significant one in that area. Based on these investigations, an identification of the Rein source as the origin of the 78 sampled brownish white, non transparent chert flakes of the Repolust Cave assemblage seems assured.

Conclusion

The goals of the present study were two-fold. The first goal focused on the differentiation of the chert sources at Baiersdorf (Germany) and Rein (Austria) producing visually similar raw materials. No other deposits within a considerably close catchment area contains comparable raw material.

The second goal concerned the provenance of Middle Palaeolithic chert artefacts from the Styrian Repolust Cave showing the same visual properties as material of the two geological sources. For this purpose, a combination of petrological, mineralogical and geochemical techniques was applied.

Due to the infrequency of fossil inclusions in both chert types the microscopic analysis did not provide sufficiently discriminative results. Petrographical (thin sections) and mineralogical (XRD, IR spectroscopy and SEM–EDX) methods also failed to differentiate the sources of Baiersdorf and Rein as well. The geochemical approach applying LA-ICPMS yielded convincing results. This study showed it is possible to clearly differentiate chert from Baiersdorf and Rein by Li (lithium) and B (boron) content. An application of the geochemical results to samples from the Repolust Cave revealed a clear coincidence between data gained from the archaeological material and the Rein data cluster.

The study demonstrated the successful application of LA-ICPMS for chert provenancing and provides a useful tool for provenance studies concerning prehistoric chert artefacts from Styria, Austria. The results are applicable to any lithic finds in that area and will contribute to investigations on prehistoric chert raw material procurement not only in Palaeolithic times.

Postscriptum

In the course of ongoing investigations, further evidence for an origin of the Repolust Cave finds in the Rein basin was found. Thin sections of some artefacts were produced. They show characteristic cross sections of charophytes filled with sphaerolitic developed chalcedony. Identical sections were detected in the nodular chert sample from Rein (thin section, Inv.No. 41837, petrographic collection Department of Geosciences, Universalmuseum Joanneum) investigated by Alker (1979). Besides quartz, moganite was detected via XRD analysis in both the chert sample from Rein and the Repolust Cave cherts. The moganite content in both cases is at the limit of detection.

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