Kupferschiefer and Other Sediment-Hosted Deposits in Central Europe: Field Trip Review

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Summary
The "Kupferschiefer and Other Sediment-Hosted Deposits in Central Europe" field trip (22 May-1 June 1986), focussed upon the stratiform copper ore (Kupferschiefer) deposits of West Germany and Poland, was a major success. Trip leaders effectively communicated the stratigraphy associated with these deposits, the sulphide zonation, and the controls of mineralization (particularly location with respect to siltstone alteration zones) with paleotopography. Replacement textures by oxides and copper sulphides and cross-cutting relationships of ore zones with respect to lithologies indicate diagenetic or epigenetic emplacement of ore. While many crucial questions have been answered, several remain.

Introduction
Kupferschiefer, or copper shale, deposits are stratiform deposits associated with Permian sediments covering approximately 600,000 km² of Europe, from northern Great Britain to western Russia, and are mined today in East Germany and Poland. After being mined for copper for almost 800 years, the Kupferschiefer continues to produce new deposits; in southwestern Poland, recently discovered mines contain estimated reserves of at least one billion tonnes of 1.5-2.0% copper and approximately 30 g/tonne silver (White, 1986).

The Kupferschiefer is a thin, carbonaceous shale or marl which lies at the base of the Upper Permian, or Zechstein sediments. This shale overlies Lower Permian terrestrial, red-coloured sandstones and conglomerates (Rotliegenges) and transitional white-to-grey sandstones (Weissliegenges), which in turn overlie older Paleozoic volcanics and sediments (locally metamorphosed during the Variscan orogeny). The Kupferschiefer forms the base of the lowest of three to five marine-evaporite cycles in the Zechstein sediments.

Mineralization occurs in the Kupferschiefer and its adjacent sediments (Zechstein limestone above, and Weissliegenges below). Highest metal grades occur adjacent to Rote Fäule, a hematitic alteration of Rotliegendes and Zechstein sediments. Moving away from Rote Fäule (generally basinward), typical metal zonation is: chalcolite, bornite, chalcopyrite, galena, sphalerite and pyrite/marcasite. Silver, an important by-product in Kupferschiefer mines, is associated with copper; other metals (including cobalt, gold and platinum) are also enriched in these deposits, but are not currently recovered.

Model(s) of ore genesis in these deposits have ranged widely over time: (1) epigenetic emplacement of metals by hydrothermal solution, (2) syn-sedimentary precipitation of metals in an eutinic basin; (3) early diagenetic precipitation of metals from groundwater ascending via evaporation in overlying sabkhas. Papers presented at the Symposium on Sediment-Hosted Stratiform Copper Deposits, at Ottawa, Canada, in May 1986, suggest that several workers have returned to a diagenetic or epigenetic model of Kupferschiefer mineralization related to convecting hydrothermal fluids.

Kupferschiefer Field Trip
The "Kupferschiefer and Other Sediment-Hosted Deposits in Central Europe" field trip (22 May - 1 June 1986), presented in association with the symposium, provided a rare opportunity to view the Permian sediments and Kupferschiefer deposits of both West Germany and Poland. The trip was organized into three parts: the German Kupferschiefer excursion (I), the German Sedimentary Exhalative excursion (II), and the Polish Kupferschiefer excursion (III). The sedimentary-exhalative portion of the trip included tours of the Marsberg and Rammelsberg copper deposits. While fascinating in their own right, these deposits will not be discussed in this summary. Also, several stops in Germany and Poland which are not essential to this summary have been excluded.

This field trip was very well organized and led by Canadian, German and Polish geologists. The participants are indebted to the organizers and to the host countries for making this an excellent trip. The guidebook (Jowett, 1986) is similarly well organized and is recommended to the reader. This review will focus on observations and questions raised by the actual field experience. The excursion's purpose, "to view the continental volcanic and clastic rocks of the Rotliegendes and the marine carbonates and evaporites of the Zechstein, and the relationship of ore mineralization to facies, paleo-geography and paleotopography" (Jowett, 1986) was fully accomplished.

Part I: German Kupferschiefer. During the first segment of the field trip, participants observed portions of the Rotliegendes clastics and volcanics, and the overlying Zechstein marine sediments. Participants spent the first field day (23 May) in the Saar-Nahe basin, a northeast-trending basin located southwest of Frankfurt where the largest continuous exposures of Rotliegendes occur, and where the Rotliegendes reaches a maximum thickness of 5000 metres. The upper half of the lower Rotliegendes, viewed near Oderheim, contains lacustrine siltstones, locally containing as much as 5000 ppm copper and lesser amounts of lead and zinc. Overlying sediments grade upward into a deltaic sequence of alternating sandstones and mudstones followed by massive sandstones. Thin coal beds scattered throughout the deltaic sediments locally contain anomalous copper or uranium.

Portions of the upper Rotliegendes were viewed in Waldbockheimer, including endiamic volcanics, interbedded sandstones, lapilli-bearing conglomerates and rhyolitic tuffs. These are overlain by a rhyolitic conglomerate and a thick sequence of massive laticiferous flows. The Saar-Pfalz rhyolite, seen near Bad Kreuznach, is an alkaline rhyolite which intruded the Rotliegendes sediments. It is one of a series of alkaline intrusions which indicates rift-related igneous activity during Permian deposition.

On the second field day, near the former mining district of Richelsdorf, we observed the uppermost Rotliegendes, the Cornberg sandstone, and the first cycle of Zechstein sediments (including the Kupferschiefer). Uppermost Rotliegendes is a thick sequence of non-marine sandstones, pebble conglomerates and lesser shales, with a characteristic reddish matrix. This portion of Rotliegendes was visible at both the Schuchard Sandstone Quarry in Cornberg and the Mündern Bante Mine.

Cornberg Sandstone, an equivalent of Weissliegenges, was seen only at the Schuchard Quarry. This cross-beded white sandstone of disputed origin (eolian, fluviatile or shallow marine) has an undulating surface which is in sharp contact with Kupferschiefer. The laminated shale thickens to 85 cm in the sandstone taphons and almost pinches out over crests. Organic carbon, copper (averaging 1%), lead and zinc are concentrated in the lower portions of the shale.

At the Mündern bante mine, Kupferschiefer rests directly upon a relatively flat surface of bleached Rotliegendes (Graufliegenges). Metals - dominantly zinc in this area - are again concentrated in the lower, organic-rich portion of the shale. As is characteristic throughout the Kupferschiefer, copper is most concentrated at the base, lead in the middle, and zinc in the upper part of the mineralized zone. This sequence is repeated whether it occurs within tens of centimetres of shale, or tens of metres of various sediments.
Above the Kupferschiefer lies the Zeche-
steinkalk, a marly limestone with a biotur-
bated base and anhydrite nodules near the
top. Overlying the Zechesteinkalk at the
Münden bunte mine, Anhydritknoten schiefer
(with the interbedded anhydrite layers now
dissolved out) and Shaie Breccia (solution
breccia of Lower Werra Anhydrite) complete
the first cycle of the Zechestein.

At the Münden mine and in drill core seen
in Cornberg, the Rote Limestone is bleached
to a greenish-grey or yellowish-grey colour
for several metres below the Zechestein contact.
Such alteration in colour due to reduction of
iron oxides, was called "Grauliegendes" by
miners. This form of bleaching has also de-
veloped locally in Wessielegendes and, where
Rote Limestone is quite thin, in the underlying
schists or sediments. The Grauliegendes
consistently underlies the Zechestein sedi-
ments. Causes of these lenses of reduction are
disputed; proposed reasons range form
pre-Zechestein weathering to sabkha forma-
tion or to reduction during Zechestein sedi-
mentation. Grauliegendes may contain anomalous copper concentrations — locally
appearing to be associated with downward
movement of metals from the Kupferschiefer
at the Münden mine. However, the copper-
rich zone in the Grauliegendes also may be
separated from the Kupferschiefer by a copper-
poor zone. The cause of such zoning is
unclear.

One critical type of alteration introduced to
us on the second day was the Rote Fäule, a
zone of oxidation characterized by develop-
ment of hematitic patches. Rote Fäule gener-
ally occurs near paleotopographic highs in
Zechestein seas; it is never adjacent to
Grauliegendes; but it forms in sediments
ranging from the Rote Limestone to anhydrite in the
Zechestein; and it is generally barren, but con-
sistently occurs adjacent to the highest-
grade mineralization. The classic basinward
zonation, found throughout Europe is:
hematite — chalcocite — bornite —
chalcopyrite — galena — sphalerite — pyrite.

To emphasize the importance of this zonation
with respect to Rote Fäule, the Garman trip
leaders noted a drillhole in which Rote Fäule
was found stratigraphically high in the sec-
tion. Here, the vertical zoning mentioned
above was reversed; copper was highest on
top, with chalcocite on top and chalcopyrite
at the base of the copper zone, and lead and
zinc below the copper. Thus, location of Rote
Fäule and not lithology, appears to control
metal zonation. For all its importance, how-
ever, Rote Fäule is not well-understood.

Enigmas of Rote Fäule and Grauliegendes
provided lively discussion among participants.

Participants also viewed sections where
the Rote Lignite is only five metres thick.
The grade of Kupferschiefer mineralization is
not dependent upon the thickness of
the Rote Lignite.

The third field day was mainly devoted to
observing basin-edge Zechestein deposits in

The Basal Limestone forms a sharp contact
with underlying Wessielegendes (which is
locally present) or Rote Lignite. The Kupfer-
margel (averaging 2.7 mm thickness) includes
the Spotted Marl, a grey marl commonly col-
oured by large hematitic spots (Rote Fäule),
and the Copper-Bearing Shale, a dark grey-
 fissile marl, averaging 0.8%-11% copper in
the mine. The Zechestein Limestone, over-
lying the Kupfermargel, includes a lower unit,
the Lead-Bearing Marl, and an upper dolomi-
tic limestone to dolomite. (Please note: these
are stratigraphic units, as defined by marker
beds — see editor’s note in Oszczepalski et
al., 1986.) Rote Fäule is developed in Basal
Limestone, Spotted Marl, and lower Copper-
Bearing Marl, while copper is concentrated in
the upper Copper-Bearing Marl and lower
Lead-Bearing Marl. Silver is associated with
the copper. At the Konrad mine, only copper
and silver are recovered. Anhydrite is also
mined from one of the near-surface members
of the Upper Zechestein.

The Rudna mine, toured on 28 May, occurs
in the Fore-Sudetic Monocline, which is
bounded on the southwest by the Fore-Sude-
tic Block. Along with the Lubin and Polkowice
mines, the Rudna exploits a northwest-trend-
ing, continuously mineralized zone (the
Lubin district) covering approximately
600 km². Farther northwest on this same
trend lies the Sieroszowice deposit, which is
currently being developed.

Stratigraphy within Rudna is quite similar
to that found in Konrad, with a few notable
exceptions. Wessielegendes sand waves,
ranging between 5 and 43 metres in thick-
ness, occur throughout the deposit; the
Border Dolomite (< 15 cm thick) is the equiv-
alent of the Basal Limestone seen at Konrad;
and the Kupferschiefer is a black, laminated
shale here, not a marl. This shale can be as
thick as 90 cm, but locally pinches out over
crests of Wessielegendes sand waves.

Copper mineralization is present in the
Wessielegendes. Kupferschiefer and/or
Lower Zechestein Limestone. Within the Kup-
ferschiefer, rich copper ore (5-15% Cu) oc-
curs as disseminations, and beddingparallel
and near-vertical veins. Within the
Wessielegendes, copper contents, ranging
0.45% Cu, tend to be highest in sand wave
crests. Where anhydrite cement occurs in the
sandstone crests, however, no copper is
present and only minor pyrite, galena and
sphalerite may occur. Copper ore zones can
be as thick as 20 metres. One interesting ob-
servation was the presence of repeated ore
bands (defined by high chalcocite at the base
to low chalcocite at the top), ≤ 2 cm thick,
within the rich Wessielegendes ore. Exact
mineralogy and reasons for this banding are
unclear at the moment. The lower portions
of Zechestein Limestone may be copper-rich, but
copper content decreases upward, while lead
and zinc increase. Zoning of sulphide min-
erals relative to Rote Fäule (which is located
in the western edge of the deposit), is the
same sequence as noted in Germany. Silver is most strongly associated with chalcocite and bornite. At Rudna, as opposed to Konrad, all the base metals and silver are recovered. Petrographically, the sulphides reflect the regional zonation. Framboidal pyrite is the earliest sulphide to form, and is consistently replaced by copper sulphides. Hematite prevalently replaces copper sulphides.

On the eighth field day, the shoreward facies of Zechstein sediments in southwestern Poland, and the interaction of Rote Fäule with mineralized zones were examined. The Nowy Kossoci quarry and Lena open-pit mine occur in nearshore facies equivalents of the Konrad mine within the North-Sudetic Basin. The stratigraphy of these two deposits is very similar to that at Konrad except that the marls are increasingly carbonate-rich toward the paleoshoreline. Copper mineralization occurs stratigraphically higher near the Lena mine; it is almost entirely within the Lead-Bearing Marl, whereas in the Nowy Kossoci quarry, it is dominantly in the Copper-Bearing Marl. At Nowy Kossoci, where an overlap of copper mineralization and Rote Fäule of approximately one metre occurs, hematitic spits have halos of sulphides—the opposite of the usual trend. The complex relations of oxides and sulphides suggest possible oscillation of redox zones in this area.

The Polish geologists’ understanding of paleogeographic settings, metal zonations, relations of mineralization to stratigraphy and Rote Fäule, and sedimentary environments of deposition are impressive. Discussions with Polish geologists and synthesis of the group’s observations have provided an understanding of the essential characteristics of the Polish Kupferschiefer deposits. Copper mineralization cuts across stratigraphy at a low angle, and is strongly associated with the boundaries of Rote Fäule, the richest ore parallels Rote Fäule boundaries, which are at a slight angle to the Zechstein’s paleoshoreline. District-wide ore grades or metal contents are not correlated with thickness of either Zechstein or Rotliegendes sediments. Zoning of mineral sulphides with respect to Rote Fäule is consistent; copper sulphides consistently replace pyrite, usually in the order of mineral zonation, and hematite generally (but perhaps not always) replaces copper sulfides. Iron content of Rote Fäule and pyritic zones are roughly equal, however organic carbon content increases from 0% in Rote Fäule to 10% in the pyrite zone.

Several ambiguities, in addition to those noted with specific reference to Germany, still remain regarding the Kupferschiefer deposits. First, Polish geologists suggested that, on a regional scale, copper mineralization is generally associated with a calcite-rich zone which also cross-cuts stratigraphy at a low angle. This is not obvious in the stratigraphic sections, and the limestone versus dolomite distribution was unclear from our observations. If a relationship between mineralization and calcite is present, it may reflect mineralizing processes. This topic is being investigated (Oszczepalski, in press). One question is whether any similar relationship is observed in the German Zechstein sediments.

Second, there is some discussion as to whether the Kupfermergel of Poland is truly equivalent to the Kupferschiefer; certain characteristics suggest that it more closely resembles part of the Zechsteinkalk. One way to answer this question is to perform detailed studies of the Kupferschiefer and Kupfermergel in Poland to see whether the detailed stratigraphy described by Kulick et al. (1984) is present in the Polish “equivalents”.

Third, the importance of the Rote Fäule has been well-established on a regional scale, and some petrographic work (Oszczepalski and Rydzelewski, 1983; Rydzelewski, 1978) has been done. This author believes, however, that further study of Rote Fäule, and particularly of the 50-80 cm thick transition zone to chalcocite, would shed important light on the questions of mechanisms of ore deposition. Rydzelewski has observed three types of hematite in these sediments: disseminated hematite in pore fillings with no suggestion of replacing sulphides; hematite gradually replacing individual sulphide grains; and hematite-rich spots (e.g., in the Spotted Marl) forming a spotty appearance. The question of which type of hematite truly represents the Rote Fäule deserves more study.

The final question, the goal of studying Kupferschiefer deposits, is to understand how they form. The experience of this field trip has convinced the author that metal zonation must be related to diagenetic/epigenetic processes associated with formation of the the Rote Fäule. Two major theories seem to be surfacing at the moment: (1) the metals were leached from Rotliegendes sediments and transported through Zechstein sediments during diagenesis via convective flow of oxidized brine (Jowett in Jowett, 1986a, p. 42-52); and (2) metal deposits resulted from the interaction of two brines, an ascending, hot, metal-rich brine associated with Rote Fäule formation, and descending, cold, alkaline brine (Kuchta and Pawlikowski, 1986). The first theory includes two variations: Jowett (op. cit.) argues strongly that mineralization occurred during late diagenesis; Oszczepalski (in press) believes that copper mineralization mainly occurred during early diagenesis and was remobilized during late diagenesis. The cursory nature of one field trip does not permit confidence in choosing between the two mechanisms which currently seem to be most sensible. Furthermore, it is unclear to the author how one would differentiate between metals introduced by late diagenetic influx of brines, and simply remobilized metals. Perhaps the continued work on stable isotopes, fluid flow paths, fluid chemistry and fluidrock reactions will shed light on this. The author’s main conclusion from the Kupferschiefer field trip is that much important work has been accomplished toward understanding these deposits, but new questions have resulted.

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References


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