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Sedimentary environments of the vertebrate-bearing Norian deposits from Krasiejow, Upper Silesia (Poland)

Vertebraten-führende sedimentäre Ablagerungsbereiche im Norium (Obere Trias) von Krasiejow, Oberschlesien (Polen)

with 2 figures and 2 plates

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Abstract
The Norian, Upper Gipskeuper-Steinmergelkeuper succession, cropping out in Krasiejow (Upper Silesia), represents redbed facies assemblage, forming under fluctuating dry to semi-dry climatic conditions. The dominant facies type are the alluvial deposits formed on gently sloped, sandflats to mudflats with small, ephemeral lacustrine basin(s). The vertebrates *Fossillagerstätte* accumulated in such lacustrine depressions that were dry during extremely drought periods. The accumulated skeletal material underwent replacement through debris flow mass movements triggered by catastrophic runoffs. The region was also influenced by intensive synsedimentary tectonic mobility.

Zusammenfassung
Die norische Abfolge Oberer Gipskeuper-Steinmergelkeuper, die im oberschlesischen Krasiejow ausstreicht, ist als Rotsediment-Folge entwickelt und bildete sich unter wechselnd trockenen bis semiariden klimatischen Bedingungen. Alluviale Ablagerungen bilden den vorherrschenden Faziestyp, der auf leicht geneigten Sand-/Tonebenen mit engräumigen ephemeren Seen entstand. In solchen lakustrinen Senkungsbereichen, die während extremer Dürreperioden austrockneten, entstand allmählich die Vertebraten-Fossillagerstätte. Das sich anreichernde Skelettmaterial unterlag Veränderungen durch Massenbewegungen in Geröllströmen, die durch katastrophenartige Abflussereignisse ausgelöst wurden. Die Region kennzeichnete ferner eine synsedimentäre tektonische Mobilität.

1 General setting

The studied region is situated in the western part of Upper Silesia (Fig. 1), which is well known for a spectacular Muschelkalk succession, representing one of the most classical, Middle Triassic key sections in Europe. Because of the scarce number of outcrops and wells penetrating the Upper Triassic, this interval is much less recognised, despite a long history of geological investigation (ROEMER 1867). Since the 1970's the Upper Triassic clayey rocks have been attractive for industrial purposes and a relatively large quarry has been opened near Krasiejow village. The quarry, where 18 metres of variegated muddy sediments crop out, recently became known from the very rich vertebrates *Fossillagerstätte* (DZIK et al. 2000). Unfortunately, both the age and the sedimentary context of these fossil-bearing deposits have not been studied in detail, hence the proposed evolutionary inferences (DZIK et al. 2000, DZIK 2003) could be premature.

The present paper deals with sedimentary processses and the general environmental and stratigraphical context of the Upper Triassic deposits from the western Upper Silesia region. The study, first carried out in the outcrop, was completed with a borehole providing 17 meters of the profile (Fig. 2). Based on data from another borehole, situated some 4 km westward from the outcrop, the Middle Keuper shows a typical lithostatigraphical succession consisting of Lower Gipskeuper ca. 50 m thick, Schilfsandstein 35 m, Upper Gipskeuper ca. 60 m, and the incomplete, eroded Steinmergelkeuper 54 m (KLAPCINSKI 1993).

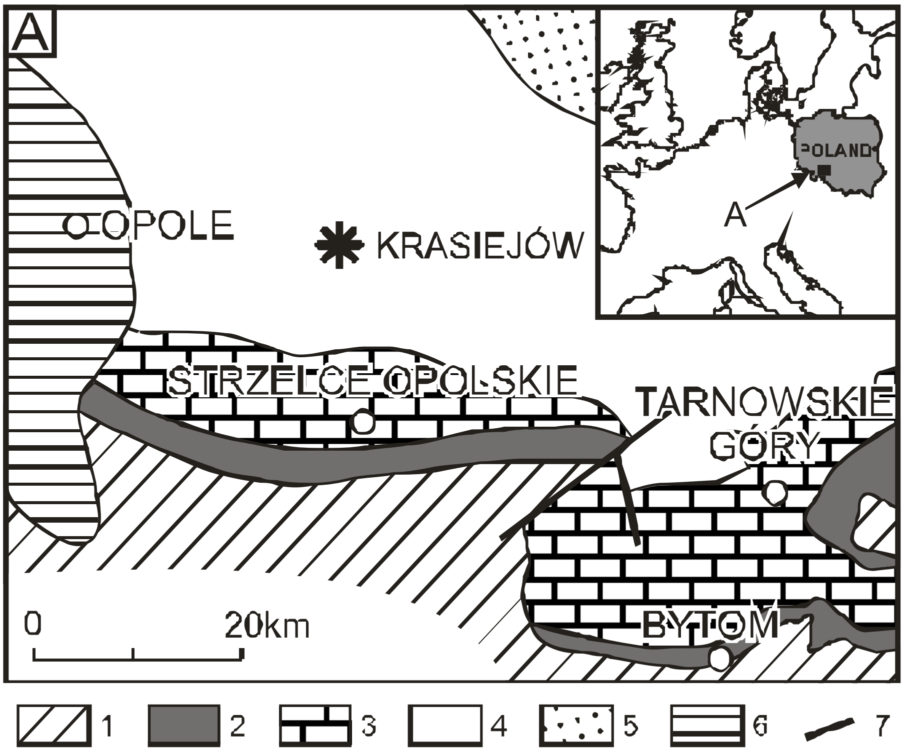

Fig. 1: Geological sketch map of the study area.
1 – Carboniferous 2 – Buntsandstein 3 – Muschelkalk 4 – Keuper
5 – Jurassic 6 – Cretaceous 7 – more important faults

2 Sedimentary facies characteristics

The sequence analysed is dominated by variegated mudstones and siltstones, which comprise in the lower part, nodules and veins of gypsum (Plate 1 A). The sediments are dominated by a reddish palette of colours with grey planar or spotty intercalations (Plate 1B).

The coarser-grained deposits are mostly composed of silty and sandy material that comprise the plane-bedded, cross-bedded and rippled alluvial sediments (Plate 1 C, D, F). The primary structures are commonly obliterated due to postdepositional, pedogenic processes. However, from the remnant structures one may recognize the parallel laminations and small scale ripple-drift cross-lamination (Plate 1 F) as the dominating primary sedimentary features. In some cases a small-scale fining upward trend is also visible (Plate 1 G).

Some of the beds or bed sets are defined by an erosional lower bounding surface (Plate 1 E and G), in particular the sheet-like grey, conglomeratic beds reaching up to 20 cm in thickness and composed of carbonate grains ranging between 1 – 5 mm in diameter. The clasts are mostly reworked pedogenic carbonate nodules but skeletal debris of bivalves are also present in some layers (Plate 1 I). The width of the alluvial, commonly amalgamated sheets (Plate 1 H), visible in the quarry, exceeds 400 meters and their erosional incision reaches up to 3 meters.

The transport direction frequently varied throughout the section but generally the N and NW-directed transport dominated, with an exception for the middle part of the section, where an eastward direction has been found. Similar N and NW transport directions, have been found in another outcrop (Lipie Slaskie), situated some 20 km eastward from Krasiejow.

In addition to the fluvial sediments, 3 massive debris flows (mudflows) horizons have been found in the outcrop part of the section (Fig. 2; Plate 2 F and K). The succession discussed is built up from several alluvia sets divided by paleosoil horizons. Thickness of the palesoil-bounded sets ranges between 1 and 7 metres.

The pedogenic horizons form mostly brown, nodular and friable mudstones, which may be interpreted as incipient paleoweathering horizons (regolith). They pass gradually or cover sharply the underlying host substrate, i.e., to more compact variegated mudstones and claystones (Plate 2 A and C). The soils display rather poorly preserved root traces that pierce the underlying host rocks diffusively and yield mottled red-grey fabrics (Plate 2 B).

As well as the regolithic soils, other pedogenic fabrics are the fine pedogenic nodules and vadoids entombed within the clastic substrate (mainly weathered mudstones, Plate 2 D). Both types of paleosoils display a wide spectrum of features diagnostic for their pedogenic origin (Plate 2 D; FREYTET & PLAZIAT 1982).

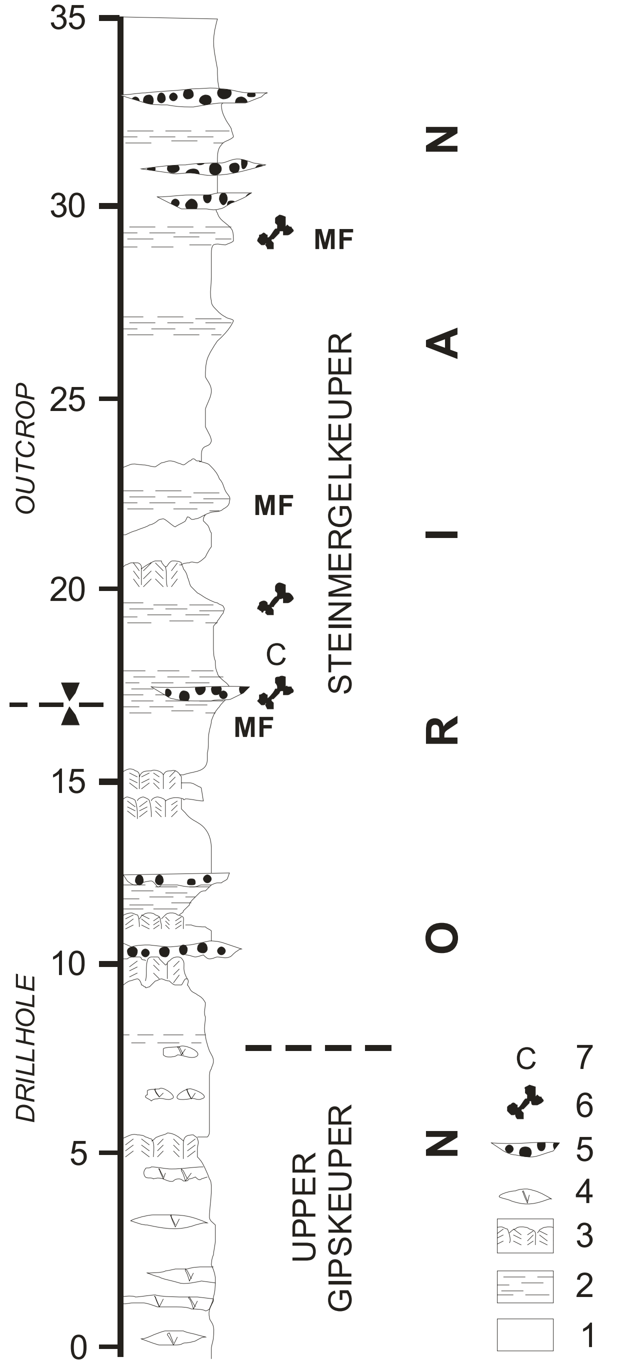

Fig. 2: Lithologic succession and lithostratigraphy of the studied section.

1 – reddish mudstones and siltstones
2 – grey-coloured horizons
3 – palaeosoil horizons
4 – gypsum
5 – conglomerates (composed of redeposited vadoids)
6 – bone-bearing horizons
7 – celestite aggregates
MF – mudflow deposits

Considering the soils in terms of pedological classification, they represent aridisols catena, with dominating cambisol type of soil (VOS & VIRGO 1969, FITZPATRICK 1986). Such soils are typical for semi-arid climatic conditions, with dry and wet seasons.

The colour mottling seems to reflect the early diagenetic oxidation of the iron hydrated oxides (grey colored) leading to mature iron oxides (haematite) and resulting finally, in reddening of the primary grey sediments (TURNER 1980). This process seems to be strongly controlled by the groundwater circulation regime because the rootlets canals, or planes of some synsedimentary faults cutting the red mudstones, served as groundwater conduits and are covered with a grey patina (Plate 2 C and I).

The gypsum-bearing complex generally displays similar sedimentary features as the evaporate-free red-bed deposits. The sulphates form displacive nodules growing within the mudstones and gypsum layers that are up to 3 cm thick (Plate 1 A). Very small gypsum nodules line the rootlets canals and define the gypcrete paleosoils. Well developed regoliths mark the exposure periods and breaks in sedimentation. Gypsarenitic horizons indicate episodes of reworking and redeposition following the catastrophic runoffs.

The synsedimentary faults are common feature visible in the section. The faults fade upsection and are covered by an undisturbed sedimentary set, indicating the syndeposionary nature of the faults. The observed faults are normal, transcurrent, and hinge faults (Plate 2 I and J); however it is difficult to estimate the throw because of the syntectonic erosion. The maximum throw visible in the quarry does not exceed 1 meter in scale.

Other features indicating synsedimentary tectonic mobility in the basin are liquefaction structures and slicken-side deformations. The latter, however, might also originate due to seasonally alternating wetting/ drying processes, affecting of the superficial layer of the exposed sediments (Plate 2 C).

3 Sedimentary environments – interpretation

From the described sedimentary characteristics, the sedimentary environment may be interpreted as a mudflat area gently sloping to north – northwest. A high proportion of the parallel lamination and small-scale rippled cross-stratification (Plate 1) indicates the upper flow regime conditions and rapid accretion of sediments. Taken together with the lack of well defined channel deposits and the common occurrence of the cambisol paleosoils, allows one to recognize the sediments from Krasiejow as typical sheetflood deposits formed by ephemeral streams system under semi-dry climatic conditions. The dipping of the mudflat suggests that it was bounded to S and SE by an elevated area, most probably by uplifted older rocks: the Carboniferous (Culm) sandstones and the lower-middle Triassic sandstones and limestones (see Fig. 2). This area underwent early Cimmerian tectonic movements from the late Ladinian onward (SZULC 2000).

No typical lacustrine sediments have been found in the outcrop. However, the common occurrences of redeposited unionid bivalves (Plate 1 I) and Chara debris (Plate 2 H) suggest the existence of some limnic conditions in the nearby area (see also discussion below). The gypsum layers of the lower complex might have originated in small, ephemeral playa pans. The gypsum displacive nodules formed within the sediments during evaporation of the groundwater.

An interesting conclusion about the sedimentary basin dynamics comes from the analysis of the vadoid-bearing conglomerates. As a rule, the vadoids form some 2 – 10 % of the paleosoil volume unit, implying that the 10 cm thick layer of the vadoid conglomerate is derived from rewashing of at least a 1 m thick paleosoil horizon. This process helps one to visualize the cannibalistic (re)sedimentation mechanism dominating the studied mudflat area. Also the gypsarenites originated in a similar way.

4 Fossils composition and its environmental significance

The fauna assemblage comprises pelecypods, gastropods, conchostracans, ostracods and vertebrates. The plants are represented by poorly preserved debris of *Equisetum* and common *Characea* gyrogonites.

There are several publications dealing with the paleontological and systematic aspects of the fossils (DZIK et al. 2000, DZIK 2001, 2003, OLEMPSKA 2004, SULEJ 2002, 2005); however, their burial conditions and fossil preservation context is still a subject of debate. Most interesting are the taphonomical problems of the vertebrates *Fossillagerstätten*, occurring 6 meters below the top of the section. According to taphonomical analysis, the skeletal debris (found in ca. 1 m thick bed) comprise well preserved but mostly disarticulated skeletons of various vertebrates (Plate 2 L), mainly adult forms of labyrinthodonts, aetosaurs and thecodonts and dinosauromorphs (DZIK et al. 2000). The bones are chaotically arranged (some elongate bones occur in upright position) and do not show any damage resulting from predator activity (pers. com. K. KSIAZKIEWICZ). Vertebrates are accompanied by pelecypods (unionids), gyrogonites and coalified plant debris.

The bones "float" in massive, grey mudstones that also enclose irregular stringers of vadoidal grainstones (Plate 2 K). The topmost 10-30 centimetres of the bone-bearing mudstones is reddish, marking subaerial exposure and paleoweathering phenomena. The lower bounding surface of the bed is uneven and shows small scours or even cm-sized protrusions into the underlying undisturbed sediments. Based on the sedimentary features, the bone-bearing bed is a typical high viscosity debris flow deposit, encompassing a relatively narrow sheet of replaced bone-bearing mudstones.

Considering the problem of mass accumulation of the skeletal fragments, it seems most probable that this *Fossillagerstätte* is of a secondary nature and represents redeposited taphocoenosis that formed originally by dying out in some shrinking shallow lacustrine or palustrine basin during drought periods. Subsequent catastrophic runoffs or synsedimentary faulting, triggered mass movement processes in the region, also involved the bone-bearing sediments.

Another example of taphonomic mechanism is illustrated by the sieved, vadoid conglomerates encompassing pelecypod shells and Chara debris (Plates 1 I and 2 H). Such a mixed composition of the conglomerates indicates episodic, but strong, fluvial erosion, following runoff events. The erosion affected both the lacustrine/palustrine deposits and the mudflat sediments flanking the storm channels.

5 Stratigraphical position of the bone-bearing sediments

The chronostratigraphic position of the discussed section is not yet clear. Lack of age-diagnostic fossils, including palynomorphs, makes stratigraphical statements uncertain. Nonetheless, the lithostratigraphical framework (which reflects climatostratigraphical constraints) is quite clear and allows one to recognise the gypsum-bearing, lower part of the profile from Krasiejow as the uppermost Upper Gipskeuper (Weser Formation, see DEUTSCHE STRATIGRAPHISCHE KOMMISSION 2002) and the overlying, bone-bearing variegated succession, as the Steinmergelkeuper (Arnstadt Formation, see DEUTSCHE STRATIGRAPHISCHE KOMMISSION 2002).

DZIK et al. (2000) assumed the bone-bearing succession as a time and facies equivalent of the Lehrbergschichten from SW Germany. The Lehrberg-Schichten (or Lehrberg-Bänke) are certainly older lithological units than those from Krasiejow, since they occur in the lower section of the Upper Gipskeuper, not only in SW Germany but also in Thuringia and Lower Saxony. As a rule they lie not more than 30 metres above the Schilfsandstein fluvial clastics (Stuttgart Formation; GEYER & GWINNER 1986, DOCKTER 1995, BEUTLER 1998), whereas the present succession is situated from 60 to 110 metres above the top of the Schilfsandstein (ASSMANN 1929, SIEWNIAK-MADEJ 1982, KLAPCINSKI 1993).

Furthermore, the lithological properties of the typical Lehrbergschichten, with the outstanding 2-4 massive, dolomitic lacustrine horizons, differ significantly from those observed in the Krasiejow. Taking all together disproves the assumption by DZIK et al. (2000) and also implies a different chronostratigraphic interprettation of the vertebrate *Fossillagerstätte*, which was postulated by DZIK et al. (2000) as Carnian. It seems that the Norian age of the vertebrate-bearing succession from Krasiejow is more reliable, as already suggested by ORLOWSKA-ZWOLINSKA (1983), who has included to the Norian even the uppermost part of the Upper Gipskeuper.

6 Conclusions

The section of the Upper Triassic from Krasiejow encompasses the Upper Gipskeuper and Steinmergelkeuper sediments. The sedimentary facies represents a typical redbed assemblage, displaying gradual evolution from evaporitic playa-mudflat deposits to more humid, evaporate-free, mudflat- sandflat sediments. This palaeoenvironmental replacement reflects a climate pluvialisation phenomenon in Norian times.

Amelioration of climatic conditions involved gradual reestablishment of vascular plants that, in turn, favoured the appearance and development of the herbivorous, and then carnivorous, saurids in Germany and in Silesia (SCHOCH & WILD 1999, DZIK et al. 2000). The tetrapods lived in the flat mudflat area and were concentrated near to ephemeral and small lacustrine basins. During particularly severe drought catastrophes, the vertebrates followed the shrinking lake space and finally died out, forming spectacular skeletal concentrations. These “Fossillagerstätten” underwent, however, reworking during subsequent mass-movement displacement, driven by catastrophic runoff events.

The basin fill shows signs of multiple resedimentation with intervening periods of paleosoil formation. The ephemeral streams reworked the earlier laid, muddy sediment and the soils, and redeposited the eroded material almost in place (Plate 2 M). Such a mechanism of cannibalistic resedimentation is evidenced by reworked pedogenic nodules that, after reworking and grain fractionation, formed specific, sieved “conglomeratic” alluvia.

The sediments under discussion show common structures evidencing vigorous synsedimentary tectonic mobility, which was a common phenomenon in the entire Germanic Basin during Norian times (DECZKOWSKI & GAJEWSKA 1977, RÖHLING & BEUTLER 1993, FRISCH & KOCKEL 1999).

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Plate 1

A & B – Core fragments from the drilled gypsum-bearing (A) variegated mudstones of the Upper Gipskeuper succession. Scale bar – 10 cm.

C – Plane-bedded conglomerates and siltstones.

D – Obliquely stratified alluvial deposits of the Steinmergel succession.

E – Detail from C. Note the erosional contact between the paleosoil horizon and the alluvial sediment (dotted line).

F – Small scale ripple-bedding from the Steinmergel silty and sandy alluvia.
Arrow indicates transport direction. Coin diameter is 8 mm.

G – Graded alluvial deposits composed of sieved pedogenic nodules (lower part of the bed) and parallely laminated reddish siltstones. Note the erosional base of the conglomerates.

H – Amalgamated sheetflood deposits composed of vadoidal conglomerates.

I – Current-transported conglomerate composed of convex-up disposed unionid shells and pedogenic nodules.

Scale bars (but Fig. A, B and I) are 1 m. Photo D, E and H taken by HANS HAGDORN.

Plate 1

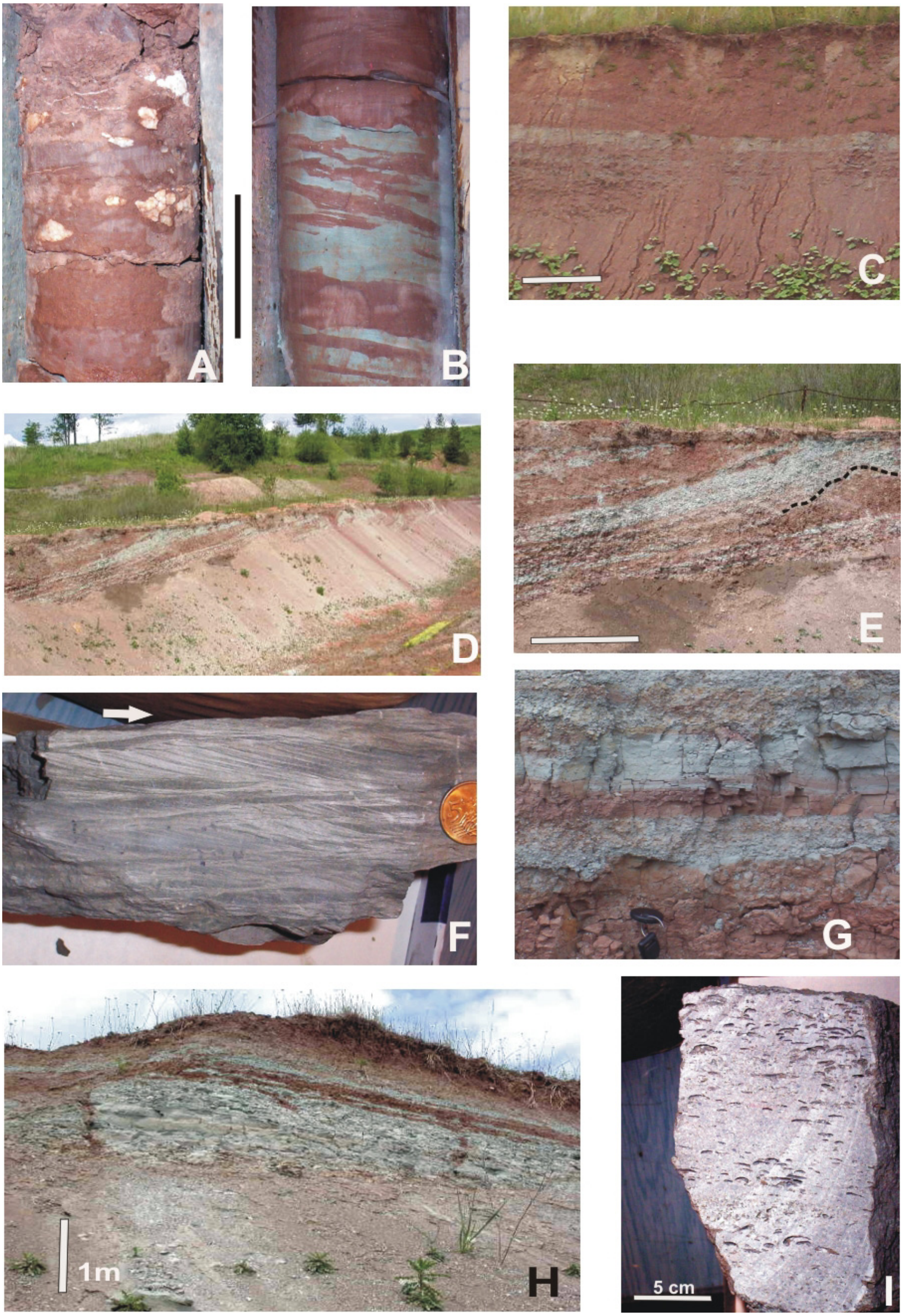


Plate 2

A – Section of the thick (> 1.5 m) paleosoil horizon (arrow) covering discordantly (dotted line) the layered alluvial deposits and massive, mudflow complex. Note the grey dying of the small synsedimentary faults (middle of the section).

B – Paleosoil with mottled fabrics related to irregular rootlets system.

C – Cambisol horizon featured with slicken-sided cracks and covered by fluvial conglomerates. Note the diffusively dyed contact between the soil and alluvium.

D – Grey calcisol horizon with large, pedogenic calcareous nodules.

E – H – Thin section views of the conglomerates composed of reworked pedogenic nodules featured with septarian cracks (E) and comprising debris of ostracods (F), bones (G) and charophyte gyrogonites (H).

I – Transcurrent, synsedimentary fault (arrow) within the Steinmergel sediments.

J – Bunch of small scale normal faults (arrows) cutting the Steinmergel alluvia.

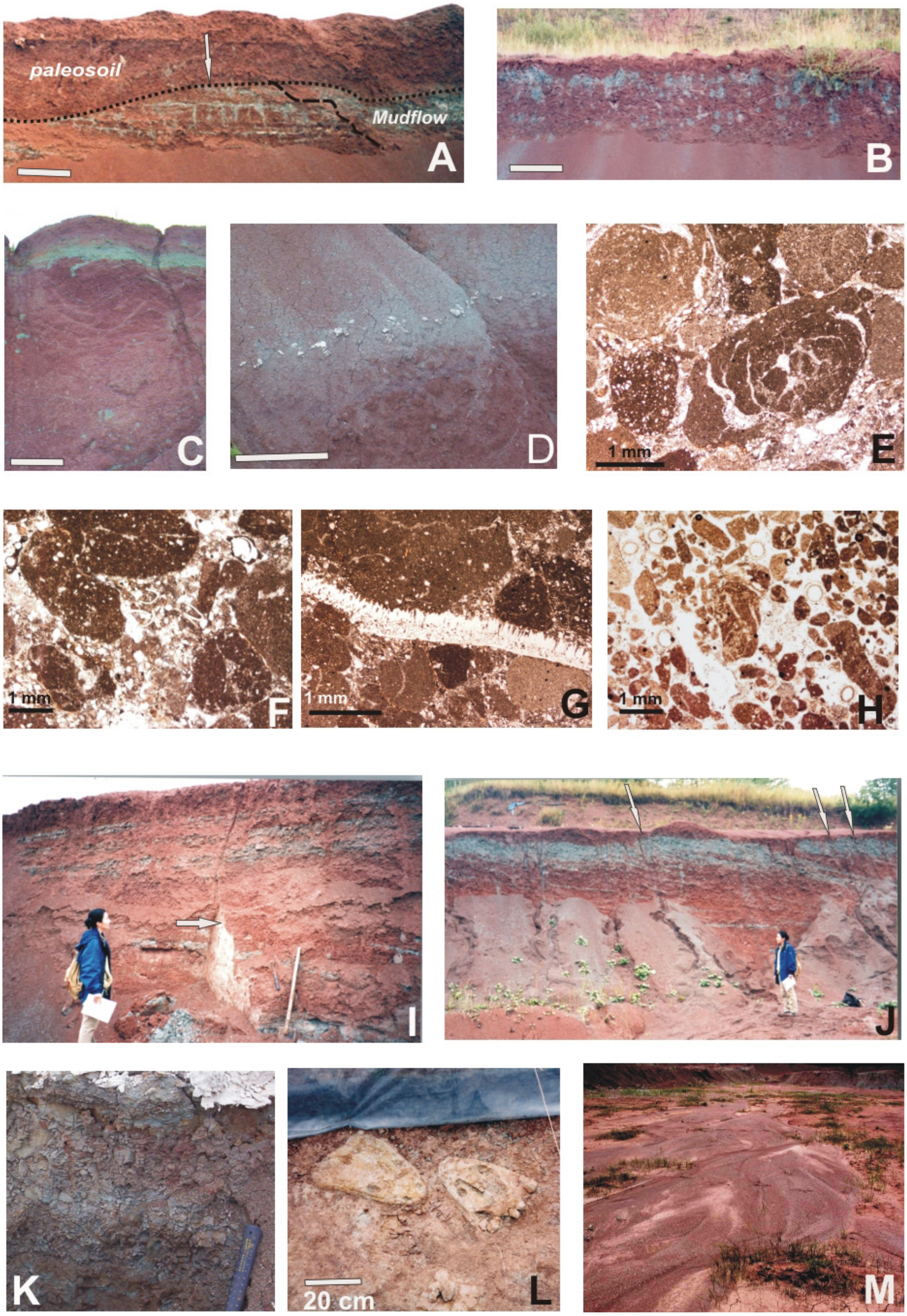
K – Massive and chaotically arranged mudflow bearing the vertebrate bones (cemented with plaster of Paris the uppermost part of the bed). Hammer handle for scale.

L – Plane view of the main bone-bearing mudflow horizon with *Metaposaurus* skulls.

M – Present-day analogue of the ephemeral braided stream systems shaping the late Triassic environments in the studied region. Photo taken in the Krasiejow claypit by HANS HAGDORN in June 2004, after heavy runoff.

All scale bars on the field photographs are 1 m.

Plate 2



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