JAHRBUCH DER GEOLOGISCHEN BUNDESANSTALT
Jb. Geol. B.-A. | ISSN 0016–7800 | Band 144 | Heft 2 | S. 191–221 | Wien, Oktober 2004

The Hollabrunn-Mistelbach Formation (Upper Miocene, Pannonian) in the Alpine-Carpathian Foredeep and the Vienna Basin in Lower Austria – An example of a Coarse-grained Fluvial System

SLAVOMÍR NEHYBA*) & REINHARD ROETZEL**)

21 Text-Figures and 4 Tables

Niederösterreich
Alpin-Karpatische Vortiefe
Wiener Becken
Flusssystem
Sedimentologie
Gravel-bed-river-Ablagerungen
Braid-Delta-Ablagerungen

Österreichische Karte 1 : 50.000
Blätter 22, 23, 24, 25, 38, 39, 41

Contents

*) SLAVOMÍR NEHYBA, Institute of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, CZ-611 37 Brno, Czech Republic.
**) REINHARD ROETZEL, Geologische Bundesanstalt, Neulinggasse 38, 1031 Wien.
e-mail: reinhard.roetzel@geolba.ac.at.

Die Hollabrunn-Mistelbach-Formation (Obermiozän, Pannonium) in der Alpin-Karpatischen Vortiefe und dem Wiener Becken in Niederösterreich – Beispiel eines grobkörnigen fluviatilen Systems

Zusammenfassung

In der Alpin-Karpatischen Vortiefe und dem Wiener Becken in Niederösterreich wurden in 65 Aufschlüssen zwischen Krems und Zistersdorf Ablagerungen der obermiozänen (pannonen) Hollabrunn-Mistelbach-Formation untersucht. Dabei konnten zwei genetisch miteinander verwandte Ablagerungsmilieus unterschieden werden. Das im Großteil der Aufschlüsse dominierende Gravel-bed-river-System geht gegen Osten in ein Braid-Delta-System über. In den Ablagerungen des Gravel-bed-river-Systems sind kiesige und sandige Rinnensedimente und Überflutungssedimente die großmaßstäblichen Bauelemente. Die kiesigen Rinnensedimente können weiter in Rinnenbodensedimente (channel lags), longitudinale Rinnenbarren (gravel bars), kiesige Ablagerungen mit normal oder parallel zur Strömung orientierten Anlagerungsgefügen (lateral/downstream accretion deposits) sowie kiesige Rinnen (gravelly channels) untergliedert werden. In den sandigen Rinnensedimenten ist die Unterscheidung von sandigen Rinnen (sandy channels) und sandigen Ablagerungen mit normal oder parallel zur Strömung orientierten Anlagerungsgefügen (lateral/downstream accretion deposits) möglich. Bei den Überflutungssedimenten wurden Feinsedimente der Überflutungsebene (floodplain fines) sowie Ablagerungen in verlandenden Rinnen (abandoned channel fills) unterschieden. Die untersuchten Ablagerungen des Braid-Delta-Systems repräsentieren den proximalen Deltabereich. Dort konnten Ablagerungen der Verteilerrinnen (distributary channels), Mündungsbarren (mouth bars), kiesige Strände (gravelly beaches), Ablagerungen des küstennahen Bereiches (foreshore, shoreface) und des Zwischenrinnenbereiches (interdistributary area) unterschieden werden. Darüber hinaus werden die Typen von fluviatilen Systemen und die kontrollierenden Faktoren für den Fazies-Aufbau (Verlagerung und Vereinigung der Rinnen, Tektonik, Klima, Seespiegelschwankungen) sowie Sediment-Herkunft, Transport und Ablagerungs-Prozesse diskutiert. Als Ablagerungsmodell für die Sedimente der Hollabrunn-Mistelbach-Formation ist ein Braided-river-System mit vertikalen und lateralen Übergängen in stärker pendelnde fluviatile Systeme wie z.B. einem kiesigen Wandering-river-System anzunehmen.

Abstract

In the Alpine-Carpathian Foredeep and the Vienna Basin in Austria deposits of the Hollabrunn-Mistelbach Formation of the Upper Miocene have been studied in 65 outcrops between Krems und Zistersdorf. Two genetically related depositional environments were recognised. The depositional environment of a gravel-bed river is dominant in the majority of the outcrops. Towards the east this system developed into a braid-delta environment. Larger scale architectural elements recognised within the gravel-bed river deposits are gravelly channel fills, sandy channel fills and overbank deposits. The larger scale elements can be subdivided into elements at a smaller scale. The gravelly channel fill elements can be subdivided into channel lags, bars, lateral/downstream accretion deposits and channels. The sandy channel fill elements were subdivided into lateral/downstream accretion deposits and channels. The overbank elements can be subdivided into abandoned channel fills and floodplain fines. The studied deposits of the braid-delta represent the proximal part of the delta and can be subdivided into deposits of distributary channels, mouth bars, gravelly beaches, foreshore and shoreface deposits and interdistributary areas. Furthermore the different types of fluvial styles, the controlling factors of the facies architecture (channel/channel belt migration and avulsion, tectonics, climate, lake-level changes), provenance, transport and depositional processes are discussed. For the Hollabrunn-Mistelbach Formation a braided fluvial style with vertical and lateral gradations to a higher sinuosity fluvial style, i.e. a gravelly wandering river is supposed.

1. Geological Setting and Former Investigations

The mostly coarse-grained clastic fluvial to deltaic sediments of the Hollabrunn-Mistelbach Formation (HMF) extend on the surface in a WSW–ENE direction from Krems towards Hohenwarth, Ziersdorf, Hollabrunn and the Ernstbrunner Wald to the surroundings of Mistelbach and further to the Steinberg fault near Zistersdorf over a length of more than 86 km. The width of this sediment body is between 3 km and 14 km, and reaches almost 20 km in the Mistelbach area, west of the Waschberg Unit (Text-Fig. 1). In the Vienna Basin, east of the Steinberg fault, the accompanying prodelta-sediments extend subsurface far to the east up to the Slovakian area (HARZHAUSER et al., 2004; KOVAČ et al., 1998).

Especially in the west the deposits of the HMF form mostly forested elevations in the present landscape, due to their gravelly ground. Thus a relief inversion has taken place, where the finer grained, older marine sediments at the former margins of the fluvial system were eroded, leaving back the coarse fluvial sediments of the HMF.

The top surface of the HMF follows a well-defined level between 350 m and 365 m between Krems and the Waschberg Unit, with few slightly higher elevations of 375 m to 390 m nearby Stratzing and Hohenwarth, in the western part of the distribution area (e.g. FINK & PIFFL, 1975; HASSINGER, 1905a). East of the Zaya Gate, which is the narrow valley breaking through the Waschberg Unit, the top surface of the HMF sinks down to obviously deeper altitudes of 200 m to 300 m.

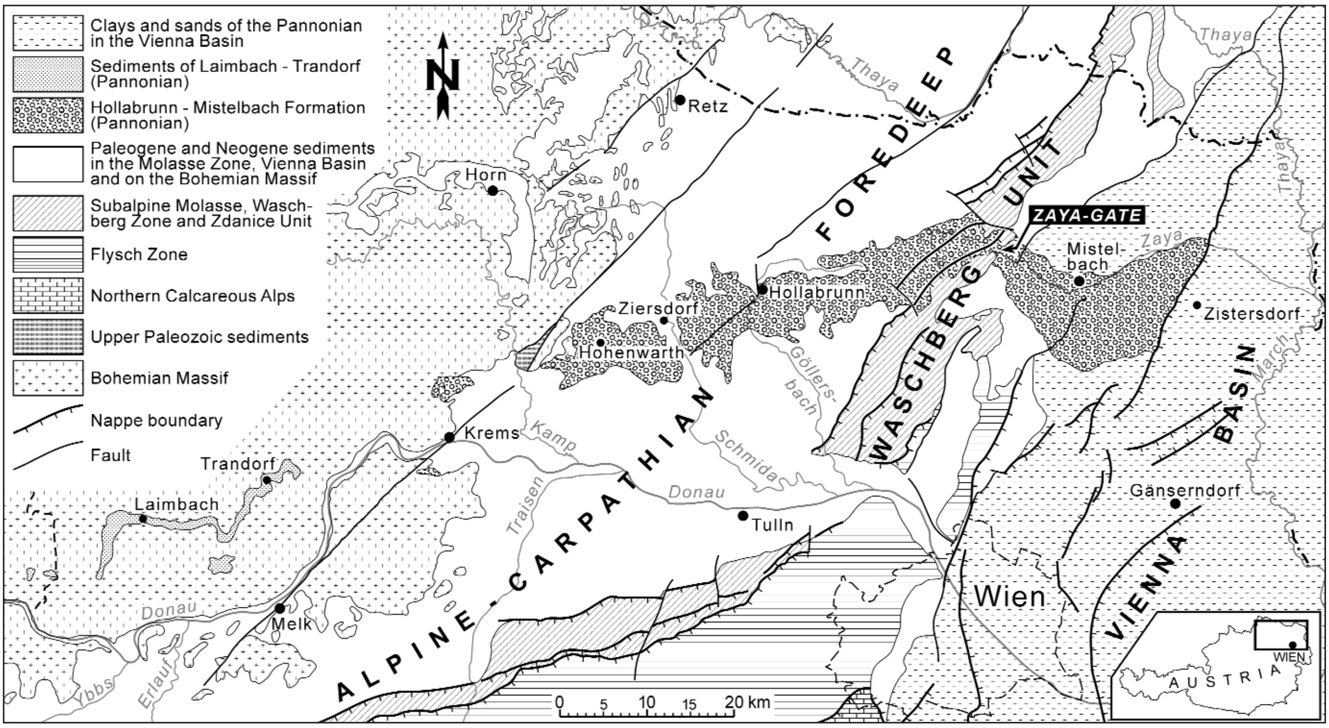
In the Alpine-Carpathian Foredeep sediments of the HMF are lying on sandy and clayey deposits of the Karpatian (Laa Fm.), Badenian (Grund Fm., Gaindorf Fm. and equivalents) and Sarmatian (Ziersdorf Fm. and equivalents), whereas east of the Waschberg Unit, in the Vienna Basin, they mostlie overlie Sarmatian sands and clays.

Detailed mapping in the Hollabrunn area showed that the erosive base of the HMF forms a depression, with thinning-out of the sediment body towards the northern and southern margin.

Presumably this depression, which was occupied by the fluvial system during the Pannonian, was already established in the Middle Badenian and has also been used during the Sarmatian. This can be concluded from Sarmatian sediments lying beyond the HMF nearby Ziersdorf and Hollabrunn (e.g. ROETZEL, 2003).

The maximal thickness of the deposits of the HMF is supposed to be more than 100 m in the west, about half of the thickness confirmed by drilling (MOSHAMMER et al., 1999). The thickness diminishes towards the east in the Mistelbach area.

In Upper Austria the “Coal-bearing Freshwater Beds” (Kohleführende Süßwasserschichten) of the Hausruck and Kobernaußer Wald are stratigraphically corresponding to the sediments of the HMF. It is not clearly solved, if both formations belong to the same discharge system of a Proto-Danube, because of a big spatial gap between them (e.g. MACKENBACH, 1984). Coarse-grained sediments of



Text-Fig. 1.
Simplified geological map of northeastern Austria with location and extent of the Pannonian Hollabrunn-Mistelbach Formation.

probably Pannonian age in the valley of Laimbach – Pöggstall – Trandorf in the southern Bohemian Massif (FUCHS & ROETZEL, 1990) could be a western continuation of the HMF (e.g. STEININGER & ROETZEL, 1996). Also NAGL & VERGINIS (1989) interpreted this valley as a paleovalley of the Danube.

In the Vienna Basin, east of the Steinberg fault, in Lower Pannonian sediments, which are stratigraphically corresponding to the HMF, sands and gravels are interfingering with silts and clays (JANOSCHEK [1951]: "großer unterpannoner Sand"; GRILL [1968]). In these sediments NW–SE-oriented, lens-shaped sandy to gravelly bodies, separated by pelitic sediments, can be reconstructed by drillings. These coarser grained bodies are laterally oscillating and are interpreted as subaquatic deltaic lobes (KREUTZER, 1990). Recently HARZHAUSER et al. (2004) gave a detailed summary of the lithostratigraphy and biostratigraphy in the Pannonian in the Vienna Basin.

In the older literature the Hollabrunn-Mistelbach Formation was subdivided into the Hollabrunn gravels ("Hollabrunner Schotter"; "Hollabrunner Schotterkegel") in the Alpine-Carpathian Foredeep and the Mistelbach gravels ("Mistelbacher Schotter"; "Mistelbacher Schotterkegel", "Mistelbacher Schotterfächer") east of the Waschberg Unit, in the Vienna Basin (e.g. GRILL, 1968; GYURITS & KURZWEIL, 1976; BRUNNACKER et al., 1979).

The fluvial origin of these sediments was recognised very early (e.g. SUESS, 1866), however, for a long time the gravels were described together with the quaternary terraces of the Danube river as "Belvedere Schotter". HASSINGER (1905a,b) was the first, who postulated the coarse-grained sediments to be deposited by a Proto-Danube. He also described a fining of grain size from west towards east (HASSINGER, 1905a). VETTERS (1914) noticed a different petrographic composition of gravels from various outcrops east of Hollabrunn and supposed different ages within the gravel complex. This latter observation was confirmed by SICKENBERG (1928, 1929), who determined Sarmatian mammals from basal gravel beds near Hollabrunn. A more detailed study of gravel composition by KEINDL (1929) showed, that these coarse-grained sediments have their source area in both the Bohemian Massif and the Alps.

We owe our knowledge about the extent and distribution of the Hollabrunn and Mistelbach gravels to detailed geological mapping during the Fifties of the 20th century by GRILL and WEINHANDL (e.g. GRILL, 1958, 1968; WEINHANDL, 1957–1959). A study of the sedimentary petrography and partly sedimentology of the Mistelbach gravels was done by GYURITS (1970) and GYURITS & KURZWEIL (1976), who interpreted the Mistelbach gravels as fluvial and partly deltaic deposits of the Lower Pannonian Danube. BRUNNACKER et al. (1979) did a similar petrographic study in some outcrops of the Hollabrunn gravels, east of Krems. In recent time sedimentological and paleontological investigations in the Pannonian of the northern Vienna Basin were done by HARZHAUSER et al. (2000, 2003).

Detailed mapping over the last 12 years in the area east and west of Hollabrunn on map sheets ÖK 22 Hollabrunn, ÖK 23 Hadres and ÖK 39 Tulln (ÖK 22: ROETZEL et al., 1998; ÖK 23 and ÖK 39 in progress), led to new research activities concerning the gravel complex of the HMF. The lithostratigraphic unit was newly defined by assembling the genetically allied Hollabrunn gravels and Mistelbach gravels as Hollabrunn-Mistelbach Formation (cf. ROETZEL et al., 1999).

Petrographic studies of the gravel composition were carried out by BATÍK (1996, 1997, 1998, 2000), GYURITS (1970), GYURITS & KURZWEIL (1976), KEINDL (1929), NOVÁK (1994) and to a limited extent by PETRASCHECK (1921). Gravels of the HMF were mostly classified as polymict and well sorted with well-rounded pebbles. Quartz pebbles are dominant. The presence of pebbles and cobbles of sedimentary rocks, especially of several types of limestones and dolomites is typical. Also various cherts (black, brown, etc.), fine- and medium-grained sandstones (quartzose, calcareous, micaceous, glauconitic) and greywackes were recognised. The crystalline pebble suite is composed of biotite granites, quartzites (micaceous, graphitic), rhyolite ignimbrites, granulites, biotite gneisses, sillimanite-biotite paragneisses, biotite migmatites, amphibolites, and chlorit-

Table 1.
List of the studied outcrops of the Hollabrunn-Mistelbach Formation (cf. Text-Fig. 2).

ic-sericitic mica schists. Quartz, carbonate, mica and feldspar form the sandy matrix.

GYURITS & KURZWEIL (1976) and BATÍK (2000) recognised a dominance of quartz within fine-grained gravels, whereas coarse ones are polymict. Moreover they observed a high portion of spherical and discoidal shaped pebbles and low portions of elongated and bladed pebbles in the finer grained fraction. These results were explained by longer transport paths of the smaller pebbles from remote source areas in the Alps or primary differences in grain size, respectively.

BATÍK (1997, 2000) stated that the lower part of the HMF east of Hollabrunn is formed by coarse, less well-sorted and highly polymict gravels (60–95 % quartz, 0–30 % limestones, and less than 5 % crystalline rocks) with maximal clast size of up to 35 cm, whereas the upper part is both finer grained and nearly monomictic (quartzose). Recent investigations by ROETZEL (2003) suggest, that the coarse and polymict "lower part" of the gravels is most likely Sarmatian in age and does not belong to the HMF.

BRUNNACKER et al. (1979) described rapid quantitative changes of the heavy mineral spectra within and also between four profiles of the Hollabrunn gravels east of Krems, though all the spectra are dominated by garnet and epidote. These differences in quantity were explained by short-distance transport with frequently changing directions or by grain size variations and selective weathering. Also NOVÁK (1993, 1994, 1997) noticed a heavy mineral association with a high content of garnet (> 75 %) and an important contribution of epidote together with changing quantities of staurolite, cyanite, rutile, and zircon within the HMF in the surroundings of Hollabrunn.

GYURITS & KURZWEIL (1976) described two periods of accumulation of the Mistelbach gravels. Following these authors the first one corresponds to rapid deposition of alluvial fans. After a transitional stage the second period reflects "purely fluvial sedimentation" of somewhat finer grained material.

The source area of coarse clasts of the HMF was assumed both at the eastern margin of the Bohemian Massif and in the Eastern Alps. GYURITS & KURZWEIL (1976) and BATÍK (2000) supposed a strong dominance of Alpine pebbles (eastern part of the Northern Calcareous Alps and North Alpine Flysch Zone) and only very weak input from the Bohemian Massif (Moldanubicum, Austrian Moravicum of the Thaya Dome). The area of the Waschberg Unit was an important local source in the surroundings of Mistelbach (GYURITS & KURZWEIL, 1976). These authors supposed quartz to derive dominantly from quartz-phyllites and similar rocks of the western Greywacke Zone.

The beginning of deposition of the HMF is dated into the Pannonian Zone A/B (MN 7/8 – Asteracium) (DAXNER-HÖCK, 1996; HARZHAUSER et al., 2004; PAPP in GRILL, 1968; ROETZEL et al., 1999; STEININGER, 1999). But only a minor part of the sediments can be attributed to Zone A/B or B. The bulk of the HMF is connected with Zone C of the lower Pannonian (MN 9 - lower Vallesium). Younger ages of upper Pannonian Zone H (MN 12) are supposed for deposits in the surroundings of Hohenwarth, which are located in the relatively highest altitudes. The whole time span of deposition is supposed to be about 4 Ma (ROETZEL et al., 1999).

From the Pannonian sediments of the HMF a lot of mammal faunas are reported (e.g. GRILL, 1968; PIA & SICKENBERG, 1934; RABEDER, 1985; ZAPFE, 1949). The sediments contain a typical "*Hipparion* fauna" with *Hippotherium primigenium, Gomphotherium (Tetralophodon) longirostre, Deinotherium giganteum, Aceratherium bavaricum, Anchitherium aurelianense, Chalicotherium goldfussi, Microstonyx (Korynochoerus) palaeochoerus, Dorcatherium naui, Amphiprox anocerus,* and *Miotragocerus pannoniae* (THENIUS, 1982a). Stratigraphically important are the Proboscidea (*Deinotherium giganteum, Gomphotherium angustidens, G. longirostris, G. longirostris avernensis*: BACHMAYER & ZAPFE [1976]; ZAPFE [1957]) and Perissodactyla (*Diceros, Chalicotherium, Anchitherium, Hippotherium*: BERNOR et al. [1988, 1993]; STEININGER [1963]; THENIUS [1950, 1957]; ZAPFE [1974]). Micromammals (Insectivora, Rodentia) of the HMF were reported from Magersdorf near Hollabrunn and Bullendorf in the Mistelbach area (DAXNER-HÖCK [1975, 1996]; DAXNER-HÖCK et al. [1990]). A tooth of a hominoid primate (THENIUS [1982b, 1983]; DAXNER-HÖCK [2000]), which was found in Mariathal near Hollabrunn, is especially remarkable.

Molluscs in the HMF are mainly described from the surroundings of Mistelbach. The faunas with *Mytilopsis (Congeria) ornithopsis, Melanopsis impressa*, respectively *Mytilopsis (Congeria) hoernesi* are typical for the mollusc zone Pannon B and C according to PAPP (in GRILL, 1968). HARZHAUSER et al. (2000, 2003) reconstructed a transgression of the Lake Pannon with the help of mollusc associations in the outcrop Pellendorf, causing a shift from fluvial to limnic and brackish-littoral environments. Abrupt facies changes are ascribed to synsedimentary tectonics.

Ostracodes, mostly from Pannonian Zone B, are reported from Mariathal east of Hollabrunn (GRILL, 1968; WEINHANDL, 1957) and several outcrops from the Mistelbach area (GRILL, 1968; GYURITS, 1970).

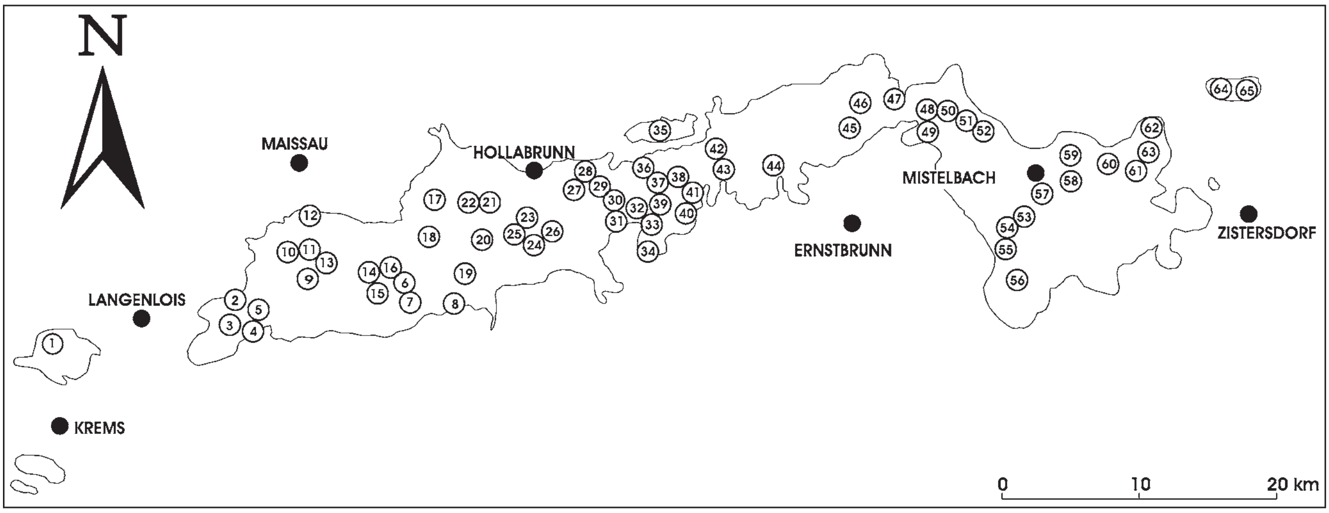
Plant remnants were recovered from pelitic layers in Rohrbach (KOVAR, 1979) and in a gravel pit of Ebersbrunn (KOVAR-EDER, 1988). From Rohrbach a fresh-water association of a foreshore and shoreface area of a eutrophic standing-water body, containing *Trapa heeri, Typha latissima*, and *Nymphaea* sp., is reported. The leaf flora from Ebersbrunn, which contains *Salix lavateri, Populus populina, Liquidambar europaea,* ? *Platanus leucophylla, Zelkova zelkovaefolia, Carpinus pyramidalis, Nyssa* sp., and *Quercus kubinyi* is a typical association from a riparian forest. Additionally very few pieces of lithified wood were found in the HMF (CICHOCKI, 1988).

The paleoclimatic analysis of the elements of flora and fauna suggests a warm temperate climate without a dry season and with mild, probably frostless winters (BERNOR et al., 1988; KOVAR-EDER, 1987, 1988; THENIUS, 1982a, 1983). The climate is approximately comparable with the estimations given by GREGOR (1982) for phytozone OSM 4, with a mean annual temperature of 12°–15°C, a mean January temperature >0°C, a mean July temperature ≤25°C and annual precipitation of 1000–1200 mm. However, the microclimate around Lake Pannon differs slightly (KOVAR-EDER, 1987). Towards the Upper Pannonian a distinct shift to dry conditions is derived from the mammal faunas (HARZHAUSER et al., 2004).

The paleoenvironmental reconstruction of the Lower Pannonian shows mesophytic forests with wet-land vegetation next to an extensive lakeside with a rich but strongly reduced aquatic fauna and a very diverse land fauna on the contrary (PAPP & THENIUS, 1954; RÖGL et al., 1986).

According to the paleogeographic and paleoenvironmental reconstruction given by RÖGL (1998), RÖGL & STEININGER (1983), MAGYAR et al. (1999) and HARZHAUSER et al. (2003, 2004) Lake Pannon was a lake with lowered salinity and endemic fauna, similar to today's Caspian Sea. In the northwesternmost part of the Lake Pannon, the Vienna Basin, several fluvial inputs from the west and north-

Number	Name of outcrop	ÖK-Sheet	BMN - coordinates	
			X-coordinate-M34	Y-coordinate-M34
1	Stratzing NNW	38	695800	369200
2	Stettenhof WSW - Fünfeckiger Stein	38	709200	371800
3	Stettenhof SW - Rosskopf	38	709145	371275
4	Gösing WSW	38	709710	370010
5	Stettenhof SW	38	710400	371550
6	Glaubendorf SSW	39	720600	373530
7	Baumgarten am Wagram NW	39	721250	372565
8	Ameistal W	39	724800	372320
9	Hohenwarth ESE	22	714485	373871
10	Pfaffstetten I WSW	22	713647	376577
11	Pfaffstetten II SW	22	713800	376500
12	Ravelsbach SSE	22	714811	378306
13	Ebersbrunn SSW	22	714840	374835
14	Radlbrunn S - Fa. Krötlinger	22	718570	373920
15	Radlbrunn S - Fa. Kigu	22	718789	373783
16	Glaubendorf SW - Am Donati	22	720075	374282
17	Fahndorf SE	22	723275	379030
18	Rohrbach NE	22	723177	376481
19	Unterthern W - Windberg	22	724340	374575
20	Oberthern NE - Bibersteiner Kreuz	22	727101	376416
21	Oberfellabrunn S - I (Fa. Stecher)	22	726682	378844
22	Oberfellabrunn S - II	22	726376	379000
23	Dietersdorf ENE - Windtal (Fa.Polsterer)	22	730940	377256
24	Dietersdorf SE - Auf der Alten Heide II	22	730774	376154
25	Dietersdorf ESE - Fa.Stuag	22	731000	376600
26	Raschala S - Windtal	23	731860	376700
27	Magersdorf E	23	733870	380300
28	Mariathal ESE	23	734650	381050
29	Mariathal SE	23	734900	380700
30	Mariathal SE - Taubenkogel	23	735800	379780
31	Magersdorf SE - Grünes Kreuz	23	735800	378700
32	Porrau NNE	23	737950	377860
33	Füllersdorf WNW - Scheuhang	23	739200	376655
34	Bergau NE	23	738850	375550
35	Eggendorf im Thale NNE - Reisberg	23	738900	383850
36	Weyerburg E - Rauschern	23	739650	381300
37	Weyerburg S - Spielberg (Fa. Nentwig)	23	739250	380400
38	Weyerburg S - Spielberg	23	739400	380300
39	Füllersdorf N - Vogeltenn	23	739780	378100
40	Füllersdorf NE, SE Rieplkreuz - Kirchenholz	23	741900	377880
41	Altenmarkt im Thale SE - Brunnboden	23	741740	379750
42	Enzersdorf im Thale SSE - Hungerfeld	23	743800	382350
43	Enzersdorf im Thale SSE - NW Schloß Glaswein	23	744450	380330
44	Merkersdorf NNE - ESE Soldatenkreuz	23	748450	379380
45	Pyhra NE	24	753750	383780
46	Gnadendorf SSW	24	754815	385780
47	Zwentendorf NW	24	756875	386820
48	Olgersdorf NW - Kolmleiten	24	759060	384670
49	Schletz NNW - Schoppenberg	24	759750	383240
50	Olgersdorf N - Klosterleiten	24	760750	385310
51	Olgersdorf NE - Auf der Heid	24	761595	384355
52	Asparn a.d.Zaya N - Turnern	24	762040	384185
53	Paasdorf S	24	765630	377170
54	Paasdorf SW - Scheiblingleiten	24	764730	376980
55	Paasdorf SSW - Grundleiten	24	764470	375630
56	Pellendorf NW - Neubau E	41	765000	373200
57	Lanzendorf SW - Markweg	24	767250	379080
58	Ebendorf S - Marienkapelle	25	769500	379770
59	Mistelbach ENE - In den langen Äckern	25	770130	381860
60	Hobersdorf SW - Obersdorfer Feld	25	771800	381000
61	Kettlasbrunn N - Lüsse im Austränkfeld	25	773800	381250
62	Bullendorf SSE	25	775040	382890
63	Bullendorf SSE - Langenfeld	25	775480	382490
64	Hauskirchen W - Rainberg	25	780290	385610
65	Hauskirchen SE - Kirchberg	25	782050	385800



Text-Fig. 2.
Position of the studied outcrops of the Hollabrunn-Mistelbach Formation (cf. Table 1).

east, with a main delta system of the Proto-Danube can be reconstructed (SAUER et al., 1992).

The primary aim of this paper is the description of sedimentary facies and the reconstruction of depositional processes and sedimentary environments of the HMF. The variation of facies of the HMF from west to east, the considerable differences in altitudes of outcrops, together with the changing character of depositional processes, enable to study the evolution of a large coarse-grained fluvial system passing into the adjacent Lake Pannon in the Vienna Basin.

The presented results are based upon the study of 65 outcrops (NEHYBA, 2000, 2003). A list of the outcrops is presented in Table 1, their location in Text-Fig. 2.

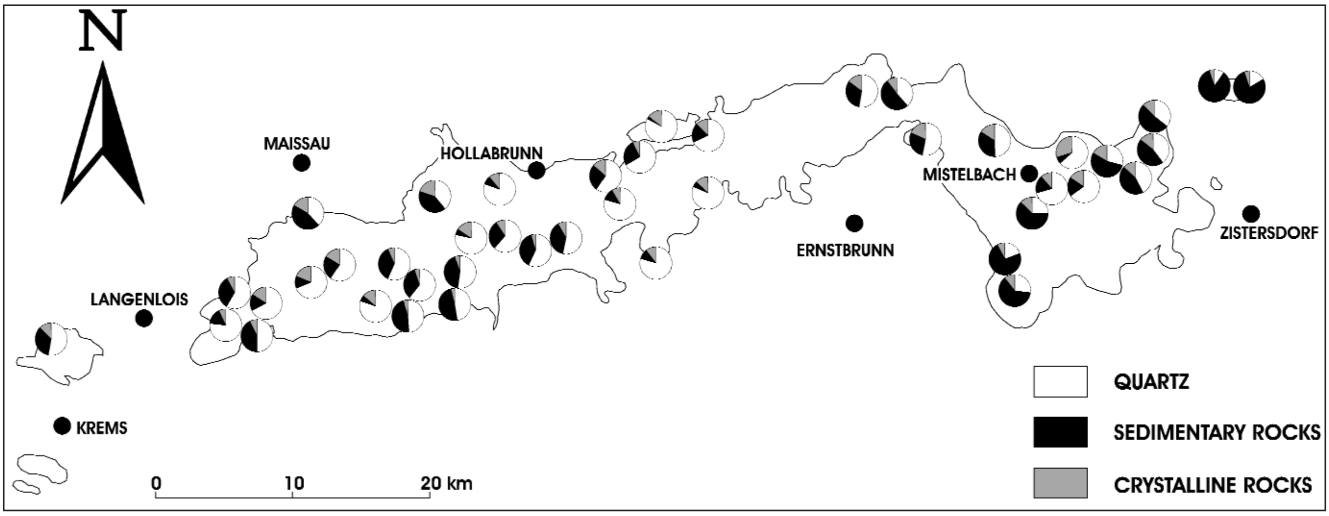
2. Petrography of Pebbles and Cobbles

The petrography of pebbles and cobbles was studied in the grain-size fraction coarser 1.6 cm (i.e. coarse pebbles and cobbles; max. clast size 12 cm in diameter) in 43 outcrops. In each investigated outcrop within 1 m^2 of a gravel bed more than 150 clasts were macroscopically determined. If gravels were absent a bed of pebbly sands was selected. Only outcrops with such coarse-grained sediments were included into the study. The general results are presented in Text-Fig. 3.

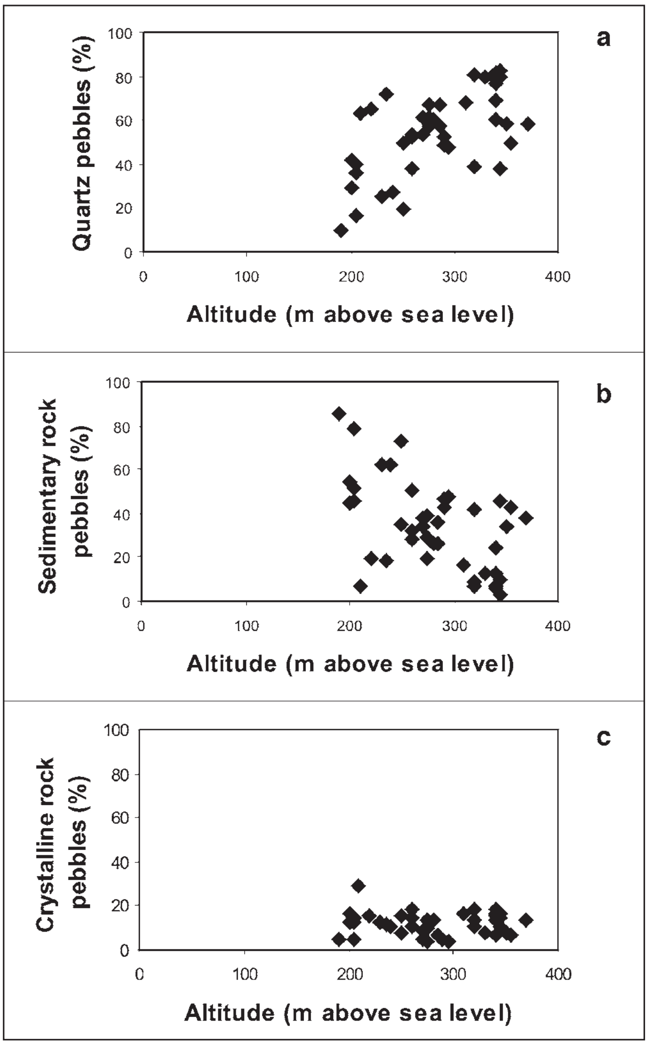
The gravels are polymict. Quartz-pebbles are often dominant, but their content highly varies (10–82.9 %). Quartz is the most frequent component in the outcrops 1–7, 9, 13, 15, 16, 19, 20, 24-26, 29, 30, 34-36, 41, 46, 49, 52, 57–59. On the other hand the lowest content of quartz-pebbles was observed in the outcrops 55, 64 and 65 (less than 20 %).

In a very generalized view the portion of quartz relatively rises towards the west and north (e.g. Text-Fig. 3), and from lower to higher altitudes of the outcrops (Text-Fig. 4a). This relation can also be connected with the fact that outcrops with higher altitudes occur primarily in the western part of the study area. However, large differences in the relative proportion of quartz can also be observed in outcrops of similar altitude. Various quartz varieties are present. Whitish, milky quartz is dominant, but also light grey and dark grey types can be found. Kaolinized remnants of feldspars and corrosive depressions on the surface of quartz-pebbles reflect their dominant origin from metamorphic rocks. In almost all outcrops a very low but important portion of red, red-brown or yellow quartzes can be observed. These pebbles probably derive from Paleozoic continental red beds. Rarely druses of quartz crystals were found. In finer fractions the portion of quartz rises.

Sedimentary rocks form a significant part of pebbles and cobbles (2.5–85.1 %). Their content generally rises towards the east and also towards the south (e.g. Text-



Text-Fig. 3.
Pebble composition in the studied outcrops of the Hollabrunn-Mistelbach Formation.



Text-Fig. 4.
Relations of the altitude of outcrops vs. the content of quartz pebbles (4a), vs. the content of sedimentary rock pebbles (4b), and vs. the content of crystalline rock pebbles (4c) in the studied outcrops of the Hollabrunn-Mistelbach Formation.

Fig. 3), and from higher to lower altitudes of the outcrops (Text-Fig. 4b). However, big differences can be observed within outcrops of similar altitude. A negative correlation between the content of quartz and the content of sedimentary rocks can be recognised (Text-Fig. 5a). Pebbles of sedimentary rocks are the most frequent components in outcrops 8, 12, 17, 47, 53, 55, 56, 60–65. The lowest content of sedimentary rock pebbles was recognised in outcrops 4, 15, 20, 21, 34, 35, 41 and 59 (less than 10%). Limestones and dolomites are the most abundant sedimentary rocks in the majority of outcrops. This is evident by a positive correlation between the content of pebbles of sedimentary rocks and the portion of carbonate pebbles (Text-Fig. 5b).

W. PAVLIK (Geological Survey of Austria; pers. comm.) studied the microfacies of some limestone pebbles from outcrops 1, 6, 12, 17, 24 and 26 and confirmed the provenance of most of them from the Northern Calcareous Alps. Pebbles that in all probability are from Ernstbrunn limestone occur in the outcrops in the surroundings of Mistelbach. Also pebbles of carbonate breccias and calcirudites were found, especially in outcrops 60–64. No carbonate pebbles were recognised in outcrops 34 and 35.

Mudstone intraclasts were found in the majority of outcrops. They are typically larger/outsized than the associated extraclasts and originate mainly from the adjacent floodplain deposits. Intraclasts are rare in several outcrops in the eastern part of the studied area, where in contrary the presence of mollusc shells is typical.

Sandstones are most abundant among sedimentary rock pebbles in outcrops 3, 12, 13, 21, 34 and 35. Various types of sandstones were recognised. Interesting is a small but never lacking portion of red sandstones and conglomerates. The content of sandstone pebbles rises in outcrops with higher altitudes. Chert pebbles were most abundant in outcrops 20, 29, 46 and 57. Slight positive correlations between the content of sandstones and chert pebbles (Text-Fig. 5c) as well as between quartz and chert pebbles (Text-Fig. 5d) can be noticed. Negative correlations exist between the presences of chert or sandstone pebbles and of carbonate pebbles (Text-Fig. 5e,f). Diatomite pebbles occur in outcrop 47. Conglomerates and breccias also form a small portion of pebbles.

Crystalline rocks form the minor portion (3.9–29.6 %) of the pebble suite. A content below 10 % was recognised in outcrops 2, 4, 6–8, 16, 19, 20, 24–26, 30, 36, 55, 64, 65, whereas a content higher than 20 % only in outcrop 59. Plutonic and metamorphic rocks (gneisses) are dominant, but also volcanics were recognised. A positive correlation can be recognised between the content of sandstone and crystalline rock pebbles (Text-Fig. 5g). Occurrences of crystalline rocks are generally higher in outcrops with higher altitudes (Text-Fig. 4c). However, the outcrop with the highest content of these pebbles was in a generally low altitude of about 210 m.

A strong downstream reduction of the portion of unstable rock pebbles is generally typical for gravelly rivers (SCHUMM, 1973; SNEED & FOLK, 1958). A simple constant trend like this could not be recognised along the total areal extent of the HMF. A reduction of the portion of unstable rocks is only possible to recognise in some clustered localities (e.g. Text-Fig. 3).

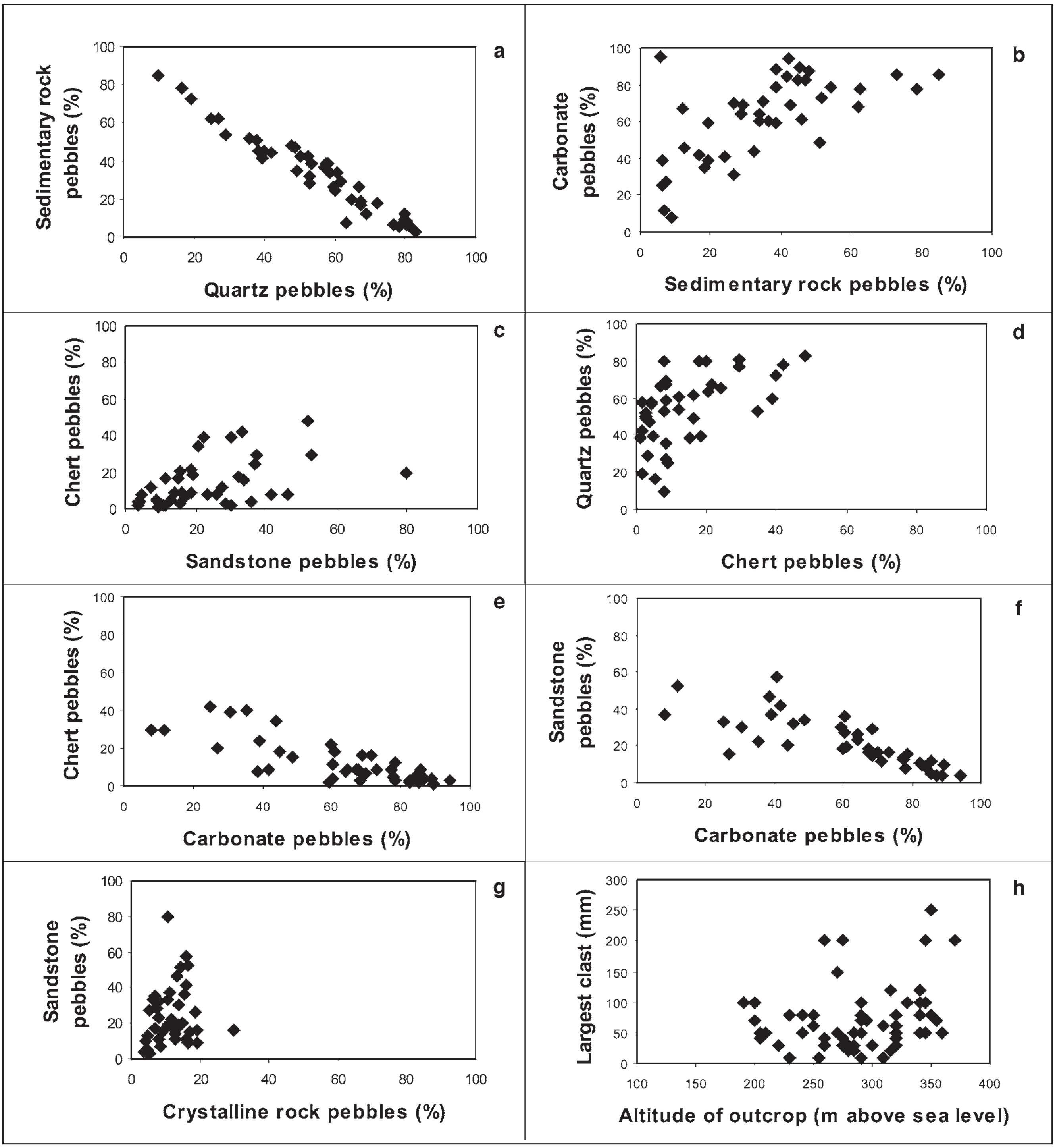
3. Pebble Size, Shape and Roundness

The study of pebble size, shape and roundness was used as additional method for better understanding the interrelationship or differences of individual outcrops.

The maximal pebble/cobble size was obtained by the measurement of the longest axis (A-axis) of the largest found extraclast at each locality (Text-Fig. 6). A generally good agreement between “the largest clast size” and “the average clast size” was observed at individual localities, which means that the “largest clast size” does not represent “outsized” components. The petrography of the measured clast varied, but carbonates form the largest found cobbles (max. 25 cm in diameter) or pebbles in the majority of outcrops. Quartz pebbles are generally smaller than the co-occurring clasts of sedimentary rocks, however, in outcrop no. 1 quartz-pebbles of about 20 cm in diameter were the largest clasts found. The size of crystalline rock pebbles in individual outcrops is usually similar to that of quartz-pebbles. Just in one outcrop (no. 3) a gneiss cobble (25 cm in diameter) forms the largest found clast. There exist no significant changes of maximal clast size in areal view (from west to east) or in various altitudes (Text-Fig. 5h).

Shape and roundness of quartz pebbles, as the most frequent pebble type, were studied in more than 40 outcrops. 50 to 70 pebbles were measured in each outcrop to obtain statistically significant data. Only coarse to very coarse pebbles (16 mm–64 mm) were studied. The average size of measured pebbles lies between 20 mm and 30 mm in most cases.

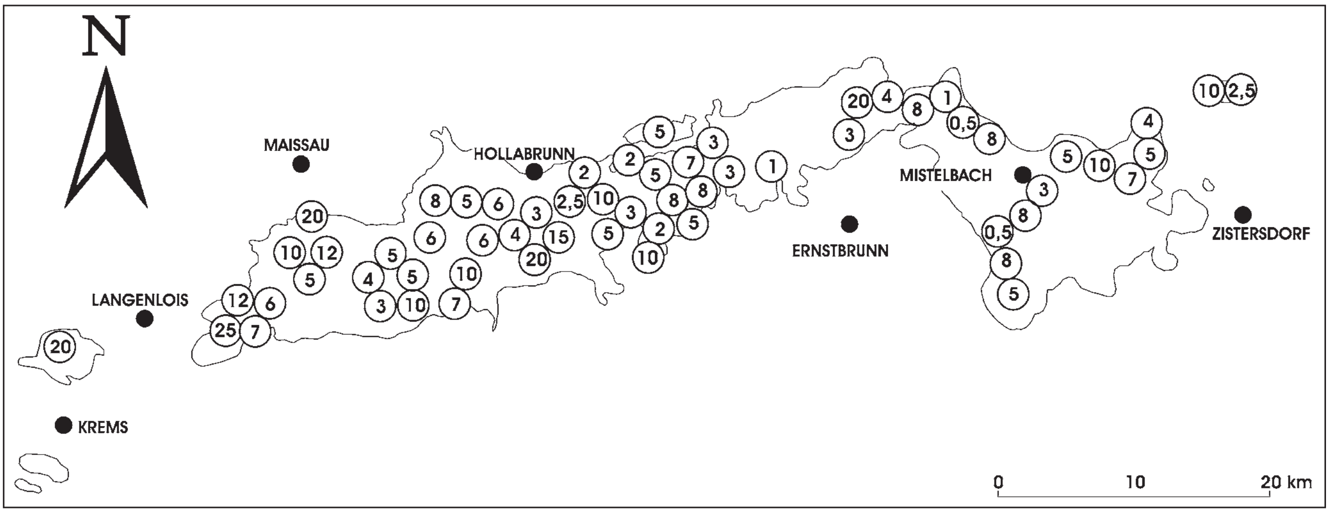
The pebble shape was classified into four classes according to ZINGG (1935). The relative portions of these classes in the studied outcrops are presented in Text-



Text-Fig. 5.
Relation of the content of quartz pebbles vs. sedimentary rock pebbles (5a), the content of sedimentary rock pebbles vs. carbonate pebbles (5b), the content of sandstone pebbles vs. chert pebbles (5c), the content of chert pebbles vs. quartz pebbles (5d), the content of carbonate pebbles vs. chert pebbles (5e), the content of carbonate pebbles vs. sandstone pebbles (5f), the content of crystalline rock pebbles vs. sandstone pebbles (5g), and the size of largest clast vs. the altitude of the outcrop (5h) in the studied outcrops of the Hollabrunn-Mistelbach Formation.

Fig. 7. Discoidal pebbles are dominant in the majority of outcrops (2, 4, 7, 8, 12, 13, 14, 16, 17, 19, 25, 26, 30, 35, 41, 42, 47, 49, 52, 53, 55, 59–62). Spherical pebbles are dominant in outcrops 1, 9, 14, 21, 24, 56, 63. Rod-like pebbles are dominant in outcrops 3, 5, 6, 20, 36, 46, 57, 58. A negative correlation between the portion of discoidal and spherical pebbles, as well as discoidal and rod-like pebbles, can be observed (Text-Fig. 8a, b). With higher content of quartz pebbles the frequency of rod-like pebbles is rising, but the frequency of discoidal pebbles decreases (Text-Fig. 8c, d). A higher presence of bladed pebbles is usually connected with a higher portion of rod-like pebbles, whereas its lower presence is connected with a rising portion of spherical ones (Text-Fig. 8e). Differences in portions of rod-like pebbles are smaller at localities with a relatively higher altitude (Text-Fig. 8f). The supposed dominant source of quartz pebbles from metamorphic rocks suggests that rod-like and bladed pebbles are reflecting their primary shape, whereas spherical and discoidal pebbles show stronger influence of transport.

A gradual change of roundness index (WENTWORTH, 1922), flatness index (CAILLEUX, 1945) or sphericity (as



Text-Fig. 6.
Maximal size (in cm) of pebbles and cobbles (excluding intraclasts) in the studied outcrops of the Hollabrunn-Mistelbach Formation.

defined by SNEED & FOLK [1958]) with prolonged river transport was described in literature (DOBKINS & FOLK, 1970; SNEED & FOLK, 1958; VASS & ELEČKO, 1977). The average value of the sphericity varies in the studied outcrops between 0.60 and 0.73 and no linear trend of its value could be recognised (Text-Fig. 9). The average value of the flatness index varies between 1.77 and 2.49 and also in this case no linear trend could be observed (Text-Fig. 10). The value of the flatness index reveals no important change towards higher or lower altitudes (Text-Fig. 8g). The average value of the roundness index lies between 292.3 and 425.6 (Text-Fig. 11). The portion of well-rounded pebbles lies between 3.1 and 32.9 % and of poor rounded ones between 0 and 8.2 %. According to roundness no significant trends were observed.

4. Facies Study

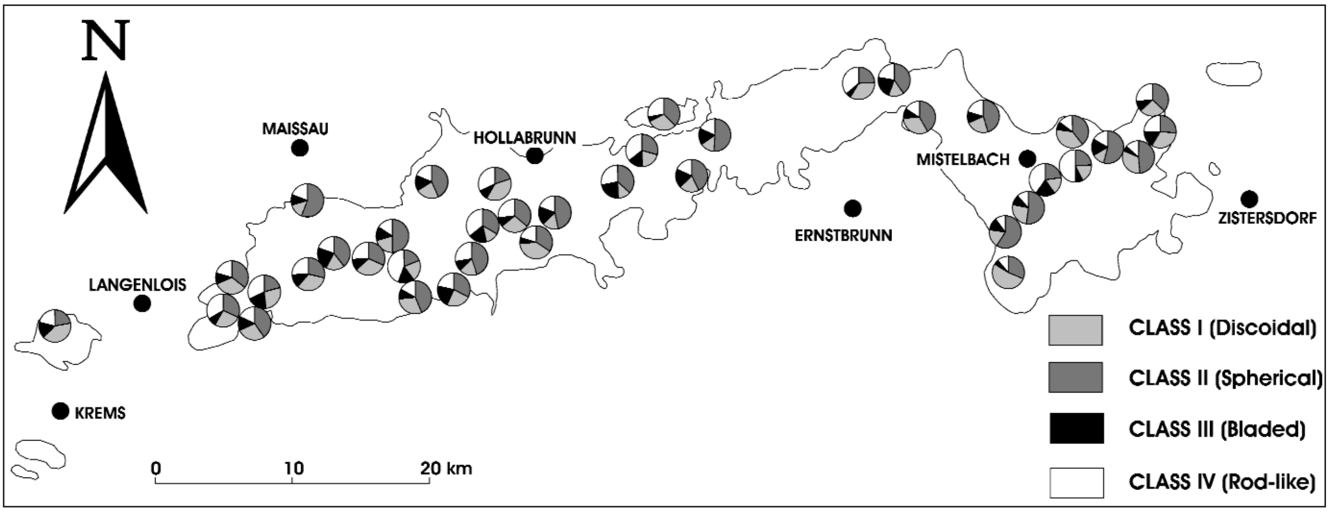
The study of the facies in the outcrops and their lateral distribution is an important tool for the recognition of depositional processes, the sedimentary environment and its evolution. Facies types of the HMF are described by employing a hierarchical scheme. The lower level is represented by lithofacies types, which are combined at the upper level to define facies associations or architectural elements (BRIDGE, 1993; MIALL, 1978; READING, 1996).

4.1. Lithofacies

The lithofacies was defined by grain size, sedimentary structures, bed configuration and its geometry. Most of the lithofacies are typical for alluvial systems and thus the majority of the employed codes generally refer to the standard lithofacies types of MIALL (1978) with critical comments of BRIDGE (1993). A list of the lithofacies codes is presented in Table 2. More than 600 m of vertical logs have been described in the studied outcrops. Lithofacies were subdivided into gravelly, sandy, fine-grained lithofacies and others. The areal distribution of these lithofacies groups is presented in Text-Fig. 12. The strongly varying length of logs in different outcrops (from 2 m to almost 30 m) influenced these results. Schematic lithostratigraphic logs of individual outcrops related to the altitude of the outcrop are presented in Text-Fig. 13.

4.2. Paleocurrent Analysis

Paleocurrent data are important for the definition of architectural elements, depositional system geometry and environmental analysis. Paleocurrent data were obtained from more than 600 measurements. Orientation of channel axis, orientation of bounding surfaces, foreset orientation of cross-stratified beds and preferred orientation of pebbles/cobbles yielded highly complex results (Text-Fig. 14a–c).



Text-Fig. 7.
Occurrences of various pebble shape classes in the studied outcrops of the Hollabrunn-Mistelbach Formation.

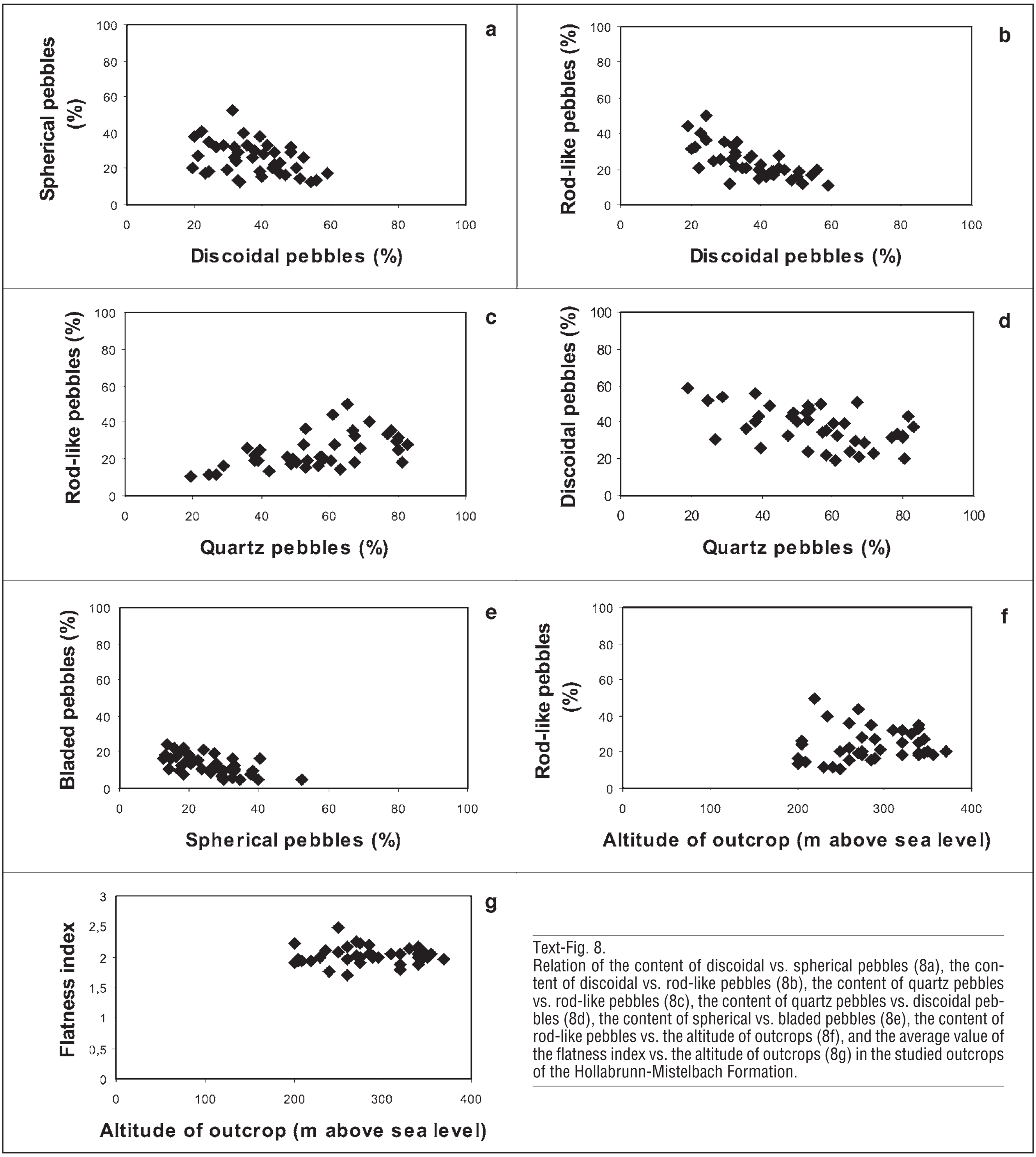
Table 2.
Lithofacies types of the Hollabrunn-Mistelbach Formation.

Lithofacies	Sedimentary structures	Interpretation
Gravelly lithofacies (G)		
Gm	Massive or crudely horizontally bedded, imbrication	Internal parts of longitudinal bars, lag and sieve deposits. Deposition from migrating bedload sheets
Gt	Trough and low-angle cross-bedding	Minor channel fills, inner curved-crested bars and dunes (lower flow regime)
Gp	Planar cross-bedding. Sometimes matrix supported and transition to Sp	Linquoid or transverse (inner) bars, strait-crested dunes or bars. Growths from older bar remnants. Higher flow regime. Mouth-bars
Gc	Lenses and horizons, massive or crude cross-bedding	Sieve and lag deposits, scour fills
Gh	Horizontal to low angle cross bedding, mollusc shells	Gravelly beaches, top parts of mouth bars
Sandy lithofacies (S)		
St	Sand, fine to very coarse, sometimes pebbly. Solitary or grouped trough cross-bedding	Channel deposits, curved-crested bars or dunes (lower flow regime), crevasse-splays
Sp	Sand, fine to very coarse, sometimes pebbly. Solitary or grouped planar cross-bedding	Linquoid and transverse (inner) bars and dunes (straight-crested), sand waves (lower flow regime), final stages of channel filling
Sr	Sand, very fine to coarse. Ripple marks and ripple cross-bedding	Final stages of minor channel infilling, top parts of channel bars or crevasse-splays (lower flow regime)
Sh	Sand, very fine to very coarse, sometimes pebbly. Horizontal lamination or bedding, parting lineation	Planar bed flow (lower and upper flow regime), top bar deposits, channel filling
Sl	Sand, fine to medium. Low angle cross-bedding	Scour and channel fills, crevasse splays
Se	Erosional scours, intraclasts, crude cross-bedding	Scour fills
Sb	Sand, bioturbated, mollusc shells or shell debris	Various sandy bedforms, extensively occupied by burrowing organisms. Interdistributary area, foreshore and shoreface environment
Fine-grained lithofacies (F)		
Fl	Very fine sand, silt and mud. Fine lamination, ripple cross lamination, ripple marks	Overbank or waning flood deposits. Abandoned channel fills, levee deposits
Fh	Mud. Horizontal lamination	Abandoned channel fills, levee, floodplain deposits
Fm	Mud, silt. Massive	Overbank and floodplain deposits, channel fill or drape deposits
Fr	Silt, mud. Rootlets	Vegetated overbank deposits. Seatearth, flood plain, soils
Fg	Mud with scattered pebbles	Interdistributary area
Fb	Mud bioturbated, mollusc shells or shell debris	Interdistributary area
Other Lithofacies		
P	Carbonate claystones sometimes with pedogenic features	Soils developed on the floodplain area

The preferred orientation of elongated pebbles (Text-Fig. 17 E) was typically perpendicular or strongly oblique to the foreset orientation of the cross-stratified beds [i.e. A(t) B(i)], whereas parallel orientation [i.e. A(p)] was less common. Elongated pebbles were often oriented parallel with the channel axis. A high concentration of clasts and high flow velocities favour long-axis orientation parallel to the current (RAMOS & SOPEÑA, 1983). Upstream imbrication in bars and along-stream orientation within channels can also be used as paleocurrent indicators.

Foresets of the cross-stratified beds were oriented parallel, oblique and also perpendicular to the channel axis or bounding surface orientation. This reflects "complex" propagation of bedforms within the channels. A perpendicular or oblique orientation of propagating bedforms (bars and dunes) to the channel axis reflects lateral accretion deposits (similarly JO & CHOUGH [2001]). However, their clear recognition in poor quality outcrops sometimes was difficult.

Channels are often oriented in eastward, northeastward, and northward directions, but also southeastward and southward orientations occur. The orientation of paleocurrents reflects a complex situation also in individual outcrops/profiles. Deviations between pebble orientation, flow direction and the direction of bar accretion are known from literature (HEIN, 1984; RAMOS & SOPEÑA, 1983). Such results are generally typical for highly mobile, rapidly shifting mid-channel bedforms and channels or even channel belts with varying water discharge. The main axial transport of the whole system was generally oriented towards the east. This orientation is often complicated by "transverse" transport directions (in most cases towards the north). The interpretation of this transverse transport as a result of tributary channels is supported by the outcomes of the study of gravel



Text-Fig. 8.
Relation of the content of discoidal vs. spherical pebbles (8a), the content of discoidal vs. rod-like pebbles (8b), the content of quartz pebbles vs. rod-like pebbles (8c), the content of quartz pebbles vs. discoidal pebbles (8d), the content of spherical vs. bladed pebbles (8e), the content of rod-like pebbles vs. the altitude of outcrops (8f), and the average value of the flatness index vs. the altitude of outcrops (8g) in the studied outcrops of the Hollabrunn-Mistelbach Formation.

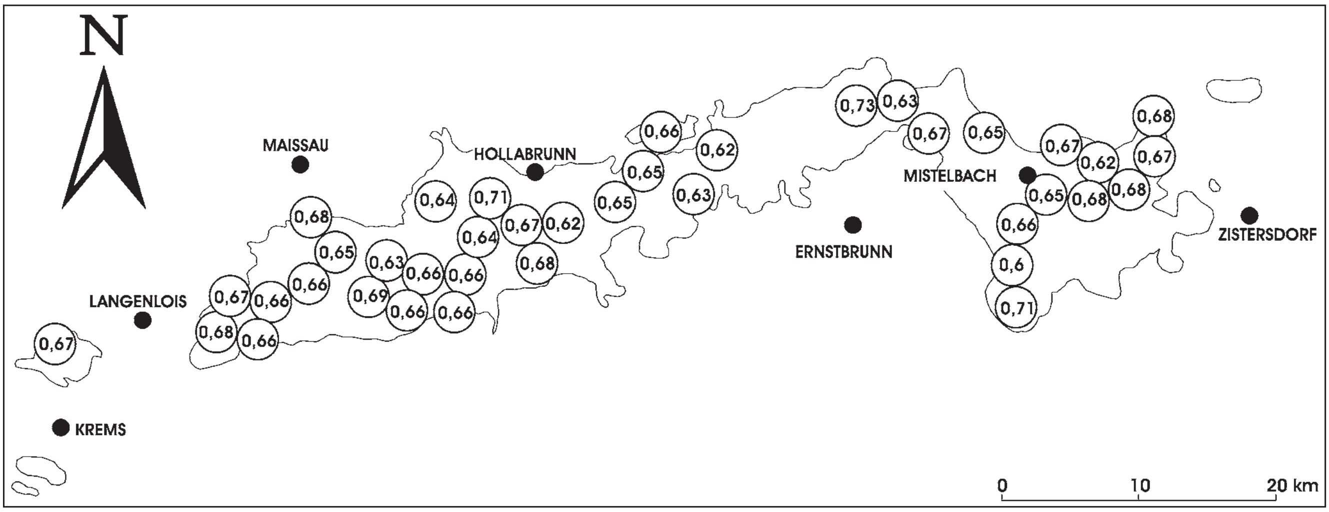
composition. Evidence of lateral accretion of bedforms could possibly indicate a wandering fluvial style.

4.3. Facies Associations and Architectural Elements

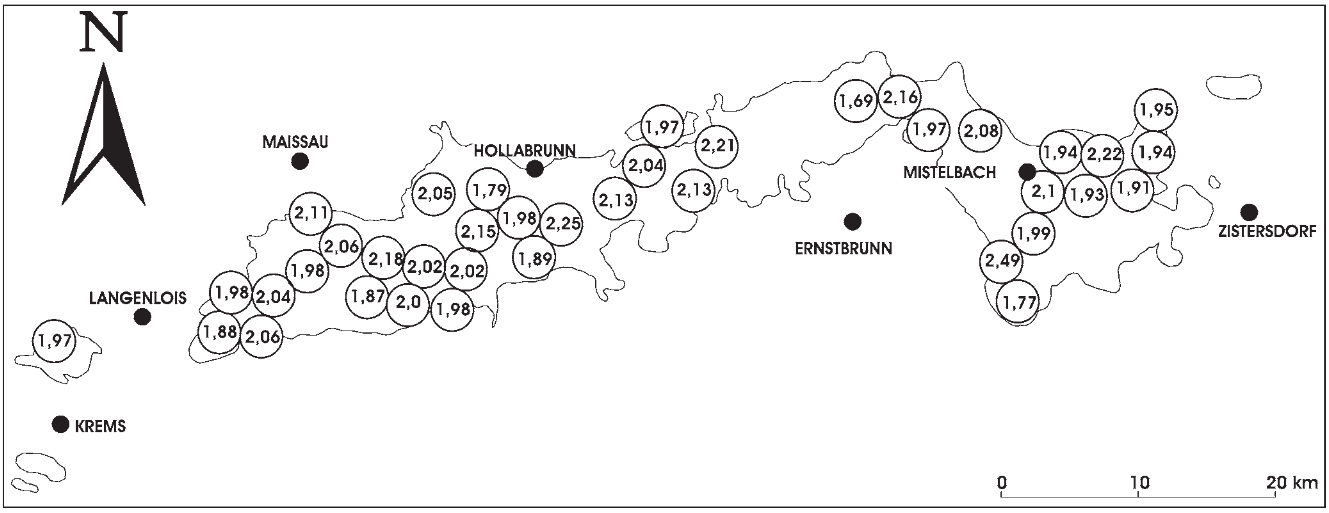
Facies associations are groups of genetically related lithofacies with some environmental significance (WALKER & JAMES, 1992). These larger scale features are in fluvial deposits traditionally assigned as architectural elements (MIALL, 1985) to emphasize their three-dimensional geometry. Within the HMF various lithofacies associations/architectural elements were recognised. A list of them is presented in Table 3. Each element has its own characteristic set of lithofacies, geometry and partly also a specific character of lateral distribution. At most locations the facies study was possible only along one outcrop wall (i.e. two-dimensional) and the outcrops were relatively small. Thus the scale and geometry of architectural elements often could not be determined satisfyingly.

Two large mutually connected depositional environments (groups of architectural elements/lithofacies associations) could be recognised within the HMF. Due to their environmental significance and spatial distribution west and east of the Zaya Gate they were ascribed to a gravel-bed river and a braid-delta environment respectively (NEHYBA, 2000, 2003). The majority of lithofacies codes can be used for both environments. There are larger and numerous outcrops in the area where the gravel-bed river deposits (more than 500 m of vertical logs) are developed compared to the area of the braid-delta deposits (about 113 m of vertical logs).

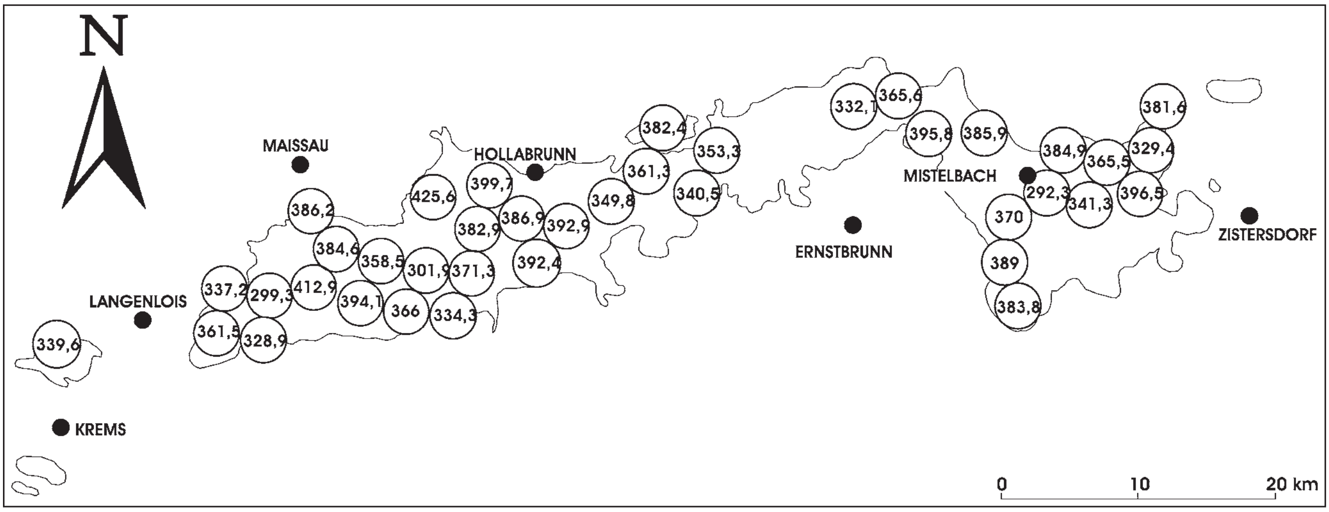
The group of gravelly lithofacies is very significant for the deposits of both gravel-bed river and braid-delta in the whole area. They form more than 62 % of the studied profiles of the gravel-bed river deposits and 45 % of the braid-



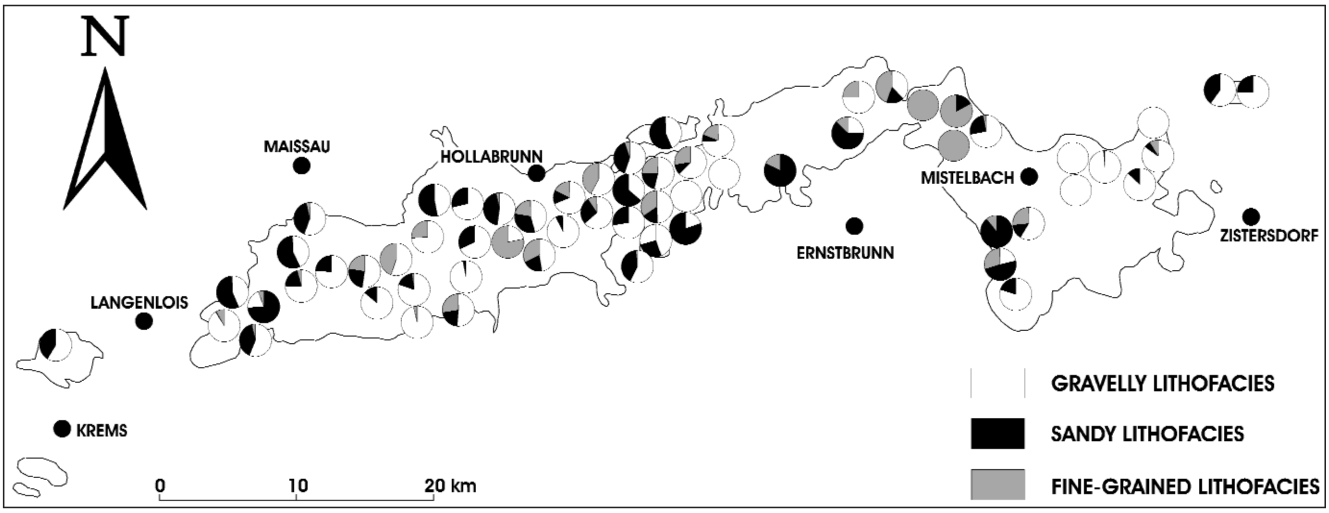
Text-Fig. 9.
The average value of the maximal projection sphericity of quartz pebbles in the studied outcrops of the Hollabrunn-Mistelbach Formation.



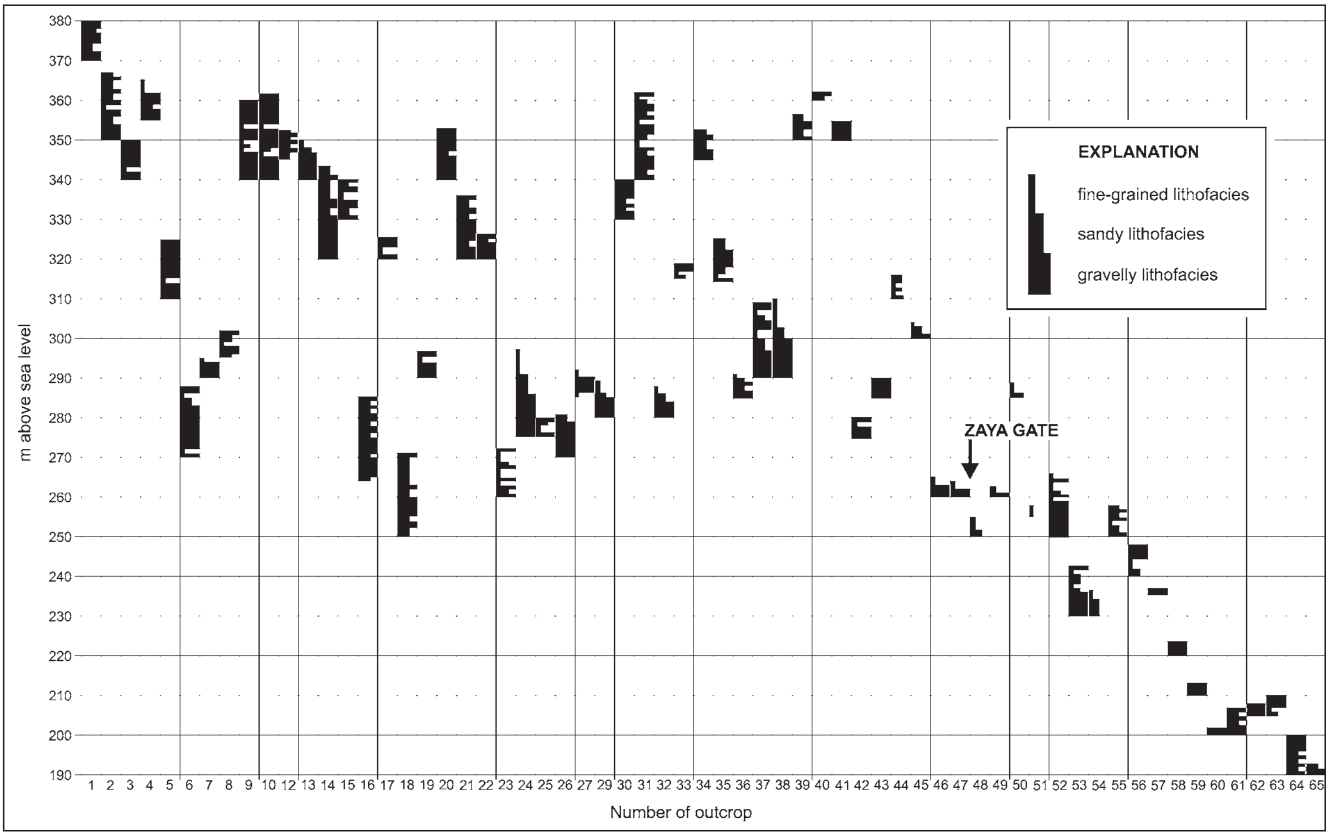
Text-Fig. 10.
The average value of the flatness index of quartz pebbles in the studied outcrops of the Hollabrunn-Mistelbach Formation.



Text-Fig. 11.
The average value of the roundness index of quartz pebbles in the studied outcrops of the Hollabrunn-Mistelbach Formation.



Text-Fig. 12.
Portion of gravelly, sandy and fine-grained lithofacies in the studied outcrops of the Hollabrunn-Mistelbach Formation.



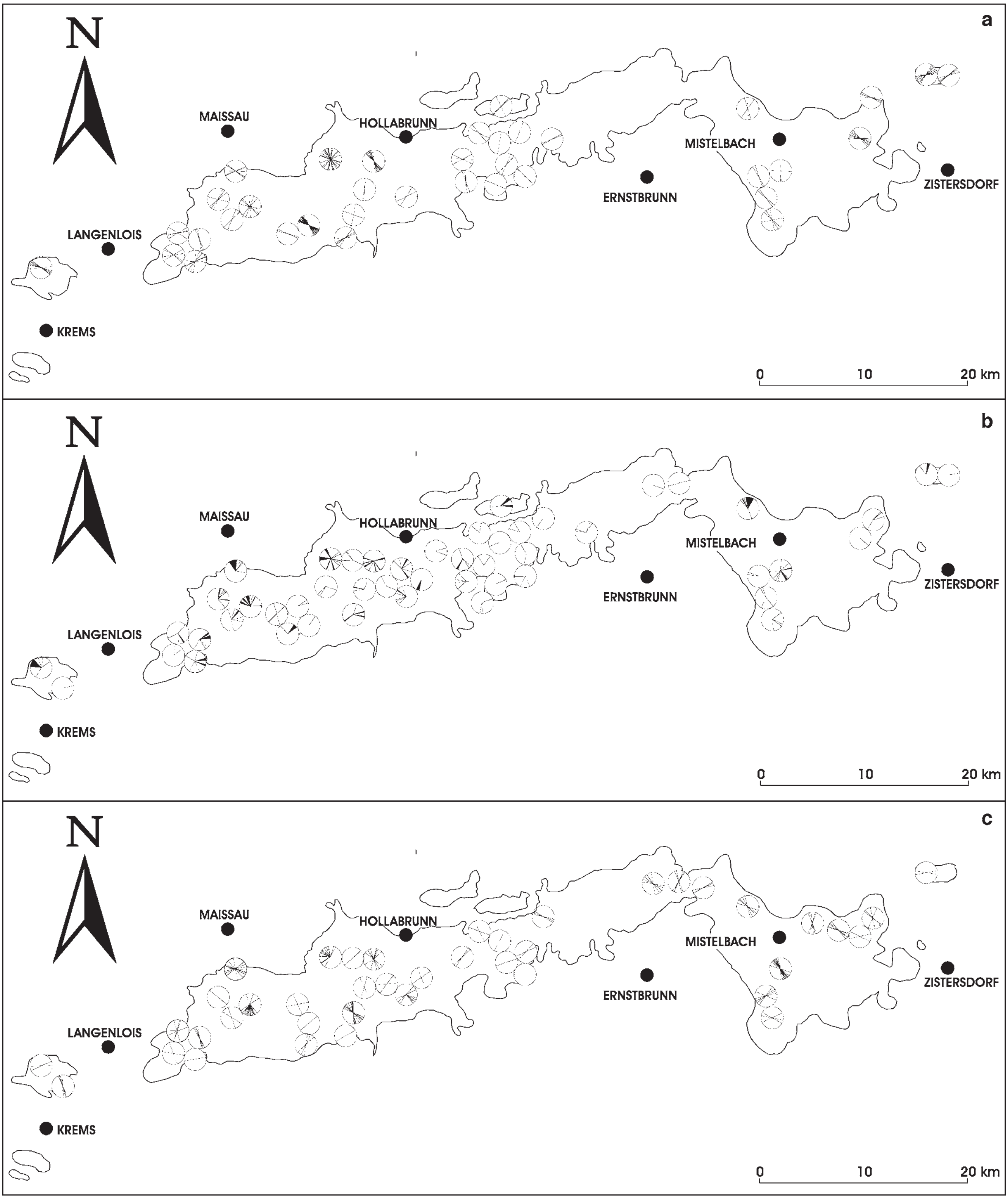
Text-Fig. 13.
Schematic lithostratigraphic logs of the studied outcrops of the Hollabrunn-Mistelbach Formation in relation to their altitudes.

delta deposits. However, the role of individual lithofacies of this group differs in these environments. Whereas Gm is significant for the deposits of the gravel-bed river, it is quite rare in the braid-delta deposits. The mean grain size of the gravelly lithofacies varies from pebbles to cobbles, with a dominance of pebbles.

The group of the sandy lithofacies forms 29 % in the gravel-bed river deposits and 28 % in the braid-delta deposits. Again the importance of individual sandy lithofacies in these environments is different. The absence of large gravelly and sandy cross-stratified sediment bodies with several meters of thickness is quite striking in the HMF. Relatively low height of bedforms reflect that they prograded in relatively shallow water.

The group of fine-grained lithofacies plays a relatively minor role in the deposits of gravel-bed river forming 8.5 % of the logs. In contrary they form a significant portion of the braid-delta deposits, i.e. 27 % of the studied profiles. The role of individual fine-grained lithofacies differs once again in these environments.

One additional lithofacies (lithofacies P) was recognised only rarely. Lithofacies P is formed by nodules or discontinuous horizons of light coloured, calcareous mudstone within the fine-grained lithofacies (usually Fl or Fh). It was recognised in deposits of the gravel-bed river and the braid-delta. Their presence in outcrops is rather subordinate and was not included in Text-Fig. 12.



Text-Fig. 14.
Paleocurrent orientations in the studied outcrops of the Hollabrunn-Mistelbach Formation.
a) Orientation of channel axis and bounding surfaces.
b) Foreset orientation of cross-stratification.
c) Preferred orientation of pebbles.

Representative examples of lithostratigraphic logs are presented in Text-Fig. 15.

Deposits of alluvial fans were not recognised but this environment is supposed to be responsible for the transverse sediment supply to the "axial" fluvial system (BLAIR & MCPHERSON, 1994) of the HMF.

Architectural elements as "building blocks" of fluvial succession are described with regard to descriptive (external shape, organisation of internal structures) and interpretative intentions. Different elements are separated by erosion/bounding surfaces, which probably can be classified as surfaces of 4th, 5th or 6th order according to MIALL (1992).

Table 3.
Architectural elements/lithofacies associations of the Hollabrunn-Mistelbach Formation.

	Lithology	Geometry and typical features
Channel lags	Gm, Gc	Thin sheet, lens; erosive uneven base; flat top
Gravel bars	Gm, Gp, Gt, rare Sh, Sp, St, Sr	Tabular, lens, wedge; erosive, flat to scoured base; convex-up top
Gravelly channels	Gt, Gc, Sp, St, Sh, rare Fl, Fh, Fm	Channel shape; erosive scoured base
Gravelly lateral/downstream accretion deposits	Gt, Gp, Sp, St, Sh, Sl	Tabular, wedge, channel; flat or channelled base; convex-up or sigmoidal internal reactivation surfaces; tops often convex-up
Sandy lateral/downstream accretion deposits	Sp, St, Sh, Sl, Se, Sr, Fh, Fl, Gc	Channel, wedge, tabular; flat or scored base; internal dipping erosion surfaces; tops are convex up, uneven, flat or gradual
Sandy channels	St, Gc, Fh, Fl	Channel shape; flat or scoured base; uneven, flat or gradual tops
Abandoned Channel Fills	Fm, Fl, Sh, Sr, Fh, Fr, P	Channel shape; flat or uneven base; erosive tops
Floodplain fines	Fl, Fm, Fr, Sl, Sr, rarely Sp, St, P	Sheet, lens, wedge shape; flat or uneven base; erosive tops
Distributary channels	Gt, Gp, St, rarely Sp, Sr, Sl, Fl, Fh, Sb	Channel, tabular; erosive concave downward base; planar tops
Mouth bars	Gp, Sh, Sr	Tabular shape; planar or uneven base
Gravelly beaches	Gh, Sr, Sh, Sb	Tabular shape
Foreshore and shoreface deposits	Sp, Sb, rare St, Sr, Fh	Tabular, lens
Interdistributary area	Fm, Fh, Fl, Fg, Fb, Sl, Sr	Tabular; planar or undulating base

These surfaces are characterized by a marked shift in grain size or scale of bedforms. They are laterally extensive over the whole outcrop and often show a relief, mutually recording the shifts of a main channel or channel belt (READING, 1996). The internal organisation of architectural elements is defined by bounding surfaces of lower order, which are less extensive and reflect local shifts of bars and subchannels. However, insufficient outcrop conditions in most cases did not allow recognising the accurate hierarchy and relationship of bounding surfaces (e.g. HOLBROOK, 2001). Contacts of HMF deposits with bedrock or confined valley margins have not been recognised.

4.3.1. Deposits of the Gravel-Bed River

The architectural elements of gravel-bed river deposits of the HMF are gravelly channel fills, sandy channel fills and overbank fines. These larger scale elements can be subdivided into elements at a smaller scale. The lateral and vertical relations of larger scale architectural elements reflect the shifting of the main channel or channel belt. A schematic block diagram of the studied gravel-bed river environment is presented in Text-Fig. 16. Structural and textural features of the studied gravel-bed river deposits are presented in Text-Fig. 17 A–H, Text-Fig. 18 A–F and Text-Fig. 19 A.

4.3.1.1. Gravelly Channel Fill Elements

Gravelly channel fill elements are subdivided into channel lags, gravel bars, gravelly channels and gravelly lateral/downstream accretion deposits. These elements are not always discrete but represent various stages of evolution of dominantly sheet like bodies deposited by sediment-laden flows spreading through a network of shallow channels. The formation of low-relief gravel bars led to repeated dividing and rejoining of channels (BRIDGE, 1997). High water discharge promotes the deposition of gravels, while sand and finer material is largely bypassing.

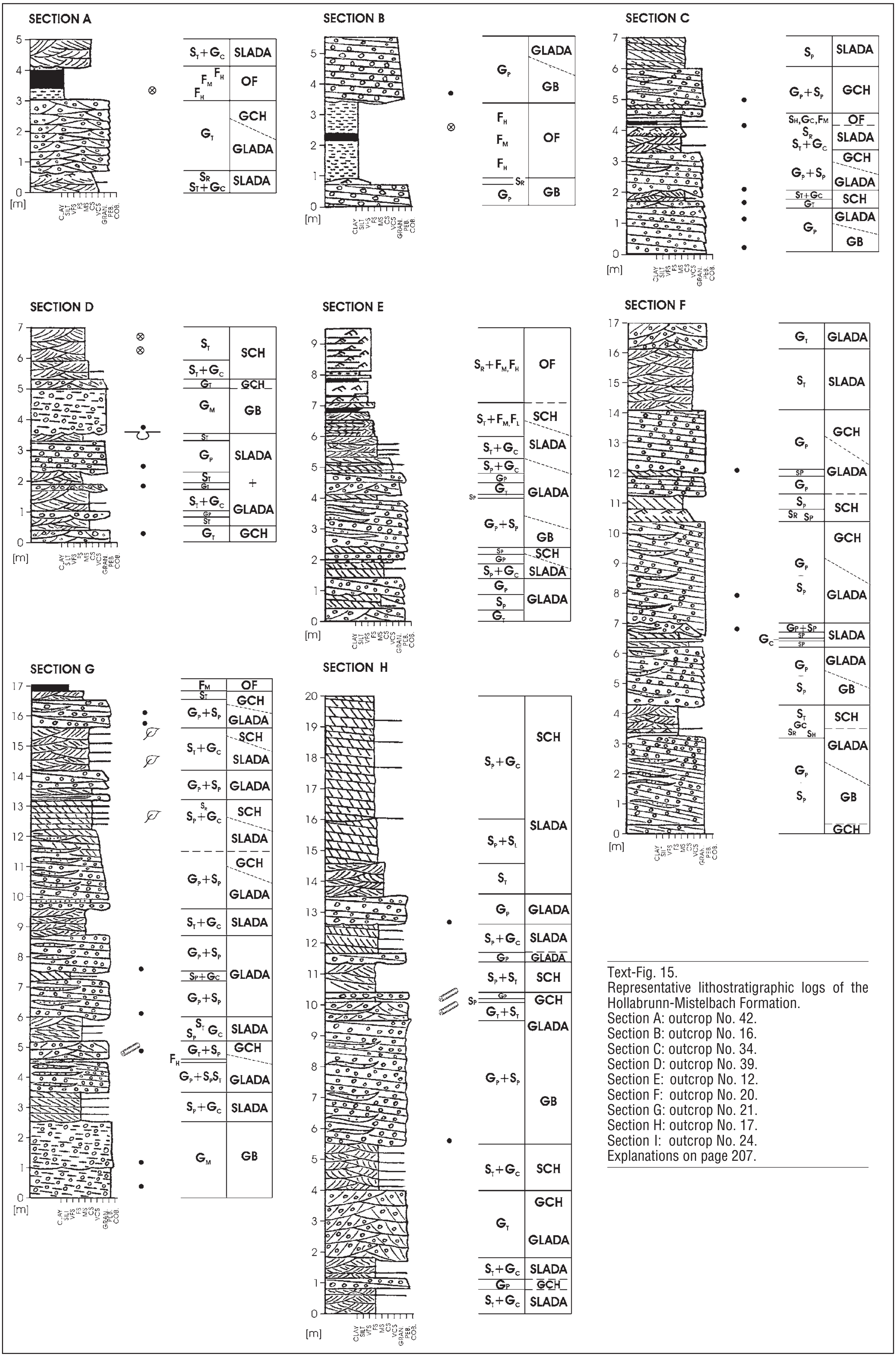
4.3.1.1.1. Channel Lags

Channel lags form relatively thin (cm to dm thick) laterally persistent sheet-like horizons or lenses. They have erosive, partly scoured, uneven bases and relatively flatter tops. Intraclasts are often oversized (up to 1 m). Wood fragments were repeatedly recognised, whereas bone debris is rare. The fabric is clast-supported both openwork and matrix-infilled. A bimodal appearance of grain size distribution (formed by cobbles and pebbles or pebbles and sand matrix) is typical. Channel lags can be crudely normal-graded, massive or crude horizontally bedded. Larger clasts tend to have A(p) or A(t) B(i) imbrication (Text-Fig. 17 E).

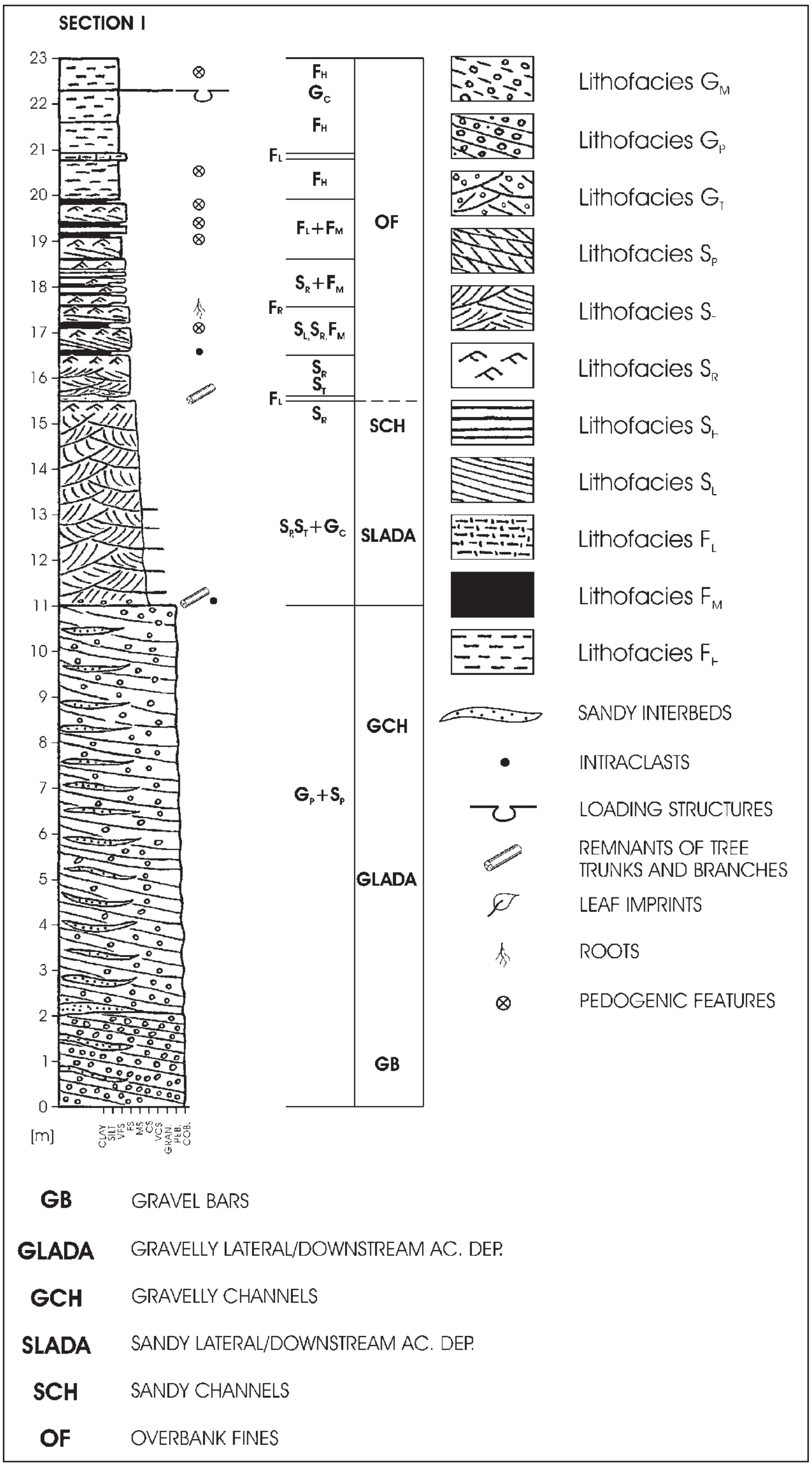
Interpretation: Channel lags represent the coarsest and least mobile bed-load material. They are deposited on a river floor immediately after erosion, when the peak flood diminishes. The diffuse gravel sheet marks a newly eroded channel-floor. Channel lags form the initial stage (nuclei) of gravel bars or occur isolated within finer grained deposits. Clasts were derived both from the drainage area and from reworking of river bars, banks and overbank deposits (HEIN, 1984; NEMEC & POSTMA, 1993). Unusually large intraclasts can reach the channel by gravitationally collapsing of cohesive banks. Coarse-grained lags within sandy beds can originate or be modified by winnowing.

4.3.1.1.2. Gravel Bars

Gravel bars are generally finer grained than channel lags and also better sorted. Their external shape resembles sheet like bodies with a maximal recognised thickness (stacked beds) of about 3–5 m. Laterally they can be traced up to about 50 m. The geometry of individual sheets can be tabular, lenticular or wedge-shaped. Such shape differences can be due to various types of bars (longitudinal, transverse, diagonal, linquoid etc.). But varying orientation



Text-Fig. 15.
Representative lithostratigraphic logs of the Hollabrunn-Mistelbach Formation.
Section A: outcrop No. 42.
Section B: outcrop No. 16.
Section C: outcrop No. 34.
Section D: outcrop No. 39.
Section E: outcrop No. 12.
Section F: outcrop No. 20.
Section G: outcrop No. 21.
Section H: outcrop No. 17.
Section I: outcrop No. 24.
Explanations on page 207.



of the outcrop wall as well as erosional processes can also influence the shape. The soles are erosive, relatively flat and only slightly scoured (10–40 cm wide and about 5 cm deep scours; Text-Fig. 17 B). The tops are typically convex upwards. Top surfaces with coarser clasts (winnowed by strong currents) were rarely recognised. The external and internal organisation of bars is presented in Text-Fig. 17 A.

Crudely flat bedded to massive gravels with cobbles and coarse pebbles (Gm) represent the internal part (core) of large bars. Gm grades both laterally and vertically into Gp or Gt. Low-angle (about 10°) cross stratification with tangential contacts to the base is the most typical structure, reflecting lateral growth of bars. Reactivation surfaces were recognised. Set thickness varies between 25 cm and 75 cm.

Internal stratification is defined by the rhythmic alternation of layers of finer and coarser grained clast-supported gravels, or an alternation of layers of clast-supported matrix-filled and openwork gravels (e.g. Text-Figs. 17F and 18 A). The thickness of such rhythmic couples is generally about 10 cm. A(t)B(i) orientation of clasts was often observed. Vertical and lateral grading connected with clast size reduction and a higher portion of sandy matrix or sandy interbeds is common.

Discontinuous, thin sandy interbeds between the gravelly beds are rare near the base but relatively common towards the top of bars. Sandy interbeds are typically about 10 cm thick and truncated by erosion. Their maximal observed thickness was about 1 m and in this case the bed was traceable for only 3 m. Sands are medium to coarse-grained, poorly or well sorted.

The lateral progradation or vertical evolution of gravel bars into gravelly or rarely sandy lateral/downstream accretion deposits and channels can be observed in some extended outcrops. But also direct contacts with overbank deposits were recognised in several outcrops, reflecting rapid abandonment of the channel (Text-Fig. 15, section B).

Interpretation: Horizontal stratification (Gm) and clast imbrication suggest deposition as a low-relief gravel sheet. Flat or gently inclined stratification reflects the conditions of rapid transport with dominant downstream accretion. Cross-stratified gravels (Gt, Gp) reflect relatively slower gravel transport, where also vertical accretion takes place (HEIN, 1984). Deposits of low-relief gravel sheets are typically interpreted as internal part of longitudinal bars, whereas cross-stratified gravels are interpreted as transverse bedforms (MIALL, 1978; RAMOS & SOPEŃA, 1983). The occurrence of multiple reactivation surfaces, textural and structural differences in adjacent sets, and presence of sandy interbeds, reflect formation of the bars during several depositional events, and also the possible existence of bar lobes. Dominance of horizontal and low-angle cross stratification, lack of "high-angle" cross-stratification and the relatively small thickness of bars all indicate, that they have developed in shallow, but powerful streams.

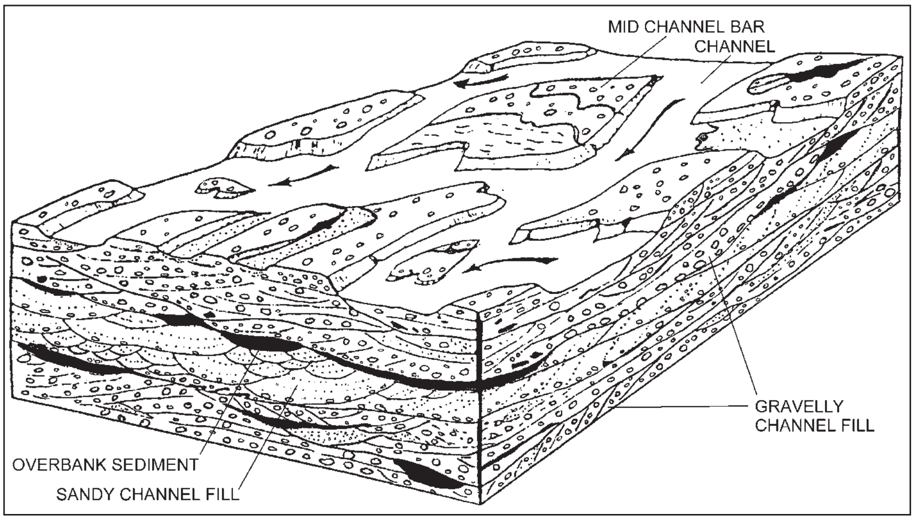
The openwork fabric and stratification defined by contrasting grain sizes may reflect changing water stages over the flood cycles (RAMOS & SOPEŃA, 1983). Both lateral and vertical reduction of the grain size may be connected with decreasing water depth over the bar or with "gravel overpassing" (MIALL, 1996).

During reduced flow, bar movement stopped and occasional crossover channels could develop and small dunes or sandy sheets were deposited from the overflow. Lateral flows along the bar margins and heads modified their shape (RAMOS & SOPEŃA, 1983).

4.3.1.1.3. Gravelly Channels

The erosive and scoured base and the channel shape are the most typical external features of gravelly channels. They generally have a higher content of sand than gravel

Text-Fig. 16.
Schematic block diagram of a gravel-bed river depositional environment.



bars and the fill varies from gravels and sandy gravels to gravelly sands, and lateral grading to sandy channels was observed. Lined up coarse pebbles (cobbles are rare) are present at the base (Text-Fig. 17 H). Mud intraclasts are several times larger than extraclast. Channels are very flat and shallow, nearly without exception. Steeply eroded basal surfaces were rarely recognised. Loading structures were rarely observed in cases, where gravelly channels overlie overbank deposits. Strata conforming roughly to the channel shape are typical for the fill, but also asymmetrical filling was observed. Planar and inclined stratification was recognised within gravels and coarse to medium sands (Text-Fig. 17 G). A relatively higher portion of sand was observed within relatively smaller channels.

Discontinuous mudstone or sandy interbeds often were recognised within gravelly channels. These interbeds have erosive tops and a maximal thickness of 0.3 m. They are traceable for several meters (Text-Fig. 18 E). Sands are commonly pebbly.

The channel widths vary between few meters and 50 m and the channel depths between several dm and 1 m. The width/depth ratio varies between 4 and 55. A rise of the channel width/depth ratio, together with the reduction of maximal and average clast size and higher content of sand can be documented in several outcrops upward the log. Generally, two types of channels can be recognised. The wider channels (width of more than 10 m) typically have a higher width/depth ratio. The relatively smaller channels (width of several meters) usually have a lower width/depth ratio. Their internal structure is complex, reflecting multistorey and complex filling. Remnants of small elevations between the channels were rarely recognised. They are about 0.5 m high and about 1 m wide.

Interpretation: The deposits represent a vertical aggradation of the channel fill during the waning stage. Vertically stacked channel-fill bodies reflect a relative stability of the channel position. The fining upward trend within the channels reflects their slow abandonment. Channels were relatively shallow and thus very sensitive to progressive abandonment and filling. Minor channel fill bodies of continually shifting small channels filled larger channels. Frequent inter-cutting of smaller channels demonstrates migration of the flow. This type of channel fill is typical for braided rivers (RAMOS & SOPEŃA, 1983). Mudstone beds together with abundant intraclasts reflect multiple rapid channel abandonment. Channel migration is connected with lateral erosion of bank material, the type of which also influences the nature of the channel fill, particularly if the material is cohesive. However, the recognised deposits reflect a dominance of non-cohesive sandy and gravelly banks. Highly erodable non-cohesive banks are favourable for the development of channels with a high width/depth ratio. The relative small scale of the channels (especially compared to the width of the whole sediment body of HMF) reflects a multichannel pattern of the paleoriver and also various types of channels (subchannels, chute-channels, etc.).

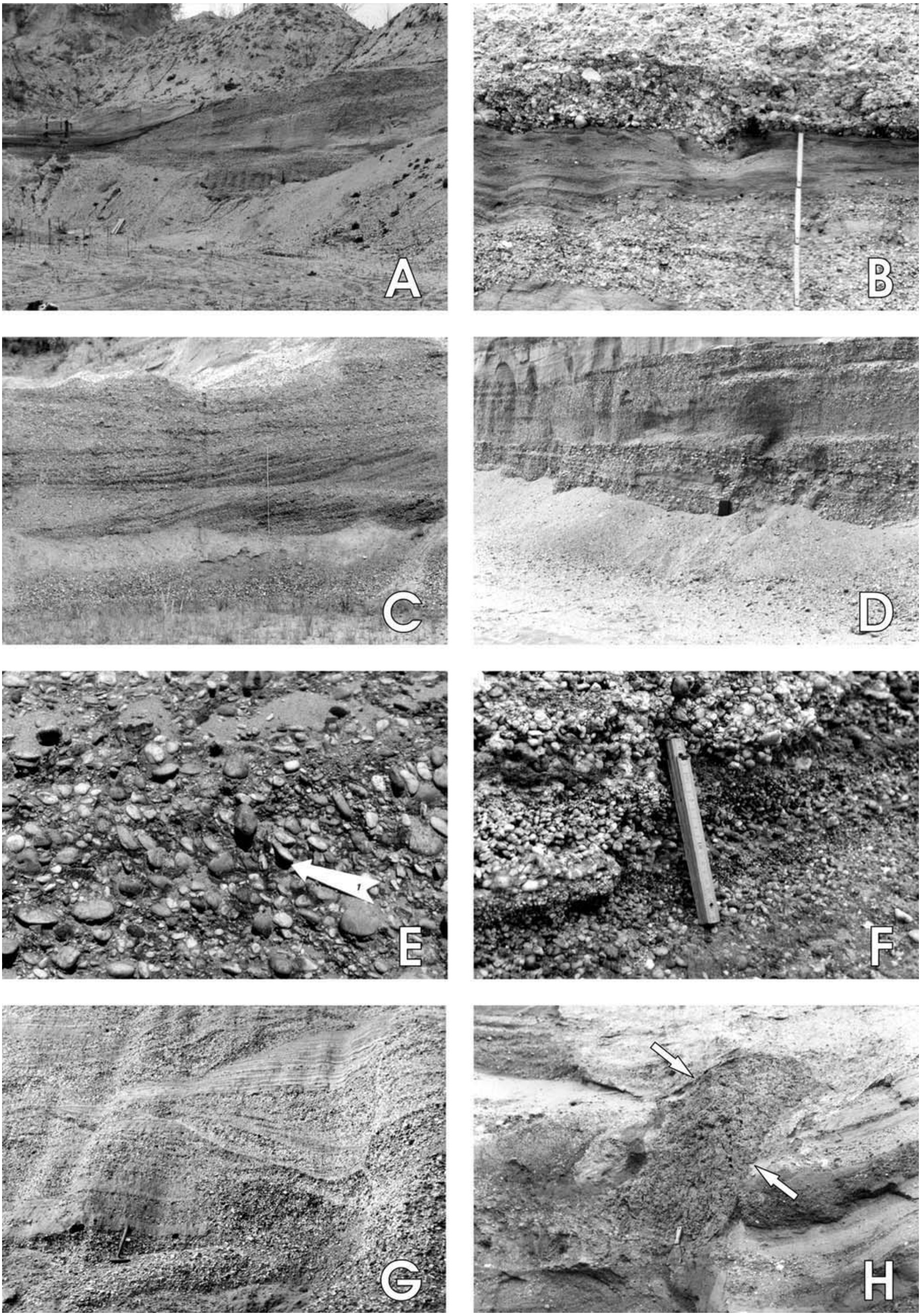
4.3.1.1.4. Gravelly Lateral/Downstream Accretion Deposits

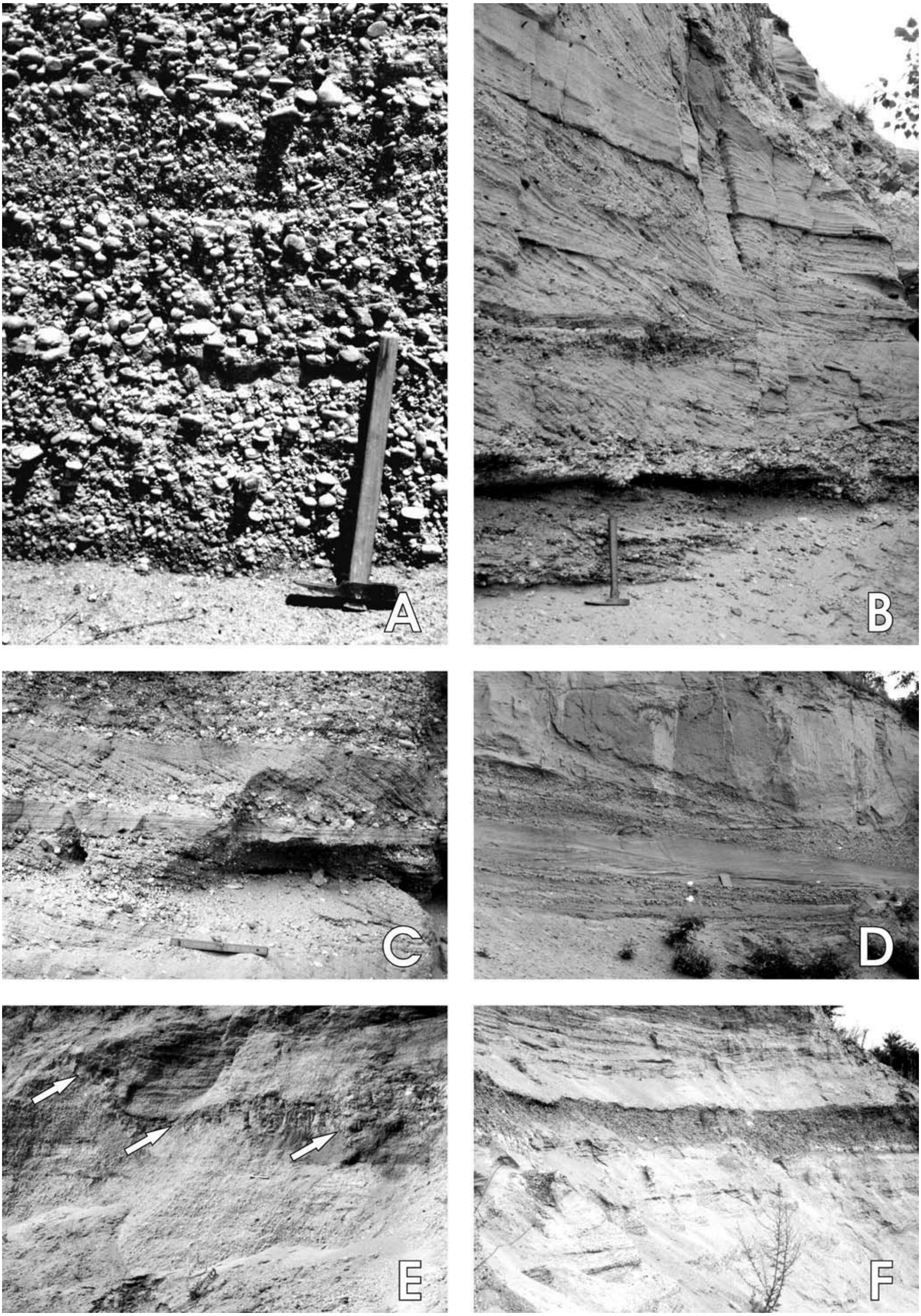
The quality of outcrops and in literature often described variable and complex character of fluvial coarse-grained accretion deposits (BRIDGE, 1993; MIALL, 1996) were the reasons for describing these deposits as lateral/downstream accretion ones.

The shape of this architectural element is typically tabular, however, wedge shape and flat, wide channel shape were also recognised. Soles are flat, concave-up or scoured. The coarsest clasts and intraclasts are located close to the base marking some higher order bounding surfaces (4th and 5th). Tops are often formed by sharp convex-up (typically 4th order) bounding surfaces. But also flat or scoured tops were observed.

Internal reactivation surfaces of characteristic shape are typical. These surfaces have a convex-up or sigmoidal shape and are gently inclined (2nd and 3rd order bounding surfaces). They are onlaping/offlaping on lower/upper bedding surfaces formed by planar or slightly undulating or convex upward higher order (4th and 5th) bounding surfaces. The thickness of individual gravelly cross-stratified beds is between 20–70 cm (usually less than 35 cm). The total thickness of multiply stacked beds exceeds several meters with a maximum of about 7 m. Low-angle (up to 10°) foreset dip is typical (Text-Fig. 17 C). Foreset dip angles between 15° and 20° were less common. Foresets have typically a sigmoidal shape. Tangential contact to the sole was noticed in some beds. A(t) B(i) orientation of pebbles was often observed. The transverse or perpendicular orientation of these paleocurrent indicators (foreset dip, imbrication) to the orientation of the channel axis and the accretion surfaces are significant features of this architectural element.

Text-Fig. 17. ➽➽➽
Structural and textural features of the studied gravel-bed river deposits in the Hollabrunn-Mistelbach Formation.
A) Section through a gravel bar (outcrop No. 24).
B) Erosive, relatively flat and slightly scoured base of a gravel bar (outcrop No. 16).
C) Vertically stacked gravelly lateral/downstream accretion deposits (outcrop No. 3).
D) Vertically stacked gravelly and sandy lateral/downstream accretion deposits with distinct differences in grain-size (outcrop No. 1).
E) Imbrication within gravel-sheet deposits (outcrop No. 19).
F) Typical openwork fabric and small-scale normal grading of gravel beds (outcrop No. 9).
G) Complex fill of a gravelly channel (outcrop No. 9).
H) Large intraclast (arrows) close to the base and the margin of a gravelly channel (outcrop No. 1).


A
B
C
D
E
1
F
G
H


A
B
C
D
E
F

Text-Fig. 18.
Structural and textural features of the studied gravel-bed river deposits in the Hollabrunn-Mistelbach Formation.
A) Alternation of relatively coarse- and fine-grained layers within gravel beds – lithofacies Gm, gravel bar (outcrop No. 19).
B) Vertically stacked gravelly and sandy lateral/downstream accretion deposits (notice variations in grain-size (outcrop No. 13).
C) Gravelly lateral/downstream accretion deposits (notice well developed grain-size segregation [outcrop No. 12]).
D) Transition of gravelly into sandy channel fill elements (outcrop No. 17).
E) Erosional pelitic relict of floodplain deposits (arrows) within a gravelly channel [outcrop No. 42]).
F) Relatively thick abandoned channel fill deposits (dark grey) within gravelly sediments of the gravel-bed river (outcrop No. 38).

Grain size and fabric of these deposits vary (Text-Fig. 17 D). Pebbles and cobbles, small pebbles and pebbly sands are dominant. Both clast-supported and matrix supported fabric was observed. Stratification is most often formed by alternation of gravelly and sandy laminae or by alternation of layers of slightly coarser and finer pebbles. Vertical reduction of the grain size was observed in some stacked beds. Vertical and lateral grading into sandy bedforms was recognised repeatedly. Discontinuous mudstone or sandy interbeds were often recognised within the dominant gravelly beds (Text-Fig. 18 B and 18 C). Lateral/downstream accretion deposits are laterally in contact with deposits of gravelly channels and bars.

Interpretation: Internal bounding surfaces indicate changes in accretion direction. The observation of more or less perpendicular orientations of accretion surfaces and foresets of cross-stratified beds reflect the presence of lateral accretion units. Paleocurrent data also reveal a parallel and oblique direction of accretion to the local flow. This indicates downstream accretion units. A complex accretionary geometry can be supposed during changing stages of discharge in the mobile channels. The scale of channel filling bedforms reflects the size of the channel. Flat, broad and mobile channel systems can be documented.

These deposits are the result of lateral/downstream accretion of mid-channel gravel bars within a multiple-channelled river and reflect the lateral mobility of high-energy bedload streams. Laterally accreted gravels probably record late stages of bar development, when vertical growth has reached some limiting height and the flow was increasingly diverted around the flanks (MIALL, 1996). The role of both vertical and lateral accretion can be documented.

The lateral/downstream and vertical grain size decrease and the alternation of sandy and gravelly cross-bedded sets reflect probably the lateral/downstream-migration process and fluctuating water discharge within the channel. Gradual fining into sands suggests a gradual diminution of the flow and filling of the channels. More rapid changes can be supposed if overbank elements are present in superposition of lateral/downstream accretion deposits.

4.3.1.2. Sandy Channel Fill Elements

Sandy channel fill elements were recognised in many studied outcrops often directly above the gravel bars or they develop gradually upwards from gravelly channels or gravelly lateral/downstream accretion deposits (Text-Fig. 18 B and 18 C). Sandy channel fill elements are several meters thick and extend laterally for tens of meters (Text-Fig. 18 D). Their remnants are also found within gravels as isolated bodies.

Sandy channel fill elements are subdivided into sandy channels and sandy lateral/downstream accretion deposits. These architectural elements can be interbedded with each other. This reflects that they were formed simultaneously in a network of shallow channels. Sandy channel fill elements often show evidence of both styles of accumulation (i.e. vertical aggradation and lateral/downstream accretion). The aggradational style is dominant in sandy channels, whereas the accretionary style dominates the internal stacking patterns of sandy lateral/downstream accretion deposits. Sandy lateral/downstream accretion deposits are more common than sandy channels in the studied outcrops.

Sandy deposits are generally supposed to reflect deposition within lower-order channels at low discharge. But they also may reflect deposits of a sand-bed river, in this case evolving from a gravelly one (Text-Fig. 15, sections F, G, H, I). This also can be connected with a change of the fluvial style.

4.3.1.2.1. Sandy Lateral/Downstream Accretion Deposits

A flat broad channel or wedge shape is most typical for this architectural element. A tabular shape is rare. The base is erosive and can be flat or scoured with small depressions (max. 40 cm wide and 25 cm deep). Usually the base is marked by a single-pebble-layer. Tops are often convex up, however, they also can be erosive or gradual (transition to overbank sediments). Strong erosion was observed in a special case, where the thickness is reduced from 1.5 m to 0.1 m, over a distance of 15 m.

Cross-stratification (both Sp and St) is the most typical structure (Text-Fig. 18 C). The thickness of individual sets varies between 10 cm and 40 cm. The maximum thickness of stacked beds was 4.2 m. An alternation of laminae with relatively coarser and finer grains is frequent. The dip angle ranges from 5° to 30°, but is generally relatively low (about 15°). Sigmoidal foresets are common. Angular contacts with the lower bounding surface were also recognised. Reverse ripples within the toeset are rare. Reactivation surfaces are common. The direction of foreset inclination is oblique to perpendicular to the dip-direction of the bounding surfaces and the channel axis.

Medium sand dominates, but grain sizes range from coarse to fine sand. Sands are typically gravelly but the gravel content differs strongly, even within adjacent sets. An alternation of more gravelly and sandier sets was multiply recognised. Pebbles and granules were observed even within fine sands. The pebbles are usually about 1–2 cm in diameter. Mudstone intraclasts were not observed. An upward reduction of grain size is a frequent feature, whereas upward reduction of set thickness is less common. Mudstone and siltstone beds are rare and restricted in extent.

Deposits of sandy channels were recognised within sandy lateral/downstream accretion deposits. Lateral transitions of sandy lateral/downstream accretion deposits to overbank deposits were also observed. Lateral and vertical transition between gravelly and sandy lateral/downstream accretion deposits can be supposed.

Interpretation: Lateral/downstream accretion deposits amongst others are products of accretion within the bars of channels (MIALL, 1996). These bars are characterized by complex accretion (i.e. both downstream and lateral) and are comparable in height and width to the channel in which they have formed (READING, 1996). Shallow and mobile channels and low-relief bars can be documented. A higher content of pebbles at the base of beds or bed-sets can be explained by "gravel overpassing" (MIALL, 1996), which is connected with bedform migration.

Variations in grain size and geometry of sets and co-sets probably reflect fluctuations of water stage and local changes in sediment supply. Reactivation surfaces reflect fluctuations of the flow regime, mostly due to seasonal changes. Bar accretion and channel scour can lead to changes in channel orientation resulting in complex accretionary geometries, commonly with superimposed minor channels, incised during changes of water stage (RAMOS et al., 1986).

4.3.1.2.2. Sandy Channels

The broad flat channel shape is the most significant feature of this element. The base is typically marked by a single-pebble-layer, and can be flat or scoured with small depressions. Tops can be both erosive and gradual.

The width of channels varies between few meters and 30 m. The depth of channels varies between several decimeters and 2.3 m. The width/depth ratio of individual channels varies between 2 and 30 (dominantly below 10). Broad, shallow scours and erosion surfaces (2nd and 3rd order bounding surfaces) indicating stage fluctuations can be followed within the channel fill.

Medium sand dominates in the channel fill, but grain size ranges from coarse sands to fine ones. An upward reduction of width and depth of the channel together with a decrease in grain size was often recognised in outcrop dimension. Coarse sand with gravel is more often in broad and flat channels, whereas narrow channels are filled by medium-fine sand. Gravel laminae were observed within sands. The pebbles are usually about 1–2 cm in diameter. Mudstone intraclasts were not observed. Grain size reduction is very typical for the channel fill. Gradual transition to overbank deposits was recognised repeatedly. Beds, which are conformable to the channel shape, are a typical style of the filling. Thickness of individual beds varies between 10 cm and 70 cm. Maximum thickness of stacked beds was 2.3 m.

Interpretation: Individual bedforms accumulated predominantly by vertical aggradation during the waning stage. Deposition is connected with low channel mobility. Evidence of water-stage fluctuations is given by internal bounding surfaces and gravel laminae. Channel fill can be classified as multi-storey. Stacked channels were very rare. The overall decline of flow strength and gradual filling of the channel is reflected by the decreasing thickness of sets, grain-size reduction and transition to overbank deposits.

Relative scarcity of sandy channel deposits, comparing with sandy lateral/downstream accretion deposits, in the studied depositional system can be explained by the high mobility of the channels. Still less frequent occurrence of mudstone beds is the result of the high mobility of channels and the erodibility of their non-cohesive bank material.

4.3.1.3. Overbank Elements

Coarse-grained bedload rivers typically carry both gravel and sand in varying proportions. But they also transport substantial volumes of suspended load, especially during floods (READING, 1996). However, the suspended matter is mostly carried through and deposited beyond the gravel reach and only part of this material may be deposited in overbank and/or abandoned channel settings.

Overbank deposits have a relatively low preservation potential in a braided river environment (RAMOS et al., 1986). They are usually remnants of overbank sediments laid down on floodplains, on the top of gravel islands or as fills of abandoned channels. Their relative abundance in the studied system could be a signal of a specific fluvial style (e.g. wandering river?), existence of several distinct topographic levels within the "river valley" or repeating changes of the whole fluvial system. Also the alternation of periods with high and low discharge, due to seasonal variations may play a role. The formally still higher portion of overbank fines is further reflected by the abundant presence of large intraclasts, predominantly near the base of gravelly channel fill elements (Text-Fig. 17 H). Such a situation may be related to major erosion surfaces, which develop by main-channel migration leading to widespread reworking of overbank sediments.

The overbank elements can be subdivided into abandoned channel fills and floodplain fines. The overbank deposition predominantly is reflected by abandoned channel fills. The less frequent occurrence of floodplain fines can be explained by highly mobile channels.

4.3.1.3.1. Abandoned Channel Fills

These deposits form channel-shaped bodies (Text-Fig. 18 E). Their thickness varies from several dm to 4.2 m. Fine-grained channel fill deposits thicker than 1 m have been recognised in several outcrops (Text-Fig. 18 F). Sometimes they are traceable for a distance of more than 20 m, but usually to a lesser extent. Erosive tops, rarely connected with loading structures, are typical.

Multiple alternations of sand-mud couplets (10 cm to 30 cm thick) can often be recognised near the base. Sh or Sr form the sand member of the couplets. Sands are sometimes pebbly. Fm and Fl form the muddy member of the couplets. Load and flame structures were recognised. These sand-mud couplets grade upwards into monotonous mudstones due to the progressive reduction of the sand member. Together with the grain-size fining a reduction of the extent of the successive beds upwards the profile was multiply observed. Mudstones are often massive (Fm) or finely laminated (Fl). In several outcrops monotonous mudstones were recognised as the only sediment type of abandoned channels. The thickness of these monotonous mudstones is max. 1.2 m.

Roots (Fr) were recognised in several outcrops. Convolute bedding was rarely detected and reflects rapid escape of the pore-fluid. Horizons of isolated nodules of whitish calcareous mudstones (facies P) within dominantly brown, green-brown to green-grey mudstones were occasionally observed. These calcareous mudstones do also occur as intraclasts in the channel area. Mudstones of various colours also differ significantly in chemistry (e.g. Table 4). Samples 2 and 4 in Table 4 originate from the calcareous mudstones, whereas samples 1, 3 and 5 are derived from brown and grey mudstone types.

Interpretation: The external channel shape reflects the important role of channelling for both the formation of depositional space and the preservation of overbank deposits. It also reflects shifting (meandering?) of the main watercourse. Abrupt lateral transitions between distinct elements reflect a position within an abandoned channel.

Generally two types of channel abandonment were observed. "Rapid" abandonment (avulsion) is connected with the occurrence of overbank deposits directly above the gravelly elements (Text-Fig. 15, sections A, B). This seemingly happened quite often and resulted in stagnant water bodies in channel-shaped depressions. Deposition from suspension after all led to the filling of these depressions. A strong dominance of fine-grained lithofacies is typical for this type of abandonment. "Gradual" channel abandonment is connected with the occurrence of overbank deposits above the deposits of sandy channels. This situation is connected with a continuous decrease of stream activity in the channel. Shifting of the thalweg is supposed. Upward fining of grain size, together with reduction of both bed extent and portion of sandy beds reflect the gradual filling of the channel. The channel fill was influenced less and less by inflows from the "main" river course (Text-Fig. 15a, sections E and I).

Soil-forming processes on the floodplain affected the freshly deposited sediments. Soil horizons are generally poorly developed in areas with rapid sediment deposition (LEEDER, 1999). The whitish calcareous mudstones can be

Table 4.
Chemical analyses of mudstones in the Hollabrunn-Mistelbach Formation. Results in weight percent. Sample 1: outcrop No. 25, Sample 2: outcrop No.14, Sample 3: outcrop No.10, Sample 4 and 5: outcrop No.19.

	1	2	3	4	5
SiO_2	53.0	8.67	52.08	12.24	56.48
TiO_2	0.72	0.12	0.67	0.19	0.78
Al_2O_3	15.99	2.57	16.77	3.87	18.18
Fe_2O_3	4.24	1.37	3.68	1.11	5.23
FeO	1.36	0.32	1.31	0.13	0.67
MnO	0.04	0.05	0.04	0.02	0.03
CaO	5.99	46.96	3.66	42.1	1.11
MgO	3.28	0.3	5.1	1.84	3.39
K_2O	2.82	0.4	3.09	0.7	2.9
Na_2O	0.37	0.25	0.32	0.23	0.2
S	0.1	0.11	0.05	0.14	0.36
CO_2	5.03	37.3	4.85	35.13	0.57
P_2O_5	0.15	0.08	0.11	0.11	0.1
H_2O-	2.81	0.4	2.65	0.72	3.68
H2O+	4.64	1.1	5.07	1.0	6.12
Total	100.5	100.0	99.45	99.53	99.80
Al_2O_3/Na_2O	43.2	10.3	52.4	16.8	90.9

interpreted as relics of calcareous paleosoils (high content of CaO). The chemistry of mudstones (e.g. Table 4) indicates big differences in the content of K_2O, Al_2O_3 and $\pm H_2O$, which can be explained by the presence of different amounts of kaolinite and hydromicas. The dominance of K_2O versus Na_2O can be explained by low amounts of montmorillonite. The positive relation of SiO_2 and Al_2O_3 reveals the occurrence of relatively coarse-grained material within the clay-fraction. A relatively low content of organic C (about 0.7 %) can be explained by intensive leaching (only 2 samples of dark grey mudstone were analysed). The groundwater probably contained high concentrations of Ca^{2+} because carbonates are important components of the HMF. Differences of the mudstone chemistry may be seen in connection with various overbank processes.

The formation of calcareous paleosoils may last several thousands of years in areas of high Ca_2^+ supply (LANG, 1993). This indicates that at least parts of the overbank area were stabilized (i.e. exposed to subaerial weathering) for such a period of time. This can be explained in terms of the margins of the channel belt, important shifts of the channel belt(s) or changes of the whole fluvial system. The frequency of channel avulsion may be in relation to tectonic, climatic (large magnitude floods) or relative lake-level changes (influencing the accommodation space by changing the erosional base) (LEEDER, 1999). Better understanding of the soil formation can be crucial for further studies (cf. MCCARTHY et al., 1999).

4.3.1.3.2. Floodplain Fines

These deposits have a sheet-like or slightly lenticular shape and laterally wedge out within distances of several meters (up to 30 m). Their thickness varies and reaches a maximum of 2.2 m. They are typically formed by an alternation of couplets, a few cm up to 20 cm thick, of a sandy bed (mainly Sl, Sr, rarely Sp, St) and a mud bed (Fl, Fm, rarely Fr) (e.g. Text-Fig. 19A, Text-Fig. 15, sections E and I). Sands are rarely pebbly. Mudstones usually dominate over sands and in some cases only sandy laminae were recognised within them. Discontinuous lentiform beds (20 cm long and 15 cm thick) of very coarse sand or granules to small pebbles were recognised occasionally within mudstones. Occurrences of facies P were also noted. Load and flame structures were observed at the base of sands. The upper surface of the deposits is often erosive (erosion by gravelly lithofacies).

Interpretation: Floodplains existed on the periphery of the highly mobile fluvial channel belt. The floodwater breaks through the channel banks and spreads as a sheet flood over the floodplain. The deceleration of the expanding flow will lead to deposition of graded sand-mud couples. Since river floods were periodic, rhythmic bedding developed. The varying magnitude of the flood events led to the alternation of relatively finer and coarser sand-mud couplets. Continued sediment supply during numerous flood events can form extended and thick packages of floodplain deposits. Discontinuous coarse-grained beds within them probably are scour-and-fill structures or microchannels.

4.3.2. Deposits of the Braid-Delta

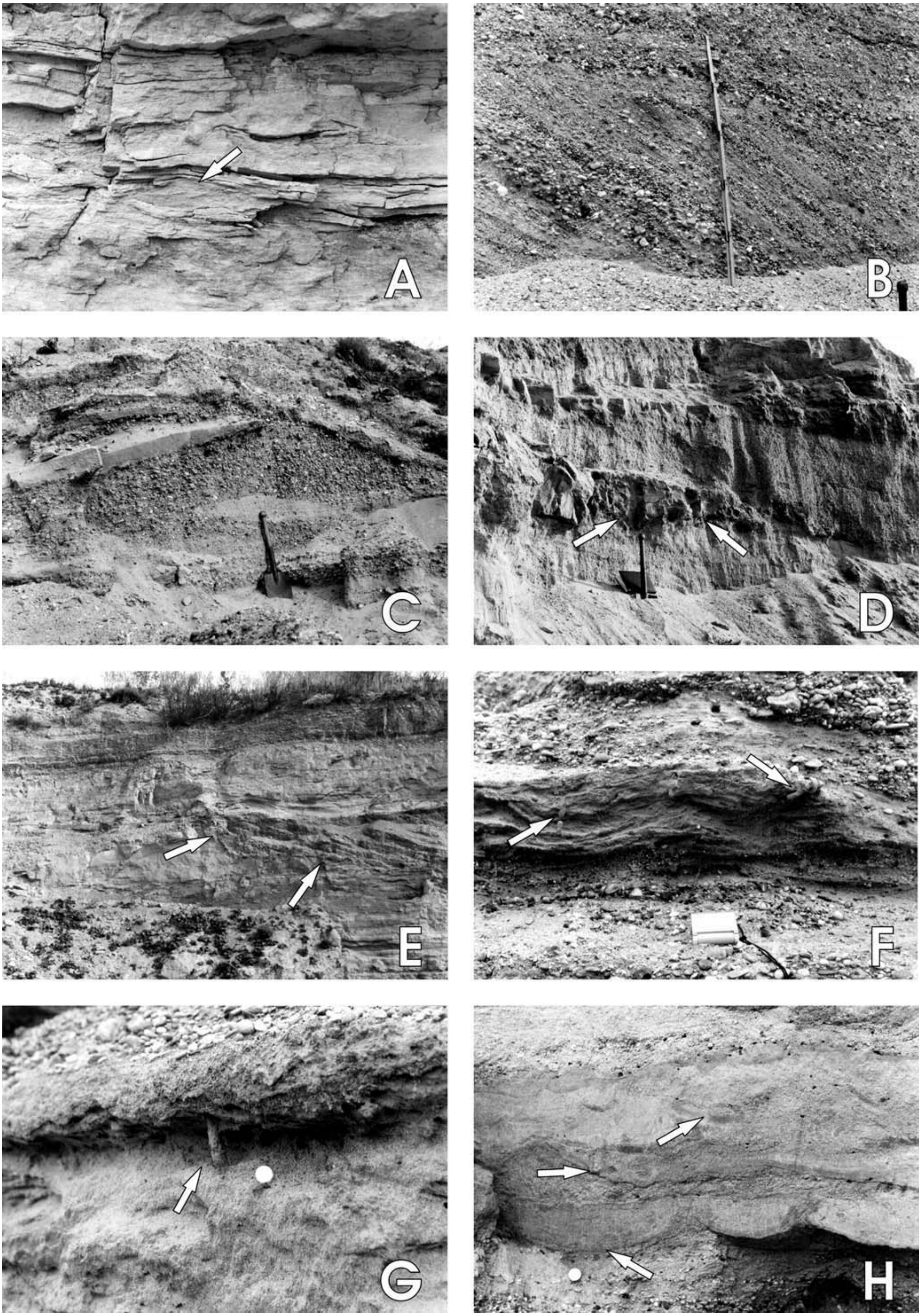
The depositional environment of a braid-delta was recognised in outcrops in the wider surroundings of Mistelbach. Outcrops in this area have smaller vertical and lateral extent, compared to the outcrops of the HMF in the west. The facies interpretation is based on the results of facies study and fossils, like mollusc shells and trace fossils. The term braid-delta is used for a braided fluvial system entering a relatively shallow, standing body of water (POSTMA, 1990).

The deposits of the braid-delta can be subdivided into deposits of distributary channels, mouth bars, gravelly beaches, foreshore and shoreface deposits and deposits of the interdistributary area (Text-Fig. 19 B-H). A schematic diagram of a braid-delta is presented in Text-Fig. 20. The studied deposits represent a proximal part of the braid-delta system because of its co-existence with a fluvial system and the dominant role of a gravelly lithofacies. The rare presence of gravelly beach and foreshore and shoreface deposits and a weak influence of littoral processes on pebble shape and roundness can be explained by a high fluvial input of coarse material into the basin and a limited extent of its redistribution along the shoreline. Low wave and current energy at the basin margin and sufficient accommodation space may be responsible for this.

4.3.2.1. Distributary Channels

Deposits of distributary channels typically show a broad and shallow channel shape. Their thickness reaches a maximum of 5.6 m and in rare cases they can be traced on a distance of 25–30 m. They have an erosive, broadly concave downward base cutting into a fine-grained or sandy lithofacies. The coarsest clasts (gravel lag) are located close to the sole. The tops are sharp and planar, but sometimes also concave downwards.

Flat sets of trough or planar cross-stratified gravels (Gt, Gp) or gravelly sands (St) with concave downward base represent the typical fill of the channels (Text-Fig. 19 C, 19 E). The length of individual sets varies between 0.25 m and 5 m. The set thickness fluctuates between 0.1 m and 0.4 m. The dip angle of cross-stratification is generally relatively low (about 15°). Small pebbles dominate in the grain-size spectrum. The maximal observed clast was about 7 cm in diameter. Gravels are mainly clast-supported with an openwork fabric, but also matrix-supported types were recognised. Distinctive stratification is caused by alternation of strata of relatively coarser and finer clasts or beds with relatively lower and higher portions of sand. A(t) B(i) imbrication is characteristic, reflecting the orientation of elongated clasts along the channel axis. Intraclasts are very rare and are mostly connected with erosional contacts to mudstone beds. They are of similar size as extraclasts. In one case an unusually large intraclast (2 m in diameter) was observed in a position at the margin of a channel. Its origin is obviously connected with undercutting and collapse of the cohesive channel bank, which led to a flattening of the steep channel edge. The occurrence of mollusc shells is infrequent. Dis-


A
B
C
D
E
F
G
H

Text-Fig. 19.
Structural and textural features of the studied gravel-bed river (A) and braid-delta deposits (B–H) in the Hollabrunn-Mistelbach Formation.
A) Floodplain deposits with symmetrical in phase ripples (arrow) (outcrop No. 24).
B) Mouth bar deposits with nicely developed foresets (outcrop No. 54).
C) Alternating coarse- and fine-grained deposits of distributary channels (outcrop No. 55).
D) Stacked distributary channel deposits reflecting channel fill and abandonment (arrows: erosional relict of a mudstone bed) (outcrop No. 52).
E) Isolated gravel-filled distributary channel (arrows) within mudstones of the interdistributary area (outcrop No. 53).
F) Foreshore and shoreface deposits represented by lenticular beds of rippled sands with abundant trace fossils (arrows) (outcrop No. 54).
G) Subvertical burrow (arrow) within foreshore and shoreface deposits (outcrop No. 54).
H) Deposits of the interdistributary area with distinct contacts of mudstones, sandy and gravelly beds; notice also penecontemporaneous deformation structures and trace fossils (arrows) (outcrop No. 47).

continuous thin (2–6 cm thick) intercalations of sandy beds (Sp, St, Sr) and erosional relics of mudstone layers (about 10–20 cm thick) were recognised within gravels.

Grain size fills of the channels sometimes reflect a fining upward trend. Facies St and rarely Sp (dip angle of about 10°) rarely can be observed above the gravelly beds. The thickness of the sands is 1.5 m at most. Relatively well sorted medium to fine sands with small pebbles at their base are typical. Coarse sand rarely was observed. The width of individual sandy sets varies from 1 m to 5 m, their thickness is about 0.15 to 0.5 m. The presence of mollusc shells or their debris is characteristic. Facies St and Sp grade upward into facies Sl and/or Sr, made up of fine to medium sand. Pebbles and granules occur within the fine sands randomly scattered (textural inversions) or as 5 cm thick at most, discontinuous and diffuse horizons. Flat laying intercalations of parallel laminated mudstones (1–5 cm thick) also can be recognised within the sands. Their contacts to the sands are usually sharp with loading structures (Text-Fig. 19 H). Sands are fining upward into mudstones of the interdistributary area. Small vertical burrows (about 2 cm deep and 1 cm in diameter) sometimes were recognised at the base of the channels. The burrows are filled with fine gravel/granules and deepen down into the deposits of interdistributary or foreshore and shoreface areas.

Interpretation: Distributary channels were cut into the deposits of interdistributary areas predominantly during flood periods. Gravelly and sandy bars migrate both laterally and downstream within the channels. The characteristic fining upward trend reflects the reduction of energetic conditions of transport. A multi-storey fill of the channels can be documented. Internal organisation of channels reflects the alternation of periods of higher and lower discharge and migration of flow and channel bedforms. Vertical accretion of bedforms finally led to channel filling and its abandonment (Text-Fig. 19 C, 19 D and 19 E). Finer grained sandy beds reflected the final filling stage of the channel and transition to the interdistributary area.

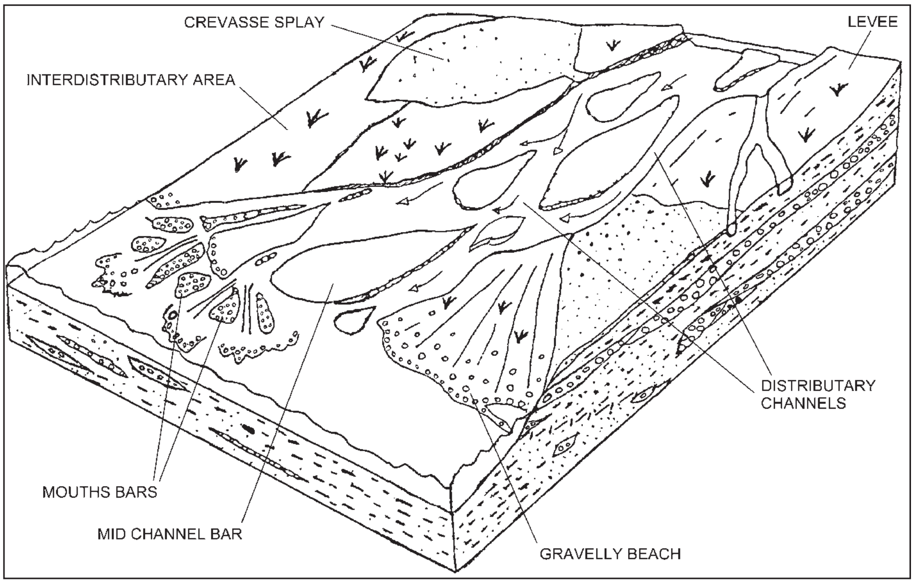
The relatively smaller scale of distributary channels, compared to the upstream fluvial channels (both gravelly and sandy channels), especially according to their depths, can be the result of a higher accommodation space/sediment supply-ratio in the depositional environment of the braid-delta. The relatively higher stability of distributary channels could be due to the cohesiveness of the banks within the interdistributary area. The important presence of gravelly lithofacies within the distributary channels is an evidence of high discharge at least during flood periods. Shells are reworked and transported as clasts and originate both from the bedrock and adjacent interdistributary areas.

4.3.2.2. Mouth Bars

Mouth bars show a typical tabular or very slightly irregular (lenticular) shape and consist of planar cross-stratified gravels (Gp). Their thickness varies between 0.2 m to 1 m (Text-Fig. 19 B). Cross-stratified gravels often grade upward into horizontally stratified gravels (Gh) and finally into rippled coarse sands (Sr). The maximal recognised thickness of stacked beds was about 3.5 m. Sharp erosive bases are typically planar or slightly curved. Pebbles and granules form the dominant portion of gravels with a maximal clast diameter of up to 8 cm.

Individual foresets have a thickness of 5–15 cm and are usually clast supported and often show an openwork fabric. Alternation of layers with slightly coarser and finer pebbles and an upward reduction of grain size are typical. The dip of foresets is relatively low (about 15°). Higher dip angles were observed in thicker beds. A (t) B (i) imbrication is dominating but also A (p) A (i) orientation was observed. The occurrence of mollusc shells is very characteristic. Inclined interbeds of fine to medium sand are also present. Both gravels and sands typically are moderately to well sorted.

Interpretation: Coarse-grained deposits can accumulate where gravelly rivers enter the sea, respectively the lake. The sediment is dumped at the end of subaqueous channels leading to the growth of gravelly mouth bars. The cross stratification reflects the lakeward accretion of the front of the bar during flood conditions. Sedimentary structures are the result of bedload material rolling and avalanching down the slipface of the bedform. Shells are reworked and occur as clasts. Mouth bars of the braid-delta



Text-Fig. 20.
Schematic block diagram of a braid-delta depositional environment.

are smaller (particularly according to height) than gravel bars of the gravel-bed river. This reflects a relatively low angle of the depositional surface of both the delta front and the foreshore and shoreface environment. Horizontally stratified gravel beds and rippled coarse sands can represent middle or upper parts of the mouth bar (RASMUSSEN, 2000). Their small thickness may indicate the deposition at the end of rapidly shifting shallow currents on the top of the bar. The accumulation of mouth bars usually continues until they are subaerially exposed (KLEINSPEHN et al., 1984 in RASMUSSEN, 2000). Later reworking of such deposits by waves or by biogenic activity may change the original sedimentary features. Deposits of mouth bars are in contact with deposits of distributary channels. A dominant role of fluvial processes during the development of the mouthbars can be supposed. A general lakeward dip of the foresets (i.e. to SSE, SE, E or ENE) can be documented.

Deposits of sediment gravity flows, which can be generated during the gravitational or current reworking of the finer material of the mouth bar fronts (RASMUSSEN, 2000), were not recognised in the studied outcrops. Such an absence and the apparent dominance of fluvial processes reflect a relative proximity of the studied outcrops to the river mouth.

4.3.2.3. Gravelly Beaches

Cross-stratified gravels typically grade upwards into horizontal or low angle cross-stratified gravels with a higher presence of mollusc shells. Horizontally laminated or rippled very fine to fine sands were recognised at the top of these gravels. Horizontally to low angle cross-stratified sandy beds alternate with lenses of granules and small pebbles. Sandy beds are 5 to 20 cm thick. Sands are often bioturbated and typically contain mollusc shells or shell debris. A good sorting of sands together with a good separation of gravel and sand are typical. Deposits of gravelly beaches are about 1 m thick and have a tabular to wedge shaped geometry.

Interpretation: Littoral processes rework the pebbly material of the river mouth. A higher importance of these processes can be supposed after the abandonment of distributary channels. The interpretation of littoral influences is strongly supported by the presence of trace fossils and mollusc shells (e.g. HART & PLINT, 1995; LEITHOLD & BOURGEOIS, 1984; NEMEC & STEEL, 1984; RASMUSSEN, 2000). Deposits of gravelly beaches were recognised relatively rarely in the HMF. They are situated close to the top of mouth bars and are possibly associated with transgressive surfaces. Pebble shape segregation as described by POSTMA & NEMEC (1990) for shoreline conglomerates was not clearly recognisable. An enriched content of discoidal and spherical pebbles together with a relatively good rounding was observed (Text-Fig. 7). Sandy beds within the deposits of gravelly beaches were interpreted as foreshore and shoreface deposits.

4.3.2.4. Foreshore and Shoreface Deposits

Tabular to broadly lenticular beds of medium to fine sands with abundant occurrences of mollusc shells or shell debris are characteristic for these deposits. Sands are usually horizontally laminated to low angle cross-stratified (Sp) or bioturbated (Sb) (Text-Fig. 19 F). Alternations of planar cross-stratified sets with relatively high dip angles of about 15° and sets with relatively low dip angles of about 3° were also found. Occurrences of lithofacies Sr, St, and Fh are subordinate. Elongated shells show a preferred orientation perpendicular to the dip of the cross stratification. The thickness of individual sets is about 5–10 cm. The compound thickness of foreshore and shoreface deposits is about 0.5–1 m and can be laterally followed up to 100 m. Sometimes parallel laminated or rippled very fine sands form the top portion of beds. Thin (about 5 cm thick) mudstone interbeds were also observed within these top parts.

These deposits sometimes were recognised on the top of gravelly beds (distributary channels, mouth bars, gravelly beaches). Alternations of 5–10 cm thick strata of coarse to very coarse sand with similarly thick strata of medium to fine sand were observed in such cases. The basal contacts of the coarse sands are mostly sharp and show loading structures. Vertical and subvertical burrows with dip angles between 45° and 80° are very characteristic, and have a maximal length of 6 cm and are about 1.5 cm in diameter (Text-Fig. 19 G). The tops of foreshore and shoreface deposits are erosive. Deposition of gravelly sediments from mouth bars, channels and beaches were recognised in superposition of the foreshore and shoreface deposits.

Interpretation: Material transported by fluvial action was deposited near the channel mouth. Littoral processes redistributed these deposits and depositional surfaces were flattened during periods of low fluvial discharge. The rhythmic alternation of relatively coarser and finer grained deposits and various bedding types were probably linked to changing energetic conditions. The abundant presence of trace fossils suggests that the sedimentation rate was sufficiently low to allow colonisation by a rich benthic fauna. Bioturbation disturbed the primary sedimentary structures.

Foreshore and shoreface deposits were recognised in association with deposits of mouth bars, gravelly beaches, distributary channels and interdistributary areas. Their cooccurrence reflects a complex relation of sediment supply, processes of its redistribution and formation of accommodation space. The role of littoral processes can rise when channels are abandoned and the sediment supply declines. A similar situation can be achieved by a lakelevel rise. From outcrop 56 HARZHAUSER et al. (2000, 2003) described a transgressive event linked to such a lake level rise.

4.3.2.5. Interdistributary Area

Deposits of the interdistributary area form tabular bodies, which are usually few meters thick and can be laterally followed for tens of meters. They were typically deposited directly above the gravelly or sandy beds of distributary channels, rarely above the foreshore and shoreface deposits. The maximum thickness was 3.4 m. The base is planar or slightly undulating.

Mudstones form the absolute dominant portion of these deposits. They are massive or parallel laminated and the occurrence of discontinuous calcrete horizons was observed several times. Mudstones with mollusc shells or trace fossils (vertical burrows) were rarely recognised (Text-Fig. 19 H). Convolute bedding and other penecontemporaneous deformation structures were also observed. Thin (maximally 10 cm thick) planar interbeds of fine to very fine sand can be followed within the mudstones. Such sandy layers have sharp, almost planar or slightly concave downward bases (Text-Fig. 19 H). Their shape resembles very flat and broad micro-channels. Sands are micaceous, very well sorted, parallel laminated or rippled. Climbing ripples were recognised too. Small pebbles (up to 2 cm in diameter) can occur in the mudstones, forming either thin pebble-strings or maximally 10 cm thick layers. Coarse clasts up to 8 cm in diameter (cobbles) were found randomly scattered within 2 to 3 m thick beds of parallel laminated very fine sand to mudstone in outcrops 47 and 48. An isolated distributary channel filled with gravels was found within the mudstones (Text-Fig. 19 E). Its width was about 25 m and the thickness was more than 1 m.

Interpretation: Dominantly laminated or massive mudstones imply quiet depositional conditions and suspension deposition from waning floods. We can suppose relatively flat interdistributary areas dominantly affected by floodplain processes. The relatively large thickness of mudstones reflects a high sediment supply and abundant accommodation space. Alternations of mud layers with erosively based sandy layers can be interpreted as levee or crevasse splay deposits (READING, 1996) generated by an alternation of flood and normal flow conditions. The role of littoral processes was limited. Soil-forming processes affected the deposits of the interdistributary area. Occurrences of calcretes reflect that the interdistributary area was not permanently water covered in the whole area.

The large flat interdistributary area was cut by distributary channels. Gradual infilling and abandonment of these channels can be followed within the profiles. An episodic sand deposition within the protected area laterally to the active distributary channels can be supposed.

Deposits of the interdistributary area usually form the upper part of the studied profiles. The distributary channels cutting into them from the top may reflect the beginning of a new depositional cycle. Erosion by the action of distributary channels may have reduced the thickness of mudstone beds. A higher preservation frequency (and larger areal extent?) of the interdistributary area deposits, compared to the deposits of the overbank environment upstream, can be supposed, because distributary channels were more widely spaced than the fluvial ones.

5. Discussion

Two scales of cyclicity motives have been originally recognised within the deposits of the HMF (NEHYBA, 2000). Fining upward (FU) cycles with a thickness of about 15–20 m represent a large-scale cyclicity (Text-Fig. 15, sections H, I). These cycles start with several meters (about 10 m) of gravel beds (lags, bars, lateral/downstream accretion deposits and channels). Several meters (about 5 m) thick sandy beds (lateral/downstream accretion deposits and channels) overlie the gravels. Relatively thick floodplain deposits can form the final part of the cycles. The thickness of the overbank deposits can be reduced because of the erosion by gravel beds of the next cycle. Cyclicity of this scale generally fits with the scale of the largest outcrops. These FU cycles could reflect lateral migration of channels and/or existence of several distinct topographic levels within the river valley (MIALL, 1996). However, the question arises whether these FU cycles could reflect various fluvial styles (i.e. transition from gravel-dominated to sand-dominated rivers). The existence of both types of fluvial styles in time and probably space can be supposed due to the observation that several meter thick gravelly and sandy depositional units are multiply alternating (Text-Fig. 15, sections F, G). Such processes could be connected with allocyclicity and changes of the base level, induced by tectonic or climatic changes in the source area or relative lake-level changes. By HARZHAUSER et al. (2004) an astronomic forcing, like the 2.35 Ma eccentricity cycle, is considered as trigger in a higher level.

The smaller scale cyclicity frequently was recognised within both gravelly and sandy lateral/downstream accretion deposits and channels (Text-Fig. 15a, sections C, D, E). Vertical FU successions are about 1–3 m thick. These cycles may have developed by the migration of mid-channel bars.

Within the braid-delta deposits the succession delta plain (distributary channels) – delta front (mouth bars) – foreshore and shoreface deposits (gravelly beaches, shoreface) – delta plain (interdistributary area) can be observed. Because of the small vertical extent of the outcrops this complete, generally FU succession could be observed only in a few outcrops, where it is about 20 m thick. The similarity of scales of the FU cycles within gravel-bed river and braid-delta deposits could probably reflect the important influence of allocyclic processes on the stacking patterns.

Marked differences between the gravel-bed river and braid-delta deposits exist with respect to the proportion of individual lithofacies. Whereas fine-grained deposits play a minor role in the studied river area their role is very significant in the braid-delta area. Gravelly and especially sandy deposits are less important in the deltaic environment. A relative dominance of gravelly channels and lateral/downstream accretion deposits in the studied river deposits could be explained by quick and frequent fluctuation of water discharge, a higher depositional slope and proximity to the source areas. A relatively higher presence of vertical accreting deposits in the braid-delta indicates a higher proportion of accommodation potential/sediment supply than in the gravel-bed river area.

Laterally extensive coarse-grained fluvial deposits with an important role of gravel bars, shallow channels and the dominance of gravel traction-current deposits are often classified as braided river deposits. However, the evidence of both gravelly and sandy lateral/downstream accretion deposits, the relatively thick and common sandy channel fill deposits and the relatively abundant overbank deposits in some outcrops are very remarkable features of the studied fluvial deposits, which are not typical for braided rivers. These features can indicate a gradation to the higher sinuosity fluvial style i.e. a gravelly wandering river (MIALL, 1996). Abundant sandy channel fill deposits in other outcrops could reflect the transition to a sandy braided river evolving from a gravelly one. We can also speculate about a coarse-grained fluvial system with several distinct topographic levels, including major and minor channels, bar surfaces, and a floodplain, spaced over a vertical range of several meters. Higher levels are active only during flood stages (i.e. deep, gravel-bed braided river – MIALL [1996]). Lateral migration of channels, in such a case, is accompanied by the aggradation of abandoned channel reaches, and the generation of fining upward successions. Relatively higher proportions of overbank deposits within the "lateral/marginal" parts of the HMF could be an indication of such topographic levels. The uncertainties according to detailed stratigraphy of individual outcrops together with the relatively small extent of the outcrops are difficulties for a clear interpretation of the fluvial style of the studied river deposits.

The complicated petrography of the source areas (especially of the eastern part of the Northern Calcareous Alps) and the varying bedrock petrography can explain the polymict and locally varying pebble composition of the HMF. Episodic transport, erosion and deposition are in general typical for coarse-grained rivers (MARZO et al., 1988; RUST, 1984). General transport from W to E was frequently complicated by "transverse" transport directions, which are generally trending towards the north. This means that additional source areas along the course of the main channel belt contributed to the component spectrum. Prolonged river transport led to a reduction of the portion of less stable rock pebbles and also to a concentration of stable clasts (dominantly quartz) in the relatively finer fraction. But tributaries, mainly from the south, supplied new material (rich in less stable rocks, like limestones and other sedimentary rocks) to the system and significantly influenced the pebble composition, especially of the coarse fraction. More distinct differences in pebble composition occur between individual outcrops in the eastern part of the study area than in its western part (e.g. Text-Fig. 3). This observation supports the idea of tributaries, which entered the system in its middle reach. Tectonic uplift in the Eastern Alps and extensive erosion led to relief conditions where coarse clasts were produced and fed into the river system of the HMF via a number of tributaries. The studied fluvial system had probably enough "spare" transport capacity and thus can be assigned as "under-saturated by coarsest clasts" (FRIEND, 1993) because additional local supply did not cause any change of the fluvial style. A schematic and speculative paleogeographic reconstruction of this river network is presented in Text-Fig. 21. Taking into account the significant thickness of the HMF, it seems quite likely, that this situation might have been complicated by several stages of development of the river system. These stages could have been controlled by changes in the source area (tectonic or climatic), or by fluctuations of the relative lake level (base level). The supposed thickness of the formation generally indicates a relatively high subsidence rate.

Upstream (tectonics, climate, bedrock geology) and downstream processes (lake-level changes) could affect the fluvial architecture in a complex manner (BLUM & TÖRNQVIST, 2000; EMERY & MYERS, 1996). The existence of several stages of deposition/fluvial styles in the studied system can be supposed. The considerable thickness of the laterally extensive deposits of the HMF and the long time span of its deposition support such speculations. JIŘÍČEK (1985) describes deltaic sandy and gravelly bodies of Pannonian age in the southern Czech part of the Vienna Basin. The petrography of pebbles (generally about 30 % of quartz, less than 10 % of crystalline rocks and more than 60 % of sediments/dominantly carbonates) strongly resembles the results from the eastern part of the studied HMF deposits. Multiple prograding/retrograding cycles of deltaic deposits into the basin during Pannonian described by JIŘÍČEK (1985) can be a response of lake-level changes. These processes could also affect the fluvial style of rivers entering the lake.

A separate stratigraphic sequence within the Pannonian (zones B/C – zone E) has been recognised for the Western Carpathian basins (BARÁTH & KOVAČ, 2000). A distinct erosive surface represents the lower sequence boundary (KOVAČ et al., 1998). The base of the HMF can be correlated with this type 1 sequence boundary. By HARZHAUSER et al. (2004) the Lower to Middle Pannonian deposits of Lake Pannon are interpreted as a single 3rd order cycle, which starts at the Middle Miocene/Upper Miocene boundary due to the glacio-eustatic sea-level lowstand TB 3.1. DECKER (1996) supposes that the strongly accelerated rift-basin subsidence terminated within the Upper Pannonian at about 8 Ma. This generally fits well with the supposed end of deposition of the HMF. The end of the deposition of the HMF can also reflect an east–west compressive event (inversion) within the Vienna Basin dated as late Pannonian (9 to 5.6 Ma) (DECKER, 1996; PERESSON & DECKER, 1996).

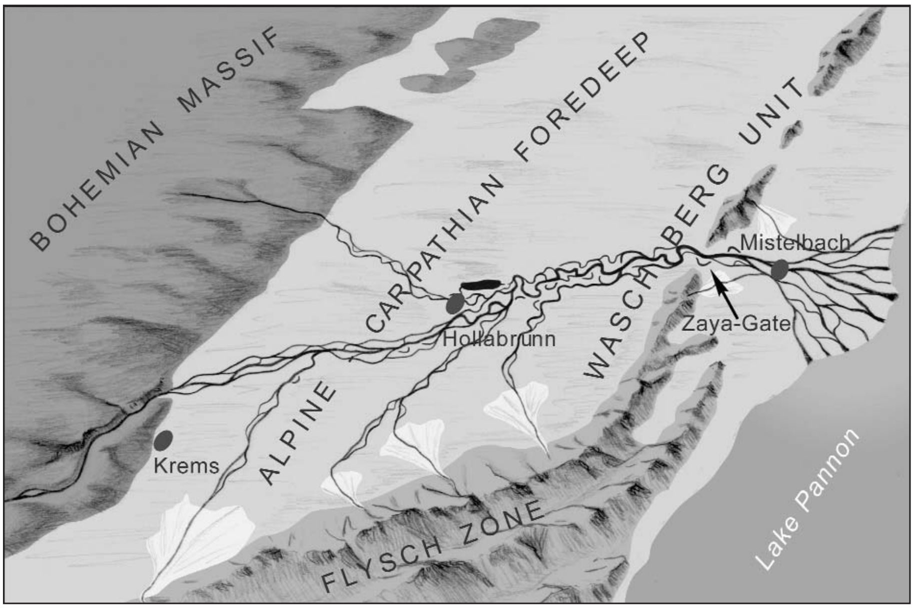
The relatively small extent of outcrops within the HMF and uncertainties according its detailed stratigraphy and total thickness do not allow to establish a detailed allostratigraphic subdivision and to identify the type of external controls influencing the system in the sense of sequence stratigraphy (BLUM & TÖRNQVIST, 2000; BURNS et al., 1997; EMERY & MYERS, 1996; MCCARTHY et al., 1999; PLINT et al., 1999; SHANLEY & MCCABE, 1994).

6. Conclusions

Two genetically related depositional environments have been recognised in the studied outcrops of the deposits of the Hollabrunn-Mistelbach Formation (HMF) between Krems and Zistersdorf. The dominant gravel-bed river depositional environment developed into a braid-delta environment towards the east.

The architectural elements of the gravel-bed river deposits of the HMF can be subdivided into three larger scale elements: gravelly channel fill, sandy channel fill and overbank fines. These larger scale elements can be subdivided into smaller ones. The gravelly channel fill elements represent the most significant deposits of the studied outcrops. They can be subdivided into channel lags, gravel bars, gravelly lateral/downstream accretion deposits and gravelly channels. The sandy channel fill elements are quite common and several meters thick. They were subdivided into sandy lateral/downstream accretion deposits and sandy channels. Overbank elements are quite commonly preserved. They can be subdivided into abandoned channel fills and floodplain fines. Relics of calcic paleosoils also have been recognised. Bedforms developed in relatively shallow, broad, and mobile channel systems. Such channels were sensitive to abandonment and filling. Two types of channel abandonment were described. The rapid shifting of relatively shallow and broad channels led to a laterally extensive bar-channel morphology. Non-cohesive sandy and gravelly banks of the channels are typical together with the frequent development of lateral/downstream accretion deposits. Gravelly wandering rivers, gravelly braided rivers and sandy braided rivers are discussed as possible fluvial environments. The role of several distinct topographic levels within the river valley is also discussed. A braided fluvial style is supposed as probable model for the fluvial environment of HMF, however, in parts a lateral and vertical gradation to a higher sinuosity fluvial style, i.e. a gravelly wandering river, is probable.

The studied deposits of the braid-delta represent the proximal part of the delta and were subdivided into deposits of distributary channels, mouth bars, gravelly beaches, foreshore and shoreface



Text-Fig. 21.
Hypothetical reconstruction of the depositional systems of the Hollabrunn-Mistelbach Formation during the Upper Miocene (Lower Pannonian) in the Alpine-Carpathian Foredeep and the Vienna Basin.

and interdistributary areas. The dominant role of fluvial processes, a high sediment input, a relatively low inclination of the depositional surface and sufficient depositional space are supposed for this deltaic environment. The relatively common trace fossils and mollusc shells suggest, that the sedimentation rate was sometimes sufficiently slow to allow colonization by a rich benthic fauna. In the braid-delta depositional environment a proportion of accommodation potential/sediment supply higher than in the gravel-bed river environment is supposed.

Fluvial and distributary channels are often oriented in eastward, northeastward, and northward directions, but also southeastward and southward orientations occur. The orientation of paleocurrents reflects a complex current pattern, which can be explained by highly mobile, rapidly shifting channels or channel-belts with varying water discharge. The main axial transport of the whole system was oriented towards the east. This orientation is often complicated by "transverse" transport directions, in most cases towards the north. The role of this transverse transport is supported by the results of the study of pebble composition.

The polymict and locally varying pebble composition can be explained by the complicated petrography of the source areas (especially in the eastern part of the Northern Calcareous Alps), the varying bedrock petrography, and mixing of material from various primary and secondary (recycled) sources. The tectonic uplift in the Eastern Alps created a relief where extensive erosion took place, providing the coarse clasts of the HMF.

The development of the fluvial system of the HMF through time was probably affected by several stages. These stages can be supposed due to the observation of large-scale fining upward cycles. Allocyclic processes like tectonic and/or climatic changes in the source area or changes of the relative lake-level (erosion base) might be the responsible factors.

Acknowledgements

The fieldwork of Slavomír NEHYBA was kindly supported by the Geological Survey of Austria. Hans-Georg KRENMAYR (Geological Survey of Austria) did the review of the article and we also want to thank him very much for numerous discussions and critical remarks. Valuable information about the stratigraphy of the Pannonian sediments came from Gudrun DAXNER-HÖCK and Mathias HARZHAUSER (Museum of Natural History, Vienna). We want to thank Wolfgang PAVLIK (Geological Survey of Austria) for the investigation of some thin sections from gravels. Monika BRÜGGEMANN-LEDOLTER and Jacek RUTHNER (Geological Survey of Austria) did parts of the graphic work.

References

BACHMAYER, F. & ZAPFE, H.: Ein bedeutender Fund von Dinotherium aus dem Pannon von Niederösterreich. – Ann. Naturhist. Mus. Wien, **80**, 145–162, 1 Abb., 8 Taf., 1 Farbtaf., Wien 1976.

BARÁTH, I. & KOVAČ, M.: Miocene sequence stratigraphic key surfaces and depositional systems tracts in the Western Carpathian basins (Central Paratethys, Slovakia). – Slovak. Geol. Mag., **6**/2–3, 92–94, Bratislava 2000.

BATIK, P.: Die Hollabrunner Schotter und ihre Zusammensetzung – I. Etappe. – Unpubl. report, Bibl. Geol. B.-A., Wiss. Archiv Nr. A-10772–RA-22,23/95, 2 + 2 S., 3 Kt., Praha 1996.

BATIK, P.: Hollabrunner Schotter, ihre Zusammensetzung, ihr Alter und ihre Provenienz. – Unpubl. report, Bibl. Geol. B.-A., Wiss. Archiv Nr. ALK 022,023 BAT/95,96, 4 S., 4 S. (Beil.), Praha 1997.

BATIK, P.: Petrographische Analyse der Hollabrunner Schotter. – Unpubl. report, Bibl. Geol. B.-A., Wiss. Archiv Nr. ALK 022,023 BAT/98, 1 S., 2+1+1 S. (Beil. 1–3), Praha 1998.

BATIK, P.: Hollabrunn Gravel of Lower Pannonian age – its composition and genesis. – Věstník Českého geologického ústavu, **75**/1, 33–36, Fig. 1–6, Praha 2000.

BERNOR, R.L., KOVAR-EDER, J., LIPSCOMB, D., RÖGL, F., SEN, S. & TOBIEN, H.: Systematic, Stratigraphic, and Paleoenvironmental Contexts of First-Appearing Hipparion in the Vienna Basin, Austria. – J. Vertebrate Paleont., **8**/4, 427–452, 11 Figs., 9 Tabs., 1988.

BERNOR, R.L., MITTMANN, H.-W. & RÖGL, F.: Systematics and Chronology of the Götzendorf "Hipparion" (Late Miocene, Pannonian F, Vienna Basin). – Ann. Naturhist. Mus. Wien, **95**/A, 101–120, 12 Figs., Wien 1993.

BLAIR, T.C. & MCPHERSON, J.G.: Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and river assemblages. – J. Sed. Research, A**64**/ 3, 450–489, Boulder 1994.

BLUM, M.D. & TÖRNQVIST, T.E.: Fluvial responses to climate and sea-level change: a review and look forward. – Sedimentology, **47**/(Suppl. 1), 2–48, Oxford 2000.

BRIDGE, J.S.: Description and interpretation of fluvial deposits: a critical perspective. – Sedimentology, **40**, 801–810, Oxford 1993.

BRIDGE, J.S.: Thickness of sets of cross strata and planar strata as a function of formative bed-wave geometry and migration, and aggradation rate. – Geology, **25**/11, 971–974, Boulder 1997.

BRUNNACKER, K., FINK, J., RAZIRAD, M. & TILLMANNS, W.: Der Hollabrunner Schotter östlich von Krems, Niederösterreich. – Z. dt. Geol. Ges., **130**, 303–322, 9 Abb., 2 Tab., Hannover 1979.

BURNS, B.A., HELLER, P.L., MARZO, M. & PAOLA, C.: Fluvial response in sequence stratigraphic framework: example from the Monserrat fan delta, Spain. – J. Sed. Research, **67**/2, 311–321, Boulder 1997.

CAILLEUX, A.: Distinction des galets marins et fluviatiles. – Bull. Soc. géol. France, sér. 5, **15**, 375–404, Paris 1945.

CICHOCKI, O.: Zur Histologie tertiärer Hölzer Österreichs. – Thesis Formal-Naturwiss. Fak. Univ. Wien, 306 S., 50 Abb., 10 Tab., 17 Taf., Wien 1988.

DAXNER-HÖCK, G.: Sciuridae aus dem Jungtertiär von Österreich. – Paläont. Z., **49**, 56–74, 1 Abb., 2 Diagr., 3 Taf. (Taf. 7–9), Stuttgart 1975.

DAXNER-HÖCK, G.: Faunenwandel im Obermiozän und Korrelation der MN-„Zonen" mit den Biozonen des Pannons der Zentralen Paratethys. – Beitr. Paläont., **21**, 1–9, 4 Abb., Wien 1996.

DAXNER-HÖCK, G.: Miocene Primates from Austria. – In: PILLER, W.E. et al.: Palaeontological Highlights of Austria, Mitt. österr. Geol. Ges., **92** (1999), 225–227, 1 Fig., 1 Tab., Wien 2000.

DAXNER-HÖCK, G., DE BRUIJN, H. & FOUSSEKIS, D.: Bericht 1989 über das Projekt „Kleinsäuger" der begleitenden Grundlagenforschung. – Jb. Geol. B.-A., **133**/3, 508–510, Wien 1990.

DECKER, K.: Miocene tectonics at the Alpine-Carpathian junction and the evolution of the Vienna Basin. – Mitt. Ges. Geol. Bergbaustud. Österr., **41**, 33–44, Wien 1996.

DOBKINS, J.E. & FOLK, R.L.: Shape development on Tahiti-Nui. – J. Sed. Petrology, **44**/3, 663–672, Tulsa 1970.

EMERY, D. & MYERS, K.J. (Eds.): Sequence Stratigraphy. – Blackwell Science, 111–133, London 1996.

FINK, J. & PIFFL, L.: The Danube from Krems to Vienna. – In: SUGGATE, R.P. & CRESSWELL, M.M. (eds.): Quarternary Studies, 127–132, Wellington (The Royal Soc. New Zealand) 1975.

FRIEND, F.P.: Control of river morphology by the grain-size of sediment supplied. – Sed. Geology, **85**, 171–177, Amsterdam 1993.

FUCHS, G. & ROETZEL, R. mit einem Beitrag von HEINZ, H.: Geologische Karte der Republik Österreich 1:50.000. Erläuterungen zu Blatt 36 Ottenschlag. – 64 S., 4 Abb., 2 Tab., 2 Taf., Wien (Geol. B.-A.) 1990.

GREGOR, H.J.: Die jungtertiären Floren Süddeutschlands. – 278 S., Stuttgart (Enke) 1982.

GRILL, R.: Über den geologischen Aufbau des Außeralpinen Wiener Beckens. – Verh. Geol. B.-A., **1958**/1, 44-54, 1 Abb., 1 Tab., 1 Kt., Wien 1958.

GRILL, R.: Erläuterungen zur Geologischen Karte des nordöstlichen Weinviertels und zu Blatt Gänserndorf. – 155 S., 9 Abb., 4 Tab., 2 Taf., Wien (Geol. B.-A.) 1968.

GYURITS, K.: Der Mistelbacher Schotterkegel. – Thesis Phil. Fak. Univ. Wien, 145 S., Beil., Wien 1970.

GYURITS, K. & KURZWEIL, H.: Grobkornsedimentation der pannonen Donau in Österreich am Beispiel der Mistelbacher Schotter. – Tschermaks Min. Petr. Mitt., **23**, 233–249, 8 Abb., Wien 1976.

HART, B.S. & PLINT, A.G.: Gravelly shoreface and beachface deposits. – Int. Ass. Sedimentologists, Spec. Publ., **22**, 75–99, Oxford 1995.

HARZHAUSER, M., DAXNER-HÖCK, G. & PILLER, W.E.: An integrated stratigraphy of the Pannonian (Late Miocene) in the Vienna Basin. – Austrian Journ. Earth Science, **95/96**, 6–19, Wien 2004.

HARZHAUSER, M., KOVAR-EDER, J. & STRÖBITZER-HERMANN, M.: Palecological significance of selected mollusc assemblages during the lower to middle Pannonian in the Northern Vienna Basin. – Mitt. Ges. Geol. Bergbaustud. Österr., **43** (Sediment 2000 – Abstracts), 57–58, Wien 2000.

HARZHAUSER, M., KOVAR-EDER, J., NEHYBA, S., STRÖBITZER-HERMANN, M., SCHWARZ, J., WÓJCICKI, J. & ZORN, I.: An Early Pannonian (Late Miocene) transgression in the Northern Vienna Basin. The paleoecological feedback. – Geologica Carpathica, **54**, 1, 41–52. Bratislava 2003.

HASSINGER, H.: Geomorphologische Studien aus dem Inneralpinen Wiener Becken und seinem Randgebirge. – Geograph. Abh., **VIII**/3, 359–564, 11 Abb., 1 Taf., Leipzig (B.G. Teubner) 1905a.

HASSINGER, H.: Zur Frage der alten Flußterrassen bei Wien. – Mitt. k.k. Geograph. Ges. Wien, **48**, 196–219, Wien 1905b.

HEIN, F.J.: Deep-sea and fluvial braided channel conglomerates: a comparison of two case studies. – In: KOSTER, E.H. & STEEL, R.J. (eds.): Sedimentology of gravels and conglomerates, Canadian Soc. Petroleum Geologists, Mem., **10**, 33–49, Calgary 1984.

HOLBROOK, J.: Origin, genetic interrelationships, and stratigraphy over the continuum of fluvial channel-form bounding surfaces: an illustration from middle Cretaceous strata, southern Colorado. – Sed. Geology, **144**/3–4, 179–222, Amsterdam 2001.

JANOSCHEK, R.: Das Inneralpine Wiener Becken. – In: SCHAFFER, F.X. (Hrsg.): Geologie von Österreich, 525–693, Wien (Deuticke) 1951.

JIŘÍČEK, R.: Deltaic development of Lower Pannonian in southern part of Vienna Basin. – Zemní plyn a nafta, **31**/2, 161–186, Hodonín 1985.

JO, H.R. & CHOUGH, S.K.: Architectural analysis of fluvial sequences in the southwestern part of Kyonsang Basin (Early Cretaceous), SE Korea. – Sed. Geology, **144**/3–4, 307–334, Amsterdam 2001.

KEINDL, J.: Untersuchungen über die tertiären Schotter des westlichen Weinviertels. – Mitt. Geogr. Ges. Wien, **72**, 283–292, Wien 1929.

KOVÁČ, M., BARÁTH, I., KOVÁČOVÁ-SLÁMKOVÁ, M., PIPÍK, R., HLAVATÝ, I. & HUDÁČKOVÁ, N.: Late Miocene paleoenvironments and sequence stratigraphy: Northern Vienna Basin. – Geologica Carpathica, **49**/6, 445–458, Bratislava 1998.

KOVAR, J.: Pflanzenreste aus dem Pannon (Ober-Miozän) von Rohrbach bei Ziersdorf (Niederösterreich). – Beitr. Paläont. Österr., **6**, 107–117, 3 Abb., 1 Taf., Wien 1979.

KOVAR-EDER, J.: Pannonian (Upper Miocene) Vegetational Character and Climatic Inferences in the Central Paratethys Area. – Ann. Naturhist. Mus. Wien, **88**/A, 117–129, 2 Abb., Wien 1987.

KOVAR-EDER, J.: Obermiozäne (Pannone) Floren aus der Molassezone Österreichs (Ihre Beziehungen zum Wr. Becken, weiteren Pannonischen Raum und nördlichen Mediterran). – Beitr. Paläont. Österr., **14**, 19–121, 17 Abb., 12 Taf., Wien 1988.

KREUTZER, N.: The Lower Pannonian Sands and the Pannonian-Sarmatian Boundary in the Matzen Area of the Vienna Basin. – In: MINAŘIKOVÁ, D. & LOBITZER, H. (eds.): Thirty Years of Geological Cooperation between Austria and Czechoslovakia, 105–111, 8 Figs., Praha 1990.

LANG, S.C.: Evolution of Devonian alluvial systems in an oblique-slip mobile zone – an example from Broken River province, Northeastern Australia. – Sed. Geology, **85**, 501–535, Amsterdam 1993.

LEEDER, M.: Sedimentology and Sedimentary basins. From turbulence to Tectonics. – Blackwell Science, 1–592, Oxford 1999.

LEITHOLD, E.L. & BOURGEOIS, J.: Characteristics of coarse-grained sequences deposited in foreshore and shoreface, wave dominated environments – examples from Miocene of south-west Oregon. – Sedimentology, **31**, 749–775, Oxford 1984.

MACKENBACH, R.: Jungtertiäre Entwässerungsrichtungen zwischen Passau und Hausruck (O.Österreich). – Geol. Inst. Univ. Köln, Sonderveröff., **55**, 175 S., 45 Abb., 2 Tab., Anhang (Tab. 1–5), Köln 1984.

MAGYAR, I., GEARY, D.H. & MÜLLER, P.: Paleogeographic evolution of the Late Miocene Lake Pannon in Central Europe. – Palaeogeogr., Paleoclimat., Paleoecol., **147**, 151–167, 1999.

MARZO, M., NIJMAN, W. & FABREGAS, C.: Architecture of the Castissent fluvial sheet sandstones, Eocene, South Pyrenees, Spain. – Sedimentology, **35**, 719–738, Oxford 1988.

MCCARTHY, P.J., FACCINI, U.F. & PLINT, A.G.: Evolution of ancient coastal plain. Paleosoils, interfluves and alluvial architecture in sequence stratigraphic framework, Cenomanian Dunvegan Formation, NE British Columbia, Canada. – Sedimentology, **46**, Oxford 1999.

MIALL, A.D.: Lithofacies types and vertical profile models in braided river deposits: a summary. – In : MIALL, A.D. (ed.): Fluvial Sedimentology, Canadian Soc. Petroleum Geologists, Mem., **5**, 597–604, Calgary 1978.

MIALL, A.D.: Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. – Earth Sci. Rev., **22**, 261–308, Amsterdam1985.

MIALL, A.D.: Alluvial deposits. – In: WALKER, R.G. & JAMES, N.P. (eds.): Facies Models: Response to Sea-Level Changes, 119–142, Geol. Society of Canada, Toronto 1992.

MIALL, A.D.: The Geology of Fluvial Deposits. – Springer Verlag, 1–582, Berlin 1996.

MOSHAMMER, B., HAVLIČEK, P., HOLÁSEK, O., SMOLÍKOVÁ, L., HEINRICH, M. & BRÜGGEMANN, H.: C6 Oberfellabrunn – Kiesgrube Stecher. – In: ROETZEL, R. (Hrsg.): Arbeitstagung Geol. B.-A. 1999, Retz, 3.–7. Mai 1999, 343–345, 1 Abb., Wien 1999.

NAGL, H. & VERGINIS, S., mit einem Beitrag von MOSER, W.: Die Morphogenese der Wachau. Versuch einer neuen Deutung. – Geogr. Jahresber. Österr., **46** (1987), 7–30, 8+3 Abb., 2 Tab., Wien 1989.

NEHYBA, S.: Bericht 1999 über sedimentologische Studien in der Hollabrunn-Mistelbach-Formation auf den Blättern 22 Hollabrunn und 23 Hadres. – Jb. Geol. B.-A., **142/**3, 387, Wien 2000.

NEHYBA , S.: Bericht 2000 über die sedimentologische Bearbeitung der Hollabrunn-Mistelbach-Formation auf den Blättern 24 Mistelbach, 25 Poysdorf, 38 Krems, 39 Tulln und 41 Deutsch Wagram. – Jb. Geol. B.-A., **143/**3, 506, Wien 2003.

NEMEC, W. & POSTMA, G.: Quaternary alluvial fans in southwestern Crete: sedimentation processes and geomorphic evolution. – In: MARZO, M. & PUIDGEFABREGAS, C. (eds.): Alluvial Sedimentation, IAS Spec. Publ. **17**, 235–276, Oxford 1993.

NEMEC, W. & STEEL, R.: Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. – In: KOSTER, E.H. & STEEL, R. (eds.): Sedimentology of Gravels and Conglomerates, Canadian Soc. Petroleum Geologists, Mem., **10**, 1–31, Calgary 1984.

NOVÁK, Z.: Bericht 1992 über die Ergebnisse der Untersuchungen von durchsichtigen Schwermineralen. – Unpubl. report Bibl. Geol. B.-A., Wiss. Archiv Nr. A-09695–RA-8,9,22/92, 2 S., 3 Kt., 1 Anl. (Tab.), Brno 1993.

NOVÁK, Z.: Bericht 1993 über die Ergebnisse der Untersuchung von durchsichtigen Schwermineralen. – Unpubl. report Bibl. Geol. B.-A., Wiss. Archiv Nr. A-10220–RA-8,9,22/93, 1+1+3 S.(Ber.), 21+2 Tab., 3 Kt. (Anl.), Brno 1994.

NOVÁK, Z.: Bericht über die petrographische Bearbeitung der Schwerminerale von Kartierungsproben auf den Kartenblättern ÖK 22 Hollabrunn, ÖK 23 Hadres und ÖK 38 Krems. – Unpubl. report Bibl. Geol. B.-A., Wiss. Archiv Nr. A-11188–RA-22,23,38/97, 17 S., 3 Kt., Brno 1997.

PAPP, A. & THENIUS, E., mit Beiträgen von BERGER, W. & WEINFURTER, E.: Vösendorf – ein Lebensbild aus dem Pannon des Wiener Beckens. – Mitt. Geol. Ges. Wien, **46** (1953), 1–109, 15 Taf., Wien 1954.

PERESSON, H. & DECKER, K.: From extension to compression: Late Miocene stress inversion in the Alpine-Carpathian-Pannonian transition area. – Mitt. Ges. Geol. Bergbaustud. Österr., **41**, 75–86, Wien 1996.

PETRASCHECK, W.: Tektonische Untersuchungen am Alpen- und Karpathenrande. – Jb. Geol. Staatsanst., **70** (1920), 255–272, 4 Abb., Wien 1921.

PIA, J. & SICKENBERG, O.: Katalog der in den Österreichischen Sammlungen befindlichen Säugetierreste des Jungtertiärs Österreichs und der Randgebiete. – Denkschr. Naturhist. Mus. Wien, **4**, XVI+544 S., Leipzig – Wien 1934.

PLINT, A.G., MCCARTHY, P.J. & FACCINI, U.F.: Nonmarine sequence stratigraphy: Updip expression of sequence boundaries and systems tracts in a high-resolution framework, Cenomanian Dunvegan Formation, Alberta basin, Canada. – AAPG Bulletin, 1999.

POSTMA, G.: Depositional architecture and facies of river and fan deltas: a synthesis. – IAS, Spec. Publ., **10**, 13–27, Oxford 1990.

POSTMA , G. & NEMEC, W.: Regressive and transgressive sequences in raised Holocene gravelly beach, soutwestern Crete. – Sedimentology, **37**, 907–920, Oxford 1990.

RABEDER, G.: Die Säugetiere des Pannonien. – In: PAPP, A., JAMBOR, A. & STEININGER, F.F.: M6 Pannonien (Slavonien und Serbien). – Chronostratigraphie und Neostratotypen, **7**, 440–463, 7 Tab. (Tab. 15–21), Budapest 1985.

RAMOS, A. & SOPEŃA, A.: Gravel bars in low sinuosity streams (Permian and Triassic, central Spain). – IAS, Spec. Publ., **6**, 301–312, Oxford 1983.

RAMOS, A., SOPEŃA, A. & PEREZ-ARLUCEA, M.: Evolution of Buntsandstein fluvial sedimentation in the Northwest Iberian ranges (Central Spain). – J. Sed. Petrology, **56**/6, 862–875, Tulsa 1986.

RASMUSSEN, H.: Foreshore and shoreface and alluvial facies in the Sant Lorenc del Munt depositional system: recognition and development. – Sed. Geology, **138**, 71–98, Amsterdam 2000.

READING, H.G. (ed.): Sedimentary environments: Processes, Facies and Stratigraphy. – Blackwell Sci. Publ., 1–593, Oxford 1996.

ROETZEL, R. [Bearb.] et al.: Geologische Karte der Republik Österreich 1 : 50.000 – 22 Hollabrunn. – Wien (Geol. B. –A.) 1998.

ROETZEL, R.: Bericht 1998, 2000 und 2001 über geologische Aufnahmen im Tertiär und Quartär auf Blatt 23 Hadres. – Jb. Geol. B.-A., **143**/3, 397–404, Wien 2003.

ROETZEL, R., MANDIC, O. & STEININGER, F.F.: Lithostratigraphie und Chronostratigraphie der tertiären Sedimente im westlichen Weinviertel und angrenzenden Waldviertel. – In: ROETZEL, R. (Hrsg.): Arbeitstagung Geol. B.-A. 1999, Retz, 3.–7. Mai 1999, 38–54, 3 Abb., 1 Beil. (geol. Kt.), Wien 1999.

RÖGL, F.: Palaeogeographic Considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene). – Ann. Naturhist. Mus. Wien, **99**/A, 279–310, 1 Tab., 10 Pls., Wien 1998.

RÖGL, F. & STEININGER, F.F.: Vom Zerfall der Tethys zu Mediterran und Paratethys. – Ann. Naturhist. Mus. Wien, **85**/A, 135–163, 2 Abb., 14 Taf., Wien 1983.

RÖGL, F., STEININGER, F.F. & VASICEK, W.: Riesen der Vorzeit – Urelefanten und Nashörner im Weinviertel vor 10 Millionen Jahren. – Katalogreihe des Krahuletz-Museums, **6**, 32 S., 18 Abb., Eggenburg 1986.

RUST, B.R.: Proximal braidplain deposits in the Middle Devonian Malbaie Formation of Eastern Gaspé, Quebec, Canada. – Sedimentology, **31**, 675–695, Oxford 1984.

SAUER, R., SEIFERT, P. & WESSELY, G.: Guidebook to Excursions in the Vienna Basin and the Adjacent Alpine-Carpathian Thrustbelt in Austria. – Mitt. österr. Geol. Ges., **85** (1992), 1–239, 200 Abb., 7 Tab., Wien 1992.

SCHUMM, S.A.: Abrasion in place: A mechanism for rounding and size reduction of coarse sediments in rivers. – Geology, **1**, 37–40, Boulder 1973.

SHANLEY, K.W. & MCCABE, P.J.: Perspectives on the sequence stratigraphy of continental strata. – AAPG Bulletin, 544–568, 1994.

SICKENBERG, O.: Säugetierreste aus der Umgebung von Oberhollabrunn. – Verh. Geol. B.-A., **1928**/9–10, 205–210, 1 Abb., Wien 1928.

SICKENBERG, O.: Eine neue Antilope und andere Säugetierreste aus dem Obermiozän Niederösterreichs. – Palaeobiologica, **2**, 62–86, 4 Fig., 2 Taf. (Taf.VII–VIII), Wien – Leipzig 1929.

SNEED, E.D. & FOLK, R.L.: Pebbles in the lower Colorado river, Texas: a study in particle morphogenesis. – J. Geol., **66**, 114–151, Chicago 1958.

STEININGER , F.: Über die stratigraphische Verwertbarkeit von *Anchitherium aurelianense* (CUV.) im Jungtertiär Österreichs. – N. Jb. Geol. Paläont., Abh., **116**/2, 149–161, 3 Beil., 1 Tab., Stuttgart 1963.

STEININGER , F.: The Continental European Miocene. Chronostratigraphy, Geochronology and Biochronology of the Miocene ”European Land Mammal Mega-Zones” (ELMMZ) and the Miocene ”Mammal-Zones (MN-Zones)”. – In: RÖSSNER, G. & HEISSIG, K. (eds.): The Miocene Land Mammals of Europe, 9–24, München (F. Pfeil) 1999.

STEININGER, F. & ROETZEL, R.: Die Landschaftsgeschichte des Waldviertels und des westlichen Weinviertels vom Jungpaläozoikum bis heute. – Känozoikum (Erdneuzeit) – Jüngeres Tertiär. – In: STEININGER, F.F. (Hrsg.): Erdgeschichte des Waldviertels. Das Waldviertel, **45**/1, 79–86, 13 Abb., 1 Tab., Horn 1996.

SUESS, E.: Untersuchungen über den Charakter der österreichischen Tertiärablagerungen. I. Über die Gliederung der tertiären Bildungen zwischen dem Mannhart, der Donau und dem äusseren Saume des Hochgebirges. – Sitz.ber. k. Akad. Wiss., math.-naturw. Cl., Abt. I, **54**/6, 87–149, 2 Taf., Wien 1866.

THENIUS, E.: Über den Nachweis von *Anchitherium aurelianense* im Pannon des Wiener Beckens. – Anz. österr. Akad. Wiss., math. –naturw. Kl., **87**/8 (1950), 174–181, 2 Abb., 1 Tab., Wien 1950.

THENIUS, E.: Über das Vorkommen von *Diceros pachygnathus* (WAGNER) im Pannon (Unter-Pliozän) des Wiener Beckens. – N. Jb. Geol. Paläont., Mh., **1956**, 35–39, 1 Abb., Stuttgart 1957.

THENIUS, E.: Zur Paläoklimatologie des Pannon (Jungmiozän) in Niederösterreich. – N. Jb. Geol. Paläont., Mh., **1982**, 692–704, Stuttgart 1982a.

THENIUS, E.: Ein Menschenaffenfund (Primates: Pongidae) aus dem Pannon (Jung-Miozän) von Niederösterreich. – Folia Primatologica, **39**, 187–200, 3 Abb., Basel 1982b.

THENIUS, E.: Ein kleiner Menschenaffe (Pongidae, Primates) aus dem Jung-Miozän (Pannon) von Niederösterreich und die paläoökologische und paläoklimatologische Problematik des Vorkommens. – Anz. Österr. Akad. Wiss., math.-naturw. Kl., **119**/4 (1982), 37–44, Wien 1983.

VASS, D. & ELEČKO, M.: Pebble shape and origin of Pozdišovce gravel formation. – Mineralia slovaca, **9**/1, 43–65, Bratislava 1977.

VETTERS, H.: Mitteilungen aus dem tertiären Hügellande unter dem Manhartsberge. – Verh. Geol. R.-A., **1914**/2, 65–74, Wien 1914.

WALKER, R.G. & JAMES, N.P.: Facies Models. Response to sea level changes. – Geol. Ass. Canada, 1–380, Toronto 1992.

WEINHANDL, R.: Bericht 1956 über Aufnahmen auf Blatt Hadres (23). – Verh. Geol. B.-A., **1957**/1, 90–92, Wien 1957.

WEINHANDL, R.: Bericht 1957 über Aufnahmen auf den Blättern Hollabrunn (22) und Hadres (23). – Verh. Geol. B.-A., **1958**/3, 274–275, Wien 1958.

WEINHANDL, R.: Bericht über geologische Aufnahmen 1958 auf den Blättern Hollabrunn (22) und Hadres (23). – Verh. Geol. B.-A., **1959**/3, A99–A101, Wien 1959.

WENTWORTH, C.K.: The shapes of beach pebbles. – US. Geological Survey, Prof. Paper, **131-C**, 75–83. Denver 1922.

ZAPFE, H.: Die Säugetierfauna aus dem Unterpliozän von Gaiselberg bei Zistersdorf in Niederösterreich. – Jb. Geol. B.-A., **93**/1–2, 83–97, 1 Abb., Wien 1949.

ZAPFE, H.: Ein bedeutender Mastodon-Fund aus dem Unterpliozän von Niederösterreich. – N. Jb. Geol. Paläont., Abh., **104**/3, 382–406, 3 Abb., 4 Taf. (Taf. 24–27), Stuttgart 1957.

ZAPFE, H.: Ein schizotheriiner Chalicotheriide aus pannonischen Schottern der Umgebung von Krems, Niederösterreich. – Sitz.ber. Österr. Akad. Wiss., math.-naturw. Kl., Abt. I, **182**, 289–299, 1 Abb., 1 Tab., Wien 1974.

ZINGG, T.: Beiträge zur Schotteranalyse. – Min. Petr. Mitt. Schweiz, **15**, 39–140, 1935.

Manuskript bei der Schriftleitung eingelangt am 28. Juni 2004

Zeitschrift/Journal: Jahrbuch der Geologischen Bundesanstalt

Jahr/Year: 2004

Band/Volume: 144

Autor(en)/Author(s): Nehyba Slavomir, Roetzel Reinhard

Artikel/Article: The Hollabrunn-Mistelbach Formation (Upper Miocene, Pannonian) in the Alpine-Carpathian Foredeep and the Vienna Basin in Lower Austria - An example of a Coarse-grained Fluvial System 191-221