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The Lignite-Bearing Sediments of the Middle Miocene Köflach-Voitsberg Embayment (Styrian Basin, Austria)

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8 Text-Figures

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Blatt 162

Steiermark
Köflach-Voitsberger Bucht
Lagerstätten
Braunkohle
Stratigrafie

Inhalt

Die Lignit führenden Sedimente der mittelmiozänen Köflach-Voitsberger Bucht (Steirisches Becken, Österreich)

Zusammenfassung

Die mittelmiozänen Sedimente der Köflach-Voitsberger Bucht und ihre angrenzenden ebenfalls nicht marinen Ablagerungen sind ein Teil der Sedimente des neogenen Steirischen Beckens. Die Köflach-Voitsberger Bucht ist in mehrere Braunkohlen führende Mulden untergliedert, die von Grundgebirgsaufbrüchen getrennt werden. Die Bucht bildet den nordwestlichen Rand des Steirischen Beckens. Durch die Position am Beckenrand sind die stratigrafisch ältesten Sedimente der Beckenfüllung aufgeschlossen.

Die in den Mulden auftretenden Faziestypen der Sedimente und auch deren Unterschiede in den einzelnen Mulden werden an Hand von Bohrprofilen der GKB-Bergbaugesellschaft beschrieben und interpretiert. Einige Überlegungen über die Mechanismen, die zur Absenkung und zur unterschiedlichen Ausbildung der Kohlenmulden geführt haben, werden diskutiert. Abschließend wird versucht, die Absenkungsgeschichte der Kohlenmulden mit tektonischen Bewegungen, die zur Bildung des Steirischen Beckens geführt haben, zu korrelieren.

Abstract

The Middle Miocene sediments of the Köflach-Voitsberg Embayment as well as their adjacent non-marine deposits belong to the Neogene Styrian Basin, a marginal basin of the Pannonian Basin. The Köflach-Voitsberg Embayment is separated into various mostly lignite-bearing depressions divided by basement highs; it constitutes the north-western margin of the Styrian Basin. Due to a position close to the basement the stratigraphically oldest deposits are excavated and show the sedimentary response to the primary subsidence of the Styrian Basin

The sedimentary facies associations occurring in the lignite depressions as well as their variation in the different depressions are described and interpreted based on several core sections from the GKB mining company. Some considerations about mechanisms for the subsidence in relation to the basement lithology and Miocene kinematics are discussed. Finally, some implications for a correlation of the sedimentary fill including the lignite seams to tectonic phases in the early formation of the Styrian Basin are discussed.

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1. Introduction

The Neogene Styrian Basin is a subbasin of the intracaparthian basins of the Pannonian Basin System (ROYDEN & HORVATH, 1988; NEUBAUER et al., 1995). Paleogeographically the basin deposits belong to the Central Paratethys area (STEININGER et al., 1985; RÖGL, 1998).

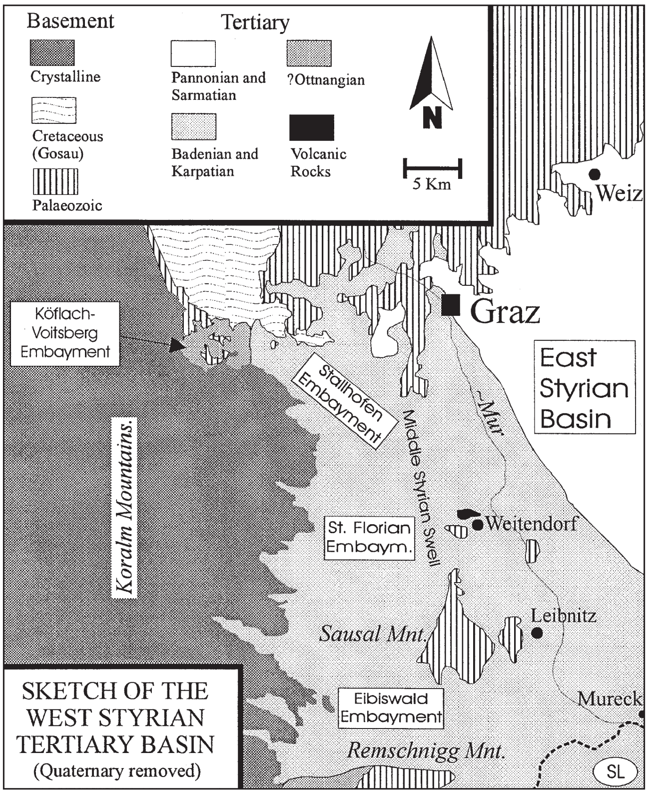
The Middle Styrian Swell divides the Styrian Basin into a West Styrian Basin and an East Styrian Basin (Text-Fig. 1). The South Burgenland Swell separates it from the Pannonian Basin.

The West Styrian Basin is divided into three main subbasins. The southernmost basin is the Eibiswald Embayment, which is followed to the north by the Florian Embayment and, at the northern end, by the Stallhofen Embayment. The Köflach-Voitsberg Embayment is a marginal subembayment of the Stallhofen Embayment (Text-Fig. 1). The basin filling in this subembayment extends from the Ottnangian into the Badenian. Sediments of Sarmatian age were only preserved in marginal areas of the Stallhofen Embayment.

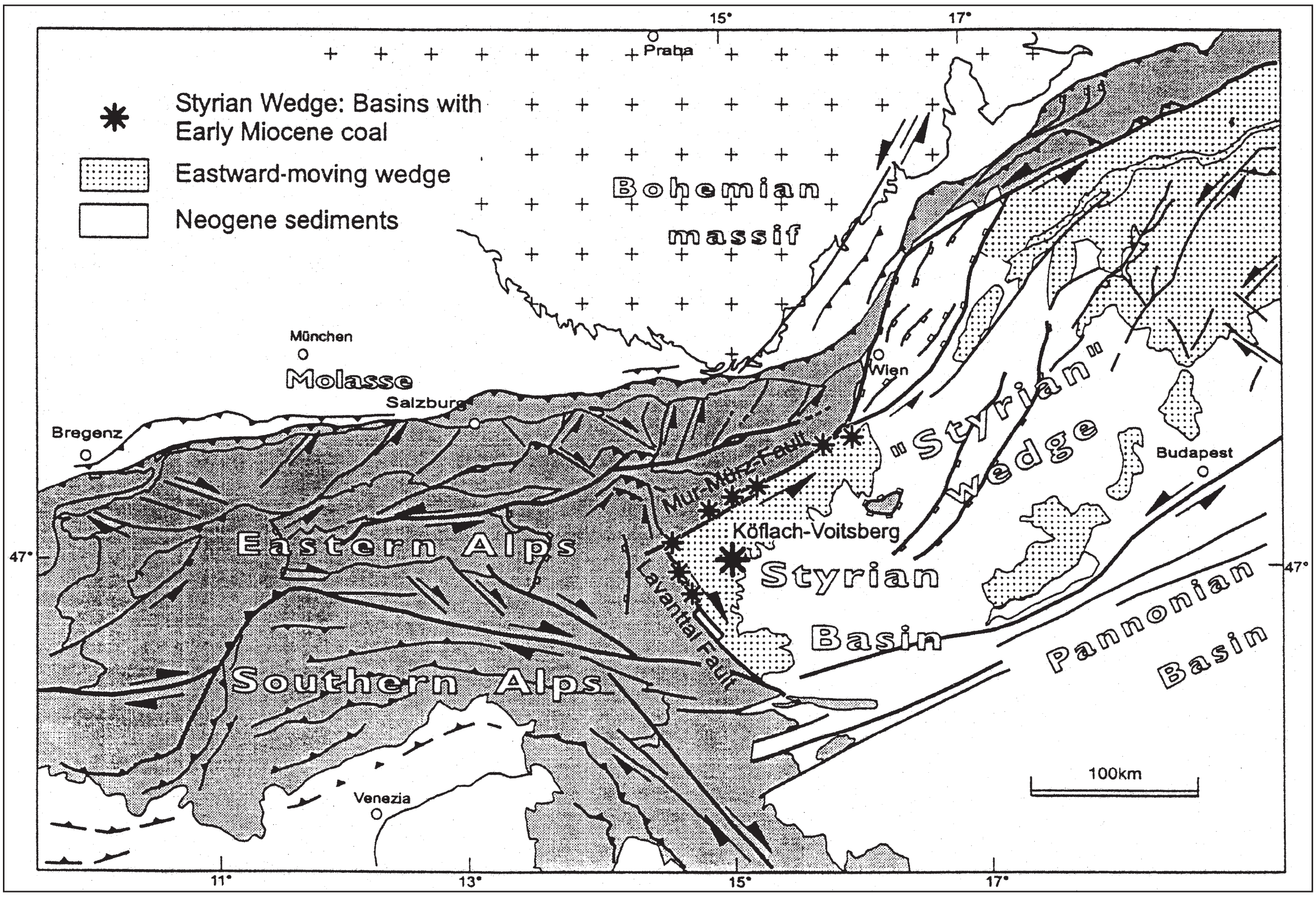
2. Geological Outlines

The origin of the Pannonian Basin is explained today largely through miocene kinematics (late collision stage) in the Eastern Alps. In the last decade, the combination between the new tectonic models “tectonic escape” and “extensional collapse” (PLATT, 1987; DEWEY, 1988) provided the basis for interpreting the development of the Carpathian Arc and the Pannonian Basin.

In the final phases of the generally northerly directed collision of the Adriatic Plate with the European Plate, crustal



Text-Fig. 1.
General sketch of the West Styrian Basin and position of the Köflach-Voitsberg Embayment.



Text-Fig. 2.
Tectonic sketch of the Styrian Wedge within the Eastern Alps and the Pannonian Basin.
After HAAS et al. (1998) and PERESSON & DECKER (1997).

sections were extruded laterally to the east ("tectonic escape"). This eastward movement of crustal sections is compensated by orogen-parallel lateral shifts ("strike-slips") running east–west. The second part of the combined model is isostatic rising of the continental crust. This may lead to a gravitational slip of higher crustal elements (nappes) from lower crust sections ("extensional collapse"). This slip occurs along flat thrust planes and is repeated numerous times (RATSCHBACHER et al., 1991a,b).

PERESON & DECKER (1997) termed the extruded crustal sections Styrian Wedge. The Köflach-Voitsberg Embayment is situated within this wedge (Text-Fig. 2). Tectonic measurements in the Embayment itself indicate a first phase (Early Miocene) of a NE–SW extension with normal faulting and sinistral NE-striking strike-slip faults (see Fig. 2a of HAAS et al., 1998). In a second phase (Middle to Late Miocene) the extension changes to E (see Fig. 2b of HAAS et al., 1998). Three phases of volcanism occure during the formation of the Styrian Basin: Uppermost Karpatian/Lower Badenian, at the Sarmatian/Pannonian boundary, and in the Pliocene (EBNER & SACHSENHOFER, 1991).

The Miocene basin fill of the Köflach-Voitsberg Embayment is the response to these tectonic movements and represents initial stages in the formation of the Pannonian Basin System.

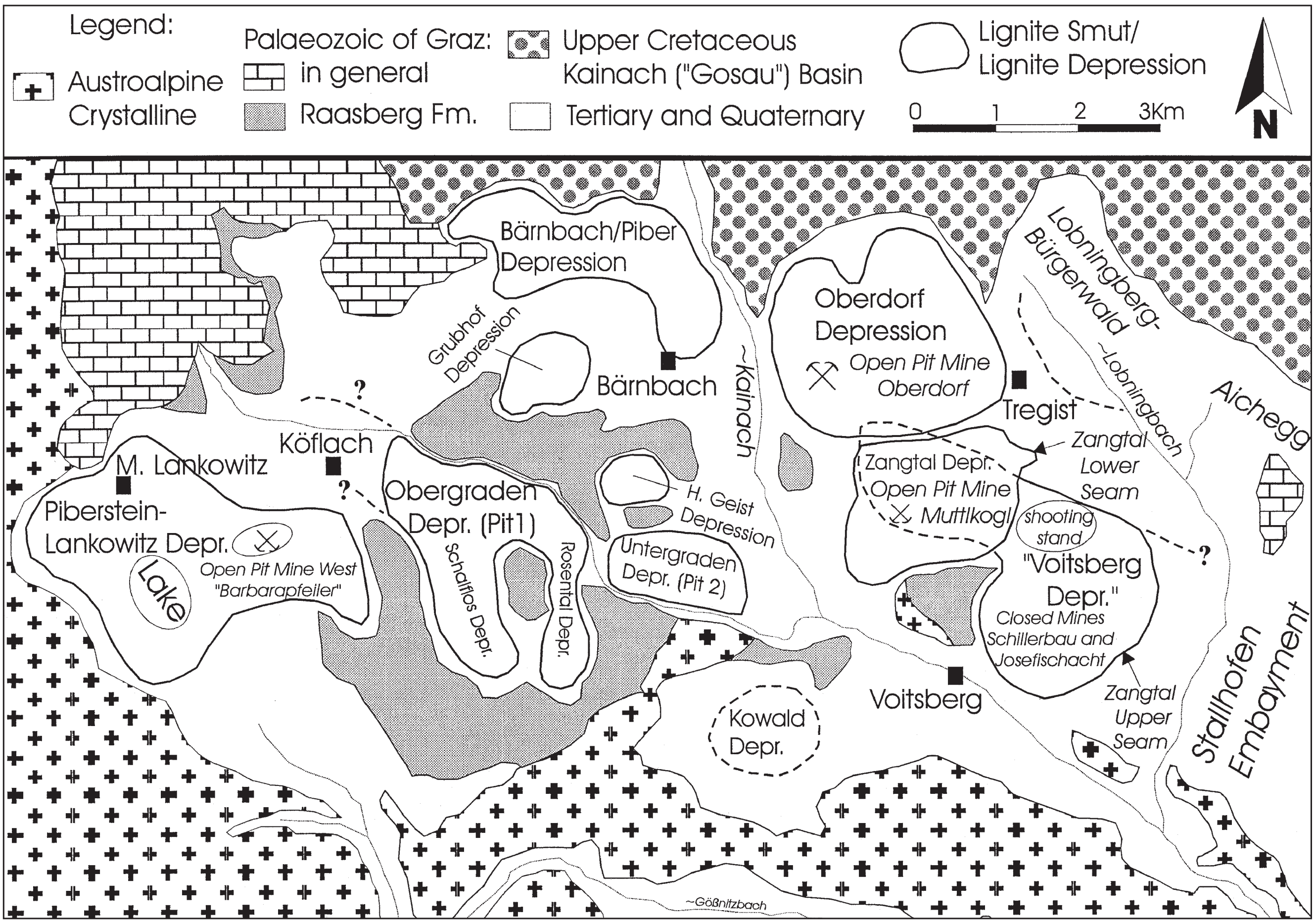
The Köflach-Voitsberg Embayment is borderd and underlain by three main basement lithologies (medium grade metamorphics – "Austroalpine crystalline", Cretaceous "Gosau" sediments and the Graz Palaeozoic in general, Text-Fig 1). The west and south borders are formed by mostly medium grade metamorphics of the Austro-Alpine Koriden Complex (Koralm mountains, Text-Fig. 3). In the North Graz Palaeozoic and Upper Cretaceous sediments ("Gosau") of the Kainach Basin (FLÜGEL, 1988) constitute the margins. In the East the Graz Palaeozoic forms the structural high of Aichegg (Text-Fig. 2), which is also the separation to the Stallhofen Embayment.

The Graz Palaeozoic in the surroundings of the Köflach-Voitsberg Embayment is formed by low-grade Devonian carbonates (Schöckelkalk Fm., Raasberg Fm.) of the Schöckel Nappe, only the structural high of Aichegg consists of the very low-grade Rannach Nappe in a higher structural level (EBNER, 1998).

The Raasberg Fm. constitutes not only parts of the margins but also the basement heights separating the lignite depressions. It forms most of the subsurface basement of the Köflach-Voitsberg Embayment and consists mainly of sandy dolomites, quarzites and serizitic schists.

The lignite-bearing sediments of Köflach-Voitsberg are developed as several depressions (POHL, 1976; WEBER & WEISS, 1983; summarised in Text-Fig 3.).

The westernmost lignite depression is the Piberstein-Lankowitz Depression, bordered and underlain half by Austroalpine Crystalline and half by the Raasberg Fm. In some minor marginal parts, the Schöckelkalk Fm. constitutes the border. The Raasberg Fm. also forms nearly entirely the margins and basement of the Grubhof Depression and the Graden Depressions (Obergraden-, Untergraden-, Schaflos-, Rosental-, and Hl. Geist Subdepressions), whereas the crystalline forms nearly entirely the basement and margins of the Kowald Depression (containing only a small smut). The Piber-Bärnbach Depression, the Oberdorf Depression and the Zangtal Depression are bordered and underlain mainly by the Raasberg Fm. The



Text-Fig. 3.
Basement lithologies and lignite depressions of the Köflach-Voitsberg Embayment.

cretaceous Gosau, Schöckelkalk Fm and the Rannach Nappe of Aichegg constitute larger stretches of the borders, but do not extend far into the covered depression basement.

The Voitsberg Depression is bordered and underlain by crystalline rocks and the Raasberg Fm. Probably some parts of the basement in the East are already formed by Palaeozoic rocks (Rannach Nappe of Aichegg). The Tregist Depression (containing one or two small smuts) is mainly bordered by the Cretaceous Gosau, but the underlying basement is additionally built of Palaeozoic rocks (Rannach Nappe of Aichegg).

The sediments of the Koeflach-Voitsberg Embayment are comprised as the Koeflach-Voitsberg Fm. The Koeflach-Voitsberg Fm. lignite deposits are separated as the Lignite Member, coarse basinal sediments as the Basis Member (EBNER & STINGL, 1998)

The border to the Stallhofen Fm. is in marginal positions, if coarse alluvial deposits (Eckwirt Member of the Stallhofen Fm.) are developed, erosional and also marked by Lobningberg Member intercalations (see below). In other areas it is a coarsening upwards transition.

Near the investigated area, volcanoclastics (various tuffs and tuffites) of the first volcanic phase (Lobningberg Member of the Stallhofen Fm.) occur (EBNER & STINGL, 1998). The Lobningberg Bed is crudely dated 17.5±2.6 Ma. (K/Ar of Biotite [BALOGH et al., 1991]). It is positioned in the Lowermost Badenian only on the basis of the regional geologic setting (EBNER et al., 1998).

A mammal fauna from the hanging wall succession above the Oberdorf Lignite Seam (part of the Lignite Member) is indicative for a MN4 mammal zone age (DAXNER-HÖCK, 1998), which corresponds to the Ottnangian/Karpatian border of the Central Paratethys stages. This stratigraphic correlation is supported by magnetostratigraphic investigations. They show a polarity change within the hanging wall succession (HERMANN et al., 1998) which is interpreted as the C5Dr/C5Dn chron change (GPTS at 17.6 Ma. [BERGGREN et al., 1995]; Ottnangian in the Central Paratethys stages).

3. Facies Associations

Three main facies associations can be distinguished in the lignite-bearing sediments of the Köflach-Voitsberg Fm. A fourth facies type is represented by the Zangtal Hangend Abfolge (Zangtal Hanging Wall Succession), which probably already belongs to the Stallhofen Fm.

Mainly occurring in the Basis Member is the debris-flow-dominated alluvial fan facies association. Matrix-supported, unsorted breccias in a clay to silt matrix (Text-Fig. 4c) are interpreted as cohesive debris flows or mudflows (LOWE, 1976). Grading is absent or crudely normal. A greater dominance of clast-support of components in the beds with silty to sandy matrix (Text-Fig. 4ab) shows more fluid during flow of the debris masses and a transition to turbulent flow conditions (SELBY, 1994). These beds are unsorted, mostly crudely normally graded or sometimes inversely graded and are interpreted as sandy, less cohesive debris flows or sheetfloods (LOWE, 1976).

Breccias consisting of very angular clasts of dolomite with much less matrix (Dolomitebreccia) at the basis of some sections are interpreted as the talus of rockslides.

All alluvial fan sediments show components that are directly derived from the underlying basement.

The second facies association is summarised as a lacustrine association.

Lacustrine depositional environments can be lakes in the floodplains (see below) or small lakes developed after the drowning of swamps. Two types of deposits are present. Silt-clay rhythmites (Text-Fig. 5d) with thin parallel-laminated laminae are interpreted as warve-like lake floor deposits (SLY, 1994). Sand layers are minor in these deposits and organic debris is mostly absent.

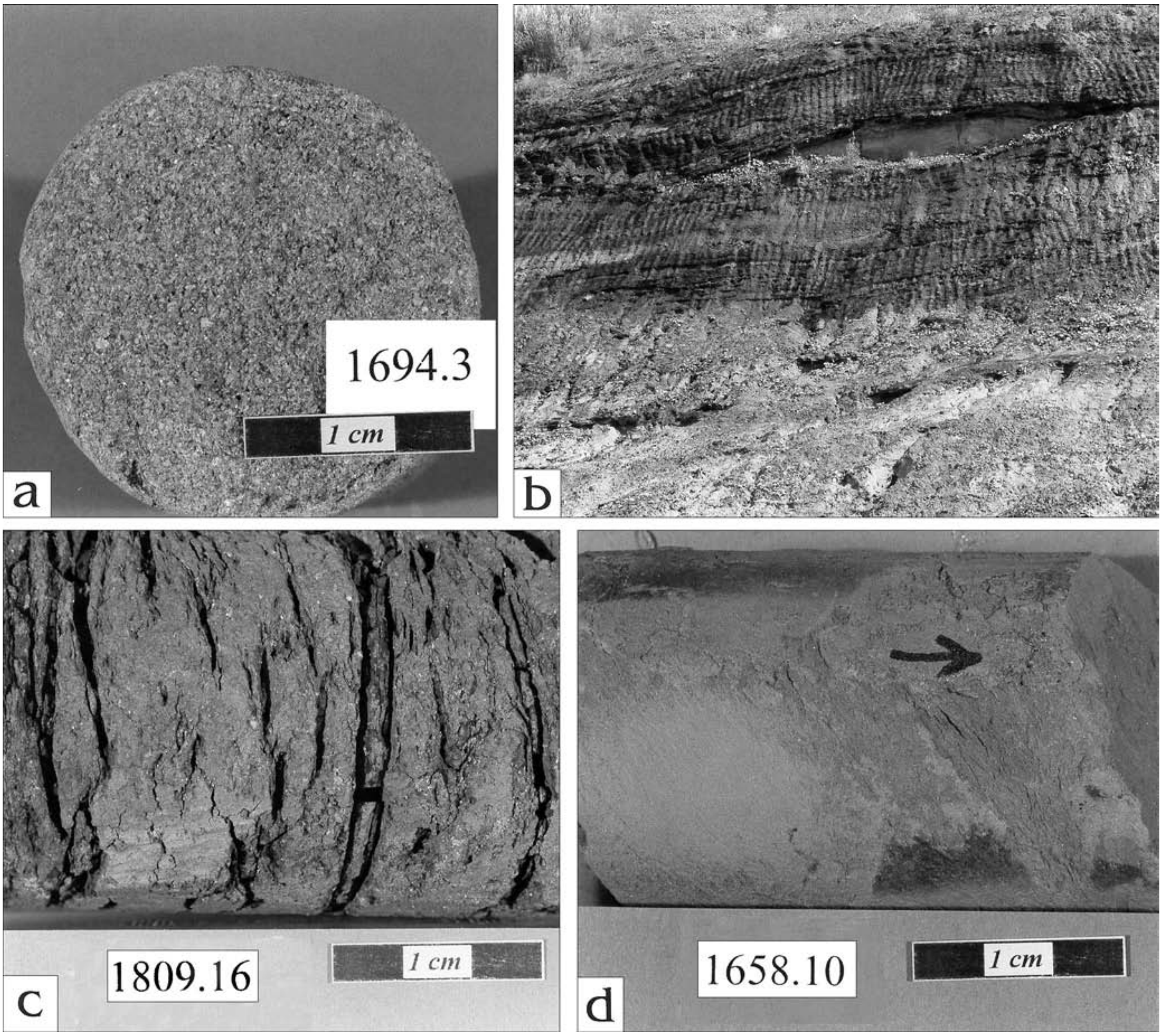
The second type is transitional to the alluvial fan facies association. Debris flows passing directly from the alluvial fan into this environment deposit turbidite-like sediments. The resulting deposits are normally graded, poorly sorted, clast- to matrix-supported breccias or gravels with sandy or silty tops. Sometimes the tops of the beds show parallel laminations. Silt or clay intraclasts are occasionally present. The matrix is mainly silty to sandy. They are interpreted as not fully developed high-density turbidity currents (LOWE, 1976) of the subaquatic part of small fan-deltas (MCPHERSON et al., 1987).

Shore or lakeside deposits are seldom recognised. Very well-sorted, organic -debris-free, structureless sand layers or nearly matrix-less gravel could represent small shorelines developed in the areas of the fan-deltas or river deltas (see below).

In most cases the alluvial fan association is followed by the third association, the fluviatile facies association. The division of the fluviatile environment into typical facies types and architectural elements (MIALL, 1985) is only possible to a limited extent based on mostly core sections. Therefore three facies types are distinguished. These are channels, swamps and overbank sediments. Channels include distributary channels as well as crevasse splay channels. The term overbank sediments includes levee, floodplain and crevasse splay sediments. Only a crude separation of these facies types is possible in the sections of the core data. For example the swamps are mainly situated in the floodplain areas, so that swamp and overbank sediments can also be summarised as the floodplain.

Very well sorted sands (Text-Fig. 5a), partly with gravel layers or gravel lags, sometimes showing planar crossbedding, are interpreted as channels. The only available surface outcrop shows that they are lensoid (Text-Fig. 5b). Text-Fig. 5b shows a larger sand- to fine gravel-filled channel in the upper middle of the picture, below this channel a clay-filled abandoned channel and to the left a further small sand-filled channel is visible. In this photo the channels are cut into the overbank association without the formation of larger levee deposits indicating that these channels probably are of crevasse splay origin (GALLOWAY & HOBDAY, 1997). The other deposits in Text-Fig. 5b are interpreted as floodplain sediments. The structureless sand layers are medium sorted and only sometimes show crudely normal grading. They are interpreted as crevasse splay sands (GALLOWAY & HOBBDAY, 1996). Between these crevasse splay sediments lignite layers alternate with organic debris, rich silts and clays (Text-Fig. 5c shows a detail of these lignite partings). They are interpreted together with the pure lignite seams as the swamp deposits. The swamp deposits also include layers of reddish clay or Fe-rich layers, seldom with some rootlets interpreted as pedogenic horizons. The fluviatile facies association is described in detail by HAAS (1998) from the open pit mine Oberdorf (Oberdorf Depression) in which some fluviatile-deltaic deposits also are present.

The Zangtal Hangend Abfolge (Zangtal Hanging Wall Succession) overlies the sediments of the Voitsberg, Tregist and Oberdorf Depressions erosively (Text-Fig. 5d). The depth of erosion is different, indicating an accentuated relief. In the Voitsberg Depression the Zangtal Upper Lignite seam (see below) is partly eroded (Text-Fig. 5d). The deposits of the Zangtal Hangend Abfolge form a fluviatile-dominated alluvial fan, in contrast to the debris flow-dominated alluvial fan facies association of the Köflach-Voitsberg Fm. They already belong to the Stallhofen Fm. and the sediments are not described in detail in this paper. Note that they contain a different spectrum of com-



Text-Fig. 4.
a) Core cross-section of well sorted fluviatile channel sands.
b) Overbank sediments in the Piberstein-Lankowitz Depression with different types of intersected channels (for explanation see text).
c) Typical core section from the overbank environment; medium-sorted siltysands (including organic debris) alternating with thin lignite layers.
d) Silt-clay rhythmites from the Obergraden depression (arrow shows upwards core direction). Visibility of warve-like structures is better in wet fresh cores.

ponents not regionally dominated (crystalline rocks, mainly gneiss) than the coarse clastics of the alluvial fan facies association.

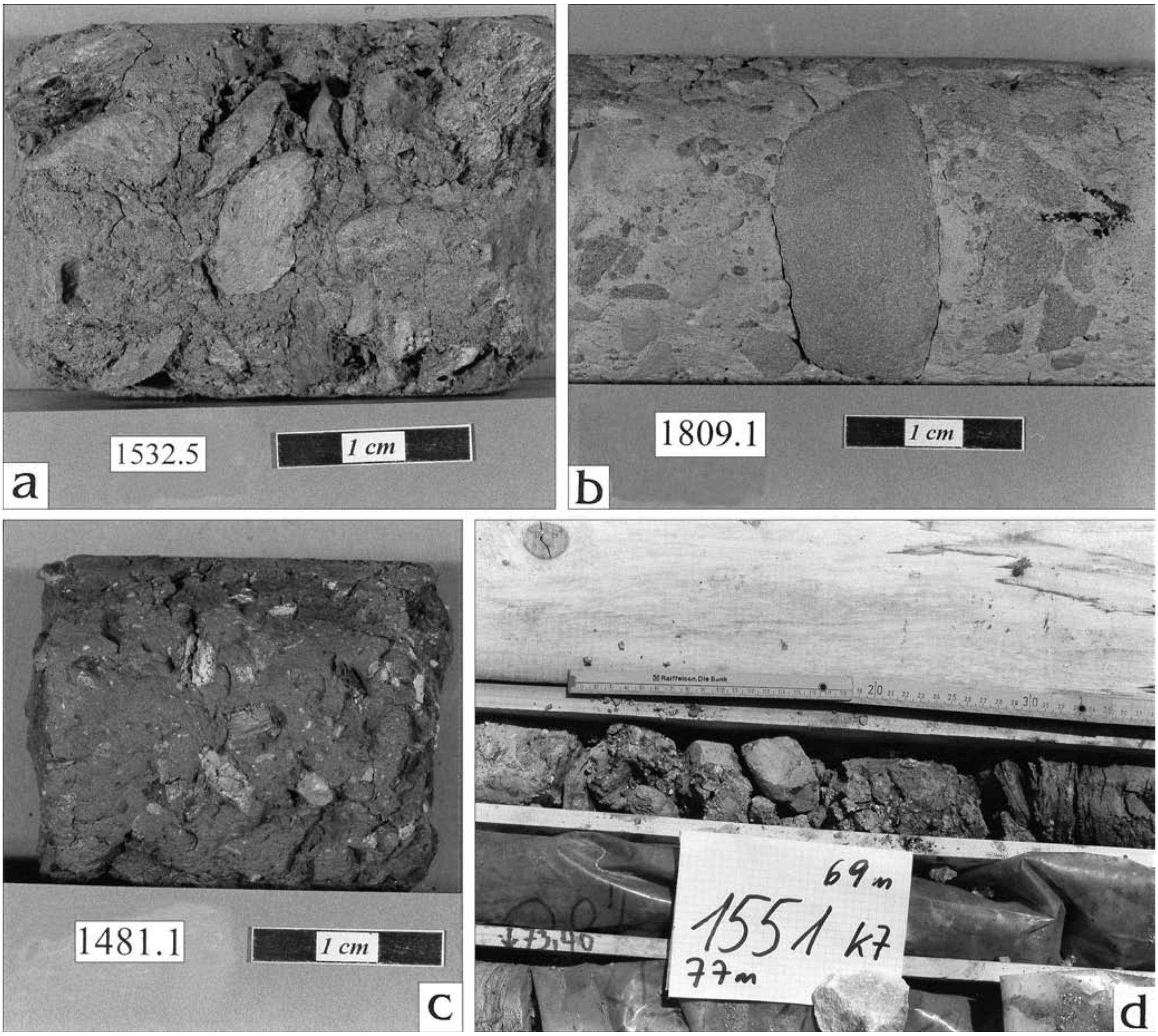
3.1. Differences of Facies Between the Lignite Depressions

The sedimentation in the Piberstein-Lankowitz Depression starts with the alluvial fan association (Text-Fig. 7, core 1481) followed by the fluviatile facies association. Lacustrine sediments or further major alluvial fan sediments are absent. The depression is fluviatil-dominated with various small overbank-swamp cycles (overbank sands followed by lignite and lignite with clay/silt partings, see cycles [arrows] in Text-Fig. A core 1494) intersected by fluviatile channels (Text-Fig. 7, core 1494). The result is that the depression is dominated by well sorted sands between the lignite seams. The seams (swamps) themselves are intersected by the fluviatile channels and the floodplains starved in several horizons. These horizons do not continue over the whole depression, so the lignite seams are not consistent.

The Obergraden Depression (very similarly developed are the other subdepressions of the Graden Depressions) shows at the basis very thin alluvial sediments (dolomite-breccias-talus) followed by a very thick lignite seam which is separated by lacustrine rhythmites into two main seams in the more central parts of the depression. The lignite seam is also overlain by those rhythmites (Text-Fig. 7, core 1658). Fluviatile deposits are minor. The lignite seams are persistent over the depression.

The depressions described above represent two extreme end members (nearly fully fluviatile-/swamp-dominated, nearly lacustrine-/swamp-dominated) of the Köflach-Voitsberg lignite depressions.

The Piber-Bärnbach Depression (Text-Fig. 8, core 1142) shows an alluvial fan facies at the basis which grades into a swamp. A second alluvial fan (Text-Fig. 8, core 1142 at depth 30 to 40 m) grades into a lacustrine delta. Various lignite seams (swamps) are intersected by lacustrine rhyth-



Text-Fig. 5.
Core samples.
a) Coarse breccias (only regional crystalline components) in silty to sandy matrix from the Zangtal depression above the Zangtal Lower Seam.
b) Coarse breccias (only regional Gosau components) in silty to sandy matrix from the Piberbach-Bärnbach Depression.
c) Breccia with reddish clay matrix at the basis of the Piberstein-Lankowitz Depression.
d) Erosive horizon directly above the Zangtal Upper Seam with reworked lignite and diatom marls.

mites as well as fluviatile channels and overbank sediments.

The Oberdorf Depression (HAAS, 1998) is more fluviatile-dominated, lacking larger lacustrine successions (rhythmites).

The Zangtal (Muttlkogl) Depression is very similar to the Oberdorf Depression but the hanging wall sediments above the lignite seam (named Zangtal Lower Seam, Text-Fig. 2) are formed by lacustrine fan delta sediments (Text-Fig. 8, core 1532). This indicates a second major subsidence of this depression, which is not developed in the other depressions. After this phase a new swamp in a newly configured depression (parts of the Zangtal Depression together with the newly formed Voitsberg Depression) is developed containing a coal seam (Zangtal Upper Seam, Text-Fig. 3) which is not recognised in the other depressions. At its southern border the Zangtal Upper Seam directly overlies the basement rocks and forms the lignite seam of the Voitsberg Depression (Text-Fig. 3).

At the top of the Zangtal Upper Seam, diatom-marls up to two meter in thickness overlie the lignite. They are interbedded with clay, marl and silt, some layers show influences of vulcanoclastics (biotite) and can be correlated with the Lobningberg Bed of the Stallhofen Fm. In core 1532 (Text-Fig. 8) these sediments are already eroded by the Zangtal Hangend Abfolge (see also Text-Fig. 5d which shows the erosional horizon).

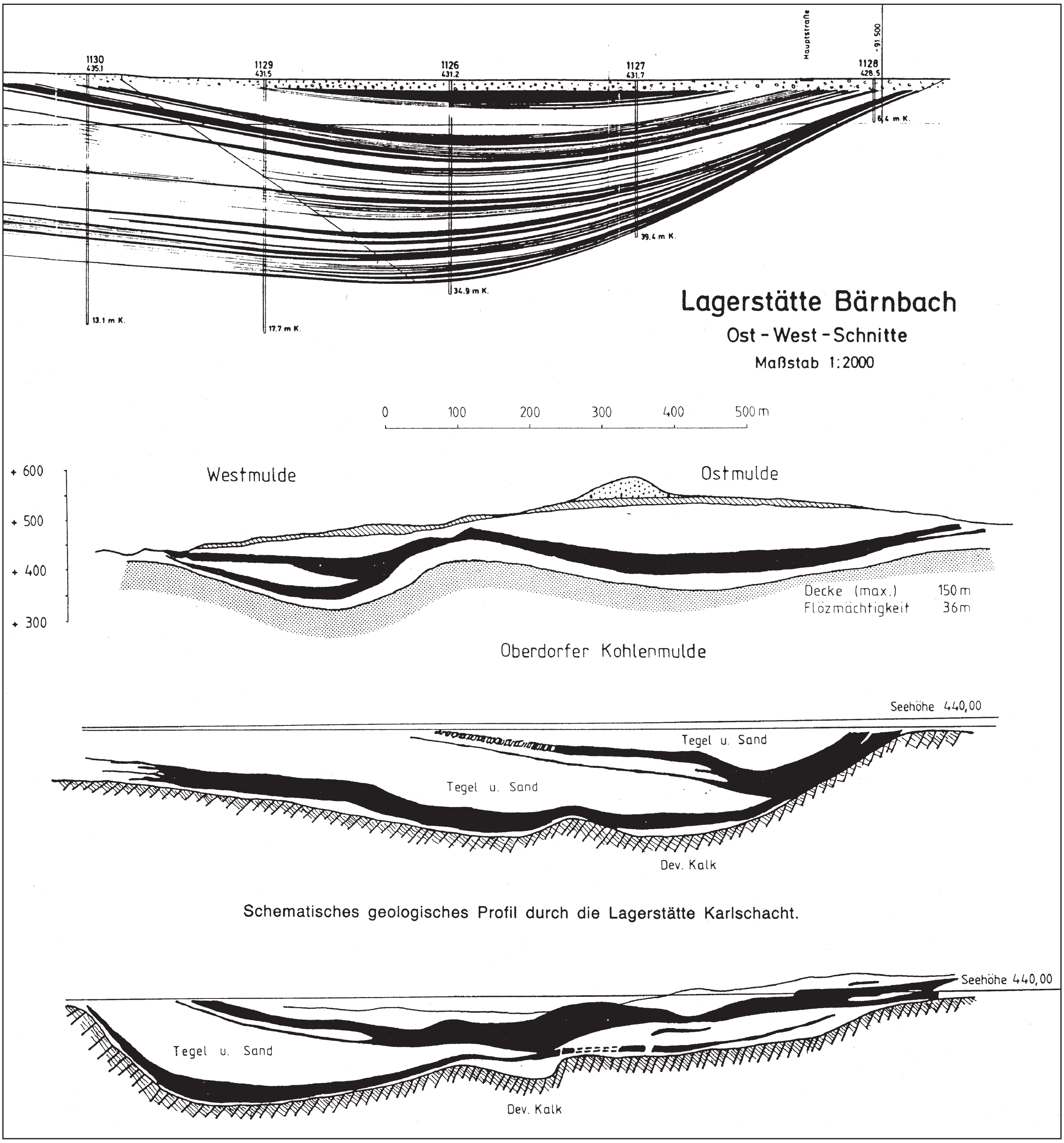
In the Tregist Depression (Text-Fig. 8, core 1308) the succession is very similar to the Zangtal Depression, but a lignite seam at the basis of the depression (at the position of the Zangtal Lower Seam or the Oberdorf lignite seam) is lacking. The coarse clastics show more lacustrine influences, indicating that this section is situated in a more distal part of a fan-delta than in core 1532 from the Zangtal Depression. The succession is followed by small lignite smuts (correlatable with the Zangtal Upper Seam) and then erosively overlain by the Zangtal Hangend Abfolge (not visible in core 1308 of Text-Fig. 8).

3.2. Correlation of the Lignite Seams of the Depressions

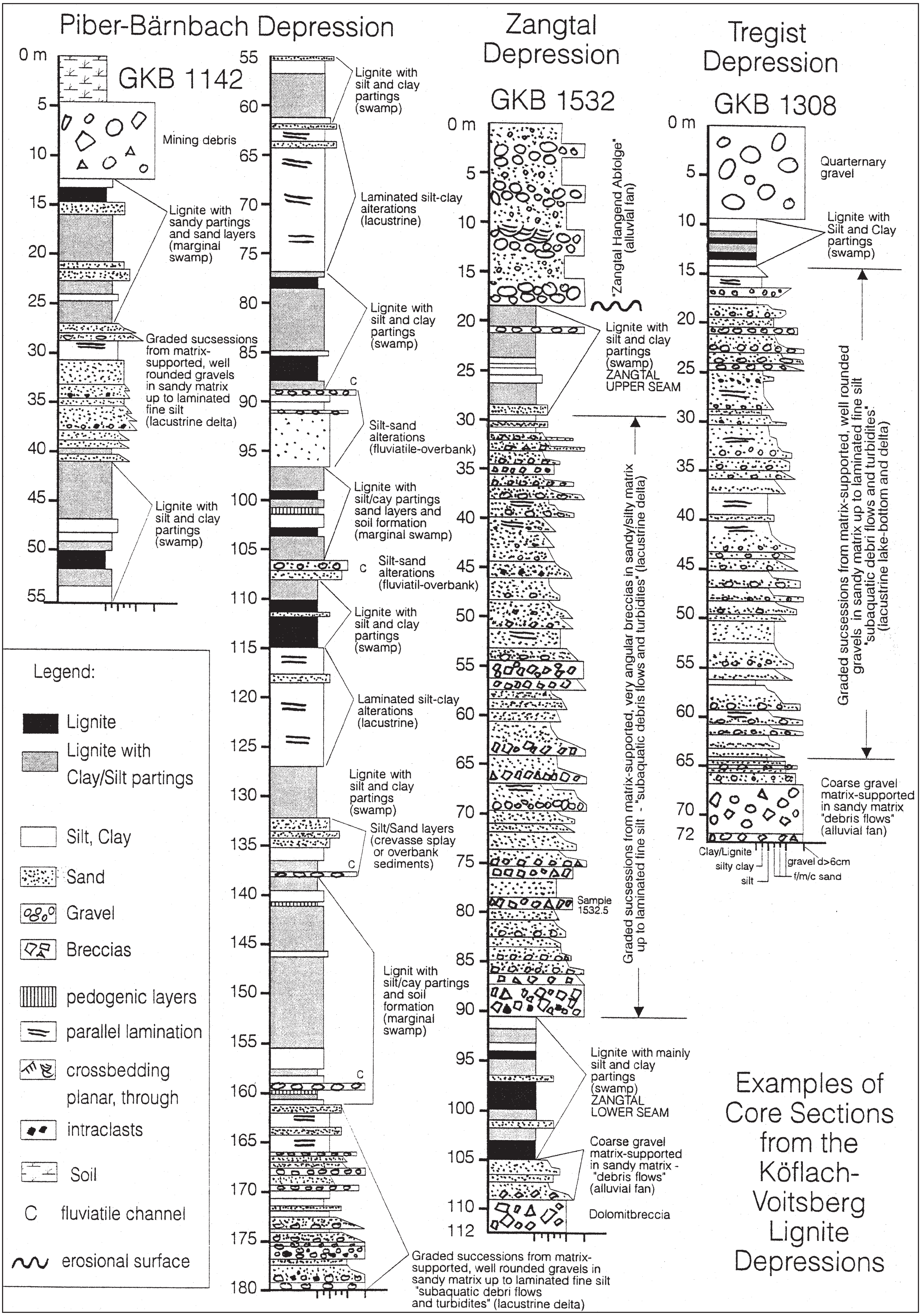
The former division into three lignite seams in each depression (without the Zangtal Upper Seam) described by KLAUS (1954) and POHL (1976) is not longer valid, but there is a crude separation into two lignite formation phases. In the Piberstein-Lankowitz Depression a longer interval with less lignite (Text-Fig. 7, core 1494, fluviatile-dominated environment) could represent the separation between the two phases. In the Obergraden Depression (Text-Fig. 6, lower two sections) the separation of the lignite seam in the central depression parts by the lacustrine rhythmites described above is obvious. In the Piber-Bärnbach Depression a strongly eroded, thick hanging wall seam (Text-Fig. 6, uppermost section) is separated by alluvial sediments visible in Text-Fig. 8 (core 1142, depth 30- 40 m; the uppermost lignite seam in core 1142 is the erosional remnant of the thick hanging wall seam). The main seam of the Oberdorf Depression is also separated into an upper and lower seam (Text-Fig. 6, second section and HAAS, 1998).

4. Subsidence of the Depressions

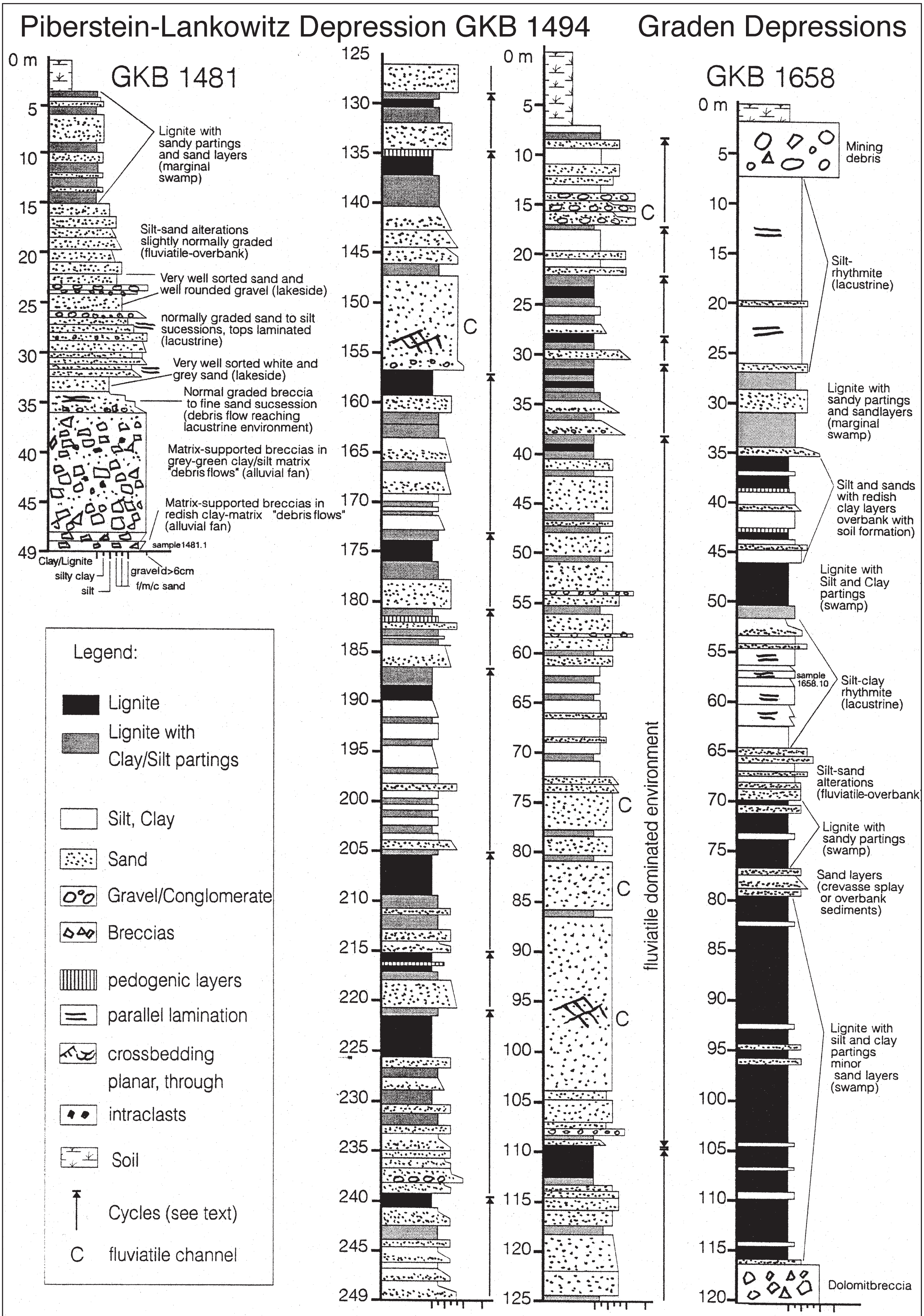
One possible reason for the variability in the sedimentary successions of the depressions could be the different basement types. In the first phase of the formation of the Köflach-Voitsberg Embayment, the Raasberg Fm. corresponds as a very rigid basement part separating its sediments into various blocks. Depressions with mainly the



Text-Fig. 6.
General sections through the Piberbach-Bärnbach Depression (above), the Oberdorf Depression (middle) and the Obergraden Depression (lowermost two).



Text-Fig. 7.
Example of core-sections from the Piberstein-Lankowitz Depression (1481, 1494) and the Graden Depressions (1658).
For location see Text-Fig. 3.



Text-Fig. 8.
Example of core-sections from the Piber-BärnbachDepression (1142), the Tregist Depression (1308) and the Zangtal Depression (1532).
For location see Text-Fig. 3.

Raasberg Fm. as basement show very fast subsidence with the development of lakes. Between the phases of sudden sinking, very slow subsidence allows the development of swamps (very thick lignite seams). In contrast, the Piberstein-Lankowitz Depression with large amounts of crystalline basement parts shows a more continuous subsidence. The crystalline basement did not respond as rigid as the Raasberg Fm and separation into blocks was not as accentuated. The other depressions are intermediate between these two extremes and show all types of facies association. The Kowald Depression, entirely on crystalline basement, contains only a small lignite smut; the Tregist Depression, situated on Gosau and Palaeozoic rocks, contains two smuts. For the formation of economic lignite in the Köflach-Voitsberg Embayment the basement of a potential depression has to be formed in extensive parts by the Raasberg Fm.

This first subsidence of the Embayment could correspond to the first tectonic phase described by HAAS et al. (1998; see their Text-Fig. 2a). In this phase, two periods of maximum tectonic activity appear (first period subsidence of the embayment and second period separation of the lignite seams). The second tectonic phase with the change of the extension direction (HAAS et al., 1998, their Text-Fig. 2b) could be correlated with the uncoupling and sinking of the Voitsberg- and Zangtal Depressions. This phase is terminated by the Zangtal Upper Seam. These two tectonic movements are closely related with the very close position of the depressions to the areas of faulting. The very regional clast composition supports this theory. The beginning subsidence of the Stallhofen Embayment and the main parts of the Styrian Basin is probably marked by the appearance of volcanism (diatom-marl, Lobningberg Bed) and then with the coarse Zangtal Hangend Abfolge erosively overlying the whole older embayment-fill. The more supraregional clast composition of these sediments supports this theory. All three tectonic movements together show a shift of the depocenters/areas of high sink rates from the basin margin into the central basin part from about NW to about SE.

5. Summary

The Miocene lignite-bearing deposits of the Köflach-Voitsberg Embayment show strong differences of their filling history, probably in response to different basement lithologies.

The subsidence of the basin and the resulting sedimentary fill can be correlated to tectonic phases which are responsible for the formation of the Styrian Basin. In the chronostratigraphic time scale the sink starts in the Ottnangian and ranges probably into the Lowermost Badenian with strong volcanic activity.

Acknowledgements

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