Lignite deposition and marine cycles The Austrian Tertiary lignite deposits – A case history

Von

Fritz F. Steininger, Fred Rögl, Peter Hochuli, Carla Müller

Aus den Sitzungsberichten der Österr. Akademie der Wissenschaften
Mathem.-naturw. Kl., Abt. I, 197. Bd., 5. bis 10. Heft

Wien 1988/89

In Kommission bei Springer-Verlag, Wien / New York

Hersteller: Agens-Werk Geyer + Reisser, 1051 Wien

Lignite deposition and marine cycles

The Austrian Tertiary lignite deposits – A case history

By FRITZ F. STEININGER, Institut für Paläontologie der Universität Wien, A-1010 Wien, Universitätsstr. 7/II, Austria

FRED RÖGL, Naturhistorisches Museum Wien, Burgring 7, A-1014 Wien, Austria

PETER HOCHULI, ESSO EPR-E, 213 Cours Victor Hugo, F-33321, Begles, France

CARLA MÜLLER, 1 Rue Martignon, F-92500 Rueil-Malmaison, France

(Vorgelegt in der Sitzung der mathem.-naturw. Klasse am 13. Oktober 1988 durch das w. M. WALTHER E. PETRASCHECK)

Contents:

Zusammenfassung:

Am Beispiel der tertiären Kohleablagerungen in Österreich werden die Zusammenhänge zwischen Kohlebildung und marinen Trans- und Regressionszyklen aufgezeigt. Ferner können mit Hilfe palynologischer Studien direkte Beziehungen zwischen Kohlebildungsphasen und Klimaentwicklung aufgezeigt werden.

Im Känozoikum Österreichs werden drei tektonisch begründete Sedimentationszyklen mit Kohleführung unterschieden:

Gosau Zyklus (Unter-Eozän)
Molasse Zyklus (Ober-Eozän bis Unter-Miozän)
Intramontaner Beckenzyklus (Mittel- bis Unter-Miozän)

Kohlebildungsphasen finden sich: im Untereozän der zentralalpinen Gosau Formation; im Obereozän des Untergrundes der Molassezone; im Mitteloligozän und im Untermiozän in nördlichen Buchten und im Oberoligozän am Westrand der Molassezone. In den intramontanen Becken fallen die bedeutendsten Kohlebildungsphasen in das Karpatien und das Mittel- bis Obermiozän. Die mittel- und obermiozänen

Kohlelagerstätten der Molassezone wurden unter denselben Bedingungen wie jene in den intramontanen Becken gebildet.

Möglichkeiten für eine ökonomische Kohleexploration in Österreich sind nur im Paläogen des Untergrundes am Nordrand des Molassebekkens gegeben.

Die im österreichischen Känozoikum bekannten Kohlebildungsphasen stehen im unmittelbaren Zusammenhang mit den weltweit auftretenden marinen (transgressiven) Zyklen und korrelieren in diesem Sinn mit den meisten übrigen tertiären Kohlelagerstätten in Europa. Diese Fallstudie zu den Kohlebildungsphasen in Österreich könnte als Basis einer erfolgreichen Untergrund-Kohleexploration dienen.

Abstract

The close relation between coal-accumulation and marine transgressive cycles is demonstrated by the Austrian Tertiary lignite deposits. Furthermore, palynological investigations show a direct correlation to climatic conditions.

Three tectonically caused sedimentary cycles with lignite deposition are distinguished:

Gosau cycle (Early Eocene)
Molasse cycle (Late Eocene to early Miocene)
Intramountain-basin cycle (Middle Miocene to Late Miocene)

Within these cycles important phases of lignite deposition are: the Early Eocene of the Central Alpine Gosau formation; the Late Eocene in the subsurface of the Molasse-Zone; the Middle Oligocene and Early Miocene in the northern bays and Late Oligocene on the western edge of the Molasse-basin. In the intramountain-basins, the main lignite phases are located in the Early/Middle-Miocene and Late Miocene. The Middle- and Late Miocene lignites of the Molasse-Zone are formed under the same conditions as the lignites in the intramountain-basins.

Possibilities for economic lignite exploration in Austria are given only in Paleogene deposits of the subsurface of the northern areas of the Molasse-basin.

The lignite phases known from Austrian Tertiary deposits are related directly to worldwide marine (transgressive) cycles and can be seen in connection with most of the other European Tertiary lignite deposits. The methodology demonstrated that the Austrian case history could serve as a basic assumption for a successful subsurface coal exploration.

Introduction

The oil crises and concern about future energy resources have caused a renewed worldwide interest in coal as a main energy source. The Tertiary lignite deposits are of main interest in this connection, especially in the northern hemisphere where large reserves are known at present. Up until now, coal exploration in the Austrian Tertiary has been carried out only on coal indications cropping out on the surface and by extending previously known deposits. Lignite indications as well as smaller and larger coal seams and measures are widespread in the Tertiary of the intramountain basins and the Molasse-Zone. These deposits have been quarried since the middle of the 18th century; most of the mines, especially those in inneralpine areas, are now closed down.

Overviews and monographic papers concerning Austrian coal deposits and mines have been published by: KOMITEE ALLGEM. BERGMANNSTAG (1903), PETRASCHECK (1922–1929; 1937), WEBER & WEISS (1983) and ZAPFE (1956).

Lignite-exploration research has been supported during the past several years by the Ministry for Economical Affairs, the Geological Survey, the States of Austria, the Academy of Sciences, the Austrian Science Foundation and the Austrian Coal-Mining Companies (see FETTWEIS, 1982; THIELE, 1983).

The goal of this study is to test the hypothesis of coal measure formation in the Austrian Tertiary deposits in relation to marine trans- and regressive cycles. This would provide a new prospective of lignite exploration, especially for subsurface coal deposits.

Most lignite deposits were formed in the transition between marine and continental facies belts. Successful exploration, however, must initially take all geological features related to basin development into account. In addition to a tectonical analysis, stratigraphy, paleogeographic reconstruction, paleoclimatology and facies analyses are important. Geophysical investigations and deepdrilling should commence only after these analyses and the relevant geological surface studies have provided a prognosis on lignitophile phases and possible lignite exploration areas.

These procedures were recommended by LÜTTIG (1971, 1977) and POHL (1981) for successful and economic exploration strategies.

This study was undertaken at the suggestion of Prof. Dr. W. E. PETRASCHECK, to whom we are very grateful for his support. The Austrian Academy of Sciences, commission on „Grundlagen der Mineral-Rohstoff-Forschung“ supported this investigation financially under Project Nr. 4223.

Lignite accumulation, marine cycles, paleogeography and climate

In contrast to the methods normally used (expensive drilling operations, etc.) to survey the geological situation of sedimentary basis with possible coal measures the encouragement of LÜTTIG (1971, 1977) proposed the following scientific approach: First of all the possibilities of coal measure deposition in a given sedimentation area as well as the possible sequence of lignitophile phases should be clarified. The accumulation of lignites is apparently directly related to marine transgressive and regressive phases and tectonics.

AHRENS & al. (1968) already demonstrated a clear relation between the generation of the lignite deposits in northern Germany and the upper Oligocene and lower Miocene marine transgression in this area. In the coal measures of the Lausitz, paralic coal seams are dominant in regressive cycles („Schuttfächerrandflöz"); these seams are clearly distinguished from the epirogenic seam type. Studies of recent peat accumulations in the Mississippi Delta (KOSTERS & al., 1987) showed the largest quantities of organic, low ash material accumulations in cut off freshwater basins of the delta; during transgressive events, accretion of organic material (up to 35 %) took place in saltwater marshes.

The significance of large scale tectonic movements in relation to the formation of intramountain basins and lignite deposition was demonstrated by CECH (1980) for the western Carpathian mountains. NEBERT (1983 a), in his detailed studies of sedimentary sequences of intramountain-basins, clearly pointed out that lignite accretion constitutes a member of the sedimentary cycle. The cycle starts with a fluviatile phase with coarse material. The raising of the groundwater table transforms the fluviatile cycle into a limno-fluviatile phase with sand and clay sedimentation.

This phase is followed by a telematic (peat-forming) phase of lignite accretion and is terminated by limnic sedimentation of marls or limestones. The following fluviatile sediments fill up the basin.

A fundamental summary of requirements for lignite formation was given by LÜTTIG (1968, 1971, 1977): initially humid, peat-forming climatic conditions must cause intense growth of peat or lignite-generating plant associations. For this process he postulates a rising groundwater table, a condition which in general is caused in connection with marine transgressive settings. Furthermore, synchronous tectonic movements must provide the necessary space in the form of sedimentary traps or basins. During this process, basin subsidence, the sedimentation rate and peat accretion, as well as the rise of the groundwater table have to be in balance for extensive peat accumulation: a high subsidence rate generates either coarse clastic sedimentation or a rapidly deepening basin without extensive nearshore marshes.

The prerequisites for possible exploration areas are therefore the development of a telematic phase – slowly subsiding marshes and coastal swamps – in the area of labile faultzones or coastal areas under marine transgressive settings.

A final prerequisite is the conservation of the lignite deposits. Favourable conditions include slowly subsiding basin margins far from river mouths and the rapid deposition of sediments on top of the seams. After the formation and the deposition of coal seams the uplift of the area or any lowering of the general base level of erosion might result in rapid destruction of the seams.

These considerations have provided the basis to investigate further possibilities of lignite accumulation in the Tertiary sedimentary basins of Austria and to provide new perspectives for lignite exploration. A similar study concerning Oligocene and Miocene lignite deposition of southeast Europe and south Asia was published recently by SUJITNO & TAUPITZ (1985), and TAUPITZ (in press).

A most important factor for the accumulation of lignite deposits in Austria is the paleogeographic evolution of Europe in Tertiary times. During the Palaeogene the Austrian sedimentation area covered the region between the Tethyan-realm and the European epicontinental sea. The northern border of this sedimentation area – the Helvetic-Zone and the basement of the Molasse-Zone showed close relations to the European archipelago up until the Eocene (BALDI, 1986; KRUTSCH & LOTSCH, 1958).

From Oligocene times onwards elongated troughs developed from the east to the west following the alpine orogene. This caused in time progressive separation from the open oceans, eventually giving rise to the Paratethys realm (BALDI, 1986; RÖGL & STEININGER 1983; STEININGER & RÖGL, 1979).

A sequence of transgressive and regressive cycles was recognized at that time troughout the Paratethys. These cycles were in accordance with and partially caused by the global sea level cycles; they were also superimposed as well as intensified by regional tectonic processes (HAQ & al., 1987; RÖGL & STEININGER, 1983; STEININGER & al., 1986; VAIL & al., 1979).

With the beginning of the Middle Miocene, intramountain-basins started to subside in the Central Paratethys. The east-west trending troughs gradually lost their paleogeographic significance. The deposition of coal measures in these intramountain-basins indicates strong interaction with the marine advances.

Two main types of climatic conditions for lignitophile phases can be distinguished:

(1) worldwide temperature changes of the oceans during Tertiary time show the following general trends as derived by faunal changes and the $^{16}O/^{18}O$ isotopic ratios (e. g.: KENNETT, 1985; MCGOWRAN, 1986; MILLER & al., 1987; MÜLLER, 1984; OBERHÄNSLI, 1986; SAVIN & al., 1981; VERGNAUD-GRAZZINI. 1984): after reaching a temperature maximum in the middle Eocene – and a slightly smaller peak in the Middle Miocene – the temperature tendences fluctuate only slightly, generally decreasing until the Pleistocene. Remarkable cooler phases are known at the Eocene/Oligocene boundary, in the upper Oligocene and later Middle Miocene. Warm phases occur in the Early Miocene and at the beginning of the Middle Miocene. The Late Miocene and Pliocene are characterized by fewer changes in isotopic ratios. Beginning in Late Miocene (Messinian) short but strong oscillations predominate. On the large scale, these temperature changes depend on plate tectonic situations as well as with the flow or the interruption of circum-equatorial current systems and the formation of polar caps (RÖGL & STEININGER, 1984; SHAKLETON & KENNETT, 1975).

(2) Regional changes of continental temperature and humidity ratios within the circum-Mediterranean area are best documented by pollen- and leaf-floras and mammal faunas (e. g. BESSEDIK & al., 1984; HOCHULI, 1978; JUNG & MAYR, 1980; KOVAR-EDER, 1987; LOPEZ-

MARTINEZ, 1987; MAI, 1967; STUCHLIK, 1979; SUC, 1984 a, b; WEERD & al., 1978):

From the Late Eocene to Lower Oligocene a subtropical, humid climate with no frosts predominates; the thermophilous elements in the pollen floras decrease steadily from the Oligocene onwards; in the upper Middle Oligocene the intermediate and arctotertiary pollen elements increase. In the Late Oligocene, decidious plants predominate; temperature and humidity decrease.

The beginning of the Miocene is characterized by a renewed worldwide subtropical warming, followed by a humid cooling phase. The climatic optimum at the Early/Middle Miocene boundary changes later to a dry and cooler phase. Only in the Late Miocene is the climate warmer again, precipitation in the Mediterranean and in middle Europe is already regionaly differentiated at this time. The salinity crisis (Messinian) of the Mediterranean results in arid climates in continental Europe.

These regional climatic fluctuations were caused by changing dimensions of the epicontinental seas and their changing connections to the open oceans as well as by the uplifts within the Alpine orogene (SHATILOVA & RAMISHVILI, 1984; TRAVERSE, 1982).

Lignitophile phases in the Austrian Tertiary – a case history

One of the most important prerequisites for coal exploration and basin analysis are detailed paleontological studies – resulting in strong facies analysis and biostratigraphies. Most essential is a consolidated correlation of continental and marine deposits by means of palynology and mammal faunas.

During the last decade a detailed stratigraphic zonation has been provided for the Tertiary of Austria; this has even enabled interregional correlations. A modern litho- and chronostratigraphic compilation of the Tertiary basins of Austria was given by TOLLMANN (1985). The stratigraphy (Figs. 2, 3) of this study follows: BALDI (1986), HOCHULI (1978), MARTINI & MÜLLER (1986), STEININGER & al. (1987).

Gosau cycle (Early Eocene)

Figure 1

The oldest Tertiary coal deposits are known from the central Alpine area of the Krappfeld(Sonnberg)-basin in Carinthia. Paleogeographically these coal seams were deposited on the southern edge of the Gosau-formation. Marine Late Cretaceous sediments are overlain by Paleocene continental red clays („Rote Tone"). During the marine advance of the Lower Eocene transgression, coal measures are deposited; according to palynological investigations they are upper Early Eocene (Palaeogene-Zone 13) in age. This transgressive event appears to be correlated in time with the worldwide Early Eocene transgressive cycle (HAQ & al., 1987).

Molasse cycle (Late Eocene to Early Miocene)

Figures 1, 2 and 4

The formation of the Molasse-trough in the Late Eocene is subsequently followed by a gradual advance of the sea across the southern border of the European continent. Deep drillsites in Upper Austria (e. g.: Puchkirchen, Hocheck, Kohleck, and Grünau 1) recovered up to 3 metre thick coal seams intercalated into the basal „Limnische Serie" (WAGNER, 1980). Palynological studies indicate that these deposits belong to Palaeogene-Zone 18. The small brown coal indication from Alt-Ruppersdorf, Lower Austria, belongs to the allochthonous Molasse-Zone (Waschberg-Unit).

Distinct worldwide transgressive events generated the coal measures from Häring (Lower Inn valley) in Tyrol. Tectonically these lignites belong to the parautochthonous Molasse-Zone and are deposited on top of the nappes of the Northern Calcareous Alps, forming so-called „piggy back" basins. Paleogeographically these formations belong to the southern border of the Molasse-basin. The coal measures are overlain by the marine „Zementmergel" formation (Nannoplankton-Zone NP 21).

In the lower Middle Oligocene (Palaeogene-Zone 20 a), limnic and paralic lignite deposition is known from embayments and inlets on the southern border of the Bohemian Massif. The most important mining districts are in Lower Austria in the area of Herzogenburg (e. g. Statzendorf, Klein-Rust, Hausheim, Oberwölbling) and in the bay of Krems (e. g. Tiefenfucha, Thallern, Angern). Groundwater drillsites in the Horn-basin revealed only lignite indications. The abandoned mines of Starzing and Hagenau are found in an allochthonous position, i. e., transported or thrusted from the south to the north. The pollen floras of these deposits demonstrate a decrease of thermophilous elements – a humid and still warm climate can be assumed. All these localities are situated at the border of a marine advance beginning in Lower Oligocene.

In the upper Middle Oligocene (Palaeogene-Zone 20 b) only a few small lignite deposits are known from the northern border of the Molasse-basin (e. g. Mursberg, Kollmitzberg, seams of Zelking). Within the pollen floras, intermedium and arctotertiary elements increase; this points to cooler and partly drier climatic conditions.

At the western part of the marine-influenced Molasse-basin in Upper Bavaria, the relation of lignite formation to marine cycles can be demonstrated most clearly: distinctive regressive and transgressive seam-cycles can be distinguished (Fig. 4). Within the lower Egerian, regressive cycle lignite deposits are known from Kössen (Tyrol) within the fluviatile-limnic „Angerberg"-formation (SCHNABEL & DRAXLER, 1976).

Within the transgressive cycle only few lignite indications can be recognized on the southern border of the Bohemian Massif (Gallneukirchen bay: Obenberg, Zirking, Standorf; Melk area: „Cyrena"-beds of Zelking; Herzogenburg area: lignitic marks of Winzing and Eggendorf).

In terms of palynostratigraphy all these localities belong to Neogene-Zone I. Arctotertiary and intermediate froms dominate; this points to the Oligocene climatic minimum.

The marine faunal elements and pollen floras (Neogene-Zone II) indicate an Early Miocene warming (uppermost Egerian to lower Eggenburgian) with subtropical to tropical climatic conditions.

The worldwide transgressive event causes marine advances far across the tableland of the Bohemian Massif in the Austrian lower Miocene. Only minor lignite indications are known from the Horn-basin (Neogene-Zone II).

Lignite deposition occurs again at the culmination of this Early Miocene transgressive event in the Ottnangian (Neogene-Zone III). The seams of the Langau-Riegersburg mining district are formed in shallow tectonic troughs on top of the Bohemian Massif tableland (OBRITZHAUSER-TOIFL, 1954; ZAPFE, 1953). In the Upper Austrian Molasse-Zone, coal indications are found in the form of coal-pebbles (scientific drillsite: Kemating K 1, Geol. Survey). In Vorarlberg the Wirtatobel-lignites are intercalated into shallow water sediments of the southern border of the Molasse-basin. The flora of Neogene-Zone III indicates a more humid climate, distinctively cooler than in Neogene-Zone II.

Uplifts of the western Molasse-basin finally resulted in the termination of marine sedimentation as far as St. Pölten at the end of the Ottnangian. Simultaneously, intramountain-basins are formed by tectonic reorganization throughout the entire Alpine-Carpathian region.

Intramountain-basin cycle (Middle Miocene to Late Miocene)

Figures 1 and 3

At the turn to the Middle Miocene the paleogeography changed due to tectonic basin evolution. An epicontinental sea covered the central parts of the Paratethys, stretching from Upper Italy across Slovenia („Transtethyan-Trench-Corridor") to Hungary and across Slovakia, reaching the Molasse-Zone north of the Danube.

In the Styrian basin extensive coal measures formed in limnic-fluviatile environments at the edge of this Karpatian sea, west of the „Sausal"-swell: The Wies-Eibiswald district (NEBERT, 1983 b) and the Voitsberg-Köflach district (KLAUS, 1954; POHL, 1976). In the Wies-Eibiswald district, seams up to 5 metres thick formed in shallow depressions; in the Voitsberg-Köflach district however, asymmetric lignite seams are known in tectonically formed basement-troughs. In the Early Badenian only minor lignite deposits accumulated in smaller embayments of the Styrian-basin due to the rapidly extending transgressive sequence (Stallhofener-Bucht, Passailer-Becken).

The Karpatian/Early Badenian marine transgression caused a remarkable rise of the groundwater table, which extended into the Central Alpine area of the Norian depression. In this depression small lignite basins formed by faulting from Tamsweg in the west, to Fohnsdorf, and in

FIG. 1

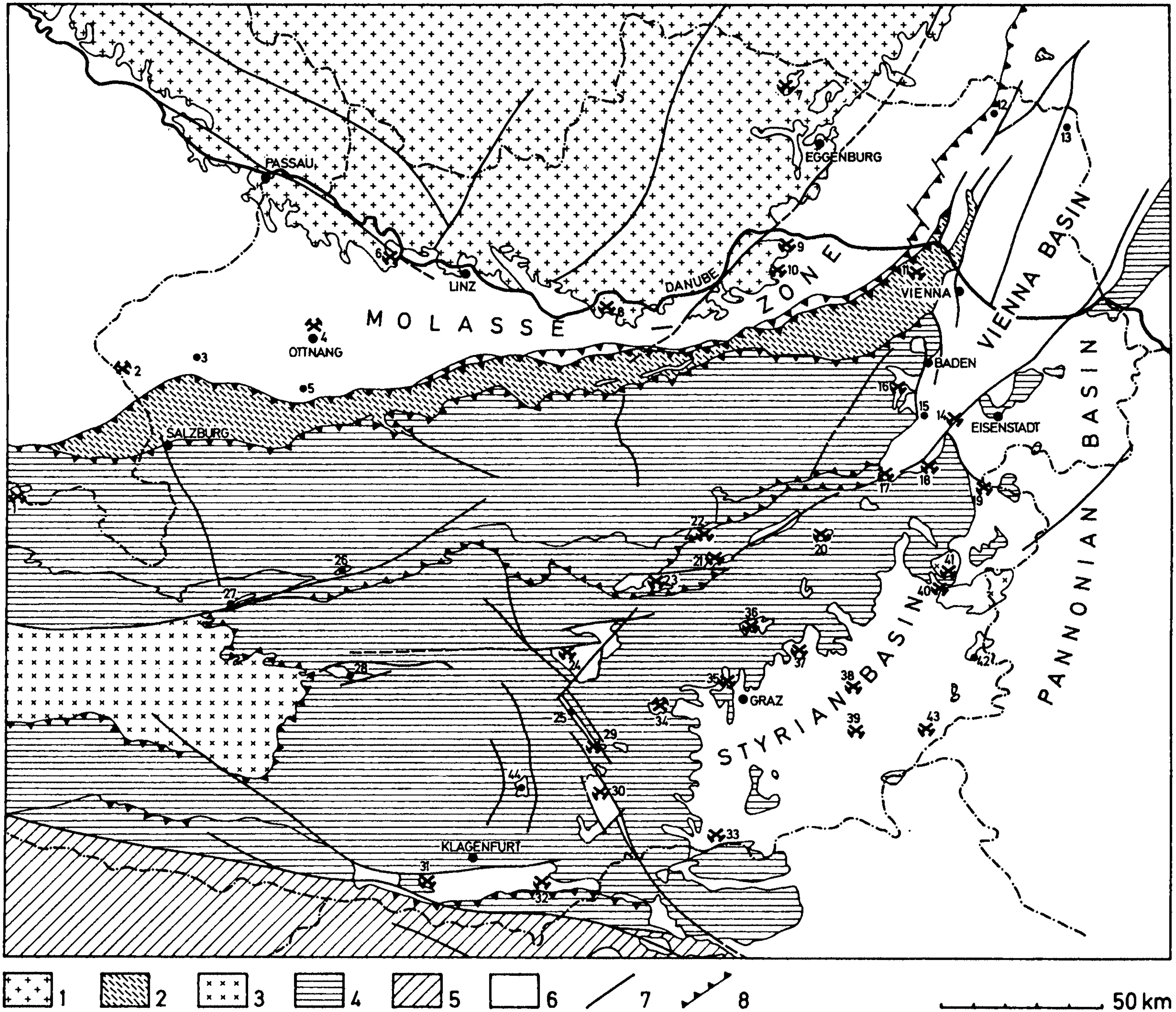

PASSAU
EGGENBURG
LINZ
DANUBE
MOLASSE
ZONE
VIENNA
VIENNA BASIN
BADEN
EISENSTADT
OTTNANG
SALZBURG
GRAZ
KLAGENFURT
STYRIAN BASIN
PANNONIAN BASIN
1
2
3
4
5
6
7
8
50 km

FIG. 2

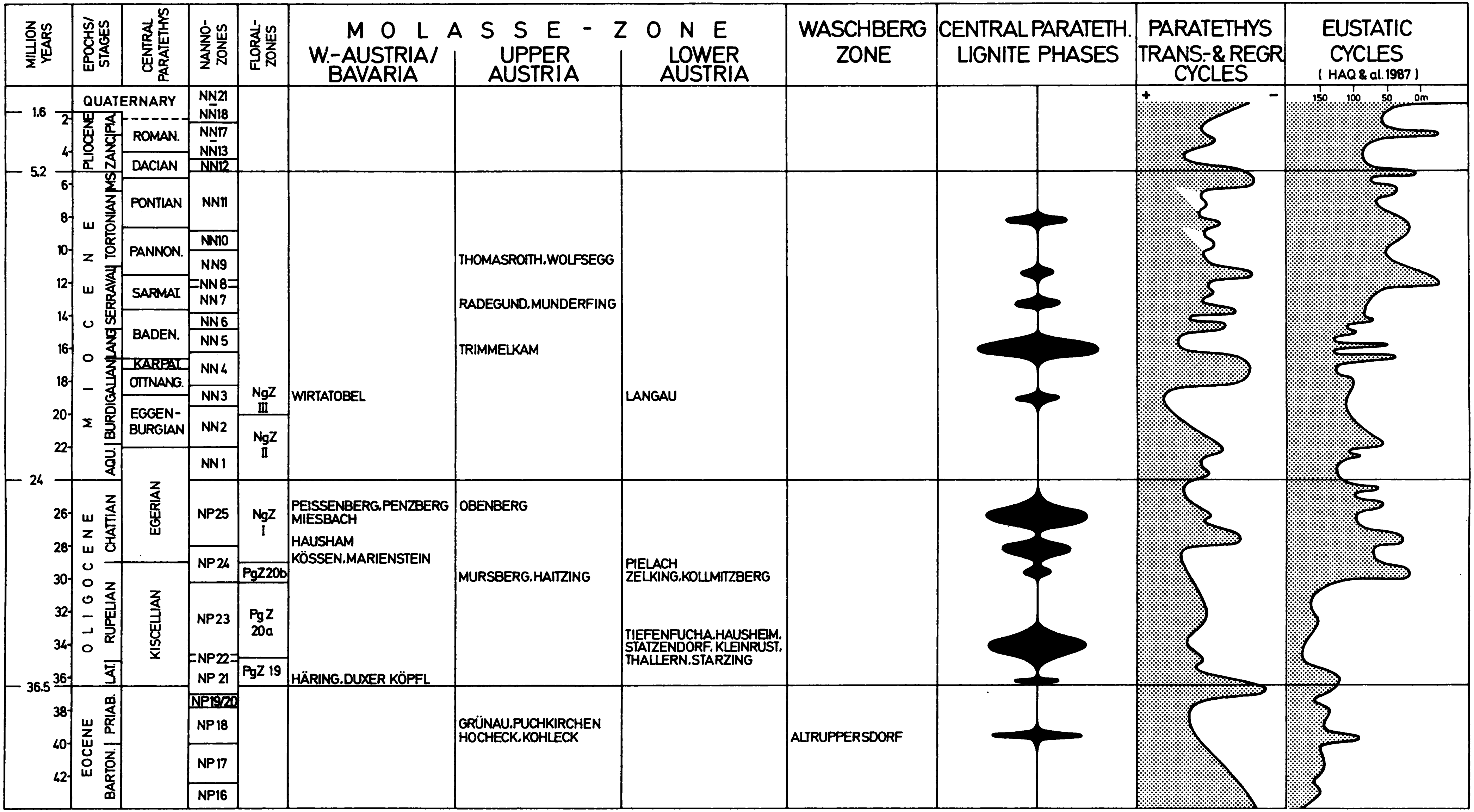
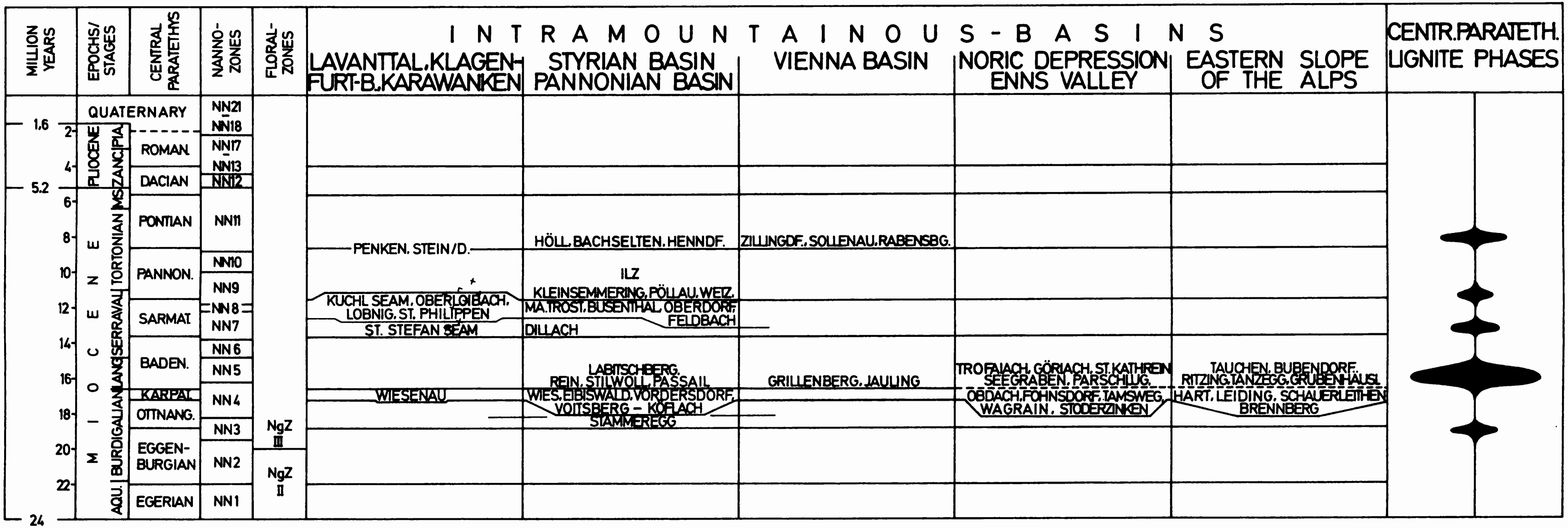
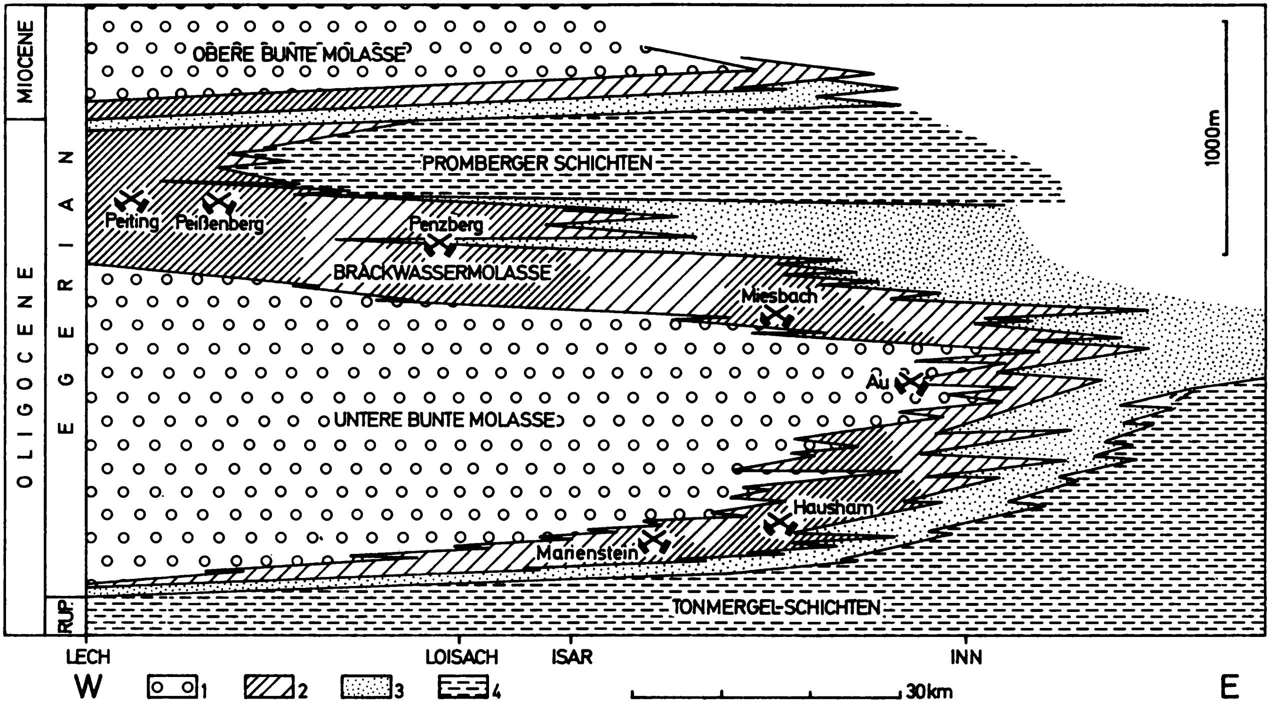

MILLION YEARS
EPOCHS/ STAGES
CENTRAL PARATETHYS
NANNO-ZONES
FLORAL-ZONES
MOLASSE - ZONE
W.-AUSTRIA/ BAVARIA
UPPER AUSTRIA
LOWER AUSTRIA
WASCHBERG ZONE
CENTRAL PARATETH. LIGNITE PHASES
PARATETHYS TRANS.-& REGR. CYCLES
EUSTATIC CYCLES (HAQ & al. 1987)
+
-
150 100 50 0m
1.6
5.2
24
36.5
2 4 6 8 10 12 14 16 18 20 22 26 28 30 32 34 36 38 40 42
QUATERNARY
PLIOCENE
ZANCLIA
MS
TORTONIAN
SERRAVAL
LANG
BURDIGALIAN
AQU.
MIOCENE
OLIGOCENE
CHATTIAN
RUPELIAN
LAT.
EOCENE
PRIAB.
BARTON.
ROMAN.
DACIAN
PONTIAN
PANNON.
SARMAT.
BADEN.
KARPAT.
OTTNANG.
EGGEN-BURGIAN
EGERIAN
KISCELLIAN
NN21
NN18
NN17
NN13
NN12
NN11
NN10
NN9
NN8
NN7
NN6
NN5
NN4
NN3
NN2
NN1
NP25
NP24
NP23
NP22
NP21
NP19/20
NP18
NP17
NP16
NgZ III
NgZ II
NgZ I
PgZ20b
PgZ 20a
PgZ 19
WIRTATOBEL
PEISSENBERG, PENZBERG
MIESBACH
HAUSHAM
KÖSSEN, MARIENSTEIN
HÄRING, DUXER KÖPFL
THOMASROITH, WOLFSEGG
RADEGUND, MUNDERFING
TRIMMELKAM
OBENBERG
MURSBERG, HAITZING
GRÜNAU, PUCHKIRCHEN
HOCHECK, KOHLECK
LANGAU
PIELACH
ZELKING, KOLLMITZBERG
TIEFENFUCHA, HAUSHEIM,
STATZENDORF, KLEINRUST,
THALLERN, STARZING
ALTRUPPERSDORF

FIG. 3



MILLION YEARS
EPOCHS/ STAGES
CENTRAL PARATETHYS
NANNO-ZONES
FLORAL-ZONES
INTRAMOUNTAINOUS-BASINS
LAVANTTAL, KLAGENFURT-B., KARAWANKEN
STYRIAN BASIN PANNONIAN BASIN
VIENNA BASIN
NORIC DEPRESSION ENNS VALLEY
EASTERN SLOPE OF THE ALPS
CENTR. PARATETH. LIGNITE PHASES
1.6
2
4
5.2
6
8
10
12
14
16
18
20
22
24
QUATERNARY
PLIOCENE
MIOCENE
ZANCLIAN
MS.
TORTONIAN
SERRAVAL.
LANG.
BURDIGALIAN
AQU.
ROMAN.
DACIAN
PONTIAN
PANNON.
SARMAT.
BADEN.
KARPAT.
OTTNANG.
EGGEN-BURGIAN
EGERIAN
NN21 - NN18
NN17 - NN13
NN12
NN11
NN10
NN9
NN8
NN7
NN6
NN5
NN4
NN3
NN2
NN1
NgZ III
NgZ II
PENKEN, STEIN/D.
KUCHL SEAM, OBERLOIBACH, LOBNIG, ST. PHILIPPEN
ST. STEFAN SEAM
WIESENAU
HÖLL, BACHSELTEN, HENNDF.
ILZ
KLEINSEMMERING, PÖLLAU, WEIZ, MA. TROST, BUSENTHAL, OBERDORF, FELDBACH
DILLACH
LABITSCHBERG, REIN, STIWOLL, PASSAIL
WIES, EIBISWALD, VORDERSDORF, VOITSBERG - KÖFLACH
STAMMEREGG
ZILLINGDF., SOLLENAU, RABENSBG.
GRILLENBERG, JAULING
TROFAIACH, GÖRIACH, ST. KATHREIN, SEEGRABEN, PARSCHLUG,
OBDACH, FÖHNSDORF, TAMSWEG, WAGRAIN, STODERZINKEN
TAUCHEN, BUBENDORF, RITZING, TANZEGG, GRUBENHÄUSL
HART, LEIDING, SCHAUERLEITHEN, BRENNBERG

FIG.4


MIOCENE
OLIGOCENE
EGERIAN
RUP.
OBERE BUNTE MOLASSE
PROMBERGER SCHICHTEN
1000m
Peiting
Peißenberg
Penzberg
BRACKWASSERMOLASSE
Miesbach
Au
UNTERE BUNTE MOLASSE
Hausham
Marienstein
TONMERGEL-SCHICHTEN
LECH
LOISACH
ISAR
INN
W
1
2
3
4
30km
E

the Mur-Mürz-fault zone, and as far as the termination of the Alps in the east. According to floral evidence and the fresh water fish fauna (pers. comm. J. GAUDANT, Paris) this area of the Central Alps had a tropical lowland character, comparable to Southeast Asia today. These paleographic and climatic conditions prevailed during the far-reaching transgressive event in the lower Badenian. At the present time a biostratigraphic correlation of the different lignite deposits is only possible by means of mammal faunas. In the Karpatian the so-called „Hypotherium"-mammal fauna is characteristic, being replaced in Badenian times by the „Conohyus"-fauna (MOTTL, 1970; THENIUS, 1960).

The lignites of the Norian depression are of high quality (approximately 5.000 kcal./kg); today all deposits are nearly depleted. The most important in Karpatian-time districts were: Fohnsdorf-Knittelfeld; Seckau-depression; Seegraben; Urgental; Parschlug. In addition to the mammal faunas, Congeria- and tuff-horizons are the most important for stratigraphic correlations. Göriach, Ratten and St. Kathrein belong to the Badenian-time districts.

The Miocene lignite depressions of the eastern border of the Alps are the continuation of the Norian depression (NEBERT, 1985; NEBERT & al., 1983). The occurrences of Brennberg (Brennbergbánya, Hungary), Hart, Leiding and Thomasberg are of Karpatian age. Tanzegg, Tauchen, Bubendorf, Ritzing, Wiesfleck and Schauerleiten are of Badenian age.

In a northeastern continuation, subsidence started during Karpatian time, with lignite accumulation in the area of the Vienna Basin (Grillenberg, Jauling) and the Korneuburg-Basin (Teiritzberg).

In a similar manner, the Karpatian/Early Badenian transgression might also have been responsible for the lignite deposits in the Enns-valley (Wagrain; Stroderzinken) as well as in the upper-Lavant-valley (Wiesenau). Palynological evidence indicates that the Stoderzinken lignite – whose stratigraphic age was uncertain – belongs into the subtropical climatic phase of the Karpatian. Tectonic uplift has raised this lignite to an elevation of 1700 metres (TOLLMANN & KRISTAN-TOLLMANN, 1963).

The Lavant-valley-Graben was flooded by the marine transgression of the lower Badenian; during the upper Badenian regressive phase, small lignite seams were generated (e. g.: Oppersdorf seams). This marine transgression also flooded vast areas of the Central Paratethys and reached the eastern part of the Alpine and the Carpathian Molasse-basin. This transgression corresponds to the worldwide Middle-Miocene transgressive event.

In the western Molasse-Zone of Upper Austria the same event caused a remarkable rise of the groundwater table and was responsible for the deposition of the limnic lignites of Trimmelkam in a shallow depression. The formation of these younger brown-coal seams of the Molasse-Zone can be seen in direct connection with the formation of lignite deposits in the intramountain-basins. The thin seams of Radegund and Munderfing in the Upper Austrian Molasse-Zone are correlated with a further advance of the reduced salinity sea of Sarmatian age (CZURDA, 1978).

South of the Alps this lower Sarmatian advance also triggered lignite accumulation in the Lavant-valley-Graben (St. Stefan) and in the Graz-basin (Dellach). During the regressive upper Sarmatian, lignite facies are known from bays of the Styrian-Basin (Graz- and Weiz-bay; Passail-Basin) and in the central basin itself (Feldbach district). Age-equivalent deposits are known from the Klagenfurt-Basin, the „Rosenbacher Kohleformation", and from the Karawanken-foreland (St. Philippen, Oberloibach, Lobnig). Of climatic interest is the subtropical pollen spectrum with the occurence of palms (pers. comm. I. DRAXLER).

Only in the Pannonian-Basin and its borderland bays is the lower Pannonian developed in a transgressiv facies. In Lower Austria the Pannonian advance extended from the Vienna Basin to Krems. The time-equivalent Hausruck lignite accumulation, with the mining districts of Wolfsegg and Thomasroith (CZURDA, 1978; POHL, 1968), seems to confirm the proposed theoretical correlation between transgressive events, the rise of the groundwater table, and coal formation. Time-equivalent lignites are also known from the Weiz and the Pöllau bays of the Styrian-Basin. The lignites of the Fürstenfeld basin belong to the Pannonian regressive cycle (e. g., Ilz: Pannonian, Zone C, KOLLMANN 1965).

During Pontian time the Central Paratethys began to dry up and the Pannonian inland sea disintegrated into larger freshwater lakes. In the Vienna-Basin extensive lignite deposits formed in slowly subsiding areas (e. g., Zillingdorf, Sollenau, Rabensburg; Dubnany, Č.S.S.R.). At the border of the Pannonian-Basin similar lignites formed in southern Burgenland (Höll-Deutschschützen, Henndorf-Göllersdorf, Bachselten-St. Michael); these continue into Hungary (Torony) (NEBERT, 1979).

The Pontian lignites of the Klagenfurt-Basin are formed on top of the crystalline basement and are overlain by the „Sattnitzkonglomerat"-formation (Penken-Turiawald, Stein a. d. Drau).

Conclusions

In general this study confirms the principles of coal accumulation in relation to marine cycles as proposed by LÜTTIG (1968, 1977). The main coal-forming phase occurs during the transgressive cycle, which causes the necessary rise of the groundwater table and subsequent growth and accumulation of peat. The lignite deposits in the Inner Alpine areas and the Molasse-Zone most clearly demonstrate the far-reaching consequences of the Middle Miocene transgressive cycle. The required specific set of simultaneous climatic and tectonic conditions prevailed during this time period.

Coal accumulation during regressive cycles is of minor importance. The most important prerequisite in this case is a very slow retreat of the sea in connection with a very slow fall of the groundwater table so that intensive erosion cannot take place.

In the Austrian Tertiary three tectonically caused sedimentary cycles with coal accumulation can be distinguished:

Gosau cycle (Early Eocene)
Molasse cycle (Late Eocene to Early Miocene)
Intramountain-basin cycle (Middle Miocene to Late Miocene)

Within these cycles a sequence of lignitophile phases occurs which are related to the marine advances (Figs. 2, 3). The important phases of lignite deposition in the Molasse-Zone occur during the Middle Oligocene (Paleogene Zone 20 a) and Middle Miocene (Lower Badenian and Lower Pannonian). The Upper Oligocene lignite accumulation is restricted to the Bavarian part of the Molasse-Zone. The main phases in the intramountain-basins are within the Early/Middle Miocene (Karpatian/Early Badenian) and the Pontian.

These main lignite phases are of far-reaching importance in the European Tertiary deposits; e. g.: lignite deposits in the Oberpfalz (GREGOR & JUNG, 1977); in the lower Rhine lignite province (HAGER, 1968; SCHULZ, 1962); in north-western Germany (HINSCH, 1980); in the Lausitz area (AHRENS & LOTSCH, 1967) and in the wider Pannonian-area (RADOCZ & al., 1987).

The present study indicates that only limited possibilities with regard to economic exploration of lignites exist in the Austrian Tertiary deposits. According to facies development, paleogeography, as well as the tectonic setting, lignite deposits not outcropping on the surface can only be expected at the northern border of the Molasse-Zone in bays of the Bohemian Massif. Such deposits can only be expected in the advance of the Palaeogene transgressive cycles, since the lower Miocene transgressive cycles already extended far into the tableland of the Bohemian Massif. With the exception of the Early Miocene lignite district of Langau-Riegersburg no further paleogeographic conditions for economic lignite deposits in this tableland of the Bohemian Massif exist.

The deposits in the intramountain-basins and the bays of the Pannonian-Basin are more or less known and nearly all exploited.

Figure 1: Schematic structural map of Austria.

1. – Crystalline of Bohemian Massif;
2. – Helvetic – Flysch- and Klippen-Zones;
3. – Penninic-Zone;
4. – East Alpine units;
5. – Southern Alpine units;
6. – Tertiary Basins;
7. – fault;
8. – overthrust.

Important lignite mines and localities:

1. Kössen
2. Trimmelkam
3. Munderfing
4. Thomasroith, Wolfsegg
5. Puchkirchen (drill-holes)

6. Mursberg
7. Langau
8. Kollmitzberg
9. Thallern
10. Statzendorf
11. Starzing
12. Altruppersdorf
13. Rabensburg
14. Zillingdorf
15. Sollenau (drill-holes)
16. Grillenberg
17. Hart
18. Leiding
19. Brennberg-Ritzing
20. St. Kathrein
21. Parschlug
22. Göriach
23. Seegraben
24. Fohnsdorf
25. Obdach
26. Stoderzinken
27. Wagrain
28. Tamsweg
29. Wiesenau
30. St. Stefan
31. Penken
32. Oberloibach
33. Wies-Eibiswald
34. Köflach-Voitsberg
35. Rein
36. Passeil
37. Weiz
38. Ilz
39. Feldbach
40. Tauchen
41. Bubendorf
42. Höll-Deutsch-Schützen
43. Henndorf
44. Krappfeld (Sonnberg)

Fig. 2: Lignite-phases and marine cycles in the Tertiary of Austria. Stratigraphy and regional position of lignite deposits in the Molasse basin.

Fig. 3: Lignite-phases and marine cycles in the Tertiary of Austria. Stratigraphy and regional position of lignite deposits in the intramountain basins.

Fig. 4: Lignite-phases and marine cycles in the Tertiary of the Western Molasse-basin, Bavaria (acc. ZÖBELEIN, 1962 and GEISSLER, 1975).

1. – continental facies,
2. – brackish facies (productive/non productive),
3. – marine sand facies,
4. – marine clay facies.

References

AHRENS, H. & LOTSCH, D.: Die geologischen Grundlagen der Aufstellung der Florenzonen im jüngeren Tertiär der Lausitz. – Abh. zentr. geol. Inst., 1967, vol. 10, p. 39–54.

AHRENS, H., LOTSCH, D., & TZSCHOPPE, E.: Gesetzmäßigkeiten der Braunkohlenbildung in der „Jüngeren Braunkohlenformation" der Deutschen Demokratischen Republik. – Proc. XXIII. Int. Geol. Congr. Praha, 1968, vol. 11, p. 9–21.

BALDI, T.: Mid-Tertiary Stratigraphy and Paleogeographic Evolution of Hungary. – Akad. Kiado, Budapest, 1986, 201 pp.

BESSEDIK, M., AGUILAR, J. P., CAPPETTA, H. & MICHAUX, J.: Le climat du Neogene dans le sud de la France (Provence, Langduedoc, Roussillon), d'après l'an alyse des faunes (Rongeurs, Selaciens) et des flores polliniques. – 1984, Paleobiol. Continent., vol. 14 (2), p. 181–190, Montpellier.

CECH, F.: Relation of coal deposits of the West Carpathians to the deep structure. – Geol. Zborn., Geol. Carpathica, vol. 31 (3), p. 295–305, Bartislava 1980.

CZURDA, K.: Sedimentologische Analyse und Ablagerungsmodell der miozänen Kohlenmulden der oberösterreichischen Molasse. – Jb. Geol. Bundes-Anstalt, vol. 121 (1), p. 123–154, Wien, 1978.

FETTWEIS, G. B.: Bemerkung zur Kohlesituation in Österreich und in der Welt. In: Energierohstoffe im Alpen-Adria-Raum. – Referate Symp. Montanuniv. Leoben 1980, p. 58–122, Graz, 1982, Amt der Steiermärk. Landesregierung.

GEISSLER, P.: Räumliche Veränderung und Zusammensetzung der Flöze in den Kohlenbergwerken Hausham und Penzberg. – Geol. Bav., vol. 73, p. 61–106, München, 1975.

GREGOR, J. & JUNG, W.: Die paläobotanische Erforschung der Oberpfälzer Braunkohle. – Bayer. Braunkohlen Bergbau, vol. 102, p. 3–12, 1977.

HAGER, H.: Zur Gleichstellung und Genese der Flöze im rheinischen Braunkohlenrevier. – Fortschritte Geol. Rheinland-Westfalen, vol. 16, p. 73–84, Krefeld, 1968.

HAQ, B. U., HARDENBOL, J. & VAIL, P. R.: Chronology of fluctuating sea levels since the Triassic. – Science, vol. 235, p. 1156–1167, 1987.

HINSCH, W.: Neogene Braunkohlenflöze in Schleswig-Holstein. – Schriften naturwiss. Ver. Schleswig Holstein, vol. 50, p. 89–106, Kiel, 1980.

HOCHULI, P.: Palynologische Untersuchungen im Oligozän und Untermiozän der Zentralen und Westlichen Paratethys. – Beiträge Paläont. Österr., 1978, vol. 4, p. 1–132, Wien.

JUNG, W. & MAYR, H.: Neuere Befunde zur Biostratigraphie der oberen Süßwassermolasse Süddeutschlands und ihre paläökologische Deutung. – Mitt. Bayer. Staatsslg. Paläont. hist. Geol., vol. 20, p. 159–173, München, 1980.

KENNETT, J. P.: Miocene to Early Pliocene Oxygene and Carbon Isotope Stratigraphy in the southwest Pacific. – Int. Rep. D.S.D.P., vol. 90, p. 1383–1411, 1985.

KLAUS, W.: Braunkohlen-Palynologie einiger west-steirischer Lagerstätten. – Verh. Geol. Bundesanstalt, vol. 1954, p. 170–179, Wien, 1954.

KOLLMANN, K.: Jungtertiär im Steirischen Becken. – Mitt. Geol. Ges. Wien, vol. 57 (1964), p. 479–632, 1965.

KOMITEE des ALLGEMEINEN BERGMANNSTAGES: Die Mineralkohlen Österreichs. – Verl. Zentralver. Bergwerkbesitzer Österr., 490 pp. Wien, 1903.

KOVAR-EDER, J.: Pannonian (Upper Miocene) vegetational character and climatic inferences in the Central Paratethys area. – Ann. naturhist. Mus. Wien, vol. 88 A, 1987, p. 117–129.

KOSTERS, E. C., OHMURA, G. L. & BAILEY, A.: Sedimentary and botanical factors influencing peat accumulation in the Mississippi Delta. – Journ. Geol. Soc. London, vol. 144, p. 423–434, 1987.

KRUTSCH, W. & LOTSCH, D.: Übersicht über die paläogeographische Entwicklung des zentraleuropäischen Alttertiärs (ohne Tethys-Raum). – Berliner Geol. Ges. DDR, vol. 3 (1958), p. 99–110, Taf. 19–29.

LOPEZ-MARTINEZ, N., AUGUSTI, J., CABRERA, L. & al.: Approach to the Spanish continental Neogene synthesis and palaeoclimatic interpretation. – Ann. Inst. Geol. Publ. Hungar., vol. 70, p. 383–391, Budapest,1987.

LÜTTIG, G.: Stand und Möglichkeiten der Braunkohlen-Prospektion in der Türkei (Känozoikum und Braunkohlen der Türkei 1). – Geol. Jb., vol. 85, p. 585–604, Hannover,1968.

LÜTTIG, G.: Typen von Braunkohlen-Lagerstätten. – Geol. Jb., vol. 89, p. 407–417, Hannover,1971.

LÜTTIG, G.: A general view of the Neogene and Quarternary of the Mediterranean with respect to lignite prospecting. – Proc. VI. Coll. Geol. Aegean Region, vol. 3, p. 1199–1216, Inst. Geol. Min. Res., Athens, 1977.

MAI, D. H.: Die Florenzonen, der Florenwechsel und die Vorstellungen über den Klimaablauf im Jungtertiär der DDR. – Abh. zentr. geol. Inst., vol. 10, p. 55–81, Berlin, 1967.

MARTINI, E. & MÜLLER, C.: Current Tertiary and Quarternary calcareous nannoplankton stratigraphy and correlations. – Newsletter Stratigr., vol. 16 (2), p. 99–112, Berlin – Stuttgart, 1986.

MCGOWRAN, B.: Cainozoic Oceanic and climatic events: The Indo-Pacific foraminiferal biostratigraphic record. – Palaeogeogr., Palaeoclimat., Palaeoecol., vol. 55, p. 247–265, Amsterdam, 1986.

MILLER, K. C., FAIRBANKS, R. G. & MOUNTAIN, G. S.: Tertiary Oxygene Isotope Synthesis, Sea Level History, and Continental Margin Erosion. – Paleoceanogr. vol. 2, p. 1–19, 1987.

MOTTL, M.: Die jungtertiären Säugetierfaunen der Steiermark, Südost-Österreich. – Mitt. Mus. Bergbau, Geol., Techn. Landesmus. Joanneum Graz, 1970, vol. 31, p. 79–168.

MÜLLER, C.: Climatic evolution during the Neogene and Quarternary, evidence by marine microfossil assemblages. – Paleobiol. Continent., vol. 14 (2), p. 359–369, Montpellier, 1984.

NEBERT, K.: Die Lignitvorkommen Südostburgenlands. – Jb. Geol. Bundesanstalt, Wien, 1979, vol. 122, p. 143–180.

NEBERT, K.: Die Kohle als Faziesglied eines Sedimentationszyklus. – Berg- u. Hüttenm. Mh., vol. 128, p. 106–112, Springer Verlag, Wien – New York, 1983 a.

NEBERT, K.: Zyklische Gliederung der Eibiswalder Schichten (Südweststeiermark). – Jb. Geol. Bundesanst., Wien 1983 b, vol. 126, p. 259–285.

NEBERT, K.: Kohlengeologische Erkundung des Neogens entlang des Ostrandes der Zentralalpen. – Arch. Lagerstättenforsch. Geol. Bundesanst. Wien, 1985, vol. 6, p. 23–77.

NEBERT, K., GEUTEBRÜCK, E. & TRAUSSNIGG, H.: Zur Geologie der neogenen Lignitvorkommen entlang des Nordostsporns der Zentralalpen (Mittelburgenland). – Jb. Geol. Bundesanst. Wien, 1980, vol. 123, p. 39–112.

OBERHÄNSLI, H.: Latest Cretaceous – Early Neogene Oxygene and Carbon isotopic record at DSDP sites in the Indian Ocean. – Mar. Micropaleont., vol. 10, p. 91–115, Amsterdam, 1986.

OBRITZHAUSER-TOIFL, H.: Pollenanalytische (palynologische) Untersuchungen an der untermiozänen Braunkohle von Langau bei Geras, N.Ö. – Sitz. Ber. Österr. Akad. Wiss., mathem.-naturw. Kl., Abt. I, Wien, 1954, vol. 163, p. 325–374.

PETRASCHECK, W.: Kohlengeologie der Österreichischen Teilstaaten. I. Teil, p. 1–272, Verl. Fachlit., Wien, 1922–24. II. Teil, p. 273–484, Kattowitzer Buchdruckerei- und Verlag. Sp. Akc., Katowice, 1926–29.

PETRASCHECK, W.: Oesterreichs Kohlenlager. Lagerstätten und Bergbau in Österreich. – In: Z. Berg-, Hütten- und Salinenwesen, Dt. Reich, vol. 1937, p. 1–8, Berlin, 1937.

POHL, W.: Zur Geologie und Paläogeographie der Kohlenmulden des Hausruck (Oberösterreich). – Diss. Univ. Wien, 1968, vol. 17, 70 pp., Verlag Notring.

POHL, W.: Zur Geologie des Braunkohlenbeckens von Köflach-Voitsberg (Steiermark). – Berg- und Hüttenmänn. Mh., vol. 121, p. 420–427, Wien, 1976.

POHL, W.: Prospektion und Exploration auf Kohle in Österreich. Strategie und Methoden. – Berg- und Hüttenmänn. Mh., vol. 126 (10), p. 446–450, Wien, 1981.

RADÓCZ, GY., BOHN-HAVAS, M. & SZOKOLAI, GY.: Neogene Brown Coal Deposits in Hungary. – Ann. Inst. Publ., Hungarici, vol. 70, p. 601–608, Budapest, 1987; (= Jb. Ungar. Geol. Anst., vol. 70), (= Proc. VIII RCMNS-Congr.).

RÖGL, F. & STEININGER, F. F.: Vom Zerfall der Tethys zu Mediterran und Paratethys. Die neogene Paläogeographie und Palinspastik des zirkummediterranen Raumes. – Ann. Naturhist. Mus. Wien, 1983, vol. 85 A, p. 135–163.

RÖGL, F. & STEININGER, F. F.: Neogene Paratethys, Mediterranean and Indopacific seaways. Implications for the paleobiogeography of marine and terrestrial biotas. – In: BRENCHLEY, P. (Ed.), Fossils and climate, p. 171–200, London, 1984 (J. Wiley & Sons).

SAVIN, S. M., DOUGLAS, R. G., KELLER, G., KILLINGLEY & al.: Miocene benthic foraminiferal isotope records: a synthesis. – Marine Micropaleont., vol. 6, p. 423–450, Amsterdam, 1981.

SCHNABEL, W. & DRAXLER, I.: Sedimentologische, palynologische und Nannofossil-Untersuchungen in der Inneralpinen Molasse des Unterinntales unter besonderer Berücksichtigung von Umschlagfaktoren. – N. Jb. Geol. Paläont., Abh., vol. 151, p. 325–357, Stuttgart, 1976.

SCHULTZ, G.: Zur Geologie der Braunkohlen bei Zulpich (Niederrheinische Bucht). – N. Jb. Geol. Paläont., Abh., vol. 116, p. 89–118, Stuttgart, 1962.

SHACKLETON, N. J. & KENNETT, J. P.: Paleotemperature history of the Cenozoic and the imitation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP sites 277, 279 and 281. – Init. Rpt. DSDP, vol. 29, p. 743–755, Washington, 1975.

SHATILOVA, I. I. & RAMISHVILI, I. SH.: Climate and flora of the Neogene of western Georgia (U.S.S.R.). – Palbiol. Continent., vol. 14 (2), p. 423–432, Montpellier, 1984.

STEININGER, F. & RÖGL, F.: The Paratethys history – a contribution towards the Neogene geodynamics of the Alpine orogene (an abstract). – Ann. Geol. Pays Hellen., t. hors. ser., 1979 (3), p. 1153–1165, Athens, 1979.

STEININGER, F. F., RÖGL, F. & DERMITZAKIS, M.: Report on the round table discussion: „Mediterranaean and Paratethys correlations". – Ann. Inst. Geol. Publ. Hung., vol. 70, p. 397–421, Budapest, 1987.

STEININGER, F. F., WESSELY, G., RÖGL, F. & WAGNER, L.: Tertiary sedimentary history and tectonic evolution of the Eastern Alpine Foredeep. – Gior. Geol. ser. 3, vol. 48, p. 285–297, Bologna, 1986.

STUCHLIK, L.: Chronostratigraphy of the Central Paratethys Neogene deposits in South Poland based on paleobotanical studies. – Ann. Geol. Pays Hellen., hors. ser., fasc. III, p. 1167–1180, Athen, 1979.

SUC, J. P.: Origin and evolution of the Mediterranean vegetation and climate in Europe. – Nature, vol. 307, no. 5950, p. 429–432, 1984 a.

SUC, J. P. (Ed.): Compilation charts Neogene faunal and floral changes. – Paleobiol. continent., vol. 14 (2), p. 485–493, Montpellier, 1984 b.

SUJITNO, T. & TAUPITZ, K. C.: Middle-Upper Miocene coal deposits in Greece and Turkey (Aegean Sea) and Sumatra (Indonesia), – a comparison. – Abstracts, VIII. Congr. R.C.M.N.S. Budapest, 1985, p. 535–538, Budapest (Hung. Geol. Survey).

TAUPITZ, K. C., in press: Oligocene/Miocene coals in southeast and southwest Asia and southeast Europe. – Training Course in Economic Aspects of Coal Exploration, Evaluation and Exploration, Bandung, January 1986. – ESCAP Workshop.

THENIUS, E.: Die jungtertiären Wirbeltierfaunen und Landfloren des Wiener Beckens und ihre Bedeutung für die Neogen-Stratigraphie. – Mitt. Geol. Ges., vol. 52, p. 203–209, Wien, 1960.

THIELE, O.: FWF – Projekt 2975 – Studien über Faziesverhältnisse, Stratigraphie und Tektonik österreichischer Tertiärbecken, insbesondere in Hinsicht auf ihre Kohlenführung und Kohlehöffigkeit (Abschlußbericht – Ergebniszusammenfassung). – Arch. Lagerstättenforschung Geol. Bundesanst., vol. 3, p. 81–89, Wien, 1983.

TOLLMANN, A.: Geologie von Österreich, Band II. Außerzentralalpiner Anteil. xv + 710 pp., Wien, 1985 (F. Deuticke).

TOLLMANN, A. & KRISTAN-TOLLMANN, E.: Das Alter des hochgelegenen „Ennstal-Tertiärs" – Mitt. österr. geogr. Ges., vol. 104 (3), 1962, p. 337–347, Wien, 1963.

TRAVERSE, A.: Response of world vegetation to Neogene tectonic and climatic events. – Alcheringa, vol. 6, p. 197–209, 1982.

VAIL, P. R., MITCHUM, R. M. Jr. & THOMPSON, S. III: Seismic stratigraphy and global changes of sea level, part 4: Global cycles of relative changes of sea level. – Mem. AAPG, vol. 26, p. 83–97, Tulsa, Oklah., 1977.

VERGNAUD-GRAZZINI, C.: Major Cenozoic climatic changes: the stable isotope record of marine carbonates in the world ocean – a review. – Paleobiol. Continent., vol. 14 (2), p. 433–473, Montpellier, 1984.

WAGNER, L.: Geologische Charakteristik der wichtigsten Erdöl- und Erdgasträger der oberösterreichischen Molasse. – Teil I. Die Sandsteine des Obereozän. – Erdoel-Erdgas-Z. vol. 96, p. 338–346, Wien – Hamburg, 1980.

WEBER, L. & WEISS, A.: Bergbaugeschichte und Geologie der österreichischen Braunkohlenvorkommen. – Arch. Lagerst. forsch. Geol. Bundesanst., vol. 4, Wien, 1983, 317 pp.

WEERD, A. VAN DE & DAAMS, R.: Quantitative composition of rodent faunas in the Spanish Neogene and paleoecological implications. – Kon. Ned. Akad. Wetensch., Proc. B, vol. 81 (4), p. 448–473, Amsterdam, 1978.

ZAPFE, H.: Zur Altersfrage der Braunkohle von Langau bei Geras in Niederösterreich. – Berg- und Hüttenmänn. Mh., vol. 98 (1), p. 12–16, Wien, 1953.

ZAPFE, H.: Die geologische Altersstellung österreichischer Kohlenlagerstätten nach dem gegenwärtigen Stand der Kenntnis. – Berg- und Hüttenmänn. Mh., vol. 101 (4), p. 71–81, Wien, 1956.

ZÖBELEIN, H. K.: Über die Bausteinschichten in der Subalpinen Molasse des westlichen Oberbayerns. – Z. deut. geol. Ges., vol. 113, p. 261–265, Hannover, 1962.