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EVOLUTION OF THE NEOGENE STYRIAN BASIN

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Regional setting

The Styrian Basin is the westernmost embayment of the Central Paratethys. Its northern and western margins as well as its pre-Tertiary basement are formed by the Penninic tectonic unit, Lower and Middle Austroalpine tectonic units and the Upper Austroalpine Paleozoic of Graz (Fig. 1). To the east the Styrian Basin is separated from the Pannonian Basin by a NNE-trending basement high, the Südburgenländische Schwelle. The Mittelsteirische Schwelle, a N-S oriented morphological basement high, separates the up to 1000 m deep Western Styrian Basin from the more than 3000 m deep Eastern Styrian Basin which is segregated into several subbasins. The relief of the basement is strongly controlled by fault tectonics. Its structure, lithologies and geophysical peculiarities are well documented in a set of maps at the scale of 1:200.000 (Kröll et al., 1988). Comprehensive geological information is provided by Kollmann, 1965; Flügel and Heritsch, 1969; Flügel and Neubauer, 1984, and Ebner and Sachsenhofer, 1991.

Stratigraphy, facies and paleogeographic evolution

A major part of our knowledge about the Styrian Basin is based on the studies of Arthur Winkler-Hermaden, carried out in the first half of this century (see for summary Winkler-Hermaden, 1951, and references cited therein). Hydrocarbon exploration in the Eastern Styrian Basin provided additional (subsurface) data (Kollmann, 1965). As detailed biostratigraphic and sedimentologic studies are still lacking for large parts of the basin (especially for younger drill holes, see Friebe and Poltnig, 1991) and seismic data are not released by the oil companies, this paper can give only our preliminary view of the evolution of the Styrian Basin.

Due to the complex tectonic evolution of the Styrian Basin individual subbasins (Fig. 1) show a quite different stratigraphic and paleogeographic evolution.

Sedimentation started probably in the Ottnangian (for correlation of the regional stages of the Central Paratethys with the Mediterranean standard stages see Rögl and Steininger, 1983; Steininger et al., 1990). The southwestern part of the Eastern Styrian Basin was characterized by fluviatil-lacustrine deposition whereas fan-delta sedimentation in a fault-controlled setting (K. Stingl, pers. comm.) prevailed in the southernmost subbasin of the Western Styrian Basin (Fig. 2).

During the Karpatian a transgression flooded the central part of the Eastern Styrian Basin (Gnas Basin) resulting in a thick succession of marine siltstones (Steirischer Schlier). Its foraminiferal fauna indicates water depths of at least 100 meters (Friebe, 1990, 1991b). Marine conglomerates (fan delta deposits ?) record the initiation of the halfgraben of Fürstenfeld at the same time (Fig. 3). Cyclic fluvial and paralic (?) sediments with major coal seams were deposited in the Western Styrian Basin (Eibiswald formation). In the south braiddelta deposits (Arnfels conglomerate) link the paralic (?) sediments of the Western with deposits of deeper water of the Eastern Styrian Basin.

In the uppermost Karpatian a tectonic event lead to a re-organisation of the basins. Block-tilting caused an uplift of the hinterland (Koralm) as well as the Sausal Mountains. This coincided with an eustatic sea-level lowstand thus forming a tectonically enhanced sequence boundary (Styrian Unconformity; Friebe, 1991b; Friebe submitted).

The Lower Badenian sea-level rise lead to (shallow) marine conditions throughout a major part of the Styrian Basin (Fig. 4). Fluvial sedimentation was restricted to the western margin of the basin. The opening of a marine seaway between Paratethys and Indo-Pacific and the re-establishment

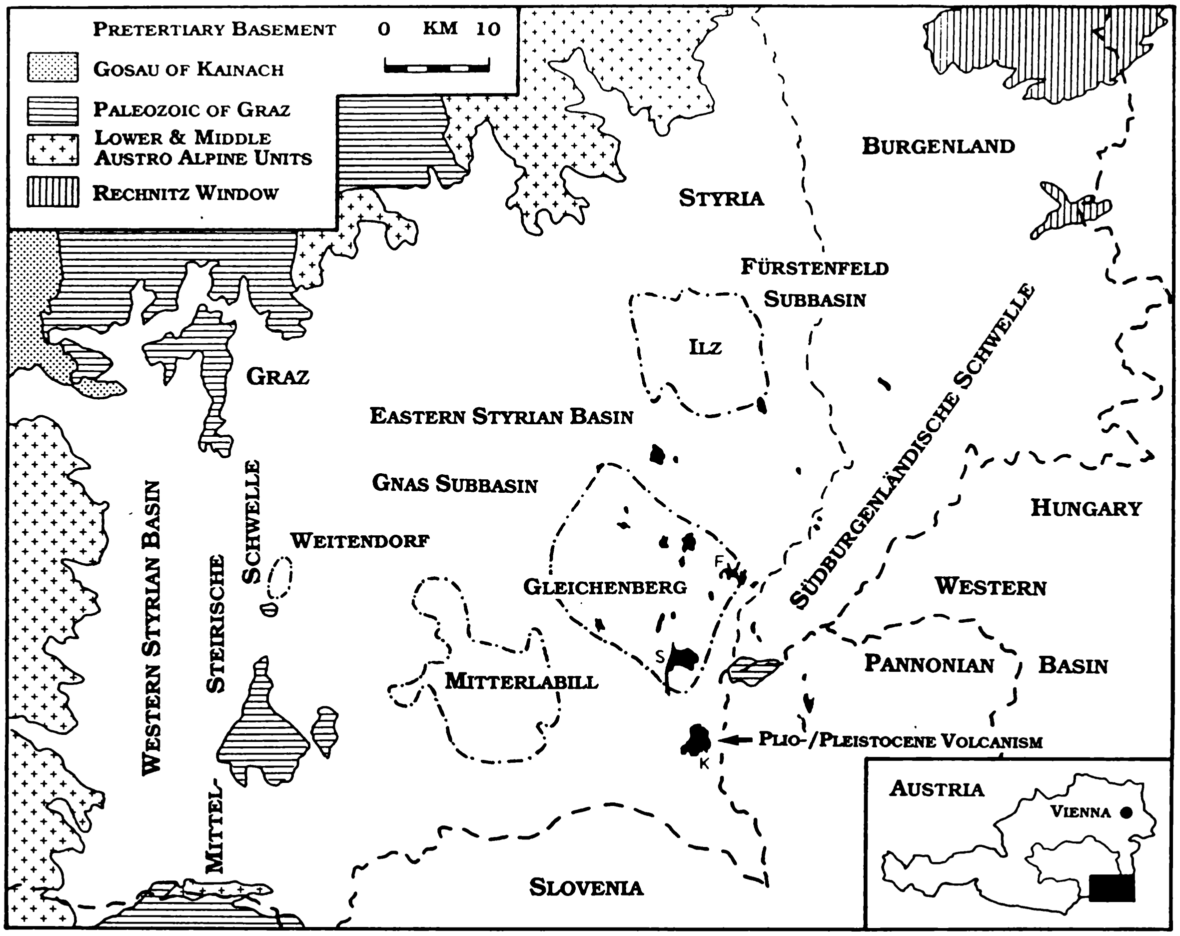

Fig.1: Location and major features of the Styrian Basin. Plio-/Pleistocene volcanism: F = Feldbach-Steinberg, S = Straden, K = Klöch.

of a circum-equatorial warm-water circulation system allowed the development of a strongly diversified marine fauna in the entire Central Paratethys (Rögl and Steininger, 1984). In the Styrian Basin coral reefs and rhodolith platforms (coralline algal limestone: Leithakalk) which were separated by siliciclastics developed on shoals both in the vicinity of the Mittelsteirische Schwelle (Weißenegg Formation) and fringing the volcanoes of the Eastern Styrian Basin (Friebe, 1990, 1991a). Within the Weißenegg Formation three depositional sequences, recording eustatic sea-level cycles, can be distinguished (Friebe, submitted).

A major sea-level drop at the end of the Badenian caused the progradation of a (braid-) delta into the Western Styrian Basin (Eckwirt gravel and Dillach Member). In the Eastern Styrian Basin this event is recorded by a (local) hiatus and unconformity, respectively.

The Sarmatian started with a new transgression. In the vicinity of Graz shallow marine sediments interfinger with fluvial deposits (Waldhof formation , Riepler, 1988). Fine-grained siliciclastics with intercalations of limestones of various microfacies are also found at the northern margin of the Eastern Styrian Basin (Rollsdorf formation). Salinity was probably slightly reduced (Krainer, 1984, 1987b). In the Western Styrian Basin Sarmatian sediments are not preserved. Shallow marine conditions prevailed throughout the Eastern Styrian Basin (Fig. 5). The Middle Sarmatian is characterized by an intercalation of fluvial conglomerates prograding from the Southwest (Kollmann, 1965). In the Upper Sarmatian a shallow marine realm was re-established (Fig. 6). In marginal areas siliciclastic shallowing-upward cycles, each terminated by a bed of ooid grainstone, reflect minor sea-level fluctuations (Friebe, in prep.). Foraminifera and mollusc associations indicate reduced salinity. Similar deposits are found at the northern margin of the basin.

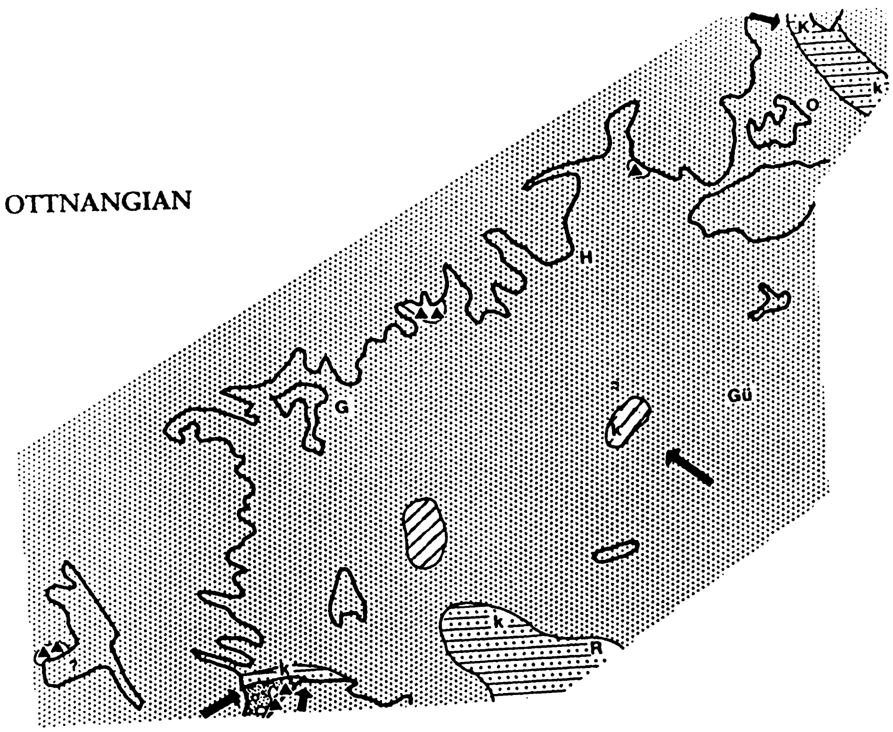

Fig. 2: Paleogeographic sketch of the Styrian Basin during the Ottnangian (Ebner & Sachsenhofer, 1991). For legend see Fig.4.

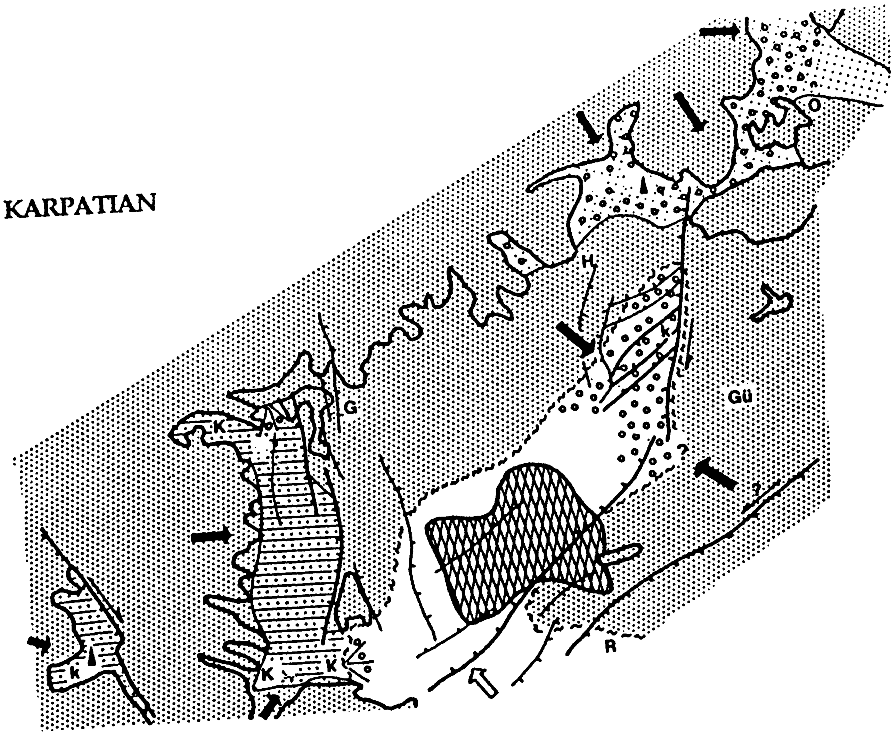

Fig. 3: Paleogeographic sketch of the Styrian Basin during the Karpatian (Ebner & Sachsenhofer, 1991). For legend see Fig. 4.

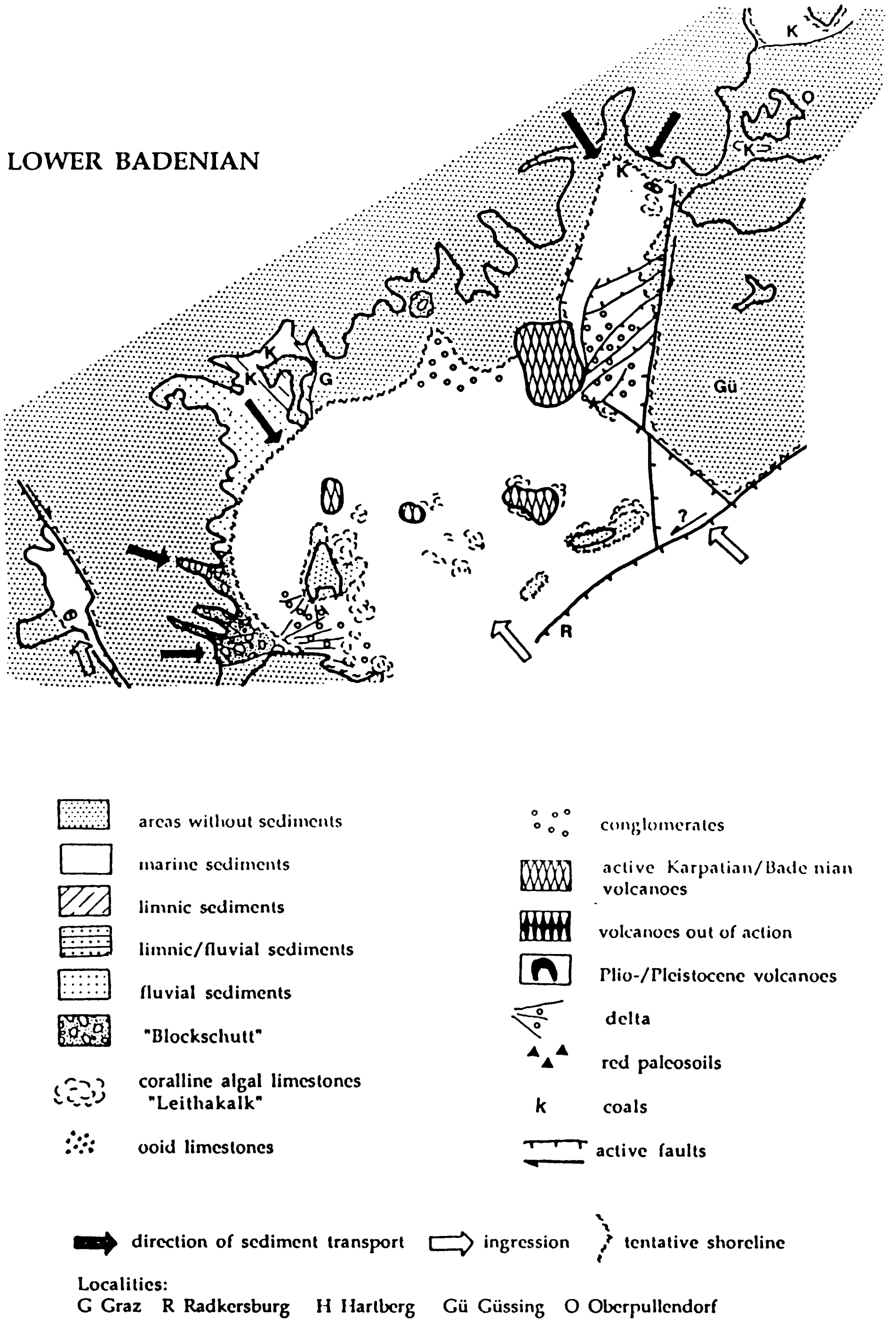

Fig. 4: Paleogeographic sketch of the Styrian Basin during the Lower Badenian (Ebner & Sachsenhofer, 1991).

The marine influence prevailed up to the Pannonian A/B. Salinity was, however, strongly reduced. Fine-grained siliciclastics were deposited in the center and southern part of the basin. The northern margin is characterized by braid-delta progradation. Delta plain sediments contain major coal seams (Weiz coal-bearing formation; Kovar-Eder and Krainer, 1988; Krainer, 1987b, 1988).

With the beginning of the Pannonian C the marine influence ceased. Coarse-grained fluvial sediments were then deposited in the northern to southeastern part of the Eastern Styrian Basin (Fig. 7). At the northern margin alluvial fans shed terrigenous siliciclastics into the Basin (Puch gravel Krainer, 1987b). They were transported southwards by maeandering streams (Kapfenstein/Kirchberg gravel). Active channels were separated by wide alluvial plains with abundant vegetation (Kovar-Eder and Krainer, 1989, 1990; Krainer, 1987a, 1987b, 1990).

Pontian fluvial sediments are restricted to the immediate vicinity of the Südburgenländische Schwelle (Fig. 8).

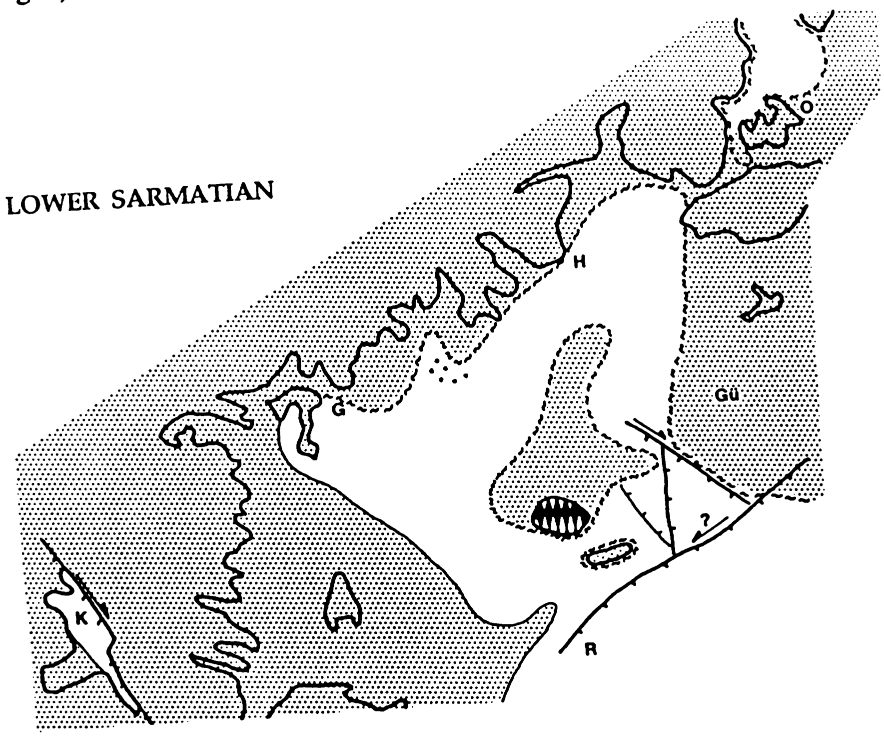

Fig. 5: Paleogeographic sketch of the Styrian Basin during the Lower Sarmatian (Ebner & Sachsenhofer, 1991). For legend see Fig. 4.

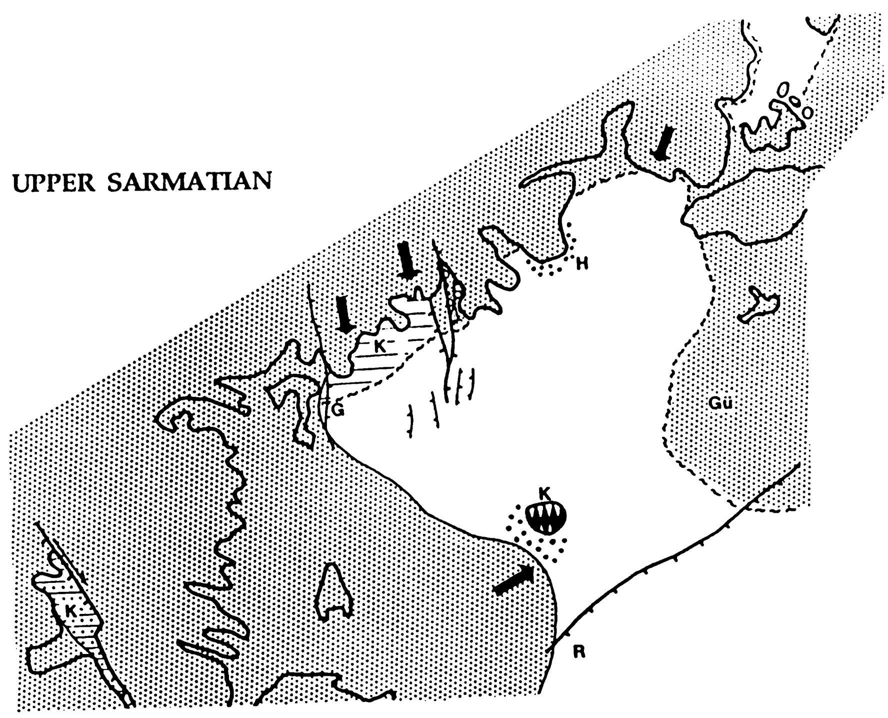

Fig. 6: Paleogeographic sketch of the Styrian Basin during the Upper Sarmatian (Ebner & Sachsenhofer, 1991). For legend see Fig. 2.

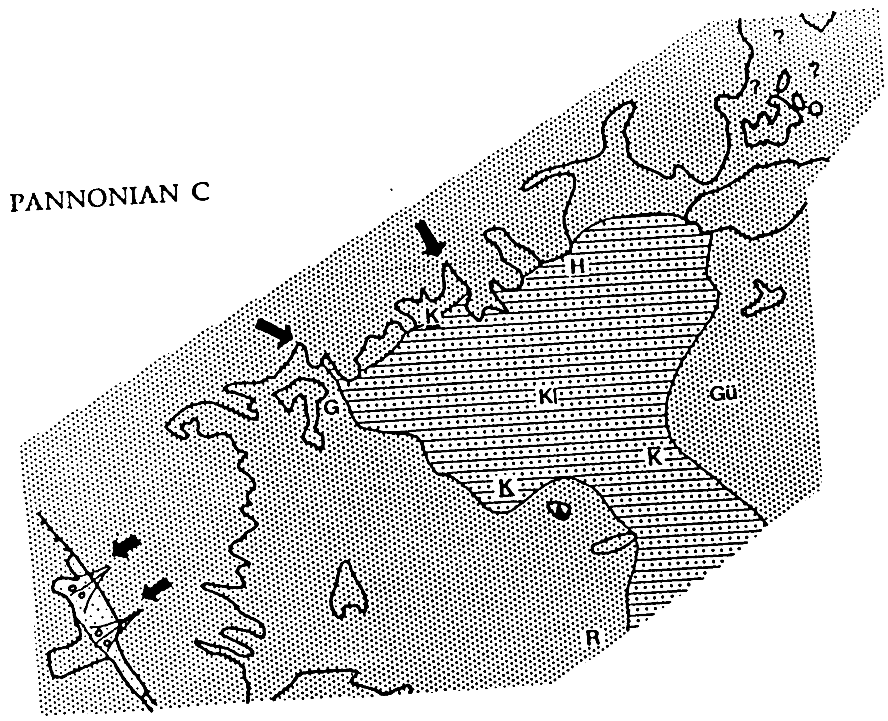

Fig. 7: Paleogeographic sketch of the Styrian Basin during the Pannonian C (Ebner & Sachsenhofer, 1991). For legend see Fig. 2.

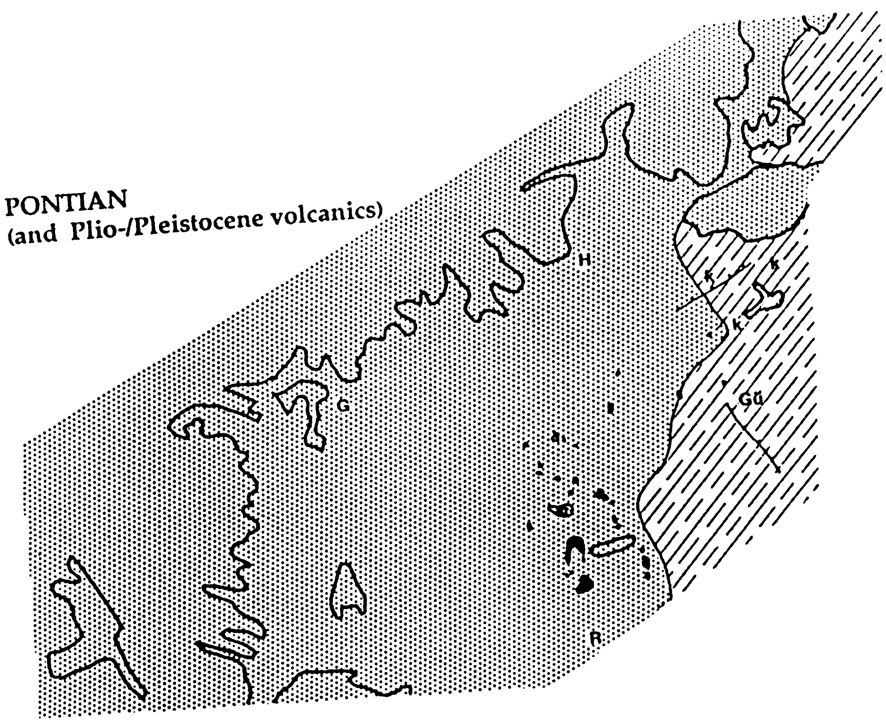

Fig. 8: Paleogeographic sketch of the Styrian Basin during the Pontian (Ebner & Sachsenhofer, 1991). For legend see Fig. 2.

The volcanic events in the Styrian Basin are related to the magmatic activities of the intra-Carpathian region. Two distinct volcanic episodes of different magmatic character can be distiguished.

Karpatian to Lower Badenian acid to intermediate volcanics are concentrated to the areas of 1) Mitterlabill 2) Gleichenberg, 3) Ilz-Walkersdorf and 4) Weitendorf (Fig. 1). Further terminal apophyses of a subvolcanic intrusion cut Lower Badenian sediments at Retznei. Vitric tuffs, sometimes altered to bentonites, are widely spread throughout the subbasins. Although most of the volcanoes are buried by younger sediments they can be mapped excellently by geophysics. Radiometric K/Ar ages ranging from 15.2 0.9 to 16.8 0.75 Ma were determined by Lippolt et al. (1975) and Steininger and Bagdasaryan (1977), the biostratigraphy of associated sediments was determined by Kollmann (1965) and Krainer (1987c).

During this volcanic episode magmatic activities probably shifted northward (Karpatian: Slovenia, southern part of Mitterlabill-Gleichenberg; Lower Badenian: northern part of Gleichenberg, Ilz/Walkersdorf, Weitendorf). In some of the southern localities Lower Badenian sediments cover the Karpatian volcanics.

Together with this regional trend a change in magma character from the subalkaline towards the boundary of the subalkaline/alkaline field occurred (Fig. 9). The generally calc-alkaline character suggests a subduction-related genesis. However, a modern genetic interpretation related to plate tectonic concepts is still missing especially in account of lacking trace element investigations. All available main element analysis of Miocene volcanics of Slovenia and Styria are shown in Fig. 9.

A second major volcanic episode of Pliocene to Pleistocene age resulted in approximately 30 to 40 occurrences of nephelinitic/basanitic lava flows and a wide variety of pyroclastic rocks related to pipes, calderas and maar structures in the Eastern Styrian Basin (e.g. Steinberg/ Feldbach,

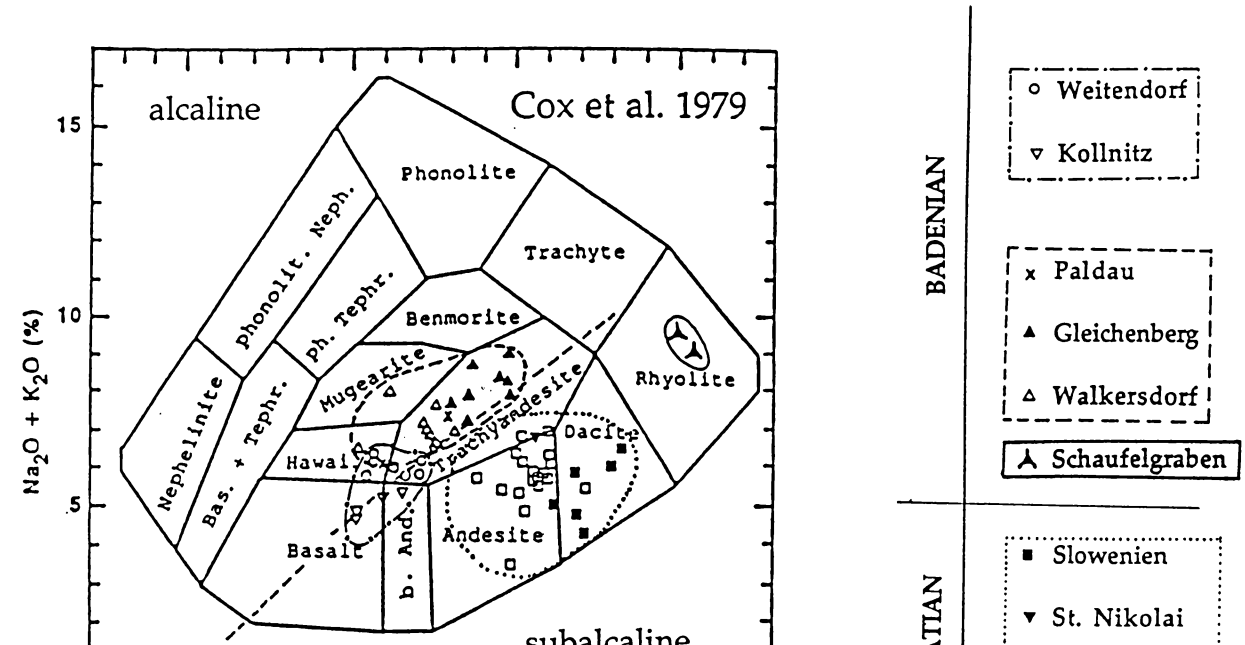

Fig. 9: Classification of Karpatian and Badenian volcanites according to Cox et al., 1979 (from published data; see Ebner & Sachsenhofer, 1991). Obviously altered samples were not plotted.

Klöch, Stradner Kogel, see Fig.1 for location) can be related to this younger volcanic period. Radiometric K/Ar ages range from 1.7 0.7 to 3.8 0.4 Ma (Balogh et al., 1989). The petrology of xenoliths suggests a source situated 50 - 80 km deep within the mantle (Kurat et al., 1980). All available analysis are plotted in Fig. 10.

Subsidence

Decompacted subsidence profiles of the Styrian Basin have been studied by Ebner and Sachsenhofer, 1991.

Subsidence in the Western Styrian, Mureck, and Gnas subbasins started in the Ottnangian and accelerated during the Karpatian, when maximum subsidence rates reached > 20 cm/100 a. This corresponds with intense normal faulting along the basin margins. An important factor for rapid subsidence in the oval shaped Gnas basin, which is characterized only by minor faults, is the load of the thick and relatively dense Miocene volcanic rocks and probably the emptying of the magma chamber underneath. Consequently in this basin the tectonic subsidence is less pronounced.

In some parts of the basin a hiatus occurred in the uppermost Karpatian. In Badenian times the area of subsidence widened, but velocity decreased (< 5 cm/ 100 a). The Badenian depocenter is located in the Halfgraben of Fürstenfeld.

In the Sarmatian the Eastern Styrian Basin subsided relatively uniformly and rapidly (up to 10 cm/100 a). Sarmatian subsidence is independent of the internal structure of the Eastern Styrian Basin, which originated in Ottnangian to Badenian times. The Western Styrian Basin and the Mureck area stayed relatively stable during this time.

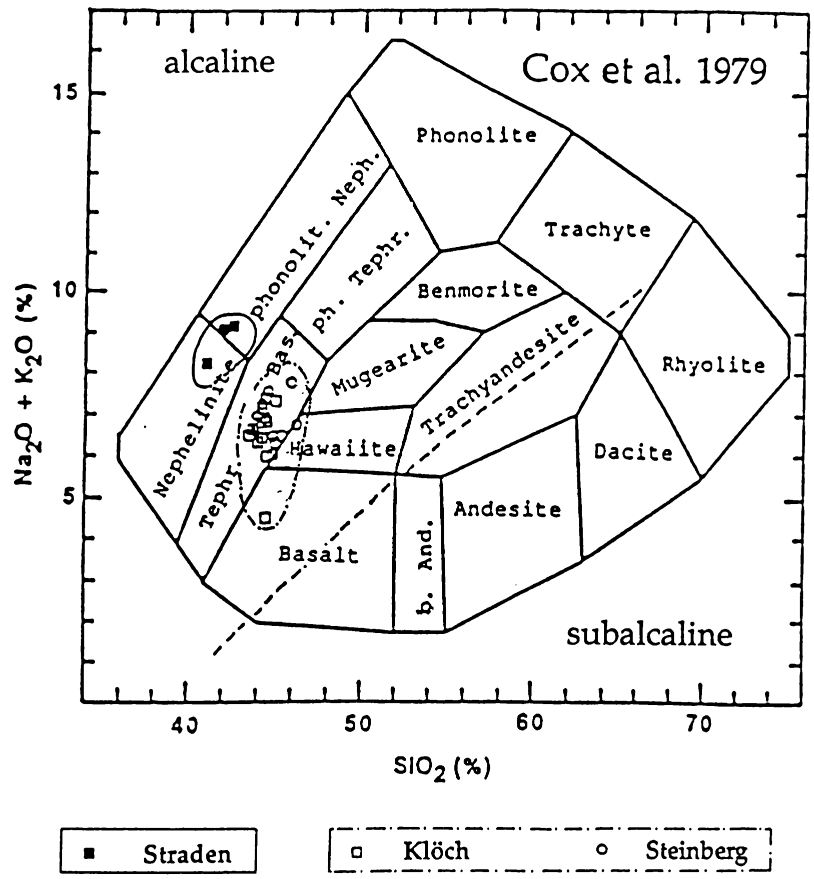

Fig.10: Classification of Plio-/pleistocene volcanites according to Cox Et Al., 1979 (from published data; see Ebner & Sachsenhofer, 1991).

Pannonian subsidence is relatively slow (< 1 cm/100 a). The depocenter shifted to the east. Therefore, subsidence also affected the northern part of the Südburgenländische Schwelle. On the other hand the Western Styrian Basin and the Mureck area were already uplifting. In Pliocene times subsidence was replaced by uplift in the whole basin. Minor sedimentation occured only in regions near the Pannonian realm.

Thermal history

The thermal history of the Styrian Basin can be deduced using vitrinite reflectance data from 150 outcrop samples and 25 drill holes (Fig. 11; Ebner and Sachsenhofer, 1991; Sachsenhofer 1990, 1991, submitted).

Vitrinite reflectance of outcrop samples is generally in the range of 0.2 %Rr to 0.4 %Rr. Local coalification maxima occur in the southwestern and northeastern basin. Some wells are characterized by a linear to sublinear increase in reflectance (e.g. Jennersdorf 1, Übersbach 1, Litzelsdorf 1). Reflectance gradients at a maturity level above 0.5 %Rr range from 0.22 to 0.37 %Rr/km. Reflectance curves of wells, located in the vicinity of Miocene volcanoes are characterized by a succession of two different gradients (e.g. Mitterlabill 1, Pichla 1, Blumau 1a). The slope-break of these curves corresponds to Karpatian (southern basin) or Lower Badenian (northeastern basin) levels. Coalification gradients of the lower segments increase towards the volcanic vents. The highest reflectance gradient (3.6 %Rr/km) can be observed in the Mitterlabill 1 well. This well is situated only 2 km west of a volcanic vent and drilled sediments above and underneath several hundred meters of volcanic rocks. Here vitrinite reflectance reaches 4 %Rr at a depth of only 1700 meters. The coalification pattern of the Eastern Styrian Basin is summarized in a schematic SW-NE trending maturation profile (Figs. 12, 13).

The one dimensional PC-version of the "Pre Drilling Intelligence" (PDI) software package of IES was used to simulate the temperature history. Calculation of vitrinite reflectance data follows a kinetic approach by Sweeney and Burnham (1990).

A good fit between measured and calculated vitrinite reflectance data from 20 boreholes is obtained with the following heat flow model (Sachsenhofer et al., 1992).

The regional, undisturbed heat flow during Karpatian and Badenian times (17.2 - 12.8 Ma) was 90 to 120 mW/m^2. Heat flow increased toward the volcanoes and locally reached 300 mW/m^2. In the southern Styrian Basin (Pichla area) this high heat flow related to volcanism already ended during the Karpatian, whereas it remained high until the Badenian in the northern and northeastern part of the basin. This is a consequence of a northeastward shift of the magmatic activity (Ebner and Sachsenhofer, 1991).

Sarmatian to Pliocene (12.8 - 1.8 Ma) heat flow is generally in the range of 65 - 100 mW/m^2. Relatively high heat flow is probably due to thinned crust beneath the Styrian Basin.

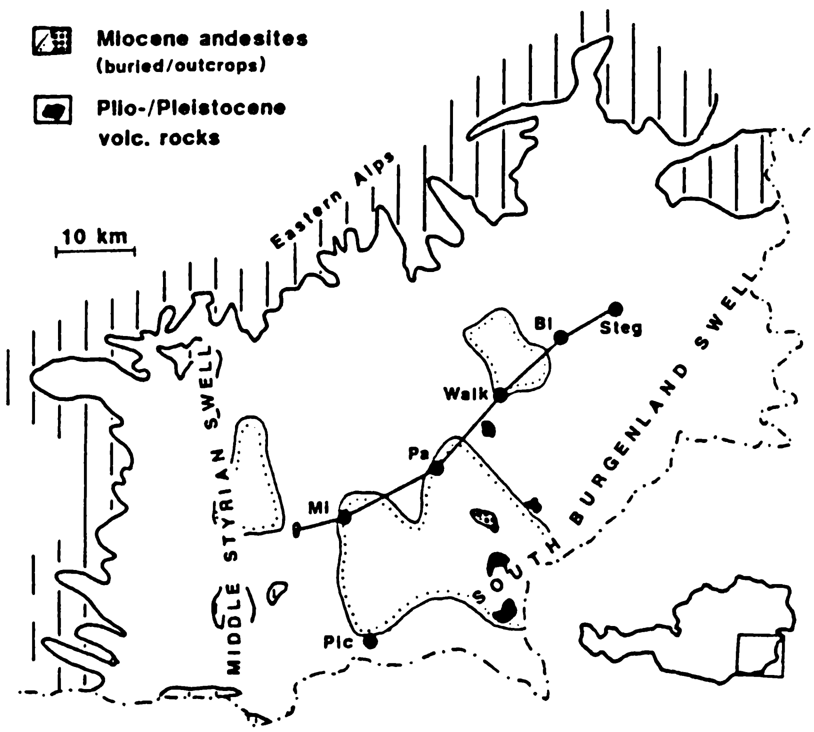

Fig. 12: Sketch map of the Styrian Basin and Location of Fig. 13 cross section. Pic = Pichla; Mi = Mitterlabill; Pa = Paldau; Walk = Walkersdorf; Bl = Blumau; Steg = Stegersbach.

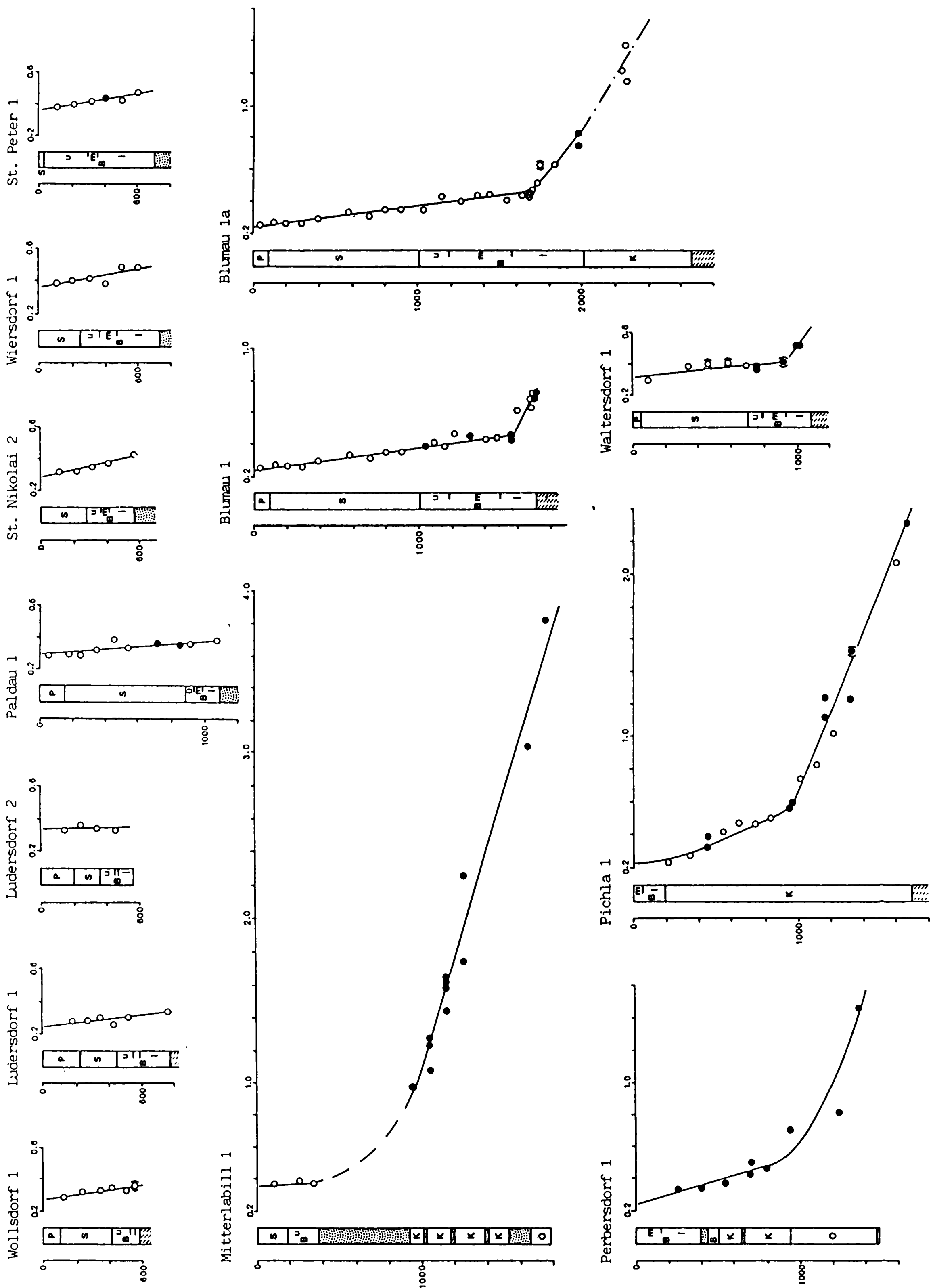

Fig. 11: Vitrinite refectance profiles from wells in the Styrian Basin (Sachsenhofer, 1991).

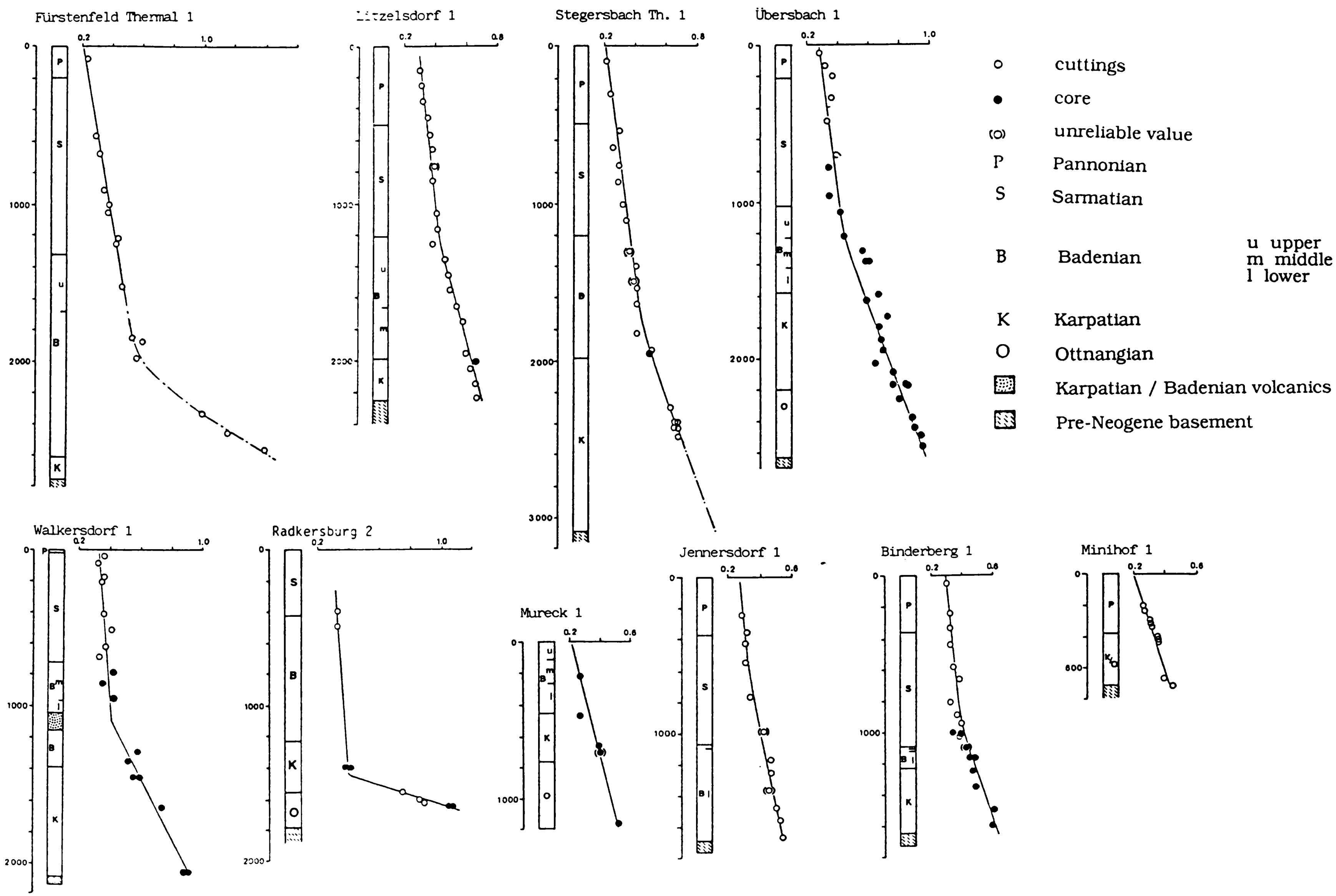

Fig.11 continued.

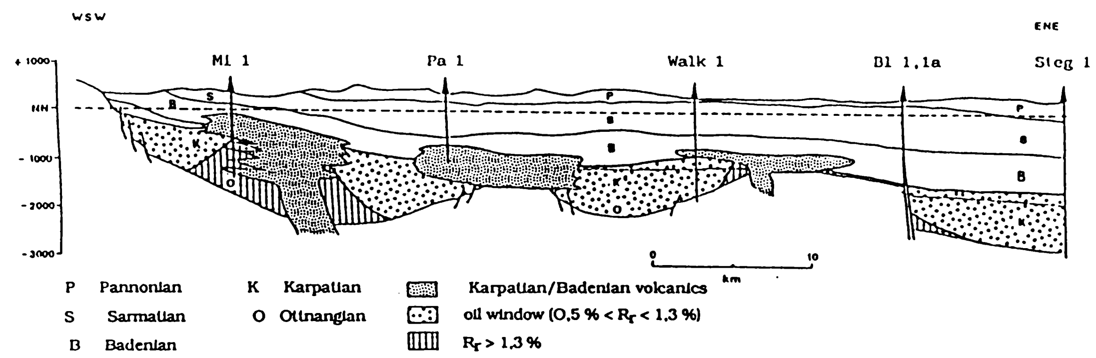

Fig. 13: Cross section through the Eastern Styrian Basin showing coalification trends. For location and abbreviations see Fig. 12.

In some areas, heat flow increased slightly during the Pleistocene. At least partly, this is a consequence of ascending hot waters flowing from deep into shallow parts of the basin (Goldbrunner, 1988). Perhaps, Plio-/Pleistocene volcanism also contributed to this heat flow increase.

Tectonic evolution

The tectonic evolution of the Styrian Basin is closely related to extensional tectonics and block tilting in connection to the east-directed continental escape of the Eastern Alps during the last stage of the alpine orogeny (Neubauer, 1988; Neubauer and Genser, 1991; Ratschbacher et al., 1991). The escaping block is bordered by the dextral Periadriatic and Vardar Lineaments to the south and a system of sinistral shear zones to the north (Defreggen-Antholz Fault, Salzachtal-Ennstal Fault, Mur-Mürz Fault).

The basement structures of the Styrian Basin are controlled by normal faults, block tilting and pull-apart processes inside the crustal wedge moved to the east. These structures were predominantly active during the Karpatian (west) to Lower Badenian (east) and formed the Mittelsteirische Schwelle as well as the synsedimentary halfgraben of the Fürstenfeld Basin. Intra-Sarmatian normal faults are known especially from the northern margin of the basin (Gleisdorf, Weiz; Krainer, 1984). Block tilting resulting in an angular unconformity (Styrian Unconformity), the development of fault-bounded swells (Mittelsteirische Schwelle, Südburgenländische Schwelle), major facies differentiations, and the Miocene volcanic activity are related to these processes (Ebner and Sachsenhofer, 1991; Friebe, 1991b).

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