nite (up to 6 vol.%) and late muscovite. This sillimanite was interpreted as a result of acid leaching by Korikovsky et al. (1987). The mafic schlieren may be several cm thick, they are composed of biotite (70–90 %), quartz, sillimanite, K-feldspar and plagioclase (An30-20). Accessories (apatite, monazite and zircon) are significantly concentrated in biotite. The abundant sillimanite is invariably enclosed by the late muscovite.

Garnet aplites are fine-grained rocks with panallotriomorphic texture, composed of cross-hatched microcline, sodic plagioclase (An10-15) and undulatory quartz. Subhedral to poikilitic garnets are almandine-spessartine in composition (Pyr8-11Alm71-72Sps15-18Grs2) showing no distinct zoning. The late muscovite also encloses fibrolite and forms symplectites with quartz.

### P-T conditions and origin of migmatites

Thermobarometric results, obtained by TWEEQU method (Berman, 1991) and the TWQ 2.01 software, yielded the temperatures of about 680 °C and pressures of 500–600 MPa for migmatites, and 630–660 °C and 300–500 MPa for aplites in the central part of the Suchý core. These P-T conditions are close to the dehydration-melting of muscovite and granite solidus. They are interpreted to record not the peak of metamorphism (partial melting) but a retrograde stage upon cooling and melt solidification when crystallization-hydration reactions between crystallizing melt and restite may have occurred.

The leucosomes are interpreted as products of muscovite dehydration melting of muscovite-rich layers in a metapelitic protolith according to reaction Mus + Plg + Qtz = Kfs + Sill + L. The prismatic sillimanite concentrated with biotite into mafic selvedges (melanosome). The muscovite dehydration melting commonly produces only limited amount of melt (e.g., Stevens and Clemens, 1993; Spear et al., 1999) which is characteristic of migmatites. Although, the calculated temperatures derived from the garnet-bearing samples did not exceed 700 °C, it is probable that the peak temperature was actually ca. 50 °C higher, reaching the muscovite dehydration melting curve (e.g., Vielzeuf and Holloway, 1988). Therefore, the late muscovite may represent a retrogressive, rehydration stage, having formed as Mu ± Qtz symplectites by the consumption of sillimanite and K-feldspar.

The diatexite (biotite granodiorite) may represent an advanced stage of muscovite dehydration melting where schlieren (biotite + sillimanite + quartz + accessories) are thought to have a restite origin. The minor garnet supports only incipient biotite dehydration melting in the metatexite/diatexite zone according to reaction Bio + Sill = Gr + Kfs + L (Spear et al., 1999). On the other hand, garnet aplites originated from a two-mica metapelites probably at higher temperatures involving both muscovite and biotite dehydration melting, producing peritectic garnet and K-feldspar (e.g. by the reaction Bio + Sill + Qtz + Ab = Kfs + Gar + L). This process, however, requires higher temperatures (about 800–850 °C) than those recorded by thermobarometry (ca. 630–660 °C ). Therefore, the latter temperature refers rather to near-solidus cooling than a peak temperature. While diatexites represent a cooler, less mobile, and restite-rich anatectic melt more or less confined to migmatites, the aplites are viewed as hotter, drier and mobile anatectic melts that penetrated into gneissic mantle.

The muscovitisation has consumed much of K-feldspar and some sillimanite (typically only fine-grained fibrolite remnants are preserved in muscovite). This strong rehydration occurred in all migmatite types and aplites/pegmatoids of the Suchý core except fine-grained, peraluminous biotite tonalites and allanite-bearing tonalites cutting the migmatites. This implies that the water-rich fluid was derived locally, presumably from the crystallizing anatectic melt. In view of such re-hydration reactions, the observed sillimanite/muscovite textural relations do not require the open-system mechanism involving alkali leaching and removal of alkalies as suggested by Korikovski et al. (1987).

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# Early Stages of Tectonic Evolution of the Pieniny Klippen Belt

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The Pieniny Klippen Belt (PKB) of the Western Carpathians is often characterized as a tectonic megabreccia, mélange, or even it was speculated to represent a chaotic sedimentary body – olistostrome. However, this peculiar “block-in-matrix” structural appearance of the PKB is mainly result of later stages of the deformation history of the PKB units, governed by along-strike transpressional and transtensional movements (e.g. Kováč and Hók, 1997). On the other hand, little is known about the dynamics of pre-orogenic rifting events and timing, geometry and kinematics of the earliest contractional phases. In this contribution a review of data about the pre-contraction history of the principal PKB units and a tentative geodynamic interpretation of Jurassic-Early Cretaceous rifting processes in the PKB and related areas are presented, as well as a model of the initial compressional stages in the area is outlined.

Based on the analysis and paleotectonic interpretation of the sedimentary rock record, three principal rifting phases are discerned in the PKB and related units:

The Hettangian-Sinemurian "wide-rift", "pure shear" type Zliechov Phase led to a more-or-less uniform stretching of the epi-Variscan continental lithosphere and created wide subsiding intracontinental basins (Zliechov, Šiprúň, Kysuca – Magura) separated by narrower subaerial highs (South-, or High-Tatric and North-Tatric Ridges). Basinal syn-rift strata are composed of mixed silici- and bioclastic sediments and bioturbated hemipelagic marlstones (Allgäu Fm.), elevated ridges show locally deep erosion and extensional discordance followed by shallow-marine deposits rich in terrigenous admixture and condensed horizons.

The Bajocian Krasín Phase particularly strongly affected areas north of the North-Tatric Ridge. The "simple shear" asymmetric extension along the foreland-ward dipping lithospheric detachment fault caused additional crustal extension in the Kysuca Basin and, finally, its probably Bathonian breakup and opening of the Vahic (South Penninic) Ocean. The break-away zone of the detachment fault might have been situated along the Infratatric Borinka halfgraben, which received exceptionally thick Middle Jurassic terrigenous scarp breccias (Somár Fm. – Plašienka, 1987). On the other hand, the Czorsztyn Ridge originated by thermal uplift above the distal, subcrustal part of the detachment fault. There, the anoxic hemipelagic Liassic-Aalenian strata are followed by syn-rift shallow marine bioclastic deposits with abundant terrigenous siliciclastic material (Smolegowa, Krupianka Fm.), accompanied by neptunian dykes and scarp breccias with signs of freshwater cementation (Krasín Breccia – Mišík et al., 1994a; Aubrecht et al., 1997), overlain by condensed Upper Jurassic post-rift strata (Czorsztyn and Dursztyn Fm.). Bajocian-Bathonian allodapic crinoidal limestones (Samášky Fm. – Aubrecht and O•voldová, 1994) deposited in slope environments (Pruské Succession). The Bathonian thermal collapse and breakup unconformity between the syn- and post-rift strata has been registered also in ridge areas south of the Vahic Ocean (Dumont et al., 1996; Wieczorek, 2001).

The Berriasian-Valanginian Walentowa Phase marks further foreland-ward migration of rifting and records breakup of the Magura Ocean. The breakup was, similarly as during the Krasín Phase, preceded by asymmetric rifting. In this case the detachment fault is interpreted as hinterland-dipping. Lithospheric extension and mantle upwelling triggered the second thermal uplift event of the Czorsztyn Ridge, reflected by syn-rift debris flow deposits and scarp breccias (Walentowa Breccia – Birkenmajer, 1977) and followed by widespread surface uplift and nondeposition until the Albian. Coeval allodapic Horná Lysá Limestone and Hauterivian turbidites occur in the basinal Kysuca Succession (Mišík et al., 1994b; Aubrecht, 1994). The same rifting event was detected also on the other side of the Magura Ocean, in the proximity of the Silesian Ridge (Reháková et al., 1995; Eliáš et al., 1996; Krobicki and Słomka, 1999), as well as in the Tatric-Fatric area (Nozdrovice Breccia – Michalík et al., 1997). Otherwise this Tatric-Fatric realm was characterized by rather uniform, calm pelagic sedimentation during the Neocomian. Remarkable subsidence of the Magura Basin to abyssal depths after the Walentowa Phase is revealed by hemipelagic and turbiditic sedimentation starting from the Barremian throughout the Cretaceous, commonly below the CCD (Švábenická et al., 1997). The Walentowa Phase was accompanied and followed by submarine extrusions of hyaloclastic alkaline basalts of the Tithonian up to Lower Albian age (e.g., Spišiak and Hovorka, 1997). The post-rift thermal subsidence in mid-Cretaceous times definitely drowned the Czorsztyn Ridge, which turned into a submerged pelagic swell (Mišík, 1994).

The arrival of siliciclastic redeposits, predominantly turbidites, into post-rift pelagic successions is usually interpreted as a manifestation of commencement of orogenic-scale contractional movements. The syn-orogenic sediments typically contain a mixture of clastic material derived from remote sources. The PKB is known to be rich in coarse-grained flysch deposits containing a lot of "exotic" pebbles. Current concepts usually interpret the source area as an intrabasinal contractional elevation (Andrusov Ridge – Birkenmajer, 1988), which completely disappeared later due to subduction. This view is not accepted here, however (cf. Plašienka, 1995). Several Cretaceous-Early Tertiary contractional phases can be discerned in the PKB and adjacent areas:

The Solírov Phase (partly corresponding to the Manín Phase of Andrusov, 1968) occurred during the Barremian-Aptian in zones south of the Vahic Ocean only. It is indicated by growth of Urgonian platforms on the former South-Tatric Ridge and by important tectonically-driven resedimentation events around the North-Tatric Ridge (Jablonský et al., 1993). Both Tatric ridges were once more elevated from pelagic depths. Though this episode could be considered also as an extensional event, it seems to closely coincide with first manifestations of shortening along the southern margin of the Fatric Zliechov Basin. Therefore it is tentatively interpreted here as a consequence of an episodic build-up of intra-plate compressive stresses. However, after foundation of important crustal-scale underthrusting zones consuming the Zliechov Basin substratum, the compressive stresses were relaxed within the lower plate, the crust returned to isostatic equilibrium and the Urgonian platforms were quickly drowned (Wieczorek, 2001). Shortly after this phase, in the Early Albian, the syn-orogenic, coarsening-upward flysch sedimentation commenced in the Fatric and Tatric domains (Poruba Fm.).

The Cretaceous advancement of the Western Carpathian orogenic wedge resulted in progressive incorporation of various crustal domains into the wedge, which is recorded by contractional deformation stages. The Albian-Cenomanian Benkovo Phase refers to underthrusting of the Zliechov Basin crust beneath the prograding Veporic wedge, coeval with syn-orogenic flysch deposition. After diminishing of this substratum, the Upper Turonian Donovaly Phase was a surface gliding event of the detached Fatric (Krí•na) nappe system. During the Donovaly Phase, the frontal parts of the Fatric, as well as Hronic (Choč) nappe systems glided far north beyond the Tatric substratum and occupied a position along the inner margin of the oceanic Vahic Basin (Plašienka, 1995).

The Senonian Selec Phase was heralded by the onset of coarsening-upward flysch sedimentation in the Vahic Belice Unit, interpreted as a beginning of the Vahic oceanic crust subduction (Plašienka, 1995). Initially distal Turonian siliciclastic turbidites (Sne•nica Fm.) reached the outer Kysuca margin of the Vahic Ocean, followed by Lower Senonian wild-flysch composed mostly of material recycled from mid-Cretaceous flysches of Fatric units, now occupying position of a "false" accretionary complex. The Senonian Gosau Group that deposited atop Fatric and Hronic nappes overlying subducted Vahic substratum may be regarded as growth strata of compressional piggy-back basins.

After elimination of the Vahic Ocean substratum, the toe of the Western Carpathian orogenic wedge came into collision with the Oravic ribbon continent (Czorsztyn Ridge and its inner Kysuca basinal slope) during the Maastrichtian-Paleocene Jarmuta Phase. The Oravic crust was thrust under the wedge, but its sedimentary cover was detached along the weak Lower Jurassic marly and shaly horizons to create a thin-skinned fold-and-thrust belt accreted to the orogenic wedge toe. Fragments of this ancient fold-and-thrust belt (fault-bend and fault-propagation folds, antiformal thrust stacks, duplexes) are frequently preserved, though strongly modified, in many places of the PKB. Prograding fronts of the wedge underwent flexural deepening, where the Upper Senonian and Lower Tertiary growth strata of the Jarmuta and Proč Fm. were deposited. Finally, the frontal elements (mainly the Czorsztyn Unit) partly overrode the innermost Magura units, especially the Biele Karpaty and/or Grajcarek Unit. Description of subsequent tectonic phases, which definitely shaped various units amalgamated within the PKB, is beyond the scope of this paper.

There are several important consequences, which may be derived from the above-described tectonic scenario. First of all, it is well known that the PKB consists of numerous lithotectonic units, the provenance of which is a matter of century-long discussions. Based on the record of the above-defined principal tectonic events, the following discrimination might be proposed:

- Units of the Slovakocarpathian (Austroalpine) provenance occurring within the PKB record only one principal Jurassic rifting event (Zliechov Phase), may or may not include Urgonian platform limestones (Solírov Phase), involve Albian-Cenomanian flysch complexes (Benkovo Phase) and record the nappe emplacement event (Donovaly Phase) by the Upper Turonian break in sedimentation. On the other hand, they exhibit weak, if any, manifestations of two younger rifting phases (Krasín and Walentowa). These attributes are applicable e.g. to the Drietoma, Manín, Klape, Orava and Ni•ná Units in the western, and to the Haligovce Unit in the eastern sector of the PKB. These appear to be related to the Fatric (Krí•na) nappe system.
- Units of the Oravic (intra-Penninic) provenance record more-or-less clearly all three rifting phases (Zliechov, Krasín, Walentowa), the last one followed by a considerable hiatus and erosion in swell areas, they do not include Urgonian carbonate platform and mid-Cretaceous flysch formations and lack Upper Turonian hiatus, as well as any signs of pre-Upper Senonian contraction. Accordingly, in contrast to the Fatric units, they do not bear symptoms of the Solírov, Benkovo and Donovaly contractional phases. Syn-orogenic flysch prograded from the inner to the outer Oravic zones during the Senonian, but their involvement into the thrust wedge and amalgamation with Slovakocarpathian units occurred at the end of the Cretaceous only (Jarmuta Phase). The swell-type Czorsztyn, basinal Kysuca-Pieniny and several "transitional" PKB units (Czertezik, Pruské-Niedzica, Branisko etc.) match these criteria.

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# Architecture of Deltaic Bodies Affected by Growth Faulting: Examples from the Bílina Delta (Neogene, Most Basin, Czech Republic)

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Growth faults are the most common deformation structures found in the sedimentary record of deltaic depositional systems. The knowledge of their geometry and architecture of delta bodies affected by growth faulting has implications for the studies of oil reservoir geometry and heterogeneity, as well as of the general controls on stratigraphic architecture.

The Early Miocene Bílina Delta is package of a fluvio-deltaic clastics deposited at the southeastern margin of the Most Basin, one of the sub-basins of the Ohře Rift basin system in North Bohemia. The Bílina Delta is interpreted as a lacustrine, fluvial-dominated, mouth-bar – type delta, with distributaries terminated by friction-dominated mouth bars, mostly with a Gilbert-type profile and a fan-like plan-view shape, characterized by steep, sandy foresets.

Growth faulting was the most important deformation process which affected the Bílina Delta depositional system. The resulting structures are faults characterized by listric fault planes and systematic stacking of a number of mouth bars on the hangingwall side. The delta bodies affected by growth faulting are characterized by large thickness and pot-like shape in cross sections oriented perpendicular to the direction of mouth bar progradation. The growth faults occur in delta bodies which are affected by synsedimentary tilting of the basin floor, or in delta bodies underlain by thick accumulation of lacustrine clays and/or a coal seam. Therefore, two main triggering processes are considered for the onset of growth faulting: (i) gravity sliding induced by basin-floor tilting, (ii) loading of thick units of mobile material. Combination of both processes is common. Generally, the fault slip magnitude and the number of vertically stacked mouth bars depended on the thickness of underlying mobile material. Because of the strong curvature of the listric fault planes, the marginal parts of growth faults are commonly aligned oblique to parallel to mouth bar progradation. Local accommodation was created due to the rotation of the subsiding hangingwall and resulted either in strong aggradation of topset strata, thickening (diverging) towards the growth fault plane, and in the formation of new mouth bars which show a basinward decrease in thickness. Whether topsets aggraded or a new mouth bar formed, depended on the ratio between the rate of deformation (subsidence) and rate of sedimentation. During progradation of an individual mouth bar, subsidence was compensated by aggradation of the topsets. The space for a new mouth bar was created during episodes of nonsedimentation which resulted from fluctuations of sediment supply. Rotation of the hangingwall side caused backtilting of the older mouth bars towards the fault plane and thus a decrease in slope of the foresets of the older mouth bar. This resulted in downlap of foresets of younger mouth bars on the backtilted fronts of older mouth bars.

Localized subsidence induced by growth faulting was an episodic process. Individual subsidence events began as a consequence of loading by deposits of a new mouth bar. The general architecture of the sedimentary packages affected by growth faulting is characterized by a decrease of mouth-bars thickness from older to younger strata, in response to a slowing subsidence, caused, in turn, by the decrease in growth fault displacement. Generally, the main phase of growth faulting is dominated by vertical stacking of new mouth bars, whereas the later faulting episodes are characterized by low displacement magnitude and the rate of creation of accommodation sufficient only for topset aggradation.