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SOME REMARKS TO AN EMPLACEMENT MECHANISM OF THE WEST CARPATHIAN PALEO-ALPINE NAPPES

(1 Fig., 2 Tabs.)

Abstract: Several data confirm the successive development of the Alpine structure of the West Carpathian Internides. For the oldest - the paleo-Alpine stage - a vast basement involvement is typical. Its distinctive Southern trend and volume - space relations of the Upper mantle - crust products indicate an overlapping of the orogene core zone with the Gemeric and South Veporic area of the Internides. From a discussion of the emplacement models criteria with paleo-Alpine typomorphic features a combination of fluid push and basement shortening mechanisms seems to be appropriate for the emplacement of the nappes. An evolution idea of paleo- and meso-Alpine structures is also outlined.

Резюме: Многие данные подтверждают сукцессивное развитие альпийского строения западнокарпатских интернид. Для самой древней-палеоальпийской стадии типическим является широкое включение фундамента в покровы. Очевидный южный тренд его активации и объемно-пространственные соотношения продуктов верхней мантии и коры назначивают перекрытие центральной зоны орогена и пространства гемерикума и вепорикума интернид. Из дискуссии критерий моделей движения покровов с палеоальпийскими типоморфическими чертами переместенных единиц интернид Западных Карпат является приемлемой для движения покровов комбинация давления флюидного столбика и сокращения фундамента. Дискутируется тоже о эволюционной модели палео и мезоальпийских структур.

Difficulties in the West Carpathian paleo-Alpine tectonic reconstruction are mainly connected with the following relations: (i) a vast modification, reorientation, wipping out and overlapping of the paleo-Alpine structural features by superimposed structures, (ii) complementary expressions of meso- and neo-Alpine structural pattern within the crust, (iii) a shortage of exact data in connection with specific problems of paleo-Alpine tectonics.

Consequently there are different ideas to some basic problems of the relevant stage of the West Carpathian Internides development (e. g. various views regarding to the homeland – root space position of the paleo-Alpine superficial nappes; Andrusov, 1968, 1975; Biely – Fusán, 1967; Mahel', 1967, 1986; Grecula – Roth, 1978, Leško – Varga, 1980; Kozur – Mock, 1973). To the same category of importance undoubtedly belongs the question of emplacement mechanism of the West Carpathian paleo-Alpine nappes which has not been particularly discussed yet. In this contribution we shall try to revaluate the available data on the Alpine development of the West Carpathians from the relevant problem point of view and to outline a possible answer to this point, hoping that in the future a more concentrate approach, it will be possible to solve the peculiar problems of this the initial stage of the present structure of the West Carpathian Internides.

As it follows from Fig. 1 we take into account in our interpretation a classical image of the West Carpathian superficial nappes. The Manín partial nappe in the sense of Mahel' (1986)

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has been included into the scheme mainly for its peculiar tectonic development (l.c.). With regard to Internides basement nappes we consider the Kraklová nappe in the sense of Mahel' (1986) except of the Muráň gneisses group in the sense of Hovorka et al. (1987). The Kráľová hoľa nappe we consider in the sense of Klinec (1966). A nappe nature of the Rimavica unit (Mahel', l.c.) follows either from its paleo-Alpine space position resulting e.g. in a high accumulation of the Alpine mobilisates or from a hardly explained image of an autochthonous nature of such a narrow basement block sandwiched between incomparatively thicker paleo-Alpine basement nappe sheets.

An overview of a polystage development of the Alpine structure of the West Carpathian Internides

A polystage development of the Alpine structure within the West Carpathian Internides area follows either from their relationships to deposition areas of Upper Cretaceous formations (and to the structural pattern of these sediments) or to a structural pattern of the Alpine internal molasse basins. The former had been developed on the paleo-Alpine i.e. on the emplacement structural frame and has been locally included into Upper Cretaceous upthrust (e.g. Miglinc valley, Považský Inovec Mts. area).

Synsedimentary basins of the latter ones has been formed on directional i.e. NE-SW and NW-SE fold/fault set or on the complementary *"ac"* faults. Structural pattern of Internide molasse bassins has been therefore clearly controlled by already existing meso-Alpine fold/fault structures. These fault sets have also been used by the centres of the West Carpathian neovolcanites. They take part in block segmentation of the West Carpathian lithosphere (Fusán – Ibrmajer – Plančár, 1979) and as follows from geophysical data many of them are active until the present time (Schenk et al. in Bližkovský et al., 1986).

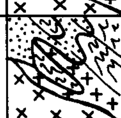
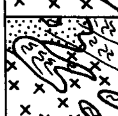
Resulting from the relevant-relationships, surface and deep structure fault sets of the West Carpathian Internides are either of Tertiary origin or they have been at least reactivited – and modified by these neo-Alpine events. A recognition of meso-Alpine structures (wiped out in this way) within a geophysical picture of the Internides crust is moreover complicated with a mutual azimuthal coincidence.

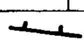
According to structural researches (Jacko, 1975, 1978; Siegl, 1976; Plašienka, 1983; Sasvári, 1983) the meso-Alpine structural paragenesis consists mainly of NE-SW and NW-SE oriented fold structures and a complementary axial plane cleavage and upthrusts sets, incl. regionally distinctive upthrust zones of the Čertovica, the Pohorelá and the Margecany type (Tab. 1). Significant structures of the paragenesis are associated perpendicularly oriented *ac* fault sets.

The discussed fold structures deform already approached units together with their autochthon. Directional upthrust zones are evidently superimposed to the fold structures and rhytmically penetrate already emplaced nappes and their basement. They are obviously situated behind nappe edges and hence they are the products of a postemplacement deformational stage. For this reason they can hardly be associated with the root/homeland areas of the paleo-Alpine nappes. Moreover Upper Cretaceous deposits are taken into this upthrust set (e.g. Miglinc valley, P. Inovec Mts.) or their segments are postkinematically healed by the Alpine granites and diorites (Vozárová – Vozár 1987; Jacko, 1975; Obernauer et al., 1980). These phenomena and a presence of either upthrust zones tectonites or the mentioned intrusives within Middle Eocene conglomerate boulders significantly precise the upper limit of their main activity.

Table 1

Tectonometamorphic development scheme of the Eastern part of the Veporic area (i.e. the Čierna hora Mts.)

Orogenic cycle	Orogenic phase	Deformational (metamorphic, * plutonic) stage	Deformational (metamorphic, * plutonic) style	Directional orientation	Metamorphic facies and their extent	Ferro and paramagnetic parageneses
ALPINE	Sa?	D_5		NE - SW	Gr. sch Chl - Ab local	Chl.
	La?	D_4 *		N - S	Amph. Hb. - Bi. local	Hb., Bi., Ti - Mag.
	Me?	D_3		NW - SE	Gr. sch. Chl. - Ab. regional	Chl., Mag., Ti - Mag., Hem.
				NW - SE	Gr. sch. Chl. - Mu. regional	Chl., Mu.
	Au?	D_2		E - W	Gr. sch. Ep. - Chl. regional	Chl.
				E - W	Gr. sch Chl. - Ab. local	Chl.
VARISCAN	S ?			E - W	Gr. sch. Chl. - Ab. local	Chl.
	Br.	*		E - W	Amph. Kf. - Mu. local	Mu.
		*		E - W	Amph. Co. - Hb regional	Bi., Mu., Hb., Mag., Ti - Mag.
		D_1		E - W	Amph. Sill. - Ga. regional	Bi., Mu, Hb., Mag.

1  2 

Symbols: 1 — Margecany type upthrust zone, 2 — nappe emplacement. Sa — Savic, La — Laramic, Me — Mediterranean, Au — Austrian, S — Sudetian, Br. — Bretonian.

Gr.-sch. — green schists facies, Amph. — amphibolite facies, Chl. — chlorite, Ab. — albite, Bi. — biotite, Mu. — muscovite, Ep. — epidote, Kf. — kalifeldspar, Co. — cordierite, Hb. — hornblende, Sill. — sillimanite, Ga. — garnet, Mag. — magnetite, Hem. — hematite, Ti-Mag. — titanomagnetite.

Structural researches (Jacko, l.c., Plašienka, 1983, 1983a; Sasvári l.c.) and a revaluation of paleo-Alpine nappes structural style (Maheľ, 1983, 1986) has shown that recumbent fold style sheared by the axial plane cleavage is typical for the Križná nappe and its basement, for a base of the Choč nappe and for the Gemeric basement nappe. Within the lower superficial nappes and their basement, new subhorizontal cleavage set, subparalel to the bedding of higher superficial sheet-like bodies had been developed. An immense load shift caused by nappes emplacement and this phenomenon have been the main cause and a catalyst for the meso-Alpine refolding of the superficial nappes and their basement as well, mainly within a profile of southern Internides.

A lower velocity channel in the depth of cca. 15 km within the Internides crust profile, crust doubling beneath the Malá Fatra Mts. (Beránek – Leško – Mayerová, 1979) and a flaty deposition of the nappes can by related to paleo-Alpine structures. Such phenomena obviously indicate basement nappes (Bally, 1981; Armstrong – Dick, 1974).

In these relations it is also interesting that the distinctive E-W trend of Moho level isohyps within the Alps and West Carpathian territory is evidently disturbed by NE-SW undulations in western part of West Carpathians (Suk in Blížkovský et al., 1986), the NE-SW and NW-SE directions dominate within the crustal level of the West Carpathians as indicate the results of the gravimetric data (Blížkovský et al. in Blížkovský et al., 1986).

We interprete a coincidence of primary E-W Moho level morphology and E-W strike of paleo-Alpine West Carpathian structures as a structural remnant of the paleo-Alpine territory shortening within the Alps-West Carpathian Tethys area, reflecting simultaneously the depth level of the paleo-Alpine crust reworking. The NE-SW and NW-SE structural trends of the crust reflect in this way the inherited structural anisotrophy directions which had been transmitted from underplatted segments of the Bohemian massif and the European platform during a continuous crustal compression of the postnappe deformational events.

Mechanism of thrust nappe emplacement

Five main causes have been obviously considered for an origin and resulting nappe emplacement mechanism within the orogenic zones: (i) – propulsion from a rear, (ii) – gravity gliding, (iii) – gravity spreading, (iv) – fluid push mechanism, (v) – shortenig of the basement. Criteria sets and typomorphic features of the mechanisms are exhaustively discussed by Hubbert – Rubey (1959), Armstrong – Dick (1974), Chapple (1978), Bally (1981), Smith (1981), Ramberg (1977, 1981), Cooper (1981) and Gretener (1981).

As follows from a discussion to the thrust/nappe problem (Price – Mc Clay, 1981; Mc Clay, 1981) a proved, at least 5 km long transport of an allochthonous sheet is necessary to consider as a basic criterion of a nappe. Further a wedge shaped thrust sheet profile is preferred, which multiplicates either a real thickness/lenght of the transported nappe sheet or a slight dip of a nappe sole.

Emplacement mechanism discussion

From voluminous data about structural development of the West Carpathian Internides it seems to be clear that West Carpathian paleo-Alpine nappes contain several significant signs which allow at least temporarily to estimate their potential emplacement mechanism. They are namely:

– a known presense of persuasive facial signs which confirm a native distribution of complementary Mesozoic depositon areas in the following order: (i) – Pieniny Klippen Zone sequence, (ii) – Tatric cover sequence, (iii) – the Križná sequence, (iv) – The Veporic cover sequence, (v) – the Choč sequence, (vi) – the Silica sequence;

– an analogical (e.g. Southward) trend of basement mobilisation incl. its nappe sheets involvement;

– an areal bounding of Mesozoic sedimentation throughs to Late Paleozoic molasse basins;

– an inverted emplacement of superficial nappes in the order: (i) – the Silica nappe, (ii) – the Choč nappe, (iii) – the Križná nappe;

– an evident tying of décollement horizons to basal plastic strata of superficial nappes;

– a tendence to an accumulation of younger formations in edges of superficial nappes and older ones in their rear parts;

– a gradual Northward onset of the top formations either shallow water of flysch ones within superficial nappe sequences;

– a strong probability of a primary an echelon e.i. tile-like position of superficial nappes (higher nappes do not exceed farther to the North than the lower ones);

– a noteworthy high amount of the Alpine intrusions, their contact metamorphites and hydrothermal/hydrometasomatic substances of the same age namely in the Southern zones of the Internide basement, e.g. in wider areas of supposed paleo-Alpine nappe homelands;

– a presence of two basement elevation ranges and their uplift coincidence with nappes movement direction (geological, paleogeographical and fission track data);

– a thick-skinned character of the West Carpathian paleo-Alpine nappes;

– an inclined trend of internal emplacement deformation/metamorphism of superficial nappes – their rising tendency either Southwards or to the nappe pile;

– a complementary coincidence of paleo-Alpine fabric in this direction either within basement sheets or their cover formations and nappes respectively;

– a downward trend of recumbent folds formation within paleo-Alpine nappes pile and a complementary rise of synemplacement deformations;

– a shortage of penetrative stretching lineations within the profile of paleo-Alpine nappes;

– a presence of either nappes pile rock material or tectonites of the Margecany upthrust zone type within boulders of Middle Eocene conglomerates.

Propulsion from a rear mechanism

A high improbability of this emplacement mechanism to conditions of West Carpathian paleo-Alpine nappes results not only from mechanical difficulties (e.g. from mechanical paradoxes discussed already by Smoluchowski, 1909; Smith, 1981 and by Cooper, 1981) but also from perfectly plastic wedge principle of Chaplès (1978) model. The latter condition is not fulfilled within West Carpathian superficial nappes. Moreover, an involvement of basement sheets into the nappes is not the case of this mechanism.

Gravity gliding mechanism

If we consider only superficial nappes of the West Carpathian Internides two fundamental difficulties arise. The first one connects the proof of existence of corresponding tectonic denudation relief within all supposed homeland areas of the nappes. The second one, is the opposite transport order of the nappes as the principles of this mechanism require. Not even one of other typomorphic features of this nappe category (c.f. Cooper, 1981) confirm a case of the mechanism within paleo-Alpine nappes of the West Carpathians.

Gravity spreading mechanism

The application of a gravity spreading model to the West Carpathians paleo-Alpine nappes is supported with much more data. The mentioned inverse emplacement course of nappes and its consequence – a successive flysch facies onset within nappe sequences, belong to them. An echelon arrangement of the superficial nappes succession is in a good agreement with the model, too. The quite common lateral replacement either of partial nappes or basic nappes "pair couples" (Maheľ, 1986) and further a substantial part of emplacement mechanism structural criteria (c.f. Cooper, 1981) also support the idea.

A significant argument againts the model is a shortage of ductility manifestations especially within profiles of superficial nappes (namely a lack of stretching lineations within the whole profile of nappes) and an absence of their space conformity either to nappes movement direction or to the axial course of the equally oriented synemplacement folds. Within the only exception of such indications (e.g. within the Križná nappe) a higher ductility is possible to explain also in other ways.

At the present erosion level of the Internides it is further difficult to make proofs about nappe movement synchronisation with (even indications) of an extensive tectonics within a roof part of the southern Internides. Some sporadic data in this way allow a contradictory explanation. Thus the Dobšiná ice cave sequence of the Gossau type beginning already by the Lower Santonian (Snopková in Andrusov – Snopková, 1976) overlies a contact plane of two the Silica nappe slices (Maheľ, 1986). This relationship, however does not contradict an eventual "piggy back" fashion transport of the Silica nappe by underlying, in the sense of the model, the younger-Gemeric basement nappe. From the last point of view is the presence of the Meliata group boulders in conglomerates of this the Upper Cretaceous formation at least of the same importance.

Basement involvement consequences to emplacement mechanism models

The above outlined degree and manifestations of the Internides basement involvement undoubtedly testify an ensialic nature of the Alpine orogenesis in the West Carpathians and simultaneously indicate a potential overlapping of the orogene core zone with southern zone of the Veporic basement and the Gemeric area. Within this territory (e.g. within the Rimavica and the Gemeric basement) is also concentraed the highest amount of the Alpine granite intrusions and hydrothermal/hydrometasomatic bodies. The zero anomaly of the West Carpathian gravity minimum (Ibrmajer, 1981) or regional gravity/magnetic anomaly axes (Pospíšil – Filo, 1980) fall either to the southern part of the Gemeric zone.

Into this a narrow strip (roughly between Lučenec–Rožňava–Košice line and the Czechoslovakian–Hungarian border) the southern boundary of Gemeric granite has also been geophysically located (l.c.). In this zone either the Alpine serpentinite bodies or divergence axis of both the tectonised slices of the Meliata group and the Silica nappe s.l. occur. In this area, a negative gravimetric anomaly has been recently confirmed (Bodnár in Šefara et al., 1987) which could be interpreted as the Alpine granite body of several thousand meters in thickness (l.c.).

As follows from relevant data, the southern margin of Gemeric basement is not only a zone of multiple physical boundaries of different but the Alpine age, but it also coincides with significant paleo-Alpine feature e.g. with the mentioned divergence axis of the Silica nappe s.l. These are the reasons for which we place a homeland area of the Silica nappe and its basal Meliata slices into this zone.

If the Gemeric zone is really the nearest one to the core zone of the orogen in the West Carpathians, its basement involvement products should also have according to fluid push model close time/volume relations to the corresponding nappes (Smith, 1981). A termination of the Silica sequence by shallow water Tithonian limestones (Mišík – Sýkora, 1980) confirms the beginning of its basement upwelling already in the Late Jurassic time. It would be hardly accidental that the signs of syn-sedimentary fault tectonics in the Czorstyn basin of the Pieniny Klippen Belt (Birkenmajer, 1985), the volcanism indices of the Pieniny ridge of the same belt (117.6–160 mil.y., Rybár – Kantor, 1978) and the glaucophanite radiometric ages of the ridge Rybár – Kantor (1978) also falls into this time interval. The disscussed features of both the opposite margins of the West Carpathian Internides basement plate are of a common nature in this way and they should be regarded as a reflection product of Mahel's (1986) Vahicum subduction.

Except for the global tectonic principles, we also support the idea by the metallogenic analysis results of Rozložník (1984). In this sense great volumes of Mg, Fe, Cr, V and Ti whose had been accumulated within hydrothermal/hydrometasomatic siderite-ankerite and dolomite-magnesite bodies or within siderite, fuchsite and chlorite-epidote veins are older than the Gemeric granites and they are of the Upper Mantle origin.

Hence we suppose that "a fluid pressure column" – a principal claim of fluid push model (Smith, 1981) has been in the West Carpathian conditions represented firstly by the Upper Mantle/Lower crust melt product and successively by a crust melt ones. There is however a lack of reliable data for a synchronization of geological informations connecting the begining of the Upper Jurassic Gemeric basement upwelling with the same age creation of ductilisation products within the Gemeric zone.

Except for the just mentioned connections it is also possible to consider the Rb/Sr 145 mil. y. age of the Gemeric (The Podsúľová) granite and the dating of 150 ± 26 mil. y. from Medzev Gemeric granite (Kovach – Svingor – Grecula, 1979) obtained by the same methode. A difference between granite bodies top level and depth of their formation in relation to granitic intrusion rate could also be consireded as a criterion. We have of course no data about the particular melt formation depth. Ideas about granitic intrusion rates are also highly different. If we, however consider 15 km (e.g. geophysicaly confirmed present bottom level of their intrusion; Bielik et al. in Blížkovský et al., 1986) as a depth of Gemeric granite formation and an intrusion rate equal to 0.84 mm/year (experimental results of Ramberg, 1972) than at an informative and very rough calculation we obtain 137.3 mil. y. as a result. The real depth age of the melt formation should not be much more higher because the Gemeric granites are of a distinctive "S" type (Cambel – Petrík, 1982). In spite of neglecting some further complications (e.g. very probable a polystage development of some bodies within the intrusion), the obtained result is remarkably close to the mentioned geological/geochronological data.

Even a purely mechanical approach to a volume comparison of Internides basement mobilisates and superficial nappes (Tab. 2) indicates a need of an additional mechanism to overthrow the mutual volume differencies. Only the volume of Gemericum mobilisates are evidently higher than the volume of associated the Silica nappe. This feature indicates a possible leading role of the mobilisates upwelling (Fig. 1) to a creation of the Silica nappe even in the case of neglection the mentioned difficulties. The last of the fundamental principle of the fluid push model – a down hill slope from the weekened basement area seems to be very probable from the discussed relationships but hardly verifiable due to its strong rebuilding by superimposed structures.

Basement shortening problem of nappe regions is in the sense of Bally's (1981) remarks and Molnar's– Gray's (1979) discussion acceptably solved either by basement subduction or reduction during eventually post emplacement tectonometamorphic events (c.f. also Hatcher, 1981). Basement nappe sheets involvement within the West Carpathian Internides profile and their internal deformation/metamorphic features clearly show that this mechanism had also taken a significant role within the Internides paleo-Alpine deformations. It also implies that it is necessary to seek a substantial part of the missing homeland areas of the superficial nappes among the allochthonous basement sheets. A syn-emplacement basement shortening leading to a complementary crust thickening of the Internides could also counterparts in the creation of the West Carpathian gravity minimum.

The above disscussed data support also Fusán's (1985) idea that the Alpine granite extent in the deph of 15 km's could be a scale of subducted part of the European platform. We would only like to add that the maximum width of the granite body in this depth is 50 km in its Western part and 28 km in the Eastern one. These are therefore very close values to the generally accepted transport lenghts of the superficial nappes in the relevant parts of the West Carpathians.

Table 2

Volumes of the paleo-Alpine nappes and substances increases within the Southern part of the West Carpathian Internides

Nappe		Surface (km^2)		Thickness (km)	Volume (km^3)		Total (km^3)
		exposed	covered		exposed	covered	
Silica		1 584	1 048	4.0	6 336	4 192	10 528
Choč		1 883	1 916	3.0	5 649	5 748	11 397
Križná	Fatric area	1 695	6 146	2.15	3 644	13 214	16 858
Križná	North Veporic area	565	1 322	1.1	621	1 454	2 075
Križná	Štiavnica isle area	—	+2 004	1.1	—	+2 204	2 204
Manín		64	—	0.75	48		48
Total		5 791	12 436		16 298	26 812	43 110

Tab. 2A – total amounts of Fatric and Veporic area of the Križná nappe topped by neovolcanites of the Banská Štiavnica isle joined data of the Fatric and Northern Veporic.

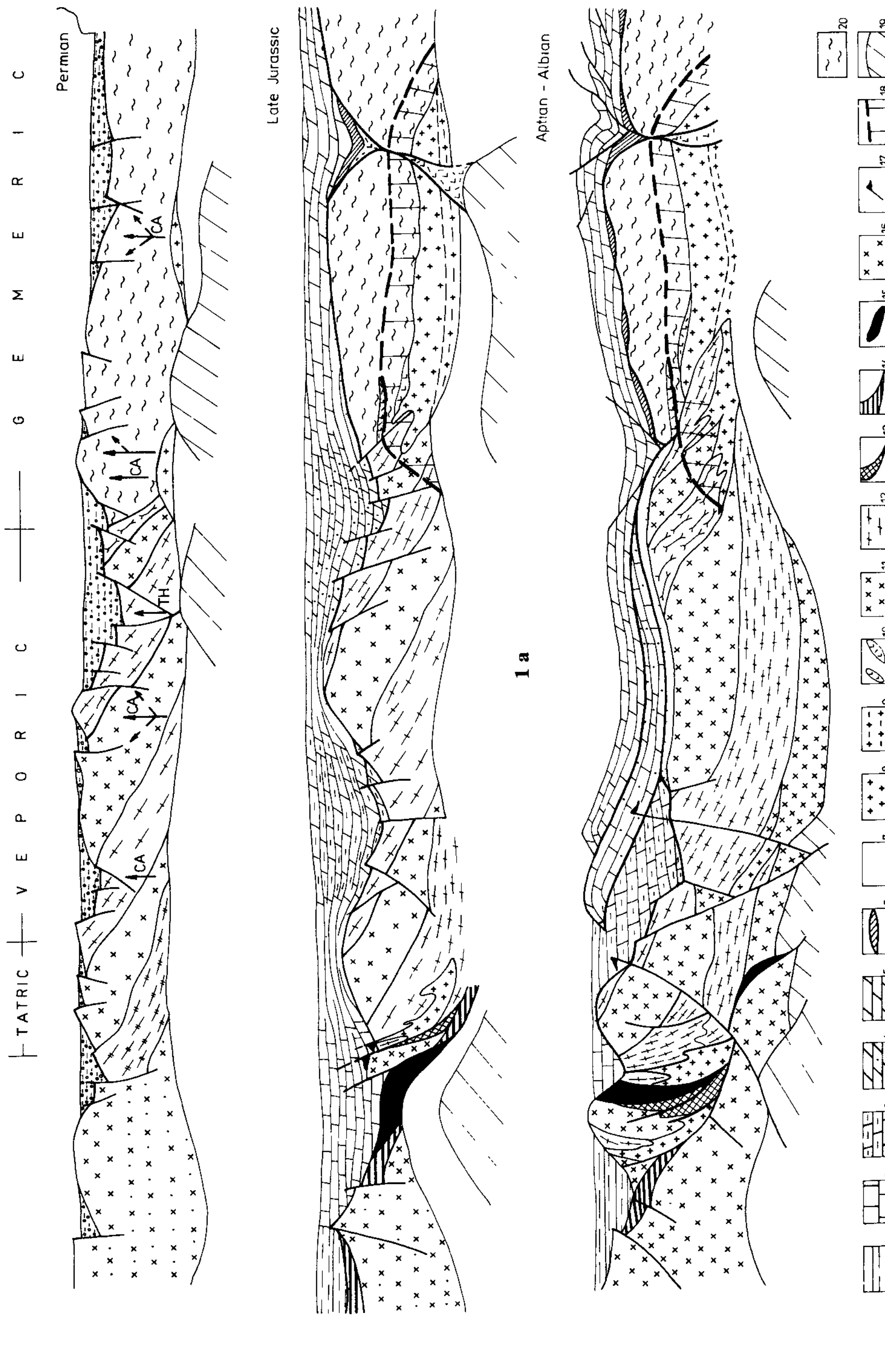
Increase of paleo-Alpine substances		Depth/Volume (km³)				Total (km³)
		0—3 km	3—5 km	5—10 km	10—15 km	
Gemeric	granitoids	861	1 312	4 926	7 040	14 139
	granitoids contact aureoles	42	?	?	?	42
	hydrothermal/ hydro-metasomatic mobilisates	903	?	?	?	903
Total		1 806	1 312	4 926	7 040	15 084
Veporic	granitoids	651	837	2 587	6 312	10 387
	granitoids contact aureoles	55	?	?	?	55
	hydrothermal/hydro-metasomatic mobilisates	347	?	?	?	347
Total		1 053	837	2 587	6 312	10 789

Tab. 2B – volumenous increases of hydrothermal (hydrometasomatic) bodies calculated as the 10 % of volume of particular rock environment.

An outline of the paleo-Alpine structural development of the West Carpathian Internides

In our interpretation we start from a dissected Late Paleozoic continental crust in the sense of Vozárová – Vozár (1978) (Fig. 1). Principal structures of the Variscan molasse basins had formed a pattern for an extensional mobility of the paleo-Alpine sedimentary throughs. The first indications of the paleo-Alpine compression had been limited (as has been mentioned above) to the edge of the subducted European platform (e.g. to the Pieniny Klippen zone area). The most pronounced signs of this the Late Jurassic mobility within the Pieniny Klippen zone (e.g. volcanites and glaucophanites) have been probably related to the same age subduction indications within the Romanian Carpathians and in the Western part of the Vardar zone (Sandulescu, 1985).

The age identity of mobility expressions within the Pieniny Klippen zone with the mentioned signs of an initial upwelling of the Southern part of the Internides basement is at least remarkable. We connect them with the Late Cimmerian begining of the European platform subduction beneath the block of the West Carpathian Internides (Fig. 1). Mahel (1986) considers the Manín phase (that had already started in Albian) as a main cause of an extensive rebuilding of the paleo-Alpine pattern of the Internides as well as a begining of more extensive overthrusts within the area. It is noteworthy that basic magmatism indications


TATRIC
VEPORIC
GEMERIC
Permian
CA
TH
Late Jurassic
1 a
Aptian - Albian
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

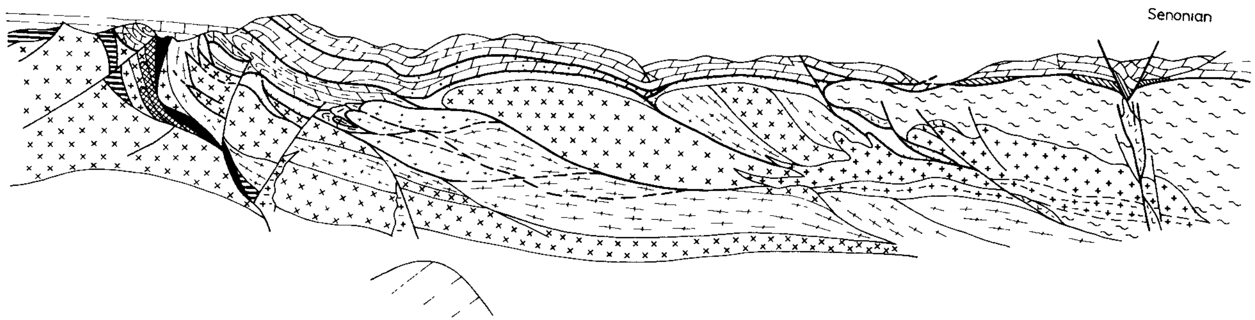

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Fig. 1. A successive scheme of the paleo-Alpine (pre-Laramian) development of the West Carpathian Internides. The Permian stage has been drawn according to Vozár (1983). In the left hand parts of the Late Jurassic to Senonian stages the ideas of Mahel' (1986) and Birkenmajer (1985) has been used.

1 – the Flysch Belt deposits; 2 – the Klippen Belt deposits; 3 – the Križná and the Manín nappes; 4 – the Choč nappe; 5 – the Silica nappe; 6 – the Meliata unit; 7 – Internide cover units, 8 – the Alpine granitoids; 9 – the Alpine intermediate plutonites; 10 – ultrabasic plutonites; b – serpentinized ones; 11 – pre-Alpine granitoids; 12 – Tatro-Veporic pre-Alpine metamorphites; 13 – mélange zones; 14 – para-oceanic crust; 15 – oceanic crust; 16 – continental crust of the North European platform; 17 – volcanites and their feeders; 18 – mobilised/weakened zone of an upwelling tendency; 19 – mantle elevation; 20 – Gemericum metamorphites.

within the Tatric, the Manín and the Križná s.s. sequences are also tied to the Aptian–Albian interval. Hence it is possible that this magmatism is bound to the first Pieniny Klippen zone width shortening and to the origin of the Pieniny cordilliera (Mišík, 1978) (Fig. 1).

Those magmatism indications are bound however to Northern and central part of the Internides. Within the Southern part of the area, in an entirely compressive regime of the orogen central zone, supported by a contineuous upwelling of ductile Upper Mantle/ lower crust products, could also result in an effective shortening of the Meliata rift area and to the sedimentation closure within the Silica sequence (Fig. 1). This event had to predate even the Manín phase as follows from the discussed data and from the presence of the Heuterivian flysch formation within the Choč sequence.

An accumulation of relevant fluid pore pressures within a plastic border zone of the Silica sequence and the basement, could lead to a divergent moution of the Silica nappe either to the North or to the South, through the edge of the Pannonian massif respectively, at the begining of the Austrian phase.

Stratigraphically and by thickness limited the Meliata sequence originally coming from an intrasialic rift through had also been transported at the base of the Silica nappe pile (Fig. 1). At some places this sequence form entirely reduced basal melange of the Silica nappe. It is possible to connect its local high pressure metamorphism either with the pre-Manín reduction of the rift roots or with the emplacement motion of the Silica nappe. Such an explanation makes also several particularities of the sequence more clearer namely: thickness/areal occurrence contrasts (e.g. mutually isolated but arealy considerable displaced occurrences), metamorphic heterogeneity of the sequence, lithostratigraphical contrasts of its individual exposures, their commonly tectonised boundaries, and slices structure of the sequence (Reichvalder, 1982). Further, a current presence of such contrasts as common occurrences of gypsum and ophiolites or radiolarites respectively, is hardly explanable in other than a tectonic manner.

The Silica nappe overthrusting had meant a great load shift. This lead to the creation of high pore pressures within underlying the Choč sequence pile, especially at its base. Hence a development/activation of deeper and more externally situated a nappe sole (Gretener, 1981) of the Choč nappe could start. A typical wedge shaped fashion (e.g. an accumulation of younger formations at the tip part of the pile and older ones at its rear part (Maheľ, 1986) strongly supported this idea.

The sole of the Choč nappe had been created at a plastic base of Variscan molasse formations. The second order detached level is once again tied to the roof of plastic Lower Triassic shales. It is however possible to join the nappe activation of the Choč sequence with a telescoping effect of the Silica nappe. One cannot, however exclude a some effective influence of a horizontal compression derived from the Gemeric basement rear. Relevant adding strain could be generated either from upwelling of ductile substances or from generally compressive regime of the Southern zone of the West Carpathian Tethyde part. A leading role of the telescoping effect, however, explains and confirms in a satisfactory way an intermittent nature of West Carpathian paleo-Alpine nappes movement as a time/pore pressure function (Oxburgh–Turcotte, 1974; Gretener, 1981).

Due to a continuous compressive regime of the Tethyde, suitable conditions arose for a development of the shear-fold the Gemeric basement nappe. At the boundary of the semi-viscous/rigid part of the crust a hydrostatic compression of ductilised infrastructure products could cause a relative accumulation of upwelling isotherms. This could lead to an increase of pore fluids pressure sensu Barker (1972) and Armstrong–Dick (1974). The strain multiplicated by horizontal shear component caused by load/heating effects (Ramberg, 1981; Gretener, 1981) could lead to the formation of weakened zone in which the sole of the Gemeric basement nappe had been created (Armstrong – Dick, l.c.).

Probably the relevant zone was recently recognised by depth geophysics (Beránek et al., 1979) in the form of a low velocity channel in about 15 km depth. Mainly subhorizontal position of the zone (and the nappe sole as well) Armstrong – Dick (l.c.) explain by a general parallelism of upwelled isotherms with the Earth's surface. Serpentinite bodies at the northern edge of the Gemeric basement nappe could also have been detached from this weakened boundary zone as it follows from the existence of an ultrabasic roof of the Rochovce granite.

An increased thermal/pressure gradient within the Gemeric basement caused either by growing column of fluid substances and by the rising Gemeric granites themselves, or by a total crust pressure growing, had lead to the development of recumbent folds and a correspondig axial cleavage/upthrust set within the weakened nappe pile. A simultaneous syn-tectonic metamorphism under regional "green schists facies" conditions within the metamorphites confirms also an advancing ductilisation of the basement and an adequate depth of the Gemeric basement nappe formation.

As it was mentioned above a subhorizontal emplacement of the Gemeric basement nappe has been confirmed in both – the Western and Eastern parts of the Veporic zone. Stratigraphically higher and simultaneously frontal formations of the Gemeric nappe pile had been overthrusted onto stratigraphically very different elements of the Veporic. This confirms firstly a later emplacement of the Gemeric basement nappe than the Choč nappe transport and secondly, a different – but at places a considerable – reduction of the Veporic cover sequence at the contact zone of both nappe units. The contact zone is also typical by a widespread structural convergence (recumbent fold, cleavage) of both the units. A considerable volume of fluid substances released by a retrograde decomposition of silicate minerals and by a prograde metamorhosis of cover units had caused a low grade metamorphic utilisation of relevant formations of both the units. These very pronounced features strongly support the Armstrong – Dick (1974) thin crystalline sheets idea for the Gemeric basement nappe. The overthrusts of the Silica, the Choč and the Gemeric basement nappe had caused and enormous loading of the Veporic basement, especially of its Southern part. This had to lead to its complementary sinking with the following consequences: (i) – an increase of the TP conditions especially within lower levels of its crust, (ii) – a relevant increase of the thermal flow namely at its rear part which was also saturated by fluid substances gained from the subducted platform plate.

An extensive amount of the Veporic basement mobilisation can be confirmed by: (i) – the great volume of the Alpine granites (Obernauer et al., 1980) accumulated within its Southern zone (e.g. within the Rimavica basement nappe), (ii) – by the above discussed regional synkinematic retrograde metamorphosis of all the three Veporic basement nappe sheets, (iii) – by the high amount of low temperature lenses/veins within the Veporic basement composed mainly of quartz-feldspars and quartz-epidotite±chlorites±carbonates.

We include into the paleo-Alpine development stage especially the quartz lenses/veins which are jointly folded by meso-Alpine folds. An evaluation of the PT conditions formation (i.e. 480 ± 67 °C and 275 ± 70 MPa) of these quartz veins/lenses which was done by Hurai (1983) indicates a depth level of about 10–12 km. Within this depth Hovorka (in Ondrášik et al., 1987) supposes a formation of the oldest tectonites at the contact of the Kráľová hoľa and the Rimavica nappes (so-called the depth facies blastomylonites with newly formed K-feldspars). A base of an areally extensive the Rožňava magnetic anomaly (beneath the Gemeric basement nappe) which is interpreted (Filo – Kubeš in Blížkovský et al.,

1985) as a metamorphite complex with basic rocks intercalations is also located within the 10–12 km depth level. The low velocity channel within the West Carpathian Internides is located approximately in the depth of 15 km (Beránek – Leško – Mayerová, 1979) but indications of shallower detachment planes are quite common. On the data base of the study of six nappe zones of the North American continent and the Alps, Armstrong – Dick (1984) suppose a thin crystalline nappe sheets formation at a 10 km depth at the temperature about 500 °C.

These data summaries indicate a real predisposition to crustal detachment zone origin within the Veporic basement, and basement nappe sheets formation within the zone. A potential influcnce of such a zone to a development of Veporic nappes is very probable, if we consider within it: (i) – an aquathermal overpressure exciting due to lithostatical load of the overlied nappes and a contemporary fluid percolation (Barker, 1972), (ii) – an increased plasticity of the zone due to discussed relations, (iii) – a change of the horizontal and vertical strain relationships from a primary 1 : 3 relation to a 1 : 1 one, due to a temperature increase (Smith, 1981), (iv) – a 1.5 MPa pressure increase corresponding to a 1 °C temperature increase at sealing conditions (Oxburgh – Turcotte, 1974; Gretener, 1981), (v) – a probability of crustal detachment zone coincidence to material crust boundary and (simultaneously) to metamorphites foliation (results of gravimetry and density crust models of the Internides, field relations) with a direct consequence to sealing conditions.

Expressive mechanical contrasts between the Rimavica, the Kráľová hoľa and the Krakľová sequences had played, according to our idea, a decisive role at their nappe individualisation. Contacts of competetively contrasting sequences had been used for detachment plane localization and probably, to a superimposed ramp-flat shortening of the Veporic as a whole.

Mutual superposition of the Veporic basement nappes and general relations to superficial nappes testify a gradual Northward activation of the basement nappe soles in the sense of the fluid push model (Smith, 1981) and a successive emplacement of basement nappe sheets. Hence an intermittent (a caterpillar) movement of the nappes seems to be very probable (Gretener, 1981). It is also possible to connect (Gretener l.c.) an internal nappe deformation with this "quiet" – relaxation periode, of the nappe's movement.

Such a mechanism could also cause a superficial nappe segmentation incl. retro-overthrusting of some parts of the Silica nappe sheets (Fig. 1). Strain trajectories of Rodgers – Rizer (1981) experimental results also confirm a possibility of such a movement course. Structural relations of the Silica nappe to the Gemeric basement nappe (Rozložník, 1977) and relations of the Upper Cretaceous formations at the Dobšiná ice cave to overthrust planes of the Silica nappe slices (Maheľ, 1986) as well as paleomagnetic data from the area (Krs et al. in Blížkovský et al., 1986) indicate the Middle Cretaceous as the latest time interval for the retro-overthrusting.

An intermittent nappe movement results also from a need of inevitable higher strain at the potential decollement plane than is the strain excited by telescoping of already emplaced nappe at the rear part of the potential nappe (Gretener, 1981). Moreover, the required strain increase can be in the case of crystalline sheets saturated e.g. by phase changes (Raleigh – Paterson, 1965) by metasomatic reactions (Platt, 1965) and by a temperature increase. It seems to be useful to mention that all the processes are widely documentable within the basement sheets of the Veporic area.

In the sense of Oxburgh – Turcotte (1974) calculations, a required temperature increment should be accumulated during a 0.5–1 mil. y. time interval after the emplacement of an overlying nappe. A consequent aquathermal pressure due to an absence of perfect sealing conditions in nature could be active after 1–2 mil. y. (Gretener, 1981). These relations explain either the postkinematic metamorphism interval within Southern sheets of the Veporic basement or the PT conditions of the paleo-Alpine epidote-zoizite-phengitic muscovite-biotite±garnet±kyanite paragenese (Vrána, 1980). We only would like to add that occurrences of this paragenesis are tied mainly to Southern Veporic basement sheets delimiting in this way the areal differences of higher basement nappes telescoping influence (incl. the Gemeric one) to their underlayer. A partial influence of the higher thermal flow due to crustal formation of the Alpine granites could not, however have been excluded.

The Albian–Cenomanian flysch formation of the Križná nappe reflects the begining of the paleo-Alpine mobilisation of its homeland area. If we consider them in the sense of Mahel' (1983) as the products of a "carried through", then the Albian–Late Turonian time interval is the very probable age of an intermittent moution of the Križná nappe. The above discussed relationships enable us to consider a telescoping of the higher superficial nappes supported by the same influence of the Kráľová hoľa nappe, to the rear of the Krakľová basement sheet as a main cause of the Križná nappe emplacement.

A relative lack of paleo-Alpine granites and a low degree of the paleo-Alpine metamorphism within the Krakľová nappe pile seems to be the result of the higher distance of the Krakľová nappe sequence from the high mobile zone of the southern margin of the Internides. The highly a ductile behaviour of the sequence during emplacement resulting in common recumbent fold formation and the corresponding low degree metamorphism of both nappe sequences is – in the discussed sense – the result of a deeper position of the sole of the Krakľová nappe in comparison with the higher Veporic basement sheets.

If our assumption about a continually deeper formations of the soles of the paleo-Alpine Internide nappes is correct and if this effect is caused mainly by higher nappes telescoping, then the Tatric range of the Internides should be in an allochthonous position. Further, the sole of Tatric overthrust have to be situated within its basement profile. The cover sequences of the unit should be deformed in an sub-autochthonous manner mainly due to the high porosity of the Upper Cretaceous sequences of the adjoining sub-Klippen zone which, in this way, had not been suitable for an accumulation of high pore pressures needed for a shallover sole formation.

The already documented paleo-Alpine overthrusts from the Malé Karpaty Mts. basement (Mahel', 1982; Putiš, 1987) and from the Považský Inovec Mts. basement (Putiš, 1983; Mahel', 1986) strongly support such an idea. The same result follows from geophysically confirmed crust doubling beneath the Malá Fatra Mts. (Beránek – Leško – Mayerová, 1979), from gravimetrically indicated presence of "light substances" beneath the Vysoké Tatry Mts. (Pospíšil – Filo, 1980) and from a magnetically verified heavier mass beneath the Tribeč and the Branisko Mts. (Filo – Kubeš, 1987; Gnojek – Filo, 1987).

Two expressive range culminations of the basement of the West Carpathian Internides (e.g. an external, the Tatric range and an internal the Veporic-Gemeric one) are – in the discussed sense – a consequence of the gradual Northward lithostatic adjustment echo of the Internides crust due to rapid load shift induced by nappe's movement. The presence of two basement uplift rows stresses in this way one of the significant features of the orogenic belts (Ramberg, 1981). Moreover, both the basement uplift rows are functionally – in time/space position and remobilisation degree trend comparable with analogous ones in the Alps, Scandinavian Caledonides, Appalachians and the Himalayas (Ramberg, 1981; Thakur, 1981).

Conclusions

For a nappe dominated terraine of the West Carpathian Internides a vast basement involvement is typical. Its distinctive Southern trend and an accumulation of geological, geophysical and structural interfaces (namely the location of paleo-Alpine divergence axis) into a narrov strip, following roughly the Slovak–Hungarian border zone indicate a spatial interference of the zone with the paleo-Alpine orogene core zone of the West Carpathians. From these points of views the zone functionally remembers the Periadriatic zone of the Alps. The other paleo-Alpine weakened zone had been bound on the Southern margin of the Veporic basement.

A Late Jurassic beginning of the Gemeric basement upwelling and the same age interval of the Meliata intrasialic rift closure seem to be counterparts of the Late Cimmerian subduction indications of the opposite, the Northern margin of the West Carpathian basement microplate.

The ultimate generator of the Internide nappe emplacement had possibly been of combined plate convergence/thermal origin. A Northward and continually deeper soles onset of either superficial or basement nappes and the opposite trend of the Alpine mobilisates volume within the Internides basement sheets strongly support the fluid push as the leading generator, especially for the emplacement of the higher superficial nappes. An additional influence of the basement shortening caused by the total compressive Tethys regime and contributed by load shift phenomenon seems to be the case especially for the basement nappe sheets and for the Križná nappe.

The present regional fold/upthrust structure of the West Carpathian Internides of the both NE-SW and NW-SE directions had been initiated by the Internides crust lithostatic adjustment to nappe emplacement load shift and completed during post-emplacement meso-Alpine deformations.

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