Contributions to Geophysics and Geodesy Vol. 31/3, 2001

Original orientation of neptunian dykes in the Pieniny Klippen Belt (Western Carpathians): the first results

R. Aubrecht
Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University[1]

I. Túnyi
Geophysical Institute of the Slovak Academy of Sciences[2]

Abstract: Measurements of neptunian dykes and their evaluation with utilizing of paleomagnetic correction for the first time provided data that enable to estimate orientation of the hypothetic Czorsztyn Swell. This ridge was individualized during Jurassic rifting and formed an axis of the so called Pienidic Domain. This domain was destroyed in the Alpine orogenic cycle. The basement of this zone was consumed, but the overlying sediments were preserved and now form the majority of the so called klippen in the Pieniny Klippen Belt which is now the most complex zone of the Western Carpathians. The klippen are tectonic blocks and lenses of mostly Jurassic limestones in softer, mostly Cretaceous envelope. As these remnants of Jurassic limestones are of different orientation, paleomagnetic corrections are necessary to complement any structural measurements in this zone. Callovian to Oxfordian neptunian dykes occurring in the Czorsztyn Unit, the sediments of which deposited in the shallowest parts of the Czorsztyn Swell, were taken as a direct indicator of the Jurassic extension. Four sites in western Slovakia were examined, possessing larger networks of neptunian dykes: Babiná, Mestečská skala, Vršatec and Bolešovská dolina. The mean orientation of the neptunian dykes was NE–SW (with N–S to ENE–WSW variations), which indicates also the most probable orientation of the Czorsztyn Swell. This direction points to NW–SE oriented Jurassic extension in that area. The paleomagnetic inclination ranging between 21° and 46°, with mean point of about 33° indicates approximately 10–30° paleolatitudes, where the Czorsztyn sedimentary area might had been located at that time.

Key words: paleomagnetic direction, neptunian dykes, Jurassic, Klippen Belt

[1]Mlynská dolina – G, 842 15 Bratislava, Slovak Republic,
e-mail: Aubrecht@nic.fns.uniba.sk
[2]Dúbravská cesta 9, 842 26 Bratislava, Slovak Republic,
e-mail: geoftuny@savba.sk

1. Introduction

Neptunian dykes represent system of synsedimentary extensional fractures, which can be well dated by the age of their filling. They reflect tectonic tension, or, eventually, gravitationally driven fracturing and cliff tilting. Opening of such dykes indicates a prevailing extensional regime.

In the Western Carpathians, as well as in the entire Tethys, the most significant period with opening of neptunian dykes was the time of Jurassic rifting. In the Alpine Central Europe the Jurassic (Liassic) neptunian dykes are known from the Eastern Alps (*Fabricius, 1962; Schöll* and *Wendt, 1971*) and Transdanubian Central Range (*Fülöp, 1976*). In the Western Carpathians, the Jurassic (mostly Liassic) neptunian dykes were described from Tatric Zone (*Radwanski, 1959; Michalík et al., 1993*), Fatric Zone – Driekyňa Succession (*Mišík, 1964; Soták* and *Plašienka, 1996*) and Silicic Zone s.l. (*Rakús* and *Sýkora, 2001* personal communication).

Neptunian dykes in the Pieniny Klippen Belt of the Western Carpathians were first mentioned by *Birkenmajer (1958)* as results of earthquakes related to the Late Jurassic orogenic movements in this area. Later on, the neptunian dykes in this zone were mentioned by *Jurkovičová (1980)*, *Halajová (1981)*, *Aubrecht (1992)*, *Mišík* and *Sýkora (1993)*, *Mišík et al. (1994b)* and *Aubrecht et al. (1997)*. However, the recent orientation of the neptunian dykes in individual klippen was evaluated only in several papers as *Mišík (1979)*, *Mišík et al. (1994a)* and *Aubrecht et al. (1998)* but without implication for the paleostress evolution in the Pieninic area.

In some areas, mainly with less complicated geology, paleotectonic reconstructions were made on the basis of neptunian dykes for instance in Jurassic of southern Italy (*Bouillin* and *Bellomo, 1990*) and Cretaceous of Polish Platform (*Wieczorek et al., 1994*). Tectonic meaning of neptunian dykes was emphasized in the papers of *Wendt (1965, 1971)*, *Winterer et al. (1991)* and *Winterer* and *Sarti (1994)*. On the other hand, the tectonic versus paleokarstic origin of the Jurassic neptunian dykes from Spain was discussed by *Winterer* and *Sarti (1995)* and *Molina et al. (1995)*. Combination of both dyke-forming factors, karstic and tectonic, was presented by *Vera et al. (1988)*, *Smart et al. (1988)* and *Di Stefano* and *Mindszenty (2000)*.

This paper deals with orientation of the neptunian dykes related to the

Middle to Late Jurassic extension in the Pieniny Klippen Belt. This zone underwent multiphase deformation history during Late Cretaceous to Neogene that resulted in its present complex tectonic structure. Despite this, it was almost unaffected by thermal overprint. As most of the klippen represent isolated blocks and tectonic lenses, which rotated along several axes, utilization of paleomagnetic methods was necessary for the reconstruction of their original position.

2. Geological and stratigraphical setting of the examined dykes

From the Pienidic units, neptunian dykes occur exclusively in the paleotopographically most elevated part represented by Czorsztyn Unit. The occurrences of the neptunian dykes in the Czorsztyn Unit were summarized by *Mišík (1993*, Fig. 1 and *1994*, Fig. 1). They are much more common in the western part of the Pieniny Klippen Belt than in its eastern part (*Aubrecht et al., 1997*). Nevertheless, only four klippen have yielded so many neptunian dykes that their orientations could be used at least for tentative statistic evaluation. The examined sites are Babiná (quarry), Mestečská skala, Vršatec and Bolešovská dolina (Fig. 1).

Babiná – quarry (Fig. 2) – the locality was described in detail by *Mišík et al. (1994a)*. It represents an abandoned limestone quarry at the foot of Babiná Hill, located above the road connecting the villages Bohunice and Krivoklát in middle Váh Valley. The klippe, recently in tectonically overturned position, contains about 13 m thick Bajocian-Bathonian crinoidal limestones, with significant network of neptunian dykes. The previous investigations of *Mišík (1994b)*, as well as new thin-section study point to the fact that almost all the neptunian dykes contain either "filamentous" microfacies or they are sterile (mainly the thinner dykes that prevented entering of bigger allochems). Though usually widespread in the whole Lower/Middle Jurassic, the "filamentous" microfacies in the Pieniny Klippen Belt occur mainly all through the Bathonian and Callovian. The Oxfordian is mostly characterized by succeeding *"Protoglobigerina"* microfacies (see *Myczynski* and *Wierzbowski, 1994; Wierzbowski et al., 1999*), which do not occur in the neptunian dykes in the klippe. The "filamentous" microfacies in open

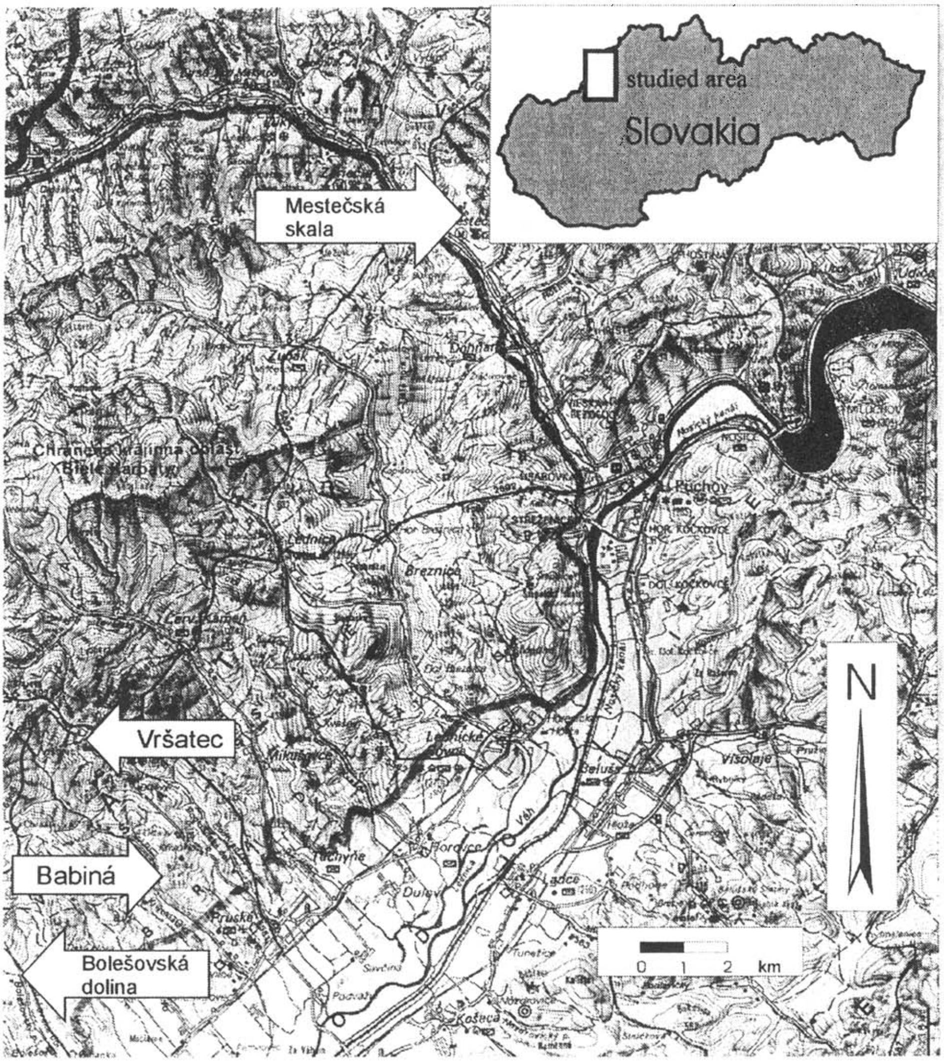

Fig. 1. Position of the examined sites with neptunian dykes.

marine sediments of the examined site occur just in relatively thin condensed layer In the red micritic Bohunice Limestone over the crinoidal limestones. Deposition of the crinoidal limestones in the Czorsztyn Unit ceased

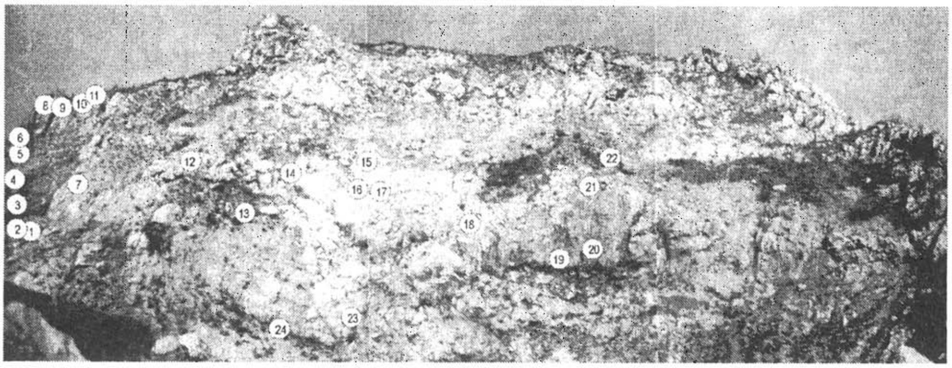

Fig. 2. Position of measured dykes in the Babiná Klippe.

in Bathonian, locally even in Bajocian (*Wierzbowski et al., 1999*). Dating of the tectogenic event responsible for formation of the neptunian dykes at this locality is then narrowed to Bathonian-Callovian.

Mestečská skala (Figs 3a,b) – the locality was described in detail by *Aubrecht (1992)*. It is a conspicuous klippe cut by a quarry at the NE margin of Mestečko village, NW of the town Púchov. In the uncovered 6 m of crinoidal limestones, in tectonically overturned position, a network of neptunian dykes occurs, their filling having source in the stratigraphically overlying red micritic Bohunice Limestone. The dyke fillings include both, the "filamentous" and *"Protoglobigerina"* microfacies. Hence, they can be dated as Bathonian to Oxfordian. It is necessary to stress, however, that in the open-marine Bohunice Limestone preserved at this locality, no "filamentous" microfacies were found (maybe eroded by bottom currents, producing a submarine hiathus).

Vršatec (Fig. 4) – the site was described in detail by *Mišík (1979)*. At this site there are the largest Czorsztyn Unit klippen in Slovak territory and maybe in the entire Pieniny Klippen Belt. They are situated above the village Vršatské Podhradie, NW of the town Ilava. Most of the dykes were measured in the klippe, on which the Vršatec Castle is built; only one thicker dyke was found in the neighbouring, more northern part of the klippe (dyke No. 6 of *Mišík (1979)* containing rich fauna of juvenile ammonoids and brachiopods). A relatively wider time-span of opening of the neptunian

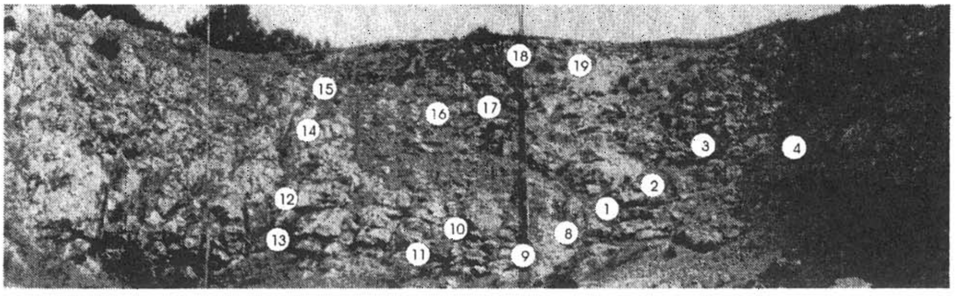

Fig. 3a. Position of measured dykes in the Mestečská skala Klippe – frontal view on the quarry.

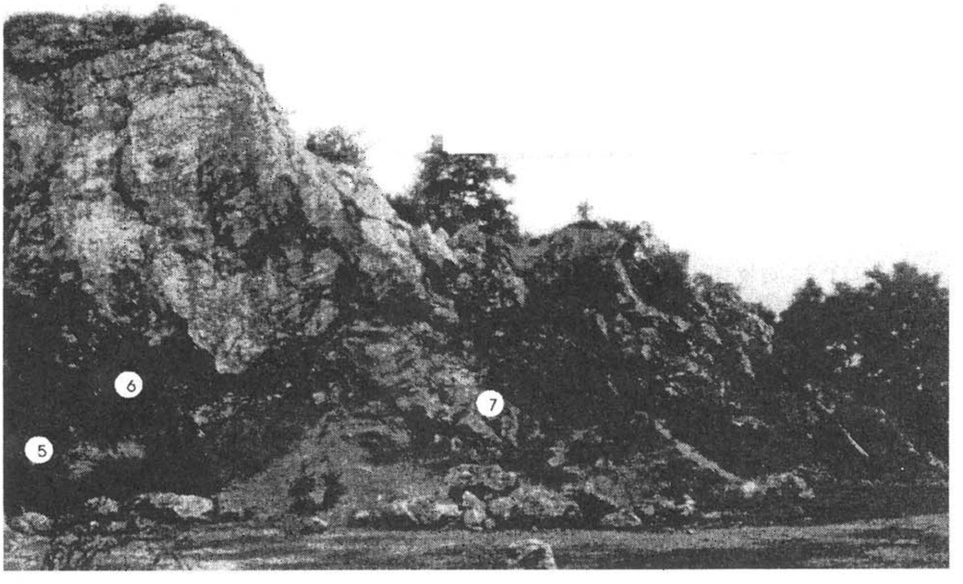

Fig. 3b. Position of measured dykes in the Mestečská skala Klippe, – right (eastern) part of the quarry.

dykes was mentioned by Mišík (l.c.), ranging from Callovian to Albian. Nevertheless, the vast majority of the dykes is of Callovian to Oxfordian age; the younger dykes are sparse and representing just local rejuvenation of the older ones (commonly multiphase filling). The most common is the filling containing the "filamentous" or *"Protoglobigerina"* microfacies or they are

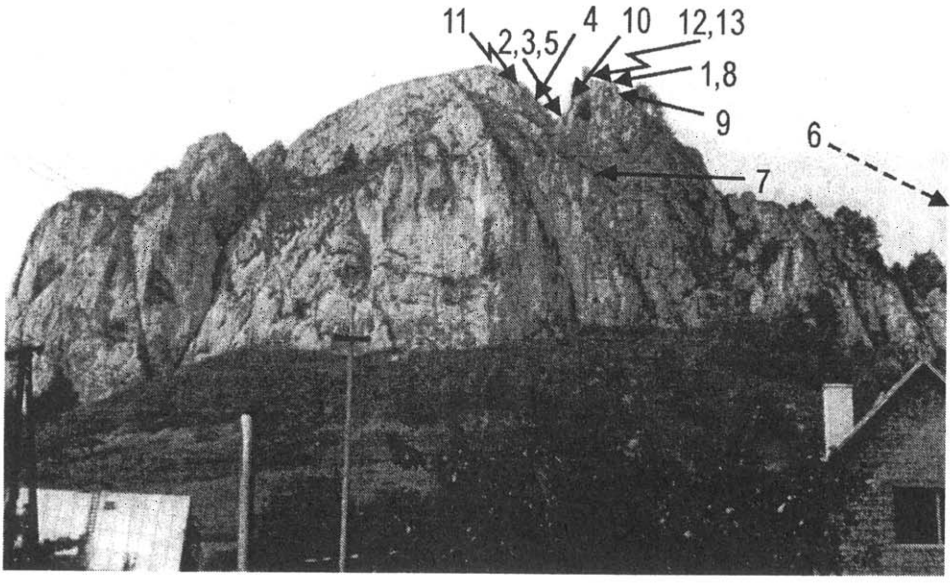

Fig. 4. Position of measured dykes in the Vršatec Klippe.

sterile. Fillings with calpionellids or Albian planktonic foraminifers are rare.

Bolešovská dolina (Fig. 5) – the locality was recently described by *Aubrecht et al. (1998)*. The klippe is located at the road in Bolešovská dolina Valley, close to its branching at its NW end. In about 5 m thick crinoidal limestones, several neptunian dykes were registered and measured. However, these older data come from the time when the klippe was relatively well exposed. Recently, the klippe is densely covered by vegetation and no later measurements were done so far. At that time, no dyke was measured, therefore, no weighed diagrams of dyke distribution could be drawn. The dykes possess either mostly sterile fillings or they contain elements typical just for the Callovian-Oxfordian microfacies ("filaments", cavity-dwelling ostracods *Pokornyopsis* sp. etc.).

The rest of the Czorsztyn Unit klippen was not convenient for the statistical analysis, as individual blocks, but may be eventually utilized in the future as one mixed statistic population collected from numerous klippen with few dykes.

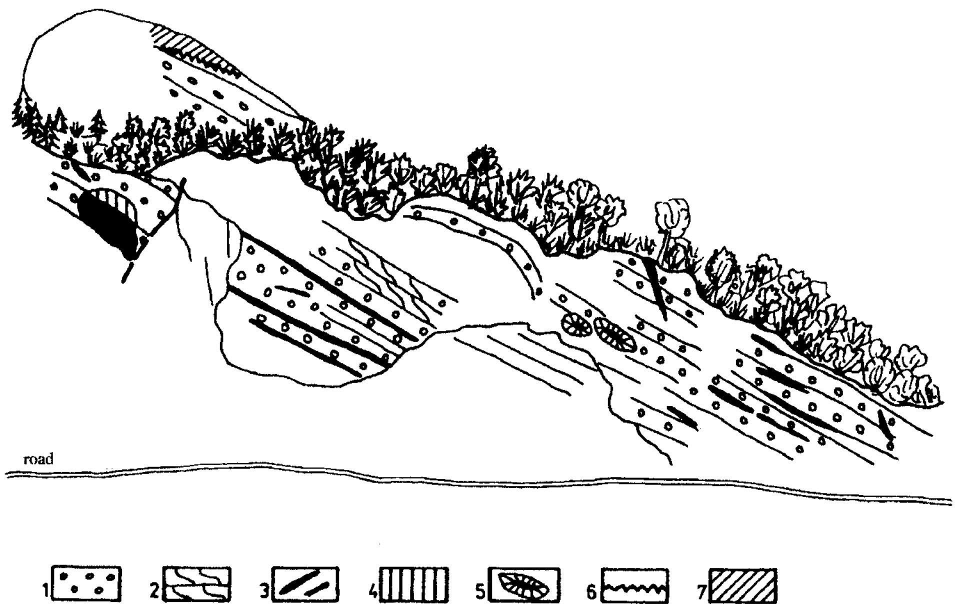

Fig. 5. Geological sketch of the klippe in Bolešovská dolina valley (after *Mišík, 1997* and *Aubrecht et al., 1998*). Explanations: 1 – crinoidal limestone, 2 – cross-bedding, 3 – neptunian dykes with micrite filling, 4 – grey microoncoidal to ooidal limestone in the cavern filling, 5 – small voids with radiaxial cement and internal sediment, 6 – Fe-Mn hardground, 7 – red biomicritic limestone with transitions to the grey microoncoidal limestone.

3. Methods used for data collection and data evaluation

The recent orientation of neptunian dykes was measured by geological compass (Babiná = 24, Mestečská skala = 19, Vršatec = 13 and Bolešovská dolina = 11 dykes measured); the results are summarized in Tab. 1. The number of neptunian dykes is not satisfactory for thorough statistical analysis of the individual klippen but could not be increased. All the main dykes in each klippe were measured and any attempt to measure more dykes would increase possibility of multiple measuring of the same dyke, which would make the statistics even more unreliable. Each measurement (except the Bolešovská dolina locality) was complemented by thickness of the measured neptunian dyke; the stratification of each locality was mea-

Tab. 1. Data of the measured dykes. DD – dip direction, d – dip value, index $_{cor}$ – after paleomagnetic and tilt correction.

Babiná — bedding = 320/71° (overturned)

dyke No.	DD°	d°	DD°$_{cor.}$	d°$_{cor.}$	thick. (cm)
1	296	71	233,9	23	14
2	305	54	284,8	22	2
3	310	71	231,7	10	3
4	111	41	160	73	17
5	114	50	161,7	64	10
6	104	50	169,3	69	5
7	137	45	142,7	64	6
8	301	68	244,3	19	14
9	355	36	348,4	44	3
10	139	83	144	26	7
11	289	24	303,9	51	10
12	208	36	287	87	8
13	126	23	145,6	86	11
14	184	73	87,5	56	1
15	103	45	166,9	73	17
16	131	50	147,8	60	10
17	79	41	174,6	87	2
18	181	18	308,3	85	5
19	288	90	202,9	37	3
20	315	77	180,2	8,2	4
21	68	17	336,7	77	7
22	163	41	124,7	71	30
23	140	37	140,2	72	16
24	128	49	150,6	61	35

Mestečská skala — bedding = 83/22° (overturned)

dyke No.	DD°	d°	DD°$_{cor.}$	d°$_{cor.}$	thick. (cm)
1	315	78	282	88,4	50
2	239	82	356,3	78,3	2
3	308	66	112	81,6	5
4	218	70	194,2	85,8	18
5	237	81	358,8	79,6	14
6	299	80	296,8	82,3	20
7	49	30	50,2	16,6	2
8	131	90	281,9	75,9	2,5
9	56	35	28,6	18,2	4
10	257	90	338,4	68,5	25
11	75	38	350,1	16,7	9
12	330	70	90,8	79,4	13
13	310	75	107,9	89,9	7
14	283	77	313,2	83,1	16
15	247	36	163,9	57	5
16	139	88	273,9	76,3	14
17	343	88	252,5	88	2
18	239	63	173,5	83	7
19	139	65	265,5	54,3	2

Vršatec — bedding = 292/77° (overturned)

dyke No.	DD°	d°	DD°$_{cor.}$	d°$_{cor.}$	thick. (cm)
1	8	50	314,7	71	10
2	106	63	90,7	41	10
3	301	50	277,9	28	10
4	45	88	165,6	68	5
5	61	59	130,1	66	15
6	280	59	234,4	21	30
7	45	36	116	88	30
8	9	34	298,6	72	10
9	317	83	5	26	15
10	60	65	135,6	63	11
11	54	50	124,8	76	60
12	244	80	174,3	47	12
13	296	82	43,6	7	14

Bolešovská dolina — bedding = 155/20° (normal)

dyke No.	DD°	d°	DD°$_{cor.}$	d°$_{cor.}$
1	72	41	14,5	42,1
2	131	54	86,2	36,5
3	122	72	81,2	55,8
4	171	36	153,1	17,5
5	135	41	85,3	22,6
6	68	32	3,2	36
7	122	45	69,3	30
8	59	32	356,8	38,6
9	153	77	118,3	56,5
10	41	41	349,6	51,5
11	333	77	118,6	83,5

sured too. Though generally known from the previous investigations, the age of some of the dykes was verified by microfacial study of thin-sections.

All the examined sites were also sampled for paleomagnetic measurements (min. 5 samples from each klippe). The samples were taken from various stratigraphic horizons and from various parts of the klippen, including both, the wall-rock (mainly Bajocian-Bathonian crinoidal limestones) and the dyke fillings (together with their source rock overlying the crinoidal limestones – mostly Callovian-Oxfordian red micritic limestone). From every paleomagnetic sample several subsamples were analysed. Thermal demagnetization on demagnetizing system MAVACS was used. Remanent magnetic polarization was measured on spinner generator JR–5. According to composition of the investigated rocks, we suppose that remanent magnetic polarization has sedimentary character. Thermal magnetic cleaning was carried out from the room temperature till 650 °C temperature with thermal step 50 °C. After each thermal step the magnetic bulk susceptibility was measured on the kappa-bridge KLY-2. The changes of magnetic susceptibility during demagnetization refer to the phase transition of magnetic material in the rock. Determination of characteristic paleodirection of each sample was carried out on the basis of the demagnetization graphs. These were thermal demagnetization curves of magnetic polarization and magnetic bulk susceptibility. Also stereographic projection and the Zijderveld diagram of XY and XZ components of remanent magnetic polarization were constructed. The main paleodirection for each locality was calculated by means of Fisher statistics. The obtained data are summarized in Tab. 2. Thermal demagnetization diagrams of representative samples are in Figs 6–9.

The recent orientations of the neptunian dykes were transformed at first by rotating the data to normal horizontal position. Stereoprojection and contour diagrams were constructed (presented here just in final summarizing forms rotated to the original position – see Figs 11 and 12). As the plain inclinations play a subordinate role at evaluation of the extensional pattern, the most proper was construction of the rose diagrams of dyke directions. They were grouped into 20°sectors. In first approach, only amounts of the dykes in the sectors were taken into consideration. This procedure was later improved by counting of thicknesses of the dykes in the sectors as the thicker dykes, as we suppose, better correspond to the general orientation of the ex-

Tab. 2. Paleodirections from the analysed samples of limestones from localities Babiná, Mestečská skala, Vršatec and Bolešovská dolina. D, I – declination and inclination before bedding correction; k, α_{95} – parameters of the Fisher statistics before bedding correction; D_{cor}, I_{cor} – declination and inclination after bedding correction; k_{cor}, α_{95cor} – parameters of the Fisher statistics after bedding correction; J – remanent magnetic polarization; κ – bulk magnetic susceptibility.

Locality	Number of samples	D°	I°	k	α_{95}	D°$_{cor.}$	I°$_{cor.}$	$k_{cor.}$	$\alpha_{95cor.}$	J[nT]	$\kappa.10^{-6}$u.SI
Babiná	20	102	-28	4.08	18.52	359	-30	4.08	18.52	0.135±0.174	-5.890±15.963
Mestečská skala	20	49	39	5.56	15.25	291	-20	5.56	15.25	0.115±0.068	-1.225±7.100
Vršatec	8	54	13	30.51	10.19	29	-34	30.51	10.19	3.700±6.520	-18.063±7.360
Bolešovská dolina	2	21	34	49.47	36.29	35	46	49.47	36.29	0.076±0.012	-11.550±2.616

tension in the sedimentary area. After comparison, both types of diagrams from Babiná, and Vršatec were in good accordance; in the second type of diagram from Mestečská skala, the somewhat minor of the two dominant directions was preferred by thickness counting. At the Bolešovská dolina locality, older data set has been used, without complete thickness counting of the dykes, hence the thicknesses could not be taken into account. The final goal was to turn the diagrams to the original N–S directions estimated on the basis of the paleomag data.

4. Results and discussion

The final orientation of maxima of the measured neptunian dykes obtained after bedding and paleomagnetic correction (Fig. 10) trends from N–S (Bolešovská dolina), through NE–SW (Mestečská skala and Vršatec) to ENE–WSW (Babiná). The mean orientation is then NE–SW. There are also some minor maxima that are perpendicular or oblique to the main ones. They can be interpreted as tension-cross gashes, along the side walls of the tilting blocks. Their opening was mostly parallel to oblique to the direction of the fracture, hence they did not reach the thickness of the dykes with perpendicular opening (direction mostly parallel with the mean extension). However, looking at the summarizing diagrams (Figs 11, 12), one of the maxima represents the dykes that are subparallel to the beddings (better

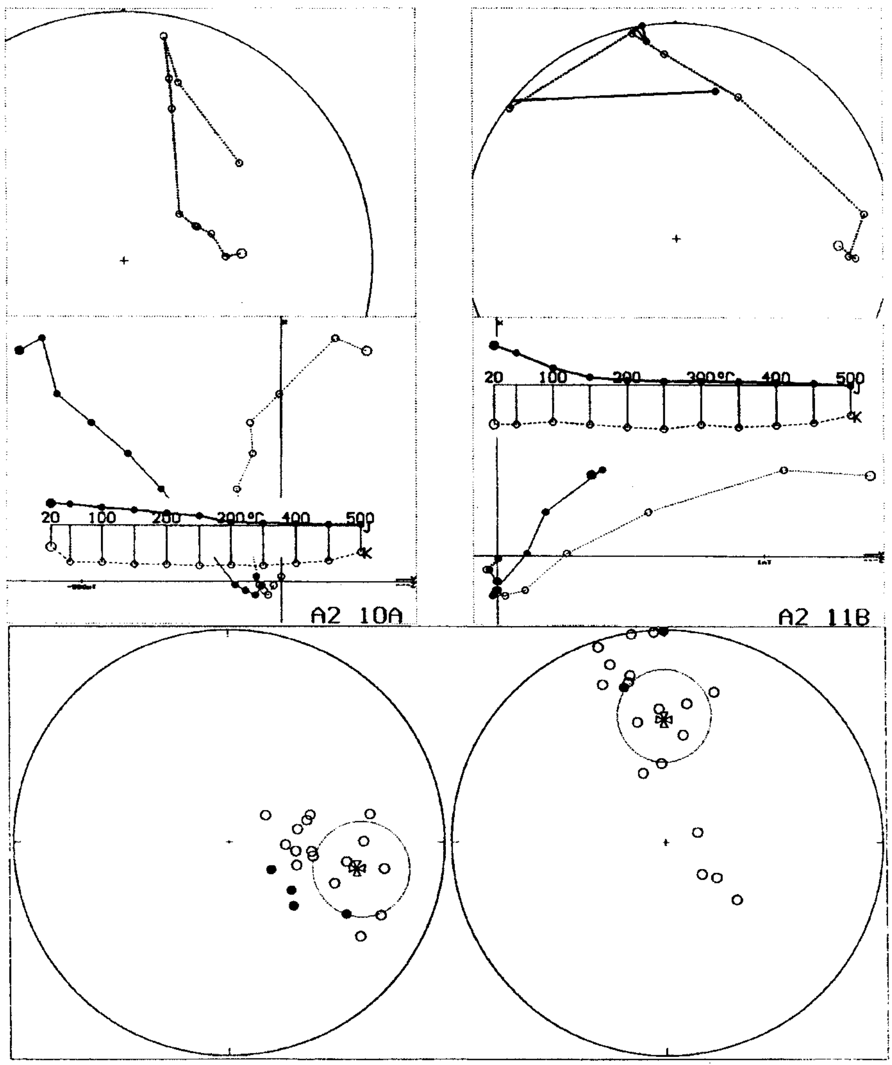

Fig. 6. Thermal demagnetization diagrams (dashed line for magnetic polarization, dotted line for magnetic susceptibility), Zijderveld diagrams of XY and XZ components of remanent magnetic polarization and stereoprojections of paleodirections during demagnetization of the samples A2 10A and A2 11B from Babiná locality. Bottom: Main paleodirections of the samples, left before tilt correction, right after tilt correction, Σ – main direction (see Tab. 2).

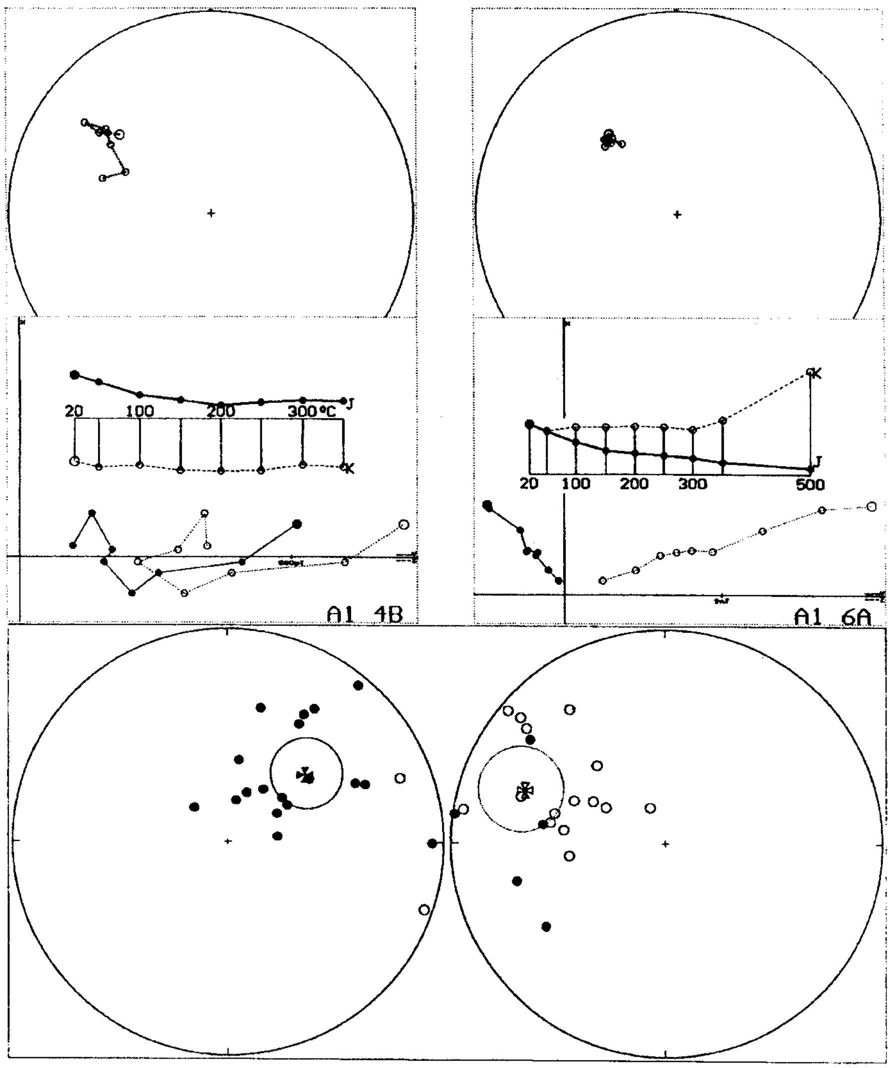

Fig. 7. Thermal demagnetization diagrams of the samples A1 4B and A1 6A from Mestečská skala locality (explanations see Fig. 6).

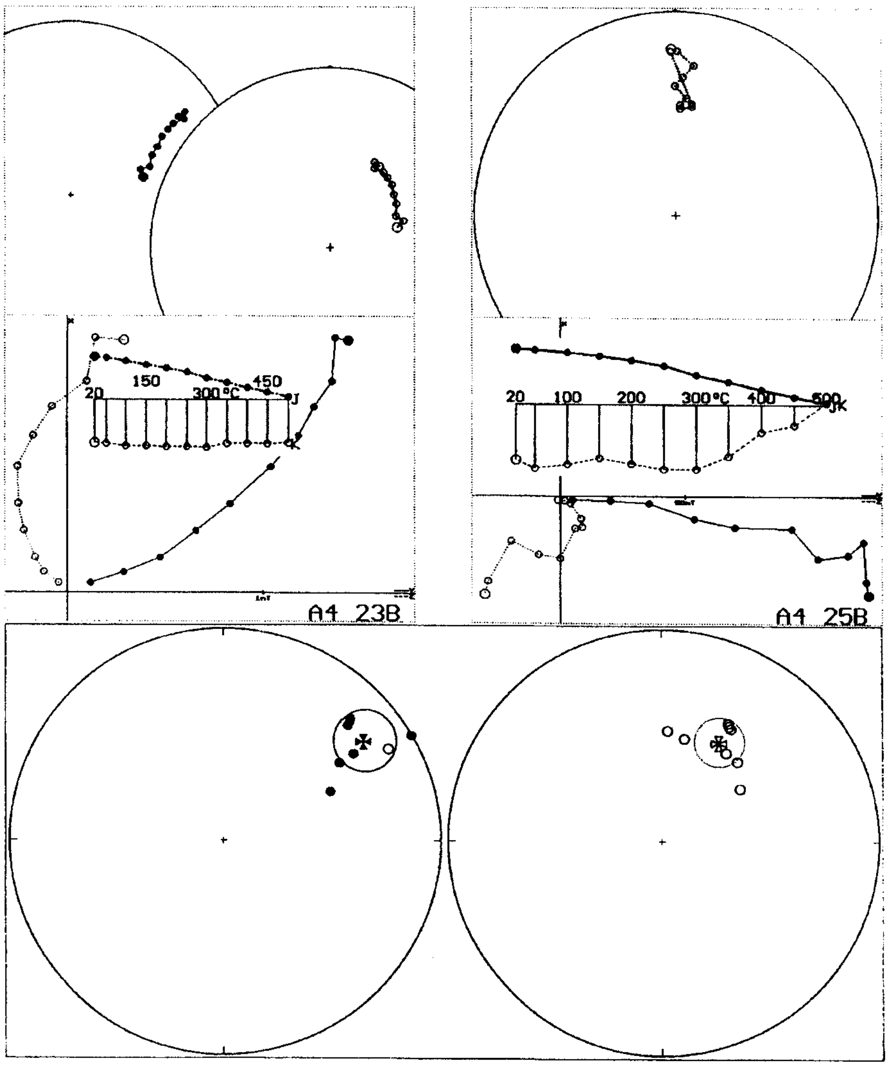

Fig. 8. Thermal demagnetization diagrams of the samples A4 23B and A4 25B from Vršatec locality (explanations see Fig. 6).

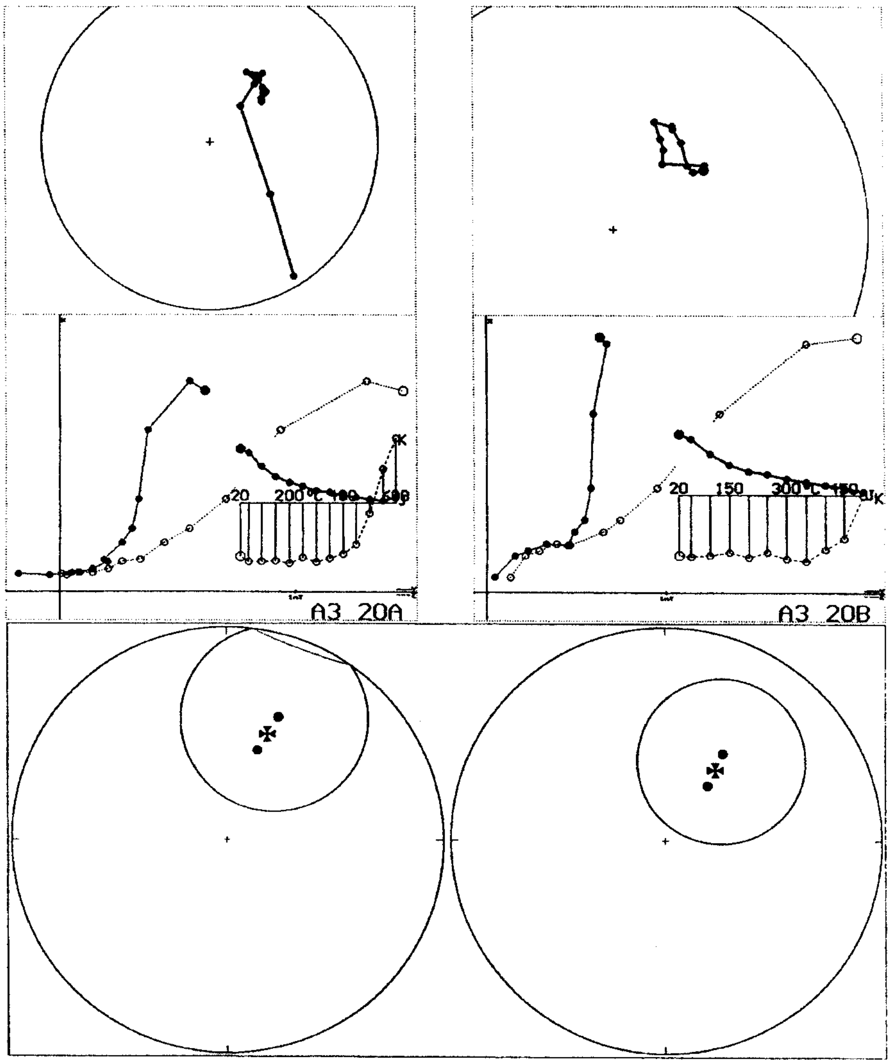

Fig. 9. Thermal demagnetization diagrams of the samples A3 20A and A3 20B from Bolešovská dolina locality (explanations see Fig. 6).

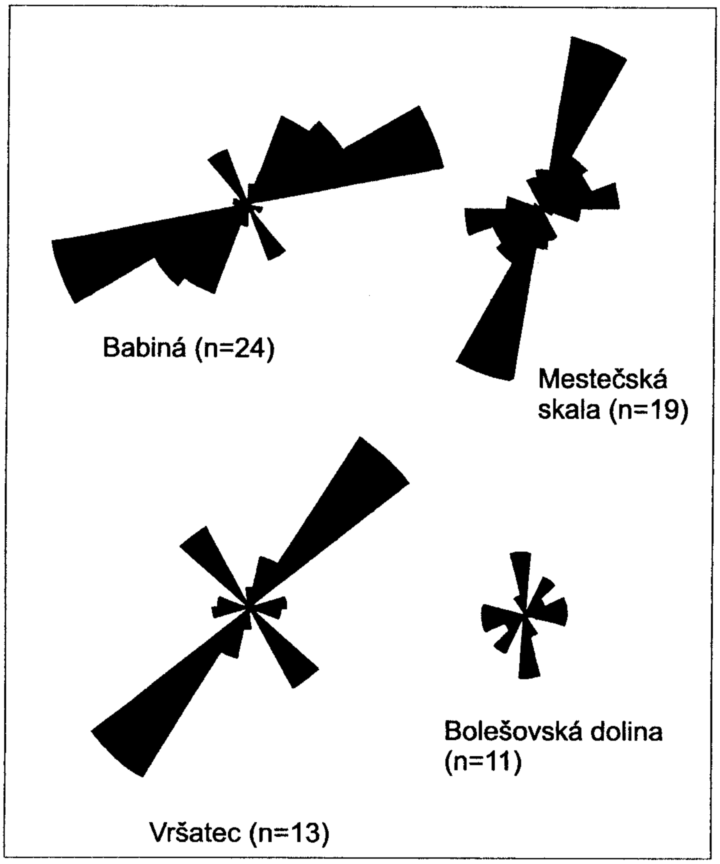

Fig. 10. Rose diagrams of directions of Callovian/Oxfordian neptunian dykes in Czorsztyn Unit, rotated to their original positions. At all localities, except Bolešovská dolina, the thicknesses of neptunian dykes were also taken into account (instead of a simple sum, the lengths of the rosette branches are given by sum of thickness values of the dykes).

named sills). Their analysis showed that in fact most of them are responsible for the perpendicular or oblique directions in the rose diagrams. Such sills represent the basal plains, along which the tiling blocks were slipping. At flat lying plains, the plain directions play subordinate role. The real tension-cross gashes are then relatively rare.

The data presented in this paper are still preliminary, but no considerable changes after their complementation are expected. The examined klippen

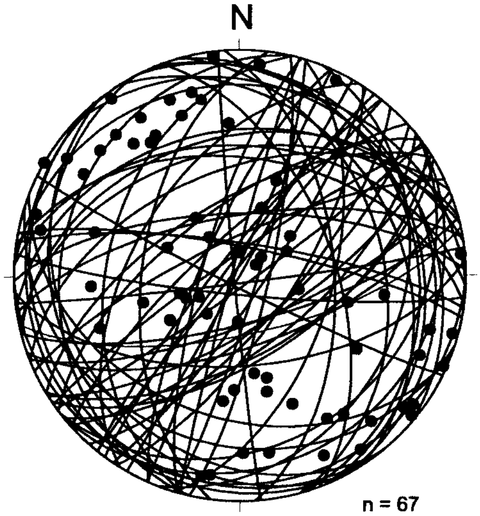

Fig. 11. Summarizing stereoprojection of plains and poles of the neptunian dykes from all of the examined localities in their original position after the paleomagnetic correction.

Fig. 12. Summarizing contour diagram of poles of the neptunian dykes of all the examined localities in their original position after the paleomagnetic correction.

are those with the densest networks of the neptunian dykes all along the Pieniny Klippen Belt. Other klippen contain just few dykes and their individual treating is senseless, if not grouped altogether in one diagram, rotated according to their paleomagnetic poles. Therefore, already in this stage of research, some conclusions may be presented. The NE–SW mean Middle to Late Jurassic orientation of the neptunian dykes can be approximated to the mean orientation of the extension in the Czorsztyn sedimentary area. It was most probably of NW–SE direction. This is consistent with the reconstruction of rifting of Neotethys (Penninic) ocean and with development of the Western Carpathians, as presented for instance by *Dercourt et al. (1990)*, *Michalík (1994*, Fig. 3*)*, *Rakús et al. (1988*, Fig. 5*)*, *Rakús (1993)* or *Stampfli et al. (1998)*. In this sense, the Pieninic units underwent the NW–SE extension, i.e. of the same direction as did the Central Western Carpathians. According to these interpretations the Czorsztyn Swell was oriented in NE–SW direction. This, however, strongly contradicts some reconstructions, where the Jurassic orientation of the zones in the Pienidic area was NW–SE (e.g. *Vašíček et al., 1994*, Fig. 3), which corresponds to NE–SW oriented extension. *Plašienka (1999*, Fig. 4.4.*)* introduced a reconstruction of more or less correctly (from the point of view of our new data) interpreted NW–SE extension, which resulted, however, in E–W to ESE–WNW oriented Oravic Zone (Oravic ≈ Pienidic). The same is true for *Channell* and *Kozur (1997)*, (Fig. 2) and *Golonka et al. (2000*, Fig. 5*)*, who presented NW–SE or WNW–ESE trending Czorsztyn Ridge that originated via generally the same oriented extension of Penninic Ocean. According to our opinion, the NW–SE extension can hardly produce an E–W, or even NW–SE trending zone (if not fan-like opening or a microplate twisting) and, therefore the Pienidic units had to be NE–SW oriented in the Middle Jurassic time.

The inclinations of the Middle to Late Jurassic magnetic pole vector resulting from our study were as follows: Babiná = 30°, Mestečská skala = 21°, Vršatec = 34° and Bolešovská dolina = 46°. The mean value was then about 33°, which corresponds to 10–30° paleolatitude at the time of origin (the dispersion of the data was taken into consideration too). This means that the Czorsztyn sedimentary area was located much more southward during the Middle/Late Jurassic than is the recent geographic position. There are still few data from the Jurassic of the Pieniny Klippen Belt with which our results can be compared. *Krs et al. (1996)* and *Houša et al. (1999)* introduced some results from the Late Tithonian of Brodno locality (Kysuca Unit – deeper part of the Pienidic Zone). Their inclination after tilt correction was 38°, which is consistent with our data.

5. Conclusions

1. Orientations of Bathonian to Oxfordian neptunian dykes were measured at four localities of the Czorsztyn Unit.
2. The dyke directions and thicknesses were evaluated and turned to their original position estimated on the basis of paleomagnetic data.
3. The mean estimated dyke orientation was NE–SW, which indicates NW–SE oriented mean extension in the Czorsztyn sedimentary area during Middle to Late Jurassic.
4. The mean paleomagnetic inclination (cca 33°) indicates 10–30° paleolatitudes, where the Czorsztyn sedimentary area might be located at that time.

Acknowledgments. The authors are indebted to Mgr. J. Schlögl for assistance at field sampling and measuring. This paper is a contribution to the project "Tectogenesis of the West Carpathian Sedimentary Basins" of Ministry of Environment of the Slovak Republic, managed by the Geological Survey of Slovak Republic. Additional financial support to R. A. was provided by grants No. 1/6169/99 and 2/7091/20 of VEGA agency.

References

Aubrecht R., 1992: Mestečská skala klippe and its importance for stratigraphy of Czorsztyn Unit (Biele Karpaty Mts., Western Slovakia). Acta geol. et geogr. Univ. Com., Geologica, **48**, 1, 55–64.

Aubrecht R., Mišík M., Sýkora M., 1997: Jurassic synrift sedimentation on the Czorsztyn Swell of the Pieniny Klippen Belt in Western Slovakia. ALEWECA symp. – Sept. 1997, Introduct. articles to the excursion, Bratislava, 53–64.

Aubrecht R., Mišík M., Sýkora M., Šamajová E., 1998: Controversal klippe of the Czorsztyn Unit in the Bolešovská dolina valley, between Nemšová and Pruské in the Váh river valley. Miner. Slov., **30**, 6, 431–442 (in Slovak with English summary).

Birkenmajer K., 1958: Submarine Erosional Breaks and Late Jurassic Synorogenic Movements in the Pieniny Klippen-belt Geosyncline. Bull. Acad. Pol. Sci., **6**, 8, 551–558.

Bouillin J.-P., Bellomo D., 1990: Les filons sédimentaires jurassiques de Longobucco-Caloveto (Calabre, Italie); application, l'étude des paléostructures d'une marge téthysienne. Geodin. Acta, **4**, 2, 111–120.

Channell J. E. T., Kozur H. W., 1997: How many oceans? Meliata, Vardar, and Pindos oceans in Mesozoic Alpine paleogeography. Geology, **25**, 2, 183–186.

Dercourt J., Ricou L. E., Adamia S., Csaszar G., Funk H., Lefeld J., Rakús M., Sandulescu M., Tollman A., Tchoumachenko P., 1990: Northern margin of Tetthys. Paleogeographical maps 1:10 000 000. Publ. GÚDŠ, Bratislava.

Di Stefano P., Mindszenty A., 2000: Fe-Mn-encrusted "Kamenitza" and associated features in the Jurassic of Monte Kumeta (Sicily): subaerial and/or submarine dissolution? Sedim. Geol., **132**, 37–68.

Fabricius F., 1962: Faziesentwicklung and der Trias/Jura-Wende in den mittleren Nördlichen Kalkalpen. Z. Deutsch. geol. Ges., **113**, 2-3, 311–319.

Fülöp J., 1976: The Mesozoic basement horst blocks of Tata. Geol. Hung., ser. geol., **16**, 1–229.

Golonka J., Oszczypko N., Ślączka A., 2000: Late Carboniferous-Neogene geodynamic evolution and paleogeography of the circum-Carpathian region and adjacent areas. Ann. Soc. Geol. Pol., **70**, 2, 107–136.

Halajová L., 1981: Terrigenous admixture in Jurassic limestones of the Pieniny Klippen Belt and structure of Babiná Klippe near Krivoklát-Bohunice. Unpublished MSc. Thesis, Manuscript, Dept. of Geol. and Paleont., Comenius Univ., Bratislava, 1–73 (in Slovak).

Houša V., Krs M., Krsová M., Man O., Pruner P., Venhodová D., 1999: High-resolution magnetostratigraphy and micropaleontology across the J/K boundary strata at Brodno near Žilina, western Slovakia: summary of results. Cretaceous Res., **20**, 699–717.

Jurkovičová H., 1980: Stratigraphy, lithology and Jurassic microfacies of the Pieniny Klippen Belt in the area of Krivoklát. Unpublished MSc. Thesis, manuscript, Dept. of Geol. and Paleont., Comenius Univ., Bratislava, 1–78 (in Slovak).

Krs M., Krsová M., Pruner P., 1996: Palaeomagnetism and palaeogeography of the Western Carpathians from the Permian to the Neogene. In: Morris A. and Tarling D. H. (eds.): Palaeomagnetism and tectonics of the Mediterranean region, Geol. Soc. London, Spec. Publ., **105**, 175–184.

Michalík J., 1994: Notes on the Paleogeography and Paleotectonics of the Western Catrpathian area during the Mesozoic. Mitt. Österr. Geol. Ges., **86**, (1993), 101–110.

Michalík J., Reháková D., Soták J., 1993: Environments and setting of the Jurassic-Lower Cretaceous succession in the Tatric area, Malé Karpaty Mts. Geol. Carpath., **45**, 1, 45–56.

Mišík M., 1964: Mikrofazielles Studium des Lias der Grossen Fatra und des Westteils der Niederen Tatra. Sbor. geol. vied, Záp. Karpaty, **1**, 7–92.

Mišík M., 1979: Sedimentological and microfacial study of the Jurassic of Vršatec Castle Klippe (neptunian dykes, bioherm development of Oxfordian). Záp. Karpaty, Sér. geol., **5**, 7–56 (in Slovak with English summary).

Mišík M., 1993: Evolution of Czorsztyn submarine elevation (Pieniny Klippen Belt) during Middle Jurassic to Early Cretaceous. In: Rakús M. and Vozár J. (eds.): Geodynamic model and Deep Structure of the Western Carpathians. Publ. GÚDŠ (Bratislava), 87–93 (in Slovak).

Mišík M., 1994: The Czorsztyn submarine ridge (Jurassic-Lower Cretaceous, Pieniny Klippen Belt): an example of a pelagic swell. Mitt. Österr. Geol. Ges., **86**, 133–140.

Mišík M., 1997: Stratigraphic and spatial distribution of limestones with calcitic, chamositic, haematitic and illitic ooids in the Western Carpathians. Miner. Slov., **29**, 83–112 (in Slovak, with English summary).

Mišík M., Siblík M., Sýkora M., Aubrecht R., 1994a: Jurassic brachiopods and sedimentological study of the Babiná klippe near Bohunice (Czorsztyn Unit, Pieniny Klippen belt). Miner. Slov., **26**, 4, 255–266.

Mišík M., Sýkora M., 1993: Jurassic submarine scarp breccia and neptunian dykes from the Kyjov-Pusté Pole klippen (Czorsztyn Unit). Miner. Slov., **25**, 6, 411–427.

Mišík M., Sýkora M., Aubrecht R., 1994b: Middle Jurassic scarp breccias with clefts filled by Oxfordian and Valanginian-Hauterivian sediments, Krasín near Dolná Súča (Pieniny Klippen Belt). Geol. Carpath., **45**, 6, 343–356.

Molina J. M., Ruiz-Ortiz P. A., Vera J. A., 1995: Neptunian dykes and associated features in southern Spain: mechanics of formation and tectonic implications. Discussion. Sedimentology, **42**, 957–963.

Myczinski R., Wierzbowski A., 1994: The Ammonite Succession in the Callovian, Oxfordian and Kimmeridgian of the Czorsztyn Limestone Formation, at Halka Klippe, Pieniny Klippen Belt, Carpathians. Bull of the Pol. Acad. Sci., Earth. Sci., **42**, 3, 156–163.

Plašienka D., 1999: Tectonochronology and paleotectonic model of the Jurassic-Cretaceous evolution of the Central Western Carpathians. Publ. VEDA, Bratislava, 1–125 (in Slovak, with English summary).

Radwanski A., 1959: Littoral structure (cliff clastic dykes and borings of Potamilla) in the High Tatric Lias. Acta Geol. Pol., **9**, 231–280.

Rakús M., 1993: Pitfalls and problems of paleogeographic reconstructions of the West Carpathian Mesozoic. In: Rakús M. and Vozár J., (eds.): Gaodynamic model and deep structure of the Western Carpathians. Publ. GÚDŠ, Bratislava, 103–107 (in Slovak).

Rakús M., Mišík M., Michalík J., Mock R., Ďurkovič T., Koráb T., Marschalko R., Mello J., Polák M., Jablonský J., 1988: Paleogeographic development of the Western Carpathians from the Anisian to the Oligocene. In: Rakús M., Dercourt J. and Nairn A. E. M. (Eds): Evolution of the northern margin of Tethys – 3. Mém. Soc. géol. France, **154**, 1–26.

Rakús M., Sýkora T., 2001: personal communication

Schöll W. V., Wendt J., 1971: Obertriadische und jurassische Spaltenfüllungen in Steineren Meer (Nördliche Kalkalpen). Neues Jb. Geol. Paläont. Abh., **139**, 1, 82–98.

Smart P. L., Palmer R. J., Whitaker F., Wright V. P., 1988: Neptunean dykes and fissure fills: an overview and account of some modern examples. In: James N. P. and Choquette P. W. (Eds): Paleokarst, Springer Verlag, Berlin, 149–162.

Soták J., Plašienka D., 1996: Upper Triassic – Lower Jurassic sediments of the Lučatín Unit in the Northern Veporicum: facial diversity and tectonic stacking. Slov. Geol. Mag., **3-4/96**, 273–277.

Stampfli G. M., Mosar J., Marquer D., Marchant R., Baudin T., Borel G., 1998: Subduction and obduction processes in the Swiss Alps. Tectonophysics, **296**, 159–204.

Vašíček Z., Michalík J., Reháková D., 1994: Early Cretaceous stratigraphy, palaeogeography and life in the Western Carpathians. Beringeria, **10**, 3–169.

Vera J. A., Ruiz-Ortiz P. A., García-Hernández M., Molina J. M., 1988: Paleokarst and related sediments in the Jurassic of the Subbetic Zone, Southern Spain. In: James N. P. and Choquette P. W. (eds.): Paleokarst, Springer Verlag, Berlin, 364–384.

Wendt J., 1965: Synsedimentäre Bruchtektonik im Jura Westsiziliens. Neues Jb. Geol. Paläont., Monatshefte, **5**, 286–311.

Wendt J., 1971: Genese und Fauna submariner sedimentärer Spaltenfüllungen im mediterranen Jura. Palaeontographica (Stuttgart), abt. A., **136**, 122–192.

Wieczorek J., Dumont T., Bouillin J. P., Olszewska B., 1994: Dajki neptuniczne w Rezerwacie Przyrody Bonarka w Krakowie – swiadectvo póznokredowych ruchów tektonicznych na Wyzynie Krakowsiej. Przegl. Geol., **42**, 12, 988–995.

Wierzbowski A., Jaworska M., Krobicki M., 1999: Jurassic (Upper Bajocian-lowest Oxfordian) ammonitico rosso facies in the Pieniny Klippen Belt, Carpathians, Poland: its fauna, age, microfacies and sedimentary environment. Stud. Geol. Pol., **115**, 7–74.

Winterer E. L., Metzler C. V., Sarti M., 1991: Neptunian dykes and associated breccias (Southern Alps, Italy and Switzerland): role of gravity sliding in open and closed systems. Sedimentology, **38**, 381–404.

Winterer E. L., Sarti M., 1994: Neptunian dykes and associated features in southern Spain: mechanics of formation and tectonic implications. Sedimentology, **41**, 1109–1132.

Winterer E. L., Sarti M., 1995: Neptunian dykes and associated features in southern Spain: mechanics of formation and tectonic implications. Reply. Sedimentology, **42**, 963–967.