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SHALLOW-CRUSTAL POST-TECTONIC EMPLACEMENT OF VEZHEN PLUTON, CENTRAL STARA PLANINA MOUNTAINS

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Abstract

Intrusive relationships of Vezhen pluton with its host greenschist metamorphic Diabase-Phyllitoid Complex evidence post-tectonic (post-metamorphic) granitoid emplacement at 314 ± 4.8 Ma. The lack of a second foliation set within the contact aureole rocks, as well as the fact that the pluton is almost isotropic, suggest passive emplacement without significant oriented stress. On the contrary, the particular emplacement mechanisms (dyking, dilatation, lateral displacement of host) point to easy resolving of the "space problem" for granodiorite magma accommodation. All structures within intrusive and host rocks indicate that the final emplacement and crystallization of Vezhen pluton took place within or above the brittle-ductile transition at approximately 8–10 km.

Key words: post-tectonic, emplacement mechanisms, shallow crust, Vezhen pluton

Introduction. The structures imprinted along the intrusive contacts of granitoid bodies as well as within their contact aureoles are important tools to obtain information about the mode and level of emplacement within the crust. These structures are frequently used criteria to divide intrusives into three major categories – pre-, syn- and post-tectonic ([1–3] and references therein) and to recognize different magma emplacement mechanisms. Generally, due to the rheological stratification of the crust (ductile, brittle-ductile and brittle; see [4,5] and references therein) the emplacement mechanisms are diverse at upper, middle and lower crustal levels [3,6].

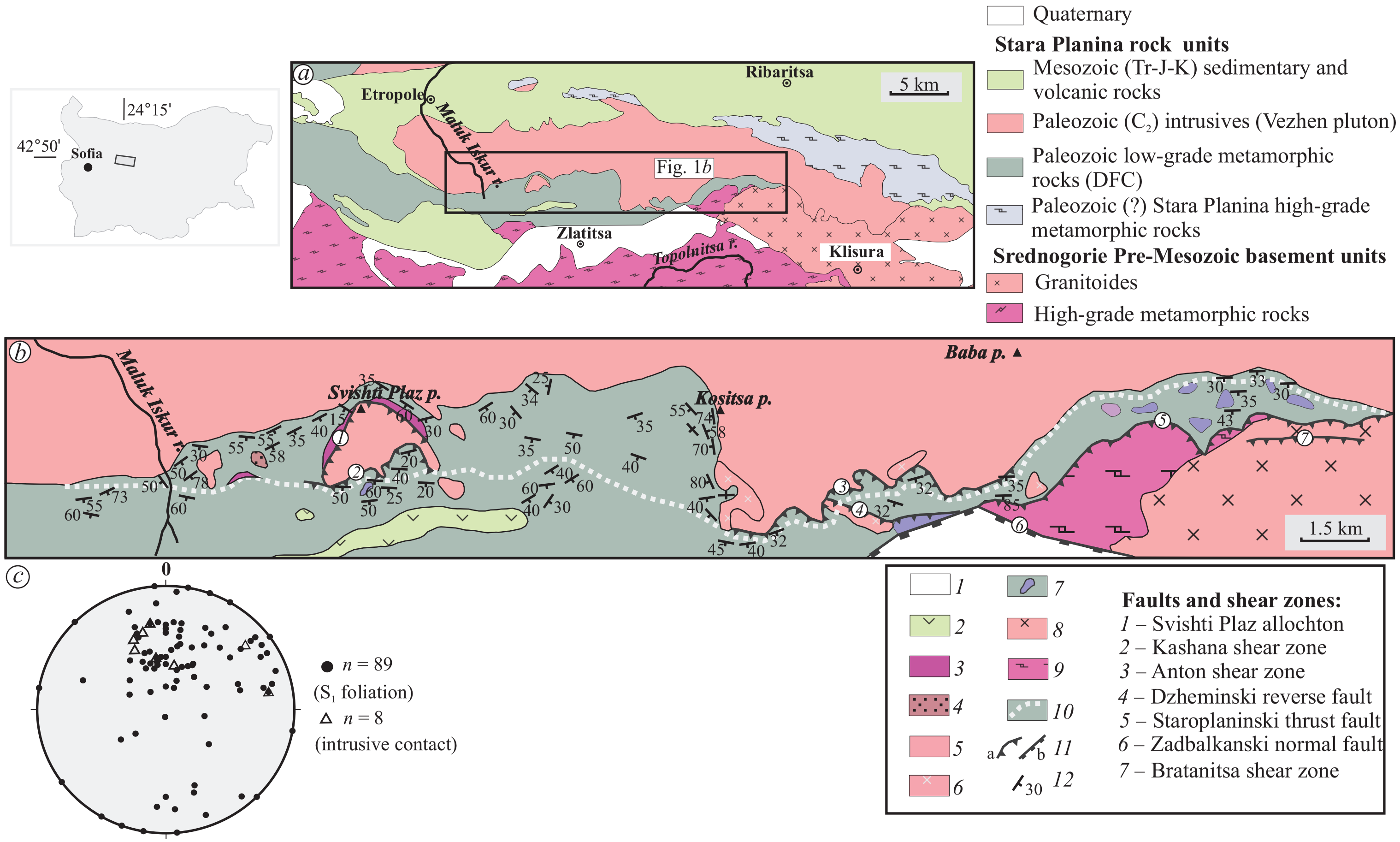
The present study is focused on the contact relationships of Vezhen pluton (part of the Variscan Stara Planina Calc-alkaline Formation) with their host Diabase-Phyllitoid Complex (DFC). Until now this aspect has been poorly considered [7–10] but, it is extremely important to define the time of the pluton emplacement with respect to metamorphic structures of the host rocks, to distinguish different emplacement mechanisms as well as the final level of magma accommodation and crystallization.

Geological setting. Vezhen pluton (VP) is a Late Carboniferous (314 ± 4.8 Ma [8]) E-W elongated intrusive massif, cropping out in Zlatitsa–Teteven part of Central Stara Planina Mountains (Fig. 1*a*). The present-day exposures allowed only part of the intrusive contact to be studied due to the Mesozoic cover to southwest, west and northwest and the tectonically superimposed relationships with metamorphic and intrusive rocks to the east and northeast (Fig. 1*a*). The pluton consists mainly of granodiorites, but dykes of granodiorite porphyrites, minor diorite or gabbro-diorite porphyrites are widespread as well [8, 11, 12, 16]. The estimated P-T conditions of crystallization are in the range of 739–770 °C and 4–5 kbar [8].

VP intruded very low-grade metamorphic rocks [13] regarded as a part of DFC [10, 11, 14]. In the studied area the complex consists of metaaleurolites and minor metapelites (phyllites), metasandstones (quartzites) as well as different in size bodies of matadiabases, metagabbros, metadiorites, etc. The mineral association of quartz, sericite, chlorite, epidote and clay minerals [11] indicates conditions close to the greenschist facies metamorphism (250–300 °C), but more precise studies are necessary to obtain accurate values. The host rocks along the intrusive contacts are transformed into hornfelses, porphyroblastic biotite-andalusite-cordierite-garnet and spotted schists, amphibolites as well as weakly recrystallized phyllites in the 50–250 m wide contact aureole [10, 13, 15, 16].

Intrusive relationships. The intrusive contact of VP with the host DFC extends about 35 km along the crest and southern slopes of Zlatitsa–Teteven part of the Stara Planina Mountains (Fig. 1*b*), thus offering a good opportunity to study their relationships.

Fig. 1. *a*) Location map of the studied area (based on Geological Map of Bulgaria 1:100 000, Map sheets Botevgrad and Teteven); *b*) Structural map of the contact relationships of Vezhen pluton and host Diabase-Phyllitoid Complex; *1* – Quaternary sediments; *2* – Upper Cretaceous volcanic and subvolcanic rocks; *3* – Lower Triassic sediments; *4* – Upper Carboniferous-Permian sediments; Upper Carboniferous Vezhen pluton: *5* – Granodiorites; *6* – Diorites; *7* – Low-grade metasediments and metavolcanics (DFC; Pz_1); Pre-Mesozoic basement rocks of the Sredna Gora Zone: *8* – Granites (Anton granite); *9* – High-grade metamorphic rocks; *10* – Outlines of the contact aureole; *11* – Faults and shear zones: a) reverse; b) normal; *12* – foliation; *c*) Equal area stereographic projection of poles of S_1 foliation planes (in and outside the contact aureole) as well as the orientations of the intrusive contact →



24°15'
42°50'
Sofia
Etropole
Ribaritsa
5 km
Maluk Iskur r.
Fig. 1b
Zlatitsa
Topolnitsa r.
Klisura
Quaternary
Stara Planina rock units
Mesozoic (Tr-J-K) sedimentary and volcanic rocks
Paleozoic (C_2) intrusives (Vezhen pluton)
Paleozoic low-grade metamorphic rocks (DFC)
Paleozoic (?) Stara Planina high-grade metamorphic rocks
Srednogorie Pre-Mesozoic basement units
Granitoides
High-grade metamorphic rocks
Baba p.
Svishti Plaz p.
Kositsa p.
1.5 km
0
● n = 89
(S_1 foliation)
Δ n = 8
(intrusive contact)
1
2
3
4
5
6
7
8
9
10
11
12
Faults and shear zones:
1 – Svishti Plaz allochton
2 – Kashana shear zone
3 – Anton shear zone
4 – Dzheminski reverse fault
5 – Staroplaninski thrust fault
6 – Zadbalkanski normal fault
7 – Bratanitsa shear zone

Fig. 1

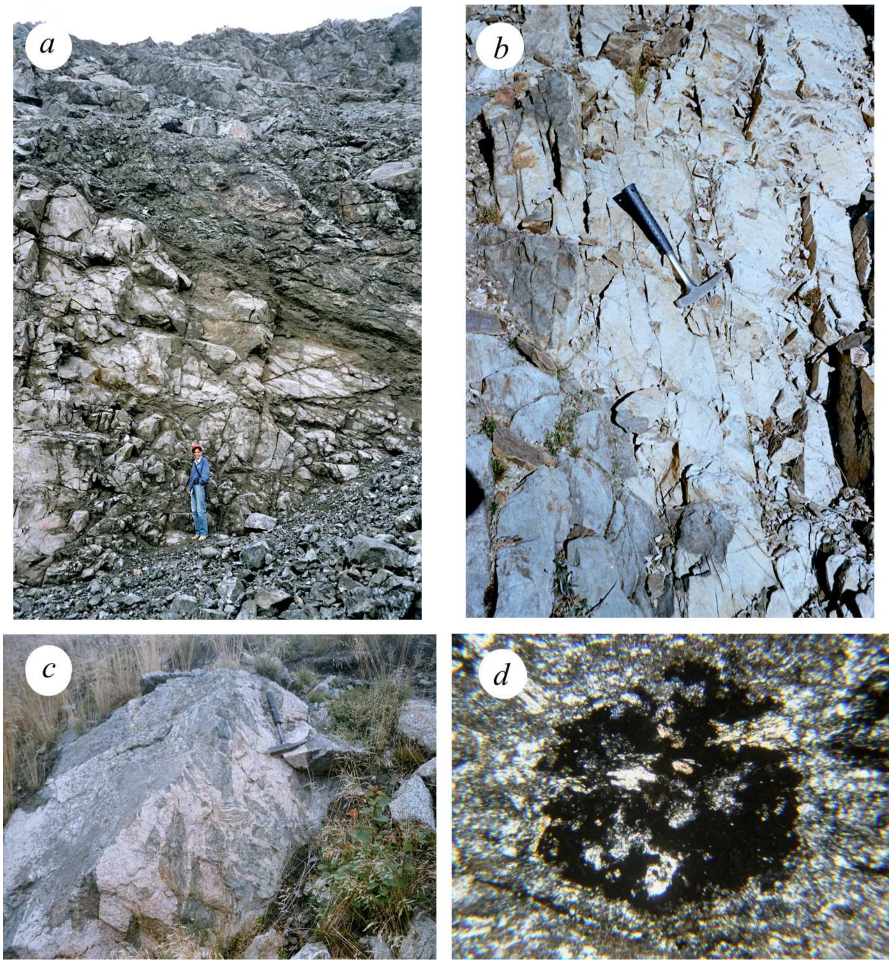


Fig. 2

Vezhen pluton. VP consists mainly of equigranular granodiorites passing locally into granites. Nevertheless, there are some facial differences between the western and eastern part of the pluton. In the western and central domains, structurally isotropic granodiorites with plagioclase, hornblende and quartz phenocrysts are widespread, passing gradually into equigranular varieties enriched in biotite. The granodiorites host numerous steeply dipping (80–90°) felsic dykes with steady NW-SE to NNW-SSE or N-S orientations (for details see [12]). On the other hand, typical of the eastern part of the pluton are almost equigranular biotite-hornblende granodiorites, locally with magmatic foliation, defined by the arrangement of biotite, hornblende, feldspar and rarely by mafic microgranular enclaves. In general, neither magmatic foliations nor lineation are characteristic for the pluton as a whole. Dykes are rare. These specific features of both parts of the pluton reflect some differences in the structural level of final crystallization of the granodioritic melt, the western one representing shallower levels of the magma chamber.

Host rock structure. Outside the contact aureole, the greenschist metamorphic foliation (S_1) of DFC has relatively steady E-W (90–110°) orientation with local deviations to NE-SW (70–75°) or NW-SE (115–130°) (Fig. 1*b*, *c*). It is gently dipping (25–45°) to the south, but locally the dips are steeper (55–75°). This metamorphic foliation has been interpreted from regional point of view as a result of thrusting of the Central Srednogorie High-Grade Metamorphic Complex over DFC along the Stargel-Boluvanya syn-metamorphic tectonic zone [17].

Pluton – host rocks relationships. The intrusive contact of VP is sharp (Fig. 2*a*) but concordant to the single foliation set (S_1) of the wall rocks (Fig. 1*c*) within the contact aureole. Generally, the contact is E-W (90–110°) oriented and gently dipping (25–45°) to the south. Deviations from this strike are not typical (Fig. 1*b*, *c*), but immediately to the west of Kositsa peak the contact of the pluton as well as the host rock foliation abruptly change their orientation. They both strike between 140–170° to 10–20° and are steeply dipping (55–80°) to the southwest or are even vertical.

Typical feature of the pluton interior is the presence of centimetre- up to metre-scale xenoliths (Fig. 2*b*, *c*) with angular shapes and irregular orientation, which are hosted just next to the intrusive contact. In the western part of the contact aureole, widespread are pluton-derived dykes (2–4 m rarely up to 10 m in

← Fig. 2. *a*) Sharp, shallow-dipping intrusive contact of Vezhen pluton concordant to the metamorphic foliation within the host DFC, "Elatsite"-pit; *b*) Granodiorite porphyrite dyke within the contact aureole. Note the stair-like morphology of the contact and small xenolith hosted within the dyke (down centre), 1.5 km SE from Svishti Plaz peak; *c*) Different in size, orientations and morphology xenoliths from DFC next to the contact of the pluton, 3.5 km W from Kositsa peak; *d*) Garnet porphyroblast within porphiroblastic schists from the contact aureole. The post-tectonic growth is indicated by the absence of strain shadows and other deformational structures, sample location is 1.8 km WSW from Svishti Plaz peak width) almost entirely represented by granodiorite porphyrites. Their orientations change from 160–170° to 10–20° or 100–130° and the dips are steep (80–90°). As a rule dykes induced intensive hydrothermal reworking of the host rocks. Their contacts are oblique or normal to the S_1-foliation and often with step-like morphology (Fig. 2*b*). Locally, reorientation and bending of foliation planes next to the dyke contacts reflect a forceful emplacement of the melt. Dykes are extremely rare in the eastern part of the contact aureole.

Additional information about the syn-emplacement processes supply garnet porphyroblasts within the schists just next to the intrusive contact. Idiomorphic garnet porphyroblasts overgrow S_1-foliation in schists without deflecting it (Fig. 2*d*). The absence of strain shadows around garnets as well as irregularly oriented inclusions within them indicate lack of rotation/deformation during porphyroblast growth.

Discussion and conclusions. The closely examined relationships between VP and the hosting DFC shed light on three general aspects: i) time relation between pluton emplacement and regional greenschist metamorphism of the host rocks; ii) particular emplacement mechanisms; and iii) emplacement depth of the pluton.

Pluton emplacement – low-grade metamorphism of DFC. Several characteristics of VP and its contact aureole are informative on the structural conditions of pluton emplacement with respect to the low-grade regional metamorphism of the host DFC. The presence of a single foliation set (S_1) both within and outside the contact aureole with generally constant orientation, as well as the lack of magmatic to high-temperature solid-state foliation next to the pluton contact, suggest passive magma emplacement without significant oriented stress. Heating induced by melt accommodation resulted only in compaction of host rock structures and their transformation into different contact metamorphic varieties (hornfelses, porphyroblastic schists, etc.) containing post-tectonic porphyroblasts. According to the well-known criteria to recognize pre-, syn- and post-tectonic granitoids [1–3], the above-mentioned features classify VP as a post-tectonic, passively emplaced intrusive.

The time sequence of these events suggests that the low-grade metamorphism of DFC took place prior to pluton emplacement at 314 ± 4.8 Ma. Quite logically seems the assumption that the regional metamorphism is connected with movements along Stargel-Boluvanya synmetamorphic tectonic zone [17] and thrusting of Central Srednogorie High-Grade Metamorphic Complex over DFC during Variscan orogeny [17,18]. The contact-metamorphic transformations just overprinted the earlier structure of the host.

Pluton emplacement mechanisms. Structures observed along the intrusive contacts of plutons reflect in general magma emplacement mechanisms operating during the final stages of crystallization history [2,3,6]. Considering VP – DFC contact relationships with regard to different emplacement mechanisms, most informative are structures imprinted in the western part of the pluton and the adjacent contact aureole. The abundance of dykes both within the contact aureole and the pluton [12] to the west of Kositsa peak suggest important role of dyking as a primary emplacement mechanism. Essentially, such a mechanism suggests easy resolving of the "space problem" [2,6] through dilation and lateral displacement of the host. Both mechanisms are responsible for fragmentation of host rocks during magma emplacement and the inclusion of xenoliths within the pluton periphery and in some dykes. Another space-making mechanism is bending of the hosts, which is evidenced by simultaneous reorientation both of the intrusive contact and the foliation to the west of Kositsa peak as well as local bending next to contacts of some dykes.

All emplacement-related structures of VP reflect quite rapid magma accommodation and crystallization processes. This inference, as well as the assumption of easy resolving of the "space problem", evidence that VP was emplaced into upper crustal levels close to or above the brittle-ductile transition [3,5,19,20]. Typical of these crustal depths are mechanism such as stopping, dilatation, roof uplift, lateral displacement of wall rocks, caldron subsidence as well as dyking.

Depth of emplacement of Vezhen pluton – indirect assessment. Indirect information about the depth of pluton emplacement within the crust could be obtained from different sources. These are particular emplacement mechanisms, width of the contact aureole, nature of the rocks outside the contact aureole, intensity of metasomatic processes, etc. [3,5,19–22].

Several characteristics point to the shallow-crustal emplacement of VP. On one hand, the host rocks of the pluton are very low-grade metamorphic rocks [10,11,13,14,16]. Their mineral association indicates metamorphic transformations in subgreenschist facies conditions (250–300 °C). On the other hand, the particular emplacement mechanisms as well as the intensive hydrothermal reworking within the contact aureole are typical features of plutons emplaced into the shallow crust, where wall rocks have initial temperatures lower than 300 °C [3]. Additional evidences to shallow level VP emplacement are: the isotropic structure of the pluton (rare magmatic foliation or lineation); the narrow contact aureole; wide occurrence of porphyry granodiorites.

Based on the presumed initial temperatures of host rocks in the range of 250–300 °C and an average geothermal gradient of 30 °C/km, it could be calculated that the approximate depths of final emplacement and crystallization of VP are 8–10 km. These values are close to or within the brittle-ductile transition of the crust. The obtained by Kamenov et al. [8] depth values in the range of 13–18 km reflect the ascent of magma, exemplifying different stages of the crystallization processes.

Concluding remarks and model of pluton emplacement history. The relationships between VP and the host DFC enable a simplified model of pluton emplacement to be deduced (Fig. 3), based on some granitoid emplacement con-

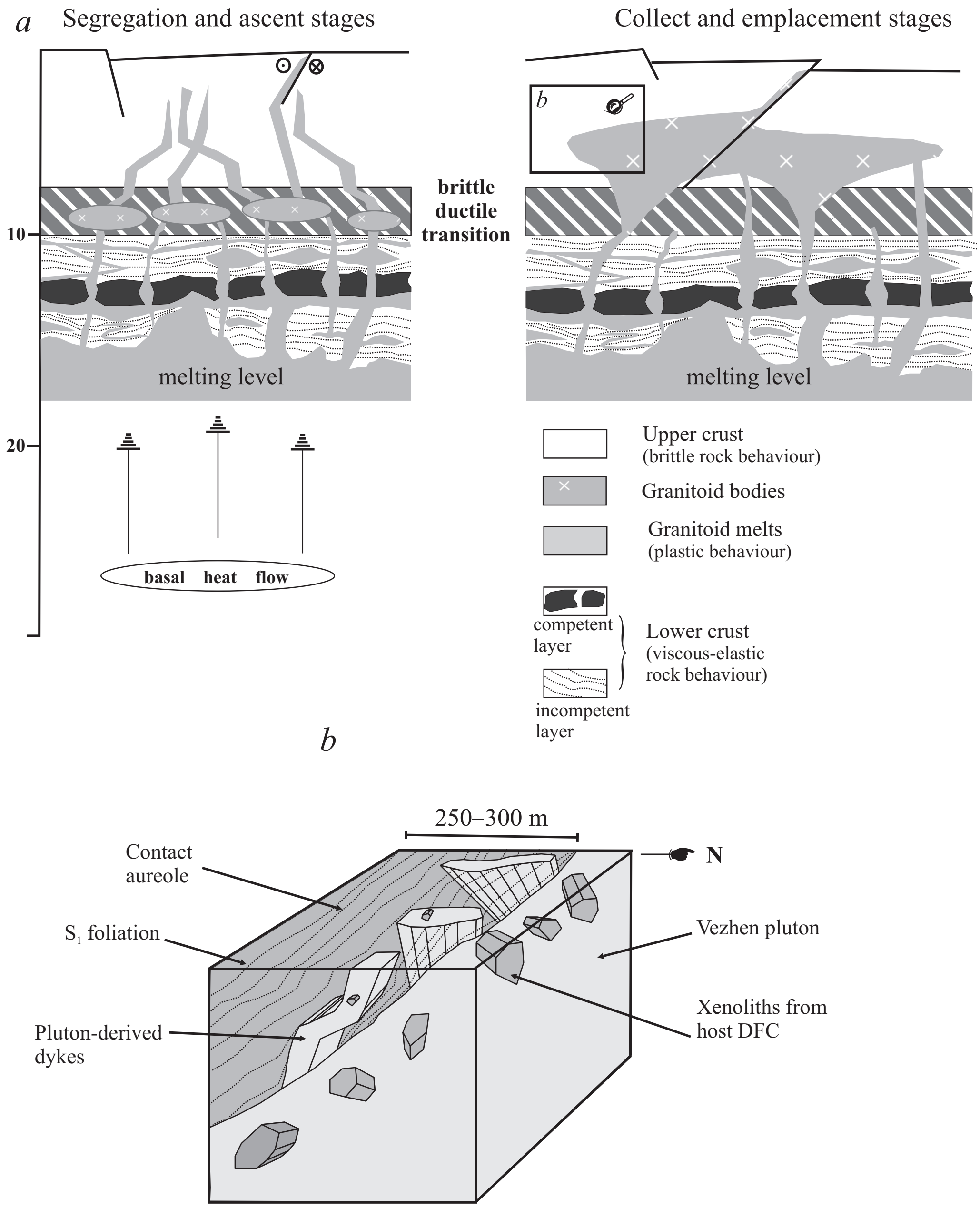


Fig. 3. *a*) Adapted model of Vigneresse [5] of granite segregation, ascent and emplacement within the upper crust with additional modifications based on the model of Vanderhaeghe [23] for the melt migration through the lower parts of the crust below the brittle-ductile transition at 8–10 km; *b*) Detail, reflecting Vezhen pluton – host Diabase-Phyllitoid Complex contact relationships

cepts [5,23]. Generally, VP is a post-tectonic intrusive emplaced at 314 ± 4.8 Ma within the already metamorphosed DFC. The lack of a second foliation set within the contact aureole rocks, as well as the fact that the pluton is almost isotropic, suggest passive magma emplacement without significant oriented stress. On the contrary, the particular emplacement mechanisms point to easy resolving of the "space problem" of magma accommodation. All structures within intrusive and host rocks indicate that final emplacement and crystallization of VP took place in or above the brittle-ductile transition at approximately 8–10 km.

REFERENCES

[1] Paterson S., O. Tobisch. Geology, **16**, 1988, No 12, 1108–1111.
[2] Hutton D. Trans. Roy. Soc. Edinburgh, **79**, 1988, 245–255.
[3] Paterson S., R. Vernon, T. Fowler. In: Contact metamorphism (ed. D. M. Kerrick), Mineral. Soc. Am., Rev. Mineral., **26**, 1991, 673–722.
[4] Handy M., A. Mulch, M. Rosenau, C. Rosenberg. In: The nature and tectonic significance of fault zone weakening (eds Holdsworth et al.) Geol. Soc. London, Spec. Publ., **186**, 2001, 305–332.
[5] Vigneresse J. L. Tectonophysics, **249**, 1995, No 3–4, 187–202.
[6] Petford N., A. Cruden, K. McCaffrey, J.-L. Vigneresse. Nature, **408**, 2000, No 6813, 669–673.
[7] Ivanov Z., K. Kolcheva, P. Cholakov, K. Kirov. Rev. Bul. Geol. Soc., **37**, 1976, No 3, 283–295.
[8] Kamenov B., A. von Quadt, I. Peytcheva. Geochem., Minarl., Petrol., **39**, 2002, 3–25.
[9] Lazarova A., I. Gerdjikov, N. Georgiev, D. Dimov. Compt. rend. Acad. bulg. Sci., **59**, 2006, No 6, 639–644.
[10] Gerdjikov I., N. Georgiev. Compt. rend. Acad. bulg. Sci., **59**, 2006, No 6, 631–638.
[11] Kujkin S., L. Milanov, I. Gercheva, S. Hristov. Jub. Ann., **18**, 1971, 179–196.
[12] Lazarova A., N. Georgiev, Z. Ivanov. Compt. rend. Acad. bulg. Sci., **58**, 2005, No 10, 1191–1196.
[13] Mandev P. Rev. Bul. Geol. Soc., **13**, 1941, No 1, 1–71.
[14] Antonov M., S. Pristavova, V. Jelev, K. Shipkova. Ann. Min. Geol. Uni., **46**, 2003, No 1, 1–6.
[15] Nikolaev G. Rev. Bul. Geol. Soc., **15-19**, 1947, 1–17.
[16] Lazarova A. PhD Thesis, 2007, 180 pp.
[17] Gerdjikov I., N. Georgiev, D. Dimov, A. Lazarova. Proc. Bul. Geol. Soc. (abstr. vol.), 2007, 24–26.
[18] Carrigan C., S. Mukasa, I. Haydoutov, K. Kolcheva. Precam. Res., **147**, 2006, No 3–4, 404–416.
[19] Yoshinobu A., T. Fowler, S. Paterson, E. Llambias, H. Tickyj, A. Sato. J. Str. Geol., **25**, 2003, No 7, 1037–1048.
[20] Dumond G., A. Yoshinobu, C. Barnes. GSA Bull., **117**, 2005, No 3–4, 383–395.

[21] Kerrick D. In: Contact metamorphism (ed. D. M. Kerrick), Mineral. Soc. Am., Rev. Mineral., **26**, 1991, 1–12.
[22] Saint-Blanquat M., G. Habert, E. Horsman, S. Morgan, B. Tikoff, P. Launeau, G. Gleizes. Tectonophysics, **428**, 2006, No 1–4, 1–31.
[23] Vanderhaeghe O. Tectonophysics, **312**, 1999, No 1, 35–55.

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