ACADEMIA ROMÂNĂ
SCOSAAR

TEZĂ DE ABILITARE

Semnificații geodinamice ale petrologiei, stratigrafiei, metalogeniei și geochimiei, cu exemple din orogenul carpatic şi din cratonul Yangtze

Domeniul fundamental: **Matematică şi ştiințe ale naturii**

Domeniul de abilitare: ***Geologie***

Autor: Marian Munteanu

Teză elaborată în vederea obținerii atestatului de abilitare în scopul conducerii lucrărilor de doctorat în domeniul *Geologie*

BUCUREŞTI, 2018

Abstract

During my professional activity, I got experience in prospecting, exploration, geological mapping, drill core logging, magmatic and metamorphic petrology, ore geology, economic geology, metallogeny, geochemistry, regional geology. I published articles on subjects such as: the subvolcanic rocks in the Bârgău Mountains (Eastern Carpathians, Romania); the manganese deposits from the Eastern Carpathians (Romania); tectonics, petrology and mineralogy of the formations in the Crystalline-Mesozoic Zone of the Eastern Carpathians; paleogeographic reconstruction of the pre-Alpine terranes in the Eastern Carpathians and in their foreland; the geotectonic evolution of the western part of Yangtze craton (China) and the associated magmatism and metallogenesis; the Panxi region and the Emeishan Large Igneous Province (South-West China). Most of the scientific research I have done an aim at the unveiling of the geodynamic processes that determined the features of the rocks and stratigraphic sequences, as shown in the habilitation thesis.

The reconstruction of the paleogeographic evolution of the pre-Alpine terranes of the Eastern Carpathians and of their foreland (Munteanu and Tatu, 2003; 2016; Munteanu and Dumitraşcu, 2010)

The Carpathian Mountains are located at the contact between the Phanerozoic (Gondwana-derived) and the Precambrian (Baltican) Europe. The Alpine successions of the Eastern Carpathians are thrust directly on the Precambrian Europe, without any recognizable Variscan of Caledonian terranes in between. This geotectonic arrangement is quite different from the foreland of the Alps, where Variscan and Caledonian (Avalonian) terranes are interposed between the Alpine thrusts and the Precambrian Europe. I consider the differences between the geotectonic configurations in front of the Alps and in the Carpathian foreland are best explained by the rifting associated with the opening of the Tethys Ocean, which cut through the terranes accreted in the Caledonian and Variscan orogenies and also through the margin of the East European Craton (Munteanu and Dumitraşcu, 2010; Munteanu and Tatu, 2016). The southern margin of the East European Craton is made up of the Scythian Platform. Along the south-western margin of the East-European Craton, there are several small blocks interposed between the craton and the Carpathian front: North Dobrogea, Central Dobrogea, Malopolska, Lysogory, Upper Silesia, Moravia and Brno. I pointed out that the Vendian sequence of the Central Dobrogea makes it distinct from the Moesian Platform. This assertion, in conjunction with the tectonic contact between the Central Dobrogea and the South Dobrogea, would support the consideration that the Central Dobrogea is not a part of the Moesian Platform (Munteanu and Dumitraşcu, 2010). Taking into account the similarities between the Scythian Platform, Central Dobrogea, Malopolska and Lysogory, I suggested that all the blocks in the front of the Eastern Carpathians are parts of the Scythian Platform (Munteanu and Dumitraşcu, 2010; Munteanu and Tatu, 2016). Therefore, the south and south-western margins of the East European Craton (from the northern shore of the Black Sea to Poland) would be made up of the Scythian Platform.

If the terranes accreted to the East European Craton during the Caledonian and Variscan orogenies have been cut by the Tethyan riftings, their fragments should be present within the Carpathian orogen or behind it (Munteanu and Dumitraşcu, 2010;

Munteanu and Tatu, 2016). The Eastern Carpathians include a fragment of pre-Alpine crust sheared during the Paleozoic and Cretaceous, which makes up the basement of the Crystalline-Mesozoic Zone. This pre-Alpine crust contains a stratigraphic sequence similar to that of the paleocontinent Avalonia (Munteanu and Tatu, 2003): a late Proterozoic sequence of carbonate platform type (Rebra Group), a pan-African (Cadomian) volcano-sedimentary formation (Pietrosu Bistriței porphyroids), and an Ordovician arc assemblage (Tulgheş Group). Parts of this sequence can be recognized in the Western Carpathians and Southern Carpathians, as well. In the Crystalline-Mesozoic Zone of the Eastern Carpathians, the Avalonian-type succession is overthrust by Bretila Group, which is an EEC-type terrane rather than an Avalonian one and is probably a fragment of the Scythian Platform. An Ordovician (Avalonian) amalgamation of the Crystalline-Mesozoic Zone deduced from the tectonic and lithostratigraphic features (Munteanu and Tatu, 2003) is supported by numerous geochronological data produced during the late two decades.

The geotectonic evolution of Panxi region and the Emeishan large igneous province (Munteanu et al., 2013)

The article synthesized the data on the Panxi region and added new insights on its tectonic evolution and on the generation of the Emeishan large igneous province. The Panzhihua-Xichang (Panxi) region is a tectono-magmatic province located in the western part of the Yangtze craton. Its structural pattern, defined by NS-trending deep faults, which, as pointed out in the article, is superimposed on a zone of late Proterozoic crustal extension. The Panxi region evolved as a continental rift in the Permian, and was subsequently subjected to compression, caused mainly by the Himalayan collision. This induced the uplift of its axial (Kangdian rise) and western parts, generating a horst-type structure within the former rift graben. At ca. 260 Ma, mantle plume-related magmatism in the Panxi region generated the large igneous province of the Emeishan flood basalts, which also includes ultramafic and silicic volcanic rocks and numerous intrusive bodies (peridotites, pyroxenites, layered gabbros, syenites, granites). A geochemical distinction between high-Ti and low-Ti Emeishan basalts can be made, but just with the significance of compositional end-members since the published data cover the entire compositional range between the high-Ti and low-Ti types. Similar compositional variation occurs in the ultramafic lavas (picrites and komatiites) intercalated in the sequence of the Emeishan basalts, which are considered to be the products of undifferentiated primary magmas. Considering the picritic composition of the primary magmas, a deep-seated differentiation of large volume of magma is needed to produce the extrusion of the relatively evolved Emeishan basalts.

World class Fe-Ti-V oxide ore deposits are associated with the layered gabbros, while the ultramafic intrusions can host small Ni-Cu and PGE sulfide deposits. In the article it is noticed that the ore deposits generated by the Emeishan magmatism occur only within the structurally uplifted parts (western and central) of the Panxi region. The spatial concentration of the world class Fe-Ti-V oxide deposits within a relatively small area from the most uplifted part of the Panxi region and their occurrence almost exclusively in Proterozoic country rocks suggests their formation a greater depth than the initial depth of the Ni-Cu(-PGE) sulfide deposits, many of which are located in Paleozoic rocks.

A model of geotectonic evolution was proposed for the Panxi zone in the article, which combines the rift tectonics with the mantle plume magmatism.

Petrogenesis of the mafic-ultramafic Yanbian dikes: implications for the Emeishan magmatism (Munteanu et al., 2017).

Numerous olivine-rich dikes intruded the late Proterozoic Yanbian terrane, Sichuan, SW China. The dikes are less than 10 m thick and show thin aphanitic chilled margins (c. 10–20 cm wide), whereas most of the dike volume comprises coarse porphyric rocks made up of olivine grains up to 2 cm in size set in a groundmass consisting of clinopyroxene, plagioclase, Fe-Ti oxides, a second generation of olivine, hornblende and biotite. Chrome-spinel occurs mostly as inclusions in the olivine phenocrysts, but also in the groundmass. The geochemical investigation of 25 dikes suggested a meimechite-type composition of the coarse-grained rocks and a basaltic composition of the chill margins. The sum of REE contents is 46–67 ppm in the coarse rock and 104–137 ppm in the chill margins. Chondrite-normalized REE and primitive mantle-normalized values show identical trends in all dikes, suggesting that they are comagmatic. The initial $^{87}Sr/^{86}Sr$ and $\varepsilon_{Nd(t)}$ (t = 260 Ma) of the dikes display values in the ranges 0.7041-0.7060 and 0.66-5.25, respectively. Olivine composition varies greatly, with Mg# values of 72.0-93.9. The Cr number of the spinel is 0.62-0.76. Clinopyroxene is Ca-rich (0.76-0.89 Ca atoms per formula unit). Although $^{40}Ar/^{39}Ar$ investigations did not yield definitive results, the mineralogical and geochemical similarities between the studied dikes and the ultramafic lavas in the Emeishan large igneous province support their emplacement during Emeishan magmatism. Almost all elements unrelated to olivine (Ti, Al, Ca, P, Cu, Zr, Sr, Ba, Y, REE, U, Th, etc.) show strong positive inter-element correlation both in the chill margins and in the coarse-grained rocks, suggesting their concentration in the melt. The chilled margins (Mg# = 55-63) would have been in equilibrium with moderately Mg-rich olivine (Mg# up to 84). Therefore, the most Mg-rich olivine crystallized from a more primitive magma and was transported in the dikes by a more evolved melt with a composition similar to that of the chill margins. Flow differentiation could explain the concentration of the olivine phenocrysts in the inner parts of the dikes while some melt was expelled towards the dike walls. Based on the composition of the most Mg-rich olivine, the Mg# of the primary magma was estimated to be 82–84. A meimechite-like composition for the primary magma (MgO=27–28%, FeO=10–11%, TiO_2 > 1%) was calculated by adding olivine with progressively higher magnesium number to the composition of the chill margins. The constraints of the mineral assemblage and simulations by MELTS modeling suggest magma evolution by olivine + Cr-spinel fractionation at P = 5 kbar. Elemental and Sr–Nd isotopic ratios indicate negligible crustal contamination. It is inferred that the primary magma resulted from the melting of a small fraction of mantle plume material in conjunction with melting of S-depleted subcontinental lithospheric mantle material.

The geotectonic evolution of the Western Yangtze craton during the Neoproterozoic (Munteanu et al., 2006;2010a; Munteanu and Yao, 2007; Munteanu and Wilson, 2009)

The Yangtze craton in South China has been central to the debate on the configuration of the Neoproterozoic supercontinent Rodinia. The consolidation of the Yangtze platform was traditionally seen as the result of two main tectono-magmatic events, at ca. 1000 Ma and ca. 850–800 Ma. The older one was occasionally equated with the Grenvillian, but recent data supported its consideration as a distinct event, referred to as the Sibao orogeny. The Neoproterozoic orogeny is known as Jinning, its end (ca. 800Ma) marking the final consolidation of the Yangtze platform. This is in

agreement with the evidence of Neoproterozoic subduction under the northern, western and southern margins of the Yangtze craton. Recent ideas propose the presence of a mantle plume under the Yangtze craton, in the interval ca. 825–740Ma, which induced rifting and anorogenic magmatism associated with the breakup of Rodinia. One outcome of the plume model is the inexistence of the Neoproterozoic Jinning orogeny.

In the western margin of the Yangtze craton, intrusive rocks with the age of 890-740 Ma are widespread. Many of these intrusions have been studied after the year 2000, the resulting data being interpreted in favour of either subduction or mantle plume.

Nevertheless, a comprehensive analysis of the geological data, especially those gathered from the Yanbian terrane (composed of the volcano-sedimentary Yanbian Group and several intrusions emplaced within it) reveals strong evidence of a mid Neoproterozoic subduction under the western margin of the Yangtze craton (Munteanu and Wilson, 2009). The arguments for subduction can be summarized as follows:

(1) Mineral assemblages and mineral chemistry

(a) Hornblende is widespread in the intrusions of the Yanbian terrane and occurs in all rock types. The best example is the Gaojiacun mafic-ultramafic intrusion, where hornblende was one of the last minerals to crystallize and it is mostly an interstitial phase in the inner(cumulate) zone of the intrusion. There are several lines of evidence for the magmatic origin of hornblende in Gaojiacun intrusion, at least in its oikocrystic form. Many cumulus plagioclase crystals in leucogabbroids contain tiny euhedral brown hornblende crystals, which indicates the crystallization of hornblende along with the plagioclase. In some gabbronorites, intercumulus plagioclase including oikocrystic hornblende with pyroxene chadocrysts has been found. This suggests formation of intercumulus hornblende prior to the crystallization of the intercumulus plagioclase. Commonly, cumulus olivine, clinopyroxene and plagioclase included in oikocrystic hornblende are corroded, but not altered. In fact, they are better preserved in the hornblende oikocrysts than outside them. This difference is most conspicuous for olivine, which often is intensely or completely serpentinized in the mass of peridotites and dunites, while in hornblende oikocryst from the same rocks it frequently is almost serpentine-free. This is evidence for hornblende crystallization at relatively high temperatures, outside the serpentine stability field. After crystallization, hornblende protected the included minerals, like a shell.

The presence of primary hornblende is evidence for the hydrous character of the parental magma, a feature common to subduction-related magmas.

(b) Clinopyroxene compositions in the Gaojiacun intrusion vary from Ca-rich augite to diopside. Such calcic compositions of clinopyroxene are usually related to crystallization from hydrous magmas.

(c) Plagioclase in the inner (layered) zone of the Gaojiacun pluton displays high anorthite contents, often higher than 85%. This suggests crystallization from a hydrous magma, as the anorthite content of plagioclase is increased by high water concentration in the magma.

The significance of plagioclase composition is more straightforward when it is considered in conjunction with olivine composition. In arc cumulate gabbros, olivine with $Fo < 80$ coexists with calcic plagioclase ($An > 85$), a feature which is not typical for cumulate gabbros formed in other geodynamic settings. The gabbroids from the

Gaojiacun intrusion contain olivine with compositions in the range $Fo_{72-78.5}$ and plagioclase with $An_{80-94.6}$, thus supporting an arc geotectonic setting.

(2) Igneous petrographic association

The Neoproterozoic intrusions from the western margin of the Yangtze craton make up a chain more than 1000 km long. The intrusive chain is made up of granites (calc-alkaline), tonalites, quartz diorites, diorites, and a few gabbros, with no syenite or peralkaline granite. This petrographic association is typical for magmatic arcs and very similar with the composition of the Andean–Cordilleran. A cross-arc compositional zonation can be remarked, with diorites prevailing in the west (oceanward) and granites towards the east (continentward), similar to the east-Pacific arcs.

(3) Bulk-rock geochemistry.

All intrusions, from granites to gabbros, and along the entire intrusive chain, show arc-type geochemistry. The arc-type geochemical patterns were sometimes attributed to an inheritance from older subduction-related events. This does not seem to be the case, because the arc geochemistry is in perfect agreement with the other geological characteristics of the Neoproterozoic intrusions and their country rocks.

(4) Stratigraphy

Two late Proterozoic terranes, made up of volcano-sedimentary successions and intrusive rocks, have been identified on the western margin of the Yangtze craton: the Bikou terrane, in the north, and the Yanbian terrane, in the south. The Bikou terrane, with the age of ca. 900–700 Ma contains turbiditic sequences with features characteristic to fore-arc accumulation. The Yanbian terrane contains turbiditic flysch with Bouma sequence, indicating its genesis in relation with a subduction zone. The age of the flysch successions in the Yanbian Group was constrained to ca. 870 Ma.

(5) Magmatism and deformation

Some of the mid Neoproterozoic intrusions from the western margin of the Yangtze craton exhibit penetrative foliation, while other ones are not deformed. This aspect is most obvious in the Yanbian terrane, which includes two adjacent plutons: Gaojiacun (ca. 810 Ma) and Tongde (ca. 820 Ma). While Tongde is gneissic along its contact with the Yanbian Group (metamorphosed under greenschist facies conditions), Gaojiacun and its satellite intrusions are not deformed; moreover, Gaojiacun induced contact metamorphism in the Yanbian Group, and its contact aureole contains undeformed porphyroblasts. These relations between deformation and magmatism clearly indicate at least one phase of barrovian metamorphism after the emplacement of the Tongde intrusion and before the solidification of the Gaojiacun intrusion. A metamorphism capable to generate schistosity in magmatic rocks cannot be explained by crustal extension, but by convergent plate margins. Therefore, it clearly indicates Neoproterozoic collisions, probably succeeded in time, in a way similar with the accretion of the Cordilleran suspect terranes.

Magma dynamics in the intrusions cluster from Lengshuiqing (Munteanu et al., 2010a,b; 2011)

Lengshuiqing is part of the late Proterozoic igneous province from the western margin of the Yangtze craton. The Lengshuiqing cluster comprises several intrusions emplaced in the Neoproterozoic Yanbian Group. Five ultramafic-mafic intrusions

from the Lengshuiqing cluster contain Ni–Cu ore (pyrrhotite+pentlandite+chalcopyrite) hosted in ultramafic cumulate zones (peridotite+olivine pyroxenite with cumulus olivine and Cr-spinel, and intercumulus pyroxenes, hornblende, phlogopite and plagioclase). Olivine-free diorite-quartz diorite ± gabbro and granite zones commonly occur above the ultramafic rocks. The genesis of the intrusions (conduit-related accumulation versus differentiation from stagnant magma) was investigated. The amount of sulfides in the intrusions from Lengshuiqing is one order of magnitude bigger than the sulfides that can be dissolved by a volume of mafic magma similar with the volume of the intrusions. Most intrusions from Lengshuiqing have bulk composition (peridotite ± diorite ± granite) more magnesian (MgO = 21-22%; Mg# > 78) than the deduced composition of their parental magma (MgO = 9-11%; Mg# = 64-67). This indicates the accumulation of sulfide and mafic silicates from a volume of magma much larger than the volume of the intrusions, which can be explained by the fractionation from magma ascending through the intrusions to shallower depths. A continuous supply and vent of magma is consistent with the lack of chilled margins, the melting of the wall rocks and the generation of high-temperature mineral assemblages (K-feldspar, diopside, and sillimanite) in the Yanbian Group next to the intrusions. The intrusions from Lengshuiqing are seen as microchambers on conduits draining olivine-, Cr-spinel-, and sulfide-bearing mafic magma from a larger staging chamber.

Plan of career development

The development of my professional career is based on the knowledge accumulated from the previous activities. These include prospecting and exploration, geological mapping at the surface and underground, core logging, resource/reserve calculation and classification, study of rocks at the optic microscope, use of ArcGIS, work with the electron microprobe and scanning electron microscope, processing of data from assays and from geochemical investigations (major components, trace elements, isotopes), teaching of mineralogy, ore petrology and exploration, coordination of Honours Students Projects and Master theses. I worked or collaborated with research and academic institutions (Geological Institute of Romania, Economic Geology Research Institute of the University of the Witwatersrand; Rhodes University-South Africa) and with exploration and mining companies (ARGES Enterprise for Geological Prospecting and Exploration, Piteşti, Romania; Anglo Platinum, Johannesburg, South Africa; Sichuan Bureau for Geology and Mineral Resources). I worked in several international and national projects.

In the future, I plan to develop my career in the following directions:

- To investigate the paleogeographic evolution of the terranes in the Carpathian Mountains and of the crustal blocks in the proximity of the Carpathian orogen.
- To study the mafic-ultramafic rocks and their metallogeny, as well as to assess the potential of mineral resources of the Romanian territory.
- To coordinate PhD theses in the School of Advanced Studies of the Romanian Academy and to transfer my knowledge to the PhD candidates and to the students.
- To participate to national and international projects together with the PhD candidates from the School of Advanced Studies of the Romanian Academy.
- To disseminate the scientific results by posting them on the webpages of the projects, by their presentation during symposia, conferences, congresses and other professional meetings and by publication in ISI-ranked journals and in books.

References

Munteanu, M., Dumitraşcu, C., 2010. Geology of the Iacobeni tectonic window (in Romanian). 113 p., Editura Tehnopress, Iaşi.

Munteanu, M., Tatu, M. 2003. The East-Carpathian Crystalline-Mesozoic Zone: Paleozoic amalgamation of Gondwana- and East European Craton-derived terranes. Gondwana Research, 6, 185-196.

Munteanu, M., Tatu, M., 2016. Insights into the pre-Alpine geotectonic arrangement in the Carpathian realm. AAPG Europe Regional Conference 19-20 mai, 2016, Bucureşti. Petroleum Systems of Alpine-Mediterranean Fold Belts and Basins

Munteanu, M., Wilson, A., 2009. The South China piece in the Rodinian puzzle: Comment on "Assembly, configuration, and break-up history of Rodinia: A synthesis" by Li et al. (2008. [Precambrian Res. 160, 179–210]. Precambrian Research, 171, 74-76

Munteanu, M., Yao, Y. 2007. The Gaojiacun intrusion: Rift- or subduction-related? Comment on "Revisiting the "Yanbian Terrane": Implications for Neoproterozoic tectonic evolution of the western Yangtze Block, South China" by Li et al. (2006. [Precambrian Res. 151 (2006. 14–30]. Precambrian Research, 155, 324-327.

Munteanu, M., Yao, Y., Wilson, A.H., Chunnett, G., Luo, Y.N., Zhao, Q.X. 2006. The Gaojiacun mafic–ultramafic complex (Sichuan, SW China-Late Proterozoic magmatism at the western margin of the Yangtze Craton. Acta Geol. Sinica, 80, 705-723.

Munteanu M, Wilson AH, Yao Y, Harris C, Chunnett G, Luo Y, 2010a. The Tongde dioritic pluton (Sichuan, SW China. and its geotectonic setting: Regional implications of a local scale study. Gondwana Research, 18, 455-465.

Munteanu, M., Wilson, A.H., Yao, Y., Jiang, S.Y., Chunnett, G., Luo, Y., Mafurutu, L., Phadagi, R., 2010b. A conduit-related genesis of the Lengshuiqing intrusive assemblage (Sichuan, SW China. Journal of Volcanology and Geothermal Research, 189, 118-130

Munteanu M, Wilson AH, Yao Y, Chunnett G, Luo Y., 2010c. Sequence of magma emplacement and sulfide saturation in the Gaojiacun–Lengshuiqing intrusive complex (SW China. Mineralium Deposita 45, 517-529.

Munteanu M, Wilson AH, Yao Y, Chunnett G, Luo Y., Sibanda, S. 2011. The Lengshuiqing Ni-Cu deposit, Sichuan, Southwestern China: ore characteristics and genesis. Canadian Mineralogist, vol. 49, 1599-1626.

Munteanu, M., Yao, Y., Wilson, A.H., Chunnett, G., Luo, Y.N., He, H., Cioacă, M.E., Wen, M.L., 2013. Panxi region (South-West China.: Tectonics, magmatism and metallogenesis. A review. Tectonophysics, 608, 51-71.

Munteanu, M., Wilson, A.H., Costin, G., Yao, Y., Lum, J.E., Jiang, S.Y., Jourdan, F., Chunnett, G., Cioacă, M.E., 2017. The mafic-ultramafic dykes in the Yanbian Terrane (Sichuan Province, SW China): Record of magma differentiation and emplacement in the Emeishan Large Igneous Province. Journal of Petrology, 58, 513-538.