THE EVOLUTION OF MAPPING AND STRUCTURAL MODELS OF THE NEOGENE CĂLIMANI-GURGHIU-HARGHITA VOLCANIC RANGE

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Abstract. The Miocene-Quaternary Călimani-Gurghiu-Harghita (CGH) volcanic chain attracted naturalists and geologist attention since the end of 18th to the beginning of 19th century by its majesty and splendor. The knowledge, including mainly petrography, volcanology and mapping improved in a sequence of steps up to the present times. Here is an overview of the main aspects and hallmarks related to the progresses of mapping in CGH and understanding its geological structure.

Keywords: geological mapping, Călimani-Gurghiu-Harghita volcanic range.

Résumé. La chaîne volcanique miocène-quaternaire Călimani-Gurghiu-Harghita (CGH) a attiré l'attention des naturalistes et des géologues de la fin du 18e au début du 19e siècle par sa majesté et sa splendeur. Les connaissances, y compris principalement la pétrographie, la volcanologie et la cartographie, se sont améliorées en une séquence d'étapes jusqu'à nos jours. Voici un aperçu des principaux aspects et caractéristiques liés aux progrès de la cartographie en CGH et à la compréhension de sa structure géologique.

Mots-clés: cartographie géologique, Călimani-Gurghiu-Harghita chaîne volcanique.

1. INTRODUCTION

Romania hosts a lot of volcanic rocks on his territory, largely distributed in all the geological terranes since Precambrian to Quaternary times. Among the best preserved volcanic edifices, the Călimani-Gurghiu-Harghita volcanic chain, Miocene-Quaternary in age (~ 11–0.03 Ma), is the most representative of all. Complex volcanic activity generated a large number of composite volcanoes with eroded craters or calderas, but also with numerous effusive domes and a large variety of volcaniclastic deposits. This was the reason that such a large-scale volcanic area (of. ca. 160 km long) attracted the interest of geologists during the last century or so.

Here we give an overview on the evolution of mapping and on the way how the understanding of the evolution of volcanic edifices and their products evolved since the 19th century up to the present times. In Fig. 1 the location of the Călimani-Gurghiu-Harghita volcanic chain (CGH hereafter) is shown in the framework of the regional map of the Carpathian-Pannonian Region.

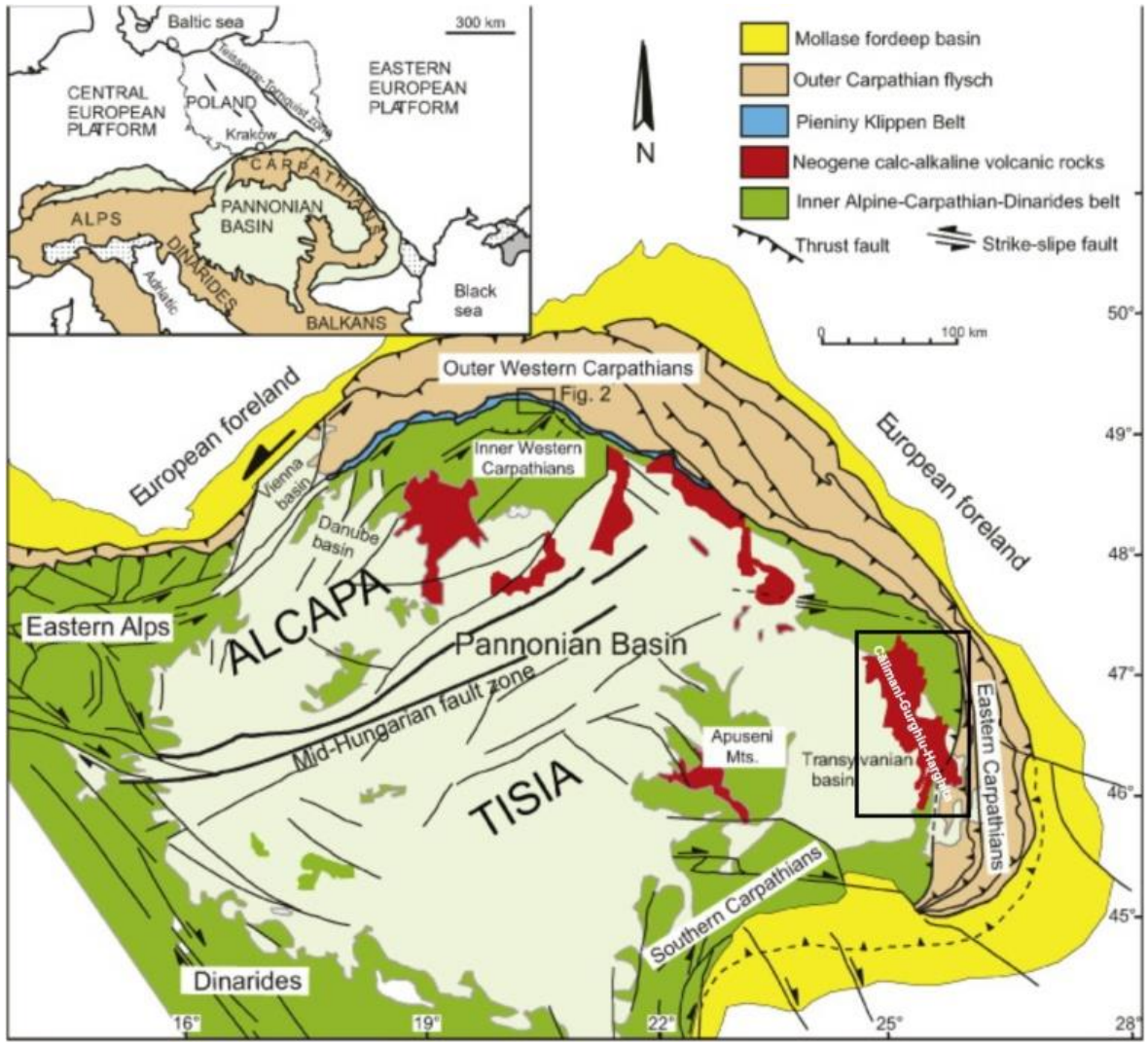


Fig. 1. Location of the Călimani-Gurghiu-Harghita (CGH) volcanic chain (framed) in the context of a simplified geological map of the Carpathian-Pannonian region.

2. EARLY GEOLOGICAL MAPS SHOWING CGH

The earliest geological maps have been realized in the 18th and 19th centuries within the Habsburg Empire by foreign voyagers or naturalists (e.g., Townson –1797; Staszic –1815; Beudant –1822; Lill von Lilienbach –1833; Boué –1834, Bielz –1854) using the available earlier mining and topographic maps. We use information regarding the CGH chain from monographies on the geological mapping of Transylvania during the 19th century (e.g., Brezsnyánszky, 1996; Stelea, 2011; Korodi *et al*., 2015). The voyagers or naturalists were attracted by the richness in mineral resources of the broader region and the long history of mining in Transylvania. These natural scientists expose the general contour of CGH, as a whole or partially, in their maps. The shape of the volcanic chain is only roughly defined and the volcanic formations were represented as one single geological formation and reproduced as so in one single color. One of these maps, known as a geognostic map, was realized by Wilhelm Haidinger in 1845 (e.g., Korodi *et al*., 2015).

The best outlined map of the CGH chain belongs to an eminent geologist, Franz Ritter von Hauer (1822–1899), chief geologist of the Imperial and Royal Geological Institute of Austria, and his co-workers who used excellent topographic maps already existing at that time. The maps were achieved during the 19th century in the Austro-Hungarian Empire.

In 1861, Franz Ritter von Hauer edited a geological map of Transylvania in Hermannstadt (Sibiu today) on a scale of 1:576,000 (Hauer, 1861), later included in the first geological monography of Transylvania ("Geologie Siebenbürgens"; Hauer, Stache, 1863).

It seems that the actual geological mapping labor of the CGH belongs to Franz von Hauer, but he also was helped by the Austrian geologist Ferdinand von Richthofen (1833–1905) who mapped the Harghita volcanic range. The second map was published in Vienna in 1863 (Fig. 2). It is obvious that this second map reproduces better than the previous one the shape of CGH and its relationships with adjacent geological formations. The map displays two colors: a darker green in the center of the chain, representing massive rocks, and light green representing "fragmented volcanic rocks" sideways from the central part. The cartographic representation of the CGH chain is exquisite for the time it was published. This is the reason why we complement Fig. 2 with the portrait of Franz Ritter von Hauer in sign of our deep appreciation for his work at the time Volcanology was not yet a science.

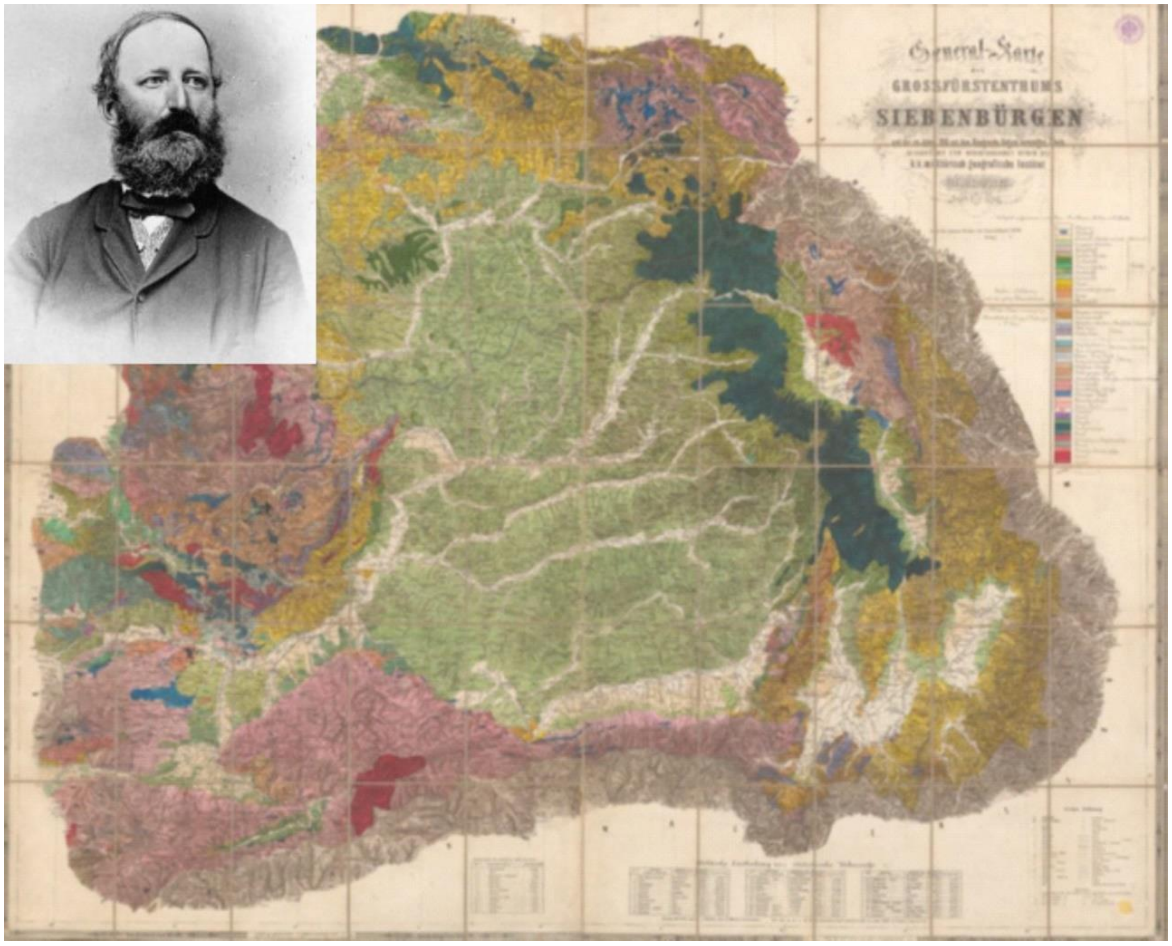


Fig. 2. Geologische Übersichts-Karte von Siebenbürgen, 1:288,000 (Hauer *et al.* 1863). Source: Collection of the Library of the Geological Survey of Austria (from Korodi *et al*., 2015). In the upper left is the portrait photo of Franz Ritter von Hauer the author and editor of the geological map of Transylvania (*Source*: Archive of the Geological Survey of Austria/Geologische Bundesanstalt).

A partial map of CGH (South Gurghiu-Harghita) was published as "The geological map of Seklerland at scale: 1:288,000" by Herbich in the year 1878; however, it is not better than the previous ones.

The next advance in geological mapping of CGH was done by the Hungarian geologist and geographer Lajos Lóczy (Hungarian name), known as Ludwig von Lóczy (German name) who lived from 1849 to 1920. He was the director of the Hungarian Geological Survey from1908 up to 1920. After long-lasting research projects his work resulted, after his death, in compilation of the "Geological a map of Hungary and the adjacent regions of the neighboring countries" published in 1922, including Transylvania (Fig. 3).

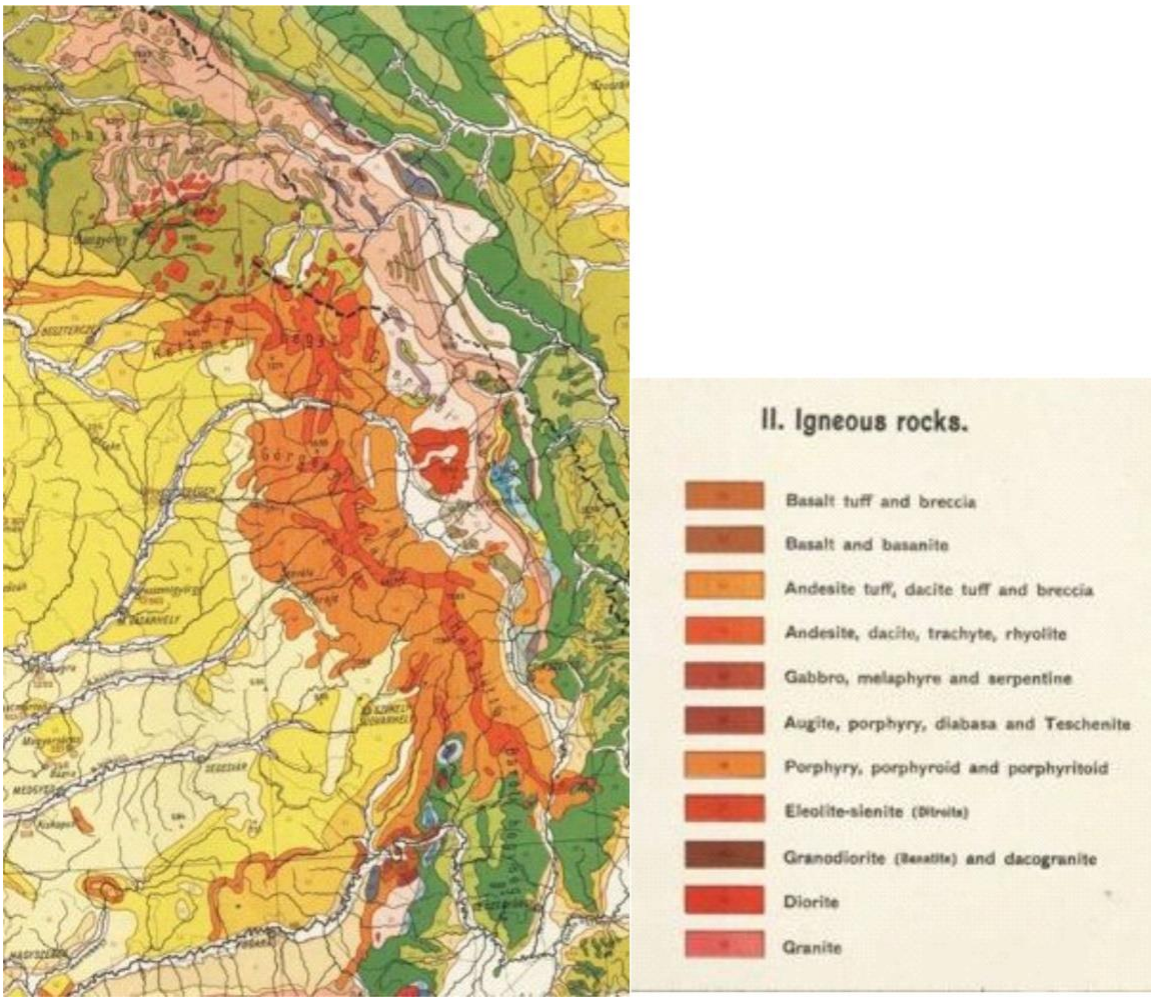


Fig. 3. Geological map and legend of igneous rocks showing the CGH chain (in reddish-brownish colors) cut from the Geological map of Hungary, 1:900.000, 1890–1910 (published in 1922).

The map shows an improved and more detailed outer contour of the volcanic area (Fig. 3), but it is not enhanced from the volcanological point of view as compared to the map of Franz von Hauer (Fig. 2) since the massive rocks, named correctly as andesites or dacites, are shown as a very narrow area in the axial part of the chain, on the top of the spatially much more developed volcanic structure and the "volcaniclastic rocks", considered as andesitic and dacitic tuffs and breccia in the legend. This latter information is a real contribution with respect to previous knowledge.

3. THE FIRST GEOLOGICAL MAPS MADE IN ROMANIA UP TO THE SECOND WORLD WAR – GEOLOGICAL INSTITUTE

Little is known on the mapping activity of CGH since the 1906 the year when the Geological Institute of Romanian was established by a Royal Decree signed by His Majesty Carol I, King of Romania. Very simplified versions of the Geological map of Romania are known published by I.P. Voiteşti (1876–1944) and by G.M. Murgoci (1872–1925) (Stelea, 2011), on which CGH is shown and marked as a single unit and one color. However, in the archives of the Geological Institute we could find the first Geological map of Romania published in 1927 with CGH clearly shown (Fig. 4).

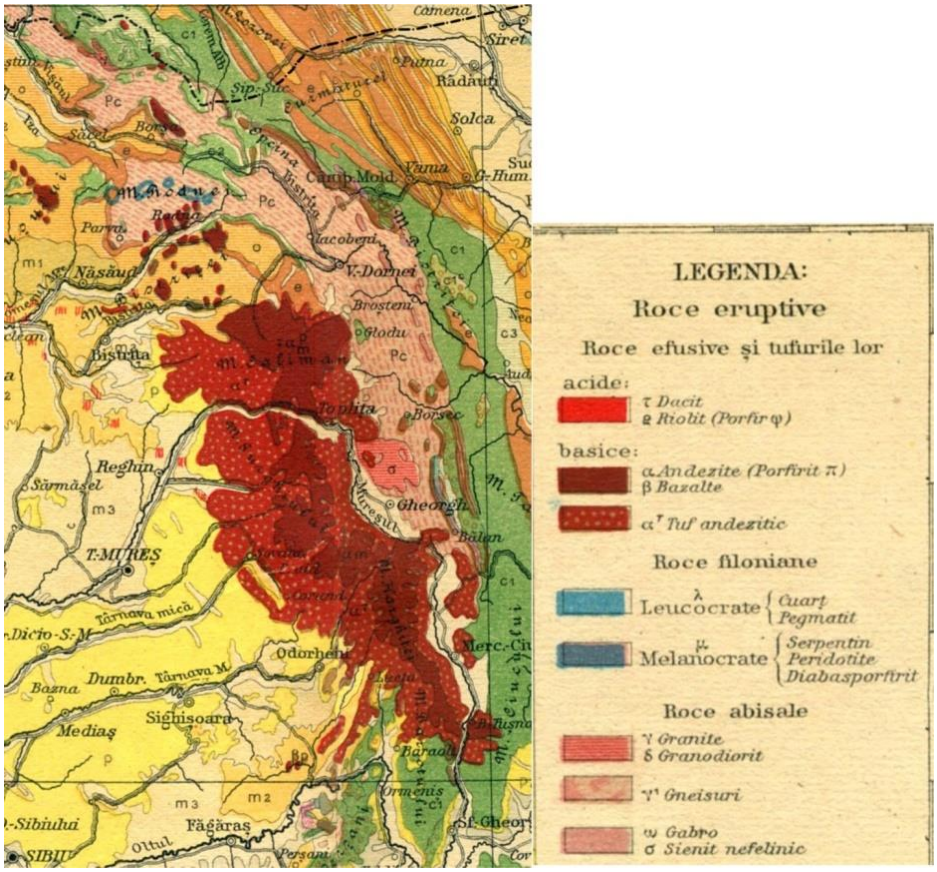


Fig. 4. Part of the Geological map of Romania and the legend of eruptive rocks showing the CGH chain (dark red tones); "Institutul Geologic al României" scale 1:2.500.000, 1927.

There are no visible improvements as compared to the previous maps, the region of CGH being covered by "andesites" in the central area of the chain, surrounded by "andesitic tuffs". Close to CGH range, the alkali basalts of the Perşani Mts. are displayed for the first time, however only with two occurrences known at that time.

The first mapping endeavor initiated by the Geological Institute was the realization of a general geological compilation map of Romania, including all previous and relevant geological information available complemented by new observations and all those interpreted in a coherent structural way. This large map, at scale 1:500,000 started by Ludovic Mrazek and finished by George Macovei between 1936 and 1959, is the first Geological map of Romania started before and finished after the

2nd World War. This map published under the auspices of the Romanian Academy and the Geological Committee was extremely well appreciated both in the country and internationally. The sheet that includes CGH was printed in 1951, being exquisitely hand-drawn by the cartographer F. Wahnig. It is an obvious result of predecessor's field studies. The CGH chain is depicted here in a coherent manner (Fig. 5). For the first time the term stratovolcano is used, also the main craters/calderas ("căldări vulcanice") are shown; the development of effusive rocks is well delimited by volcaniclastic rocks (e.g., agglomerates and tuffs) in the surrounding areas. Besides the dominating andesites basalts in the south-eastern part of the Călimani Mts. area are also shown. The Perşani Mts. basaltic field is also correctly outlined.

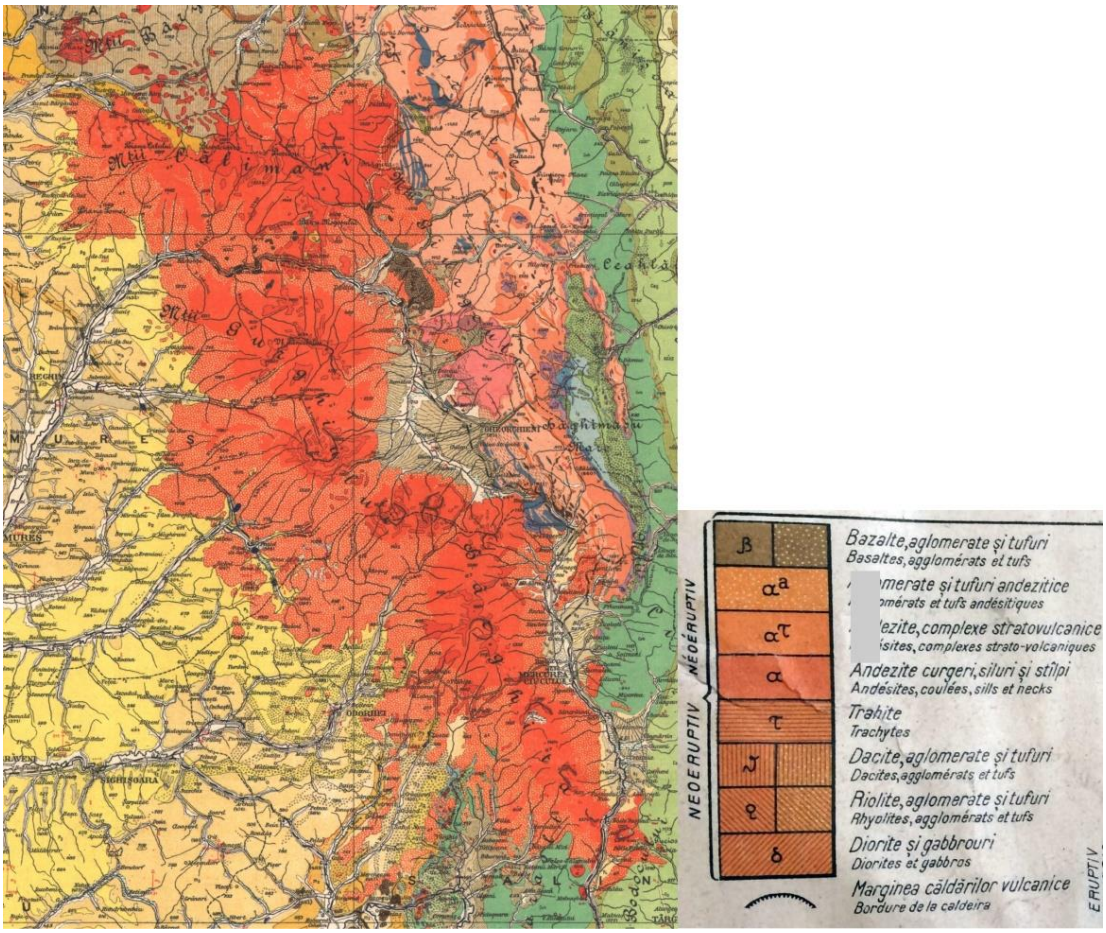


Fig. 5. Part of the Geological map of Romania and the legend, scale 1:500.000, 1951, showing the CGH chain (in red tones).

4. POSTWAR-COMMUNIST PERIOD

During the Communist political regime in Romania the knowledge on the geological structure of the country, including areas covered by volcanic rocks, gain a serious impetus by centralized and systematic institutional research aiming at valorization of the mineral potential of the country. Mapping of Neogene volcanic areas, hosting Romania's most important precious metal ore deposits,

was a priority task of geological institutions at various levels, organized in a nation-wide network, including the Geological Institute (basic research and general mapping at scale 1:200,000, then 1:50,000, and 1: 1.000.000), and the so-called Prospecting Entreprises at both national (IGPSMS, IMR, IFLGS) and territorial (IPEG's) level, performing, besides ore-indication search, detailed geological mapping (at scales 1: 10,000 and 1: 5,000). Meanwhile, knowledge on the structure and evolution of the volcanic areas advanced by research undertaken, mostly non-systematically at Universities (Bucharest, Iaşi, Cluj), by academic people interested by the subject. As the spatially most extended Neogene volcanic area of Romania, the CGH chain was constantly targeted by such mapping and research activities during the Communist period (1945–1990) stimulated by the underlying assumption that it probably hosts numerous economically important ore deposits similar to the better known (for centuries) Apuseni Mts. and Baia Mare region, famous for their richness in mineral deposits of Au, Ag, Cu, Pb, Zn.

4.1. MAPPING IN THE COMMUNIST PERIOD

The nation-wide mapping program aimed at covering the whole territory of Romania with sheets of geological maps at scale 1: 200,000 was undertaken for decades (between 1960 and1969) by the Geological Institute in a huge effort involving many experts in all domains of the geological science, including those specialized in volcanic formations. This resulted in realization of a series of map sheets at scale 1: 200,000 which could be assembled as a mosaic, in one single large Geological Map of Romania. This new map capitalized and included all relevant information from earlier mapping and studies, and an impressive amount of new information obtained by coordinated archive and field-based work. The territory of the CGH chain was covered by a number of 4 1: 200,000 sheets, most of it included in sheets Toplița and Odorhei, and some peripheral areas in sheets Bistrița and Târgu Mureș. The new map marked a significant progress in the cartographic representation of the CGH chain. The large-scale pattern of the map representation is dominated by a new structural concept on the buildup of the chain, elaborated by Rădulescu (1964) and Rădulescu *et al*. (1964a, b) for the Gurghiu and Harghita Mts. segment of the chain and generalized for the whole CGH, namely the existence of two structural levels reflecting two evolutionary stages of volcanism in the CGH chain: 1) a lower structural entity, represented by the so called "volcano-sedimentary formation", roughly equivalent with the peripheral volcaniclastic rocks (or "andesitic tuffs") of the older maps, resulting from an older, dominantly explosive volcanic stage, and 2) an upper structural entity of the overlying stratovolcanic edifices in the axial part of the chain, resulting from a dominantly effusive activity. This two-level structure is reflected in the map representation and legend labeling of the map, as seen, for example in the Odorhei sheet (Fig. 7). However, the lower structural unit is not detailed at all, appearing as a continuous peripheral map entity all along the CGH chain. In contrast, the upper unit is detailed according to the petrographic features of the mapped volcanic rocks petrography (andesites, dacites, and basalts). Moreover, since most of the CGH chain is overwhelmingly dominated by andesites, various types of andesites are separated and depicted as map units, according to their mineral compositions, mostly amphibole-bearing andesites being distinguished from pyroxene andesites, but more petrographic types also appear. As so, the 1: 200,000 scale map of the CGH chain is, basically, a petrographic map with little, if any, volcanological meaning. The only map item having volcanological signification, is the specific marking of crater/caldera areas in the central parts of the upper-unit stratovolcanic edifices, already present also in older maps.

Year 1973 is an important hallmark, since Romania held an International Symposium of Volcanism and Metallogenesis organized by the University of Bucharest in the coordination of Professor Dan P. Rădulescu. Below there is the map published by Prof. Dan P. Rădulescu and his co-workers for the Congress guide (Fig. 6) that has a similar legend as the 1:200.000 scale map discussed above.

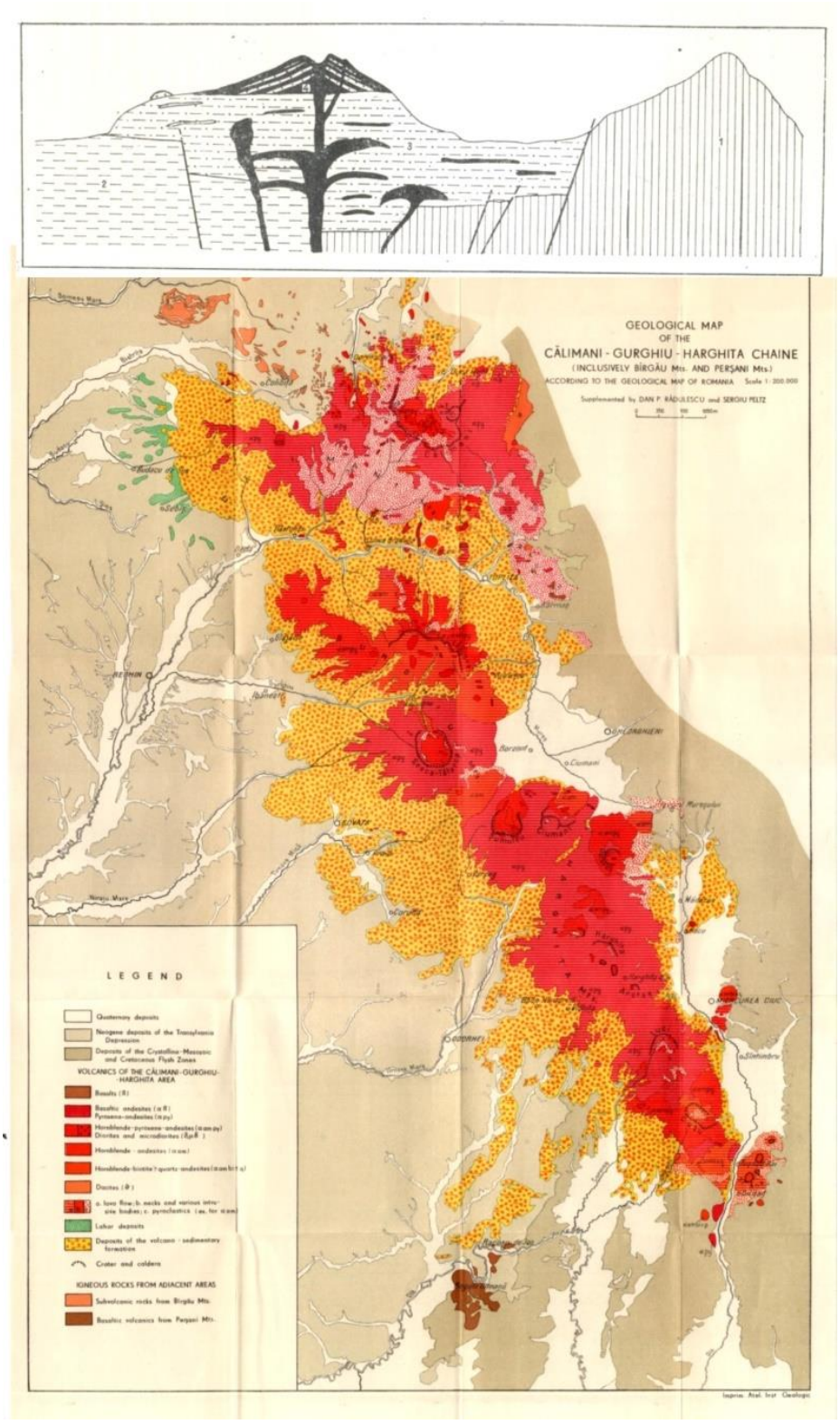
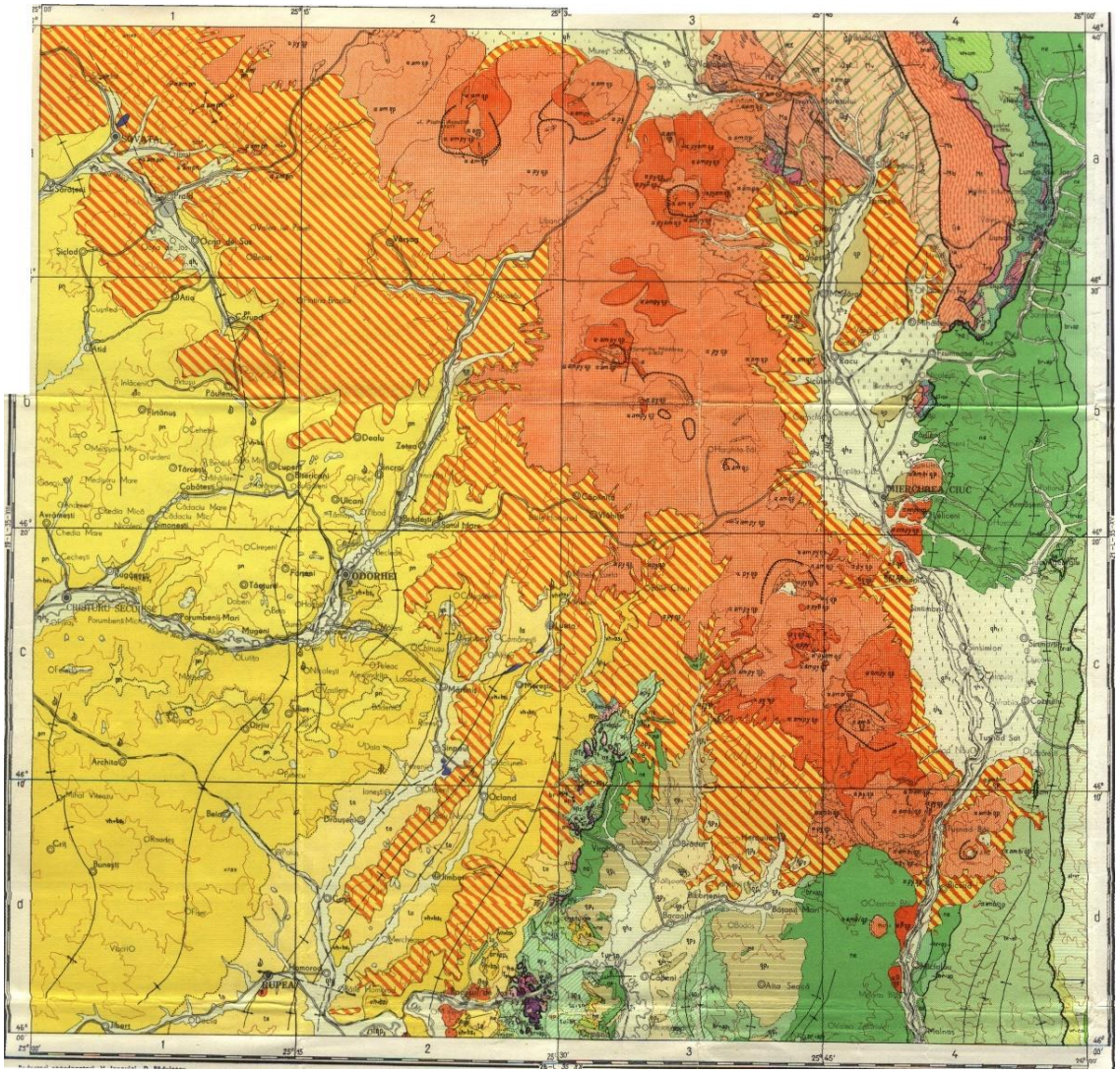


Fig. 6. Geological map of CGH included in the guidebook of the *Symposium on Volcanism and Metallogenesis* (Rădulescu *et al*., 1973); the top panel shows the two compartment model, acc. to the same reference.



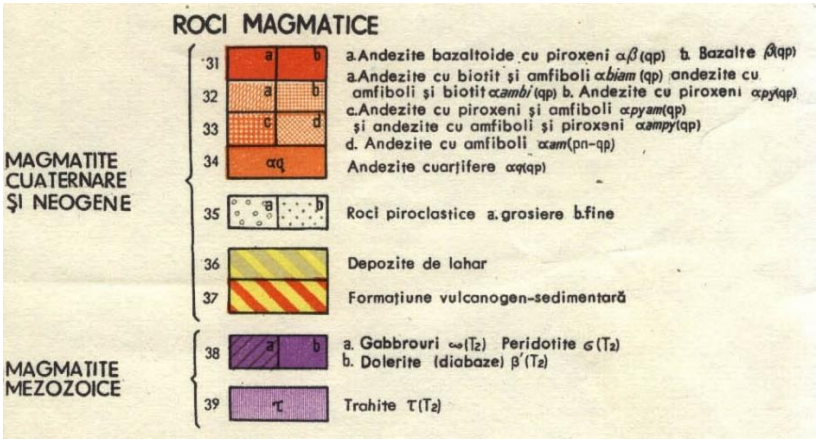


Fig. 7. Odorhei sheet of the 1:200,000 scale map of Romania showing the southern half of the CGH chain (in red tones) with part of legend including only the magmatic rocks (lower panel) (Ianovici *et al.*, 1968)

The latest development in mapping the CGH chain during the Communist regime is the elaboration of the 1: 50,000 scale maps, as part of a national mapping program of the Geological Institute aiming at mapping part of the national territory, namely the mountainous and hilly areas of the country. Within this program, a number of 1: 50,000 scale maps were realized and published on the territory of the CGH chain. Some of those maps were quickly published after finishing the 1: 200,000 mapping program, taking into account that the larger-scale mapping resulted in enough information to allow the drawing of more detailed maps. For example, sheet Sânmartin covering part of the South Harghita Mts. was published in 1972 (Săndulescu *et al*., 1972). These more detailed maps, however, retained the structural model and interpretation of the 1: 200,000 scale maps, as the Sânmartin sheet published clearly displays (Fig. 8). This detail is important because later, neighboring 1: 50,000 map sheets, elaborated according to a new structural model and to new information on the composition and age of volcanic rocks, will not fit with these sheets. It is important to note that, the 1: 50,000 scale maps of the CGH chain realized so far benefited from information gained during geological prospection works performed by various institutions, at scale 1:10,000 and 1:5,000, as well as from information included in various scientific publications.

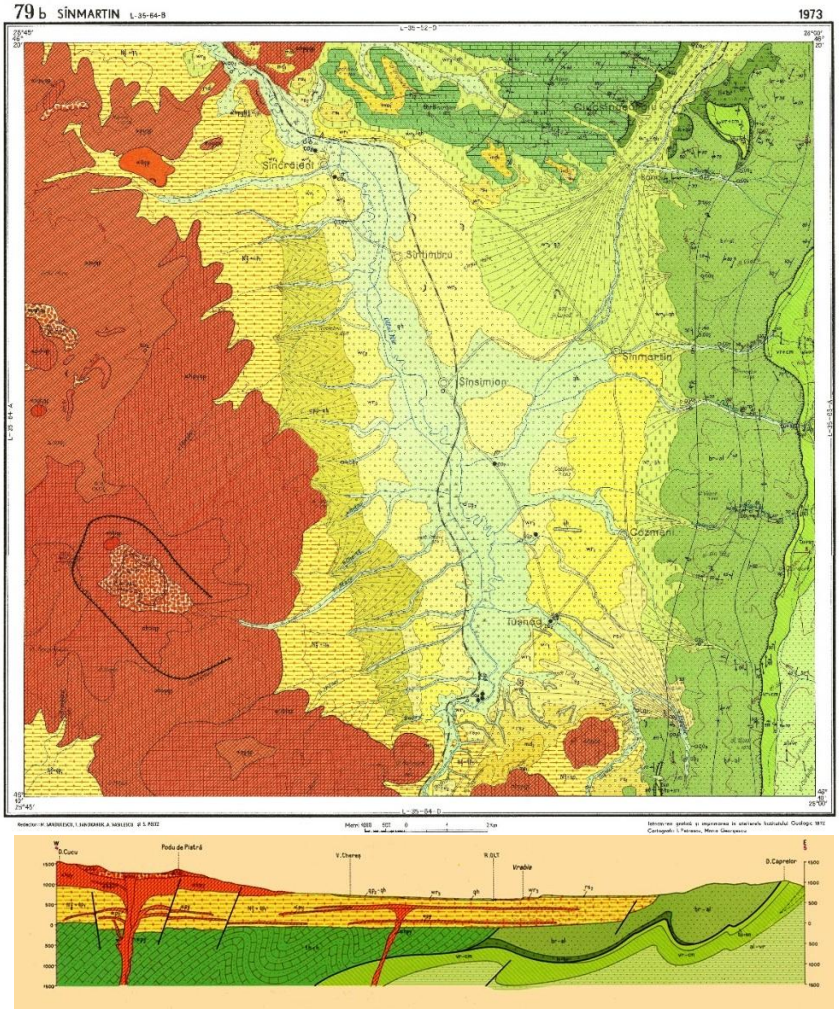


Fig. 8. Sheet Sânmartin of the 1: 50,000 scale map of Romania (Săndulescu *et al*., 1972) and a cross-section (lower panel) showed according the structural model of Rădulescu (1964) and Rădulescu *et al*., (1973). The massive volcanic rocks are depicted in red tones (different patterns correspond to different rock types), the lower structural unit (volcano-sedimentary formation) with yellow and red pattern, and the pyroclastic rocks within the Cucu volcano craterial area with red-white pattern.

The 1: 50,000 scale geological mapping program of the Geological Institute was not finalized, being interrupted indefinitely soon after the 1989 political changes because the absence of financing. At this time the up-to date picture of this mapping program in the CGH chain is the following: 7 sheets (Poiana Stampei, Șarul Dornei, Voșlăbeni, Miercurea Ciuc, Odorheiu Secuiesc, Chirui, Sănmartin) ready and published, 6 sheets (Poiana Stampei, Coșna, Negoiul Românesc, Stânceni, Toplița, Vlăhița,) ready but not finalized and published, and the rest of the sheets not even started. This latter case mostly concerns the middle part (Gurghiu Mts.) of the CGH chain. The perspectives of finalizing the 1: 50,000 scale mapping of the CGH area in the future is nil, since the persons having expertise in volcanology and mapping are old and retired and there is nobody to follow them, not to speak about the total lack of leadership and financial support for such an activity.

A mention has to be made on the large amount of information "buried" in many unpublished professional reports of various institutions performing prospection and exploration work during the Communist regime, including detailed mapping.

4.2. EVOLUTION OF IDEAS RELATED TO THE STRUCTURE OF THE CGH CHAIN

The post-2nd World War Communist period can be divided into two parts, according to the prevailing structural concept of the CGH chain.

In the 1945–1964 time period there was no any generally accepted structural model of the CGH chain. This time interval could be characterized by two competing views, promoted by the informally called "Cluj School" and "Bucharest School", respectively. The so called "Cluj School" represented by Zoltán Török and Ioan Treiber claims, based on their long-term work and experience in the Călimani Mts., that the volcanic activity in the CGH chain was preceded by intense intrusive magmatism giving rise to shallow intrusive bodies beneath the today's volcanic range, uplifted and exhumed, which served as an "intrusive basement" for the following volcanic activity (Török, 1956; Treiber, 1955, 1957). In contrast, based on his Gurghiu and Harghita fieldwork and experience, Dan P. Rădulescu, the informal leader of "Bucharest School", claimed in his published article (e.g. Rădulescu, 1960), that all magmatic rocks interpreted as being intrusive (i.e., sub-volcanic), are in fact parts of the volcanic edifices and, as so, do not predate volcanic activity but they are contemporaneous with that. Paradoxically, later on, it turned out, that both parties were right: prevolcanic intrusive activity was going on, indeed in the Călimani and northern Gurghiu Mts, but not farther south, whereas all intrusive rocks mapped in the Southern Gurghiu and Harghita Mts. are coeval, indeed, with the rest of the rocks making up the volcanic edifices. (e.g., the recent simplified volcanological map of CGH published by Seghedi *et al*., 2017; Fig. 9).

Year 1964, when trend-setting papers were published (Rădulescu, 1964; Rădulescu *et al*., 1964 a, b) it was a turning point in the evolution of ideas about the structure and evolution of the CGH chain. The model, as already mentioned, assume two structural units corresponding to two evolutionary stages of the volcanism: an early one, the so called "volcano-sedimentary formation" mapped at the peripheries of the chain, and a later one, dominantly effusive, giving rise to the axial stratovolcanic edifices with obvious topographic expression (e.g., Peltz, Peltz, 1968). This model (Fig. 6) became so influential and undisputable that it was the unique paradigm and adopted by all the researchers since during the Communist regime as the only valid structural model of the CGH chain. Even more, this model is still embraced, in particular within the geographical community in Romania, despite that fact, that it was infirmed in the 1990's, as shown in the next section. This model was adopted also in the geological map of Romania, scale 1:1.000.000 (Săndulescu *et al.,* 1978).

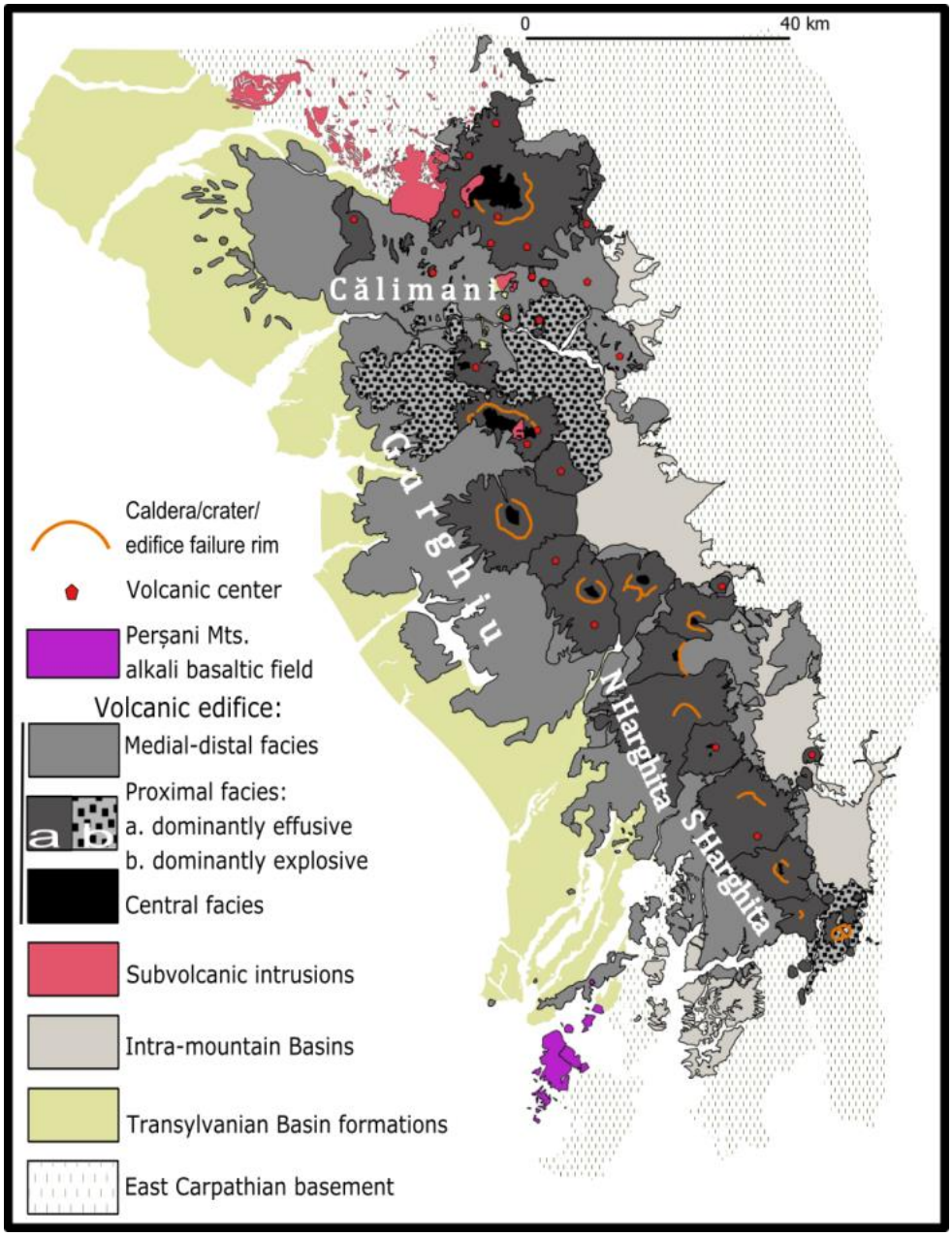


Fig. 9. Simplified volcanic facies map of the Călimani-Gurghiu-Harghita volcanic range (modified from Szakács and Seghedi, 1995), acc. Seghedi *et al.* (2019).

The geological structure of the northern part of the Călimani segment of CGH, including its major volcanological features and time-space evolution was mostly elucidated by I. Seghedi in his PhD thesis (Seghedi, 1987), but only later published (Seghedi *et al.*, 2005). According to this study, the huge Călimani Caldera volcanic edifice is both underline by pre-volcanic intrusions (pre-volcanic intrusive basement", as the "Cluj School" claimed), and is pierced by a post-caldera monzodiorite intrusion (acc. to the "Bucharest School") (Fig. 10).

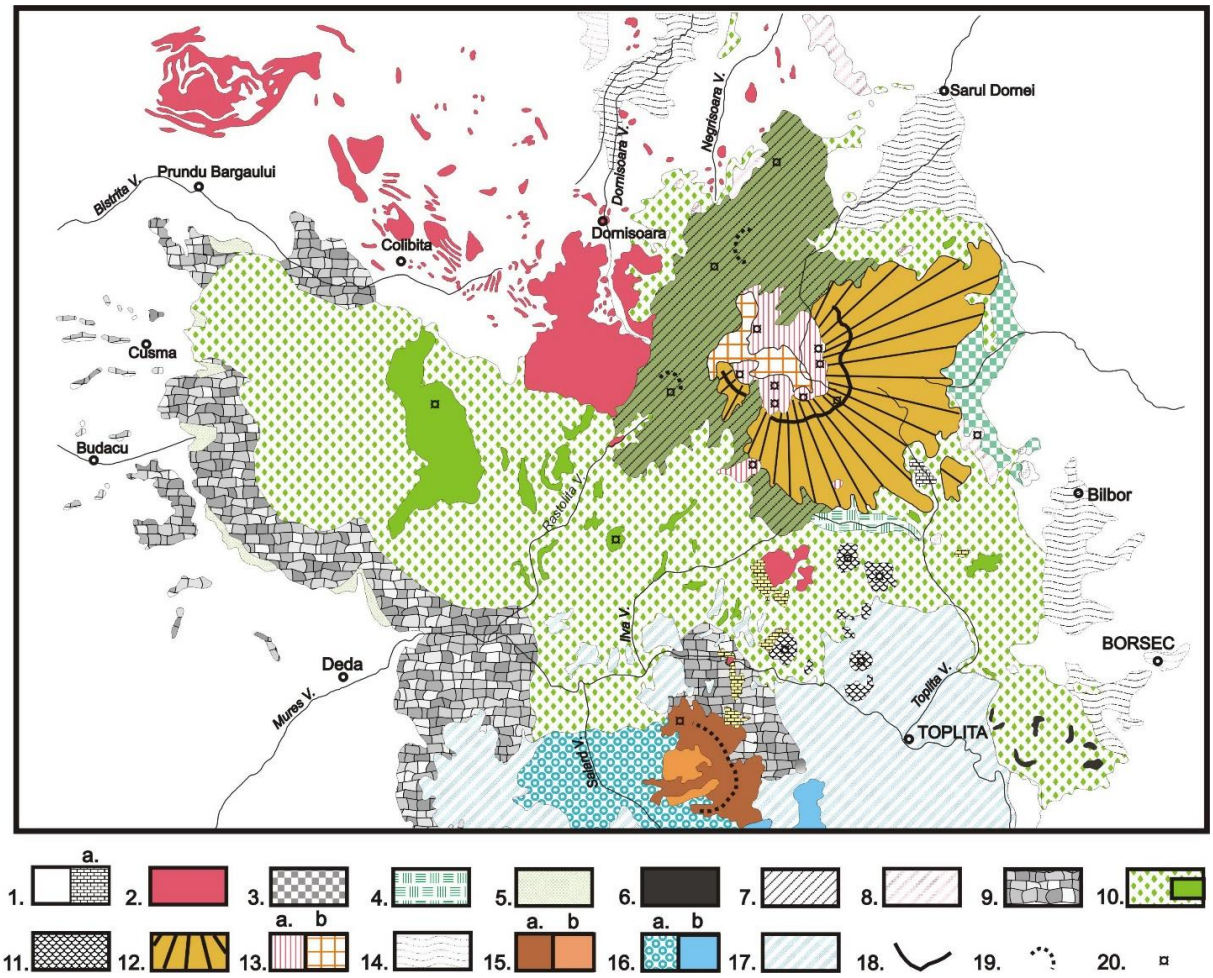


Fig. 10. Volcanological map of the Călimani Mts. and northernmost part of the Gurghiu Mts. (acc. to Seghedi *et al*., 2005, modified). Legend: 1. Prevolcanic basement (a – inside the volcanic area), 2. Early intrusions, 3. Drăgoiasa formation, 4. Lomaș Formation, 5. Budacu Formation, 6. Sărmaș basalt shield volcano, 7. Rusca-Tihu stratovolcanic edifice, 8. Aphyric andesite lavas, 9. Rusca-Tihu debris avalanche deposit, 10. Rusca-Tihu volcaniclastic formation with intercalated lava flows, 11. Peripheral domes, 12. Călimani Caldera lava flows, 13. Post-caldera volcanic rocks, 14. Upper Pliocene-Quaternary sedimentary basins, 15. Jirca volcanic edifice, 16. Fâncel-Lăpușna pre-caldera rocks, 17. Fâncel-Lăpușna volcaniclastic Formation, 18. Topographic caldera rim, 19. Topographic crater rim, 20. Volcanic vent.

The 1: 50,000 scale mapping activities performed by the Geological Institute in the pre-1990 period, resulted in important findings related to the volcanic structure of the CGH at its various parts (those mapped) prefiguring the need for introduction of a new structural model of the whole CGH, supported by numerous radiometric age data and finalized later, in the 1990's.

5. POST-COMMUNIST PERIOD

The post-Communist period (1990 – present) brought a number of essential changes in both mapping and understanding the structure and evolution of the CGH chain.

5.1. MAPPING IN THE POST-COMMUNIST PERIOD

The geological mapping at scale 1:50,000 in the territory of CGH continued after the political changes of late December 1989 in Romania for a number of years as long as financial support of this activity was granted. A number of new map sheets were initiated whereas work on others continued, some of them even finalized and published, others unpublished. As a result, the northern part of CGH (Călimani Mts. and northernmost part of the Gurghiu Mts.) became practically covered by mapping activities and related studies, whereas in the southern third of the chain new map sheets were added (e.g., Chirui, published in 1991 and, Vlăhiţa, not published). However, the researchers involved in this activity had to cope with a serious dilemma when working on map sheets adjacent to older sheets, mapped using mostly rock petrography with little, if any, structural meaning, whereas the new works intended to offer a cartographic representation significant from the structural and volcanological point of view. These circumstances obliged the geologists to find "compromise" graphic solutions at the boundaries between the old and the new maps, obviously at the expense of accuracy.

At present the situation of the scale 1: 50,000 map of Romania in the territory of the CGH chain is the following: 7 sheets (Poiana Stampei, Șarul Dornei, Voșlăbeni, Miercurea Ciuc, Odorheiu Secuiesc, Chirui, Sănmartin) ready and published, 6 sheets (Poiana Stampei, Coșna, Negoiul Românesc, Stânceni, Toplița, Vlăhița,) ready but not finalized and published, and the rest of the sheets not even started. This latter case mostly concerns the middle part (Gurghiu Mts.) of the CGH chain. The perspectives of finalizing the 1: 50,000 scale mapping of the CGH area in the future is nil, since the persons having expertise in volcanology and mapping are old and retired and there is nobody to follow them, not to speak about the total lack of leadership and financial support for such an activity.

5.2. EVOLUTION OF IDEAS RELATED TO THE STRUCTURE OF THE CGH CHAIN

The continuation of the mapping program for a number of years after 1990, as well as the completion of other volcanologic, petrologic and metallogenetic studies at the Geological Institute of Romania, led by a few researchers also benefiting from international cooperation including PhD research of foreign students in the area, and research stages at high-quality foreign universities and laboratories, enabled rising the knowledge on the volcanic structure and evolution of CGH to a higher level. The major factors allowing such an important qualitative step forward were: 1) performing a statistically significant large number of radiometric dating of volcanic rocks in international Academic cooperation (mostly at the Geochronology Laboratory of the Institute of Nuclear Research – ATOMKI – in Debrecen, Hungary), and 2) access to up-to-date analytical facilities at foreign laboratories through fruitful international cooperation resulting in high-quality and consistent petrological information (major and trace element data, including REE distribution, and stable isotopic analyses, microprobe analyses of rock-forming and accessory minerals). All these developments allowed the involved researchers to understand not only the time-space evolution of volcanism in CGH but also its petrogenetic aspects and geodynamical connections (e.g., Lexa *et al.*, 2010; Pécskay *et al.*, 2006; Seghedi *et al.*, 2004, 2019), despite the major shortcomings related to the mapping activities mentioned above. This important gain of geochronologic and petrogenetic information, corroborated with the results of earlier mapping-obtained information, as well as the progress of volcanological knowledge worldwide internalized by Romanian researchers (by up-to-date professional literature but also by stages of study and visits at active volcanic areas of the world (e.g., Japan, Mexico, Canary Islands, Cascade range of U.S.) led to the formulation of a new view on the structure of the CGH chain, consistent with international models of volcanism and volcanic areas.

The first modern volcanological studies (modern period in volcanology starts with the complex eruption of Mt. Saint Helens volcano, in USA, on 18.05.1980) were conducted in the Harghita Mts. starting with the late 1980's and continued in the 1990's by local case studies (Szakács, Seghedi, 1989, 1991; Szakács, Jánosi, 1989).

Incorporating information gained during mapping and localized research on particular volcanoes (Călimani, Şumuleu, Cucu, Ciomadul) with radiometric age data and petrologic information, a new structural model of the CGH chain emerged (Szakács, Seghedi, 1995) substituting the earlier "two structural compartments" of Rădulescu *et al*. (1973). According to this new model, expressed in terms of volcanic facies, the peripherally occurring volcaniclastic deposits are the low-lying medial ring-plane facies of the neighboring axial composite volcanic edifices (central and cone facies) to which they are coeval, according also to the radiometric age data. This structural concept is illustrated by the facies sketch-map of the CGH chain (Szakács, Seghedi, 1995, Fig. 11). Moreover, all individual volcanic edifices were accurately identified, nominated and outlined at the level of their cone and central facies with their respective boundaries traced on the map (Fig. 11). However, on these early maps, the peripheral volcaniclastic deposits could not be individualized, related to their source volcanoes and, as so, marked cartographically (Fig. 11).

The next step was the recognition and genetic interpretation of the lithological composition of the peripheral volcaniclastic formations. In this respect the recognition of the large-volume debris-avalanche deposits (DAD's), as the major component of the medial facies volcaniclastic formations, was an important progress. First, two of them (the Rusca-Tihu DAD and the Vârghiş DAD) were recognized, dated and outlined (Szakács, Seghedi, 2000), realizing that these large-volume formations are distributed over huge areas transgressing not only volcano boundaries but also the limits between volcanic segments (such as the ca. 8 Ma old Rusca-Tihu DAD, originating in the North-Western Călimani Mts., covering large areas to the west, south-west and south, in both the Călimani Mts., and Northern Gurghiu Mts., underlying younger volcanic formations and even whole volcanic edifices). More recently, further DAD's were identified in all CGH segments, realizing that this kind of volcaniclastic deposits is the overwhelmingly major component of the medial volcaniclastic ring-plain facies around the composite volcanic cones (Seghedi *et al*., 2017). The combination between the facies distribution of volcanic deposits and the space-time migration of volcanism from north-west to south-east resulted in an intricate complex structure of the medial facies, making difficult to trace back individual volcaniclastic formations (such as DAD's) to their source volcanoes, and represent this cartographically in an accurate and suggestive manner (e.g., Figs. 9, 11). This task is still to be realized in the next future. However, at the scale of individual CGH segments the volcanological approach including current knowledge into the map representation of volcanic structures and formations is realized and published in professional papers in the case of the Călimani Mts. (Seghedi *et al*., 2005; Fig. 10). In contrast to earlier maps, this new type of cartographic image of the area is much more relevant and illustrative from the volcanological point of view. The 1: 50,000 scale map sheets covering most of the Călimani Mts., being mostly completed, this new cartographic concept of the area is not reflected in the published official maps series.

Another significant progress in understanding the geological structure of the CGH chain, including its basement, is represented by the recognition of structural coupling and interaction between large volcanic edifices and their pre-volcanic basement including plastically deformable rocks, leading to the process called "volcano spreading", with consequence in both the edifices (lateral spreading and central subsidence), and basement (salt extrusion and enhanced diapirism, formation of revers fault swarms) as pointed out in the western side of the Călimani, Gurghiu and North Harghita Mts. at their conjunction with the Transylvanian Basin (Szakács, Krézsek, 2006).

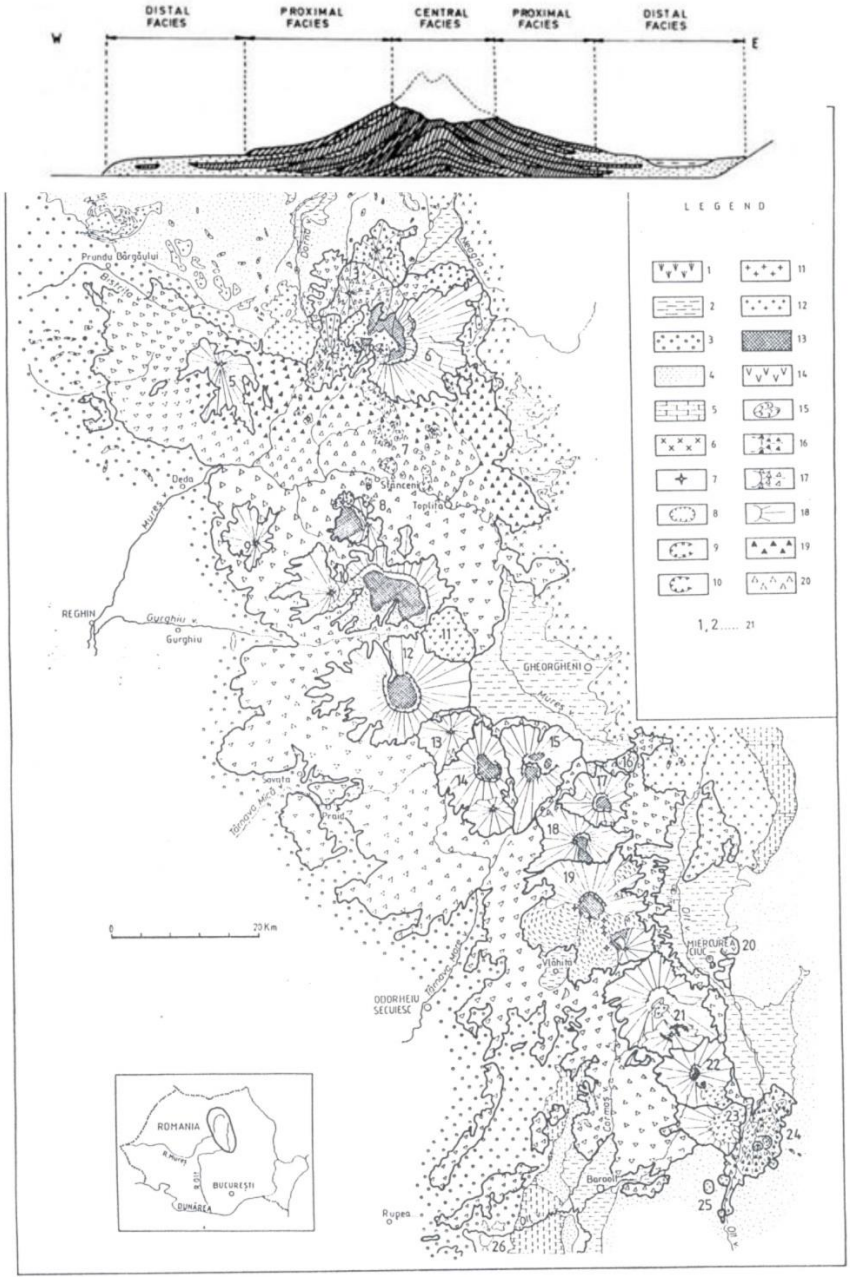


Fig. 11. The first volcanological map of CGH drawn according to the volcanic facies concept (Szakács and Seghedi, 1995); the corresponding structural model is shown in the top panel. Legend: 1. Quaternary swamp or lake deposits; 2. Tertiary postvolcanic and synvolcanic sediments; 3. Tertiary prevolcanic molasse sediments of the Transylvanian basin; 4. Cretaceous-Tertiary sediments of the East Carpathians Flysch zone; 5. Late Paleozoic-Cretaceous sediments of the East Carpathians; 6. Precambrian-Paleozoic metamorphic and plutonic rocks of the East Carpathians Crystalline-Mesozoic Zone; 7. Neck; 8. Crater; 9. Caldera-like depressions; l0. Collapse calderas (caldera fault); 11. Porphyritic intrusive rocks; l2. Fine porphyritic intrusive rock; l3. Volcanic core complexes; l4. Extrusive domes; l5. Lava flows; l6. Pyroclastic cone; l7. Stratovolcanic cone; l8. Effusive cone; l9. Coarse pyroclastic rocks – proximal facies; 20. Mudflow, debris avalanche, debris flow and ephemeral stream epiclastic volcanic rocks; 2l. **Volcanic edifices and areas**: CĂLIMANI MTS: l. Drăgoiasa; 2. Lucaciul; 3. Tămăul; 4. Rusca-Tihu; 5. Moldovanul; 6. Călimani; 7. South Călimani volcanic field; GURGHIU MTS.: 8. Jirca; 9. Obârşia; 10. Fâncel-Lăpuşna; 11. Bacta; l2. Seaca-Tătarca; l3. Borzont; l4. Şumuleu; 15. Ciumani-Fierăstraie; NORTH HARGHITA MTS.: 16. Răchitiş; l7. Ostoroş; l8. Ivo-Cocoizaş; 19. Vârghis; SOUTH HARGHITA MTS.: 20. Şumuleu Ciuc; 21. Luci-Lazu; 22. Cucu; 23. Pilişca; 24. Ciomadul; 25. Bicsad-Malnaş field.

6. CONCLUSIONS

There is an obvious quality increase starting from the earliest maps up to recent times in the CGH volcanic range. The improvements are closely connected with increasing knowledge mostly due to volcanological studies since 1980 that made an important step worldwide. This progress starting with simple understanding of volcanic structures up to the evolved concepts of volcanic facies around volcanoes and up to the understanding of the role of debris avalanche deposits in the volcanic development of CGH was concisely revealed. Such results, not yet completed implied, besides an enormous amount of hard fieldwork of numerous geologists, aquisition of a large volume of data in different domains (petrography, geochemistry and volcanology) that we hope to be in the benefit of the future generations of geologists studying CGH.

Statement: Ioan Seghedi (mostly cap. 1, 2, 3 and 6) and Alexandru Szakács (mostly cap. 4 and 5) contributed similarly to the text.

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