Dávid Karátson · Daniel Veres ·
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Ciomadul (Csomád), The Youngest Volcano in the Carpathians

Volcanism, Palaeoenvironment, Human Impact

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Preface

"My own guiding principle…is the idea of the brotherhood of peoples – becoming brothers and sisters in spite of all wars and conflicts"

(Béla Bartók on his Cantata Profana, 1931)

During his life, the main aim of Béla Bartók, the greatest Hungarian composer of the twentieth century, was to understand and popularize the folk music of the people living in the Carpathian Basin. As a result of his own field trips, he collected thousands of original Slovakian and Romanian folk songs. While doing so, he was working in the Austro-Hungarian Monarchy, which indeed comprised a diverse range of people, languages and cultures. Bartók's work greatly contributed to recognizing the values of ancient Hungarian, Romanian and Slovakian folk music. Ironically, during the years of his collection work (the first two decades of the twentieth century), instead of building brotherhood, the peoples of the Carpathian Basin were infected by growing nationalism. Eventually, the Monarchy participated in the First World War, at the end of which the Austro-Hungarian empire fell apart and the descendant states (Austria, Hungary, Czechoslovakia, the Ukrainian part of the Soviet Union, Romania and Yugoslavia), each with a significant number of minorities, became enemies. Unfortunately, the hostile and tense relations were conserved, and after the Second World War, the peoples of the Carpathian Basin (except for Austria) lived under communist regimes for four depressing decades of comradely "friendship". After the political changes in 1990, with several countries becoming EU member states, these relations have been slightly improving, but are far from satisfying.

Hundreds of years earlier, the situation was completely different, in particular, in the eastern region of the Carpathian Basin called Transylvania (Erdély in Hungarian, Überwalt or later Siebenbürgen in German, and Ardeal in Romanian). There, according to the historical record, Hungarians (represented partly by a specific ethnic group, the Székelys, also known in German-speaking countries as Szeklers), Vlachs (Romanians), and Germans (Transylvanian Saxons) had inhabited the area from at least the twelfth century. These people cooperated in many ways, making Transylvania in the Middle Ages a powerful and rich country of subsequent principalities.

The land of Transylvania, especially its eastern part—the Eastern Carpathians—which was populated mainly by the Székelys, is rich in natural resources and beautiful landscapes. Rising above 1500–2000 metres, the Eastern Carpathians consist of a number of mountain ranges constituting a typical orogen (a so-called thrust-and-fold belt). On the internal side of the orogen, the most common of a huge variety of rocks are andesite and dacite—volcanic rocks that reveal an extended, c. 10 million year-long volcanic history that lasted almost up to today. As a result, well-preserved volcanic landforms, covered by dense forests and divided by breathtaking, smaller to larger basins, dominate the landscape. At the southern end, where volcanism is the youngest, post-volcanic phenomena, such as mofettes, sulphurous precipitations, and precious mineral waters, make the land unique in East-Central Europe.

This southern tip of the volcanic chain is called the Ciomadul-Puturosu Hills (in Romanian), or, in the language of the surrounding Székely Hungarian inhabitants (the largest minority in Romania), the Csomád-Büdös Hills. Puturosu/Büdös means 'stinky', the name clearly reflecting the sulphur odour obvious at several localities. This name is known from written sources from the early eighteenth century and its correct interpretation was given at first by the Saxon mineralogist Johann E. Fichtel, who wrote that *der sogenannte Bůdősch […] ein von innen noch immer brennender Vulkan ist*, that is, *the so-called Stinky Hill … is a volcano still burning from within* (Nachricht von den Versteinerungen des Großfürstenthums Siebenbürgen, 1780). Stinky Hill, with its sulphurous caves and therapeutic mofettes (carbon dioxide emanations) became famous Europe-wide, attracting visitors and scholars from remote countries too.

In addition to Stinky Hill, a major attraction of the Ciomadul-Puturosu Hills are its twin craters: the older, larger Mohoş (Mohos), which is already breached and filled by a peat bog, and the younger, deeper and circular-shaped Sf. Ana (Szent Anna), in English St. Anne, which hosts a picturesque crater lake. The mysterious lake with its dark waters was first mentioned on maps in the mid-eighteenth century. It was highly appreciated by the local people, especially in summertime benefitting from its particular location and cold microclimate. Moreover, for more than two centuries, the area has given momentum to scientists from nearby towns to remote countries, eventually leading to international collaborations, studying the peculiarities of the related volcanism—rocks, minerals, raw materials, rare plant species, and archaeological findings.

It has turned out that the history of the land is not less diverse and complex than that of the people who lived or still live there. Due to the unique and continuous research efforts, we do know that Ciomadul was the site of the youngest eruption of the whole Carpathian Basin less than 30 thousand years ago and that its volcanic activity dates back to almost 1 million years. We know that the twin craters were formed by colossal explosive eruptions—first sourced at Mohoş, then at Sf. Ana crater—during the final eruptive phase from c. 50 thousand to less than 30 thousand years ago. We have also learned a lot about the palaeo-environmental history of the latest period of volcanic activity—the Late Quaternary—by studying the unique record of the lacustrine infill of the twin craters.

The idea of this book was born in 2015, when an international research group, including the present editors, started to pursue a complex volcanological project on the eruptive activity of Ciomadul. Several of us, however, had already been working in the area for many years and realized that the scientific results, alongside a large amount of information accumulated in the past decades, are important not only for the research community, but also for the greater public.

In view of this, we believe that the exciting, multidisciplinary research results obtained in this remarkable area and the lessons emerging from Ciomadul's studies should not only be presented to the international professional audience (geologists, volcanologists, botanists, archaeologists, historians, and teachers in natural and human sciences), but also disseminated in the local and regional context for the Székely Hungarians and Romanians, who live together with the volcano, for the thousands of visitors each year arriving from wider areas, and for those planning a trip to the volcanic landscape to support their eco-conscious tourism. Thus, the book aims to serve scientists to get acquainted with the scientific characteristics of Ciomadul from as many aspects as possible and to provide information at a general level for interested laypersons and decision-makers. Fulfilling these objectives, the book presents the state-of-the-art of science in a style that intends to remain reader-friendly, trying to match popular scientific requirements as much as possible.

As the Council of Europe recognized, regional or minority languages are part of Europe's cultural heritage and their protection and promotion contribute to the building of a Europe based on democracy and cultural diversity. In harmony with this, in this book, we follow the European Charter for Regional or Minority Languages (1992) about the use of toponyms: when first mentioned in a chapter, either in the text or in figures/maps, the official (i.e. Romanian) names are always followed (in brackets) by the names used by the minority population (i.e. the Székely Hungarians).

The book is divided into two parts. The first part, after summarizing the research history of Ciomadul, presents the details of the volcanism and related topics in eight chapters; the second part deals with the palaeo-environmental aspects of the larger area, along with its human history in nine chapters.

Chapter 1 (Csaba Jánosi et al.) covers the geoscientific exploration, including the earliest written records along with the origins of names and their map representation, and milestones in geology and volcanology, with an emphasis on dating volcanic rocks, the use of mofettes and mineral waters, as well as botanical research, history, and tourism. Chapter 2 (Liviu Matenco) introduces the reader to plate tectonics and the geological structure of the larger area of Ciomadul, the Southeast Carpathians. Chapter 3 (Dávid Karátson et al.) presents details of the eruptive activity of Ciomadul: how volcanism evolved, what kind of eruptions occurred, and what volcanic landforms and deposits were produced. Chapter 4 (Alexandru Szakács and Ágnes Gál) deciphers the origin of volcanic rocks: their study, their nomenclature, and their formation including magma genesis and differentiation. Chapter 5 (Sabine Wulf et al.) considers the explosive eruptions of Ciomadul in a regional context, presenting how pyroclastic formations can be

correlated by using tephrostratigraphy. Chapter 6 (Daniel Veres et al.) presents the details of syn- and post-eruptive landscape evolution, and explains contemporaneous surface processes by investigating sedimentary successions and interbedded pyroclastic layers (tephras) in the larger Ciomadul area. Chapter 7 (Alexandru Szakács) considers the exciting question of the current status of Ciomadul volcano, with emphasis on potential future activity and the media coverage of the topic. Finally, Chapter 8 (Csaba Jánosi et al.) presents the peculiar minerals, mofettes and acidulous mineral waters of Ciomadul, including its famous spa culture.

Part II starts with Chapter 9 (Enikő K. Magyari et al.) that presents the palaeo-environmental changes of Ciomadul in the past 30 thousand years as revealed and deciphered from boreholes drilled into the lake sediments of Sf. Ana. Chapter 10 (Krisztina Buczkó et al.) focuses on the specific history of the lake, showing the limnological changes, also based on the lacustrine infill. Chapter 11 (Ioan Tanţău et al.) presents the Holocene vegetation history of Ciomadul using, again, borehole records, in particular, pollen data from both Mohoş and Sf. Ana, placing the results into the context of the Southeast Carpathians and showing human impact. Chapter 12 (Jack Longman et al.) covers the variations of chemical elements in the Mohos lacustrine infill, presenting how these changes can be related to specific environmental (e.g. climate) events and human-driven metal pollution. Chapter 13 (Zoltán-Róbert Para and Krisztina Tóth) shows the present-day flora and fauna of Ciomadul, ranging from the brown bear through the peat bog communities to rare species such as Siberian ligularia or mouse-eared bats. Chapter 14 (Marian Cosac et al.) presents interesting findings from caves in the karst area of Vârghiş (Vargyas) Gorges, that host Ciomadul ash layers and help with the timing of human appearance and abandonment in Palaeolithic times. Chapter 15 (Sándor-József Sztáncsuj and József Puskás) deals with the long time interval from the Neolithic to the Bronze Age, listing the surprisingly rich archaeological finds of the larger region. Chapter 16 (István Botár) shows the details of the earliest human settlements and human history in the Ciomadul region from the age of migrations (3rd century) to the Middle Ages (15th century). Finally, Chapter 17 (Ágnes Herczeg et al.) provides an account of the landscape history and land use from the Middle Ages to modern times, and the concept of the Ciomadul-Balvanyos Region, along with present-day and future eco-tourism.

The chapters in this book are authored by over fifty colleagues, who have been gathered from local Székely Hungarians through Romanian scientists to researchers from Hungary and all over Europe (France, Germany, United Kingdom, The Netherlands), all recognized in their research field. Hopefully, the diverse author content itself symbolizes the main aim of the book as described above, at least this time exceeding the stressed historical-political past of the Carpathian countries—and in harmony with the Bartókian concept.

Budapest, Hungary
July 2021

Dávid Karátson
on behalf of the editors

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01 August 2021

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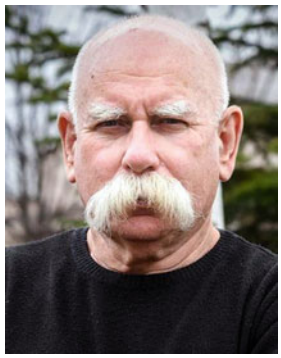
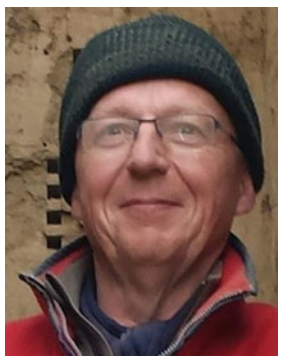
Enikő K. Magyari Palynologist focusing on the environmental history of the Carpatho-Balkan Region during the last 30,000 years using pollen, plant macrofossil, and multi-proxy palaeoecological methods.



Csaba Jánosi Retired geologist, environmentalist, creating nature trails, developing mineral water- and spa culture, and giving popular scientific talks in his homeland, the Ciuc (Csíki) Basin.



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Part I

Volcanic Eruptions, Landscape Evolution and Postvolcanic Phenomena

History of Research: Geoscientific Exploration of the Ciomadul Hills

1

Csaba Jánosi, Dávid Karátson, and Ferenc Wanek

Abstract

Székelyland in Transylvania (Romania) has few regions as unique as the Ciomadul (Csomád) Hills in their unparalleled beauty. Professionals have been researching this distinctive volcanic region for centuries. Earth scientists study the young volcanic cones, igneous rocks, mineral springs, and mofettas; limnologists probe the waters of Sf. Ana crater lake; botanists roam the peat bog of the Mohoș crater. Ancient fortresses of the region are fascinating subjects for archaeologists, rich folklore and traditional beliefs have inspired many of the greats of Hungarian literature. And research is still on going in recent times.

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1.1 Geographic Setting

The Ciomadul (Csomád) Hills form the southernmost part of the volcanic region of the Călimani-Gurghiu-Harghita (Kelemen-Görgényi-Hargita) mountain range on the east side of the Transylvanian Basin, Romania. It is wedged between the Ciucului (Csíki-havasok) and Bodocului (Bodok) mountains, and the Lower Ciuc (Alcsíki) and Bixad (Sepsibükszád) basins (Fig. 1.1). Nestled in the centre of the volcanic structure, and giving the region its charm and most attractive geographical feature, are the twin craters filled by Lake Sf. Ana (in Hungarian, Szent Anna; in English, St. Anne) and the peat bog of Mohoș (Mohos). Lake Sf. Ana is the site of the last volcanic eruption of the Carpathian-Pannonian region. The somewhat older Mohoș is filled by a peat bog, drained by the Roșu (Veres) stream. In the north, at the edge of the Ciuc (Csíki) Basin, the Ciomadul Hills are bordered by the separate cones of Haramul Mic (Kis-Haram), Haramul Mare (Nagy-Haram), Haramul Ierbos (Fű-Haram), Scaunul Vârghisului (Vargyasszéke), the long ridge of the Ciomadul Mare (Nagy-Csomád), and the truncated cones of Vârful Surduc (Szurduktető) and Vârful Cetății (Vár-tető) (Fig. 1.2). On its southern border is the separate eruption centre of Heghieşul Mare (Nagy-hegyes). To the east, on the border of Harghita (Hargita) and Covasna (Kovászna) counties, rise the solitary cones of the Puturosu (Büdös/Stinky) Hill and Balvanyos

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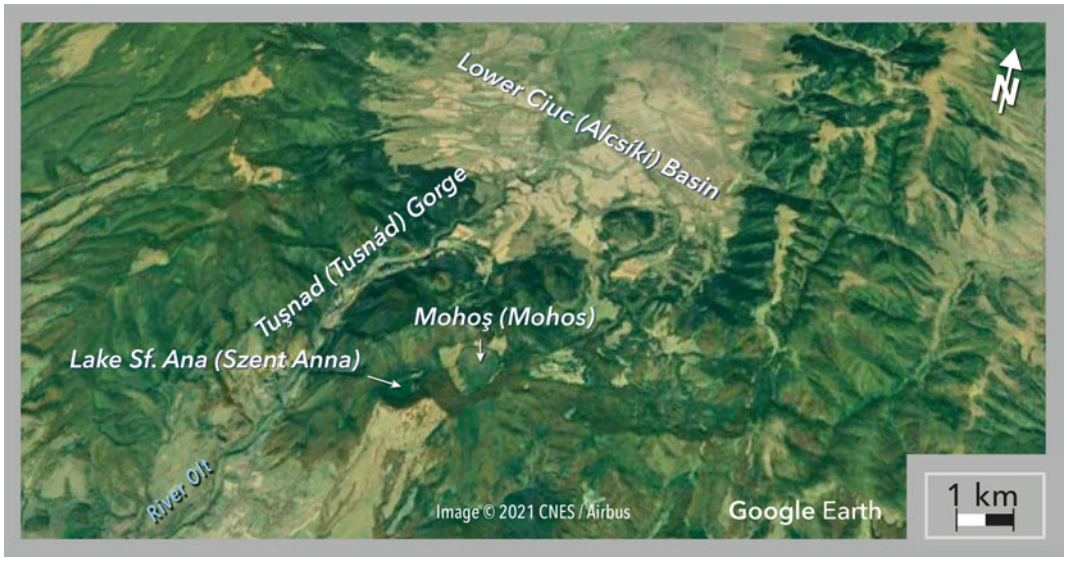


Fig. 1.1 Located between the Lower Ciuc (Alcsíki) Basin in the north and the enlarging alluvial plain of River Olt leaving the Tuşnad (Tusnád) Gorge to the south, the Ciomadul Hills mostly consist of a group of amalgamated volcanic cones (so-called lava domes) which are truncated by a twin crater: Sf. Ana/Szent Anna (occupied by a crater lake) and Mohoş (Mohos) (already filled by a peat bog). Oblique Google Earth image

Fig. 1.2 The Ciomadul Hills as viewed from the north (*Photo* Dávid Karátson). The flat-topped cone to the left is Haramul Mare (Nagy-Haram); on the right, Vârful Surduc (Szurduk-tető) overlooking the Tuşnad (Tusnad) Gorge

(Bálványos) Hill. Scientific literature often groups these together with Ciomadul itself, referred to as Ciomadul-Puturosu (Csomád-Büdös) Hills (see more in Chap. 3). "*This term was used by Antal Koch a good hundred years ago, and also by Ferenc Herbich—although in a reverse order, since they called the entire area of these mountains as the Stinky (Puturosu/Büdös) massif*" writes András Kristó (1995), a teacher of geology-geomorphology, and a renowned twentieth century naturalist of Székelyland.

1.2 Medieval to Early Modern Written Records of Ciomadul Hills

In this chapter, to review the history of geoscience of the Ciomadul area, the "Land of the Giants and Fairies" as it was known in medieval times, we must recall the earliest legend of the region. The people who inhabited the area explained the mysterious peaks and mountain lakes with an "origin story". The great Hungarian storyteller, Elek Benedek, recounts the tale this way (*A Szent Anna-tó keletkezése*/The origin of Lake Sf. Ana):

"*A long time ago, where the slow waters ripple today, there was a proud castle reaching to the sky on top of a high mountain. Across this castle there was another castle on the mountain peak above the Stinky (Puturosu/Büdös) Cave. These two castles belonged to two brothers who could never see eye to eye and were constantly quarrelling. The only thing they agreed on was to torment their serfs in the villages. Once the lord of the castle above Stinky Cave won an exquisite golden carriage and six magnificent horses by playing cards. He hurried over to his brother to brag about his win, being convinced that no finer horses could be found near or far. He promised his brother his castle and all his possessions if he could come to Stinky Castle with even better horses.—I'm coming with twelve! sneered the brother. He ordered his servants to bring the fairest maidens to him from the countryside. He then selected twelve of them, the most beautiful was Ana. The brother seized the girls, harnessed them up, and—instead of horses—made the girls pull his carriage. He was whipping them mercilessly. As blood was streaming from Ana's back, she cursed the brutal lord wishing the earth would swallow him up. Right then and there the earth shook with thunder and lightning, the tower swayed, and then the entire castle collapsed sinking into deep waters. Where once the proud castle stood, there was a lake with twelve lovely swans swimming in the waves. They swam ashore, shook themselves and became maidens again. Eleven of them fled back to their villages but Ana stayed by the lake. She built a chapel on the shore and lived out her life there in silent prayer. After news of her spread far and wide, pilgrims started to visit the chapel. The people called the lake Sf. Ana in memory of the saintly girl.*"

The first written record of any place names from the Ciomadul Hills is found in the Mikó family's forest survey report, prepared for the Hungarian King, Louis the Great, in 1349. As most of the early written documents in Hungary, this is in Latin as well. "*Prima scilicet meta incipit in campo Bezedmezew uocato, a parte septem-trionali, ubi iuxta metam terream, aliam de nouo similiter terream, in cuiusquidem Campi alia parte uersus partem orientalem, vnam metam terream iuxta antiquam, deinde progrediendo, ad eandem partem orientalem ad toberch kuzberch et Bydushyg peruenitur, abhinc eundo ad partem meridionalem peruenitur ad Somburfw, directe ulterius eundo, uenitur ad Gerebenchfw, et Zaldubuspotakfw, quod declinat ad fluuim Olth (…)*". Boér and Tamás (2018) offer a translation in their book *Szentanna:* "*The first border sign is at a place called Bezedmezew, in its northern parts, where a new earthen mound was erected beside the old one. In this same field, to the east, another earthen mound was built beside an old one. Then travelling further in the same easterly direction, they reached Toberch, Kuzberch, and Bydushyg. From there they headed south towards Somburfw, and from there straight on to Gerebenchfw and Zaldubospotakw, which slopes towards the river Olt.*" Further investigation of the place names makes it probable that Jimbor village (Somborfalva, part of present-day

Bixad/Sepsibükkszád), the Jimbor (Zsombor) stream, and Bója (Boiu), or Bója Hill at Tuşnad (Tusnád), can be linked to Zsombor, the tenth century Transylvanian '*gyula*' (chieftain of the Hungarian tribes), and to his son, Bója. Geographical names ending with the letter '*d*', such as *Csomád* or *Tusnád*, also suggest this early origin.

The lake is first mentioned as Lake Sf. Ana in a Latin manuscript *Siculia* in 1702 by István Lakatos, pastor of the Cozmeni (Csíkkozmás) parish: "*The deepest is Lake Sf. Ana above the mountains of Tuşnad, surrounded by peaks and without an outflow. Near the lake there are ordinary stones suitable for building and carving*". There are two theories about the origin of the name. One is that the lake was named after Saint Anne by the medieval sulphur miners of Turia (Torja), Tuşnad, and Lăzărești (Csíklázárfalva) who considered Virgin Mary's mother to be their patron saint. While in another theory, Jesuit inspiration is behind the name. Jesuit monk Ferenc Kunits states in his book *Dacica siculica,* printed in Cluj (Kolozsvár/Klausenburg) in 1731: "*Close to the same place rises Sf. Ana's mountain, the top of which is largely occupied by a lake. It can be walked around in three hours and is so deep that it has refused to give up her secret to anybody trying to measure her depths. (…) Her secrets include that at certain times her waters swell higher than the sea, though no rivers feed her; other times her waters flood the fields below. The storms and intense hail arising from here destroyed the neighbouring countryside so much so that its people, not trusting their own human strength, were forced to seek God's and the saints' intervention. Their hope was not in vain. With unprecedented fear of God, and reverence to Sf. Ana, the mother of Mary, they named the mountain Sf. Ana. God listened to their prayers and yearly supplications and quieted the elements.*"

The chapter *Útiképek Székelyföldről* (Travels in Székelyland), in Lajos Réthi's 1868 volume *Magyarország képekben* (*Hungary in Pictures*), mentions the pilgrimage to Lake Sf. Ana. "*The people feel a certain mystical reverence for the lake (…). Pilgrimages are usually held here twice a year; each time multitudes come from the surrounding Catholic regions: Gheorgheni (Gyergyó), Ciuc (Csík), and the northwestern part of Trei Scaune (Háromszék). The pilgrims walk slowly around the lake and chant holy hymns following their priest. I was told that a long time ago people believed that a monster, the grandson of fairy-tale dragons was living in the lake. So, at the pilgrimages they prayed for the demise of this monster. The priest sang: »The monster living in this lake«; to which the people answered in unison »Drop dead and be lost!« The people got used to chanting this answer so much that when the priest started the litany of the saints, the people still answered the same!*".

Mózes Vitos recalled in one of his *Csíkmegyei Füzetek* (*Notes from Ciuc*) (1894–1902) that these pilgrimages on St. Anna's feast day "*often counted crowds of twenty or thirty thousand. Due to bloody fights and rowdy behaviour of drunkards these pilgrimages were banned. First, by Bishop Ignácz Battyáni on August 13, 1786, then a second time for the same reasons in 1844 by Bishop Miklós Kovács, shortly after the pilgrimages started again in the 1830s.*"

The crater lake of Ciomadul first appeared on a published map around 1720. Johann Baptist Hofmann's map of Transylvania shows the lake with a "*videlt palus*" (certainly a lake) note. The map of the Josephinian Land Survey of Transylvania (compiled between 1763 and 1787) already shows a St. Anna Teich (with the location of the nearby chapel), as well as other locations such as Büdes Hogy, Csomal *[sic]*, Kis Hegyes, Nagy Hegj above Bükszat, Kö Ponk, Fenÿas Ponk, Nagÿ Harrom as well as several streams, like Sombor Patak, Hallasag Patak. An earlier map in Ignaz Müller's manuscript from 1769 shows a "Lacus S. Anna", but this particular document was top secret, so much so it remained unknown to his contemporaries. Anton Wenzely's map, printed in 1789, also shows the crater lake of Ciomadul as *S. Anna See*, accompanied by a geographical place name of *Varteteje* (Vârful Cetăţii). The lake increasingly became a symbol of the Ciomadul region for visitors, and at the same time a major focus of later scientific research (Fig. 1.3).

Fig. 1.3 Crater lake of Sf. Ana (Szent Anna) in winter, from the Belvedere lookout point established near the winding road leading down to the lake. Even with global warming, the ice on the lake freezes tens of centimetres every year and can last until March (*Photo* Dávid Karátson)

1.3 Getting to Know the Geology and Volcanology of Ciomadul

1.3.1 History of Geological and Volcanological Research

The first geological study of the Ciomadul Hills, including the Putorosu Hills and Stinky Cave of Turia, was published by mineralogist Johann Ehrenreich Fichtel of Sibiu (Nagyszeben) in the second volume of his major work, *Beytrag zur Mineralgeschichte von Siebenbürgen* (Contributions to the Mineral History of Transylvania), *Nachricht von den Versteinerungen des Großfürstenthums Siebenbürgen* (Report on the Fossils of the Grand Duchy of Transylvania), published in Nürnberg (Fichtel 1780). In the postscript of the second volume, on p. 122, he wrote: "*...der sogenannte Bůdősch (Büdöshegy) […] ein von innen noch immer brennender Vulkan ist...*", meaning "the so-called Stinky Hill […] that is still a burning volcano inside". He gave detailed descriptions of the volcanic host rocks of Stinky Cave, which he called "sulphur cave", along with its gas emissions and sulphur precipitations. He even mentioned the sulphur springs of the area that were already known at his time. Relying on scientific literature, he correctly identified Puturosu Hills as a volcanic structure, comparing it to the Solfatara near Naples in Italy. His descriptions greatly contributed to making the Puturosu Hills known throughout Europe and attracting travellers and researchers alike.

There is a description of Puturosu Hills by an unknown author in the 1838 issue of the magazine *Mulattató* (Entertainer), published in

Kronstadt (Braşov/Brassó) and written in Hungarian. In the article titled, *A Torjai Büdös-hegy* (The Stinky Hill of Turia), he said "*I can state with certainty that it was a mountain spewing fire, and then it quieted down—but when did it last explode and when did it fall asleep? Even the oldest legends are silent about that*".

The first comprehensive geological work on Transylvania also discussed the Ciomadul Hills, confirming the earlier writers' hypotheses. This first synthesis of geological observations, *Geologie Siebenbürgens* (Geology of Transylvania), was written by Franz Ritter von Hauer and Guido Stache, published by the *Vereine für Siebenbürgische Landeskunde* (*Association for Transylvanian Heritage [a Transylvanian Saxon organization]*) of Sibiu (Hermannstadt/Nagyszeben), and was printed in Vienna, Austria in 1863. The book was associated with a 1:576,000 scale geological map (Fig. 1.4) edited by von Hauer, with contributions by Albert Bielz, Ferdinand von Richthofen, Guido Stache, and Dionys Štur who divided the territory of Transylvania for geological mapping. The Harghita

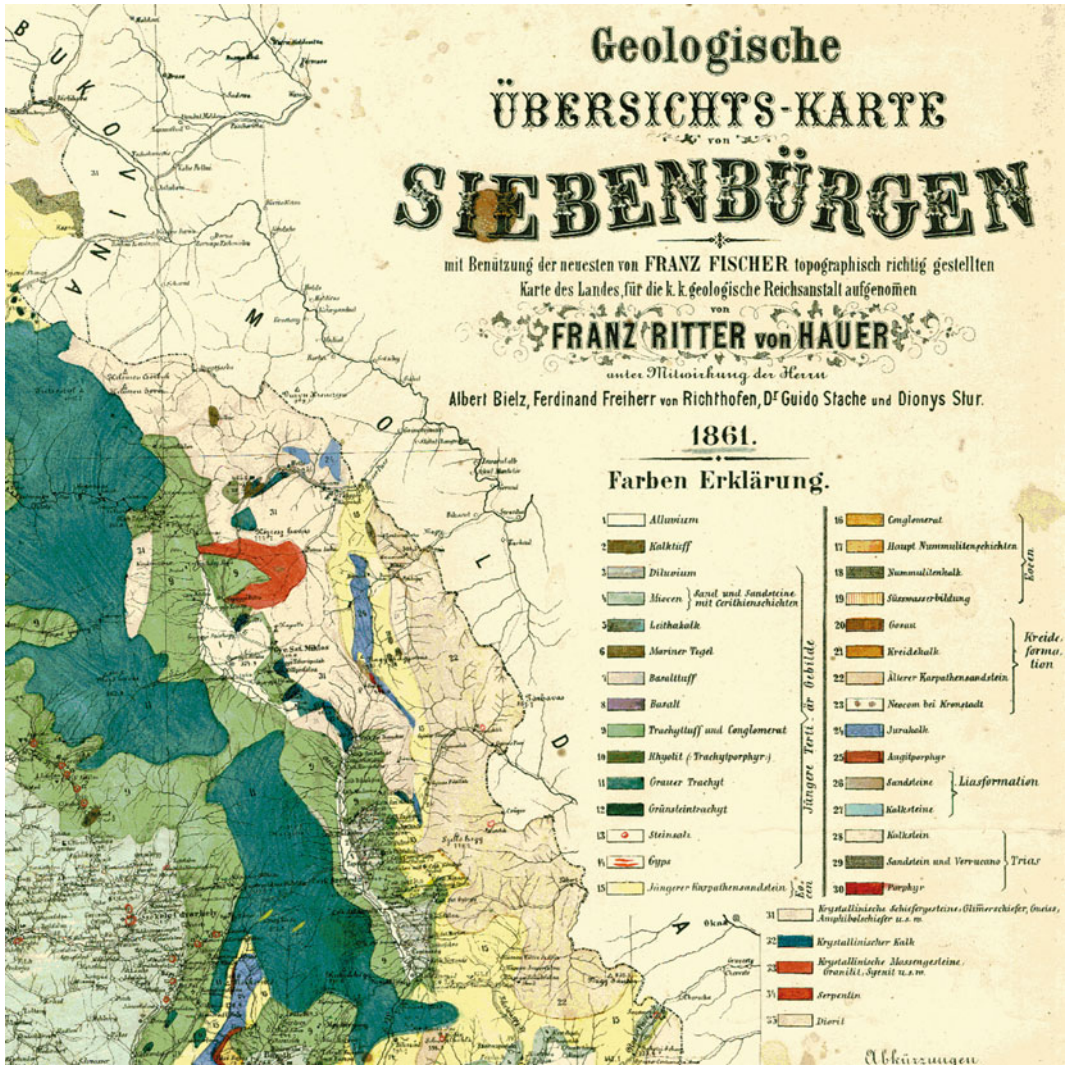


Fig. 1.4 Detail of the first comprehensive geological map of Transylvania (1861) displaying the "trachytes" of the Ciomadul Hills in the context of the Harghita Mountains. Scale 1:576,000

Fig. 1.5 Lake Sf. Ana (Szent Anna). Drawing by Gusztáv Keleti from Balázs Orbán's *A Székelyföld leírása történelmi, régészeti, természetrajzi s népismei szempontból* (History, archaeology, natural history and folklore of Székelyland, 1868), engraved by Károly Russ

Mountains was mapped by Ferdinand Richthofen (Korodi and Hoffmann 2016).

After visiting the Ciomadul Hills, Balázs Orbán, a famous writer, etnographer, photographer of the nineteenth century, interpreted correctly the phenomenon of Lake Sf. Ana. In the third volume of his major work, *A Székelyföld leírása történelmi, régészeti, természetrajzi s népismei szempontból* (History, archaeology, natural history and folklore of Székelyland, 1869), he postulated that "*The funnel shape of the circular ridges it occupies, the red trachytic debris around the lake, and the traces of fire on the nearby hillsides, point to the fact that it is the crater of an enormous volcano, now filled with water*" (Fig. 1.5).

1878 marked a turning point in the study of Lake Sf. Ana and Puturosu Hills, when two papers were published by researchers at the Department of Mineralogy and Geology of the Hungarian Royal University at Cluj. Under the leadership of department chair Antal Koch, chemistry professor Antal Fleischer and assistant Sándor Kürthy analysed the rocks and minerals of the region, as well as the mineral precipitations connected to the volcanic activity. The results were published—almost simultaneously—in two separate papers. One was an important regional assessment, *A Székelyföld földtani és őslénytani leírása* (Geological and palaeontological description of Székelyland) by Ferenc Herbich, included in the *Annales of the Royal Geological Institute of Hungary* (Magyar Királyi Földtani Intézet Évkönyve). The other was a report by Antal Fleischer and Antal Koch: *Jelentés a tórjai Büdös és vidéke földtani viszonyairól, forrásairól, gázkiömléseiről és a Büdös-barlang csepegéséről* (Report on the geology, mineral springs, fumaroles, and the precipitations of Stinky Cave in the region of Puturosu of Turia), published in the *Annales of the Székely Association of Culture and Economy*. Koch published these data again in more detail in his 1900 synthesis, *Az Erdélyrészi-medence*

harmadkori képződményei—Neogén csoport (The Tertiary Formations of the Transylvanian Basin—The Neogene Group; Koch, 1900).

József Budai recognized the acidic (silica-rich) nature of the rocks of the Ciomadul Hills, describing them as trachyte—using contemporary terminology. Budai published his results, *Adatok a Hargita déli részének petrographiájához* (Contributions to the petrography of southern Harghita), in the *Bulletin of the Hungarian Geological Society* in 1881. Based on Budai's work and on Mór Pálfy's 1895 paper, *A Hargita andezites kőzeteiről* (On the andesitic rocks of the Harghita), published in the *Az EME Orvos–természettudományi Értesítője* (Medical-Natural Science Bulletin of the EME), in 1900, Koch classified the Ciomadul rocks as biotite andesite, noting that they are "really close to dacites".

Károly Papp's excellent work also needs to be mentioned here. His paper, *A futásfalvi Pokolvölgy környéke Háromszék vármegyében* (The region of Pokolvölgy/Devil's valley at Futásfalva/Alungeni in Trei Scaune County), published in 1912 in the *Bulletin of the Hungarian Geological Society*, discussed in detail the post-volcanic activities, mineral springs, and estimated that the volcano last erupted 300,000 years ago. Papp was also the first to notice the volcanic ash layers and pointed to their significance.

János Bányai, probably the best scholar and promoter of the geology of Székelyland in the first half of the twentieth century (Fig. 1.6), published an outstanding study in the *Bulletin of the Hungarian Geological Society* (Bányai, 1917). His paper, Kézdivásárhely vidéke Háromszék vármegyében (The region of Târgu Secuiesc in Trei Scaune County), correctly described the pumiceous layers of the Fehérmartok outcrop near Târgu Secuiesc (Kézdivásárhely) being associated with the activity of the Ciomadul volcano. "*Below the thin topsoil is a yellowish sand which turns light grey in the deeper parts. About 2 m from the surface this sand is divided into upper and lower parts by a 0.2 m thick lapilli layer of amphibole-biotite andesite pumice. / Pieces of this pumice, varying from rice to fist size, form a strikingly bright layer in the sand. On closer examination, the*

Fig. 1.6 János Bányai, geologist, teacher, writer, museologist (1886–1971), at his home desk in Odorheiu Secuiesc (Székelyudvarhely). *Source* collection of Rezső Haáz Museum, Odorheiu Secuiesc, photographer unknown

porous structure is evident to the naked eye. 2–3 mm hexagonal, brown biotite flakes, and 2–3 mm long, glassy amphibole needles can also be observed in the matrix. Under a loupe, the matrix shows silky fibres and plagioclase minerals./[…] So, we can conclude that part of this material is made up of redeposited debris from the andesite around Lake Sf. Ana." We have to point out—in light of recent research—that the pumiceous layer in question is not redeposited debris, but a primary pyroclastic unit from one of the last explosive eruptions of Ciomadul (see Chap. 3 on volcanism).

Lajos Lóczy Sr. (1849–1920), geologist, geographer, director of the Hungarian Geological Institute and the second chair of Geography Department at the University of Science (later Eötvös Loránd) in Budapest, presented a short but to-the-point lecture at the Hungarian Geological Society in 1918. The lecture material was also published as a short communication, *A Szent Anna-tó vulkáni krátere* (The volcanic crater of Lake Sf. Ana) in the *Bulletin of the Hungarian Geological Society* in the same year. Lóczy recognized Sf. Ana and Mohoş as twin craters, the explosive nature of their eruptions, and their young age. He correctly described "*the thick layer of pumice and ash draping the slopes toward Bixad village*", and called contemporary Hungarian geologists to make it their priority to explore and study the volcanic ranges around Sf. Ana lake.

János Bányai, following his 1917 paper, continued to publish about the region of Lake Sf. Ana. In a 1940 supplement to the journal *Székelység* (The Székelys)—which he also edited—he wrote an article, *A Szent Anna tó és környéke* (The district of Lake Sf. Ana), and was the first to describe the geographical features of Ciomadul Hills. He interpreted the crater of Mohoş and its original western part as a caldera of an earlier explosion, in which later the crater of Lake Sf. Ana formed. He also published a comprehensive description of the Ciomadul Hills in a book on local history, *Székelyföld írásban és képben* (Székelyland in words and pictures), printed in Budapest in 1941. He detailed the natural history of the Ciomadul Hills in the chapters *A székelyek és Székelyföld* (The székelys and Székelyland) and the *Székelyföld tájai* (Landscapes of Székelyland).

A study was published in 1956 in the journal of the Romanian Academy of Sciences, *Comunicările Academiei R. P. România* (*Communications of the Academy of P. R. of Romania*) by geologists Dan Slăvoacă and Constantin Avramescu of Bucharest, who questioned the depression of Lake Sf. Ana as a volcanic crater and argued for a structural basin. Similarly, Constantin Privighitoriţa denied the crater nature of the lake in his study published in 1970 in the *Lucrările Colocviului de Limnologie Fizică* (*Reviews of the National Colloquium on Physical Limnology*), basing his opinion on an erroneous geological assessment. He explained the formation of the lake basin as erosional mass wasting of lava layers that were sitting on top of volcanic ash on the Cretaceous basement.

In 1964, Aurelia Lazăr and Adela Arghir published a petrological study of the rocks in the Ciomadul area in the journal of the Romanian Institute of Geology, *Dări de Seamă ale Şedinţelor* (Meeting Reports). They distinguished green hornblende andesite, basaltic hornblende andesite and augite hypersthene andesite, and estimated active volcanism lasting up to the Pleistocene.

Starting from the 1970s, Wilfried E. Schreiber, professor of geology at the Babeş-Bolyai University of Cluj-Napoca, investigated the volcanic morphology of Harghita Mts, including the Ciomadul Hills. In his 1972 study *Incadrarea geografică şi geneza masivului Ciomadu* (Geographical setting and genesis of the Ciomadul massif), published in the *Studia Universitatis Babeş–Bolyai, Geologia-Geographia,* he presented the young volcanic landforms of Ciomadul on a map, including the "cones", interpreting them correctly as distinct eruption centres, and the explosive twin craters (Fig. 1.7). After further works, in 2006 Schreiber and co-author Enikő Unger published this map in the *Földtani Közlöny (Bulletin of the Hungarian Geological Society);* in that paper they also interpreted the erosional volcanic features in the light of the entire Southern Harghita Mountains.

Studying the rocks of the Southern Harghita and Ciomadul, János Treiber, professor of

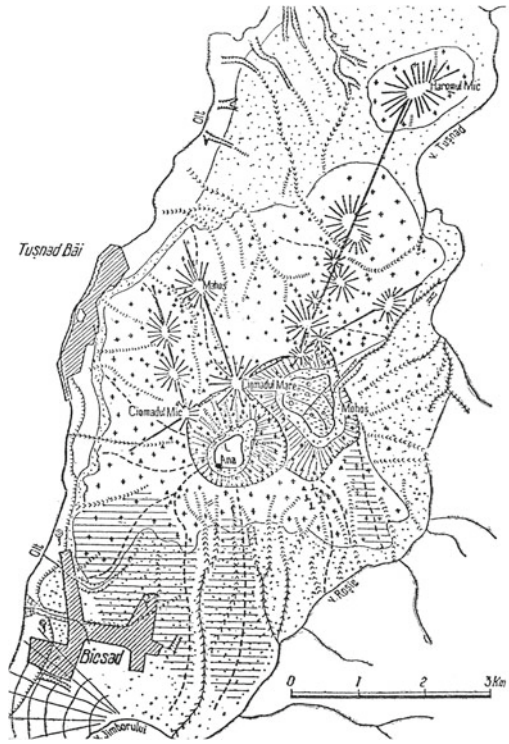
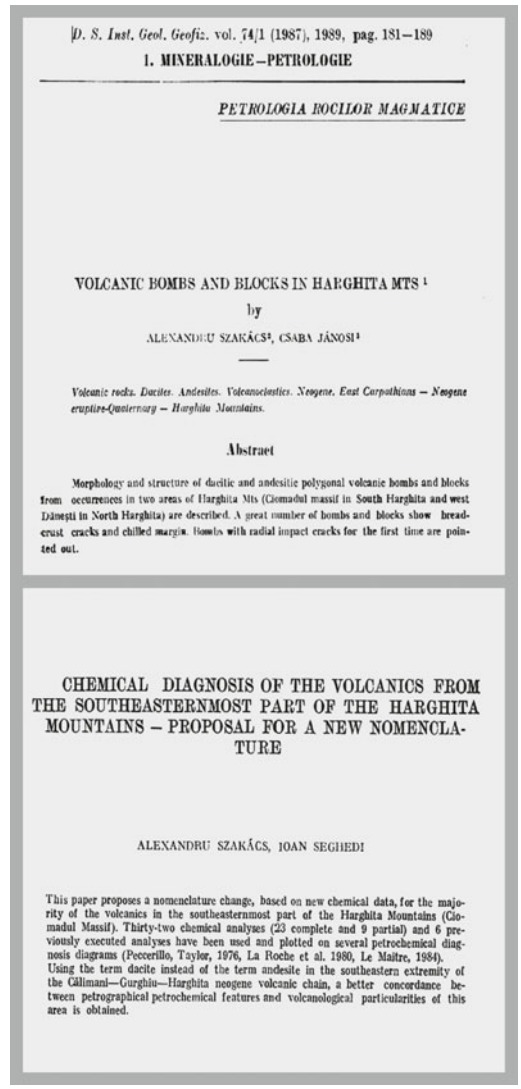


Fig. 1.7 Volcanic geomorphological interpretation of the Ciomadul Hills (Schreiber 1972). For details, see text


D. S. Inst. Geol. Geofiz. vol. 74/1 (1987), 1989, pag. 181–189

1. MINERALOGIE–PETROLOGIE

PETROLOGIA ROCILOR MAGMATICE

VOLCANIC BOMBS AND BLOCKS IN HARGHITA MTS [1]

by

ALEXANDRU SZAKÁCS[2], CSABA JÁNOSI[3]

Volcanic rocks. Dacites. Andesites. Volcanoclastics. Neogene, East Carpathians – Neogene eruptive-Quaternary – Harghita Mountains.

Abstract

Morphology and structure of dacitic and andesitic polygonal volcanic bombs and blocks from occurrences in two areas of Harghita Mts (Ciomadul massif in South Harghita and west Dănești in North Harghita) are described. A great number of bombs and blocks show bread-crust cracks and chilled margin. Bombs with radial impact cracks for the first time are pointed out.

CHEMICAL DIAGNOSIS OF THE VOLCANICS FROM THE SOUTHEASTERNMOST PART OF THE HARGHITA MOUNTAINS – PROPOSAL FOR A NEW NOMENCLATURE

ALEXANDRU SZAKÁCS, IOAN SEGHEDI

This paper proposes a nomenclature change, based on new chemical data, for the majority of the volcanics in the southeasternmost part of the Harghita Mountains (Ciomadul Massif). Thirty-two chemical analyses (23 complete and 9 partial) and 6 previously executed analyses have been used and plotted on several petrochemical diagnosis diagrams (Peccerillo, Taylor, 1976, La Roche et al. 1980, Le Maitre, 1984). Using the term dacite instead of the term andesite in the southeastern extremity of the Călimani—Gurghiu—Harghita neogene volcanic chain, a better concordance between petrographical petrochemical features and volcanological particularities of this area is obtained.

Fig. 1.8 Front pages of geological-volcanological works published in the 1980s by Alexandru Szakács, Ioan Seghedi and Csaba Jánosi (for details, see text)

petrology at the University of Cluj, concluded that the second biotite andesite phase and the third pyroxene andesite—basalt phase of the volcanic activity of the Pilişca (Piliske) and Ciomadul are contemporary, and their activity ended in the Pleistocene. His study was published in 1974 in the university's publication on geology and mineralogy, *Studia Universitatis Babeş-Bolyai, Geologia-mineralogia*.

In 1982, in connection with his petrological investigations, the first author of this chapter, Csaba Jánosi, geologist, delineated exploitable pumice occurrences on the outer edge of the crater: on the Câmpul Lung (Hosszúmező) of Tuşnad and on the eastern slopes of Coacăze (Kukojzásorka). He also described the "bread-crust bombs" of Ciomadul that were first mentioned in the first part of the twentieth century: in 1922 Jenő Cholnoky discussed the characteristic breadcrust bombs of Ciomadul, and Viktor Zsivny provided mineralogical studies on them in 1929. The Comloş ditch (Komlósárok) below Băile Tuşnad (Tusnádfürdő) was considered as the main occurrence of these volcanic bombs. Jánosi recognized additional locations in the gullys of the Rosu and Disznyó streams on the southern slopes of Muntele Lacului (Tóbérc). In 1989, Alexandru Szakács and Csaba Jánosi published a comprehensive study on these volcanic bombs in the journal, *Dări de seamă ale şedinţelor* (Meeting Reports, Geological and Geophysical Institute of Romania) (Fig. 1.8).

Alexandru Szakács and Ioan Seghedi began their state-of-the-art volcanological and volcano-geological studies in the late 1980s. Their petrological analyses confirmed and demonstrated in detail that the previously described high-silica andesite is predominantly dacite. Their investigations shed first light on the lava dome character of Ciomadul volcanism and on the explosive nature of the last eruptions. Zoltán Pécskay and Dávid Karátson joined this work in the early 1990s. Pécskay conducted the first K–Ar radiometric dating of the volcanic rocks. In 2015 Szakács and his colleagues published the results of their comprehensive, decades-long investigations in the paper, *Eruptive history of a low-frequency and low-output rate Pleistocene volcano, Ciomadul, South Harghita Mts., Romania*, in the journal *Bulletin of Volcanology* (Szakács et al. 2015).

Crisan Demetrescu and Maria Andreescu have been examining the geothermal conditions of Romania, including the Eastern Carpathians. In their 1994 study they reported a highly focused heat flux anomaly under the Ciomadul area with temperatures exceeding 800 centigrade at a depth of 20 km. Continuing this line of research, Mihaela Popa and colleagues analysed the earthquakes of the Southeast Carpathians and published their results in *Pure and Applied Geophysics* (Popa et al. 2011). They found that—in addition to the Vrancea zone, which caused the earthquakes of Bucharest—the Ciomadul Hills also present considerable seismic activity with earthquake centres (hypocentres) occurring in a peculiar, vertical arrangement. Based on the reduced velocity of seismic waves, Popa and colleagues inferred the presence of partially molten rock material (magma) between depths of 8–20 km. Balázs Kiss and his colleagues identified two types of amphiboles in the dacites of Ciomadul, and published their data in *Contributions to Mineralogy and Petrology* (Kiss et al. 2014). One type of amphibole can be associated with the silicate-rich magma system of the upper crust at the depth of 8–12 km. The other type of amphibole forms—sometimes with further change of the former—when additional molten mafic material is pushing up from below. Szabolcs Harangi and colleagues published a study in 2015(a) in *Journal and Volcanology and Geothermal Research*, where, based on magneto-telluric investigations (i.e. which examines the electrical resistivity distribution beneath the surface), they confirmed the presence of magma even today, at an estimated depth of 5–20 km. In the deeper regions a partially molten phase is probable. Mickael Laumonier and his team estimated the amount of the magma to be 20–58 cubic kilometres, drawing attention to the fact that this volume is more than one of Ciomadul's entire erupted mass so far (Laumonier et al. 2019).

Examining the evolution of volcanic landforms in his 1996 morphometric study in *Journal and Volcanology and Geothermal Research*, Dávid Karátson explained the relatively large diametre of the Ciomadul twin craters by their explosive origin and the intense frost shattering and related slope processes during the last glacial period. From the late 2000s, Karátson and his colleagues studied the relationship between the volcanic activity and the resultant volcanic landforms. In his 2007 monograph, *A Börzsönytől a Hargitáig* (From the Börzsöny to the Harghita Mts.), Karátson gave detailed descriptions of two key outcrops of the last explosive volcanic activity, the one near Băile Tuşnad and another one in the gorge of the Roşu (Veres) stream draining the Mohoş peat bog. Karátson and his co-authors' 2013 article in *Journal and Volcanology and Geothermal Research* identified the lava domes of Ciomadul as Peléan-type and coulée-type (the latter being asymmetrical domes emplaced on a slope). Comparing the domes' morphometric characteristics with other lava domes worldwide, Karátson and colleagues estimated the Ciomadul domes 10–100 thousand years old. This age was also supported by preliminary zircon dating. Using this dating method on zircon grains (separated mainly from pumice clasts), Szabolcs Harangi and his colleagues reported a chronology of the explosive eruptions in *Journal and Volcanology and Geothermal Research* (Harangi et al. 2015b).

The focus of the latest research is the age progression of the eruptions, the development of lava domes, their eruptive rates, and the late-

Fig. 1.9 Geological-volcanological field work at Ciomadul. **a** Geophysical exploration of the lacustrine infill of Lake Sf. Ana (*Photo* Dávid Karátson). **b** Deposit of one of the latest pyroclastic-flows (so-called block-and-ash flow) with an outsized prismatically jointed block (*Photo* Csaba Jánosi). **c** Studying the pyroclastic sequence of one of the latest explosive eruptions, the Târgu Secuiesc ('TGS', Kézdivásárhely) eruption (*Photo* Dávid Karátson). **d** Sampling massive dacite lava boulders for K–Ar radiometric dating (*Photo* Dávid Karátson)

stage explosive activity (Fig. 1.9). Karátson et al. (2016, 2017) and Wulf et al. (2016) published on the late-stage explosive eruptions 50–30 thousand years ago and the related tephrostratigraphy. Most recently, Molnár et al. (2018, 2019) used zircon dating to decipher the development of the lava domes. Pierre Lahitte, Dávid Karátson and their colleagues published a two-part study in *Bulletin of Volcanology* (Lahitte et al. 2019; Karátson et al. 2019), where they presented the Cassignol-Gillot K–Ar technique for dating the lava domes, compared the results of different radiometric methods, and estimated the lava production rates of Ciomadul. Chapter 3 of this book will give more details about the latest research, the problems already solved and the questions still outstanding.

1.3.2 Age of the Last Volcanic Eruptions

After it became obvious in the nineteenth century that the Ciomadul Hills were a—geologically speaking—young volcano, the last two hundred years saw a number of earth scientists trying to estimate the exact timing of the last eruptions. It is no surprise that this question is of interest not just for researchers but also for the general public. While the timing of stages and phases of volcanism cannot be understood without knowing the history of volcanism (see Chaps. 3–6), it is worth tracing how researchers thought about the age of the last eruptions over time (Fig. 1.10).

In his already cited monograph published in 1900, Antal Koch was the first to attempt to

Fig. 1.10 Artist's vision of the youngest eruptions of Ciomadul that may have been witnessed by Palaeolithic Man (*Picture credit* Edvárd Takács)

pinpoint the age of the eruptions when he wrote on p. 325: "*The volcanic activity that produced the pyroxene andesite of the southernmost peaks of the Harghita and the basalts along the Olt river, most probably occurred during, or at the very end of, the last phase of the Tertiary, and perhaps even in the Quaternary*".

Regarding the young age of the eruptions, Jenő Cholnoky's statement, undoubtedly exaggerated, should be quoted from his study published in 1922: "*Barring the lush vegetation cover, one could expect renewed eruptions at any moment*". Around the same time, in 1929, Gyula Szádeczky-Kardoss connected the problem of volcanic activity with human prehistory in his study, *A Székelyföld képződése* (The Formation of Székelyland): "*In the south, Saint Anne mesmerizes everyone with her virginally whole crater and pristine waters within. The pure volcanic sand on the diluvial terraces around Puturosu shows that the eruptions on the southern reaches continued until even humans appeared. These early men made rudimentary stone tools from the opals and other volcanic rocks*". Indeed, knapped stone tools can be collected north of Vârful Cetății (Vártető) on the high terrace of the Olt river at Balinoş (Balinos), and at Lăzăreşti. Polished stone tools have been found in Tuşnad's district called Falumejjéke and in Câmpul Capelei (Kápolnamező), south of Lăzăreşti. Although exact, radiometric dating was not available at that time, Cholnoky wrote in his 1941 work, *Erdélyi képek* (Images of Transylvania): "*The crater of Lake Sf. Ana is fresh and intact (…) Geologically speaking, the activity of the volcano had only recently ceased. 'Recently' means that it may have been erupting 100,000 years ago.*" As we shall see in later chapters, Cholnoky, who often put forward bolder hypotheses than his contemporaries, could have been even bolder with this suggestion…

Agreeing with Cholnoky's hypothesis, András Székely wrote about the Ciomadul Hills in 1959