"BABEŞ–BOLYAI" UNIVERSITY CLUJ-NAPOCA

FACULTY OF GEOGRAPHY

DOCTORAL SCHOOL OF GEOGRAPHY

PhD THESIS

(Summary)

GIS-ASSISTED GEOLOGICAL CARTOGRAPHIC STUDY. APPLICATIONS IN TRANSYLVANIA AND BANAT

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CONTENTS

Keywords: Transylvania, Banat, historical cartography, geological map, GIS, map projection, georeference, cartographic analysis.

Introduction

Historical cartography is a research area that represents on international level a new approach to the study of the past and its comparison with the present based on the scientific investigation of the old maps using GIS techniques. (Korodi et al., 2015).

Old geological maps are extremely important sources of information about the state of geological knowledge of a specific period. However, for an old map to be a reliable source of information for the present researches it is required to know and to take into consideration – beside the accuracy of the geological content – also its topographic accuracy (Korodi & Hofmann, 2016). The estimation of the topographic basis (projections, geodetic datums, prime meridians), as well as the determination of the parameters must be done in order to geo-reference an old geological map, and also to perform further GIS applications (Galambos, 2009a). Using GIS techniques, old and modern geological maps can be integrated into a GIS database, in order to analyse and compare old geological data with modern ones, and consequently to track the evolution of geological knowledge in time (Korodi & Bartos-Elekes, 2016; Korodi & Hofmann, 2016).

The aim of this work is to present the evolution of the geological cartography in Transylvania and Banat: on the one hand by researching the history of geological surveys correlated with the evolution of geology as a science; on the other hand through GIS applications namely: georeference of some old Transylvanian geological maps and their integration into a GIS database. As a result of this study we have obtained a summary table with the data of the studied maps. The cartographic analysis of some Transylvanian geological maps is also a goal of this PhD thesis, as well as the analysis of the cartographic accuracy and comparison of the geological content of some detailed geological maps related to the coal mining area of Anina. This analysis has highlighted the importance of knowing the topographic accuracy in addition to the accuracy of the geological content of these historical geological maps.

At the same time, due to the fact that the map representation techniques have developed simultaneously with the progress of geology as a science, this work aims to point out the main stages of evolution of geological knowledge and changes in the paradigm in this discipline.

The topic of the PhD thesis has been motivated by the fact that the field of (thematic) historical cartography is still insufficiently explored in our country. This topic has also been motivated by the desire to bring back to the attention of the scientific community a part of our cultural heritage, namely some old geological maps that have been lost in Transylvania over time.

This work is notable for its high degree of interdisciplinarity, due to the fact that it involves knowledge in the field of geology, history of geology and history of geological cartography, as well as practical aspects of cartography (and historical cartography) and geomatics (using GIS applications). The research topic and the proposed results also have a high degree of innovation, because a similar study has not yet been realized in our country.

In order to achieve the objectives proposed in the doctoral thesis, we carried out several activities and applied several research methods, as follows:

● Consulting the scientific literature and identifying the maps

● Procurement of the geological maps necessary for the study

● Processing of the old Transylvanian geological maps: realizing the GIS database, as well as the cartographic analysis of some of the maps

● Cartographic analysis and comparison of the geological content of the detailed geological maps related to the coal mining area of Anina

● Publication and dissemination of the results (scientific articles, presentation at conferences)

1. Localization of the studied area

Transylvania is a historical-political-geographical entity in Central Europe that has gone through a complex historical-political evolution over time and has had different territorial expansions.

In this chapter we specify that in the present research we refer to Transylvania, on the one hand in the broad sense of the historical-political-geographical interpretation, namely to the territory which extends eastward to the Eastern Carpathians and southward to the Southern Carpathians, consequently it encompasses beside the historical Transylvania, also the historical Crişana and Maramureş, as well as historical province of Banat of Temes (in chapter 3, *History of geological cartography in Transylvania*). On the other hand, we refer separately to the two historical-political-geographical entities

(Transylvania and Banat) for the GIS applications (realized in chapter 4, just as in chapter 5).

2. Current state of research

We presented briefly in chapter 2 the previous researches in the field of historical (geological) cartography, with particular reference to similar studies, as well as GIS applications on old geological maps representing the territory of the Habsburg Empire (or the Kingdom of Hungary, or Transylvania), respectively to similar studies published internationally. At the same time, we mentioned the researches on historical topographic maps, these being particularly valuable for us, because these maps represent the topographic basis for geological surveys.

3. History of geological cartography in Transylvania

The purpose of the chapter 3 is to present with details – on the basis of documentation – the history of geological cartography in Transylvania, from the first maps with geological content (early 18th century) to modern geological maps published in the 20th century, in close correlation with the evolution of the geology as a science.

This chapter was elaborated on the one hand by processing the already existing articles related to the history of geological mapping of the researched area, on the other hand based on the "original" reports and studies edited and published especially in the 19th century, as well as at the beginning of the 20th century by the geologists who carried out these geological surveys and mapping activities. We highlighted the extremely important role of the Imperial and Royal Geological Institute founded in Vienna in 1849, and also of the Royal Hungarian Geological Institute founded in 1869 in these research and mapping activities of the Habsburg Empire.

The cartographic representation methods reflect the evolution of the geology as a science. Thus, the evolution of geological cartography was correlated with the main stages of the evolution of geological knowledge, as well as with the changes of the approaches in this discipline. The studied maps were presented with special respect to their geological content (their legend), and to the used cartographic representation techniques.

The first maps with geological content, edited in the 18th century were the mine maps, respectively the topographic maps containing geology related data and showing the occurrences of the most important mineral resources (Brezsnyánszky & Turczi, 1998). The economic booming of the territories liberated from the Ottoman rule had a stimulating effect on the development of the geological mapping, as well as the interest given to research and exploitation of natural resources (Barczikayné Szeiler et al., 2009). These maps are considered the forerunners of the early geological maps (Brezsnyánszky, 1985; 1996; Brezsnyánszky & Síkhegyi, 2007).

The first map showing also the territory of Transylvania was compiled by **Luigi Ferdinando Marsigli** (1741) (Fig. 1.).

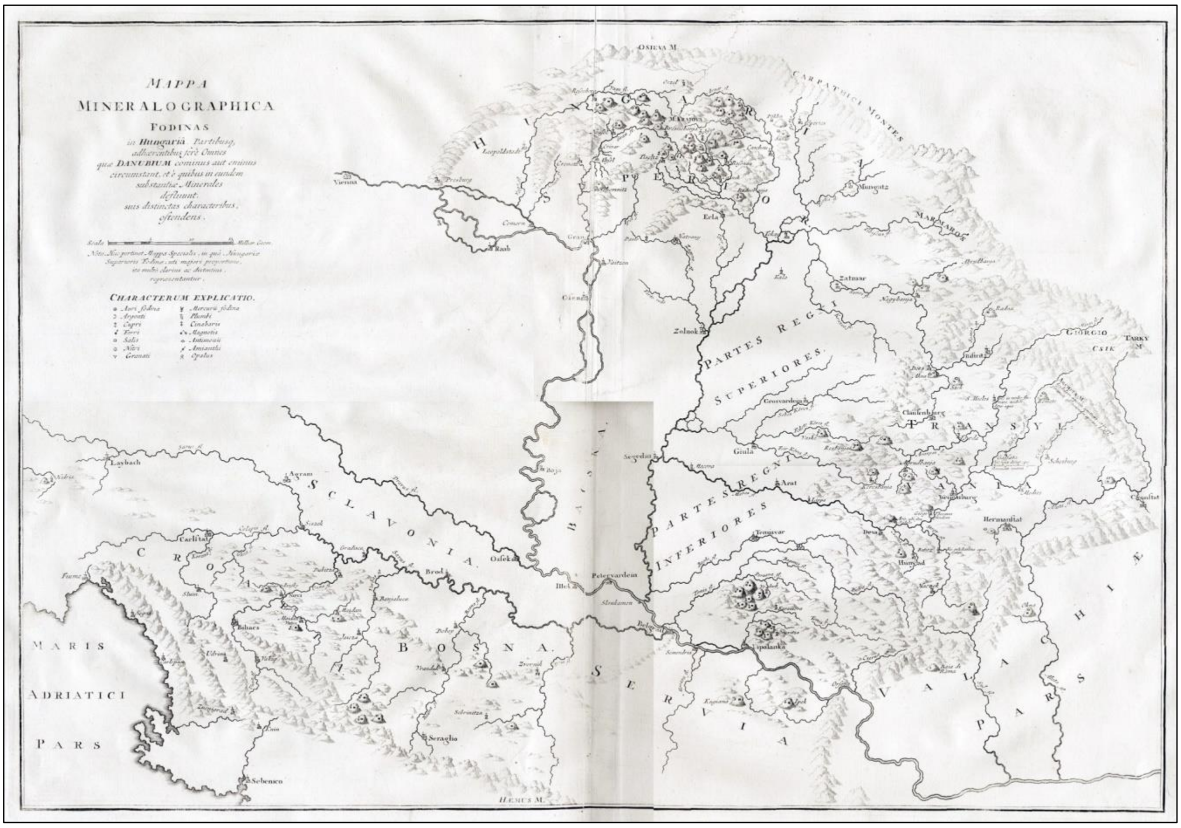


Fig. 1. The mineral map [...], ~1:1,550,000 (Marsigli, 1741). Source: Collection of the Library of the Geological and Geophysical Institute of Hungary, Budapest.

Map representation techniques evolved in the second half of the 18th century, simultaneously with the increase of specialization, respectively with the development of new disciplines within geology, furthered by the fact that scientific conception of geology – as a separate branch of science – started to complete itself (Brezsnyánszky, 1996; 2003). Consequently, the maps containing geological data gradually developed from the mineralogical and petrographic maps to the geognostic maps (Wołkowicz & Wołkowicz, 2014). Petrographic maps show only the spread of different rock types, while geognostic maps also contain data regarding the condition of formation, as well as the relative age of the rocks. These early geological maps were plotted especially by foreign travellers and natural historians, for example the geognostic map edited by **François Sulpice Beudant** (1825) (Fig. 2.).

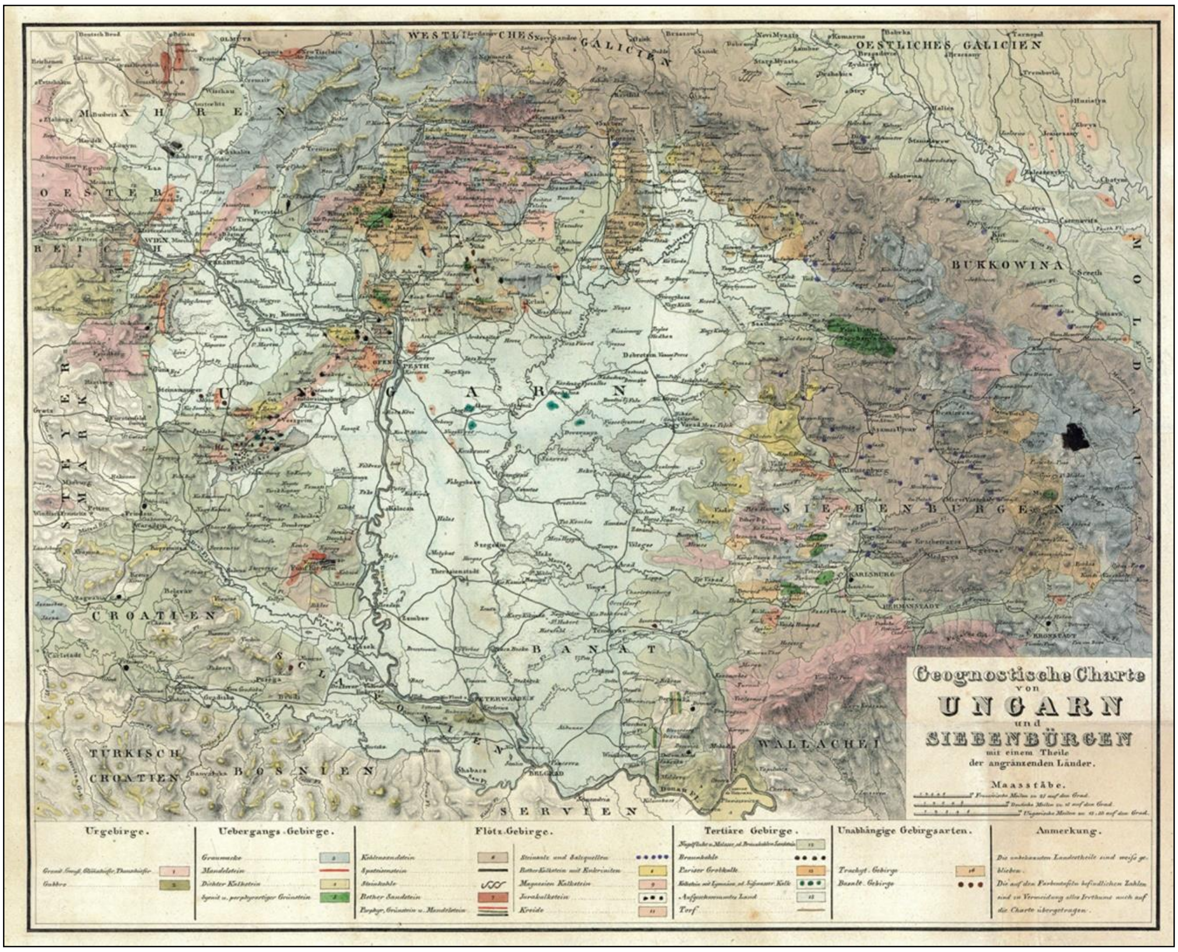


Fig. 2. Geognostic map of Hungary and Transylvania, with a part of the neighboring countries, 1:1,000,000 (Beudant, 1825). Source: Collection of the Library of the Geological and Geophysical Institute of Hungary, Budapest.

Based on the geological data collected in the first half of the 19th century, and based on the mine maps, as well as other previously plotted maps, **Wilhelm Haidinger** compiled the first geognostic map showing the entire Habsburg Empire (Haidinger, 1845) (Fig. 3.).

The basic principles of geological cartography used even today, according to which geological formations are represented by their age, formation conditions, and petrographic composition, developed in the first half of the 19th century simultaneously with the basic principles of the modern geology. (Brezsnyánszky & Turczi, 1998; Barczikayné Szeiler et al., 2009). The beginning – in the mid-19th century – of the systematic and detailed sheet-by-sheet geological mapping of the Habsburg Empire can be considered a reference point. The economic booming of the Monarchy had a stimulating effect on the development of the geological mapping, since the industrial revolution required science-based geological researches (Pentelényi & Síkhegyi, 2012). On the other hand, the geological mapping was furthered by the 2nd Military Survey which provided the topographic basis with an increasing accuracy.

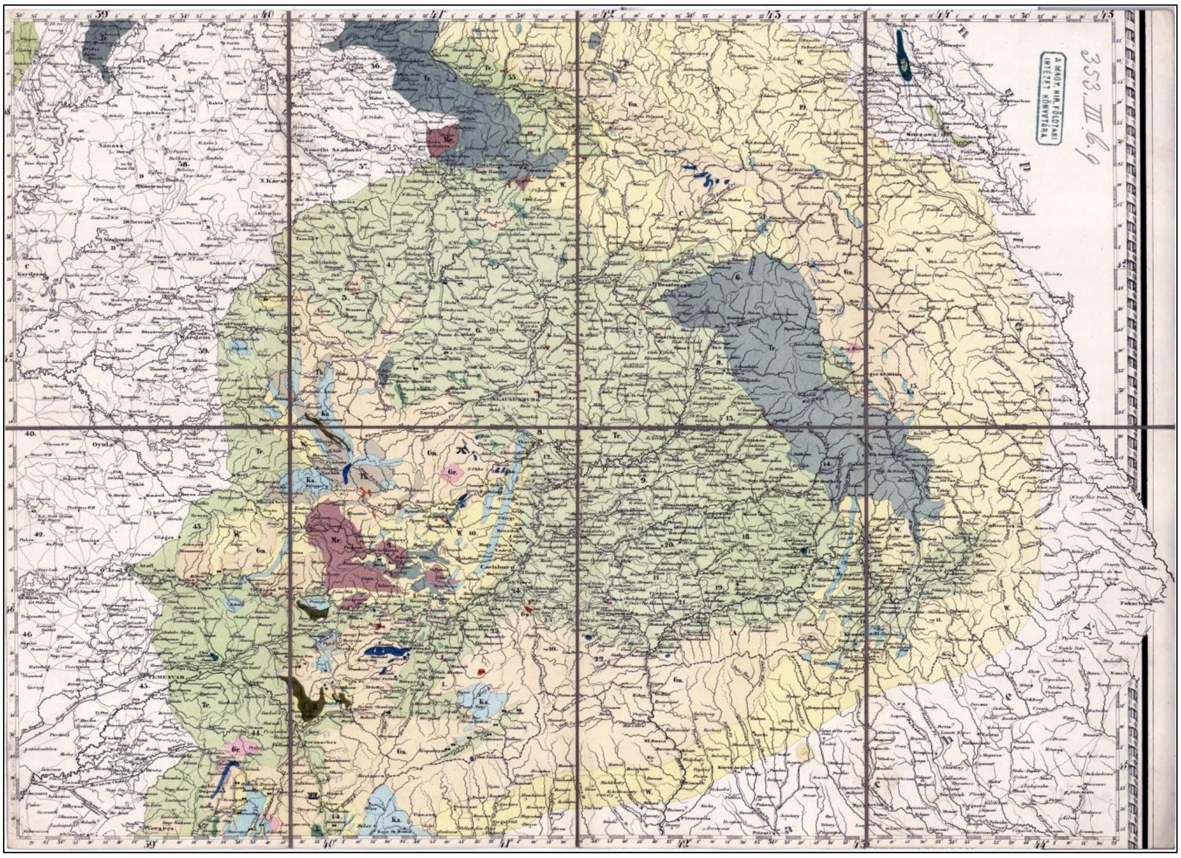


Fig. 3. The overall geognostic map of the Austrian Empire, Sheet VI., 1:864,000 (Haidinger, 1845). Source: Collection of the Library of the Geological and Geophysical Institute of Hungary, Budapest.

The first systematic sheet-by-sheet geological mapping of the Habsburg Empire (eg. Fig. 4.) began in 1851 based on the deduced 1:144,000 detailed topographic maps of the 2nd Military Survey. In addition to that, a surveying for overall mapping of the Habsburg Empire on a scale of 1:576,000, as well as on a scale of 1:288,000 also started in 1856 (Hauer, 1863:3–6; Brezsnyánszky et al., 1999).

Principality of Transylvania and Banat were classified important provinces of the Austrian Empire for exploitation of mineral resources therefore the geological mapping of these territories represented a priority task for the Imperial and Royal Geological Institute.

The overall geological map of Principality of Transylvania (Fig. 5.) compiled by **Franz Ritter von Hauer**, **Dionys Štur** and **Guido Stache** (Hauer et al., 1863) is the most outstanding achievement of the Transylvanian geological mapping activity of the second half of the 19th century. In our work we also presented some previously plotted maps (some of them have remained manuscripts) which are less known and researched by the scientific community, used by **Hauer** and his colleagues for editing this last one.

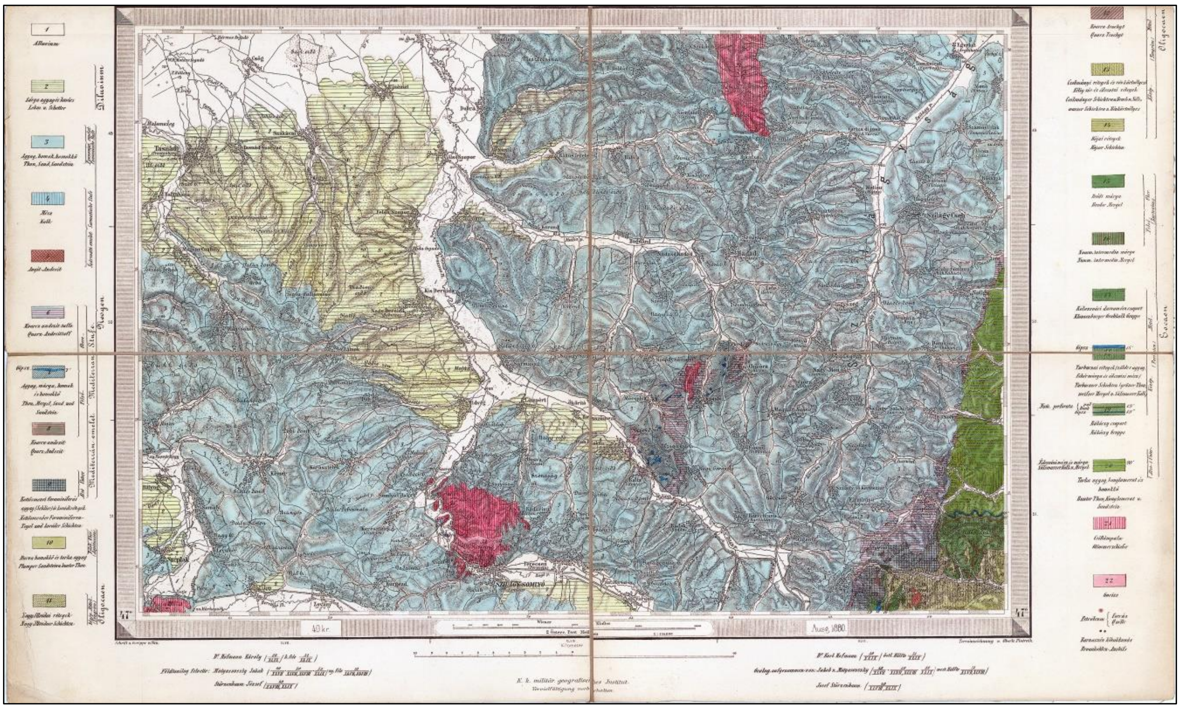


Fig. 4. . Geological map on a scale of 1:144,000, Tăşnad–Şimlelul Silvaniei region, 1:144,000 (Hofmann et al., 1883). Source: Collection of the Library of the Geological Survey of Austria, Vienna.

The second systematic sheet-by-sheet geological mapping of the Austro–Hungarian Monarchy began in 1869 (Schnabel et al., 1999) based on the deduced 1:75,000 detailed topographic maps of the 3nd Military Survey. Starting with 1870, the systematic sheet-by-sheet geological mapping of the Hungarian Kingdom had become exclusively the task of the Royal Hungarian Geological Institute (Hauer, 1870; Brezsnyánszky et al., 1999). The map series covering the Hungarian Kingdom, entitled *A magyar korona országainak részletes geológiai térképe 1:75000* [The detailed geological map of the countries of the Hungarian Crown on a scale of 1:75,000] was published between 1885–1914. The survey and publication of this map series was interrupted by the World War I (Barczikayné Szeiler et al., 2009). Nevertheless there were published some map sheets related to Transylvania and Banat for example the map sheet *Abrudbánya* [Abrud] (Gesell & Pálfy, 1905) (Fig. 6.).

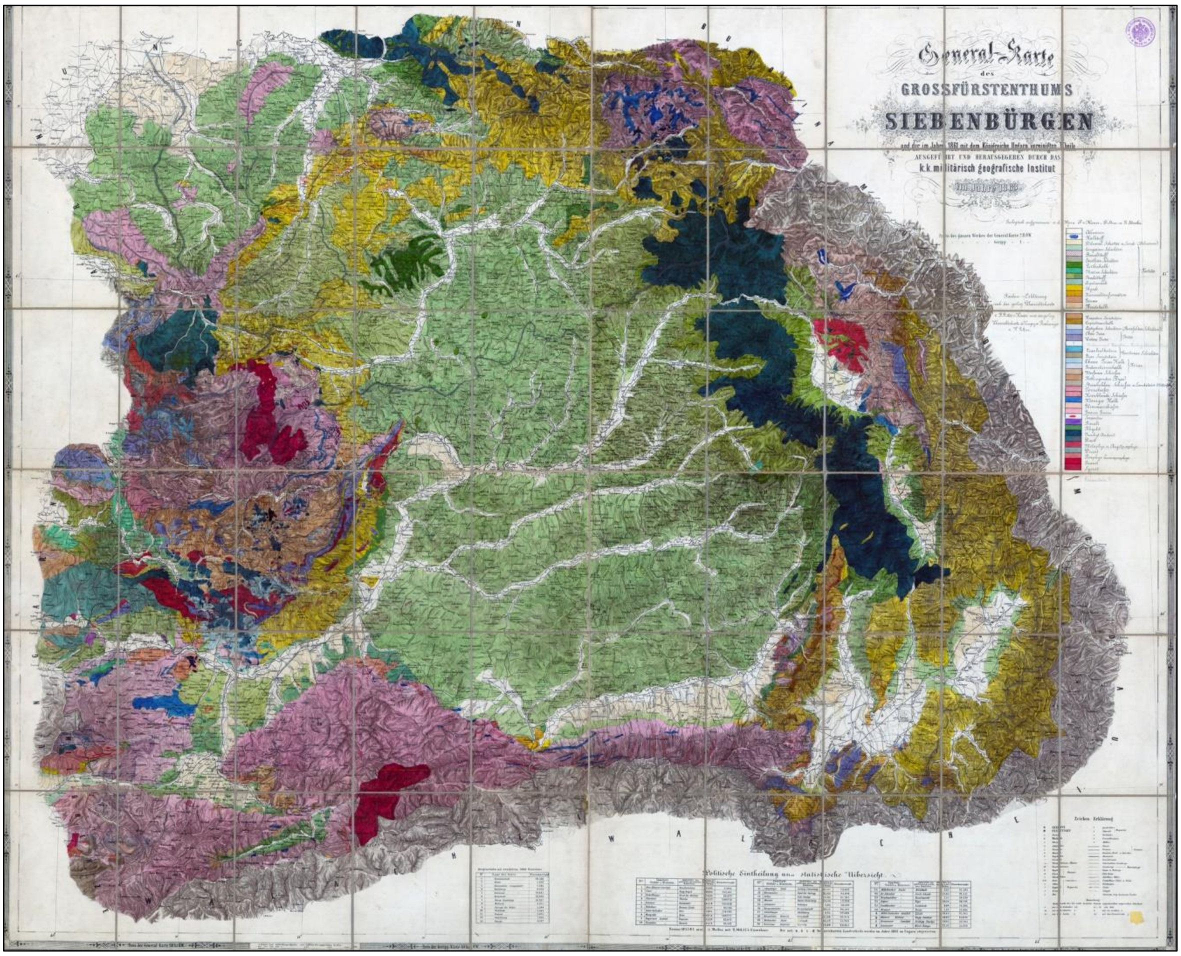


Fig. 5. The overall geological map of Transylvania, 1:288,000 (Hauer et al., 1863). Source: Collection of the Library of the Geological Survey of Austria, Vienna.

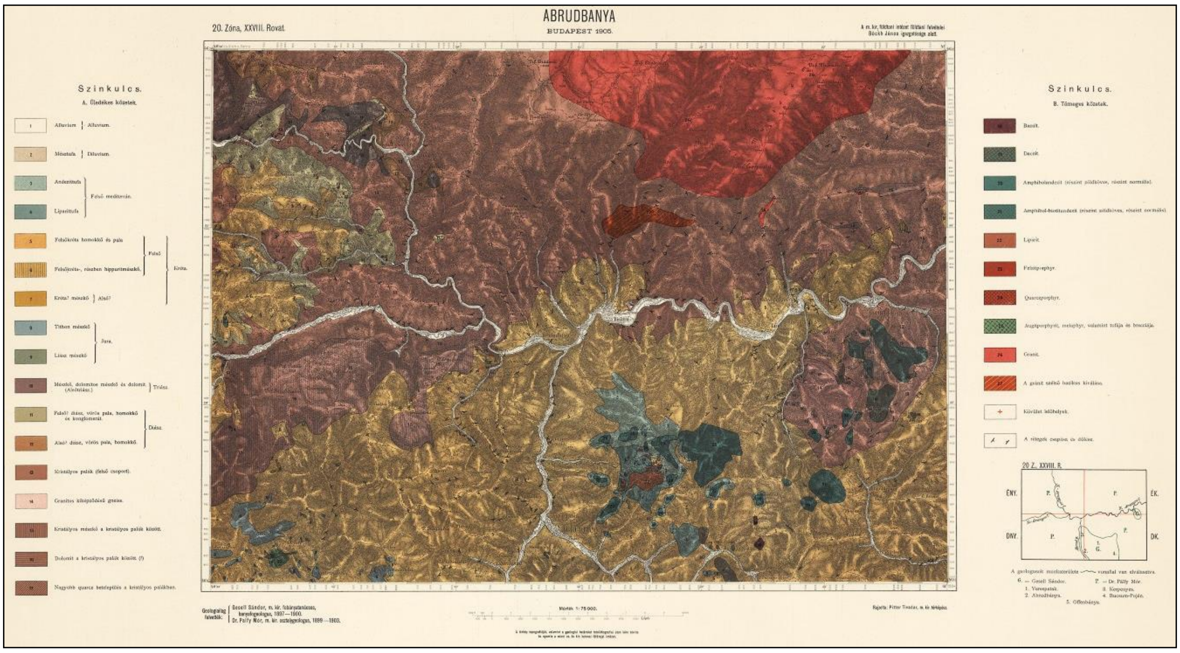


Fig. 6. The detailed geological map of the countries of the Hungarian Crown on a scale of 1:75,000, Sheet Abrud, 1:75,000 (Gesell & Pálfy, 1905). Source: Collection of the Library of the Geological and Geophysical Institute of Hungary, Budapest.

The evolution of geology (including the evolution of stratigraphy as a branch of geology) required the revision of the graphic methods used in geological mapping. Thus, the International Geological Congress, Bologna (1881) established the unified colour system, as well as the geological nomenclature, applied for modern geological maps (Brezsnyánszky & Síkhegyi 2007). In this respect, the most outstanding achievement of the geological mapping activity of Hungary before World War I is the map compiled by **Lóczy Lajos** (Lóczy, 1922) (Fig. 7.) (Maigut, 2010). This map was plotted in manuscript form between the years 1890–1910 on a scale of 1:360,000, and it was published post-mortem by **Papp Károly** in 1922 on a scale of 1:900,000 (Galambos 2006; Galambos & Unger, 2009; Maigut, 2010). Its legend is edited according to the principles accepted at the Bologna Geological Congress (1881).

Fig.7. Geological map of Hungary and its neighbouring countries, 1:900,000 (Lóczy, 1922). Source: Collection of the Library of the Geological and Geophysical Institute of Hungary, Budapest.

The 20th century has brought a significant change in paradigm and has revolutionized geology by the concept of the global tectonics. Both in geological researches and in the cartographic representation methods of the geological formations, have been introduced the chronostratigraphic notions accepted and used nowadays too. Moreover, the geological map series (related to Transylvania) plotted in the second half of the 20th century use the chronostratigraphic notions accepted today for the intra-Carpathian regions. Concerning the tectonic interpretations, identification of the nappe structures represents a reference point, reflected also in the cartographic representation techniques of the maps compiled in this period. We can mention here the geological map series on the scale of 1:200,000 (e.g. Fig. 8.), as well as on the scale of 1:50,000 (e.g. Fig. 9.) published by the Geological Institute of Romania.

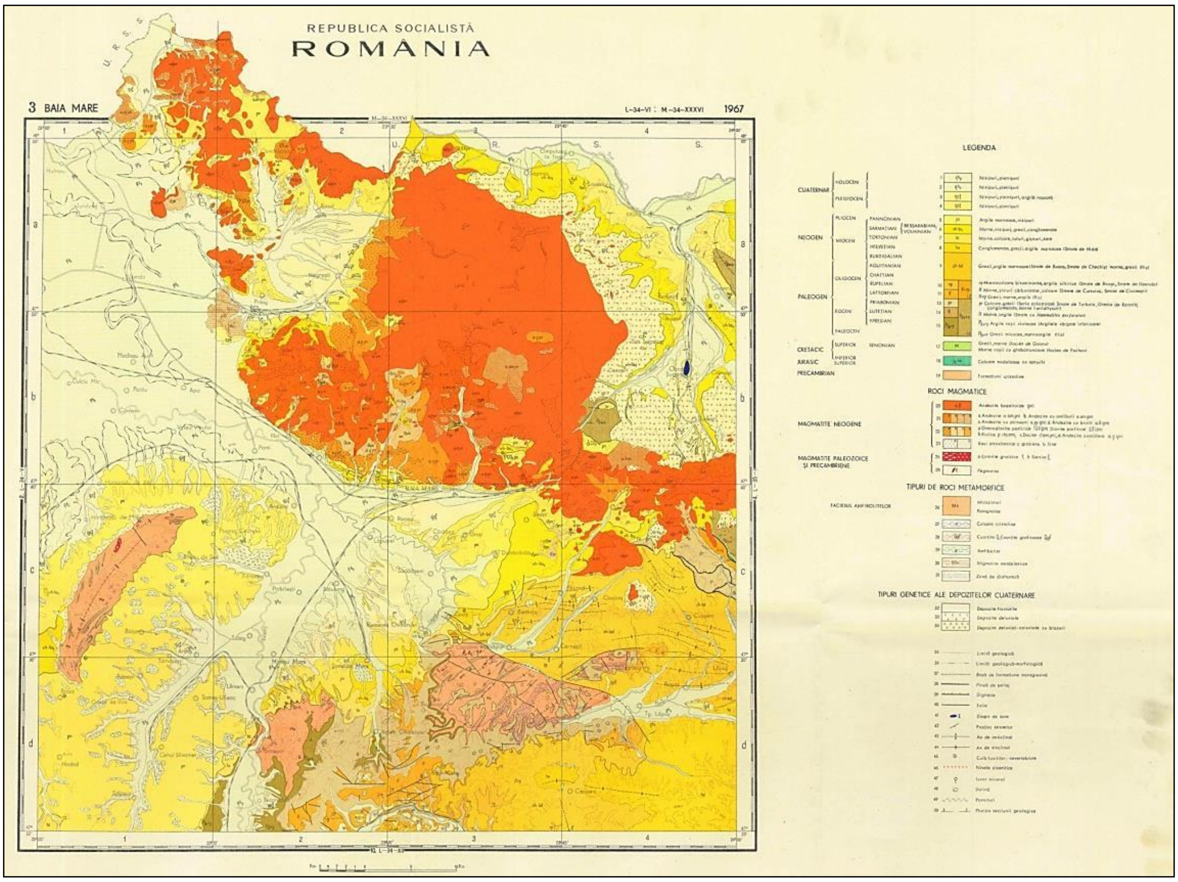


Fig. 8. *The geological map of Romania*, Sheet Baia Mare (L-34-VI), 1:200,000 (eds. Saulea et al., 1967). Source: “Lucian Blaga” Central University Library of Cluj-Napoca, Library of Geology.

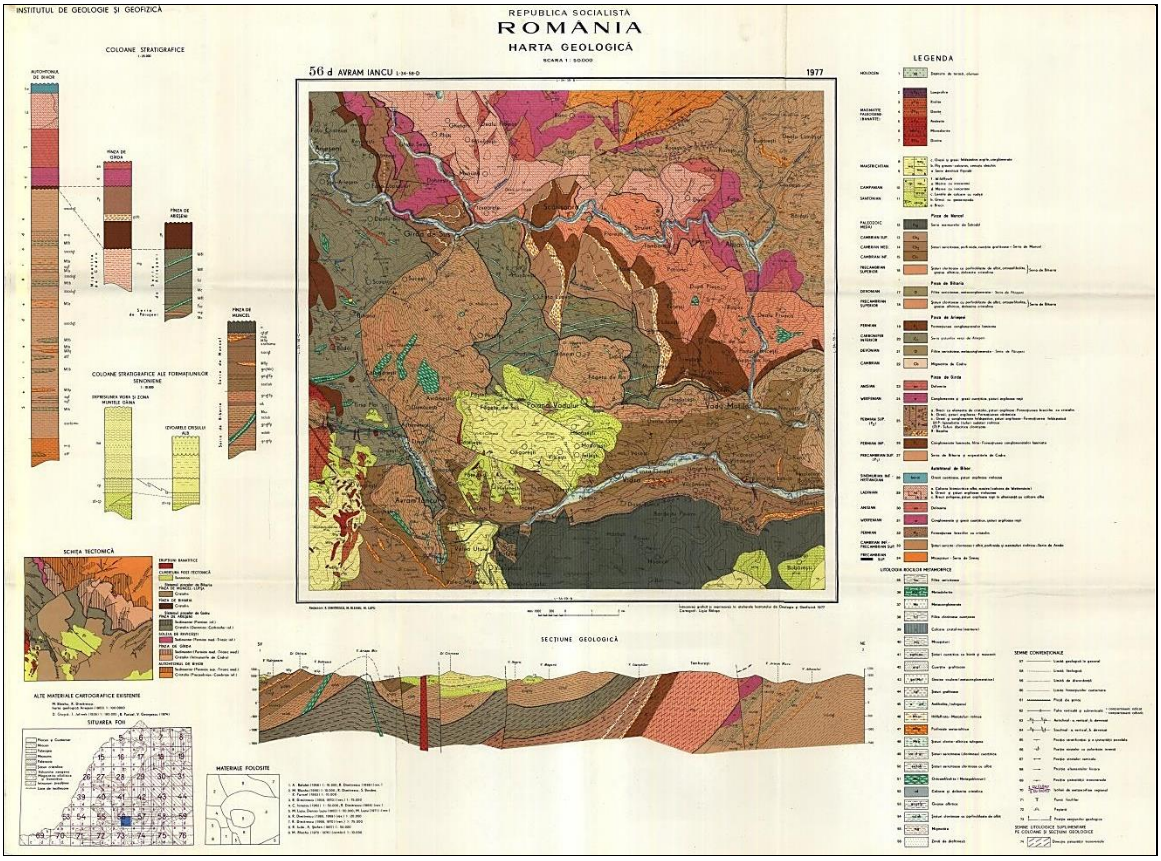


Fig. 9. *The geological map of Romania*, 1:50,000, Sheet Avram Iancu (L-34-70-B), 1:50,000 (eds. Dimitrescu et al., 1977). Source: "Lucian Blaga" Central University Library of Cluj-Napoca, Library of Geology.

4. GIS application in Transylvania: georeference and cartographic analysis of some old geological maps

A GIS database that integrates geological maps related to Transylvania was created in chapter 4, by georeferencing the maps in their initial projection system, then by reprojecting them into a projection system used nowadays too, namely Stereo70 projection. In order to achieve this objective, the possible topographic basis (cartographic projections and their parameters, used prime meridians) of the geological maps were determined, then the methods of defining the control points (GCPs – Ground Control Points) were presented.

As a result of the georeferencing process, we've obtained a summary table with the data of the studied maps (Appendix 1. attached to the PhD thesis). At the same time, we performed in this chapter the cartographic analysis of some geological maps, as a validation of the results of the georeferencing. The investigation of the topographic accuracy together with the study of the geological content of the maps makes possible the analysis and comparison of old geological data with modern ones, and consequently the tracking of the evolution of geological knowledge in time (Korodi & Bartos-Elekes, 2016; Korodi & Hofmann, 2016). This analysis has a high degree of innovation, because a GIS database, respectively the cartographic analysis of these geological maps related to Transylvania has not yet been realized.

The integration of the old geological maps into a GIS database is based on the *georeferencing*. The georeferencing methods of the studied geological maps are presented in the subchapter 4.3. In general, for an accurate georeferencing of a map it is important to know or to assess its geodetic basis, especially as what regards the projection, geodetic datum and prime meridian used. Thus, the first step of georeferencing was to find the possible topographic maps that could represent the topographic basis for the geological mapping (Korodi & Hofmann, 2016). If we do not have certain data about the possible topographic map used, and a map graticule is drawn on the map, the analysis of the network of the meridians and parallels could be useful to determine the possible projection.

In the process of definition of the control points we applied different methods, depending on data marked on the maps: if the coordinate grids are drawn and/or geographic coordinates are indicated; if neither the coordinate grids nor the geographic coordinates are indicated, but we know the nomenclature of the sheet of the map, we can calculate the coordinates of the corner points of the map; and last but not least, objects with well-known coordinates can be established as control points (although this has to be the last option in the georeferencing process). When defining the control points we also have to take into consideration the prime meridian used (the studied geological maps used prime meridian of London, Ferro, as well as Greenwich).

The last step of the georeferencing is the *rectification*, which was performed with Global Mapper (www.globalmapper.com/helpv11/datum_list.htm).

The cartographic projections of the maps and their parameters were determined in subchapter 4.3.1. Early overall geological maps, published until the mid-19th century, were generally projected in the *equidistant conic projection* (Galambos, 2009b; 2010; Timár et al. 2010). However, this projection was used later too, until the first half of the 20th (Galambos, 2010) century, especially on some small-scale maps showing Hungary (from that time).

The topographic surveys carried out in Romania in the first half of the 20^{t}h century (after the World War I) used (also) the Lambert–Cholesky projection (conformal conic projection) with Clarke 1880 datum (Bartos-Elekes et al., 2007; Bartos-Elekes et al., 2008;

Crăciunescu et al., 2011). We do not have exact data about the parameters of this cartographic projection, thus we substituted this projection with conformal conic projection of Lambert (with Clark 1880 datum) in the process of the georeferencing. This was possible due to de fact that the analysed maps have a small scale.

The first systematic sheet-by-sheet geological mapping (on a scale of 1:144,000) used as topographic basis the deduced 1:144,000 detailed topographic map sheets of the 2nd Military Survey. The projection system of this topographic survey is considered (but not identical) to be the *transverse cylindrical Cassini–Soldner projection*, on the hybrid ellipsoid Zach–Oriani (Varga, 2002; Timár et al., 2004; Jankó, 2007:64). In the Principality of Transylvania the point of the origin of the triangulation network was set to the observatory on the hill of Dealul Ocna Sibiului, while in Partium (as in Hungarian Kingdom in general) the geodetic datum Wien–Stephansdom was used (Galambos et al., 2020).

The overall geological maps on a scale of 1:288,000 and 1:576,000 were compiled using the *pseudoconic equal-area Bonne projection* (Jankó, 2007:80–83), on the Zach–Oriani hybrid ellipsoid. The exact parameters of this projection are not known (Korodi et al., 2015), thus to determine them we used the Ocna Sibiului datum for maps showing Transylvania, respectively Buda-1821 datum in the case of the geological map of Banat (Foetterle et al, 1861). The point of origin of the projection was defined analysing each map separately.

The geological map series on a scale of 1:75,000 of the second systematic sheet-by-sheet geological mapping of the Austro–Hungarian Monarchy is based on the topographic map sheets of the 3rd Military Survey (Jankó, 2007:101–102). The approximate projection – implemented in GIS software –of this survey is considered the *sinusoidal* projection defined on the Bessel 1841 ellipsoid (Timár & Molnár 2008; Molnár & Timár, 2009). The maps were georeferenced using the Hermannskogel (Vienna) datum, although using a single point of origin for the entire Austro–Hungarian Monarchy leads to significant errors in georeferencing, especially on the periphery of the Monarchy (Timár & Molnár, 2008; Molnár & Timár, 2009). These horizontal errors were corrected afterwards by shifting the georeferenced image without rotation using the *Shift Selected Layer(s)* tool in Global Mapper. The latitude and longitude of the centre of the projection were determined separately for each map sheet at the intersection of the Equator and the central meridian of each map sheet (Timár & Molnár, 2008; Molnár & Timár, 2009).

The map sheets on a scale of 1:100,000 published between 1958–1959 by the Geological Institute of Romania, then on a scale of 1:200,000 and 1:50,000 compiled after the 1960s are based on the topographic map sheets projected in *Gauss–Krüger* projection (*transverse cylindrical projection*), on the Krasovski-1940 ellipsoid (introduced in Romania in 1951). Although in 1973 Romania adopted the Stereo70 projection, the geological map sheets (studied in this work) published after this date had also been projected in Gauss–Krüger.

The georeferencing methods detailed in the PhD thesis (estimation of the topographic basis, determination of map projections, as well as the parameters and defining the control points) have been applied on some geological maps related to Transylvania with the aim of integrating them in a GIS database. The obtained results together with other data (title, scale, source, etc.) have been summarized in a table.

In this work we studied some maps which do not have a definite or certain cartographic projection, for example the geognostic map of the Austrian Empire by **Haidinger** (1845). The base map of the **Haidinger**'s geognostic map is supposed to be the map by **Fallon** (Fallon, 1822) which is a deduced map of the 1st Military Survey. We don't have information about the geodetic datum and projection of the maps of the 1st Military Survey (Jankó, 2007:22–24; 51). Thus, we analysed the possible projection of the map by **Fallon** (1822) by the appearance of the grid lines: the meridians are straight lines, the angular distance between them is reduced. Therefore, we consider that the projection of the map by **Fallon** (1822) can be substituted with a *tangent conformal conic projection* (Korodi et al., 2015). Nevertheless, based on the fact that the geodetic and topographic basis of the map by **Haidinger** (1845) is uncertain, the georeference was performed using coordinates of 45 settlements as control points. The rectification of the sheet VIII of the geological map by **Hauer** (1867–1871) was also realized using coordinates of 44 settlements as control points. Although the base map of the **Hauer** map is supposed to be the topographic map by **Scheda** (Scheda, 1856), we couldn't determine the exact parameters of the projection of the map, due to the fact that we obtained only one map sheet without unambiguous border information (Korodi et al., 2015).

4.4. Cartographic analysis of some old geological maps related to Transylvania

Old geological maps can be a reliable source for current research, only knowing and taking into account not only the accuracy of their geologic content, but also their cartographic accuracy (Korodi & Bartos-Elekes, 2016; Korodi & Hofmann, 2016; Korodi et al., 2017). Hence, the cartographic analysis of old geological maps could be extremely useful when we overlap several georeferenced geological maps edited at different times, in order to extract geological information or to analyse and compare previous geological data with modern ones, consequently to track the evolution of geological knowledge in time (Korodi & Bartos-Elekes, 2016; Korodi & Hofmann, 2016; Korodi et al., 2017).

Cartographic analysis was performed for the following geological maps: Geognostic map of the Austrian Empire by **Haidinger**, 1845 (*Geognostische Uibersichts-Karte der Oesterreichischen Monarchie*); Geological map of the Principality of Transylvania by **Hauer** (Hauer, 1861) (*Geologische Uibersichts-Karte von Siebenbürgen*); Geological map of the Principality of Transylvania by **Hauer**, **Štur** and **Stache**, 1863 (*Geologische Übersichts-Karte von Siebenbürgen*); Overall geological map of the Austro–Hungarian Monarchy by **Hauer**, 1867–1871 (*Geologische Übersichts-Karte der Österreichisch−Ungarischen Monarchie nach den Aufnahmen der k. k. geologischen Reichsanstalt*); Geological map of Seklerland by **Herbich** (Herbich, 1878) (*A Székelyföld Földtani térképe*); Geological map sheet on a scale of 1:144,000, Tășnad–Șimleul Silvaniei (*Tasnád és Szilágy-Somlyó vidéke)* (Hofmann et al., 1883); Geological map sheet on a scale of 1:100,000, Arieșeni (*Harta geologică a R. P R.*, Foaia Arieșeni (L-34-58)) (eds. Bleahu & Dimitrescu, ?).

The cartographic accuracy of the maps georeferenced by using coordinates of some settlements was analysed on their images exported on the surface of Google Earth (Fig. 10., Fig. 11.). The horizontal accuracy of the fit is usually of 0–2.5 km, respectively of 1–1.5 km, which is acceptable for the small scale of the maps (1:864,000 and 1:576,000) and taking into account the printing technique of the map by **Haidinger** (being printed on cloth-backedness), as well as the manual introduction of the control points (Korodi et al., 2015).

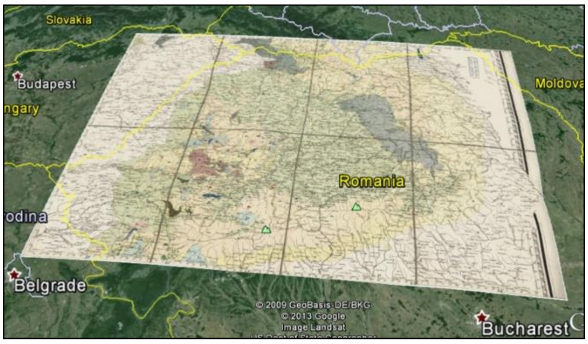


Fig.10. Sheet VI of the geognostic map by Haidinger (1845) on the surface of Google Earth. (Source: Korodi et al., 2015).

Fig. 11. Sheet VIII of the geological map by Hauer (1867–1871) on the surface of Google Earth. (Source: Korodi et al., 2015).

The cartographic accuracy of the other maps was analysed using the MapAnalyst software application (MapAnalyst 1.3.23 and MapAnalyst 1.3.35) (Jenny & Hurni, 2011; www.mapanalyst.org). As old maps we imported the georeferenced images of the studied maps, rectified in their initial projection, then reprojected into Mercator projection (using Global Mapper v.16.1). As new reference map we used the Open Street Map (OSM) (www.openstreetmap.org) in Mercator projection. Distortion grids, displacement vectors and circles, standard deviation, root mean square position error and other statistical and visualisation indicators were computed by using pairs of control points defined on the old geological map, as well as on the new reference map (e.g. Fig. 12.).

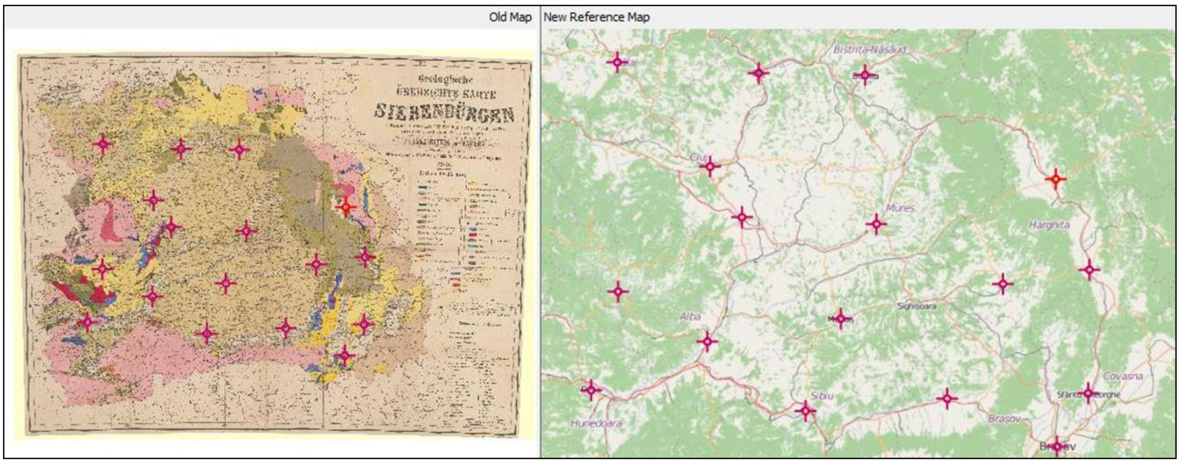


Fig. 12. The distribution of the control points on the map by Hauer (1861) (old map), respectively on the Open Street Map (reference map) in MapAnalyst (Source: Korodi & Hofmann, 2016).

We used Helmert-4-Parameters transformation for matching the coordinate systems. The results of our computing with the help of the MapAnalyst software application, as well as the results of the analysis made on the georeferenced maps' images exported on surface of Google Earth are summarized in the Table 4.1. Table 4.1 contains data concerning the number of control points, the type of the new reference map (or platform) used, as well as the statistical indicators and errors obtained after the transformation (e.g.: rotation error, standard deviation, root mean square error).

Table 4.1. Cartographic analysis of some geological maps related to Transylvania.

Map	Scale	Number of control points	New reference map (platform)	Rotation	Standard deviation (m)	Mean position error (m)
Geognostic map of the Austrian Empire (Haidinger, 1845)	1:864,000	45	Google Earth	–	0–2.5 km	–
Overall geological map of the Principality of Transylvania (Hauer, 1861)	1:576,000	17	OSM	0.117°	772 m	1092
Overall geological map of the Principality of Transylvania (Hauer et al., 1863)	1:288,000	15	OSM	0.032°	587 m	830 m
General geological map of the Austro–Hungarian Monarchy (Hauer, 1867–1871)	1:576,000	44	Google Earth	–	1–1.5 km	–
Geological map of Seklerland (Herbich, 1878)	1:288,000	12	OSM	0.194°	309 m	437 m
Geological map 1:144,000, Tășnad–Șimleul Silvaniei (Hofmann et al., 1883)	1:144,000	25	OSM	0°	118 m	167 m
Geological map 1:100,000, Arieșeni (eds. Bleahu & Dimitrescu, ?)	1:100,000	22	OSM	0°	384 m	544 m

The cartographic analysis has revealed that the mathematic base of the geological mapping significantly improved from the mid-19th century until the second half of the 20th century. In the case of small-scale general (overall) maps we observed average horizontal errors up to 2.5 km, while in the case of medium- and large-scale maps with a well-defined topographic basis the average errors gradually decreased from 587 m (on the map: 2.03 mm) to 118 m (on the map: 0.82 mm). In the case of the latter maps we calculated values of the rotation errors under 1°.

Figures 13–16 illustrates the distortion grids, respectively the displacement vectors and circles resulting from calculations made with the MapAnalyst software application. In general we can note that the distribution of the displacement vectors is not systematic but accidental; therefore, it is caused by surveying errors, printing techniques (some of them being printed on cloth-backedness), and post processing methods (e.g. scanning) and not by the georeferencing problems.

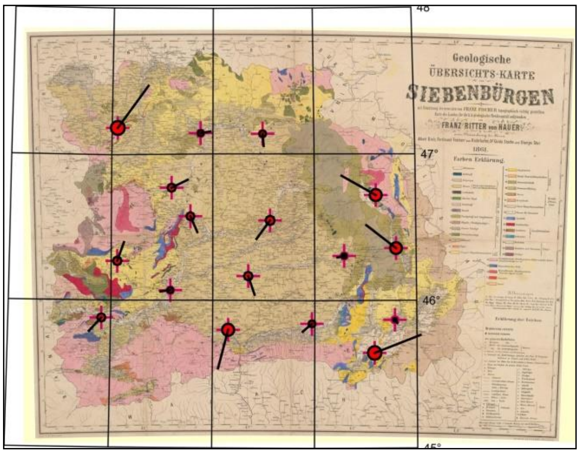


Fig. 13. Local variations of the displacement errors on the geological map of Principality of Transylvania by Hauer (1861), visualized in MapAnalyst. The scale factor of the displacement vectors and circles is 20 (Source: Korodi & Hofmann, 2016).

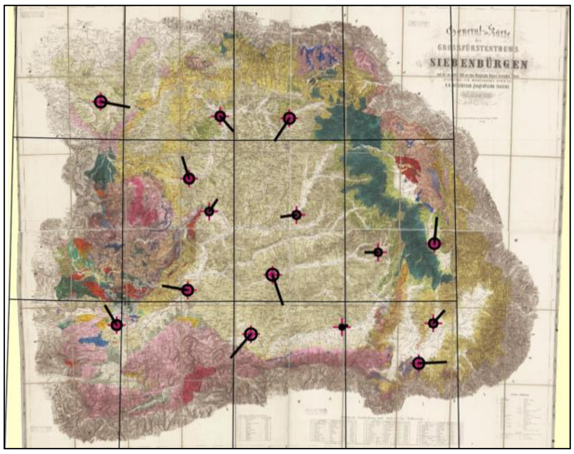


Fig. 14. Local variations of the displacement errors on the geological map of Principality of Transylvania by Hauer et al. (1863), visualized in MapAnalyst. The scale factor of the displacement vectors and circles is 20 (Source: Korodi et al., 2015).

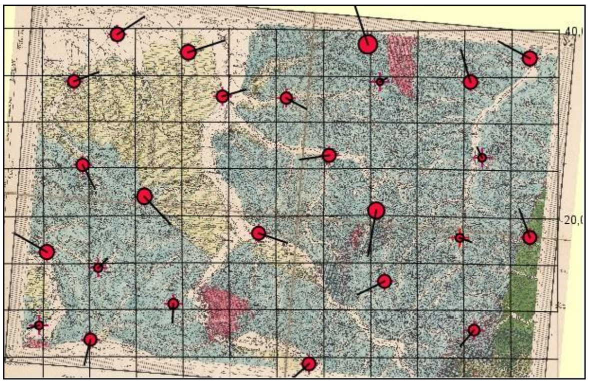


Fig.15. Local variations of the displacement errors on the geological map sheet Tășnad–Șimleul Silvaniei (Hofmann et al., 1883), visualized in MapAnalyst. The scale factor of the displacement vectors and circles is 20.

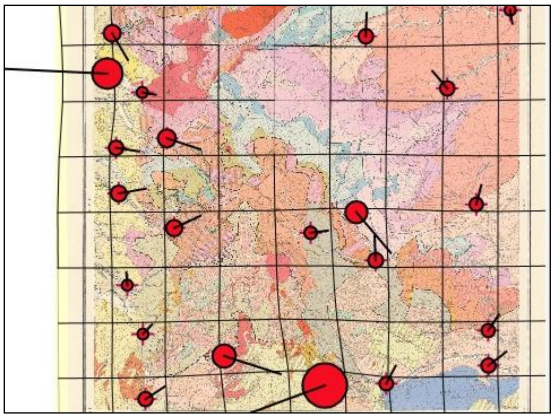


Fig. 16. Local variations of the displacement errors on the geological map sheet Arieșeni (eds. Bleahu & Dimitrescu, ?), visualized in MapAnalyst. The scale factor of the displacement vectors and circles is 10.

In the case of the geological map sheet on a scale of 1:100,000 Arieșeni (eds. Bleahu & Dimitrescu, ?) the local variation of the displacement errors, as well as the computed distorsion grid show us quite large distorsions on some parts of the map.(Fig. 16.). The statistical indicators obtained after transformation in MapAnalyst reveal the same result. However, we believe that these errors are mainly due to the manual introduction of the control points, because we encountered some difficulties in identifying the pairs of the control points on both the old map and the new reference map. Starting from the presumption that the topographic accuracy of this map is higher than what resulted from the cartographic analysis performed with MapAnalyst software application, we georeferenced and integrated into the same GIS database the geological map on a scale of 1:50,000, sheet Avram Iancu (eds. Dimitrescu et al., 1977) in order to overlap the georeferenced images of the two maps and to also analyse in this way the mathematic accuracy. We used the *Swipe Image* tool in Global Mapper for that analysis (Fig. 17.)

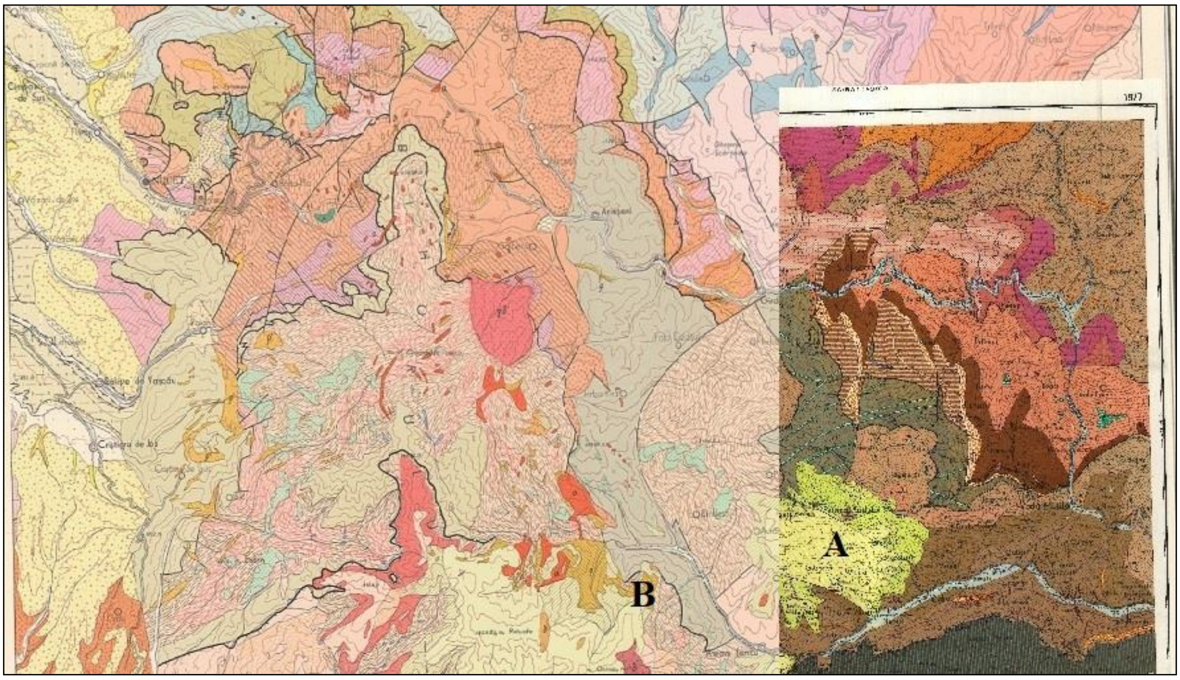


Fig. 17. Overlap of the geological map on the scale of 1:50,000, sheet Avram Iancu (**A**) over the map on a scale of 1:100,000, sheet Arieșeni (**B**).

Analysing in this way the content of the two overlapped maps, we observed that the hydrography fits on both map sheets, only the position of some settlements differs. We also assumed that the geological map sheet on a scale of 1:50,000 (Arieșeni) compiled later on a larger scale has a better cartographic accuracy than the map sheet on a scale of 1:100,000. At the same time, the geological content (especially regarding the limits of the geological formations) of the two maps is very similar, with the mention that the map sheet on a scale of 1:50,000 is more detailed than the other map. Thus, we came to the conclusion that the resulting cartographic errors of the map sheet Arieșeni on a scale of 1:100,000 (eds. Bleahu & Dimitrescu, ?) are caused on the one hand by the initial errors of the topographic survey, on the other hand by manual introduction of the pairs of the control points.

5. Application in Banat on some old geological maps related to the coal mining area of Anina

Performing some practical (GIS) application on detailed maps compiled in the second half of the 19th century and the first half of the 20th century (or to be more precise, between 1850 and World War I) showing the coal mining area of Anina (in Banat) aimed to highlight the importance of knowing the cartographic accuracy (along with the correctness of the geological content) of old geological maps.

The coal mining area of Anina is located in the South-Western part of Romania, Caraș-Severin County, in the historical province of Banat of Temes. In geological terms, the Anina coal mining area is located along the Anina Anticline, oriented approximately North–South, with Lower Jurassic coal bearing strata along both of its flanks (Popa, 2005; Kędzior & Popa, 2013).

In this chapter we presented in detail the evolution of geological mapping of the coal mining area of Anina (in a broad sense the Banat Mountains). We mentioned that the Imperial and Royal geological Institute, then the Royal Hungarian Geological Institute, as well as the Imperial Royal Privileged Austrian State Railway Company (*k. k. priv. Österreichische Staatseisenbahngesellschaft*) had a key role in this research and mapping activity, due to the fact that the Court Chamber set a high value on scientific researches and geological mapping of the mining areas in Banat. The results of this research concerning the evolution of geological mapping in this area were obtained mainly on the basis of the articles and reports published by the geologists of the time, who participated in these geological research and mapping activities. In this respect it is outstanding the research and mapping activity of some accomplished Austrian geologists of the Imperial and Royal Geological Institute (Vienna), such as: **Johann Kudernatsch**, **Franz Foetterle**, **Ferdinand Lidl von Lidelscheim**, **Benedikt von Roha,** etc.; then, after the Austro–Hungarian Compromise (1867) the activity of some famous Hungarian geologists of the Royal Hungarian Geological Institute (founded in 1869), such as: **Telegdi Roth Lajos**, **Böckh János**, **Halaváts Gyula**, **Schafarzik Ferenc**, **Adda Kálmán**, etc.

We also detailed the geological content of the maps (especially the legend), their topographic basis (if relevant), and other elements indicated on the maps that helped us in performing the cartographic analysis, namely: the track of the railway, the scale marked on the maps, the North arrow, lines indicating the magnetic North, etc. Then we performed the cartographic analysis of the geological maps compiled between 1850 and 1884 (subchapter 5.3.2), as well as the georeference and comparison of the geological content of the maps edited between the Austro–Hungarian Compromise (1867) and World War I (subchapter 5.4.2.).

5.3.2. Cartographic analysis of the maps

The cartographic analysis was performed for the following geological maps: the manuscript map Anina – Banat (*Steierdorf Banat*) (***, ~1850); Geological map of the middle part of the Banat Mountains (*Spezialkarte des mittleren Theiles des Banater Gebirgszuges*) (Kudernatsch, 1857); Geognostic map of the Banat district: comprising the imperial and royal mountain territory complex. The mining region Oraviţa and Bocşa (*Banater Domäne: enthaltend den vormaligen k. k. aerarischen Montan-Complex nebst den Staats. Herrschaften Oravicza und Bokschan: Geognostische Karte*) (*** [Foetterle], 1860); Geological map of Anina in Banat (*Geologische Karte von Steierdorf im Banat*) (Roha, 1867[?]); Overall geognostic map of the Anina coal mining region (*Geognostische Übersichtskarte des Kohlenbergbau Terrains von Steierdorf*) (***, 1872[?]). These maps didn't use topographic surveys, consequently we can't talk about projections and geodetic datums they could have used. Only one of them, the geognostic map of the Banat District (*** [Foetterle], 1860) has a graticule drawn, which proved to be completely useless for georeferencing (because the meridians and parallels were "drawn" on the map without any accordance to reality). Consequently, these maps cannot be georeferenced in the "classical" way, determining the map projections, geodetic datums and defining the control points. Therefore, the georeferencing of these maps is limited to the interpolation of a grid onto them (using GIS softwares) and the running of the gridlines and especially our calculations show the accuracy and reliability of the old maps (Korodi et al., 2017). Furthermore, the cartographic analysis of these maps is a necessary step in measuring their reliability in recent studies (Korodi et al., 2017).

The cartographic analysis of the geological maps related to the coal mining area of Anina, compiled between the years 1850–1884 was also performed using the MapAnalyst software application. As new reference map we used the Open Street Map (OSM), or – if it hadn't enough details – we resorted to the current Romanian topographic maps on a scale of 1:25,000. The results of our computing with the help of the MapAnalyst software application are summarized and visualized in the Table 5.1., as well as in Figures 18–22. Table 5.1. contains data concerning the number of control points and the type of the new reference map used for the accuracy analysis, as well as the statistical indicators and errors obtained after the transformation (e.g. the corrected scale of the maps, rotation, standard deviation, mean position error) (Korodi et al., 2017).

Tabel 5.1. The accuracy analysis of the maps (Source: Korodi et al., 2017).

Map	**Number of control points**	**New reference map**	**Corrected scale**	**Rotation (clockwise)**	**Standard deviation (m)**	**Mean position error (m)**
Anina – Banat (~ 1850)	15	OSM	1:90,300 – 1:105,000	17–21°	1315–1445	1860–2043
The map by Kudernatsch (1857)	14	topographic	1:102,900–1:121,600	6–12°	1042–1109	1473–1569
The geognostic map of the Banat district (1860)	19	OSM	1:72,900–1:74,000	4–5°	1145–1155	1620–1634
The map by Roha (1867[?])	15	topographic	1:9,750–1:10,050	83–84°	44–47	62–66
The overall geognostic map of the Anina coal mining region (1872[?])	12	topographic	1:9,900–1:9,950	64–65°	48–50	68–71

Figures 18–22 illustrates the cartographic accuracy of the old maps. We can see the old maps on the left side of the images, where the red network represents the interpolated graticule, and the displacement vectors and circles are located around the control points. The new reference map with the real position of the grid and of the control points is on the right side of the images.

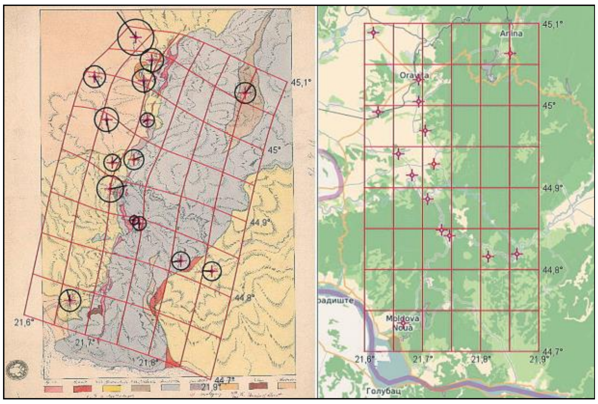
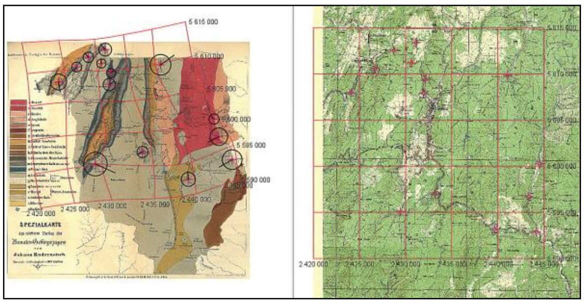


Fig. 18. Cartographic analysis of the map Anina – Banat (***, ~1850) visualized in MapAnalyst (Source: Korodi et al., 2017).

Summarizing the results, we can distinguish two phases in the geological mapping between the years 1850–1884. The first phase contains the maps plotted before the 2nd Military Survey (from around 1850 until 1864), namely the following: Anina – Banat (***, ~ 1850); the geological map of the middle part of the Banat Mountains (Kudernatsch, 1857); the geognostic map of the Banat district [...] (*** [Foetterle], 1860).



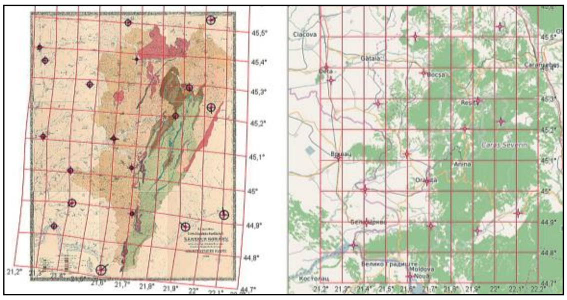
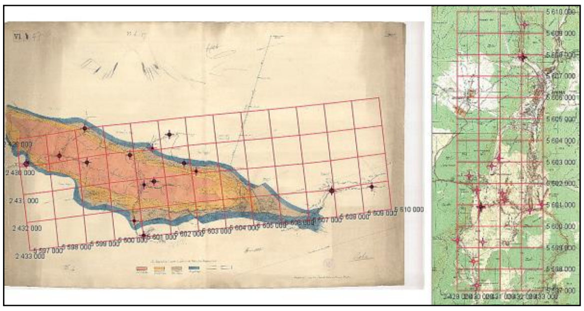


Fig. 19. Cartographic analysis of the map by Kudernatsch (1857) visualized in MapAnalyst (Source: Korodi et al., 2017).

Fig. 20. Cartographic analysis of the geognostic map of the Banat district (*** [Foetterle], 1860) visualized in MapAnalyst (Source: Korodi et al., 2017).

These maps represent a larger area, their scale is at about 1:100,000. At the same time, we can mention that the scale of these maps became more precise (on the first two maps its fluctuation is at about 20%, on the third one it is at about 1%). The precision of their orientation also became better and better, the errors decreased from at about 20° to 4°. Their displacement accuracy is 1–2 km (in reality), that is 1–2 cm (on the map) (Korodi et al., 2017).

The second phase contains the maps compiled between the years 1864–1884, namely the following: The geological map of Anina in Banat (Roha, 1867[?]); the overall geognostic map of the Anina coal mining region (***, 1872[?]). These maps represent a smaller area (both of them only the Anina Anticline). Their scale is larger (1:10,000), the variation of the scale is negligible (less than 1%). The orientation is more and more precise (from 10° to an error less than 1°), while their displacement accuracy is at about 50 m (in reality), that is 0.5 cm (on the map) (Korodi et al., 2017). At the same time, we can mention the progress in the geological content of the maps as well (in the beginning the petrographic-type map is characteristic, then the stratigraphic conception is more and more reflected, and the structural elements are also present).



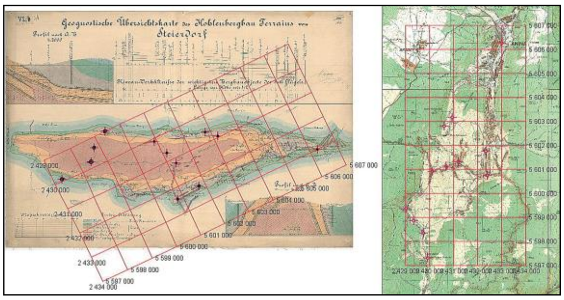


Fig.21. Cartographic analysis of the map by Roha (1867[?])) visualized in MapAnalyst (Source: Korodi et al., 2017).

Fig. 22. Cartographic analysis of the overall geognostic map of the Anina coal mining region (***, 1872[?]) visualized in MapAnalyst (Source: Korodi et al., 2017).

After the Austro–Hungarian Compromise (1867) the systematic and detailed geological mapping of the Hungarian Kingdom (and of the historical province of Banat) was gradually entrusted to the Royal Hungarian Geological Institute (Brezsnyánszky et al., 1999). These were the years when the second systematic sheet-by-sheet geological mapping of the Austro-Hungarian Monarchy started, based on the map sheets (on a scale of 1:75,000) of the 3rd Military Survey (Jankó, 2007:101–102). The geological map series was published later, between the years 1885–1914, after the publication of the topographic map sheets on a scale of 1:75,000. At the beginning, in 1868, as well as in 1869 the Austrian were still involved and continued the systematic and detailed geological research and mapping activity, especially in the North-Eastern part of Hungary, as well as in the Banat Military Frontier (Southern and South-Eastern border of the province). From 1870 the systematic sheet-by-sheet geological mapping of the Hungarian Kingdom had exclusively become the task of the Royal Hungarian Geological Institute (Hauer, 1870; Brezsnyánszky et al., 1999). Publication of the map series related to the territory of the Hungarian Kingdom entitled *A magyar korona országainak részletes geológiai térképe 1:75000* [The detailed geological map of the countries of the Hungarian Crown on a scale of 1:75,000] was interrupted by the World War I (Barczikayné Szeiler et al., 2009).

The coal mining area of Anina is represented at the boundary of two map sheets (on a scale of 1:75,000), namely: the map sheet *Temeskutas und Oraviczabánya* [Gudurica and Oraviţa] (Telegdi Roth et al., 1909) (Fig. 23.), respectively *Krassova és Teregova* [Caraşova and Teregova] (Telegdi Roth et al., 1903) (Fig.24).

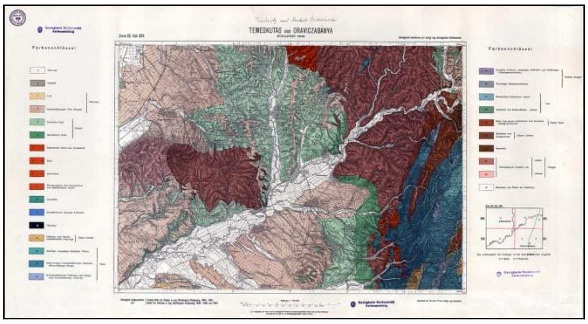


Fig.23. Gudurica and Oraviţa, 1:75 000 (Telegdy Roth et al., 1909). Source: Collection of the Library of the Geological Survey of Austria, Vienna.

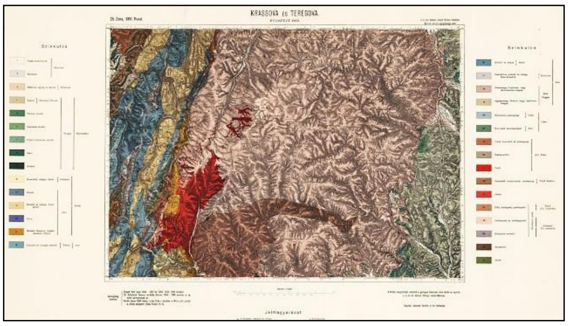


Fig. 24. Caraşova and Teregova, 1:75 000 (Telegdy Roth et al., 1903). Source: Library of the Geological and Geophysical Institute of Hungary, Budapest.

The Austrians continued to pay attention (also) to these regions of the Austro–Hungarian Monarchy, which were considered economically and strategically important regions. This is proved by the fact that they also compiled these geological map sheets on a scale of 1:75,000 in manuscript form: Zone 25 Col. XXV. Gudurica and Oraviţa Nemţească (***, ?), (Fig. 25.), respectively Zone 25 Col. XXVI. Caraşova and Teregova (***, ?) (Fig. 26.).

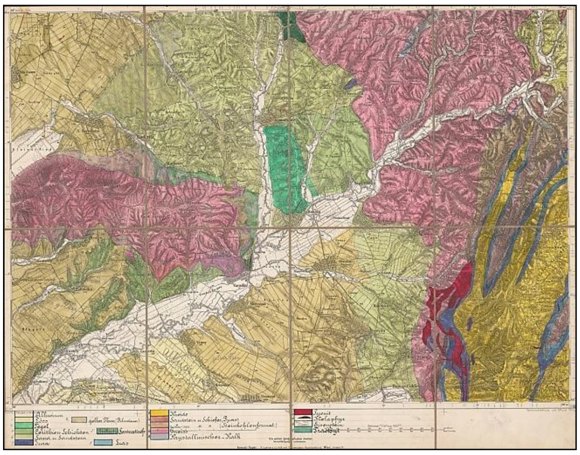


Fig. 25. Zone 25 Col. XXV. Gudurica and Oraviţa Nemţească (***, ?). Source: Collection of the Library of the Geological Survey of Austria, Vienna.

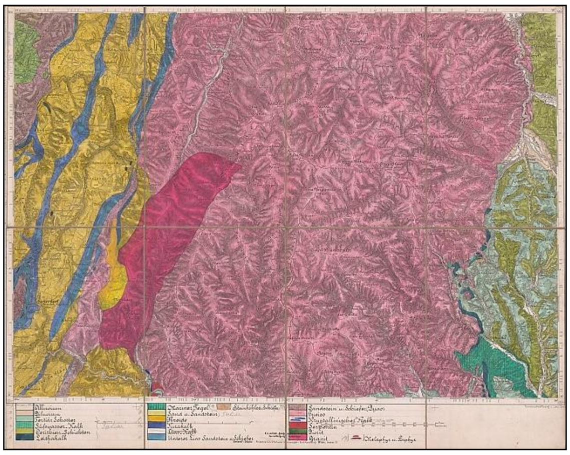


Fig. 26. Zone 25 Col. XXVI. Caraşova and Teregova, 1:75 000 (***, ?). Source: Collection of the Library of the Geological Survey of Austria, Vienna.

5.4.2. Georeference and comparison of the geological content of the maps

In this subchapter we presented the georeferencing methods of these map sheets, which used as topographic basis the detailed maps on a scale of 1:75,000 of the 3rd Military Survey. The georeference of these geological map sheets is equivalent to the rectification of the topographic map sheets, which has been already performed and published by others (Biszak et al, 2007, www.mapire.eu). Consequently, we georeferenced the geological map sheets according to the methods described by **Timár Gábor** and **Molnár Gábor** (Timár and Molnár, 2008; Molnár and Timár, 2009), using the sinusoidal projection, this being considered the approximate projection –implemented in GIS software – of the 3rd Military Survey. The georeferencing was performed using the Global Mapper software. The maps were first rectified in their initial cartographic projection, afterwards we cut the frame of the maps, in order to obtain a continuous mosaic of the two map sheets, and in the end we reprojected them in Gauss–Krüger projection. This method was applied to both the Hungarian, as well as the Austrian map sheets.

The geological map sheet Anina (L-34-104-D) (Năstăseanu and Savu, 1970) on a scale of 1:50,000 was georeferenced and integrated in the same GIS database, in order to be a reference map for the analysis of the geological content of the old geological maps. The geological map series on a scale of 1:50,000 used the Gauss–Krüger projection with geodetic datum S-42 (Pulkovo 1942), referenced on the Krasovski-1940 ellipsoid. The georeference of the geological map sheet Anina was also made using the Global Mapper software. After overlapping the maps we noticed that the old geological map is displaced by ca. 200 m (to the East) compared to the modern geological map. We corrected this error by shifting without rotation the georeferenced image to the West (270°) using the *Shift Selected Layer(s)* tool in Global Mapper.

The comparison of the geological content of the maps was made in Global Mapper using the *Image Swipe* tool and was illustrated with several figures. This tool allows the chosen layer (image) to be “pulled” over the other layer, so that the layer below becomes visible, or more precisely, both layers can be viewed at once, consequently the content of several overlapping layers becomes comparable.

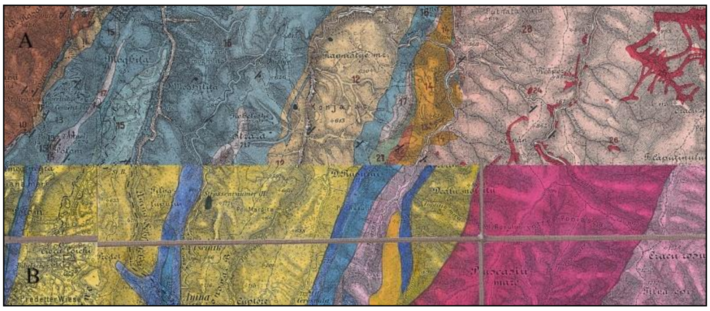


Fig. 27. Comparison of the Hungarian (A), and the Austrian (B) geological map sheets (fragment of the overlapping maps).

Analysing the geological content of the geological map sheets, it is noticeable at first sight that the Hungarian (A) and the Austrian (B) geological map sheets differ significantly (Fig. 27.).

We also compared the mosaic of the Hungarian (e.g. Fig. 26) and the Austrian (e.g. Fig. 29) map sheets with the modern geological map on a scale of 1:50,000 (the latter representing the reference geological map), and we came to the conclusion that the geological content of the Hungarian map sheets is very similar to that of the modern map, they are also much more accurate and detailed than the Austrian manuscript maps. This comparison was illustrated with several figures. The Hungarian map sheets have a high geological accuracy, the boundaries of the geological formations largely coincide with those represented on the modern map. We noticed differences especially in the nomenclature, as well as in the geological “resolution” of the maps (the modern map contains much more chronostratigraphical subdivisions than the Hungarian map sheets). The fact that the Austrian manuscript maps have a lower geological accuracy than the

Hungarian maps, as well as the modern map, proves to us that they were most likely compiled on the basis of previous researches and mapping activities, prior to the publication of the topographic map sheets on a scale of 1:75,000 of the 3rd Military Survey (before the 1880s). Consequently, it proves to us that the Austrians did really finish the systematic and detailed geological mapping of this region after 1870, although they edited the map sheets on a scale of 1:75,000 based on previous geological research and mapping activity.

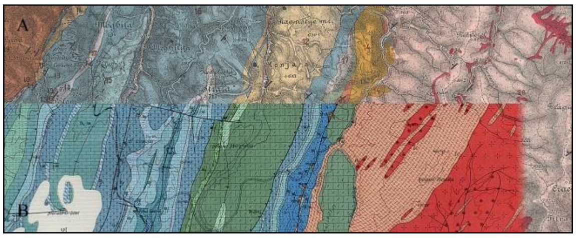


Fig. 28. Comparison of the Hungarian map sheets (A) with the modern map (B) (fragment of the overlapping maps).

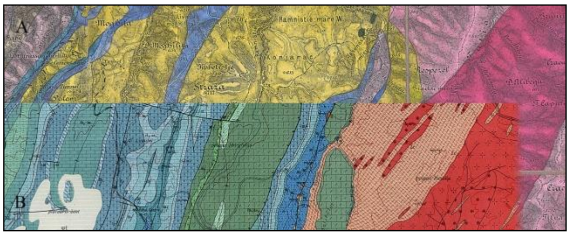


Fig. 29. Comparison of the Austrian map sheets (A) with the modern map (B) (fragment of the overlapping maps).

Final conclusions

Old geological maps are part of our cartographic heritage (in a boarder sense they are part of our cultural heritage) therefore their study is extremely important in the perspective of the history of cartography (in this case the history of geological cartography).

The analysis and exploration of their topographic basis has a special practical importance, because it allows us to georeference them, and thus to integrate them into a GIS database.

This analysis represents an innovative study, due to the fact that a GIS database that integrates the geological maps related to Transylvania has not been realized so far.

The GIS application performed on the geological maps related to Transylvania, as well as on the detailed maps showing the coal mining area of Anina (Banat) aimed to highlight the importance of taking into consideration the cartographic accuracy. This analysis, together with the study of the geological content of the maps is necessary when the goal is to test their reliability for the present researches. All the more so, as these old geological maps can show with quite good cartographic precision geological excavations or mining works that are no longer found in the field today. Therefore, the study of the geological content together with the cartographic analysis makes possible the overlapping of several maps from different periods, in order to compare their geological data, consequently to track the evolution of geological knowledge in time.

This work is notable for its high degree of interdisciplinarity, due to the fact that it involves knowledge in the field of geology, history of geology and history of geological cartography, as well as practical aspects of cartography (and historical cartography), and geomatics (using GIS applications).

As a possible continuation of this study, a more detailed analysis can be performed by overlapping several geological maps from different times. The comparison of their geologic content together with their cartographic analysis could reveal on the one hand the evolution of the geological knowledge in time, on the other hand the degree of credibility and reliability of previous geological data for recent researches.

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