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HEAVY MINERAL DISTRIBUTIONS IN UPPER CRETACEOUS BOZEŞ FORMATION (APUSENI MOUNTAINS, ROMANIA) – IMPLICATIONS FOR SEDIMENT PROVENANCE

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Abstract. Upper Cretaceous sedimentary deposits from southern part of the Apuseni Mountains are of a special importance in constraining the tectonic evolution of this region. Therefore, the Upper Cretaceous units within this region, such as Bozeş Formation, have to be properly described in terms of provenance and basinal evolution. This study represents the first extensive investigation of heavy mineral assemblages of siliciclastic rocks from Upper Cretaceous Bozeş Formation, in order to constrain their source types. The heavy mineral analysis implies identification of mineral species, but also the description of the crystal habitus. The associations are similar in all studied samples and consist mainly of moderate rounded grains of garnet, zircon, epidote, tourmaline, rutile and titanite. Two main, contrasting sources are deciphered on the base of heavy mineral analysis. These are represented by a low to medium metamorphic unit, and an older sedimentary succession, with smaller contributions from acid igneous rocks.

Keywords: heavy minerals, rock source, Upper Cretaceous, Bozeş Formation, Apuseni Mountains.

1. INTRODUCTION

Constraining the provenance of siliciclastic sediments is very important for tectonic reconstruction and basin analysis. The clastic sediments are bearing fingerprints of many factors, and the type of source rocks is between the most important, together with weathering, sorting or diagenetic processes (Johnsson, 1993; von Eynatten, 2004).

Heavy minerals are high density constituents of siliciclastic sediments (Mange & Maurer, 1992). They occur in a wide range of rock types, either as main minerals, like amphiboles, pyroxenes or micas, or as accessory phases, such as zircon, apatite, tourmaline etc. The heavy mineral studies may provide crucial information on sediment provenance, in terms of source rock types, transport directions, subsequent processes (as alteration or diagenesis) etc. (*e.g.* Basu & Molinaroli, 1989; Meinhold et al., 2010; Morton, 1985, 1991; Turner & Morton, 2007).

Only recently such heavy mineral studies were performed in Romania, on sedimentary rocks from various tectonic units, *e.g.* Upper Cretaceous Gosau basins from Apuseni Mts. (Schuler & Frisch, 2006), Upper Cretaceous Hateg basin from Southern Carpathians (Bojar et al., 2010) as well as Miocene siliciclastic rocks from Eastern Carpathians Foreland basin (Dill et al., 2012).

Apuseni Mts. are part of the Alps-Carpathians-Dinarides chain. They are the result of the collision of Tisia and Dacia microplates in the Upper Cretaceous, preserving the suture in the southern part of the mountains. Thus, syn-orogenic sedimentary units from this area are of special importance from tectonic point of view (Bălc et al., 2011), such as, for example, the Bozeş Formation from south-eastern part of the Apuseni Mts is.

The aim of this paper is to apply for the first time a heavy mineral analysis in order to constrain the source rock types of siliciclastic material from Upper Cretaceous Bozeş Formation. In this area, previous provenance studies focused on paleocurrents and petrographic analyses (Antonescu et al., 1963; Bleahu & Dimian, 1963; Dimian & Popa-Dimian, 1964).

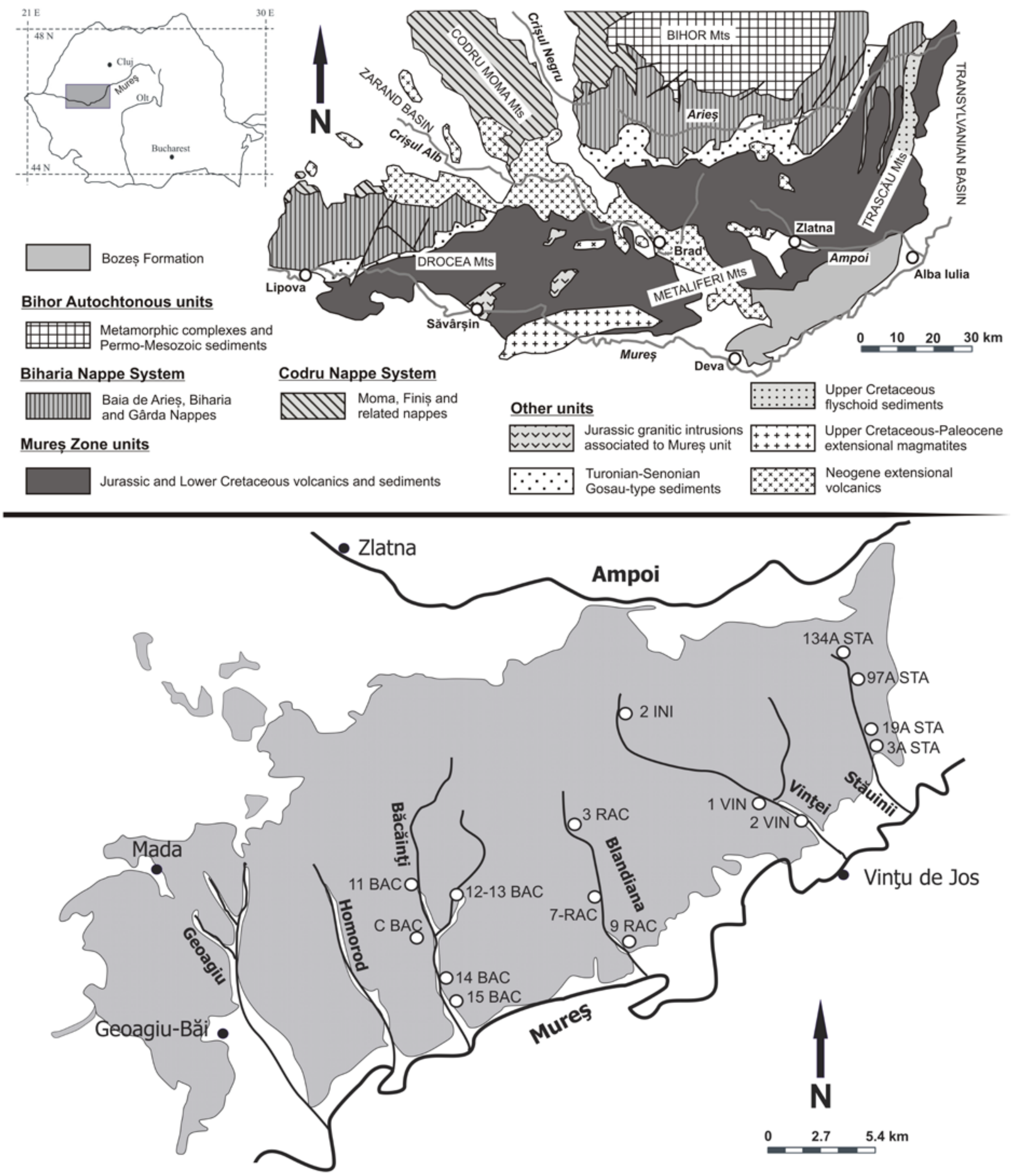

Figure 1. Sketch of the main Alpine tectonic units in the Southern Apuseni Mts, showing the location of the Bozeş Formation (simplified after Balintoni et al., 2009) (upper part) and enlarged map of the Bozeş Formation, with location of the studied samples (after Geological maps of Romania, 1: 200.000, Turda and Orăştie sheets) (lower part).

2. GEOLOGICAL SETTING

The component units of Apuseni Mountains, namely Bihor Unit, Apusenides and Western Transylvanides, originate in the Preaulian Craton and the Transylvanian Tethys (Săndulescu, 1984, 1994). They were affected by three deformation events: so-called Austrian (Albian - Aptian), Pregosau (intra-Turonian) and Laramian (Maastrichtian – Danian) (Bleahu et al., 1981; Balintoni, 1997). Tectonically, the Apuseni Mts. are constituted by four major Alpine units, namely Bihor Autochtonous, Biharia Nappe System, Codru Nappe System and Mureş Zone units (Balintoni, 1997) (Fig. 1).

Bozeş unit (or Bozeş nappe in older studies) crops out in the Southern Apuseni Mts. As established by Ghiţulescu & Socolescu (1941) or Bleahu et al. (1981), Bozeş unit, with its main litostratigraphical constituent, Bozeş Formation (Ghiţulescu & Socolescu, 1941), as well as with smaller Bobâlna and Geoagiu Formations, represents the uppermost unit among the Western Transylvanides.

Bozeş Formation consists of 3000m-thick, turbidite-type sedimentary sequence (mainly grey sandstones and silty marls, with microconglomeratic levels in the upper part). Based on macro- and microfauna, the age of the formation was established as Upper Santonian - Campanian - possible early Maastrichtian (Dimian & Popa-Dimian, 1964; Tomescu et al., 1969; Marincaş & Mânecan, 1971; Marincaş, 1973; Bălc et al., 2007, 2012).

There are few provenance studies performed on sediments from Bozeş Formation, referring mainly to the transport direction. Based on the identified erosional structures on the sandstone surfaces (as groove, flute or deltoidal casts), as well as petrography of the coarser siliciclastic rocks, Antonescu et al. (1963) and Dimian & Popa-Dimian (1964) proposed a E - W dominant transport direction of the detrital material.

Although traditionally Bozeş Formation is considered part of the Apuseni Mts. from geological point of view, recently some controversy occurred over its tectonic affiliation. Balintoni (2003) grouped Bozeş Formation, Bejan Formation and Rapolt and Poiana Ruscă crystalline units within the frame of Bozeş unit, and tectonically affiliated them to the Southern Carpathians. Although this hypothesis was adopted by few authors, it is still much controversial, and it is beyond the purpose of this paper to bring arguments for any of the tectonic ideas in use.

3. MATERIALS AND METHODS

Fifteen sandstone samples were selected from the study area, following four of the major valleys which crosscut the Bozeş Formation: Stăuinii, Vinţei, Blandiana (Răcăştiei) and Băcăinţi (Fig. 1).

Heavy mineral concentrates were obtained according with the standard methods. The selected samples, each weighing about 2-3 kg, were repeatedly crushed in a jaw-crusher. Then the samples were sieved and <250μm fractions were separated. The clayey material was removed through repeated washing, while for removing the carbonates an acetic acid treatment (9°) was applied. Heavy fractions were separated by density using di-iodomethane (CH_2I_2), a heavy liquid with a density of 3.325 g/cm^3. The obtained concentrates were evenly mounted on microscope slides using synthetic resin.

The heavy mineral identification and counting was done using a polarization microscope (transmitted and reflected light). Various heavy mineral species were identified by means of their optical properties according with Mange & Maurer (1992). For the relative abundances of heavy minerals in a sample, the Fleet method (Fleet, 1926) was applied, which means that all grains on the microscope slide are taken into account. Thus, at least 100 grains were considered for each sample, with few exceptions due to the insufficient number of grains separated. For graphical presentation and data interpretation similar minerals in which concern stability and provenance were grouped together.

4. RESULTS

Heavy mineral point counting of the Bozeş sandstones reveals quite relative uniform mineral assemblages (Table 1). Garnet and zircon are the dominating minerals. Rutile and epidote can be also abundant, even surpassing zircon in some samples. Only few grains of staurolite, titanite or tourmaline occurred within the heavy mineral assemblages. Very rare grains of zoisite or chloritoid are included within other minerals category.

Garnet occurs in variable concentrations (between 20.7 and 84.7%). With few exceptions (samples 134A-STA, 1-VIN and C-BAC), it is the heavy mineral occurring in the largest quantities. The grains are in most cases medium rounded.

Zircon concentration is rather high (between 3.2 and 40%), being the most abundant heavy mineral in the above-mentioned samples, where garnet is less. Most of the zircon grains are colorless or pale pink, slightly to moderate rounded, as well as very elongated euhedral crystals, some fragmented, can be observed.

Rutile is also a very resistant mineral to transport and weathering. It can be found in Bozeş sandstones up to almost 35.2% of counted heavy minerals, mainly as very rounded grains or crystal fragments, brownish or reddish in color. Small, irregular, greenish crystals of epidote are characteristic for some of the studied sandstones (up to 11.2%), only in sample 9-RAC being the second mineral as abundance (50 grains, *cca* 16%).

Few angular, yellowish crystals of staurolite and even less of slightly rounded or angular tourmaline or pale yellow, rounded titanite complete the heavy mineral assemblages of Bozeş samples.

5. DISCUSSIONS

Every heavy mineral is affected by different processes, from the very first moment it is released from its host rock, until extraction for study. These factors may affect the reliability of the provenance information given by heavy mineral analysis (*e.g.* Pettijohn et al., 1987; Morton, 1985).

Table 1. Number of counted heavy minerals for the studied Bozes sandstones and the ZTR index calculated as percent (see text for details). Symbols: Gr – garnet, Zr – zircon, Ep – epidote, Ru – rutile, Tu – tourmaline, St – staurolite, Total – total counted grains, ZTR – ZTR index.

	Gr	Zr	Ep	Ru	Ti	Tu	St	Others	Total	ZTR
Stăuinii Valley										
3 STA	75	25	3	10	0	0	3	1	117	29.91
19A STA	70	20	10	0	0	0	2	3	105	19.05
97A STA	100	65	7	34	0	0	0	5	211	46.92
134A STA	115	135	10	55	0	0	2	3	320	59.38
Vinţului Valley										
2 INI	64	6	0	10	0	0	0	2	82	19.51
1 VIN	30	46	4	10	0	1	0	5	96	59.3□
2 VIN	63	21	0	14	2	10	0	0	110	40.91
Răcăştiei Valley										
3 RAC	31	5	6	25	0	2	1	1	71	45.07
7 RAC	75	35	4	15	0	0	0	0	129	38.76
9 RAC	232	10	50	15	0	0	0	7	314	7.96
Băcăinţi Valley										
11 BAC	60	15	11	5	2	0	2	3	98	20.41
12-13 BAC	160	35	15	25	0	0	0	5	240	25.□0
14 BAC	75	65	10	46	6	0	13	10	225	49.33
15 BAC	200	19	5	7	2	0	0	3	236	11.02
C BAC	75	155	16	100	5	0	7	10	368	69.29

Two are the most important factors to evaluate: *hydraulic sorting*, operating during transport and resulting in selective grain accumulation, and *post-depositional, diagenetic effects*, strongly related to stability of heavy minerals, and which can influence the heavy mineral spectra, by eliminating the less resistant grains (Mange & Maurer, 1992).

5.1. Stability of heavy minerals

Zircon is one of the most stable minerals, being characterized by extreme weathering resistivity and transport stability (Schuller & Frisch, 2006) due to small size and lack of cleavage (Mange & Maurer, 1992). It can survive several sedimentary cycles, as well as diagenesis and metamorphism. In Bozeş sandstones, most of the zircon grains are medium rounded, which points to their polycyclic character.

Turmaline and rutile display similar features to zircon, being ultrastable both mechanically and chemically, and rounded rutile and tourmaline of Bozeş unit are indicative of a recycled material too.

Garnet is a relatively stable heavy mineral. However, it is sensitive to dissolution during both burial diagenesis and surficial weathering (Morton & Hallsworth, 1994). Thus, in most cases, it not survives to repeated recycling episodes of sediments (Hallsworth & Chisholm, 2008). Therefore, the rounded garnet grains from Bozeş sandstones are most likely subject of a unique sedimentary cycle.

Although a widespread mineral, epidote is relatively unstable within diagenetic conditions, the number of epidote grains decreasing with the depth of the buried sediments (Mange & Maurer, 1992). Titanite is characterized by similar chemical instability, usually decomposing in early stage of diagenesis (Morad & Aldahan, 1985). Only few epidote grains and very rare titanite crystals are found in the heavy mineral assembleges of Bozeş samples (Table 1), except for sample 9-BAC, with a relatively high epidote concentration, which might be the case of a well-sealed part of the basin (Mange & Maurer, 1992).

Apatite is a stable mineral and therefore it may survive several cycle of reworking, but no apatite grains were founded in Bozeş sedimentary rocks. Although apatite is known as being extremely sensitive to acid dissolution, thus almost missing in acidic geochemical environments (Morton, 1984, 1986), its absence in Bozeş sedimentary samples is most probably due to the high density of the heavy liquid used for mineral separation.

Hubert (1962) defined the ZTR (zircon-tourmaline-rutile) index as a measure of the mineralogical maturity of heavy mineral assemblages. The ZTR index is calculated as the percentage of the three mentioned minerals from the total counted heavy minerals. Bozeş sandstones display a wide range of values, from 7.92 to 69.29 (average 36.13) with zircon as the dominating mineral (zircon>rutile>tourmaline) (Table 1). The

ZTR values of Bozeş unit point to a low to medium level regarding the maturity of heavy mineral suites.

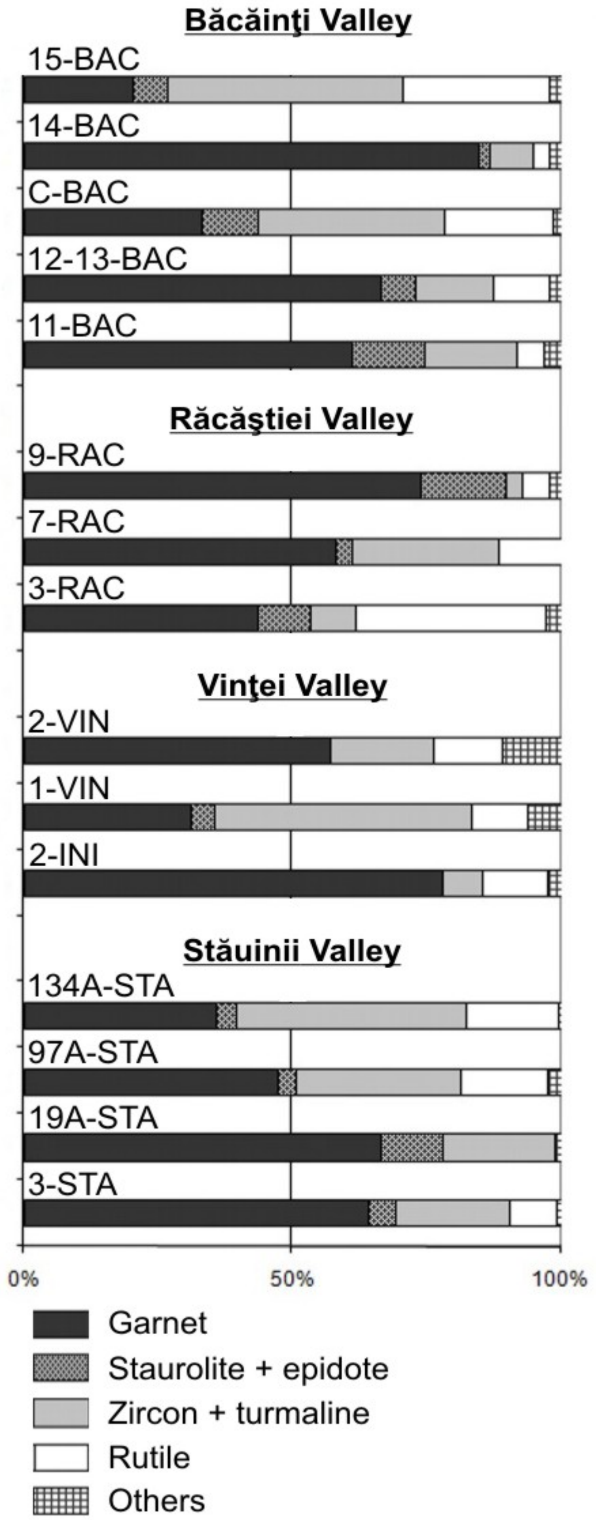

Figure 2. Heavy mineral assemblages of Bozes siliciclastic rocks.

5.2. Hydraulic sorting

During sediment transportation and deposition, mineralogical and chemical differentiations of clastic sediments are influenced by hydraulic sorting (Nesbitt & Young, 1996), due to the preferential accumulation of weathering-resistant heavy minerals, such as zircon, apatite, monazite and titanite. Because these accessory phases are the main hosts for some trace and rare earth elements (*e.g.* Zr, Y, U, Th, Nb, Ta; Cullers et al., 1979; Mass & McCulloch, 1991), their preferential accumulation may produce irregular chemical variations in rock composition. Thus, by examining the abundances and co-variations of selected chemical elements, the intensity of hydraulic sorting can be estimated (La Flèche & Camiré, 1996).

Using geochemistry of sandstones from Bozeş Formation (including all samples presented in this study), Pojar & Zaharia (2012) evaluated the effect of hydrodynamic sorting for Bozeş sandstones as being relatively negligible.

5.3. Implications for source rock types

To establish possible rock types which acted as source for Bozeş sedimentary material, heavy minerals with similar provenance and stability are presented together (Fig. 2).

Garnet is common in heavy mineral suites of Bozeş siliciclastic sediments. It is generally interpreted to indicate metamorphic source rocks (Mange & Maurer, 1992), although garnet may also occur in magmatic rocks (Deer et al., 1992). Staurolite and epidote are both deriving from low to medium-grade metamorphic rocks too, therefore they were grouped together (Fig. 2), but their contributions in Bozeş heavy mineral suites are much less than the garnet one. However, considering these three minerals together (35-90%), it is obvious that a metamorphic unit was the main material supplier in Bozeş sedimentary basin.

Zircon, tourmaline and rutile form the second major group of Bozeş heavy mineral assemblages (ZTR group). It is generally thought that they indicate a continental crustal provenance (von Eynatten & Gaupp, 1999). Zircon and tourmaline are common in acidic to intermediate granitoids, as well as in some metamorphic rocks, while rutile is primarily provided by the high-presure metamorphic rocks (Force, 1980; Schuller & Frisch, 2006). Nevertheless, all these three minerals can be supply through erosion of older sedimentary successions, and such a source is inferred for Bozeş unit, due to the large quantity of rounded ZTR grains. A smaller contribution of some granitoid rocks is expected, as pointed out by the presence of euhedral zircon grains, while the very elongated ones are specific for volcanic/pyroclastic deposits (Mange & Maurer, 1992).

Apatite is not discriminative for any special provenance area (Kutterolf et al., 2008), thus its absence does not influence the identification of the source rock types.

Based on paleocurrent directions and petrographical studies, Dimian & Popa-Dimian (1964) proposed the western and south-western part of the uplifted basement of the Transylvanian basin as the main source for Bozeş sediments. This consists of a low to medium-grade metamorphic unit of chloritoid schists, various quartzites and micaschists, with associated Upper Jurassic limestones, banatitic rhyolite tuffs, Cretaceous sandstones and marlstones, as well as ophiolites. The source rocks as inferred by the heavy mineral study are consistent with this provenance, except that no heavy mineral characteristic for ophiolites was identified (*e.g.* Cr-spinel, pyroxene).

However, as mentioned, the tectonic affiliation of the Bozeş unit during Upper Cretaceous is rather controversial, therefore the tectonic units which acted as sources might be different, and additional analyses may be implied to solve this.

6. CONCLUSIONS

Heavy mineral analysis proves to be an important tool in deciphering the rock types which acted as sources for sediments of Upper Cretaceous Bozeş Formation. The heavy mineral spectra indicated two major source types. The large amount of garnet, epidote and staurolite, can be attributed predominately to low to medium metamorphic sources. The ultrastable mineral group, of zircon, tourmaline and rutile, represented mainly by rounded grains, points out the erosion of an older sedimentary source. The heavy mineral assemblages indicated two major source types for Upper Cretaceous Bozeş Formation.

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REFERENCES

Antonescu, E.M., Balş, St., Georgescu, F., Georgescu, V., Mantea, Gh., Mihăilescu, N., Panin, N. & Tomescu, C., 1963. *Sedimentological data about the Senonian-Danian deposits from Vinţu de Jos-Geoagiu area*. Studii şi Cercetări de Geologie, 8, 2, 215–234 (in Romanian).

Balintoni, I., 1997. *Geotectonics of the metamorphic terrains in Romania*. Editura Carpatica, Cluj Napoca, 176 pp. (in Romanian).

Balintoni, I., 2003. *Towards an improved model of the Laramian Transylvanides*. Studia Universitatis Babeş-Bolyai, Seria Geologia, Special Issue, 13–20.

Balintoni, I., Balica, C., Cliveţi, M., Li, Q-L., Hann, H.P., Chen, F. & Schuller, V., 2009. *The emplacement age of the Muntele Mare Variscan granite (Apuseni Mountains, Romania)*. Geologica Carpathica, 60, 6, 495–504.

Basu, A. & Molinaroli, E., 1989. *Provenance characteristics of detrital opaque Fe–Ti-oxide minerals*. Journal of Sedimentary Petrology, 59, 922–934.

Bălc, R., Suciu-Krausz, E. & Borbei, F., 2007. *Biostratigraphy of the Cretaceous deposits in the Western Transylvanides from Ampoi Valley (Southern Apuseni Mountains, Romania)*. Studia Universitatis Babeş-Bolyai, Seria Geologia, 57, 1, 23–32.

Bălc, R., Zaharia, L., Suciu-Krausz, E. & Kristaly, F., 2011. *New Upper Cretaceous deposits in the South-Eastern Trascau Mountains (Apuseni Mts., Romania)*. Carpathian Journal of Earth and Environmental Sciences, 7, 1, 17–26.

Bălc, R., Sylie, L. & Zaharia, L., 2012. *Calcareous nannofossils and sedimentary facies in the Upper Cretaceous Bozeş Formation (Southern Apuseni Mountains, Romania)*. Studia Universitatis Babeş-Bolyai, Seria Geologia, 57, 1, 23–32

Bleahu, M. & Dimian, M., 1963. *Stratonomic characteristics of the Cretaceous series from Metaliferous Mountains.* Proceedings of the Vth Congress of the Carpathian-Balkan Geological Association, III, 1, 81–95.

Bleahu, M., Bordea, S., Lupu, M., Ştefan, A., Patrulius, D. & Panin, Ş., 1981. *The structure of the Apuseni Mountains*, Guide to Excursion B3, XII Congress of the Carpathian-Balkan Geological Association, Bucharest, 107 pp.

Bojar, A.V., Bojar, H.P., Ottner, F. & Grigorescu, D., 2010. *Heavy mineral distributions of Maastrichtian deposits from the Haţeg basin, South Carpathians: Tectonic and palaeogeographic implications*. Palaeogeography, Palaeoclimatology, Palaeoecology, 293, 319–328.

Cullers, R.L., Chaudhuri, S., Kilbane, N. & Koch, R., 1979. *Rare earths in size fractions and sedimentary rocks of Pennsylvanian-Permian age from the mid-continent of the USA.* Geochimica et Cosmochimica Acta, 43, 1285–1301.

Deer, W.A., Howie, R.A. & Zussmann, J., 1992. *An Introduction to the Rock-Forming Minerals,* 2nd edition, Longman, Essex, 696 pp.

Dill, H.G., Iancu, G.O., Ionesi, V., Sârbu, S.,

Balintoni., I & Botz, R., 2012. *Petrography and mineral chemistry of Bessarabian siliciclastic rocks in the Eastern Carpathian Foreland Basin (Romania and Republic of Moldova)*. Neues Jahrbuch für Geologie und Paläontologie, 263, 3, 199–226.

Dimian, E. & Popa-Dimian, M., 1964. *Stratigraphical and sedimentological data on the Cretaceous formations between Mureş and Ampoiului valleys*. Dări de Seamă ale Comitetului de Stat Geologic, (1961-1963), 1, 107–130 (in Romanian).

Fleet, W.F., 1926. *Petrological notes on the Old Red sandstones of the west Midlands*. Geological Magazine, 63, 505–516.

Force, E.R., 1980. *The provenance of rutile*. Journal of Sedimentary Petrology, 50, 485–488.

Ghiţulescu, T.P. & Socolescu, M., 1941. *Etude geologiques et miniere des Monts Metalliferes.* Anuarul Institutului Geologic, XXI, 181–463.

Hallsworth, C.R. & Chisholm, J.I., 2008. *Provenance of late Carboniferous sandstones in the Pennine Basin (UK) from combined heavy mineral, garnet geochemistry and paleocurrent studies*. Sedimentary Geology, 203, 196–212.

Hubert, J.T., 1962. *Zircon-tourmaline-rutile maturity index and interdependence of the composition of heavy minerals assemblages with the gross composition and texture of sandstones*. Journal of Sedimentary Petrology, 32, 440–450.

Johnsson, M.J., 1993. *The system controlling the composition of clastic sediments*. In: Johnsson, M.J., Basu, A. (Eds.), Processes controlling the composition of clastic sediments. Geological Society of America, Special Papers, 284, 1–19.

Kutterolf, S., Diener, R., Schacht, U. & Krawinkel, H., 2008. *Provenance of the Carboniferous Hochwipfel Formation (Karawanken Mountains, Austria / Slovenia) - Geochemistry versus petrography*. Sedimentary Geology, 203, 246–266.

La Flèche, M.R. & Camiré, G.E., 1996. *Geochemistry and provenance of metasedimentary rocks from the Archean Golden Pond sequence (Case Berardi mining district, Abitibi subprovince)*. Canadian Journal of Earth Sciences, 33, 676–690.

Mange, M.A. & Maurer, H.F.W., 1992. *Heavy minerals in colour*. Chapman & Hall, London, 147pp.

Marincaş, V., 1973. *The age of the Bozeş strata.* Studia Universitatis Babeş-Bolyai, Geologia, 1, 39–46 (in Romanian).

Marincaş, V. & Mânecan, D., 1971. *Contributions a la stratigraphie du cretace superieur dans la region de Geoagiu*. Sargetia, 8, 21–37

Mass, R. & McCulloch, M.T., 1991. *The provenance of Archean clastic metasediments in the Narryer Gneiss Complex, Western Australia: Trace element geochemistry, Nd isotopes, and U-Pb ages for detrital zircons*. Geochimica et Cosmochimica Acta, 55, 1915–1932.

Meinhold, G., Reischmann, T., Kostopoulos, D., Frei, D. & Larionov, A.N., 2010. *Mineral, chemical and geochronological constraints on the age and provenance of the eastern Circum-Rhodope Belt low-grade metasedimentary rocks, NE Greece*. Sedimentary Geology, 229, 207–223.

Morad, S. & Aldahan, A.A., 1985. *Leucoxene-calcite-quartz aggregates in sandstones and the relation to decomposition of sphene*. Neues Jahrbuch für Mineralogie, 10, 458-468.

Morton, A.C., 1984. *Stability of detrital heavy minerals in Tertiary sandstones from the North Sea basin*. Clay Minerals, 19, 287–308.

Morton, A.C., 1985. *Heavy minerals in provenance studies*. In: Zuffa, G.G. (Ed.), Provenance of Arenites. Reidel, Dordrecht, 249–277.

Morton, A.C., 1986. *Dissolution of apatite in North Sea Jurassic sandstones: implication for the generation of secondary porosity*. Clay Minerals, 21, 711–733.

Morton, A.C., 1991. *Geochemical studies of detrital heavy minerals and their application to provenance research*. In: Morton, A.C., Todd, S.P., Haughton, P.D.W. (Eds.), Developments in Sedimentary Provenance Studies. Geological Society Special Publications, 57, 31–45.

Morton, A.C. & Hallsworth, C., 1994. *Identifying provenance-specific features of detrital heavy mineral assemblages in sandstones*. Sedimentary Geology, 90, 241–256.

Săndulescu, M., 1984. *The geotectonics of Romania.* Editura Tehnică, Bucharest, 336 p. (in Romanian)

Săndulescu, M., 1994. *Overview on Romanian Geology*. Romanian Journal of Tectonics and Regional Geology, 75, 2, 3–15.

Nesbitt, H.W. & Young, G.M., 1996. *Petrogenesis of sediments in the absence of chemical weathering; effects of abrasion and sorting on bulk composition and mineralogy*. Sedimentology, 43, 341–358.

Pettijohn, F.J., Potter, P.E. & Siever, R., 1987. *Sand and Sandstone*. 2nd edition, Springer, New York, 553 pp.

Pojar, I. & Zaharia, L., 2012. *Testing the heavy mineral accumulation in Bozeş sedimentary rocks (South Apuseni Mts., Romania)*. Acta Mineralogica Petrographica, Abstract Series, Szeged, 7, 109.

Schuler, V. & Frisch, W., 2006. *Heavy mineral provenance and paleocurrent data of the Upper Cretaceous Gosau succession of the Apuseni Mountains (Romania)*. Geologica Carpathica, 57, 1, 29–39.

Tomescu, C., Panin. F., Georgescu, G., Mantea, G. & Antonescu, E., 1969. *Contributions to the stratigraphy of the Upper Cretaceous deposits from Southern Apuseni Mountains*. Studii şi Cercetări de Geologie, Geofizică şi Geografie, Seria Geologie, 14, 1, 239–252 (in Romanian).

Turner, G. & Morton, A.C., 2007. *The effects of burial diagenesis on detrital heavy mineral grain surface textures*. In: Mange, M., Wright, D.T. (Eds.), Heavy Minerals in Use. Developments in

Sedimentology, 58, 393–412.
von Eynatten, H., 2004. *Statistical modeling of compositional trends in sediments*. Sedimentary Geology, 171, 79–89.
von Eynatten, H. & Gaupp, R., 1999. *Provenance of Cretaceous synorogenic sandstones in the Eastern Alps: constraints from framework petrography, heavy mineral analysis and mineral chemistry*. Sedimentary Geology, 124, 81–111.

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