BLUE QUARTZ AROUND THE GLOBE

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Abstract. Blue quartz occurs in a variety of geological settings worldwide and its colour is often produced through the Rayleigh scattering of light off nanometre size mineral inclusions with uncertain identity. Despite this fact, dedicated mineralogical studies on the topic are few and most references mention only the location and inferred causes for the blue colour. The literature consulted for this paper suggests an occurrence pattern consisting mainly of continent-continent collision type zones, with some exceptions owed to local geological particularities. The majority of magmatic, metamorphic and even hydrothermal occurrences are located in zones which underwent upper amphibolitic – granulitic facies conditions and outline the Grenville, Variscan, Pan-African, Ross orogens and others. A link between the causes of the coloration and the geological conditions is also apparent, in the sense that rutile and ilmenite inclusions are most often cited as the colouring agents of magmatic and metamorphic blue quartz, while the hydrothermal variety presumably owes its colour to various mineral or fluid inclusions. The correlation between gold and uranium deposits and blue quartz is also mentioned by various authors. Although a significant number of papers mention the connection between high grade metamorphism and blue quartz at a local or regional scale, the present paper is probably the first to approach the topic at a global scale. The blue quartz occurrence of the Albești granite, Argeș County, Romania, an occurrence unknown in the geological literature on blue quartz, is also brought into attention.

Keywords: blue quartz, rutile, granulitic, Albești.

Rezumat. Cuarțul albastru de pe cuprinsul globului. Cuarțul albastru apare într-o varietate de contexte geologice pe tot cuprinsul globului, iar culoarea sa este deseori generată de dispersia Rayleigh a luminii de către incluziuni minerale nanometrice cu identitate incertă. În ciuda acestui fapt, studiile mineralogice dedicate subiectului sunt puține, iar majoritatea referințelor menționează doar localizarea sau cauzele presupuse ale culorii albastre. Literatura de specialitate consultată pentru realizarea acestei lucrări sugerează un tipar de ocurență constituit mai ales din zone de coliziune de tip continent-continent, cu unele excepții datorate particularităților geologice locale. Majoritatea ocurențelor magmatice, metamorfice și chiar hidrotermale sunt localizate în zone care au suferit condiții de facies amfibolitic superior - granulitic și care conturează orogenurile Grenville, Varisc, Pan-African, Ross și altele. O legătură între cauzele colorației albastre și condițiile geologie este de asemenea aparentă în sensul că incluziunile de rutil și ilmenit sunt cel mai des citate drept agenți de colorare a cuarțului albastru magmatic și metamorfic, în timp ce despre varietatea hidrotermală se presupune că și-ar datora culoarea diferitelor incluziuni minerale și fluide. Corelația dintre zăcămintele de aur și uraniu și cuarțul albastru hidrotermal este și ea menționată de diferiți autori. Cu toate că un număr semnificativ de lucrări menționează legătura dintre metamorfismul de grad ridicat și cuarțul albastru pe plan local sau regional, lucrarea de față este probabil prima care abordează tema la scară globală. Este adusă în atenție și ocurența de cuarț albastru din granitul de Albești, județul Argeș, România, o ocurență practic necunoscută în literatura geologică cu privire la cuarțul albastru.

Cuvinte cheie: cuarț albastru, rutil, granulitic, Albești.

INTRODUCTION

Of all the various coloured varieties of quartz, most of which are nothing more than reflections of local physical and chemical conditions, certain blue varieties have the potential of becoming an indicator for regional metamorphic/tectonic conditions and even a marker for Au and U mineralisations. By comparison to regular quartz, the blue variety has a larger number of submicron and nanometre size mineral inclusions, is usually enriched in Ti (100-300 ppm) and formed at temperatures ranging between 700-900ºC, according to SEIFERT et al. (2011). Geological literature mentions, on many occasions, the opalescent character of blue quartz crystals (POLDERVAART (1966), HAEBERLIN et al. (2002), JAYARAMAN (1939), NOCKOLDS (1931), LOVE et al. (2010), WHEELER et al. (2010) and others) and a colour zoning, as reported by MULLER et al. (2012), BARKER & BURMESTER (1970), ZOLENSKY et al. (1988), SEIFERT et al. (2011) and HEINRICH (2014). However, most references only provide brief descriptions or information with respect to location, with a few notable exceptions which deal with or comment on blue quartz occurrences, such as POLDERVAART (1966), SEIFERT et al. (2011), O'BRIEN et al. (2015), ELLIOT (1994); BAILEY & GIBSON (2004), JAYARAMAN (1939), SOLARI et al. (2003), MULLER et al. (2012), BEA et al. (2007), WHEELER et al. (2010), DEL GRECO et al. (2016), NAVIDAD & CASTINEIRAS (2011), FERNANDEZ et al. (2008), HADLEY & GOLDSCHMIDT (1963), FURCRON et al. (1947), ZOLENSKY et al. (1988), HEINRICH (2014), WISE (1981), ESPENSHADE & POTTER (1960) and HERZ & FORCE (1987).

Despite the lack of centralised data, by consulting a significant volume of literature, the present paper aims to summarize the causes of the coloration and the scale and pattern of the global distribution. It will also bring to attention the blue quartz occurrences from the Albești granite, Argeș County, Romania, occurrence which is nonexistent from the standpoint of the available international geological papers.

CAUSES FOR THE COLORATION

The coloration of the blue quartz crystals is attributed to one of the following reasons: coloration owed to blue mineral inclusions such as dumortierite, aerinite or magnesio-riebeckite and coloration caused by the Rayleigh type scattering of light by submicron inclusions, referenced in JAYARAMAN (1939), SOLARI et al. (2003), BARKER & BURMESTER (1970), ZOLENSKY et al. (1988), HEINRICH (2014), WISE (1981), HERZ & FORCE (1987) and ROSS (1943). This paper refers to the latter category because of its potential geological and economic significance.

In minerals, Rayleigh scattering, the elastic scattering of light, is produced by nanometre size inclusions. It is the same type of scattering that causes the blue colour of clear daytime sky. The colour is only visible in reflected light, because only short wavelengths are scattered, while long wavelength radiation is transmitted (this is why at dawn and dusk the sky is reddish-orange). The intensity of the blue colour is dependent on particle size, spatial density and the brightness of the background (the darker the background, the more intense the colour). The apparent brightness of the background can be affected by the degree of fracturing or grain size. In the case of the Albești granite, the colour of the quartz grains appears deeper when observed over a dark background, such as biotite. However, when fractured quartz crystals or clusters of millimetre size grains are observed, the blue colour seems to have a lighter hue. Fracture planes or grain boundaries represent discontinuities which reflect some of the light and thus act as secondary light sources. In this case, the observed colour is a combination of the blue colour in reflected light mixed with a small amount of the reddish-orange colour from the transmitted light passing from the discontinuity surface to the observer.

The most cited inclusions in blue quartz are rutile needles **-** SHERATON et al. (1987), O'BRIEN et al. (2015), SEIFERT et al. (2011), JAYARAMAN (1939), NOCKOLDS (1931), SOLARI et al. (2003), MULLER et al. (2012), BEA et al. (2007), GILLULY (1933), BARKER & BURMESTER (1970), HEINRICH (2014); THOMPSON et al., (1993), WISE (1981), ESPENSHADE & POTTER (1960), HERZ & FORCE (1987), ROSS (1943) and PARKER (1962). Another frequently cited type of inclusions is represented by ilmenite plates - SEIFERT et al. (2011), SOLARI et al. (2003), MULLER et al. (2012), WISE (1981) and ROSS (1943). Other inclusions are biotite - SEIFERT et al. (2011), NOCKOLDS (1931), MULLER et al. (2012) and HEINRICH (2014), graphite - O'BRIEN et al. (2015), SEIFERT et al. (2011) and PARKER (1962), tourmaline - SEIFERT et al., (2011), MULLER et al., (2012), BARKER & BURMESTER (1970), WISE (1981) and PARKER (1962), zircon - BARKER & BURMESTER (1970) and ZOLENSKY et al., (1988), apatite - ZOLENSKY et al., (1988), WISE (1981) and ROSS (1943) and magnetite - WISE (1981) and PARKER (1962). Fluid inclusions are in a class of their own, in the sense that they are yet to be clearly identified as the cause for the blue coloration and represent only a theoretical possibility. Still, their association with blue coloured quartz crystals is cited by NOCKOLDS (1931), ANDERSEN et al. (1990), ZOLENSKY et al. (1988) and PARKER (1962).

The issue becomes more complicated when certain varieties are heated. POLDERVAART (1966) and JAYARAMAN (1939) report blue quartz occurrences which lost their colour when heated to 950ºC and 300ºC, respectively, despite the fact that their mineral inclusions did not change size, thus still satisfying the dimensional requirements for Rayleigh scattering. This phenomenon suggests the existence of more than one colouring agent within the same crystal, possibly a temperature sensitive phase such as fluid inclusions.

METAMORPHIC GRADE

The literature reviewed for the purpose of this paper has consistently shown the presence of two metamorphic grades related to blue quartz occurrences: amphibolitic - MUNSKSGAARD et al. (1992), VALVERDE-VAQUERO & DUNNING (2000), BARTH et al. (2008), HADLEY & GOLDSCHMIDT (1963), THOMPSON et al. (1993) and granulitic - SHERATON et al. (1983), MUNSKSGAARD et al. (1992), O'BRIEN et al. (2015), DUBE et al. (1995), SOLARI et al. (2003), ANDERSEN et al. (1990), LOVE et al. (2010), BARTH et al. (2008), HERZ & FORCE (1987) and others; overall, the granulitic conditions are by far the most cited. The mechanisms by which high grade metamorphic conditions favour the appearance of light scattering inclusions is still unclear, although exsolution during the retrograde phase appears to be the most popular explanation. Later medium to high grade metamorphic events may lead to a loss of colour, as is the case with parts of the Ollo de Sapo Formation, Spain. This does not mean that blue quartz does not occur in the absence of metamorphism. The most famous example comes from the rhyolite (llanite) of Llano, Texas, which hosts the most, and arguably the best studied blue quartz occurrence. Microscopic investigations carried out by the authors on thin sections of five different blue quartz occurrences have shown the Llano variety as being the only one with no undulate extinction. Also, unlike the other four occurrences, the crystal edges are sharp and euhedral and the bulk of the grains are inclusion free under the petrographic microscope. Just as in the case of heat sensitive blue quartz, this shows that there is no single answer to the blue quartz question. However, the Llano occurrence is an exception not only in terms of metamorphism, but also in the general pattern of global blue quartz distribution.

GOLD AND URANIUM

Although also associated with Sn, Sb and W – HAEBERLIN et al. (2002) and FILHO (1984), in terms of economically important mineralisations, blue quartz is more frequently associated with Au - HAEBERLIN et al. (2002), CASSIDY et al. (1998), DUBE et al. (1995), LEWRY et al. (1978), FRIEDMAN et al. (2014) SAHOO &

VENKATESH (2014) and U - FILHO (1984), MARUEJOL et al. (1987) and MARQUIS et al. (1990). This variety of blue quartz appears to be hydrothermal in nature and therefore it is not necessarily indicative of high grade metamorphism associated with continental collisions, even though it fits the global distribution pattern. In the absence of relevant studies on hydrothermal blue quartz, it is impossible to assess the connection between the blue colour and host rock composition. However, it is reasonable to assume a combination of fluid and mineral inclusions capable of scattering light. Future studies on hydrothermal blue quartz from Rio delle Ossa, Italy, available to the authors, may shed some light on this potentially economically significant quartz variety (Fig. 1).

Figure 1. World map showing blue quartz occurrences. The black dots represent magmatic/metamorphic blue quartz, blue dots represent hydrothermal blue quartz associated with Au and U deposits and the red contours represent shield units. Notice the relationship between blue quartz occurrences, shield units and orogenic belts. Modified after https://mapswire.com/world/physical-maps/.

GLOBAL DISTRIBUTION

After consulting a significant volume of papers reporting blue quartz, a number of 245 occurrences have been located, which outline a pattern consistent with the large-scale geological features of each respective continent. Figure 1 presents the distribution of the blue quartz occurrences identified up to this point. It is worth noting that most occurrences outline orogenic belts linked to supercontinent building events from various geological periods or border shield units. In North America, most locations outline the southern limit of the Canadian Shield, the Trans-Hudson and Grenville orogens. South American locations represent granitic intrusions in the Andes, Guianan and Brazilian shields. In Africa, the occurrences are concentrated in the Trans-Sahara Belt to the West, the East Africa Orogen and Mozambique and Zambezi Belts to the East and in the northern part of the Kalahari craton in the South. In Europe, the locations outline the Variscan front, through Spain, France, Germany, the Czech Republic, Poland and possibly Romania, and the Irish, Scottish and Scandinavian Caledonides in northern Europe, outlining the Baltic Shield. In Asia, blue quartz has been reported in the Altai Mountains, Mongolia and the Tian Shan Mountains, northern China, at the extremity of the Sino-Korean Shield, but the majority of occurrences are reported in the charnockites of the metamorphic terrane of southern India, part of the larger Indian Shield. In Australia, the occurrences border the Yilgarn craton to the West, are contained within the Early Proterozoic Orogens of central Australia and the Paleozoic New England and Lachlan orogens to the East. Antarctic blue quartz is located along the Transantarctic Mountains, the Tula and Prince Charles Mountains and the shoreline of Ingrid Christensen Coast, bordering the Antarctic Shield.

In terms of age, the occurrences range between 2.7 Ga in the Canadian Shield, to 1.2 Ga in the Grenville Belt and 490 Ma in the Variscan Front (even though the rocks are older than the Variscan orogeny, they were overprinted by the metamorphic events associated with it).

If the observed pattern is correct and the metamorphic conditions generated during continental collisions are responsible for the blue coloration of quartz grains, there is the theoretical possibility that Alpine blue quartz also exists. If this is the case, the metamorphic terrains of the appropriate age would be the best place to look for them.

THE BLUE QUARTZ OF THE ALBEȘTI GRANITE

The Albești granite (Fig. 2) is Early Ordovician in age and formed by crustal anatexis. It underwent a medium temperature and medium to high pressure metamorphic episode and is now hosted by the Leaota crystalline formations (South Carpathians). It is peraluminous-calc-alkaline in character and its normative CIPW composition plots in the monzogranite field, close to the monzonite. Just like other European granites and gneisses of comparable age and metamorphic history (Ollo de Sapo gneiss in Spain, Cevennes gneiss of the French Central Massif and the Rumburk granite of Germany, to name a few), its most striking characteristic is the blue quartz.

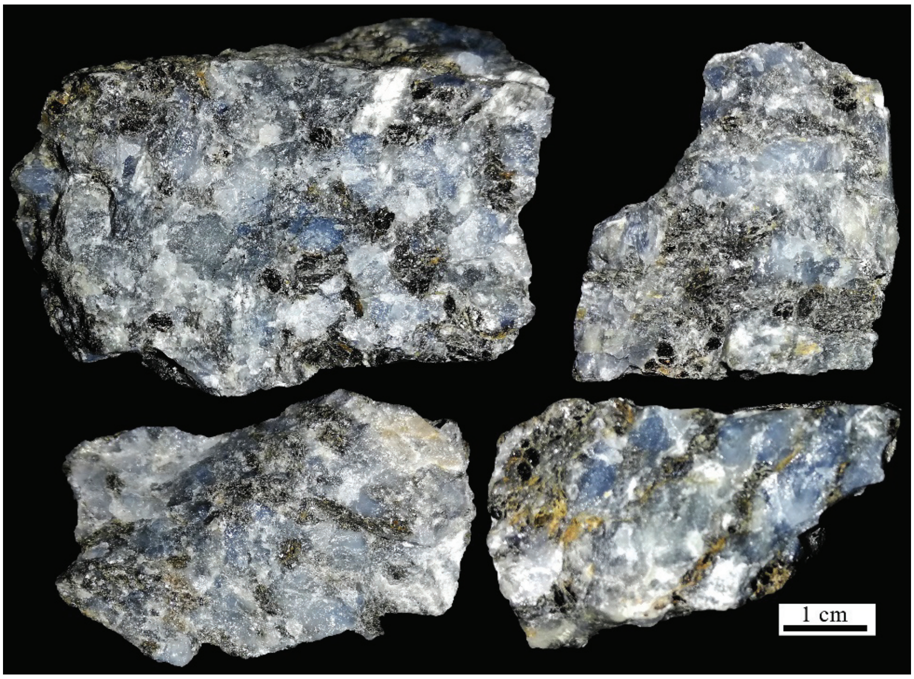

Figure 2. Four representative samples of Albești granite with clearly noticeable blue quartz grains.

Preliminary investigations performed on samples collected from the Valea Caselor Valley, Dragoslavele, Argeș County, Romania, have shown a chromatic behaviour compatible with Rayleigh scattering and thermal sensitivity with regards to colour. The quartz grains have an opalescent appearance, present a colour zoning and show plenty of mineral and secondary microscopic fluid inclusions (although too large in size to produce light scattering). Albești granite samples are currently under investigation in an attempt to establish the identity of the scattering agent responsible for the blue colour.

CONCLUSIONS

Despite its apparent simplicity, blue quartz proves to be a mineralogical challenge. The difficulties in studying it arise from the variety of inclusions, their nanometre size, the possibility of multiple causes and the wide geological spectra of occurrence. Also, quartz is not necessarily the most exciting mineral to study and is often dismissed by mineralogists even though, because of its wide spectre of inclusions, ionic diversity and variety of occurrence, it potentially holds an important geological and geochemical record. However, not all quartz occurrences are characteristic or insightful in any significant way, but blue quartz has a rather particular characteristic which could potentially be correlated with specific geological processes or geochemical features.

While the causes for the blue coloration and the geological conditions of occurrence are, apparently, too many to allow a model with global significance, a review of the body of geological literature points to the fact that some features are much more frequently cited than others: most inclusions can be narrowed down to ilmenite, rutile and fluid inclusions; the host rocks, which cover a wide range of compositions and emplacement environments, have high grade metamorphic conditions as a common feature. On the other hand, some occurrences may indeed reflect particular geochemical conditions, as suggested by ZOLENSKY et al. (1988) in the case of the Llano blue quartz.

When placed on a world map, the blue quartz occurrences plot within the major ancient orogenic belts or border cratonic units, in full agreement with the metamorphic requirements of most blue quartzes. There are occurrences that do not fit the pattern and could be the result of local geochemical/geological conditions, but the general observed trend points to a coherent and mostly predictable distribution. There is also the issue of the geological origin of the colour. While metamorphic, and most of the times magmatic blue quartz can be consistently linked to major collisional events, hydrothermal blue quartz has a wider range of occurrence, although it appears to prefer shear zones associated with cratonic edges, as suggested by the abundant literature on the Canadian Shield blue quartz.

The geological significance of blue quartz is still poorly understood, especially when referring to the metamorphic variety, which is the largest in both spatial extent and number of occurrences. However, there is the potential for blue quartz to become a telltale mineral for specific metamorphic and geochemical conditions, provided that sufficient statistically significant occurrences are thoroughly studied. Also, because of the association with Au and U deposits, blue quartz may shed new light on ore formation and aid prospecting endeavours.

Understanding the causes and conditions of formation will allow the assessment of the actual geological and economical importance of blue quartz and will shed light on a largely unknown and ignored worldwide natural process.

REFERENCES

ANDERSEN T., AUSTRHEIM H., BURKE E. A. J. 1990. Fluid inclusion in granulites and eclogites from the Bergen Arcs, Caledonides of W. Norway. *Mineralogical Magazine*. Mineralogical Society. Cambridge University Press. **54**: 145-158.

BAILEY K. A. & GIBSON H. L. 2004. A field description of the Myo Rhyolite, Flin Flon and Creighton, Saskatchewan. *Summary of Investigations 2004*. Saskatchewan Geological Survey. Regina. **2**(A-1). 11 pp.

BARKER D. S. & BURMESTER R. F. 1970. Leaching of quartz from Precambrian hypabyssal rhyolite porphyry, Llano County, Texas. *Contributions to Mineralogy and Petrology*. Springer. Berlin Heidelberg. **28**(1): 1-8.

BARTH A. P., ANDERSON J. L., JACOBSON C. E., PATERSON S. R., WOODEN J. L. 2008. Magmatism and tectonics in a tilted crustal section through a continental arc, eastern Transverse Ranges and southern Mojave Desert. In: Duebendorfer E. M. & Smith E. I. (Eds.) *Field Guide to Plutons, Volcanoes, Faults, Reefs, Dinosaurs and Possible Glaciation in Selected Areas of Arizona, California and Nevada*. Geological Society of America. Boulder. **11**: 101-117.

BEA F., MONTERO P., GONZALEZ-LODEIRO F., TALAVERA C. 2007. Zircon inheritance reveals exceptionally fast crustal magma generation processes in Central Iberia during the Cambro-Ordovician. *Journal of Petrology*. Oxford University Press. Oxford. **48**(12): 2327-2339.

CASSIDY K. F., CHAMPION D. C., WYBORN L. A. I. 1998. *A geochemical study of granitoids of the Boddington Gold Mine*. Australia Geological Survey Organisation. Symonston, Canberra. Professional Opinion. 34 pp.

DEL GRECO KASSANDRA, JOHNSTON S. T., SHAW JESSICA. 2016. Tectonic setting of the North Gondwana margin during the Early Ordovician: A comparison of the Ollo de Sapo and Famatina magmatic events. *Tectonophysics*. Elsevier. Amsterdam**.** **681**: 73-84.

DUBE B., DUNNING G., LAUZIERE K. 1995. Geology of the Hope Brook Mine, Newfoundland, Canada: A Preserved Late Proterozoic High-Sulfidation Epithermal Gold Deposit and its Implications for Exploration. *Economic Geology*. Society of Economic Geologists. Littleton. **93**: 405-436.

ELLIOT C. G. 1994. Structural relationships across the Tabbernor Fault, Nielson Lake area, Trans-Hudson Orogen, Saskatchewan. *Current Research. Canadian Shield*. Natural Resources Canada. Ottawa. **1994**(C): 113-120.

ESPENSHADE G. H. & POTTER D. B. 1960. Kyanite, sillimanite and andalusite deposits of the Southeastern States. *Professional Paper*. Geological Survey. Washington. **336**: 120 pp.

FERNANDEZ C., BECCHIO R., CASTRO A., VIRAMONTE J. M., MORENO-VENTAS I., CORRETGE L. G. 2008. Massive generation of atypical ferrosilicic magmas along the Gondwana active margin: Implications for cold plumes and back-arc magma generation. *Gondwana Research*. Elsevier. Amsterdam. **14**: 451-473.

FILHO P. M. F. 1984. The Rio Preto Uranium Occurences, Goias, Brazil. In: Ferguson J. (Ed.) *Proterozoic Unconformity and Stratabound Uraniu Deposits*. Report of the working group on uranium geology organized by the International Atomic Energy Agency (IAEA) issued by the IAEA, Vienna. 338 pp.

FRIEDMAN R. M., GABITES JANET E., LOGAN J. M. 2014. U-Pb and Ar/Ar ages from the Bonaparte mine, southern British Columbia: Late Middle Jurassic Au±Cu vein mineralization. *Geological Fieldbook 2013*. British Columbia Ministry of Energy and Mines. Toronto. **1**: 59-66.

FURCRON A. S., TEAGUE K. H., CALVER J. L. 1947. Talc deposits of Murray County, Georgia. *Geological Survey Bulletin.* Georgia State Division of Conservation. Atlanta. **53**. 75 pp.

GILLULY J. 1933. Replacement origin of the albite granite near Sparta, Oregon. In: Stanton T. W. (editor). Shorter contributions to general geology 1932-33. *Professional paper*. U.S. Department of the Interior, Geological Survey. Washington. **175**: 65-81.

HADLEY J. B. & GOLDSCHMIDT R. 1963. Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee. *Professional Paper*. U.S. Geological Survey. **349**(B): 118 pp.

HAEBERLIN Y., MORITZ R., FONTBOTE L. 2002. Paleozoic orogenic gold deposits in the Central Andes and its foreland, South America. *Ore Geology Reviews*, Elsevier. Amsterdam. **22**: 41-59.

HEINRICH P. V. 2014. Llanite and the blue quartz of Texas. *The Backbender's Gazete*. Huston Gem & Mineral Society. Huston. **45**(5): 5-12.

HERZ N. & FORCE E. R. 1987. Geology and mineral deposits of the Roseland District of Central Virginia. *Professional Paper*. U. S. Geological Survey. Washington. **1371**: 56 pp.

JAYARAMAN N. 1939. The cause of colour of the blue quartzes of the charnockites of South India and the Champion gneiss and other related rocks of Mysore. *Proceedings of the Indian Academy of Sciences - Section A*. Springer. **9**(3): 265-285.

LEWRY J. F., SIBBALD T. I. I., REES C. J. 1978. Metamorphic patterns and their relation to tectonism and plutonism in the Churchill Province in Northern Saskatchewan. *Metamorphism in the Canadian Shield*. Geological Survey of Canada. Ottawa **78**(10): 139-154.

LOVE G. J., FRIEND C. R. L., KINNY P. D. 2010. Palaeoproterozoic terrane assembly in the Lewisian Gneiss Complex on the Scottish mainland, south of Gruinard Bay: SHRIMP U-Pb zircon evidence. *Precambrian Research*. Elsevier. Amsterdam **183**: 89-111.

MARQUIS P., BROWN A. C., HUBERT C., RIGG D. M. 1990. Progressive alteration associated with auriferous massive sulfide bodies at the Dumagami Mine, Abitibi Greenstone Belt, Quebec. *Economic Geology*. Economic Geology Publishing Company**.** Littleton. **85**: 746-764.

MARUEJOL PATRICIA, CUNEY M., FUZIKAWA K., NETTO ANA MARIA., POTY B. 1987. The Lagos Real subalkaline Granitic Complex (South Bahia, Brazil): a source for uranium mineralisations associated with Na-Ca metasomatism. *Revista Brasileira de Geociencias*. Sociedade Brasileira de Geologia**.** São Paulo **17**(4): 578-594.

MULLER A., WANVIK J. E., IHLEN P. M. 2012. Petrological and chemical characterization of high-purity quartz Deposits with examples from Norway. In: Gotze J. & Mockel R. (Eds.) *Quartz: Deposits, Mineralogy and Analytics*. Springer Geology. Berlin. 71-118.

MUNKSGAARD N. C., THOST D. E., HENSEN B. J. 1992. Geochemistry of Proterozoic granulites from northern Prince Charles Mountains, East Antarctica. *Antarctic Science*. Cambridge University Press**.** **4**(1): 59-69.

NAVIDAD M. & CASTINEIRAS P. 2011. Early Ordovician magmatism in the northern central Iberian Zone (Iberian Massif): new U-Pb (SHRIMP) ages and isotopic Sr-Nd data. In: Gutierrez-Marco J. C., Rabano I., Garcia-Bellido D. (Eds.) *Ordovician of the World*. Cuademos del Museo Geominero. Instituto Geologico y Minero de Espana. Madrid. **14**: 391-398.

NOCKOLDS S. R. 1931. The Dhoon (Isle of Man) granite: a study in contamination. *Mineralogical Magazine and Journal of the Mineralogical Scociety***.** Cambridge University Press. Cambridge. **22**(133): 494-509.

O'BRIEN J. J., SPRY P. G., TEALE G. S., JACKSON S. E., KOENIG A. E. 2015. Gahnite composition as a means to fingerprint metamorphosed massive sulfide and non-sulfide zinc deposits. *Journal of Geochemical Exploration.* Elsevier**.** Amsterdam **159**: 48-61.

PARKER R. B. 1962. Blue quartz from the Wind River Range, Wyoming. *American Mineralogist*. Mineralogical Society of America**.** Chantilly. **47**: 1201-1202.

POLDERVAART A. 1966. Archaean charnockitic adamellite phacoliths in the Keimoes-Kakamas, Cape Province, South Africa**.** *South African Journal of Geology*. Geological Society of South Africa**.** Johannesburg **69**(1): 139-154.

ROSS C. S. 1943. Occurrence and origin of the titanium deposits of Nelson and Amherst Counties, Virginia. Shorter Contributions to General Geology 1941-42. *Professional Paper*. U. S. Geological Survey. Washington. **197**: 59 pp.

SAHOO P. R. & VENKATESH A. S. 2014. 'Indicator' carbonaceous phyllite/graphitic schist in the Archean Kundarkocha gold deposit, Singhbhum orogenic belt, eastern India: Implications for gold mineralization vis-à-vis organic matter. *Journal of Earth System Science*. Springer**.** Berlin/Heidelberg. **123**(7): 1693-1703.

SEIFERT W., RHEDE D., THOMAS R., FORSTER H.-J., LUCASSEN F., DULSKI P., WIRTH R. 2011. Distinctive properties of rock-forming blue quartz: inferences from a multi-analytical study of submicron mineral inclusions. *Mineralogical Magazine*. Cambridge University Press**.** Cambridge. **75**(4): 2519-2534.

SHERATON J. W. & COLLERSON K. D. 1983. Archaean and Proterozoic geological relationships in the Vestfold Hills – Prydz Bay area, Antarctica. *Journal of Australian Geology & Geophysics*. Australian Government Publishing Service. Canberra. **8**: 119-128.

SHERATON J. W., TINGEY R. J., BLACK L. P., OFFE L. A., ELLIS D. J., WOLF K. H. (Editor), 1987. *Geology of an unusual Precambrian high-grade metamorphic terrane – Enderby Land and western Kemp Land, Antarctica*. Australian Government Publishing Service. Canberra. 51 pp.

SOLARI L. A., KEPPIE J. D., ORTEGA-GUTIERREZ F., CAMERON K. L., LOPEZ R., HAMES W. E. 2003. 900 and 1100 Ma Grenvillian tectonothermal events in the northern Oaxacan Complex, southern Mexico: roots of an orogen. *Tectonophysics*. Elsevier. Amsterdam **365**: 257-282.

THOMPSON J. B. Jr., ROSENFELD J. L., CHAMBERLAIN C. P. 1993. Sequence and correlation of tectonic and metamorphic events in southeastern Vermont. In: Cheney J. T. & Hepburn J. C. (Eds.) *Field trip guidebook for the northeastern United States: 1993 Boston GSA*. 1993 Geological Society of America Annual Meeting & 85th Annual New England Intercollegiate Geological Conference, October 25-28, Boston, Massachusetts. Vol. I B1-B. 26 pp.

VALVERDE-VAQUERO P. & DUNNING G. R. 2000. New U-Pb ages for Early Ordovician magmatism in Central Spain. *Journal of the Geological Society*. London. **157**: 15-26.

WHEELER J., PARK R. G., ROLLINSON H. R., BEACH A. 2010. *The Lewisian Complex: insights into deep crustal Evolution*. In: Law R. D., Butler R. W. H., Holdsworth R. E., Krabbendam M., Strachan R. A. (eds). *Continental Tectonics and Mountain Building*. Geological Society. London. 880 pp.

WISE M. A. 1981. Blue quartz in Virginia. *Virginia Minerals*. Virginia Division of Mineral Resources. Charlottesville. **27**(2): 9-12.

ZOLENSKY M. E., SYLVESTER P. J., PACES J. B. 1988. Origin and significance of blue coloration in quartz from Llano rhyolite (llanite), north-central Llano County, Texas. *American Mineralogist* Mineralogical Society of America. Chantilly. **73**: 313-323.

***. Free Physical Maps of the World. 2019. https://mapswire.com/world/physical-maps/ (accessed February, 2019).

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