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Preliminary study of quartz gravel and veins occurring in the Equimina region, Benguela (Angola): potential uses in industry.

Estudio preliminar de gravas y vetas de cuarzo existentes en la región de Equimina, Benguela (Angola): usos potenciales en la industria.

J.V. Lisboa[1*], L. F. Pereira[2], A. Osório[2], J. F. Rodrigues[1], J. Fernandez[3], A. Oliveira[1] and J. Manuel[4]

1 Laboratório Nacional de Energia e Geologia, Estrada da Portela, Bairro do Zambujal, 2610-999 Amadora, Portugal. *vitor.lisboa@lneg.pt; jose.feliciano@lneg.pt; alvaro.oliveira@lneg.pt.
2 UTE PLANAGEO (IGME, LNEG, IIA), Parque Tecnológico de Asturias 13A. 33428, Llanera (Asturias), Spain. lfrfpereira@gmail.com; osorio.c.andre@gmail.com
3 Instituto Geológico y Minero de España (IGME), CSIC, 33005 Oviedo, Spain. j.fernandez@igme.es
4 Instituto Geológico de Angola (IGEO), Cidade de Kilamba, Luanda, Angola. jose.manuel@igeo.gov.ao

Abstract: Vast occurrences of quartz in veins and extensive gravel beds in the coastal area of Equimina, approximately 100 km south of Benguela, constitute the object of this study, aiming for its industrial use. These occurrences are related to Paleoproterozoic gneisses and migmatites on which they outcrop. The veins are quite dismantled on the surface, and show a pronounced strike scattering, but the NE-SW orientation prevails. Some veins are pegmatitic (feldspar, quartz, and mica), others, if not the majority to the East in the study area, have a strong predominance of milky quartz with low content of other minerals. Except for a superficial and removable patina of iron oxides that often coats the quartz, it is free of visible impurities. Chemical analysis confirms high purity (SiO_2 > 99.5%) and very low content of penalizing oxides. Although the composition of quartz is suitable for use in the ceramic and glass industry, due to the ways it occurs, the main potential of this abundant resource in the studied area is for the refractory and metallurgy industry. Besides the chemical composition, the size of the gravel mostly meets the dimensional requirements for silicon metal production, needing minimal beneficiation.

Key words: quartz, gravel, vein, chemical composition, metallurgy.

Resumen: *Grandes yacimientos de vetas de cuarzo y extensos lechos de grava en el litoral de Equimina, aproximadamente a 100 kilómetros al sur de Benguela, constituyen el objeto de este estudio, con vistas a su uso industrial. Estos indicios afloran entre gneises y migmatitas paleoproterozoicos. Las vetas de cuarzo están bastante desmanteladas superficialmente y muestran una pronunciada dispersión del rumbo, pero prevalece la orientación NE-SW. Algunas vetas son pegmatíticas (feldespato, cuarzo y mica), otras, si no la mayoría hacia el Este del área estudiada, tienen un fuerte predominio de cuarzo lechoso con bajo contenido de otros minerales. Excepto por una pátina superficial y removible de óxidos de hierro que a menudo recubre el cuarzo, está libre de impurezas visibles. Los análisis químicos confirman una alta pureza (SiO_2 > 99,5%) y un contenido muy bajo de óxidos penalizadores. Si bien la composición del cuarzo es adecuada para su uso en la industria cerámica y del vidrio, por la forma en que se presenta, el principal potencial de este recurso es para la industria refractaria y metalúrgica. Además de la composición química, el tamaño de la grava cumple mayormente con los requisitos dimensionales para la producción de silicio metálico, necesitando un procesamiento mínimo.*

Palabras clave: *cuarzo, grava, veta, composición química, metalurgia*.

INTRODUCTION

Quartz is the main source of silicon, which has a high importance and application in different industrial sectors. Silica (SiO_2) in the stable phase under normal pressure and temperature conditions, called α-quartz or low-temperature quartz, is the most widely distributed quartz mineral group in rocks, constituting one of the most abundant minerals in the Earth's crust, around 12.6% (Götze, 2009). α-quartz is one of the crystalline forms of silica, and crystallizes with the trigonal system, trapezohedral class (3 2). Pure quartz is colourless and transparent. In general, the crystals are mostly transparent or opaque white due to internal inclusions and fissures (milky quartz); the presence of inclusions and impurities (e.g., iron, manganese, titanium) reduces transparency and gives quartz different shades (yellow, pink, violet, grey, or black).

In the area to the east and northeast of the Equimina settlement, about 40 km from Dombe Grande, an extensive and dense network of veins that were installed in the Paleoproterozoic migmatite and gneissic bedrock originated widespread gravel and quartz blocks beds. The preliminary recognition of these quartz occurrences indicates its potential for industrial use. The objective of

this work is to carry out a preliminary assessment of the possible uses for this industrial mineral. The proximity to the important city of Benguela (about 100 km) and the port of Lobito constitutes an added value for marketing this raw material. This study is part of the mapping and characterization work on industrial rocks and minerals carried out for the Geological Institute of Angola (IGEO), within the scope of the Map of Rocks and Industrial Minerals of Angola (CARMINA) subproject, of the PLANAGEO project, completed in 2022. The CARMINA sheet 274B-Equimina (Pereira et al., 2022) encompasses the study area.

GEOLOGICAL SETTING

The geology of the studied area is marked by a strong dichotomy: the eburnean units of the Angola Shield (Congo Craton) outcrop in the eastern part of the map; to the west, outcrops the Meso-Cenozoic sedimentary succession of the Benguela peri-Atlantic basin (Fig. 1). The regional eburnean basement is composed of two complexes of highly deformed rocks (Lopes et al., 2021): i) the intra-eburnean gneissic-migmatitic complex results from the large scale migmatization of a granitoid crust with intermediate and mafic terms (tonalites, quartz-diorites and diorites), whose gneissic fabrics result from a shearing deformation event of great intensity and regional extension. Two U-Pb (SHRIMP) ages were obtained (1975 ± 8 Ma and 1995 ± 8 Ma) and are interpreted as the crystallization ages of leucogranitic leucosomes; ii) the Meva-Binga Gneissic Complex corresponds to an eburnean porphyritic granite. A U-Pb (SHRIMP) age of 1948 ± 6 Ma is interpreted as the crystallization age of the granite. The gneissic fabric is due to intense shear deformation that generates mylonitic and ultramylonitic bands.

A dense network of doleritic gabbro veins (sub-ophitic gabbros and dolerites with and without olivine, undifferentiated) belonging to the Basic Dyke Supersuite of SW Angola, intersects the Gneissic Migmatite unit. These dykes with preferential orientation NW-SE to WNW-ESE (N45° to N70°, sub-vertical) present, from a petrographic point of view, medium to coarse granularity and ophitic to intersertal texture, with essential mineralogy consisting of labradorite, pigeonitic augite and very scarce olivine. They have been attributed to an age of ca. 1200 Ma (Carvalho, 1983).

To the West, the Benguela peri-Atlantic basin occurs with notable prominence. Several detrital and carbonate sequences are defined with the intercalation of an important evaporitic unit. Such sequences are organized in relation to the stages of Atlantic rifting (syn-rift sequence, transitional sequence, post-rift sequence).

Geomorphologically, the area is located on the Atlantic Flexure Surface (Feio, 1964, 1981), a flat surface with a noticeable slope, and of variable width, whose western limit may be the coastal cliff line, in which case there is no coastal platform.

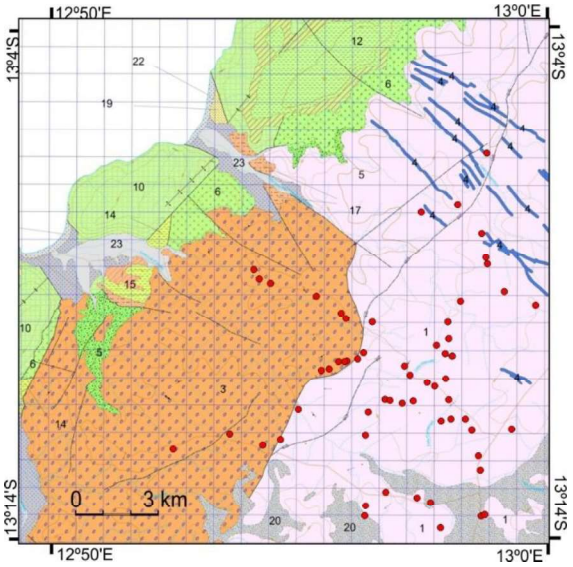

FIGURE 1. *Extract from sheet 274-B (CARMINA) geological map, according to the mapping of sheet D-33/G Equimina (1:250,000): Intra-Eburnean Gneissic-Migmatite Complex (1-Gneissic Migmatites); Meva-Binga Gneissic Complex (3- Ocellated Orthogneisses with lenses of more or less mylonitized leucogranites); Basic Dykes Supersuite of SW Angola (4- Sub-ophitic gabbros, and dolerites with and without olivine, undifferentiated); Meso-Cenozoic Benguela sedimentary basin (sin-rift sequence: 5, transitional sequence: 6, post-rift sequence: 10, 12, 14, 15, 16, 17, 19); Surface Deposits (20, 22; 23 - Quaternary detrital units). Red dots (GPS points): dispersion of quartz veins and gravel beds.*

QUARTZ INDUSTRIAL CLASSIFICATION

Quartz is processed according to its crystal size, visual transparency, and the definition of its external morphology, that is, the existence of natural crystal faces (Guzzo, 2008). For various industrial purposes, quartz extracted from pegmatite veins and masses can be classified according to visual transparency. According to that author, crushed fragments (so-called “lascas”) are classified into first to fifth grade class. Although subjective, this classification is associated with the content of fluid inclusions (milky portions) and fissures contained in the quartz *lasca*. In Portugal, in the industrial market, quartz appears, in terms of quality, with commercial designations (Fernandes, 2006): 1st grade quartz (Type I): crushed to different sizes or produced in different particle sizes, it has a white or pink colour, and low levels of alumina (<0.1%) and Fe oxides (<0.05%); 2nd grade quartz (Type II): white colour, sometimes greyish and may present some impregnations of Fe oxides (brownish colour).

Thus, depending on its compositional characteristics and primary processing (e.g., crushing, grinding, classification), quartz constitutes raw material for several industrial sectors, namely ceramics (construction, refractory, porcelain) metallurgy, glass, optics, electronics, chemistry, and pharmaceutical (in fillers and extenders), abrasives, fiberglass, and aggregates. Quartz without impurities, completely colourless or white, is essentially intended for the optical industry.

RESULTS AND DISCUSSION

In the study area located in the Atlantic Flexure Surface, primary and secondary quartz deposits (Campbell, 1946; Kuzvart, 1984) can be observed covering areas of the Paleoproterozoic bedrock. The primary deposits of economic importance (Fig. 2a) refer to the dense network of quartz veins and lenses installed in the Paleoproterozoic geological units. Two types of veins can be distinguished in the study area: (i) pure pegmatitic veins with coherent planes and dips cross-cutting the Paleoproterozoic bedrock; and (ii) erratic and essentially quartz lenses and veins, with poorly defined dips, sometimes sub-horizontal. These two types are probably connected, and the latter can be a result of the differentiation and enrichment process of the same fluids/melt. This type has more economic relevance than the pegmatitic veins due to the quartz enrichment. The field observations of these quartz-only veins, points out a structural control that somehow marks the sheared contact between the Meva-Binga unit and the Gneissic migmatites. The secondary deposits (Fig. 2b) correspond to the extensive beds of gravel and quartz blocks resulting from the dismantling and erosion of the veins. 75 registration points were made, corresponding mainly to primary quartz deposits (Pereira et al., 2022).

FIGURE 2. *a) Aspect of dismantled quartz vein (primary quartz deposits); holes can be seen in the quartz vein blocks, where micas were present; the Fe oxides patina can also be seen in fissures and in a few clasts. b) Extensive gravel superficial beds associated with the dismantling of quartz veins (secondary quartz deposits).*

As the veins are quite dismantled on the surface, their spatial continuity is generally poorly defined. The observed vein thicknesses range from 0.5 to 8 m, and their extents are also variable ranging from 4 to 40 m. The main vein azimuthal directions are: 85˚, 65˚, 45˚, and ranging 145˚ to 180˚; dips are mostly subvertical, otherwise dipping 74˚→270˚, 65˚→315˚. A pronounced strike scattering is noticeable, but the predominance of the NE-SW to E-W orientation is evident (Fig. 3). Most of the veins are pegmatitic, essentially made of quartz, with a predominance of milky quartz, but also hyaline; the presence of well-developed micas (biotite and muscovite) is scarce, but there are traces of their existence (holes with smooth faces, where the micas were present before their complete alteration. A superficial patina is frequently observed both on the veins and clasts surface, and along some small fractures filled with iron oxides. Within the quartz mass, almost no impurities can be found, when observed with the naked eye or using a handheld magnifying glass (10x).

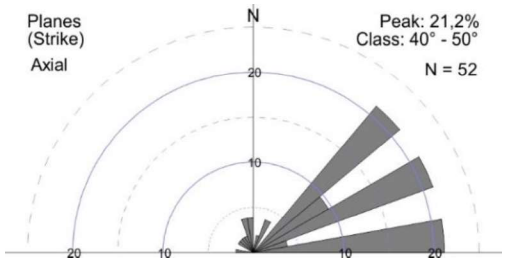

FIGURE 3. *Rose diagram representing the veins' strike in the 52 GPS points where measuring was possible.*

The chemical composition is one of the main factors for the characterization of industrial minerals, conditioning their use for various industrial purposes. The chemical analysis of quartz samples representative of the extensive gravel beds associated with vein occurrences reveals a composition that satisfies the conditions for various industrial sectors regarding oxide contents (Table I) as discussed below.

Fine ceramics: use high purity ground silica (99% SiO_2) as a refractory and stabilizing agent, preventing expansion flaws. According to Ferreira and Daitx (2000), the usual characteristics of quartz sand for the ceramic industry are: particle size between 30 and 140 mesh (0.60 to 0.105 mm); 93.5 to 99.8% SiO_2; 0.035 to 0.70% Al_2O_3 and 0.02 to 0.08% Fe_2O_3. In the study area quartz is not found as sand, but mainly in gravel-sized clasts, which also facilitates the required grinding process.

Glass: the use of quartz as a resource for glass is economically more profitable if it is in sand or as a by-product already transformed into small sizes, resulting from extraction for other purposes (e.g., aggregates), therefore, this will not be an economically viable use.

Refractories: Quartz is involved in the production of refractory ceramics, as it is used in the manufacture of silica bricks, furnace linings, as foundry sand, etc. The quartz used in the production of refractories is normally crushed to obtain sizes between 0.24 – 3.80 cm, and must have low levels of iron, alkali, and phosphorus (Fernandes, 2006). The quartz in the Equimina area, in

addition to its quality, has the advantage of being already partly crushed.

Metallurgy: the metallurgical industry uses 80-90% of Si in the forms of Si, Fe-Si, Al-Si, and Ca-Si (Fernandes, 2006). Industrial metallurgical quartz is used to manufacture silicon metal, silicon ferroalloys (ferrosilicon, silicon manganese), silica fume, and silicon carbide. In the production of silicon metal, the diameter of the *lascas* must be on average between 3 and 12 cm, and the rock must contain: at least 98.5% or 99% SiO_2, values of $Fe_2O_3 < 0.1\%$, $Al_2O_3 < 0.15\%$, $CaO < 0.2\%$, and $MgO < 0.2\%$ (Fernandes, 2006). For the ferrosilicon production, silica fine clasts cannot be present either, but slightly higher amounts of these oxides are permitted. Chemical analyses of the samples (Table I) correspond to 1st quality quartz ($SiO_2 > 99.5\%$) with very low content of penalizing oxides, which show lower values than the maximum acceptable, particularly to produce silicon metal and ferrosilicon. The analysed samples match, respectively, to a very slightly pink milky quartz and milky to translucent quartz. In terms of major oxides, the slightly higher Fe content may justify a slight hue observed in sample 1. The trace elements content is also very low, mostly below the detection limits; the elements which content is above those limits, such as Cr and Ba, Sr, may be related respectively, to iron oxides and disseminated feldspar.

Potential areas for quartz exploitation have access via trails or paths, and are distributed over a vast area, in which quartz veins and gravel beds occur. This raw material potentially meets the requirements for metallurgical use, as the dimensions of the clasts mostly fulfil the dimensional requirements, thus needing minimal beneficiation. In addition to the veins, these gravel beds constitute a large resource, naturally "enhanced", easy to exploit. The total resources are significant, as demonstrated by the survey of vein quartz occurrences carried out (Fig. 1).

CONCLUSION

In the Equimina area, close to the main interprovincial road with access to the city of Benguela (about 100 km away), important quartz resources occur over a vast area. These occurrences in the form of gravel and vein deposits relate to two geological units of the Pre-Cambrian bedrock: Ocellated Orthogneisses and Gneissic Migmatites, with a greater concentration in the latter and in the contact between units. Quartz is predominantly milky and hyaline, with no visible contamination, except sometimes a superficial and easily removable patina of iron oxides. The chemical analysis confirms high purity. Considering the type of occurrence and size of quartz clasts, their most suitable application is in the refractory industry and especially in metallurgy.

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(%)	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	P.R.
Sp1	99.71	<0.35	0.07	<0.02	<0.04	<0.20	<0.20	<0.05	<0.04	<0.04	0.06
Sp2	99.59	<0.35	0.04	<0.02	<0.04	<0.20	<0.20	<0.05	<0.04	<0.04	0.11
(ppm)	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Ba**	**Ta**	**Sn**	**W**	**Th**	**Hf**
Sp1	<3	8	<3	<3	<3	44	<6	<9	<9	<5	<5
Sp2	<3	<3	<3	<3	<3	<15	<6	<9	<9	<5	<5
(ppm)	**U**	**Ni**	**Zn**	**Pb**	**Sc**	**V**	**Cr**	**Co**	**Ga**	**As**	**Sb**
Sp1	<6	<7	<6	<6	<7	<5	17	<5	<5	<6	<8
Sp2	<6	<7	<6	<6	<7	<5	9	<5	<5	<6	<8

TABLE I. *Results of chemical analysis of major and minor elements carried out on 2 quartz samples.*