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Série Negra black quartzites - Tomar Cordoba Shear Zone, E Portugal: mineralogy and cathodoluminescence studies

Estudios mineralógicos y de catodoluminiscencia en las cuarcitas negras de la Serie Negra-Zona de Cizalla de Tomar Cordoba, E de Portugal

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Abstract

The Proterozoic black quartzites associated with important gold mineralisation prospects that crop out within the Tomar Cordoba Shear Zone in the northern Alentejo province have been previously referred to and interpreted to be metacherts, (meta)lydites, phthanites and quartzites. However, the range of terms used thus far implies a specific protolith and environment of deposition, i.e. a chemical vs. a clastic depositional environment.

Mineralogically these rocks contain a variety of minerals, namely quartz, biotite ± chlorite, pyrite, chromite, ilmenite, chalcopyrite, pyrite with inclusions of magnetite, rutile, Fe-oxides, marcasite and arsenopyrite. In addition, amorphous carbon is an important constituent of these rocks.

These black quartzites also contain substantial quantities of fine inclusions of possibly at least V-bearing titanite and V-bearing epidote-allanite, occurring with Fe-Ti-Cr-V oxides in the quartz. These inclusions are locally evenly distributed in the quartz grains indicating that these grains were recrystallised during their metamorphic evolution.

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The use of CL shows evidence of different generations of quartz, i.e. quartz cores different from the rims that could represent detrital sand grains. CL has also shown that these rocks exhibit a tectonothermal history when the CL properties of the different quartz generations are observed.

There is probable indication that these rocks had a sandstone protolith (i.e. a clastic precursor) and hence should rather be termed quartzites or metasandstones.

Key words: Tomar Cordoba Shear Zone, Série Negra, black quartzites, mineralogy, CL, Proterozoic, quartzites/metasandstones

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1. INTRODUCTION

Within the Tomar Cordoba Shear Zone (TCSZ), NE Ossa Morena Zone (figure 1) several lens-shaped, dark or black, silicified units crop out (figure 2), which are typical of the Série Negra metasedimentary succession. Over the last three decades, these units have been variously referred to as metacherts, (meta)lydites, phthanites (siliceous shales) and quartzites in the literature (e.g. GONÇALVES, 1971; GONÇALVES & FERNANDES, 1973; GONÇALVES *et al.*, 1971, 1972a, 1972b, 1978; ABALOS & EGUÍLUZ, 1989; GONÇALVES & CAVALHOSA, 1994; PEREIRA, 1995, 1999; PEREIRA & SILVA, 2000; BANDRES *et al.*, 2002, amongst others). This range of terminology and interpretation has been brought about by the ambiguous appearance of these black silicified units in the field, which in some cases is very fine grained although in others is coarser grained. However, the chosen nomenclature implies the difference between chemical and clastic sedimentation processes and, ultimately, whether these have been correctly applied to the rocks in question.

Due to the persistence of the terms *metachert*, *(meta)lydite*, *phthanite* and *quartzite* in the literature, the purpose of this

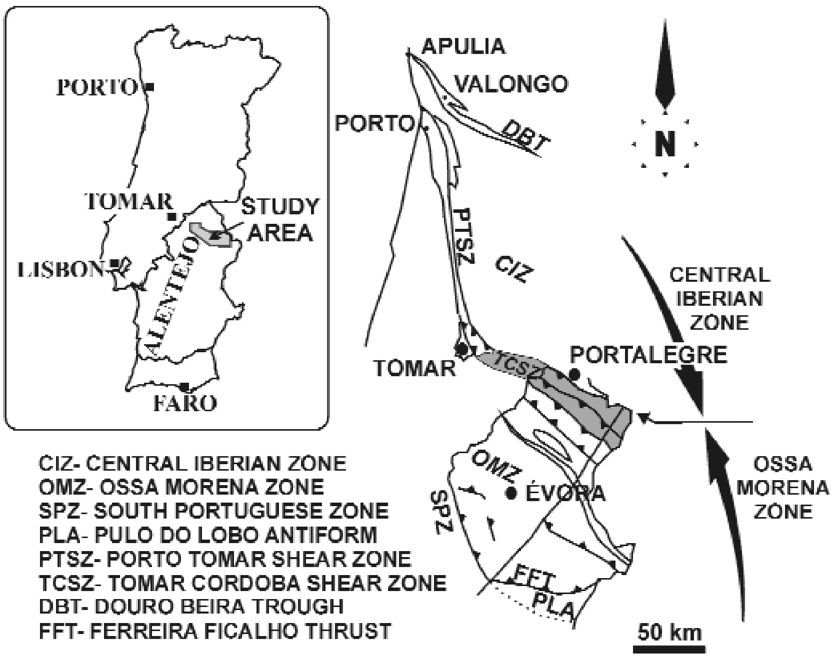

Figure 1. The location of the TCSZ in relation to the other major structures and the tectonostratigraphic domains. (Adapted after SILVA, 1997).

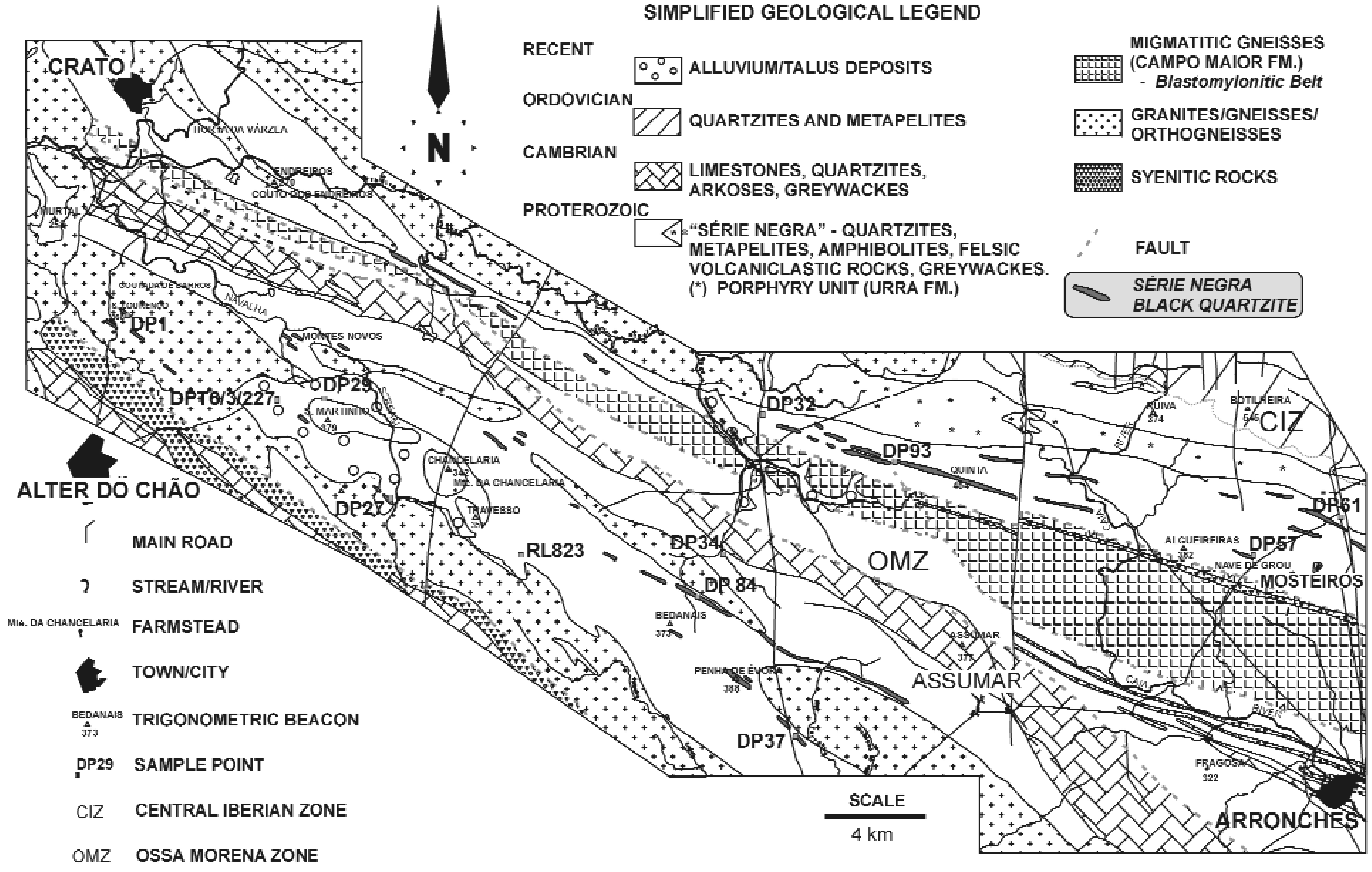

Figure 2. Simplified geological map of the study area showing the aerial extent of the Série Negra rocks (Morenos and Mosteiros Formations) and other Preterozoic rocks (Campo Maior and Urra Formations) with the sample locations plotted (adapted after GONÇALVES *et al*., 1971, 1972a, 1972b; PERDIGÃO *et al*., 1977).

paper is to provide a first approach to the correct lithological nomenclature of these units by combining several field and petrographic observations with support from mineralogical data and preliminary cathodoluminescence (CL) studies.

2. **GEOLOGICAL AND STRUCTURAL SETTING OF THE TCSZ**

The study area is located in the northern Alentejo province (figure 1 inset) in the Crato-Alter do Chão-Arronches area (figure 2). The Série Negra (*Black Series*) is a package consisting of metasedimentary (meta-arenites and metapelites), basic igneous (amphibolites and banded amphibolites) and felsic volcanic (metarhyolites) rocks (e.g. OLIVEIRA *et al.*, 1991; de OLIVEIRA, 2001). The Série Negra occurs juxtaposed on both the north and south limbs of a large structure. This structure contains, from north to south, low-grade metamorphic rocks (greenschist facies) to intermediate-grade metamorphic rocks (amphibolite facies) separated by a central corridor of high-grade metamorphic rocks (the Blastomylonitic Belt), all collectively known as the TCSZ. The Blastomylonitic Belt separates rocks of lower metamorphic grade (greenschist facies) in the north of the TCSZ from rocks of higher metamorphic grade (amphibolite facies) in the south of the TCSZ.

The TCSZ is a geologically complex and diverse zone showing intense deformation and metamorphism contemporaneous with a large sinistral displacement, which may be due to a large intracontinental sinistral fault active during the Variscan Orogeny (BERTHÉ *et al.*, 1979) with displacements of 100 km (BURG *et al.*, 1981) to 300 km (ABALOS & EGUÍLUZ, 1992). Recent studies (PEREIRA & SILVA, 2001) have shown the Tomar Cordoba Shear Zone to be a major Eohercynian-Hercynian sinistral transcurrent fault overprinting a Cadomian arc localised at a convergent margin of Gondwana.

The Portuguese sector of the TCSZ comprises a series of fault-separated, polymetamorphic structural-tectonic subdomains (PEREIRA, 1995; 1999) where the Neoproterozoic Série Negra rocks crop out. The maximum age for the final stages of sedimentation have been documented ca. 565 Ma (SCHÄFFER *et al.*, 1993). Stratigraphically the Série Negra is made up of the (lower) Morenos and (upper) Mosteiros Formations (OLIVEIRA *et al.*, 1991). The Morenos Formation is made up of micaceous schists that are locally garnet-bearing, limestones and calc-silicate rocks, meta-arkoses, meta-arenites (quartzites) and micaceous and siliceous schists, amphibolites and metapyroclastic rocks (OLIVEIRA *et al.*, 1991). The Mosteiros Formation consists of black schists/slates, greywackes, black cherts (quartzites?), limestones and amphibolites (OLIVEIRA *et al.*, 1991). North of the Blastomylonitic Belt and unconformably overlying the Mosteiros Formation occurs the Urra Formation made up of a lower porphyry unit and an upper pelite/greywacke unit (OLIVEIRA *et al.*, 1991). At the TCSZ borders, a (Lower) Cambrian sequence of platform sediments is preserved, which unconformably overlies the Neoproterozoic Série Negra metasediments and consists of micaceous schists, amphibolites, metamorphosed carbonate rocks and pelitic schists (OLIVEIRA *et al.*, 1991; PEREIRA, 1995).

The TCSZ is intruded by several pre-Hercynian, syn-Hercynian and late- to post-Hercynian rocks (e.g. the Nisa granite batholith) as well as peralkaline rocks (see figure 2).

3. BLACK QUARTZITES WITHIN THE TCSZ

3.1. Setting

The black quartzites crop out in relatively short, ribbon-like (lens-shaped) outcrops which trend NW-SE, parallel to the regional foliation. The quartzites are closely associated with prominent gold prospects (de OLIVEIRA, 2001). Outcrops are generally narrow and short (2-3 m wide and 5-10 m long, respectively) but can be several hundreds of metres long and up to 60-80 m high above the surrounding Alentejo plain. Within the study area only one outcrop of such magnitude is known between the villages of Assumar and Urra, site of sample DP93 in figure 2. Generally, outcrops are aligned with each other defining one or several "belts" or levels (see figure 2).

Grain size varies from outcrop to outcrop but invariably most are very fine-grained (frequent) to medium-grained (rare), highly siliceous and resistant to weathering and breakage. These rocks appear homogeneous in some outcrops although in others there is a marked inhomogeneity that defines centimetre-scale layering that may represent relict bedding.

3.2. Mineralogy

The mineralogy of these black quartzites was investigated in two ways. The first was through optical microscopy using both transmitted and reflected light.

The second was a study of the constituent heavy minerals, involving the collection of two bulk samples, DP27 and DP93, each representing a homogenised sample across the face of each respective outcrop. The reason for choosing these particular samples is that DP27 is slightly coarser-grained than DP93 and shows centimetre-scale layering, which may be relict bedding. Folding is not seen on outcrop scale even though the outcrop is approximately 5.5 m x 1.0 m. Sample DP93 is finer-grained and shows tight folding (Hercynian D2). Also, these samples are located in different metamorphic domains. Sample DP93 is located north of the Blastomylonitic Belt (figure 2), in low-grade (greenschist facies) metamorphic rocks whereas sample DP27 is located south of the Blastomylonitic Belt (figure 2) amongst higher-grade (amphibolite facies) metamorphic rocks.

The samples were individually milled to 1 mm in an adjustable jaw crusher and sieved to extract the < 45 mesh (0.355 mm) fraction. This fraction was panned to preconcentrate it, washed in alcohol and then dried. The dried samples were further concentrated using a heavy liquid {bromoform [$CHBr_3$; density (ρ) = 2.88)]} to remove the "lighter minerals" with ρ < 2.88. Samples were split into non-magnetic, super magnetic and magnetic fractions. Table 1 exemplifies and quantifies the phases of sample preparation. The individual minerals were then identified using a binocular microscope and quantified in relative terms of their total contribution to sample composition.

3.3. **Petrographic results**

Petrographically these black quartzites are primarily made up of quartz (± biotite ± chlorite). In thin section, quartz grain sizes vary from 6 to 63 μm in a fine-grained sample and from 30 to 600 μm in a coarse-grained sample. In the coarser-grained samples accessory biotite (± chlorite) is found interstially to quartz and at times aligned parallel to the regional foliation (NW-SE) of these rocks. However, sample RL823, taken from a tabular black quartzite outcrop SE of Travesso (figure 2), in addition to containing the above mentioned minerals, also contains small (6 mm) zircons and plagioclase (de OLIVEIRA, 2001).

The most common opaque phase seen interstially to quartz is amorphous carbon (figures 3A and B). Within the quartz, there are very fine mineral phases, which create a blue-grey shadow (figure 4) at low magnification (5x/10x) in plane polarised light and which disappears at higher magnifications. These are heavy mineral concentrations (discussed below). The heavy mineral concentrations are observed in very thin wafers, up to 200 μm thick, as darker streaks across the samples.

In addition, rare, discrete sub-rounded grains of magnetite (at times with nuclei of spinel; figure 3A), chromite and ilmenite have been observed. These are larger than the accompanying quartz grains and their roundness implies abrasion.

Other accessory opaque minerals include euhedral pyrite with traces of chalcopyrite, euhedral pyrite with magnetite inclusions (magmatic origin?), rutile, Fe-oxi-

			Sample DP27	Sample DP93
Bulk weight			22 kg	27 kg
Mass of < 45 mesh fraction			4 kg	4 kg
Mass of Panned concentrate			1.60 kg	1.91kg
2x split of panned concentrate before bromoform treatment			0.398 kg	0.478 kg
Mass of concentrate	Magnetic fraction	Super magnetic fraction	1.19 g	1.35 g
		Magnetic fraction	1.43 g	6.38 g
	Non-magnetic fraction		0.0658 g	0.1875 g

Table 1. Quantification of the steps in the concentration of the heavy minerals for bulk samples DP27 and DP93.

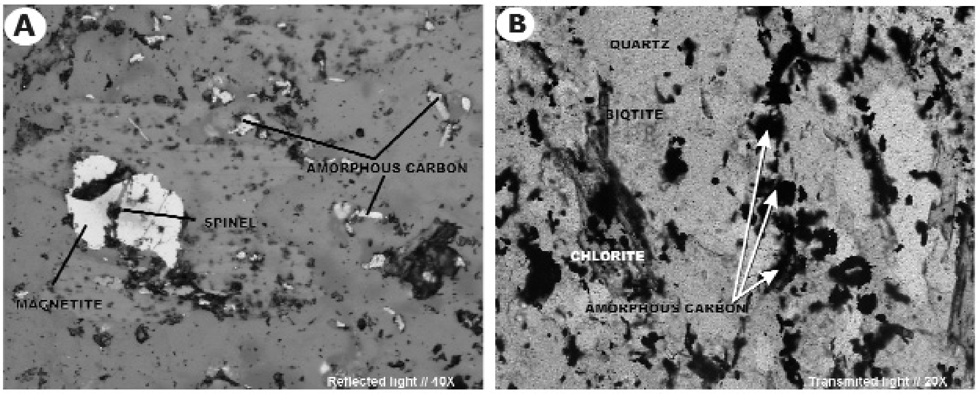

Figure 3. Photomicrographs of black quartzite sample DP27 located in São Martinho East showing, A- Amorphous carbon and a grain of magnetite with a nucleus of spinel (Reflected light; 40x; parallel polars, FOV = 0.3 mm). B- Amorphous carbon (opaque) and partially chloritised biotite grain (Transmitted light; 20x; parallel polars, FOV = 0.45 mm).

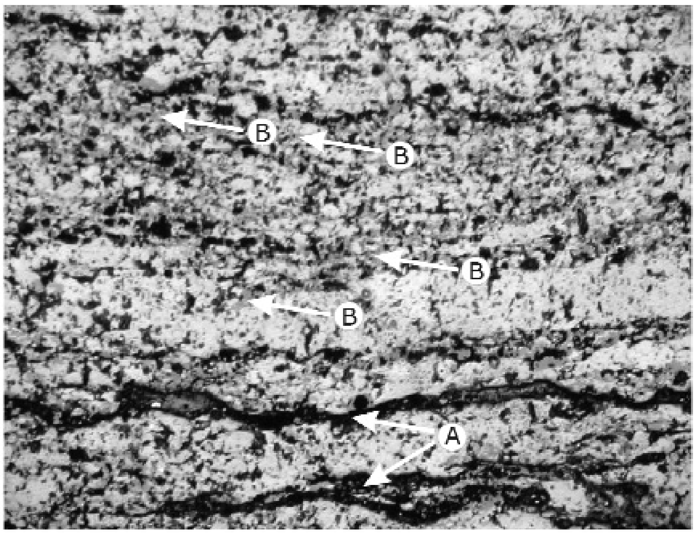

Figure 4. Reflected light photomicrograph of sample DP84 (black quartzite) showing remnant bedding defined by Fe-oxides (A) as well as the grey(-blue) shadows of submicroscopic V-bearing and/or radioactive mineral inclusions in quartz (B). (FOV = 0.52 mm).

des, marcasite (after pyrrhotite) and euhedral arsenopyrite crystals. No gold grains were observed in these units unlike nearby metapelitic rocks of the Série Negra, which sporadically show sulphide and gold mineralisation.

3.4. **Heavy mineral concentrates**

Heavy mineral concentrates were obtained by crushing and processing cleaned samples. The heavy mineral concentrates yielded, through heavy mineral separation, three separate fractions; non-magnetic (NM), super magnetic (SMG) and magnetic (MG). The Fe-oxides in the MG fraction are weakly magnetic to the extent that they will adhere to a magnet if brought into direct contact with the magnet. The magnetite in the SMG fraction is strongly magnetic.

Susceptibility values of $0.01x10^{-3}$ SI, $1.60x10^{-3}$ and SI $0.01x10^{-3}$ SI (sample DP27) and 0.0, $2.24x10^{-3}$ and $0.03x10^{-3}$ SI (sample DP93) were obtained for the individual NM, SMG and MG fractions respectively.

The results of the heavy mineral separation in samples DP27 (higher metamorphic grade) and DP93 (lower metamorphic grade) are summarised in table 2. A common heavy mineral mixture observed in both samples in the SMG fraction is quartz with black inclusions (heavy minerals).

Sample DP93			**Sample DP27**		
Minerals	Fraction	Relative % within fraction	Minerals	Fraction	Relative % within fraction
Euhedral pyrite	NM	75-100%	Euhedral pyrite	NM	75-100%
Anatase	NM	<1%	Andalusite	NM	<1%
Cinnabar	NM	<1%	Rutile	NM	<1%
Magnetite	SMG	5-25%	Zircon	NM	<1%
Fe-oxides	MG	50-75%	Magnetite	SMG	5-25%
			Fe-oxides	MG	50-75%
			Biotite	MG	5-25%
			Tourmaline (euhedral; broken)	MG	<1%
			Ilmenite	MG	<1%
			Amphibole	MG	<1%
			Staurolite	MG	<1%

Table 2. Results of the heavy mineral separation carried out on black quartzite samples DP27 and 93. NM- non-magnetic, SMG- super magnetic, MG- magnetic. (Adapted after SALGUEIRO & PATEIRO, 2000).

3.5. **Carbon content**

The petrographic study of some samples of the black quartzites revealed that the samples contain considerable quantities of amorphous carbon. The carbon content of these quartzites was analysed at Actlabs using an Eltra CS-800 automated carbon sulphur analyser. Carbon content was determined by combusting, at 1370ºC in a oxygen atmosphere, a weighed sample with Fe-chips and a tungsten accelerator. Moisture and dust are removed and a solid infrared detector measures the CO_2 gas. Carbonate (content) can be determined after first determining total C content. A weighed sample is placed in a ceramic crucible and 25% HCl is added dropwise until the reaction is no longer observed to drive off the CO_2. The sample is then dried on a hot plate at low temperatures until dry. Samples are subsequently analysed in the same fashion as for total carbon. The carbonate concentration is the difference between the total carbon and the reacted carbon, calculated as CO_2 (written com., ERIC HOFFMAN, 1999).

The carbon content of the black quartzites of the Série Negra varies from 0.09% to 1.27%, with the highest value being recorded in sample DP27 (table 3). An increase in the carbon content does not positively correlate with a darker coloured rock. Actually, two samples of pale quartzites from the Série Negra in the study area yielded analytical results of 0.05 and 0.32% C (de OLIVEIRA, 2001).

Raman analysis of carbonaceous material is useful in determining the type of carbon present in the sample. Of the three types of “carbon materials”, diamond, amorphous carbon and graphite, diamond shows a strong peak at 1330 Rcm^{-1}, graphite a strong wide peak at 1585 Rcm^{-1} while amorphous carbon will show a low

	Sample number	Carbon (wt%)
Black quartzite	DP1	1.25
	DP27	1.27
	DP32	0.45
	DP34	0.18
	DP37	0.36
	DP57	0.09
	DP61	0.20
	DP84	0.37
	DP93	0.47

Table 3. Carbon content (not as carbonate) of a few of the Série Negra black quartzite samples collected within the study area. Detection limits for C are 0.01%. (Adapted after de OLIVEIRA, 2001).

broad peak around 1350 Rcm^{-1} (MURPHY *et al.*, 1998; figure 5 inset).

A Jobin-Yvon T6400 spectrometer with an Olympus BX40 microscope attachment and a liquid-N_2 cooled CCD detector with an Ar ion laser (with 500mW power at the source) of 514.532 nm as excitation radiation, was used in single spectrograph mode to analyse the carbonaceous material in sample DP27.

Several bands showed up due to the presence of quartz and resin in the samples. The following bands, namely 219, 403, 589, 606, 665, 950, 1345, 1585, 2044 and 2153 are not characteristic of quartz or resin. In the 1345 Rcm^{-1} region, a low broad peak is evident indicating the strong probability of the presence of amorphous carbon (figure 5). In the 1585 Rcm^{-1} region a short, low peak is seen (figure 5) which is not characteristic of the peak for graphite (figure 5 inset). The spectrum in the 403 and 500-600 Rcm-1 regions is characteristic of the anatase polymorph of TiO_2. Since the primary objective of this exercise was to identify the carbon species, the other bands were not interpreted at the time (NIEUWOUDT, 2000).

4. **PRELIMINARY CATHODOLUMINESCENCE (CL) STUDIES**

CL imaging is a highly effective technique for discriminating detrital quartz from authigenic quartz in quartz-cemented sandstones (e.g., SIPPLE, 1968; HOGG *et al.*, 1992; HOUSEKNECHT, 1991; RAMSEYER & MULLIS, 2000; MILLIKEN & LAUBACH, 2000) and can detect quartz of different origins or reveal processes of crystal growth, recrystallisation, alteration or diagenesis by variable CL colours (GÖTZE *et al.*, 2001). Contrast in CL between bright detrital quartz and more weakly emitting quartz cement survives to at least 200 °C in deep sedimentary basins, although at some still-poorly defined level of heating, homogenisation of quartz CL occurs (e.g., SPRUNT *et al.*, 1976; RAMSEYER *et al.*, 1988). However, preliminary work by some of the authors suggests that the differentiation between quartz grain and cement survives longer (to higher temperatures) in the blue-wavelength CL emissions.

Images used for this study were acquired using an Oxford Instruments MonoCL2 system attached to a Philips XL30 SEM operating at 15 kV using a large spot size. The detectors and processing used for these images record CL emissions in the range of 185 to 850 nm (ultraviolet through visible into near infrared) and convert them to grey-scale intensity values. Acquisition of colour images using scanned CL requires filters and superposition of multiple images. Scanned CL imaging was applied to several samples in this study (DP1, DP27, DP51, DP61, DP64, DP84 and DP93) in an effort to obtain evidence on the nature of the samples prior to metamorphism.

Two samples (DP1, DP27) showed evidence of CL textures that can be interpreted to represent relict quartz grains with quartz overgrowth cements. Figures 6A and B show that a sandstone precursor to these quartzites is plausible given the CL image obtained. It is clear that the quartzites are composed of equant regions of lighter coloured CL that are

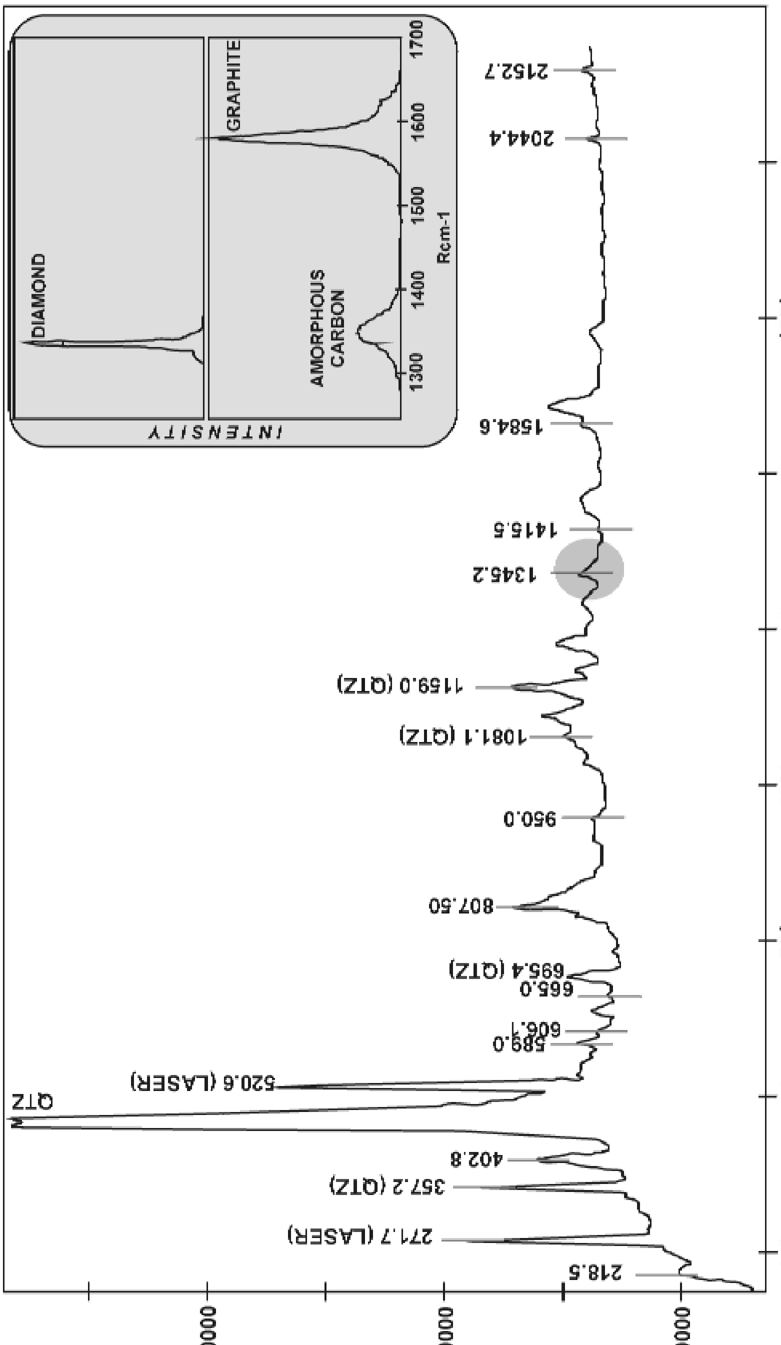

Figure 5. Raman spectrum obtained for the carbon inclusions in Série Negra black quartzite sample DP27. The low, broad peak at 1345 Rcm-1 (shaded) is characteristic of amorphous carbon reflecting its presence in these rock types. Inset shows examples of spectra for the various carbon types (after MURPHY *et al*., 1998, figure 5).

the right size and shape to represent former detrital sand grains. The fuzziness of the CL at the boundaries of these different areas most likely represents the effects of incipient homogenisation that could have gone to completion had the rocks been heated further.

Many of the samples manifest relatively uniform CL except for bright luminescent halos around a first generation of mineral inclusions (figures 6C and D). Development of such cathodoluminescent halos in quartz by radiation damage is a well-known phenomenon (e.g. OWEN, 1988; RINK & ODOM, 1989; MEUNIER *et al.*, 1990). The identification of the mineral inclusion is hampered by their very small size. However, a few of the halos in samples DP27 and DP84 were cut through the centres allowing the acquisition of EDS spectra of the mineral inclusions. Figure 7 shows the EDS spectrum for the halo-producing mineral inclusions in sample DP27. The principal elements detected are Ti, Si and Ca, with additional amounts of Al, V, Cr and Fe. The obtained spectra indicate that there is more than one mineral that is producing the CL halos shown in figures 6C and D. These are possibly at least V-bearing titanite and V-bearing epidote-allanite, occurring with Fe-Ti-Cr-V oxides.

The use of CL has also yielded some results concerning the tectonic and fluid flow history in these rocks. figures 6C and D also show microfractures in the rocks that are post metamorphic although the tectonic history of these rocks is not the focus of this work. The quartz in these fractures is clearly prominently zoned rather than yielding a fuzzy CL image. Hence, we can be certain that these are from a later, more brittle stage of deformation after peak metamorphism. Therefore, these fractures are evidence of late fluid flow that has overprinted the bulk chemistry of these rocks. The fractures also clearly cut across the radiation halos (figure 6C) and yet the fracture-filling quartz has been there long enough to show faint halos itself, hence giving some idea as to the timing of the fractures and precipitation of the fracture-filling quartz.

Figures 6E and F show a fracture filled with Fe-oxide with some V-bearing minerals. This second generation of V-bearing minerals clearly post dates the quartz precipitation in this fracture, which places it in another period of cooler brittle deformation that post dates peak metamorphism. This yields further evidence that the lower temperature portion of the history of these rocks was accompanied by significant chemical modification.

5. DISCUSSION

Mineralogically these rocks are composed of quartz, biotite ± chlorite, local feldspar, and magnetite, chromite and ilmenite. Accessory minerals include pyrite, chalcopyrite, rutile (anatase), marcasite and arsenopyrite. Amorphous carbon is also an important component of these rocks.

These black quartzites also contain substantial quantities of interstitial Fe-oxides, magnetite and pyrite as well as very fine inclusions of V-bearing minerals and/or radioactive minerals in the quartz. These inclusions are locally evenly distributed in the quartz grains indicating that

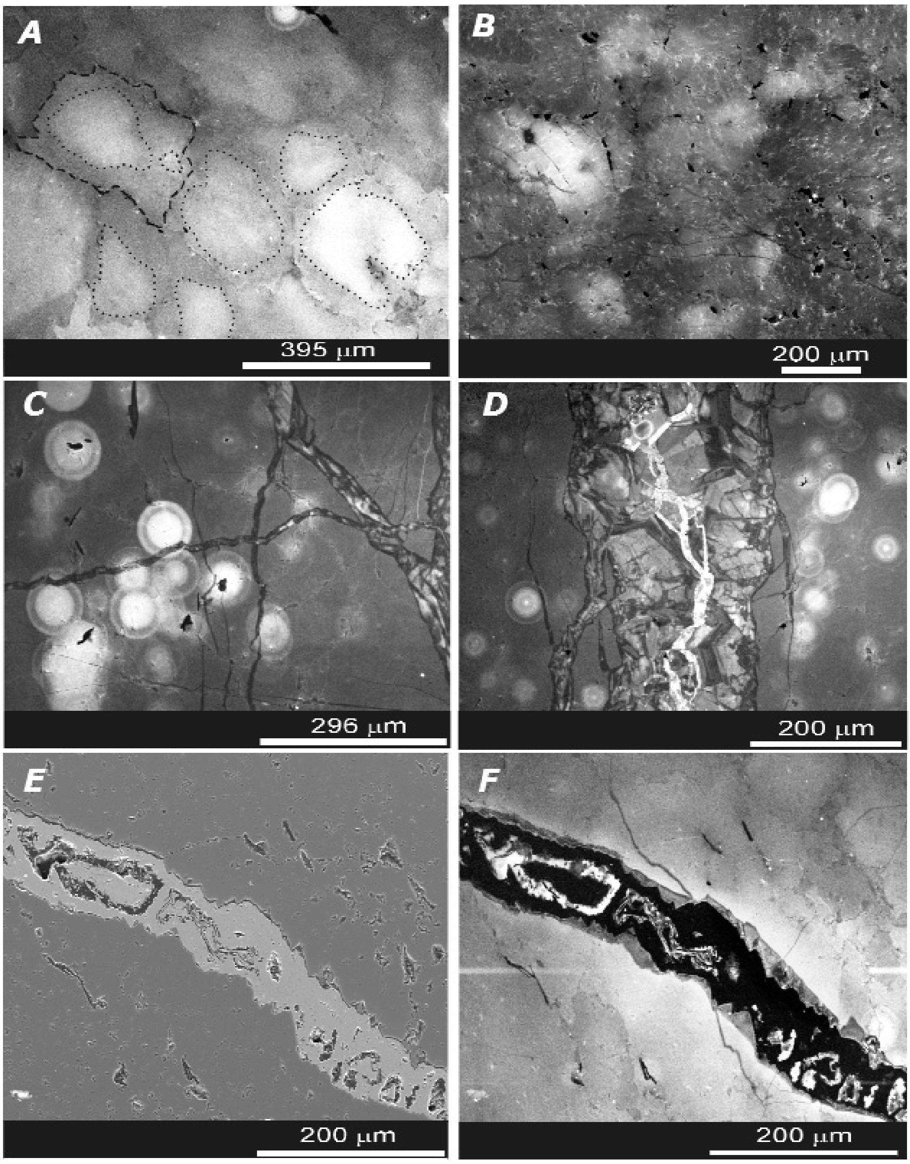

Figure 6. A- Panchromatic scanned CL image of sample DP1 showing support for the existence of a quartz cemented protolith. There are equant regions of light grey CL (dotted) that are about the right size and shape to represent former sand grains. The 'fuzziness' of the CL at the boundaries of these different areas most likely represents the effects of the incipient homogenisation that would have gone to completion if the rocks were heated further. One clear quartz grain boundary is shown in dashed lines (Note: the light grey regions referred to in A are in fact blue while the surrounding regions are purplish to pink); B- Panchromatic scanned CL image of sample DP27 further supporting for the existence of a quartz cemented protolith.

these grains were recrystallised during their metamorphic evolution. Magnetite occurs both as discrete large grains and also as very finely disseminated small grains. Together with the other finely disseminated Fe-oxides and the V-bearing mineral and/or radioactive mineral inclusions, magnetite is responsible for the black shadow(s) observed at low magnifications in thin section. The high concentrations of the heavy minerals are believed to be responsible for the black colour of these quartzites. By contrast, the pale quartzites of the Série Negra also exhibit rare, small (< 5 μm) pyrite and arsenopyrite grains. And besides, they do not contain significant quantities of Fe-oxide minerals.

Geochemical characterisation undertaken on these rocks shows that they are the result of the weathering of a wide range of rocks, i.e., granitic, basaltic or andesitic source rocks in a passive margin to arc-type environment (de OLIVEIRA, 2001). This is corroborated by a probable (Cadomian) arc-type environment proposed by BANDRES *et al*. (2002). This variation in possible source rock is not surprising, perhaps, given what the petrography is telling us about the degree to which these samples have progressed along the metamorphic path. However, what is most interesting is that the petrographic data shows that these rocks are inhomogeneous, which means that the metamorphic processes have not entirely wiped out the evidence that related them to their initial characteristics.

CL textures, in the less deformed areas of the samples, from at least two samples are consistent with relict quartz grain overgrowth patterns being present (figures 6A and B). The CL images also show a cooler brittle deformation event with precipitation of new fracture-filling quartz and in some cases preceded by the precipitation of probable either radioactive or non-radioactive V-bearing minerals.

6. CONCLUSIONS

The characteristic dark colour of the black quartzites may be derived from the copious quantities of finely disseminated heavy mineral concentrations within the quartz grains.

Both sandstones and cherts could be possible protoliths for these rocks prior to metamorphic-induced recrystallisation. Field identification of these rocks can induce in error due to their general cherty appearance. These rocks are extremely hard and fine- to medium-grained. However, several lines of evidence point to their having a more likely detrital rather

From figure 6 (previus page)

C- Cathodoluminescence image of the bright luminescent halos around the inclusions of either radioactive or non-radioactive V-bearing minerals in sample DP84; D- Panchromatic scanned CL image of prominently zoned quartz-filled microfractures in sample DP84 that clearly post date the metamorphism; E/F- CL image and scanning electron image of post metamorphic fractures in sample DP1 respectively that are filled with Fe-oxides with vanadium. Here the precipitation of the Fe-oxide clearly post dates the fracture indicating a complex chemical history during the low temperature phase of formation of these fractures.

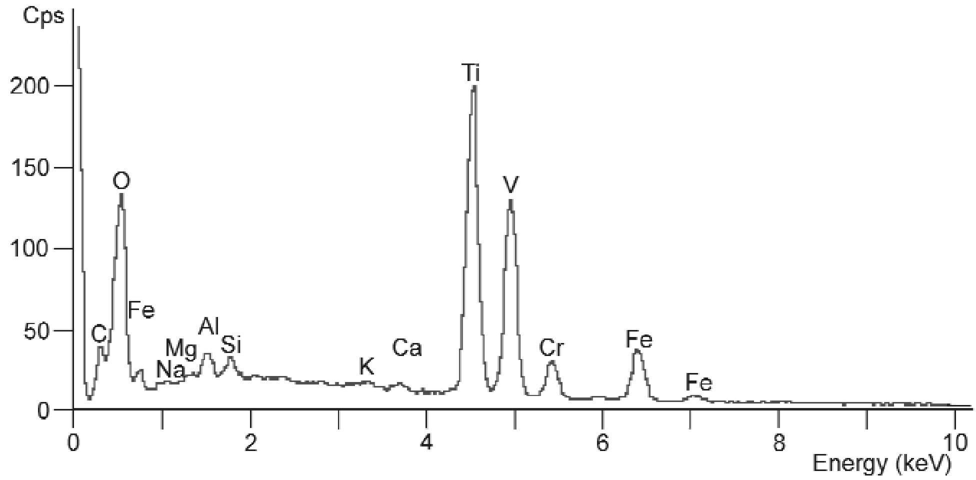

Figure 7. EDS spectrum obtained for the bright, luminescent, halo producing, disseminated minerals present as inclusions within the quartz of the black quartzites (sample DP27).

than chemical origin. These are 1) the absence, in these rocks, of the very thin layering or laminations commonly found in true cherts (though existent would probably be obliterated by metamorphic recrystallisation), 2) the presence of centimetre-scale layering that probably represents relict bedding, 3) the presence of subrounded (detrital) opaque minerals, magnetite, chromite and ilmenite (the latter also present as a metamorphic mineral), 4) the presence of abrasion resistant, heavy minerals such as zircon and tourmaline, 5) the local presence of feldspar which would indicate a more arkosic precursor and 6) CL textures from at least two samples studied being consistent with relict quartz grain overgrowth patterns.

The locally uniform distribution of either radioactive or non-radioactive V-bearing minerals is further evidence that these rocks have experienced pervasive chemical and textural reorganization. Based on the results obtained and given a more probable sandstone or arenite protolith for these rocks, the terms *chert*, *meta-chert*, *(meta)lyddite* and *phthanite* should be abandoned and the term *quartzite* or *meta-sandstone* adopted to describe these rocks of the Série Negra in the area.

Furthermore, the use of CL imaging has demonstrated that more information can be gained from these rocks regarding the timing of metamorphism in relation to the formation of brittle deformation structures.

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