PROVENANCE STUDY ON "BLACK SANDS": A CASE STUDY FROM THE LOWER CAMBRIAN FISH RIVER SUB-GROUP (NAMA GROUP, NAMIBIA)

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INTRODUCTION

Heavy mineral, mineral chemistry and geochemical whole rock analysis together with sandstone petrography was used for provenance studies on black sands and their host rocks the Haribes and Rosenhof Members, of the Nababis and Gross Aub Formations respectively (Fig. 1).The exceptional fossiliferous content of the Nama Group makes this sedimentary succession unique in the world. The occurrence of an Ediacaran fauna (Germs, 1972a, 1983, 1995), organic-walled microfossils (Germs et al., 1986) and shelly fossils (Germs, 1972b, 1974, 1983; Grant, 1990, Grotzinger et al., 1995) are indicative of a late Ediacaran age for lower Nama Group. The upper Nama Group (i.e. stratigraphically above the base of the Nomtsas Formation) is probably Cambrian in age as indicated by the occurrence of the trace fossils *Treptichnus pedum* and *Diplichnites* (Germs, 1972c; Crimes and Germs, 1982). Radiometric data are available from the Nama Group. A volcanic ash bed of the upper Kuibis Subgroup yielded a U/Pb single zircon age of 548 ±1Ma, a volcanic ash bed of the Spitzkop Member of the upper Schwarzrand Subgroup a single zircon age of 545 1±Ma. and of the early Cambrian Nomtsas Formation a single zircon age of 543 ±1Ma (Grotzinger et al., 1995). The Nama Group was deposited in a foreland basin along the western margin of the Kalahari Craton (Germs, 1974, 1995; Germs and Gresse, 1991). The Nama foreland basin originated as a response to tectonism in the adjacent northern Damara and western Gariep Orogenic Belts (Fig. 1). The lower Nama Group was mainly sourced in the eastern Kalahari Craton and the upper Nama Group from uplift from the rising northern Damara and western Gariep Orogenic Belts.

SEDIMENTOLOGY

….. The Nama Group generally accumulated in a fluvial braided river to shallow marine environment (Germs, 1983). Stratigraphically upwards the fluvial braided river environment becomes more prevalent and its sediments reddish. The black sands and the reddish host rock of the Haribes Member predominantly accumulated in a fluvial braided environment and the detrital material was transported from the northwest. The overlying and interfingering Rosenhof Member contains more shale than the Haribes Member and was deposited in a braided fluvial environment to shallow marine environment. Palaeocurrents point to a sediment transport from north to south. Two facies can be distinguished in the sandstones of the Haribes Member namely a large-scale trough-crossbedded facies and an overlying flat-bedded facies. The large-scale trough-crossbedded facies (sets up to two meters) was deposited in a braided river environment and the flat-bedded facies (up to approximately 80cm thick) predominantly in the upper flow regime of a braided river environment where fluvial channels became filled and consequently shallowed. Some sandstone layers of the flat-bedded facies may represent beach deposits. Black sands occur in both facies but are predominantly associated with the finer grained, flat-bedded facies. The host rock is mainly represented by the large-scale trough-crossbedded facies. Black sands occur very locally in the basal Rosenhof Member. The black sands were mainly deposited in thin layers of 0.5 to 1.5cm thick. At some localities they are up to 5cm thick. Thin layers of hematite and magnetite cause the black colour of the sands.

PETROGRAPHY

HOST ROCK

The sandstones in both members are typically fine to medium grained, moderately sorted arkoses according to the classification of Folk (1980). Monomineralic, undeformed quartz is generally the most abundant type (70-80%) and less than 20% of the total quartz is polycrystalline, both type being generally well rounded. The monominralic quartz type is generally non-undulatory or weakly undulatory, clear and without inclusions. The polycrystalline type displays a polygonal fabric. The feldspar content varies between 30 and 40%. K-feldspar is more common than plagioclase (albite). In some layers microcline and anorthoclase dominate. The plagioclase and K-feldspar are altered to sericite, the K-feldspar locally more than plagioclase. Grain size of plagioclase is generally smaller (fine to medium sand) than that of quartz and K-feldspars. Plagioclase and K-feldspar grains are usually well rounded. Rock fragments are abundant (<10%) and mainly of sedimentary and metamorphic origin. The sedimentary fragments mainly consist of siltsones and the metamorphic fragments of quartzite. A few fragments comprising chlorite and serpentinite with inclusions of opaque minerals occur, and are probably derived from metamorphic rocks.

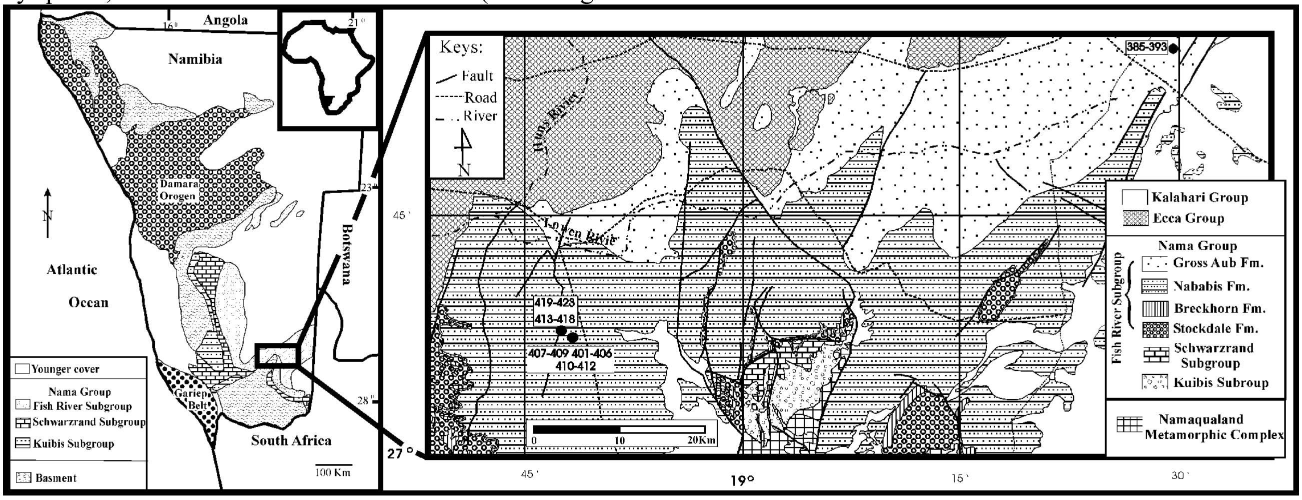

Figure 1. Geological map of the work area showing the sampling places and the regional

The cement, generally less than 5% vol., is composed by quartz, sericitic white mica and chlorite (according to XRD analysis illite and clinochlore) and in some cases calcitic. The quartzitic cement fills primary porosity in optical continuity with the surrounded clasts. Dust rims occur around the clasts showing secondary quartz growth. Clinochlore and illite are authigenic, growing in radial rims around the clasts after the quartz cement. Accessory minerals are composed by heavy minerals and detrital muscovite, which are 1% vol. the rock. Biotite also occurs, and detrital muscovite is quite abundant and large (< 3 mm), in size showing undulatory extinction. Some muscovite flakes have been bent and fractured during the compaction of relatively uncemented material indicating that this sandstone was not cemented until relatively late in its diagenetic history. The heavy mineral assemblage of the host rock is smaller in size than that of the lighter minerals and consists of a variable amount of well rounded zircons, epidotes, titanites and garnets.

BLACK SANDS

Heavy minerals in the black sands are well sorted, well rounded and medium sand in grain size, occurring as thin layers on a centimeter scale. Quartzs, feldspar, and lithoclasts are minor constituents with a content of less than 15 %. They occur between the rich heavy mineral layers, are well rounded, corresponding to medium sand in grain size. The detrital transparent heavy minerals are dominated by almandine garnet (>25% of the total number of grains). Other important transparent heavy minerals are zircon (5%), epidote-allanite (5%), titanite (5%) and rutile (5%). Apatite, serpentine, chlorite, Cr-chlorite, Cr-spinel, kyanite, monazite, turmaline, muscovite and biotite ocurrs as accessory minerals.

GEOCHEMISTRY

The rocks can be divided in three groups based on their heavy mineral content. Group 1 is relatively unaffected by heavy minerals, group 2 contains between 20 and 30% heavy minerals, and group 3 are the pure "black sands" with heavy mineral concentrations up to 75%. Group 1 can be characterized by a high concentration of silica (73 to 83%), relatively low Al_2O_3 (7-10,5%), but higher FeO concentrations (2,6 – 5,9%) and moderate concentrations of Na_2O and K_2O . Group 2 shows constantly higher abundances of Ti_2O (up to 2,55%). This correlates with FeO and Ca_2O. Also alkali elements are enriched at the cost of silica, Al_2O_3 is relatively constant (~13.6%). Interestingly, P_2O_5 is slightly enriched (close to 1%) representing the presence of apatite and combined with higher Ti_2O concentrations titanite. Group 3 reflects the "black sands" heavy mineral assemblage in its chemistry. The average silica content is around 43,5% and the Al_2O_3 7,65. Fe rises up to 35% correlating with Ti_2O (up to 14%). K_2O is depleted as well as Na_2O in nearly all samples, while Ca_2O concentrations are fairly high pointing to the presence of garnet. Determining alteration is mostly done by applying the Chemical Index of Alteration (CIA Nesbitt and Young, 1982), however in our case study the, the CIA does not reflect alteration but composition is controlled by heavy minerals, consequently, alteration should be determined by other means.

The ratio Th/U Vs. Th has been successfully employed to indirectly estimate the weathering of sedimentary rocks, as U loss can occur during recycling (e.g. McLennan et al., 1993). Group 1 shows significant weathering with values above upper continental crust (UCC) values (> 3,8; McLennan et al., 1993). In contrast, groups 2 and 3 show a diagonal trend, which is tentatively interpreted as a weathering trend. However, addition of Th-rich heavy minerals relatively depleted in U can also disturb the here-applied ratio of Th/U.

The general composition of the samples points to a rhyolitic/andesitic/alkaline trend? using Nb/Y versus Zr/Ti ratios (after Winchester and Floyd, 1977).

To decipher provenance the relation of Th, Sc and Zr can give important information regarding the source composition (McLennan et al., 1990). Group 1 has Th/Sc ratios of 1.71 and Zr/Sc around 30, group 3 in contrast displays Th/Sc ratios of 3.28 and Zr/Sc around 140. However, the trend in both groups points to a rifted margin/passive margin and a dominant recycling component. Moreover, the black sands show generally a similar trend as the unaffected samples pointing to an additiion of Th, Sc and Zr in a relatively comparable dimension.

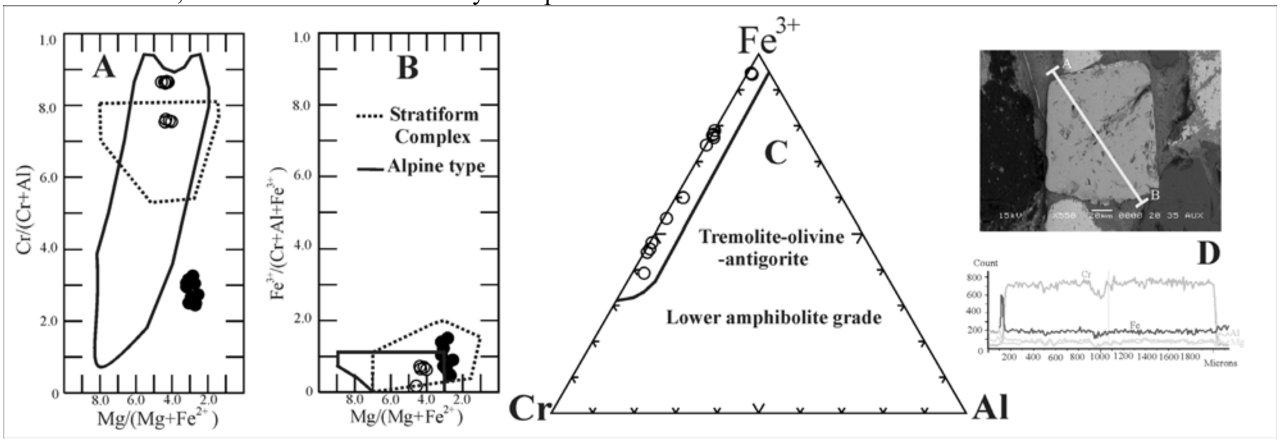

Figure 2. A) and B) chromites composition (Cookenboo et al., 1997) and C) compositions of the chromian magnetites, after Evan and Frost (1975), from the black sands (Haribes and Rosenhof Members); D) sem picture with cross section element scan of detrital chromite from a thin section of the "black sands" (diagonal bar 200 μm).

Comparative REE element patterns of all samples are relatively similar and PAAS-like (Post-Archean Australian average shale after Nance and Taylor, 1976). Trace element geochemistry and rare earth element geochemistry shows typical characteristics for upper continental crust rocks, the input of exotic material cannot be detected by using whole rock trace element geochemistry.

HEAVY MINERAL ANALYSIS

Contrary to the whole-rock geochemistry a detailed study of heavy mineral chemistry using microprobe analysis could reveal significant input of mafic/ultramafic detritus and other sources. The occurrence of detrital chromium spinel and chromian magnetite, points to a metabasic source. The chemistry of the chromian spinels suggests a source of both mafic and ultramafic rocks (Figs. 2a, b, d). High values of Al_20_3 and high values of Cr_20_3, are indicative of metamorphism of greenschist or higher grades (Cookenboo et al., 1997).

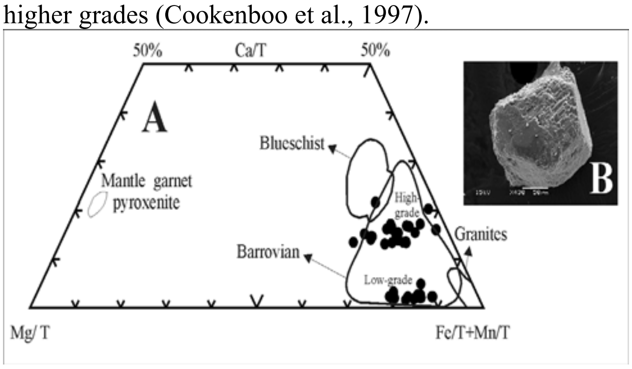

Figure 3. A) Garnet composition from the black sands (Haribes and Rosenhof Members), after Oliver (2001), B) SEM picture of dodecahedral detrital almandine of Haribes Member (bar 50 μm).

According to Evan and Frost (1975) the analyzed chromian magnetite compared with spinels from serpentinites are in the field of tremolite-olivine-antigorite (Fig. 2c), suggesting derivation from lower amphibolite-grade serpentinites. Almandine garnet is the most abundant transparent heavy mineral species in the black sands of both Rosenhof and Haribes Members. Usually, they represent more than 30 % of the total mineral content. The mineral is relatively stable during diagenesis, although a dissolution pattern textures are common buried to more than 2.1 Km (Morton, 1984, 1985), (Fig. 3b). Chemical analysis suggests a metapelite source at lower to higher amphibolite (Fig. 3a) facies according with plots presented Oliver (2001).

The majority of the detrital rutile derives from medium to high grade metamorphic rocks and recycled sediments and is virtually absent in large crystals (>40μm) in rocks such as low grade metamorphites or igneous rocks (Force, 1980, 1991). Nb and Cr concentrations in rutiles suggest a metabasic and metapelitic origin, which underwent medium to highgrade metamorphism (Zack et al. 2004). The high contents of Fe (tot) suggest an acidic or intermediate igneous source for detrital titanites (Asiedu et al., 2000). According to Corfu et. al. (2003) the study of the morphology and the observation of the internal textures in zircons (using principally cathodoluminiscence) can help in the identification of different source rocks. The zircon analysis shows a preponderance of metamorphic over igneous origins.

…..Chemical analyses of selected heavy minerals partly contradicts our whole-rock geochemical analysis, as a significant input of basic to ultra-basic material was added to the mainly felsic detrital material. The latter is manifested as well in the heavy mineral population by high amounts of zircon, garnet, epidote, rutile and titanite. Interestingly, most of the heavy minerals, with the exception of rutile, are angular to sub-angular and thus not very far transported. In contrast, the rounded quartz and felspar grains were transported under different conditions and/or from a greater distance (or were recycled?).

CONCLUSIONS

Provenance interpretation of black sands and their host rocks of the Haribes and Rosenhof Members using framework petrography and whole rock geochemistry, display mainly an upper continental crust composition, and would point to a rifted or passive margin using indicative trace element ratios. The heavy mineral study showed the existence of relatively labile but still angular grains, which were not transported far or buried rather rapidly, untypical for a "classical" passive margin setting. And exhumed basic to ultra-basic sources contributed significantly to the detrital record. This basic component was mixed with silica-rich material, which mainly points to a relative strong recycling. However, this tendency to recycling could be triggered by the massive occurrence of zircon, which raises the Zr/Sc ratio substantially in more mature detrital source terranes, fingerprinting recycled rocks. The unroofing of the folded and metamorphosed Damara orogen to deeper lithologically levels is most likely the main contributor of detrital material for the uppermost Fish River Subgroup.

Our study shows that rocks affected by enrichment in heavy minerals do not necessary mask the overall original provenance, but could reveal basic to ultrabasic components masked by the geochemical fingerprint of massive siliciclastic detritus

Finally, provenance data supports the interpretation of a depositional environment like a foreland basin, as proposed earlier by Germs (1974) based on sedimentological constraints.

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RESUMEN

Análisis de minerales densos, química mineral y geoquímica de roca total conjuntamente con la petrografía de areniscas son usados como indicadores de proveniencia en arenas negras y la arenisca que las contiene en los miembros Haribes y Rosenhof. Análisis químicos en granates detríticos sugieren una fuente metapelítica sometida a mateamorfismo facies anfibolita inferior a superior. Cantidades importantes en minerales detríticos ferro-magnesianos apunta a una fuente metabásica. La química de las cromitas y magnetitas crómiferas sugiere una roca fuente de un cuerpo ofiolítico sometido a una facies anfibolita inferior. Los valores de Nb y Cr en rutilos detríticos apuntan a una fuente metapélitica y metabásica sometida a grado medio a bajo de metamorfismo.

La composición química de las arenas negras y de la roca hospedante es similar a la de la corteza superior continental. El hecho de poseer elevadas concentraciones de Zr y enriquecimiento en LREE y empobrecimiento en elementos compatibles apunta a un ambiente altamente reciclado.

El estudio de los minerales pesados muestra la existencia de granos relativamente lábiles, los cuales no fueron transportados desde muy lejos o soterrados muy rápido, sugiriendo que provienen de un primer ciclo de sedimentación indicando un ambiente sedimentario con alta tasa de sedimentación. La causa de esta particular asociación mineral pudo ser la exposición de diferentes tipos de rocas producto del levantamiento y erosión del orógeno Damara. Del análisis de minerales pesados y la geoquímica de roca total se muestra una depositación en un ambiente de antepaís para la parte superior del Sub-Grupo en donde la parte sur del orógeno Damara actuó como la principal fuente.