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# Geological Mapping and Major Elements Characterization of the Tschaukaib Granitic Suite, South West Namibia

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ABSTRACT

Ongoing studies in the Namaqua Sector, situated in the Namaqua-Natal Metamorphic Province (NNMP), have been vital in understanding the geological activities that occurred during the Rodinia supercontinent assembly. These geological activities are usually key to discovering new mineral raw materials. The Tschaukaib Granitic Suite, which is believed to be part of the Gordonia Thrust Stack (GTS) of the Kakamas Domain, crops out within Tschaukaib Mountains and was characterized in this study on the basis of surface mapping, petrographic and major element geochemistry. Three types of granites were identified, namely: granodiorite, quartz monzonite and granite with SiO2 content ranging from 64.9 wt % to 69.8 wt %. Whole rock geochemistry further shows that they are calc-alkaline, alkali-calcic, ferroan, peraluminous ($Al_2O_3 > K_2O + Na_2O + CaO$) and have >1 % Cross, Iddings, Pirsson and Washington (CIPW) corundum. The geochemical characteristics indicates that the granitoids were emplaced during the continental collision and are formed from partial melting of recycled crustal material which took place during the Rodinia supercontinent. The geochemistry shows a conspicuous fractional crystallization signature. Geological mapping and structural analysis of the Tschaukaib Granitic Suite area shows a NW-SE and E-W trending regional foliation in the Tschaukaib Augen Gneiss (quartz monzonite) which corresponds to the main D2 Namaqua metamorphic event. Several shear zones were mapped and are consistent to the Pofadder Shear Zone which runs in the NW-SE and E-W directions, parallel to the study area. Petrographic analysis of the granitoids has identified mineral assemblages which shows that the granitoids have undergone high strain and alterations, however, it is not clear which Namaqua deformation episode brought about these features.

## Introduction

The Namaqua-Natal Metamorphic Province (NNMP) is a low-pressure, amphibolite to granulite facies belt that formed within the time span when the supercontinent Rodinia amalgamated, between 1.3 and 1.0 Ga, when a series of crustal blocks were accreted onto the southern and southwestern margins of the Kaapvaal Craton (Hartnady et al., 1985; Joubert, 1986; Van Bever Donker, 1987; Hoffman, 1991; Humphreys and Thomas et al., 1994; Eglington and Armstrong, 2003; Colliston and Schoch, 2013; Colliston et al., 2014; as cited in Angombe, 2016). The Namaqua sector is one of the two segments in the NNMP with units highly distributed in southern Namibia and comprise of terranes with metamorphic grade ranging from greenschist to granulite facies. The Tschaukaib granitic suite lies within the high grade Gordonia Thrust Stack (GTS), previously known as Kakamas Domain, which is part of the Namaqua sector (Macey et al., 2017, 2018; Miller, 2008a).

The NNMP extends from southern Namibia up to the eastern parts of South Africa (Eglington, 2006; Macey et al., 2015a; Miller, 2012; A. Pettersson, 2008), as shown in Figure 1. The GTS is dominated by granodiorites, tonalities and granites aged between 1.3 and 1.0 Ga (Bailie et al., 2017; Bial et al., 2015b). More than 200 million years of magmatic history has been recorded in the GTS, with a main phase of granitic emplacements between 1210 and 1180 Ma and less common younger plutons forming around 1100 and 1000 Ma (Bial et al., 2015b). The nature of these granitoids is often key to unravelling the tectonic history of different tectonic terranes within an orogenic belt; they can provide a detailed timeline for formation and collapse of the orogen, help constrain its P-T evolution and provide information on the nature of the lower crust and mantle (Macey et al., 2018).

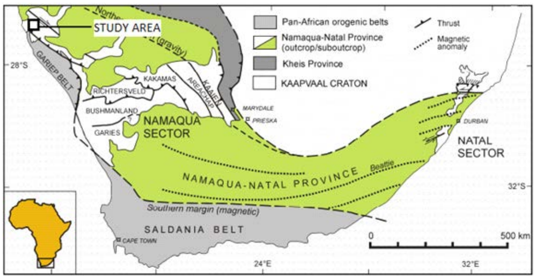


**Figure 1:** *Map of Southern Africa showing the extent of the Namaqua-Natal Province (green & white) and locality of the study area. Modified after Pettersson (2008).*

The first work done in the study area was by McDaid (1978) who identified two rock types in the Tschaukaib granitic suite, the granodiorite which was the oldest and the intruding granitic veins. Age dating done on two samples indicate an age of 1018 Ma and 1078 Ma (Burger, 1976) for the Tschaukaib granitic suite. However, there was no geochemical and petrography data. In addition, an outdated map of the Tschaukaib is available which doesn't clearly show the distribution and relationship of the units to the supracrustal rocks in the area which aids in pinpointing the tectonic setting of the suite, further contributing to the understanding of the magmatic history of the GTS. To resolve some of these matters, thorough geological mapping, major elements geochemistry and petrographic analysis of theses granitoids were employed using the current state of art technology. Detailed study of the different suites in the NMC contributes to a better understanding of the mechanisms involved in the formation of metamorphic complexes.

In addition, according to George H et al., 2005 geologic mapping provides many types of information, this may include but not limited to locating mineral, energy, and water resources needed to sustain our lively hood.

**Regional Geology**

The rocks of the Namaqua sector are traditionally subdivided into several subprovinces, which are further subdivided into terranes, based on the lithostratigraphy, grade of metamorphism, structural discontinuities and tectonic history (Miller, 2008; Angombe, 2016; Indongo, 2017). The major subdivisions of the Namaqua Sector are; Richtersveld Subprovince, Gordonia Subprovince and Bushmanland Subprovince (Eglington, 2006; Miller, 2008; Angombe, 2016). The Richtersveld and Gordonia Subprovinces occur in southern Namibia, whilst southernmost Subprovince of the Namaqua sector (Bushmanland Subprovince) is located in South Africa. Metamorphic complexes are constantly associated with several episodes of deformation which create structures/fabrics that can be correlated on a large scale creating a better representation of the forces that took place. The accepted structural nomenclature for the Namaqua – Natal Province is adopted from Joubert (1986) and summarized by Angombe (2016) in Table 1.

The NW-trending GTS is a deeply exhumed terrane with a granulite core and lower grade marginal zones (Miller, 2008b). It extends from the Excelsior-Lord Hill Shear Zone to the southern edge of the Southern Front Zone whereby near the southern edge it hosts the Pofadder-Marshall Rocks Lineament. In the southern margin the pretectonic rocks of the volcano-sedimentary Orange River Group and the Vioolsdrif Intrusive Suite have been incorporated into the Subprovince (Miller, 2012).

In addition, high grade gneisses and granitoid rocks of the Kakamas Domain, Areachab Terrane, Grunau group, Garub group and other unnamed or named units (Eglington, 2006; Miller, 2012; Macey et al., 2015) have also been incorporated. The high-grade metamorphic and intrusive rocks of the Gordonia Subprovince were most likely derived, or at least are part of a pre-existing older crust of the Richtersveld Subprovince and Areachab Terrane (Cornell et al., 2015; Macey et al., 2015).

***Table 1:** Summarized metamorphic and deformation events in the NNMP, modified from (Angombe, 2016).*

| | | |
|---|---|---|
| Deformation events | D5 | Development of brittle structures (faults, joints and quartz veins) (N-S) |
| | D4 – Crustal scale shear zones associated with brittle-ductile deformation at greenschist and amphibolite facies | Development of three brittle-ductile, dextral, NW-SE trending shear zones: The Eureka Shear Zone, Marshall Rock-Poffader Shear Zone and Speringputs Shear Zone |
| | D3 – Mega scale folding | Development of dome and basin structures |
| | D2 – Regional high-grade deformation & thrusting & terrane juxtaposition | Regional ductile L-S tectonite fabrics of higher grade & Thrusting of granulite facies Kakamas Domain on top of amphibolite facies Pella Domain (NW-SE & E-W) |
| | D1 – Greenschist facies deformation | First deformation recorded in the Namaqua Sector, overprinted by D2 and restricted to the Viooldrift Domain |

Studies done on the Garub group suggest they were deposited in an estuarine/lagoonal environment because of the high contamination of ferromagnesian material (Jackson, 1976). After deposition these rocks experienced multiple phases of tectonic reworking including high grade metamorphism and intense plutonism during the Mid-Mesoproterozoic (Pettersson, 2008; Bial et al., 2015; Macey et al., 2015; Angombe, 2016). The granitic magmas incorporated in this subprovince were dominated by reworked crustal material due to thickening of the crust and to a minor extent by mantle-derived melts which added to the growing Kalahari Craton (Å. Pettersson, 2008). During the D2 Namaqua Orogen, the rocks of the Kakamas Domain were thrust over the Richtersveld Subprovince along the LFROTZ (Indongo, 2017).

The Tschaukaib Granitic Suite has xenoliths of the metasedimentary supracrustal Garub units. The supracrustal xenoliths are found in granodioritic gneiss and two younger granites (McDaid, 1978; Miller, 2008b). The granodioritic gneiss contains large K-feldspar porphyroblasts aligned parallel to the E-W foliation and it is invaded by two sets of granite vein (McDaid, 1978).

**Materials and Methods**

Data in the form of journals, books, scientific reports, and old maps was used for efficient geological mapping and for confirmation with field observations. Field work, which was conducted over a period of 14 days from 15 June 2019 to 29 June 2019 comprised of describing rock units, investigating geological relationships, and sampling. Geological mapping was carried out on a scale of 1:30 000. The highly mountainous areas and those that were difficult to access were mapped by using high resolution ASTER and Google Earth imagery. QGis software was used to create a geological map. Major element geochemistry was analysed on ten samples of which five were from the major rock type in the area (augen gneiss), four from the granite and one from the locally distributed granodiorite were sampled during the course of this study.

Samples were prepared at the Ministry of Mines and Energy (MME) laboratory, Windhoek, Namibia, and major element analysis by XRF, Rh Tube, 3kW at the Stellenbosch University Central Analytical Facilities in South Africa. The thin section production and observation were done at the Ministry of Mines and Energy and the University of Namibia.

**Results**

**Local geology**

A detailed geological map for the Tschaukaib area was produced in this study and shown in Figure 2. The Tschaukaib Mountains comprise voluminous granitic emplacement, metamorphosing supracrustal rocks. The lithologies in the study area are listed from oldest to youngest as follows: amphibolite, garnet-sillimanite gneiss, Tschaukaib augen gneiss, granodiorite, sewage granite, pegmatite and aplite dykes. Amphibolite and garnet-sillimanite gneiss occur as xenolith within the augen gneiss and granite body and are highly distributed in the south of the study area (Figure 2). There is no direct relationship between the Tschaukaib augen gneiss and the granodiorite encountered in the field to infer the intrusion relationship. Mylonite - cataclasite's rocks are found in the shear zone areas cutting all the major rock units and infrequently offsetting the faults. There was no strong relationship between the pegmatite and aplite dykes to determine the youngest unit in the area. The significant occurrence of aplitic and pegmatitic bodies within an area can indicate the presence of Si-K-Na-Al-rich fluids which probably resulted in at least minor metasomatic effects (Kozłowski, 2002; Sherwonit, 1974).

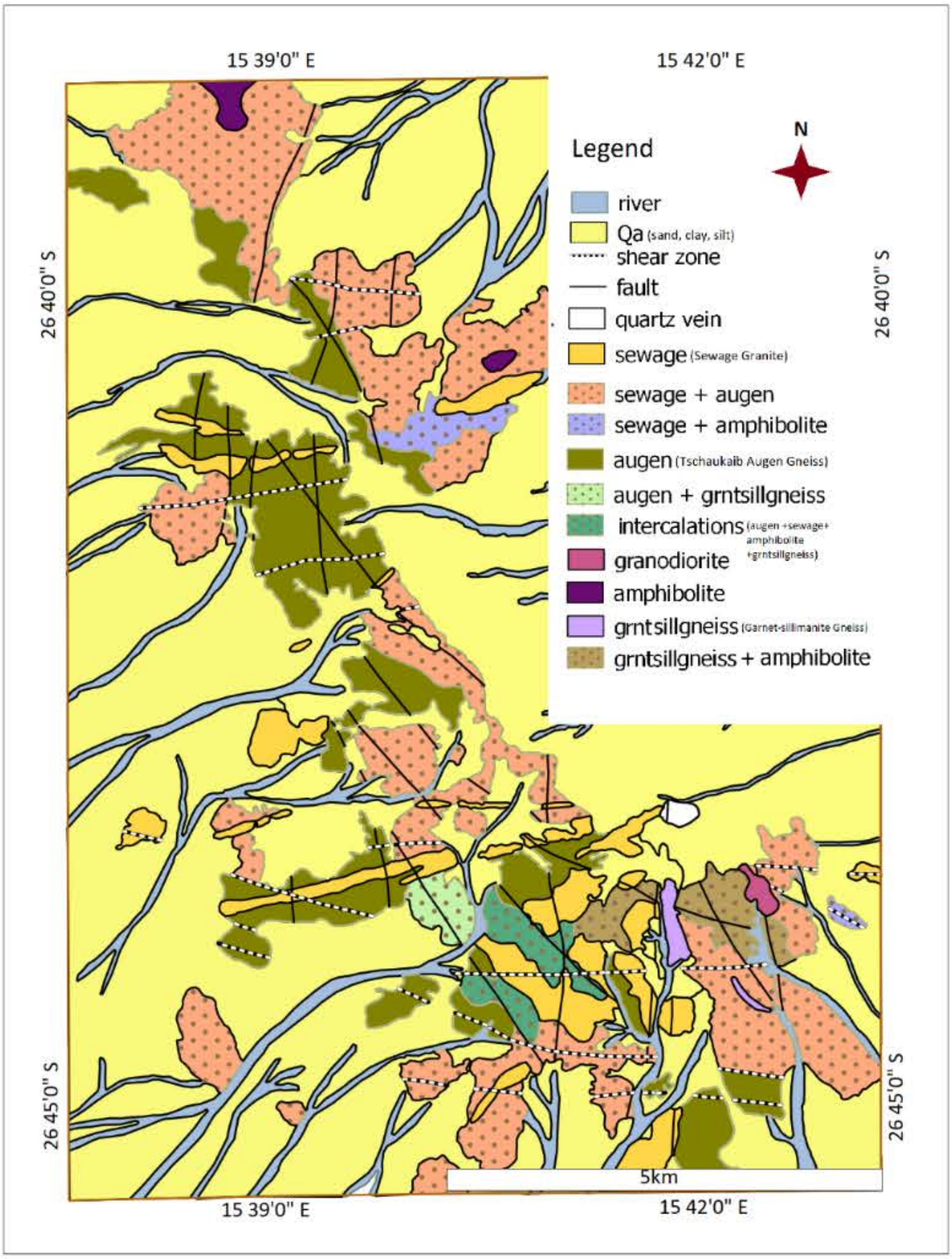


***Figure 2:*** *Geological map of the Tschaukaib area showing distribution of the major and minor lithologies encountered.*

Tschaukaib Augen Gneiss

Field photographs of rocks from the Tschaukaib Mountain in Figure 3 shows that the augen gneiss occurs as a coarse grained highly banded and sheared rock with a reddish to black weathered colour and a mesocratic grey fresh colour (Figure 3a). The modal composition is microline (35 %), plagioclase (20 %), quartz (30 %) and biotite (15 %) garnet (<3 %) observed in thin section. The gneiss is moderately to highly deformed and has a porphyritic texture with ovoid and spherical shaped porphyroblasts. The gneissic texture is defined by felsic and mafic bands. The felsic bands are represented by elongated K-feldspar porphyroblasts that range from 9 mm to 5 cm scale in size. A medium grained matrix of plagioclase, k-feldspar, quartz, and biotite hosts the phenocrysts. The gneiss has a localized migmatitic texture with resistance melts of felsic and mafic components (Figure 3b). The high strain induced in the rock can be defined by discrete crenulation cleavage and high strain zones forming 1 m thick cataclasite shear zones in the rock.

In thin section (Figure 4a) garnet occurs as inclusions in the biotite contributing to the foliation. Microcline shows tartan twinning and is often found with exsolved intergrowths of quartz. Mymerkite texture is common as vermicular intergrowths of quartz in plagioclase. The slightly altered and replaced biotite wraps around the quartz and feldspar crystals. Perthite textures are observed as exsolved plagioclase lamellae within a microcline host. Quartz exhibits strong undulose extinction and as subhedral grains in the matrix. Alteration products of biotite and plagioclase include chlorite, sericite, and slight epidote. Zircon, apatite and opaque minerals occur mainly as accessory minerals.

Granodiorite

The granodiorite was observed on southern side of the study area at location: S -26.73104399o and E 15.697288960 exposed in a small valley with a width of ~ 10 m. The medium-coarse grained granite was characterized by a mesocratic intermediate composition with an inconsistent texture, varying from equigranular to porphyritic texture (Figure 3d). The modal composition is biotite (30 %) and plagioclase (25-30 %), K-feldspar (10 %), quartz (<20 %), hornblende (<5 %). Plagioclase is randomly distributed and forms anhedral crystals less than 10 mm in size. Under the microscope (Figure 4b) the plagioclase is highly altered to sericite with subhedral granular grains. Primary quartz is found in the granular matrix and secondary quartz is found interstitial to plagioclase. Biotite forms wraps around the plagioclase and primary quartz crystals and is frequently associated with muscovite. Zircon and opaque minerals occur as accessory minerals.

Sewage Granite

The equigranular granite is medium to coarse grained granite which gradually grades into a weakly porphyritic texture at some areas. In the study area, it intrudes as dykes and large batholiths of 100 m width, intruding the Tschaukaib Augen gneiss, supracrustal and granodiorite. The dykes exhibit equigranular texture, whilst the botholith body is composed of both equigranular and weakly porphyritic textures (Figure 3). The equigranular dykes commonly occurs in the study area as E-W trending intrusive dykes commonly associated with pegmatitic veins. The dykes crosscut the NW-SE fabric of the augen gneiss and have well-formed joints.

In shear zones the rock exhibits a mylonitic-cataclasite texture running in the E-W direction. This granite is characterized by a reddish-brown weathered colour and leucocratic fresh color with pink k-feldspar phenocrysts. In general, the equigranular granite is weakly deformed and contains sparsely scattered phenocrysts of k-feldspar (Figure 3c). The weak fabric is defined by elongated euhedral phenocrysts of k-feldspar that are ≤ 2cm in size. They yield a dominant strike of NW-SE which is parallel to the regional fabric trend. Pegmatite inclusions occur in the granite throughout the study area and are more prominent in the vicinity and within the dykes. Under microscope the (Figure 4c, d) the rock is composed of plagioclase (20 %), microcline (30 %), quartz (30 %), biotite (5 %) and muscovite (2 %) of the total volume of the rocks.

Plagioclase is highly altered to sericite and around the boundaries it is altered to epidote. Microcline is the dominating feldspar (Figure 4d) and occurs as subhedral grains about 8 mm in size. Quartz also occurs as primary subhedral granular and as smaller secondary quartz occurring in the grain boundaries. Biotite and muscovite mica forms prismatic subhedral crystals with biotite highly altered to chlorite around its boundary. The muscovite surrounds and occurs as inclusions in the biotite. The micas show a slight alignment defining the weak fabric in the rock. Perthite occurs as exsolution lamellae of albite hosted in orthoclase. The granite gradually grades into a weakly porphyritic texture with the phenocrysts of feldspars reaching sizes of >10 mm in sample AJ19072.

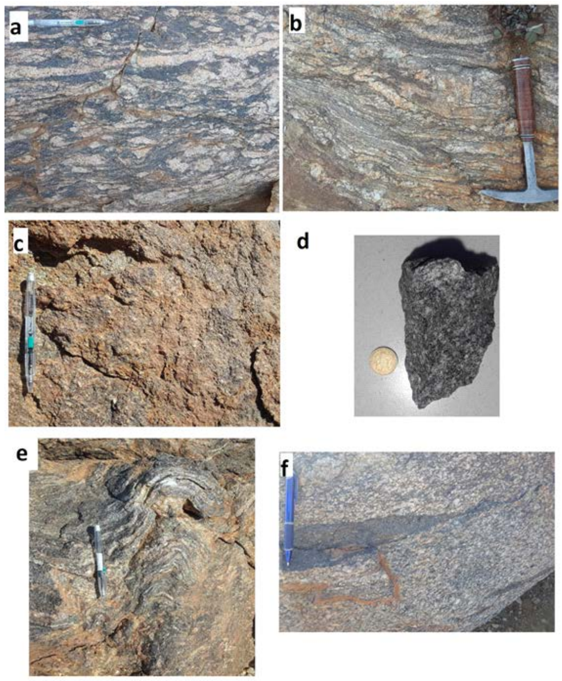

***Figure 3:*** *Field photographs of rocks from the Tschaukaib Mountain. (a) Coarse grained augen gneiss with large k-feldspar porphyroblasts in a gneissic texture. (b) Localized migmatite within the augen gneiss. (c) Weakly porphyritic medium grained granite. (d) Medium grained mesocratic equigranular granodiorite. (e) Garnet sillimanite gneiss xenolith within the augen gneiss occurring as a fold. (f) Amphibolite xenolith within augen gneiss.*

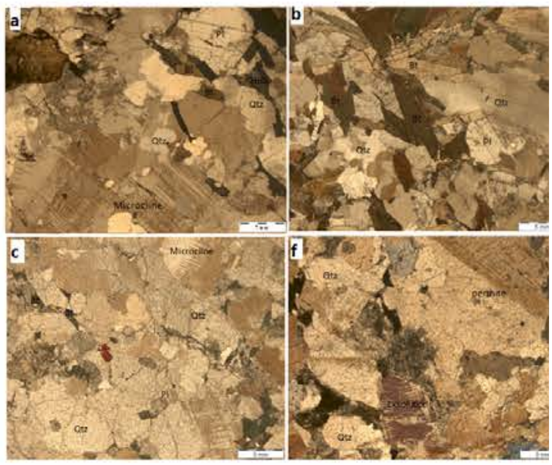

***Figure 4:*** *Photomicrograph of the Tschaukaib granitoids under cross-polarized light. (a) AJ19073 (Augen Gneiss) showing quartz (qtz), biotite (bt), hornblende (hnb) and microcline up to 20 cm in size. (b) AJ19054 (granodiorite) showing high birefringence biotite weakly foliated. (c) AJ19033 (granite) exhibiting equigranular texture and tartan twining. (d) AJ19072 (granite) shows large phenocryst of k-feldspar (>10mm) in the weakly porphyritic texture.*

**Geochemistry**

Tschaukaib augen gneiss

They have a wide range of chemical compositions, with $SiO_2$ = 66.66 - 68.39 wt %, $Al_2O_3$ = 14.29 - 14.66 wt %, CaO = 2.1 – 2.48 wt %, $Fe_2O_3$ = 4.79 - 5.68 wt %, MgO = 0.83 - 1.03 wt %, MnO = 0.07 – 0.08 wt %, $P_2O_5$ = 0.23 – 0.28, $TiO_2$ = 0.78 – 0.92 wt %. They have low alkalis compositions, with $Na_2O$ = 2.22 – 2.40 wt % and $K_2O$ = 5.2 - 5.79 wt % and total $Na_2O$ + $K_2O$ range from 7.54 to 8.01 wt % (Table 2). CIPW for corundum ranges from 1.175 – 1.308 wt %.

Sewage granite

They have a wide range of chemical compositions, with $SiO_2$ = 69.22 – 69.75 wt %, $Al_2O_3$ = 14.96 – 15.08 wt %, CaO = 1.74 – 1.76 wt %, $Fe_2O_3$ = 2.98 – 3.10 wt %, MgO = 0.58 – 0.60 wt %, MnO = 0.03 – 0.04 wt %, $P_2O_5$ = 0.13 – 0.14, $TiO_2$ = 0.48 – 0.52 wt %. They have low alkalis compositions, with $Na_2O$ = 2.51 – 2.61 wt % and $K_2O$ = 5.96 – 6.09 wt % and total $Na_2O$ + $K_2O$ range from 8.47 to 8.68 wt % (Table 2). CIPW for normative corundum ranges from 1.354 – 1.568 wt %.

Granodiorite

The one sample used in this study yielded distinct geochemical compositions with lowest silica content of 64.89 wt % and highest $Al_2O_3$ = 16.3 wt %, CaO = 3.1 wt % and MgO = 2.74 wt %. Other compositions include $Fe_2O_3$ – 5.45 wt %, MnO = 2.74 wt %, $Cr_2O_3$ = 0.01 wt %, $P_2O_5$ = 0.17 wt % and TiO2 = 0.71 wt % (Table 2). It has a relatively high $Na_2O$ = 3.31 wt % and low $K_2O$ = 2.76 and in total $Na_2O$ + $K_2O$ = 6.07 wt %. CIPW for normative corundum calculated is 2.638 wt %.

***Table 2:*** *Whole rock major element geochemistry of the Tschaukaib granitoids.*

| Sample | AJ190 19 | AJ190 40 | AJ190 55 | AJ190 61 | AJ190 69A | AJ19 062 | AJ190 69B | AJ190 22 | AJ190 73B | AJ19 054 |
|---|---|---|---|---|---|---|---|---|---|---|
| $Al_2O_3$ | 14.38 | 14.62 | 14.66 | 14.61 | 14.29 | 15.05 | 14.96 | 15.04 | 15.08 | 16.3 |
| CaO | 2.1 | 2.38 | 2.23 | 2.48 | 2.31 | 1.74 | 1.75 | 1.76 | 1.75 | 3.1 |
| $Cr_2O_3$ | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | bdl | 0.01 |
| $Fe_2O_3$ | 4.79 | 5.12 | 5.13 | 5.68 | 5.36 | 3.1 | 3.14 | 3.1 | 2.98 | 5.45 |
| $K_2O$ | 5.7 | 5.34 | 5.79 | 5.2 | 5.28 | 5.99 | 5.96 | 6.03 | 6.09 | 2.76 |
| MgO | 0.83 | 0.93 | 0.93 | 1.03 | 0.94 | 0.58 | 0.62 | 0.61 | 0.6 | 2.74 |
| MnO | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | 0.03 | 0.04 | 0.04 | 0.03 | 0.07 |
| $Na_2O$ | 2.29 | 2.37 | 2.22 | 2.4 | 2.26 | 2.52 | 2.51 | 2.61 | 2.59 | 3.31 |
| $P_2O_5$ | 0.23 | 0.24 | 0.26 | 0.28 | 0.26 | 0.13 | 0.13 | 0.14 | 0.13 | 0.17 |
| $SiO_2$ | 68.39 | 67.64 | 67.48 | 66.66 | 68.01 | 69.58 | 69.75 | 69.22 | 69.58 | 64.89 |
| $TiO_2$ | 0.78 | 0.86 | 0.83 | 0.92 | 0.91 | 0.49 | 0.5 | 0.52 | 0.48 | 0.71 |
| L.O.I. | 0.467 | 0.481 | -0.243 | 0.465 | 0.315 | 0.855 | 0.848 | 0.854 | 0.635 | 2.443 |
| SumOf Conc. | 100.0 | 100.0 | 99.1 | 99.8 | 100.0 | 100.0 | 100.2 | 99.9 | 99.9 | 101.9 |

Note: Sample AJ19062 (19,40,55,61,69A) – Tschaukaib augen gneiss, (62,69B,22,73B) – Sewage granite, AJ19054 – Granodiorite. All major elements measured in weight percentage (wt.%). LOI = weight loss or gain on ignition at 1000ºC. bdl – below detection limit.

***Table 3****: Normative calculations of the Tschaukaib granitoids.*

| Sample | AJ190 19 | AJ190 40 | AJ190 55 | AJ190 61 | AJ190 69A | AJ190 62 | AJ190 69B | AJ190 22 | AJ190 73B | AJ190 54 |
|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 28.174 | 27.615 | 26.983 | 26.746 | 29.046 | 27.778 | 28.04 | 26.682 | 26.937 | 24.832 |
| Corundum | 1.175 | 1.188 | 1.308 | 1.194 | 1.279 | 1.568 | 1.509 | 1.354 | 1.356 | 2.638 |
| Orthoclase | 33.685 | 31.558 | 34.217 | 30.731 | 31.203 | 35.399 | 35.222 | 35.636 | 35.99 | 16.311 |
| Albite | 19.377 | 20.054 | 18.785 | 20.308 | 19.123 | 21.324 | 21.239 | 22.085 | 21.916 | 28.008 |
| Anorthite | 8.916 | 10.24 | 9.365 | 10.474 | 9.762 | 7.783 | 7.833 | 7.817 | 7.833 | 14.269 |
| Hypersthene | 2.068 | 2.317 | 2.317 | 2.566 | 2.342 | 1.445 | 1.544 | 1.52 | 1.495 | 6.826 |
| Ilmenite | 0.15 | 0.15 | 0.15 | 0.171 | 0.171 | 0.064 | 0.086 | 0.086 | 0.064 | 0.15 |
| Hematite | 4.79 | 5.12 | 5.13 | 5.68 | 5.36 | 3.1 | 3.14 | 3.1 | 2.98 | 5.45 |
| Rutile | 0.701 | 0.782 | 0.752 | 0.83 | 0.82 | 0.456 | 0.455 | 0.475 | 0.446 | 0.631 |
| Apatite | 0.545 | 0.568 | 0.616 | 0.663 | 0.616 | 0.308 | 0.308 | 0.332 | 0.308 | 0.403 |
| Sum | 99.58 | 99.59 | 99.62 | 99.36 | 99.72 | 99.22 | 99.37 | 99.08 | 99.32 | 99.51 |

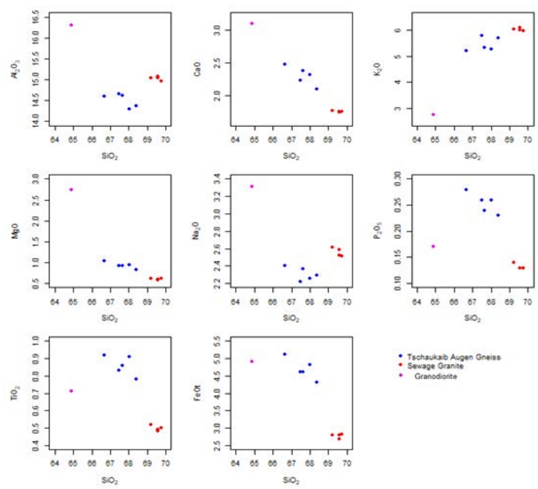


***Figure 5:*** *Major element versus silica diagrams for Tschaukaib Granitic Suite.*

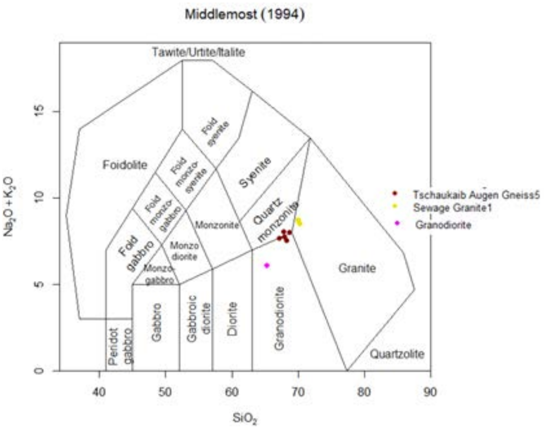


***Figure 6:*** *Alkalis versus silica diagram of Middlemost (1994) for the Tschaukaib Granitic Suite.*

Plotting samples from all plutons together (Figure 5) , the major elements show near linear variation with $SiO_2$, except $Al_2O_3$, CaO, MgO and $Na_2O$. $TiO_2$, $Fe_2O_3$, MgO, CaO, MnO and $P_2O_5$ show negative correlation with $SiO_2$ indicative of fractional crystallization. CaO may have been incorporated into early-forming calcic plagioclase. $Al_2O3$ and $K_2O$ show positive correlation with $SiO_2$, while $Na_2O$ show flat correlation. $K_2O$ increases from granodiorite, augen gneiss to sewage granite which suggests very low microcline and orthoclase crystallization in the granodiorite and higher concentrations of these minerals in the sewage granite. The Tschaukaib Suite shows consistent trends suggesting they fractionated from the same source in the order of granodiorite, augen gneiss and lastly the granite.

The granitoids of Tschaukaib granitic suite are distinguished geochemically on the $Na_2O$ + $K_2O$ versus $SiO_2$ diagram of Middlemost (1994) (Figure 6). The Tschaukaib augen gneiss straddle between the quartz monzonite and granodiorite fields. The sewage granite plots in the granite field and one sample of granodiorite lies in the granodiorite field.

All the rocks of the plutons have a dominantly peraluminous character (molar A/CNK >1) in the Frost et al. (2001) diagrams (Figure 7a). Majority of the granitoids are alkalic-calcic but one granodiorite sample plots in the calc-alkalic field (Figure 7b). The Tschaukaib augen gneiss is ferroan while, the Sewage granite and granodiorite plots in the magnesian field (Figure 7c). In the total alkalis versus silica oxide diagram both suites plot in the calc-alkaline fields (Figure 7d). The A/CNK vs $SiO_2$ (Figure 7f) diagram classify the granitoids as S-type.

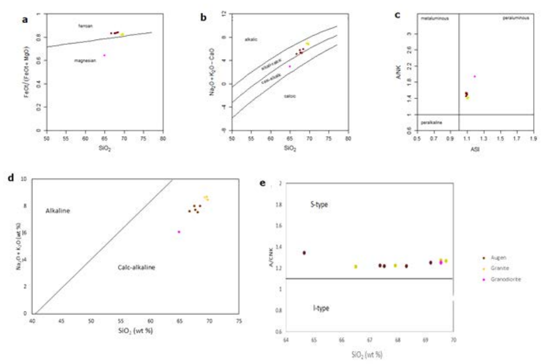


***Figure 7:*** *(a,b,c) Frost et al.(2001) geotectonic plots of the Tschaukaib granitoids. (e) $Na_2O + K_2O$ versus silica plot (adopted from Le Maitre). (f) A/CNK vs $SiO_2$ diagram of the Tschaukaib Granitic Suite differentiating between I-type and S-type granitoids.*

**Discussion**

The Tschaukaib granitic suite has foliation with NW-SE and E-W strike which is consistent with the regional fabric of the main Namaqua metamorphic event (D2) which occurred in the Mesoproterozoic (~1200-1000 Ma ago) (Miller, 2008a). The shear zones and the faults have an overall NW-SE trend and N-S which is also consistent with the D4 and D5 events of the Namaqua respectively (Angombe, 2016; Colliston and Schoch, 2000) (Table 1).

Petrographic study showed that these rocks were subjected to different degrees of alteration and metamorphic retrograde conditions shown by the presence mineral assemblages ± biotite, ± chlorite, ± muscovite and of secondary minerals such as chlorite, epidote and sericite respectively. Perthite's are common and mymekite texture indicates small-scale metasomatism or solid state exsolution of plagioclase in high grade metamorphic condition (Sherwonit, 1974; Winter, 2014), which similarly corresponds to high-grade conditions in the area. In addition, the undulose extinction of quartz in all the granitoids indicate strain which is evidenced in the field by the shear zones.

The A/NK versus A/CNK diagram indicates that the granitoids are peraluminous and they have been generated from the partial melting of meta-sediments as a result of thermal relaxation (Ugbe et al., 2016; Winter, 2014) of the Namaqua orogeny. Source of the granitoid is further suggested by the garnet sillimanite gneiss found occurring as xenolith in the Sewage granite and the Tschaukaib Augen Gneiss. Major element geochemistry shows that the augen gneiss and the granite have on average low $Na_2O$ (mean: 2.42wt%), $Na_2O/K_2O$ rations (0.38-0.50 wt %) and A/CNK ratios greater than 1.1 which is characteristic of S-type granites (Brown et al., 1984; Ghani, 2005; Winter, 2014). In addition, the granodiorite shows a more I-type character with the high Na2O (3.31 wt %) and $Na_2O/K_2O$ ratios (1.12 wt %) (Ghani, 2005; Winter, 2014) but this is contradicted by the high A/CNK consistent with S-type granites.

Based on the Bowen Reaction Serie (fractional crystallization) and the major element versus $SiO_2$ diagrams (Figure 5) the higher CaO, $Na_2O$ and lower $SiO_2$ together with inclusions of the quartz monzonite in the granodiorite further also suggests that the granodiorite was the first pluton to crystallize in the study area followed by the quartz monzonite. The cross-cutting relations, inclusions in the quartz monzonite and higher SiO2 suggest the granitic veins were formed from residual melts, hence, the youngest. The geochronological work of Burger (1976) yielded two different crystallization ages, 1018 Ma and 1078 Ma for the Tschaukaib granitic suite. Thus, current state of research suggest that the Tschaukaib granitic suite is a multiple intrusion magmatic body.

**Conclusion**

Geological mapping in the Tschaukaib granitic suite area parallels the high-grade metamorphism/thrusting experienced within the NMC with the evidence of the deformation events which brought about the shear zones, crenulation cleavage, gneissocity and augen structures. The three granitoids were identified from field observations, petrographic study and geochemical classification: quartz monzonite, granodiorite and granite. The Tschaukaib granitoids underwent significant fractional crystallization. Petrographic analysis shows replacement, alterations and high strain features highly associated with orogenic belts. Geochemical characteristics show that the calc-alkaline and peraluminous nature of the granitoids indicate they are syn-collisional granitoids which formed from partial melting of metasediments due to crustal thickening and radiogenic heat. The granodiorite shows slight signatures of mantle magma components. Combining the petrography and field relations results it is evident that the granodiorite was the first to emplace followed by the quartz monzonite and the granite body intruded both these plutons. Granite bodies and their surrounding have been known for more than 100 years as favorable sites for primary deposits (Mitchell, 2018), thorough geological investigation in the area can lead to new mineral deposits that are related to highly fractionated granitoids. Futhermore, robust geochronological studies is needed to warrant more insight on the chronology of the Tschaukaib granitic suite.

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