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# Geological setting, emplacement mechanism and igneous evolution of the Atchiza mafic-ultramafic layered suite in north-west Mozambique

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ABSTRACT

The Atchiza mafic and ultramafic-layered suite (hereafter, "Atchiza Suite) crops out in an area 330 $km^2$ west of the Mozambican Tete province. In an early account of the geology of this intrusion, it was considered the continuation of the Great Dyke of Zimbabwe, an idea that was aborted after detailed studies. Nevertheless, the Ni concentrations in the Atchiza outcrop rocks are considerable. Our investigation used field evidence, hand specimens and petrography descriptions, mineral chemistry studies using electron microprobe analysis and tectonic analysis to arrive at a plausible mineralogical composition and understanding of the tectonic setting for the igneous evolution. The mineral composition from the Atchiza Suite indicates that these are cumulates. The magmatic segregation from the petrographic and mineral composition reasoning indicates that dunite-lherzolitic peridotite-olivine gabbro-gabbronorite-gabbro-pegmatitic gabbro is the rock formation sequence. Olivine and chromite were the first phases formed, followed by pyroxene and plagioclase. In addition, it is shown that these minerals are near-liquidus crystallization products of basaltic magma with olivine Fo: 87.06 in dunite, mean values of clinopyroxene are (Wo: 36.4, En: 48.0, Fs: 15.2), orthopyroxene (Wo: 2.95, En: 73.0, Fs: 24.2) and plagioclase An: 71.3, respectively. Opaque minerals comprise Fe–Ti oxides and (Fe, Cr) spinel up to 4.8 vol.%, but chromitite layers are not present. Most of the opaque minerals are interstitial to pyroxene. Sulphides are common in gabbros, with pyrrhotite, pentlandite, chalcopyrite, pyrite and covellite together comprising 0.4–2.0 vol.%. The whole rock Rare Earth Element (REE) concentrations are mainly a result of differentiation, but slight crustal contamination/assimilation contributed to the REE contents. In addition, they also show Eu enrichment, suggesting that plagioclase fractionation was important in the rock. The Atchiza Suite preserves a deep-seated plumbing system of the continental rift environment. The intrusion resulted from the emplacement of mafic magma in space created by extensional forces. Space was created through a connecting fault generated as a result of overall extensional, torsion and slab displacement in a rift system. The geometry of the body is tectonically controlled, and it agrees with the tectonic framework of the Zambezi Belt during the Rodinia breakup in the early Neoproterozoic.


## 1. Introduction

Mafic and ultramafic rocks of considerable size become fundamental targets because of their hidden economic value. There are many cases of thorough investigations on mafic and ultramafic rocks related to Ni–Cu sulphides and Platinum Group Elements (PGE) deposits. The occurrence of these types of rocks has been related to large layered igneous intrusions and intracratonic magma conduit emplacements through sutures where extension and rifting are limited.

Mineral resources are valueless when unexplored and unexploited. To reach the stage of exploitation, geological knowledge and understanding the minerals' characteristics has become imperative. Many papers published in recent years (e.g., Ferreira Filho et al., 2010; Pereira et al., 2014; Maier and Groves, 2011) have dealt with revealing geological characteristics and the emplacement of mafic and/or ultramafic intrusions that host Ni–Cu and PGE deposits. Here, new results are presented by studying the Atchiza Suite. The results are comprised of understanding the properties and characteristics of these rocks in the setting of the ore deposit formation.

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Mafic-ultramafic rocks are not common in the Zambezi Belt, although they occasionally appear in the Tete Province (Mozambique), e.g. the Tete gabbro-anorthosite suite and the Chipera gabbro-anorthosite intrusion. Contrary to the Atchiza Suite, they are older (ca. 1005 Ma), formed in a different tectonic regime and have experienced more deformation (Evans et al., 1999; Westerhof et al., 2008).

The Atchiza Suite is often targeted for its mineral potential. The first detailed study of the Atchiza Suite was done by Vasconcelos & Hall (1948), who described the mafic-ultramafic rocks for the first time. These studies were followed up in 1955 by a team of geologists from the Longyear Company. The results of these early studies were only published in 1962. Real (1962) published another report on the intrusion, introducing the hypotheses that the Atchiza intrusion was a continuation of the Great Dyke of Zimbabwe. This was based on the geographic position and the geology of both intrusions. He also described chromite and asbestos found in the Great Dyke and Atchiza Suite to support his hypotheses. However, after detailed petrographic and chemical analyses, it was concluded that the Atchiza Suite deviated significantly from the Great Dyke of Zimbabwe, and their connectivity was abandoned (GTK Consortium, 2006).

The Atchiza Suite was mapped in detail by Hunting Geology and Geophysics Studies from 1982 to 1983, which was followed by data processing and interpretation by Anglo American in 1991. The GTK Consortium later remapped the intrusion on a 1:250,000 scale and conducted geochronology and geochemistry investigations from 2003 to 2006 (GTK Consortium, 2006; Westerhof et al., 2008).

Qualitative resource assessment and mineral potential studies show that the Atchiza Suite hosts Ni–Cu sulphides, Fe–Ti oxides, ferrichromium spinel and chromite mineralisations associated with the ultramafic rocks. Disseminated chromite occurs as a primary mineral formed during fractional crystallization with primary magnetite and olivine, but chromitite layers are absent.

All these previous studies were aimed at finding economic ore-deposits, not at understanding the origin and evolution of the intrusion. Therefore, this paper aims to provide the first comprehensive and scientific understanding of the geology, petrology, emplacement mechanism and igneous evolution of the intrusion.

## 2. Materials and methodology

### 2.1. Materials

Fresh samples are difficult to obtain in the field due to varying degrees of weathering. Fig. 1 shows examples of the alteration status of the best samples (16 in total) used in this study. The left figure (i.e., Fig. 1-A) was taken from an unaltered fine-grained olivine gabbro, and the right (i.e., Fig. 1-B) shows slightly altered peridotite. Used samples represent six different rock types: dunite, lherzolitic peridotite, olivine gabbro, gabbronorite, gabbro and pegmatitic gabbro, distinguished by their petrographic and mineral geochemistry characteristics. The selected samples cover the entire range of lithologies present in the study area.

### 2.2. Electron probe micro-analyser (EPMA)

Thin and polished sections with ~270 Å carbon coating were loaded into a JEOL JXA-8500F thermal field emission electron probe micro-analyser located at the laboratory of the Department of Material Science and Engineering at NTNU. The instrument is equipped with five Wavelength Dispersive Spectrometers (WDS) and one Energy Dispersive Spectrometer (EDS), allowing simultaneous acquisition of 5 + 16 elements. The instrument was operated at $10^{-5}$ Torr or better, at an accelerating voltage of 15 kV, 20 nA beam current, and 250 ms dwell time, with an effective beam diameter of ~1 μm (i.e., current density >25 nA/μm$^2$). Only one visiting time was performed for each programmed view, and the data were provided as element and oxide maps.

In 16 least altered and representative samples, which also were minimally altered, 568 spot analyses were carried out, of which, 292 were in olivine, 75 in pyroxene and plagioclase, 189 in oxides, 12 in sulphides and the remaining in biotite, chlorite, zircon and apatite.

## 3. Regional framework and structural-tectonic setting

The Atchiza mafic and ultramafic intrusion is located in the Zambezi Belt, which is a mosaic of juxtaposed terranes with contrasting structural and tectonic histories. The Zambezi Belt experienced two major tectonic events in the Mesoproterozoic to Neoproterozoic: (1) the breakup of Rodinia (continental rifting) and, (2) the assembly of Gondwana (continental collision and subsequent amalgamation). These two tectonic events are described by Johnson and Oliver (2004). They analysed the Southern African Cratons of the Mesoproterozoic Rodinia supercontinent, including the possible timing constraints for the breakup and subsequent Neoproterozoic (including the Pan-African orogeny) continental collision and amalgamation of Gondwana. Further, Stern (1994) correlated both tectonic events with the large structure associated with the East Africa Orogeny; Dirks and Sithole (1999) mostly studied the continental collision; Westerhof et al.

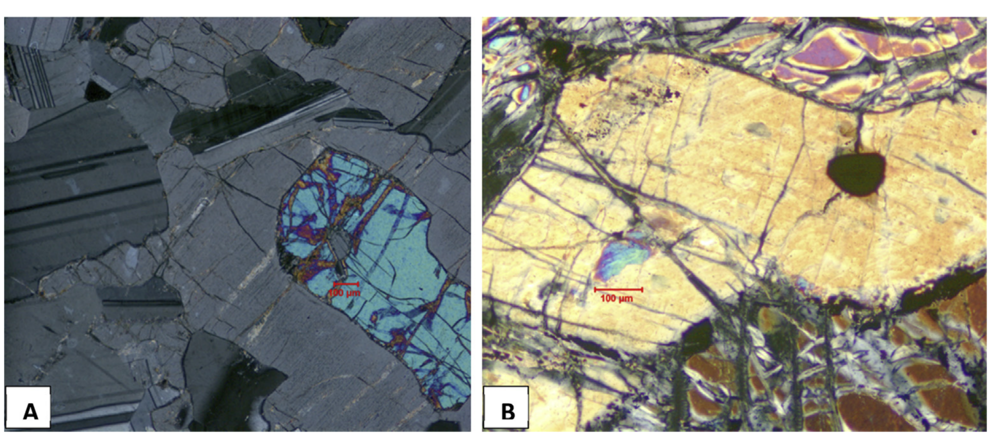

**Fig. 1.** Photomicrography of two different minerals status: A-Fine-grained olivine gabbro→Non-Altered; B-Lherzolitic peridotite→Moderate-Altered.