Compositional variations of chromites in Archean komatiites from Gorumahisani greenstone belt, Kapili area, Mayurbhanj district (Orissa)

Thesis submitted towards the partial fulfilment of the M.Sc. final examination in Applied geology of Jadavpur University, 2019

Under the guidance of Prof. Sisir K. Mondal

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Dedicated to my parents,

who are a constant support

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কলকাতা-৭০০ ০৩২, ভারত

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Certified that **Sabhyasachi Biswas**, Class Roll No.**001720402017**, a student of the M.Sc. Final Year, Department of Geological Sciences, has conducted research work under me for his dissertation thesis on **'Compositional variations of chromites in Archean komatiites from Gorumahisani greenstone belt, Kapili area, Mayurbhanj district (Orissa)'**. He has carried out his dissertation under my supervision for the partial fulfillment of the M.Sc. Final Examination (Applied Geology), 2019. This dissertation work is based on field work and sampling, hand specimen studies, sample preparation and detailed microscopy (both transmitted and reflected light), EPMA of minerals along with extensive data handling, graphical plots and interpretation of the acquired data. **Sabhyasachi Biswas** has successfully completed his dissertation with sincerity and dedication. The outcome of this research is worth publishing in a journal as well as presentable to the conference.

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Acknowledgement

I would like to thank my supervisor, Professor Sisir Kanti Mondal, for the immense support and co-operation during my field work, for helping and guiding me throughout the course of my work. I would also like to acknowledge DST-PURSE-PHASE-II, Jadavpur University, and CEFIPRA-Indo-French International Collaborative Research Project 6007-1 to Prof. Sisir K. Mondal for field and analytical support.

CONTENTS

Abstract

The Kapili area is a part of the Gorumahisani greenstone belt, which is composed of the Iron Ore Group of rocks, metamorphosed upto amphibolite facies. The study area consists of serpentinized peridotites, spinifex-textured komatiites, metabasalts and intercalated metasediments. The Kapili hillock is composed of spinifex-textured komatiites that are also found in Kolidiha which is a north-east extension of the Kapili hillock. Chromites in these komatiitic rocks are mostly skeletal in shape, some less some more, and on the basis of their alteration patterns, which is found to be a function of their shape, porosity and size, are classified under three categories. The Cr# and Cr_2O_3 concentrations in the cores of the chromites are indicative of their high-chromian origin. Bivariate plots of TiO_2, MnO, Fe^{3+}# and V_2O_5 indicate their diffusion during secondary alteration events. The homogeneity of the core and rims of the chromite grains, and crystallization of tremolite and magnesite and other carbonate minerals indicate metamorphic event which is thought to have occurred after the event of alteration.

1. Introduction

Komatiites occur mainly in Archean greenstone belts (Viljoen and Viljoen, 1969; Arndt and Nisbet, 1982). These komatiites were reported from other Archean greenstone belts viz., Barberton, South Africa; Abitibi, Canada; Kambalda, Australia; and Karasjok, Finland. Since komatiitic magma are directly derived from high degree melting of mantle plumes (30%) , acts as a window which provides key information about the composition and melting processes that occurred in deep Archean mantle (Arndt, 2003; Arndt et al., 2008). Allegré, (1982) and Arndt et al. (1998) proposed komatiitic magmas as a product of peridotite partial melting, whereas, others consider the generation of komatiites by the wet and shallow melting of hot, depleted peridotite in the mantle wedge above a subduction zone (e.g., Grove and Parman, 2004).

There are many reported occurences of komatiites from the Archean greenstone belts of the Dharwar craton, southern India and from the Singhbhum craton, eastern India (e.g., Mukherjee et al., 2012; Yadav et al., 2015). Occurences of komatiites from the Singhbhum craton are reported from the Gorumahishani-Badampahar greenstone belts belonging to the Iron Ore Group (IOG) supracrustal unit (e.g., Chaudhary et al., 2015; Yadav et al., 2015; Yadav and Das, 2017).

Chromite is a very widespread accessory mineral in almost all komatiitic rocks over a wide range of volcanic facies types, metamorphic grades and rock types (e.g., Barnes, 1998; 2000). In this study, the aim is to show the compositional variations of chromites in komatiites from Kapili area of Gorumahisani-Badampahar greenstone belt in the Singhbhum craton (**Fig. 1**).

2. Regional geology

The Indian Shield comprises four major cratons, viz., Bundelkhand, Dharwar, Bastar and Singhbhum. The Singhbhum craton covers an area of 40,000 km^2 between latitudes 21°00′ N and 23°15′ N and longitudes 84°40′ E and 86°45′ E. It is bounded in the north by the Chhotanagpur craton, in the west by the Mahanadi rift, in the south by the Eastern Ghat Mobile Belt and in the east overlained by the Bengal basin alluvium (**Fig. 1**). The general geological framework of the Singhbhum craton was established through the works of Dunn (1937) and Dunn and Dey (1942). The Archean nucleus of the Singhbhum craton comprises four main components. These are the (i) Older Metamorphic Group (OMG), (ii) Older Metamorphic Tonalitic Gneiss (OMTG), (iii) polyphase intrusions of the Singhbhum Granite Batholith, and (iv) Iron Ore Group (IOG) of rocks (**Fig. 1**). The Older Metamorphic Group (OMG) of rocks are the oldest rocks occurring south of the Singhbhum Shear Zone and named by Dunn (1929) as 'Older Metamorphics'. Its type area lies at the West of Champua, and consists of muscovite-biotite schists with sillimanite, garnet, and rocks of amphibolite facies (**Fig. 1**). Pelitic schists of the OMG are depleted in Al_2O_3 but enriched in K_2O, Cr, Ni, Rb, Th and U (insert citation). The ^{207}Pb-^{206}Pb ages of zircon cluster around 3.5, 3.4 and 3.2 Ga (Mishra et al., 1999). The Older Metamorphic Tonalitic Gneiss (OMTG) comprises felsic plutonic rocks rich in plagioclase. Alkali feldspar content is less than 10%. Pyroxene and hornblende occur as accessory minerals. OMTG is LREE enriched but less than OMG, and shows negative Eu anomaly. ^{207}Pb-^{206}Pb date is 3378±98Ma and Rb-Sr whole-rock isochron date is 3280±130Ma (Moorbath et al., 1986). The Older Metamorphic Tonalitic Gneiss (OMTG) consists of medium-grained tonalitic to granodioritic gneisses (Saha, 1994). The U-Pb analyses of xenocrystic zircons from the OMTG at Champua area by SHRIMP reveal ages in the range of 4.24-4.03 Ga (Chaudhuri et al., 2018).

The Singhbhum Granitoid Batholithic Complex occurs in the central part of the Singhbhum craton occupying about 8,000 sq. km area (Saha, 1994). Xenoliths of older tonalite gneisses, migmatite and ultramafic-mafic rocks are common within the Singhbhum Granite Complex. The Singhbhum Granite Complex consists of three phases of intrusions. Phase-I and II (SHB-A) and Phase III (SBG-B). SBG-A shows patterns similar to those of the OMTG having gently sloping REE pattern with moderately enriched LREE, flat HREE and negative Eu anomaly (Saha, 1994). SHB-B shows patterns having moderately enriched LREE, flat HREE and negative Eu anomaly. The ^{207}Pb-^{206}Pb whole rock isochron dates of the Phase-I and II are 3442±26Ma and 3298±63Ma (Ghosh et al., 1996). The voluminous granitic rocks of the SGBC were emplaced in two phases; the older emplacement age is ≈3.45-3.44 Ga (SBG-A) and the latter phase of emplacement is constrained at ≈3.35-3.32 Ga (SBG-B) (Upadhyay et al., 2014).

The Iron Ore Group of rocks consists of metavolcanics and metasediments including phyllites, tuffaceous shales, banded hematite Jasper with iron ores, ferruginous quartzite, local dolomite and volcanics (Saha, 1994; Mondal et al., 2001, 2007; Ghosh and Mukhopadhyay, 2007; Mukhopadhyay et al., 2008). The intrusives range from rhyolitic to komatiitic in composition. This group of rocks are restricted in three major greenstone belts within the craton: (i) Jamda-Koira-Noamundi belt, in the west, (ii) Gorumahisani-Badampahar belt, in the east, and (iii) Tomka-Daitari (Mondal, 2009), in the south (**Fig. 1**). Banded iron formations are associated with all of the above-mentioned greenstone belts, but have some differences in the mineralogy, geochemistry and lithological association in the different belts. Mukhopadhyay et al. (2008) obtained a SHRIMP U-Pb age of 3506.8 ± 2.3 Ma from zircons in the dacitic lava within the IOG supracrustal sequence belonging to the Tomka-Daitari greenstone belt. Basu et al. (2008) obtained a 3.4- Ga zircon U-Pb age from the volcanic rocks belonging to the western IOG in the Noamundi-Jamda-Koira greenstone belt.

Other than these major components, the Singhbhum craton also consists of the Singhbhum Shear Zone, Dhanjori group, Kolhan group, Bonai Granite, Nilgiri Granite, Chakradharpur Granite Gneiss, Soda Granite, Darjing group and Newer Dolerite Dykes.

3. Geology of Kapili area, Gorumahisani greenstone belt

The Gorumahisani-Badampahar belt trends NNE-SSW and turns to NW, forking into two arms that extend to the south and north of Haludpukur and comprises of a basal cherty quartz arenite, conglomerate, fuchsite quartzite or quartz schist. These are overlain by one or two distinct BIF horizons, separated by a band of cherty quartzite. The quartzite is 15-20m thick with numerous intercalated black chert and altered volcanic tuff. Tight folds plunging NNE are very common. Metamorphic grade ranges from greenschist to upper amphibolite facies resulting in quartzo-feldspathic veining in the contact zones with the gneisses. Metabasic rocks are dominant, locally pillowed and amygdular and are associated with agglomerates and tuffs. Metabasic rocks grade into amphibolites at the margins of the belt. The basalts are olivine tholeiites ranging in composition from picritic basalts to basaltic andesite. Ultramafic volcanic rocks range from peridotitic to komatiitic composition and some of them exhibit spinifex texture. The ultramafic rocks are mainly serpentinites, meta-pyroxenites and talc-tremolite schists. Felsic volcanic rocks form narrow and conformable lenses, which are locally tuffaceous and feldspar phyric. Fuchsite quartzite and banded calc-silicate rocks are subordinate. The Gorumahisani-Badampahar Group is intruded by 3100Ma old granite which is equivalent to SBG-II (Mahadevan, 2002).

The study area covers mainly the Kapili, Hatia, Jamubani, Chapal and Kolidiha areas (**Fig. 2**). The areas comprise mostly serpentinized peridotites, talc-tremolite-serpentinite schists, metabasalts, intercalated metasediments (quartzite). Kapili komatiites are associated with thick sequence of massive/amygdular metabasalt (occasionally pillowed) with intercalated chert and quartzite (Yadav et al., 2015). This association is stratigraphically floored by a basement of Older Metamorphic Tonalitic Gneiss (OMTG), exposed near Rairangpur, southwest of this sequence (Saha, 1994). The entire sequence, alongwith komatiites, is intruded by numerous aphophyses of younger phase of Singhbhum Granite restricting the stratigraphic position of komatiitic basalt sequence between OMTG and younger phase of the Singhbhum Granite.

The small Kapili hillock (22°21’10.6” N, 86°14’36.5” E) covers an area of ≈0.56 km^2 trending ≈N30^0E-S30^0W and located in a NW-SE linear belt in the central part of the Gorumahisani-Badampahar greenstone belt in Mayurbhanj district, Orissa (**Fig. 2a**). This hillock contains komatiites with prominent spinifex texture (**Fig. 3**). These komatiites show concordant relationship with the talc-tremolite-serpentine schist and metabasalts. The komatiitic rocks display platy spinifex textures (**Fig. 3a**) as well as random spinifex textures (**Fig. 3b**) in different parts of the hillock). Previous works by Chaudhuri et al. (2017) have shown that the Kapili area comprises both Al-depleted komatiites (ADK) as well as Al-undepleted komatiites (AUDK) (**Fig. 4**).

Primary minerals like olivine and pyroxenes are mostly altered to chlorite, tremolite, talc, serpentine and magnetite, which indicates assemblage of transitional facies in between greenschist to lower amphibolite facies of metamorphism.

4. Methodology

Sampling was carried out systematically in field in Kapili area. A total of 20 samples were collected, which consists of 9 samples taken from Kapili hill, 2 samples taken from close to Chapal, 6 samples from eastern foothill of Hatia, 2 samples from a NE extension of Kapili komatiite hill near Kolidiha and 1 sample near Samardapa village. These samples were then studied as hand specimens. Samples were carefully cut into thin slices and made into shape of glass mounting slides. Then they were ground and polished to thickness viable according to standards of thin sections. Care was taken for schistose samples that they were cut as close to perpendicular orientation as possible. After preparation, these thin sections were studied under microscope for petrography. After petrography, the samples were further polished intensively and circles were drawn on the other face of the slides for quick identification during its process in Electron Probe Micro Analyzer (EPMA). Oxide phases like chromite, ferritchromite, magnetite and ilmenite, and silicate phases like serpentine and tremolite were analysed under the CAMECA SX-100 instrument, equipped with four wavelength dispersive spectrometers (WDS), at the Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, operated at 15 kV acceleration voltage with 20 nA probe current and beam size of 1µm. The standards used were: Na-Albite, Mg-Periclase, Si-Orthoclase, Ca-CaO, Ti-Rutile, Cr-Cr_2O_3, Ba-$BaSO_4$, Al-Corundum, Mn-Rhodonite, Fe-Hematite, V-Pure vanadium, Zn-ZnS. The compositions of chromites were recalculated to cationic proportions using calculation scheme of Droop (1987).

5. Petrography

5.1. Hand specimen study

Serpentinized peridotite - Serpentinized peridotites contain serpentine, talc, amphiboles (tremolite, actinolite), oxides and sulphides (**Fig. 5a**). The rocks are medium-grained where grains are rounded to sub-rounded and moderately altered. Specific gravity of the rock is moderate. Magnetite and chromite are present, and sulphides are also seen. The sample SHB-18-24 contains less amount of sulphides than the rest. Grains in sample SHB-18-33 are coarser and specific gravity of the sample is also higher with respect to other samples. Sample SHB-18-37 shows weak schisosity.

Spinifex-textured komatiite - Samples SHB-18-20, SHB-18-21, SHB-18-25 and SHB-18-26 represent spinifex-textured komatiites (**Fig.** 5**b,c**). Compositionally, these are similar to the serpentinized peridotites, but have lower overall grain size. Spinifex textures were observed in samples. No sulphides were seen in sample SHB-18-26.

Metabasalt - Rocks are fine-grained and have a greenish tinge in its appearance (**Fig. 5d**). The rocks have moderate specific gravity. Minerals found are chlorite, amphiboles, talc, serpentine, oxides (magnetite) and sulphides. The metabasalts contain several cross-cutting veins of quartz as well.

A detailed chart consisting of the locations and hand-specimen descriptions of the samples is provided in **Table 1**.

5.2. Microscopic studies

Serpentinized peridotites - In these rocks, mostly lizardite variety of serpentine is present. Carbonate minerals also occur in patches, alongwith magnesite grains .These indicate a protolith rock containing dominantly olivine and pyroxenes. Olivine and pyroxenes have separate, sometimes alternating, zones, indicated by the distinct colonisations of serpentine-talc-magnetite and tremolite-chlorite assemblages (**Fig. 6a**).

Spinifex-textured komatiites - Unaltered orthopyroxene and serpentine are showing spinifex textures (**Fig 6c**). Lizardite variety of serpentine present, showing hour-glass texture. Chrysotile variety also found in serpentine veins. Tremolite grains with sharp boundaries cut across these patches, indicating later crystallization (**Fig 6d**). Talc and magnesite also present with tremolite (**Fig 6b**). Modally, serpentine occupies ≈30 vol%, orthopyroxene ≈15 vol%, tremolite ≈15 vol%, carbonate minerals ≈10 vol%, chlorite ≈10 vol%, talc ≈5 vol% and opaque minerals (oxides and sulphides) ≈15 vol%.

Metabasalts - The metabasalt samples are extensively altered. Dominant mineral phases present are chlorite, talc and carbonate minerals. Actinolite is present as both acicular laths as well as anhedral grains. Plagioclase feldspar present as relicts. Veins of quartz and magnesite indicate high actitivity of SiO_2 and CO_2 rich fluids. Modally, chlorite occupies ≈20-25 vol%, actinolite ≈20 vol%, talc ≈10 vol% carbonates ≈20 vol%, quartz ≈10 vol% and opaque minerals (oxides and sulphides) ≈15-20 vol%.

5.3. Chromite minerals

Chromites are ubiquitous as an accessory mineral. In the cumulate rocks, they occur as euhedral to subhedral grains (**Fig. 7a**) and in spinifex-textured rocks, they occur as cruciform or dendritic skeletal grains (**Fig. 7b**). Chromites occur as mostly subhedral grains with corrugated boundaries and range in size from as small as ≈20 µm to greater than ≈150 µm. On the basis of alteration patterns, the chromite grains can be divided into 3 types: **Type A** chromites, which are >100 µm in size, porous and slightly skeletal. (**Fig. 8a**). The core of these grains are remnant chromite and is surrounded by two rims (inner R_1 and outer R_2) representing ferritchromit and chrome-bearing magnetite respectively. The outer contact of rim R_2 has irregular contact with surrounding chlorites. **Type B** chromites, which are >100 µm are porous and highly skeletal.(**Fig. 8b**). In these grains, the chromite core is surrounded by 3 rims (two ferritchromit rims R_1, R_2 and Cr-bearing magnetite rim R_3) identified on the basis of varying reflectance. **Type C** chromites, which are <50 µm, euhedral to subhedral and negligibly fractured (**Fig. 8c**). There is no remnant chromite core in this variety. Either single rim of magnetite is seen around a ferritchromit core or a complete magnetite grain is seen. Ilmenite was also found, in the form of both euhedral grains and as exsolved oxidized laths in magnetite grains (**Fig. 8d**).

6. Mineral chemistry

Unaltered chromites from cores have higher Cr# (Cr/(Cr+Al)) and Mg# (Mg/(Mg+Fe^{2+})) than the ferritchromit and chrome-magnetite rims (**Fig. 9a**). Altered chromites show higher Fe^{3+}# than the unaltered cores (**Fig. 9c**). The Mg# for altered chromites are in the range of 0.02-0.05 (**Fig. 9a**). Mg# of cores of zoned chromites are in the range of 0.89-1.0 (**Fig. 9b**) while the ratio for outermost rims are within 0.01-0.05, similar to those. The plots of core chromites lie closer to Cr apex in comparison to the altered rims which plot on the Fe^{3+}-Cr line towards Fe^{3+}. Fe^{3+}# shows negative correlation with Mg# (**Fig 9f**). Ti and Mn show negative correlation with Mg# (**Fig 9e, g**). Ti and Mn show negative correlation with Fe^{3+}# also (**Fig 9 i, j**). Vanadium shows no definite correlation with Mg# (**Fig 9h**). Elemental oxide distribution across grains of zoned chromites has been shown in Fig 7.2, where the difference in elemental distribution patterns for **Type A** and **Type B**. In **Type A** zoned chromites (**Fig 10a**), among major elements, Cr_2O_3 is enriched in the core (~58 wt.%). Cr_2O_3, Al_2O_3, MgO concentrations drop away from the core. At the ferritchromit rim (R_1), Cr_2O_3 concentrations are ~45 wt.%, Al_2O_3 ~2.796 wt.% and MgO ~1.254. Farther away at the chrome-bearing magnetite rim, Cr_2O_3 concentrations are ~5.616-7.756 wt%, Al_2O_3 concentrations are ~ 0.221-0.371 wt% and MgO concentrations ~0.254-0.313 wt%. On the other hand, Fe_2O_3 and FeO concentrations are elevated towards the rims. While FeO increase is small (~26.467 wt% in the core to ~29.764 wt% in the core), the increase is Fe_2O_3 is very high (~6.456 wt% in the core to ~57.624 wt% in the outermost rim). In case of minor elements, MnO, TiO_2, V_2O_5 and ZnO all show a similar trend. They are deficient in the core, get enriched in the ferritchromit rim (R_1) and then their concentrations fall back in the chrome-bearing magnetite rims (R_2). There is, however, an abrupt spike in MnO and ZnO concentrations, near a fracture running across the grain. In **Type B** zoned chromites (**Fig 10b**) though, the distribution patterns are a bit different. In case of major elements, Cr_2O_3 and MgO show similar patterns, as they are enriched in the core, then depleted (drastically in the case of Cr_2O_3) in ferritchromit rim R_1, followed by a slight increase in ferritchromit rim R_2, eventually falling back to near zero-values in magnetite rim R_3. In **Fig 10b** though, there is a huge spike in concentrations of TiO_2 in the outermost rim, accompanied by a decrease of Fe_2O_3 to near-zero values. This indicates that the outermost rim has been subjected to an oxidation process, leading to complete exsolution to Ilmenite. Al_2O_3 shows pattern similar to MgO and Cr_2O_3 except that it was not enriched in the core. In case of minor elements, MnO is depleted in the core, but increases by ~5 wt% in rim R_1, followed by drop in rim R_2. In the outermost rim R_3, its concentration spikes to ~11 wt.%, since it is readily taken in the structure of ilmenite. V_2O_5 and ZnO show spatial variations concordant to Al_2O_3 pattern.

7. Discussion and conclusions

The high Cr# (0.80-1.00) in the cores of the chromite grains (**Fig 9b**) and the high Cr_2O_3 concentrations (~58%) in the cores (**Fig** 10a) indicate that the original composition of the chromites was chromium rich. As informed from the petrographic point of view, the Archean rocks from the Kapili area has suffered extensive hydrothermal alteration, indicated by ubiquitous secondary minerals like serpentine, talc, chlorite, magnesite and other carbonates in fair abundance, indicating their derivation from a protolith of olivine and pyroxenes. The effect of this alteration on the chromite grains were their zonation. This can be a result of the differential rate of diffusion of trivalent and bivalent cations causing a compositional gradient (Rollinson, 1995b). The distinct trend of Al-loss followed by loss of Cr and strong enrichment of Fe^{3+}, that is characteristic of ferritchromit (Evans and Frost 1975; Burkhard, 1993), is clearly observed in the Cr–Al–Fe^{3+} diagram (**Fig. 9c**). During ferritchromit formation, the Fe^{3+} content of the chromite grains increases due to prevalence of oxidation conditions. (e.g., Mitra et al., 1992). According to Bliss and MacLean (1975), the ferritchromit formation within Precambrian serpentinite was due to a combination of initial serpentinization that caused the development of magnetite rims around chromite, followed by later metamorphism of the assemblage, and reaction of the magnetite rims with the chromite cores to produce the Al- and Mg-poor ferritchromit rim. The event of alteration was followed by an event of metamorphism which yielded tremolite cutting across both olivine and pyroxenes zones. Fe^{3+}# vs Mg# plot shows increase of Fe^{3+} away from cores. This can be attributed to a metamorphic cause, which is supported by the Fe^{3+}-Cr-Al ternary where almost all of the altered chromites plot on the Fe^{3+}-Cr join near Fe^{3+} apex in the field of metamorphogenic ferritchromite and magnetite rims (Barnes, 2000). The negative correlation of TiO_2 and MnO with Mg# indicates that Ti and Mn were enriched in the rim, unlike Mg. Also, negative relation of MnO with Fe^{3+}# may indicate that Mn were incorporated in carbonate minerals like magnesite, which were found in the samples (Mukherjee et al., 2010). Negative correlation of Ti with Fe^{3+}# indicates either slow diffusion of Ti during metamorphism or their incorporation into Ti-bearing exsolved phases like magneto-ilmenite (as shown in **Fig. 10b**) or both. The Fe^{3+} values of the altered rims nearly concur with the Fe^{3+} values of the altered chromites in matrix, indicating alteration of both the chromites being the result of a single event. Also, metamorphism leads to enhanced diffusion of elements, leading to re-equilibriation and homogenization of the altered chromite rims (Barnes, 2000). The homogenization of the altered chromite rims can also be supported by the roundness of the core and inner rims and the sharpness of the boundaries they share.

The komatiitic rocks from the Gorumahisani-Badampahar-greenstone belt are products of extensive of alteration (serpentinization) and metamorphism upto greenschist-amphibolite transition facies. The Kapili komatiites, being a part of the same belt, also show similar evidences of alteration and metamorphism. For example, alteration of olivine and orthopyroxenes to serpentine-talc-magnesite-chlorite assemblage indicate alteration by a fluid comprising both H_2O and CO_2. Also, this causes the formation of ferritchromit rims around chromite cores and even magnetite in the outermost rims. The formation of ilmenite as grains and localized areas on magnetite rims and grains indicates that the fluid was oxidizing in nature. The presence of fractures in the chromite grains, the homogenization of their rims and the crystallization of tremolite indicate that there was an event of metamorphism. The unusually high concentration of MnO near fractures in the chromite rims is indicative of the fact that fluidization also occurred during this event of metamorphism, which allowed further diffusion of elements to the rims of chromite grains. The sharp boundaries of the tremolite grains and the fact that they cut across the rest of the assemblage indicates that the event of metamorphism was post-hyrdrothermal alteration. Hence, it can be inferred that an extensive event of alteration and consequential oxidation affected all the accessory chromite grains. Hence, smaller grains were altered at least to ferritchromite if not upto magnetite, and larger grains were zoned as an output of incomplete alteration. Later, these rims were homogenized by an event of metamorphism.

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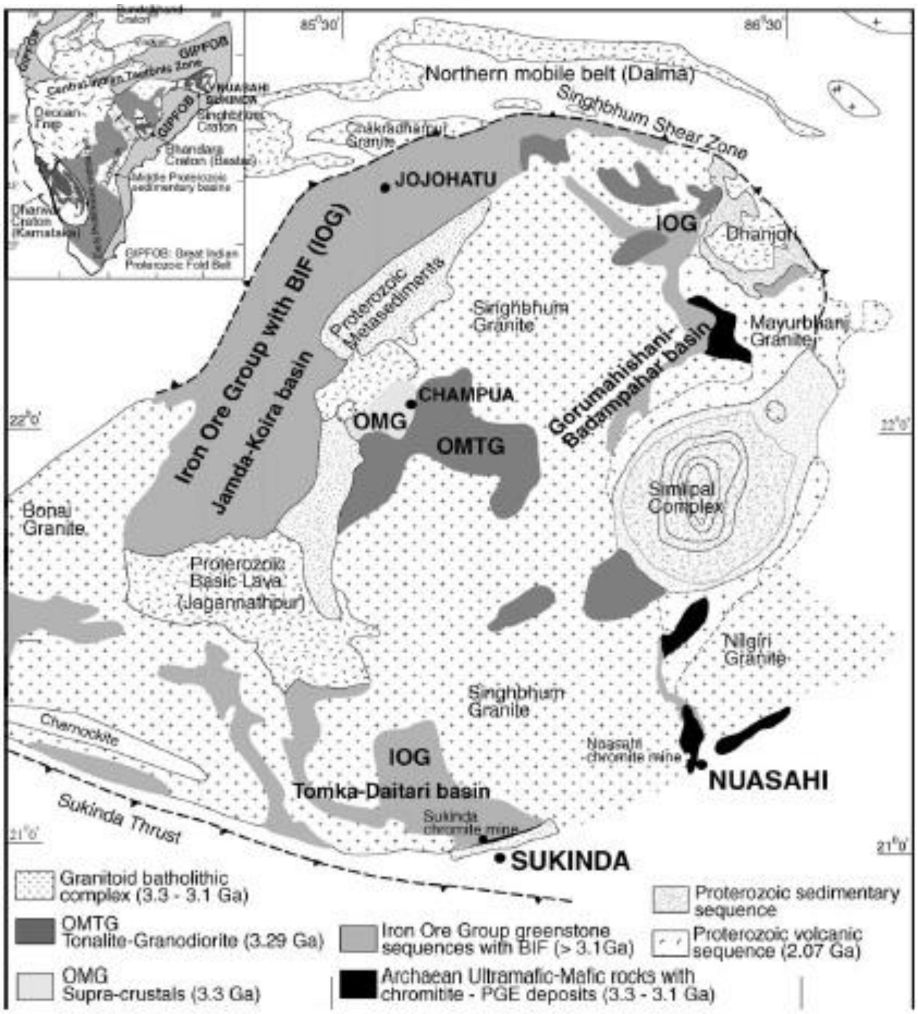


Fig 1: Geology of Singhbhum craton (after Saha, 1994; Sengupta et al., 1997). Inset map shows geology of Indian Shield

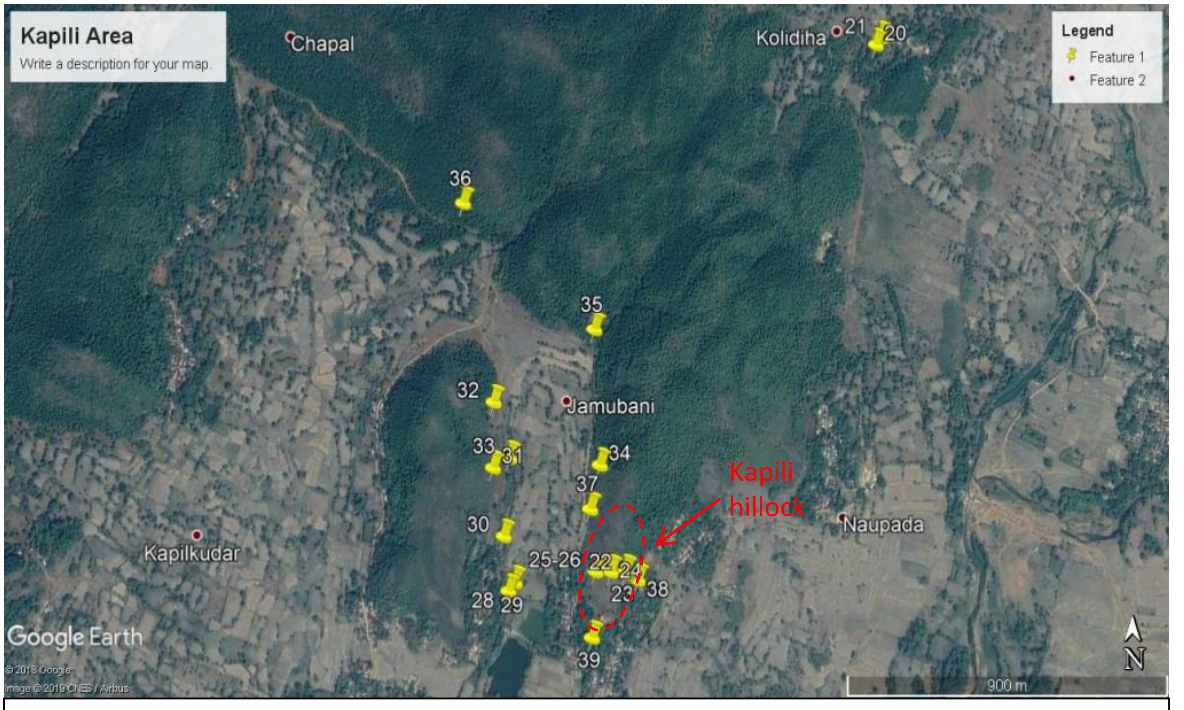


Fig 2a: Aerial view of Kapili area with locations of sampling

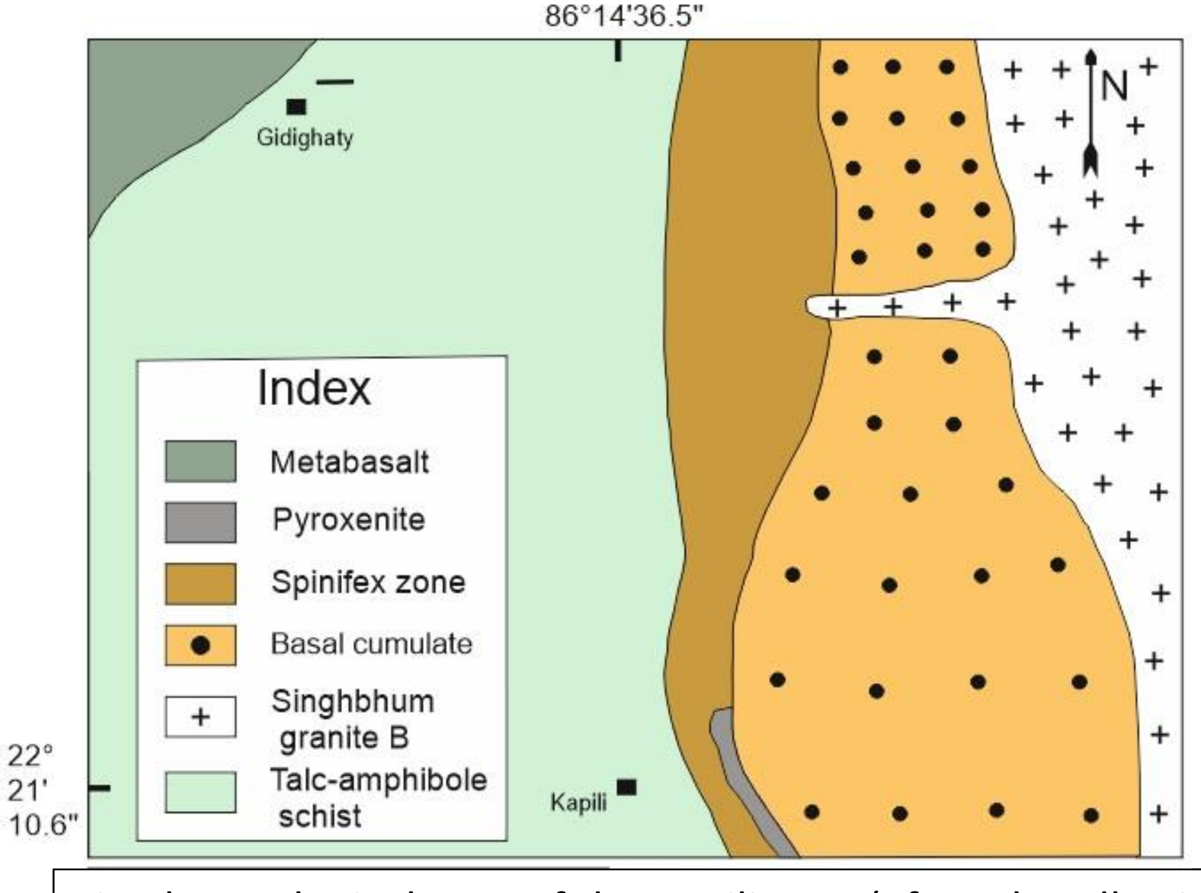


Fig 2b: Geological map of the Kapili area (after Chaudhuri et al., 2017)

(a) (b)

Fig 3: Field photographs of Komatiites. (a) Platy spinifex; (b) Random spinifex

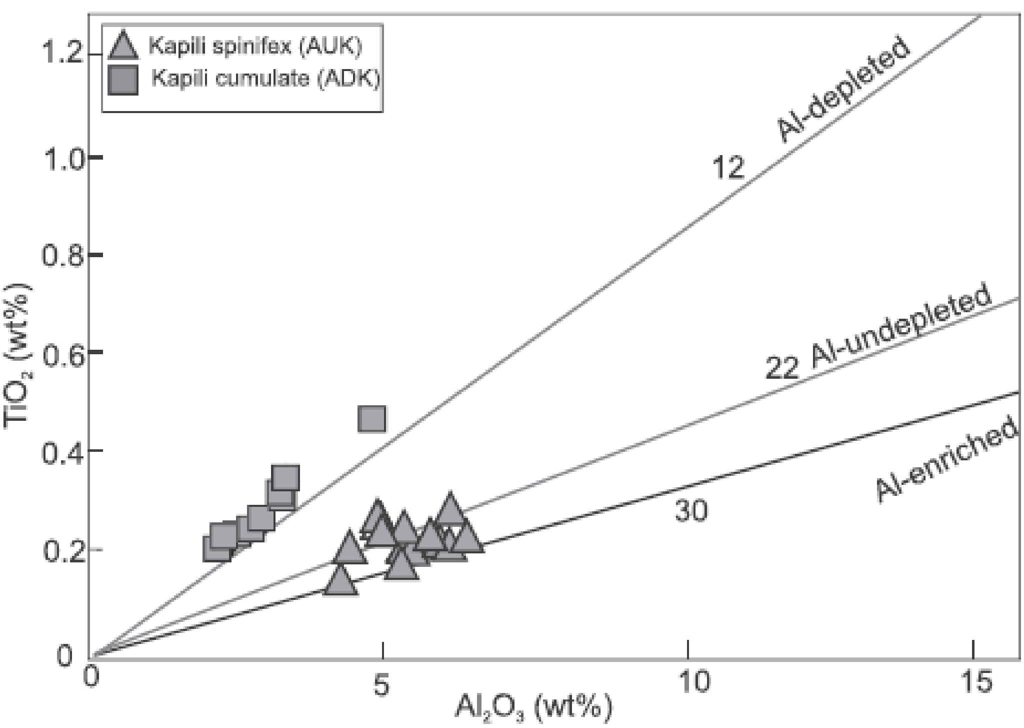


Fig 4: TiO_2 vs Al_2O_3 of Kapili komatiitic flow (Data from Chaudhuri et al. 2017, after Nesbitt et al., 1979

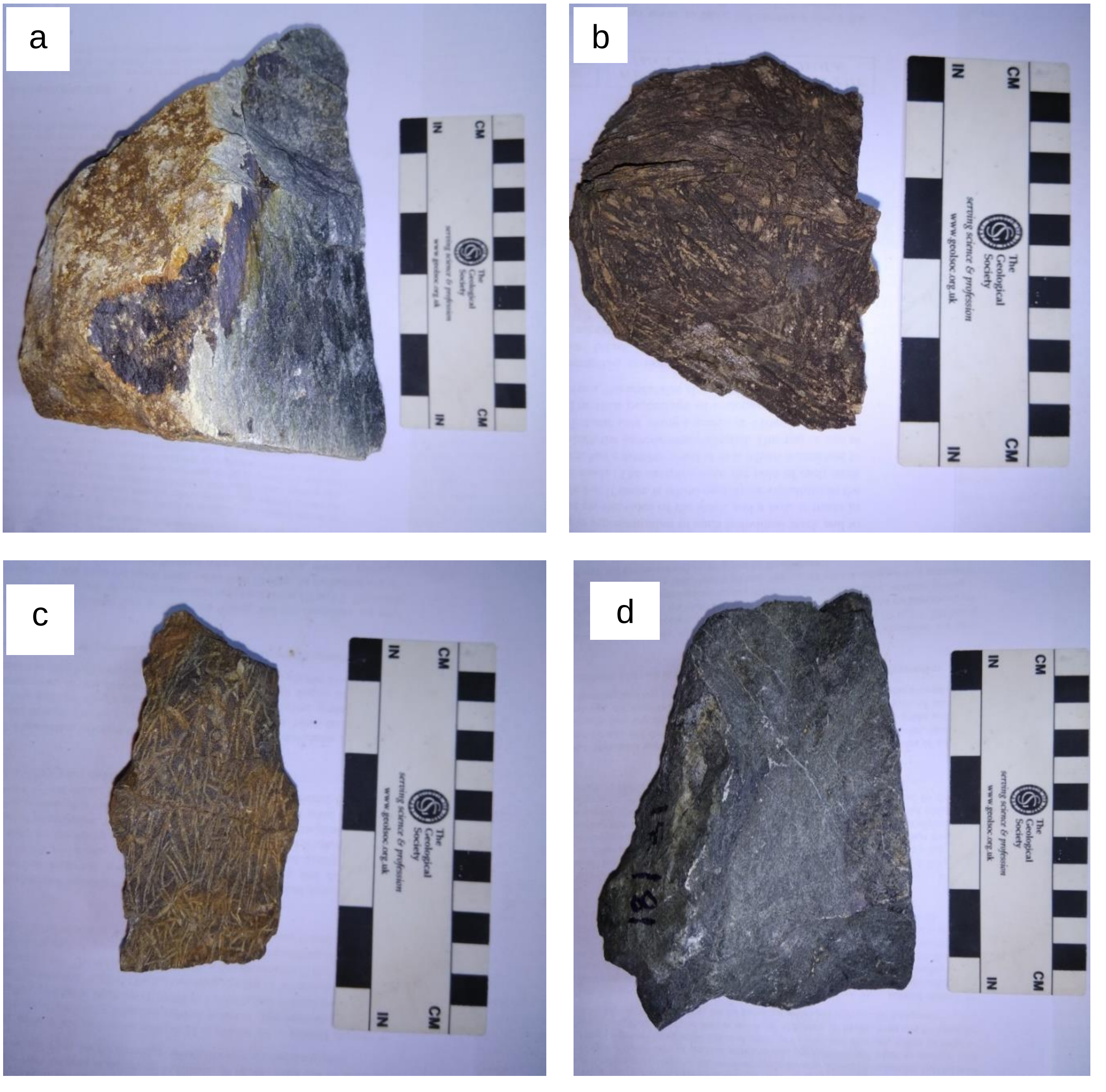


Fig 5: Representative samples of different rock types. (a) Serpentinized peridotite; (b,c) Spinifex-textured komatiites; (d) Metabasalt

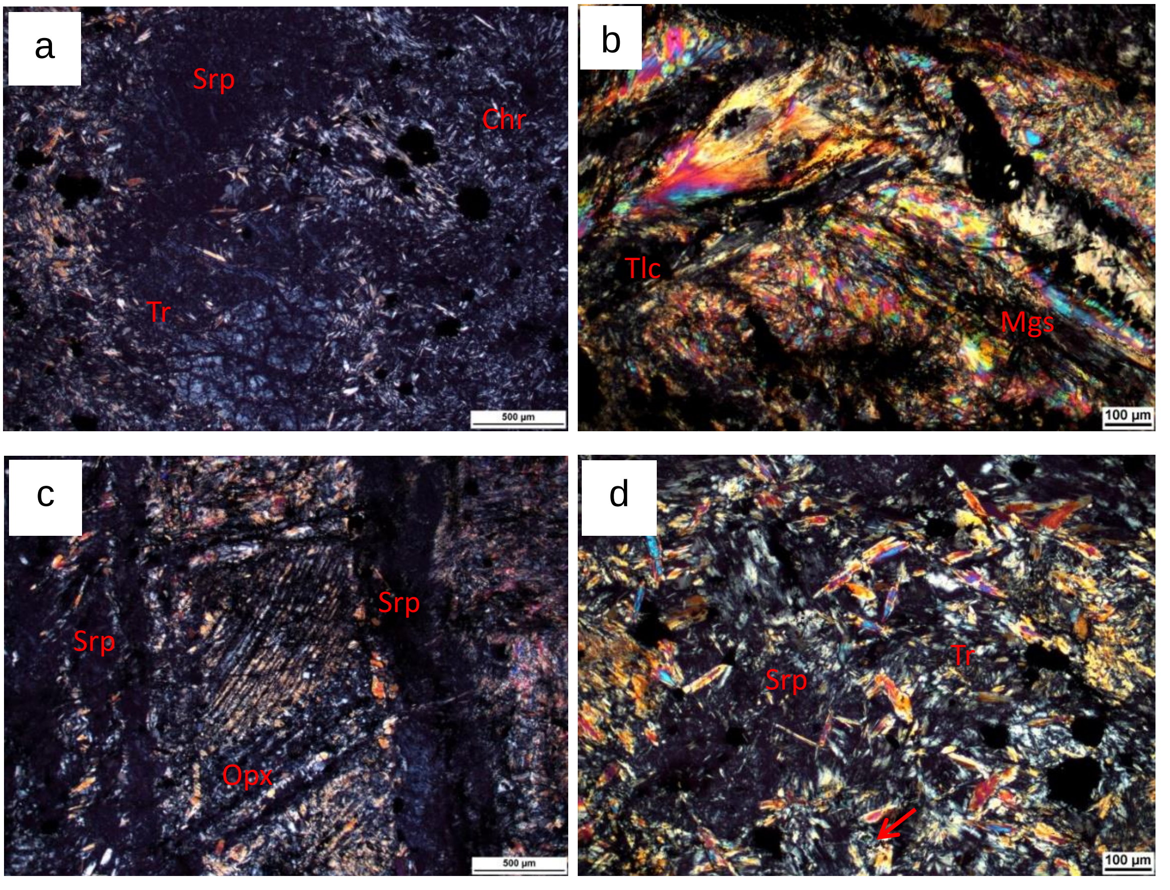


Fig 6: Photomicrographs of komatiite samples. (a) Alternate regions of olivines (altered to serpentine, magnetite and talc) and pyroxenes (altered to tremolite and chlorite); (b) Talc pseudomorphs cut across by serpentine and magnesite veins; (c) Platy spinifex-textured orthopyroxene (partially altered to tremolite and chlorite) surrounded by thick veins of serpentine. (d) Tremolite grains with well-defined boundaries cut across serpentine bands

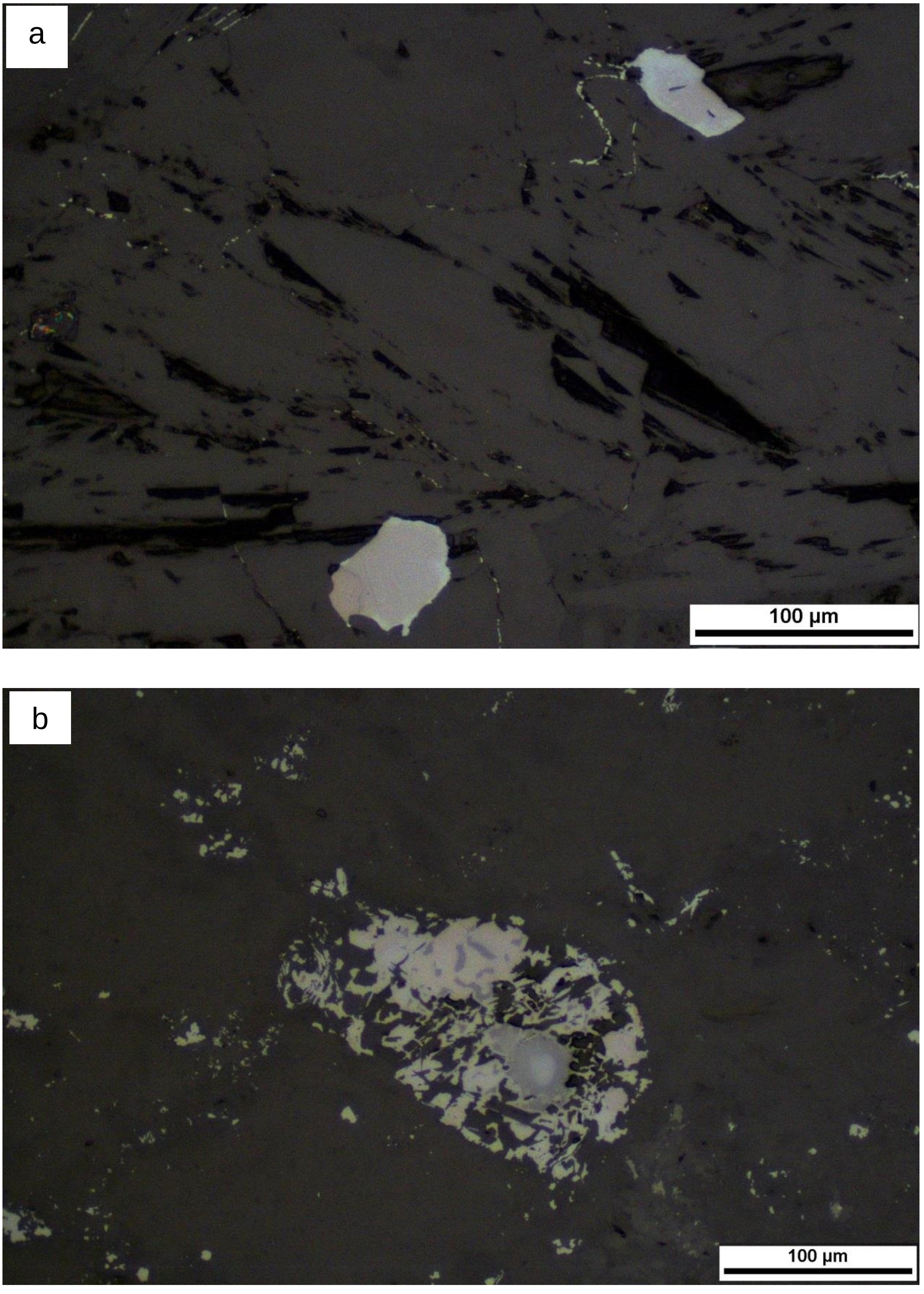


Fig 7: Photomicrographs of chromites in: (a) Cumulate rocks; (b) Spinifex-textured komatiites; under reflected light

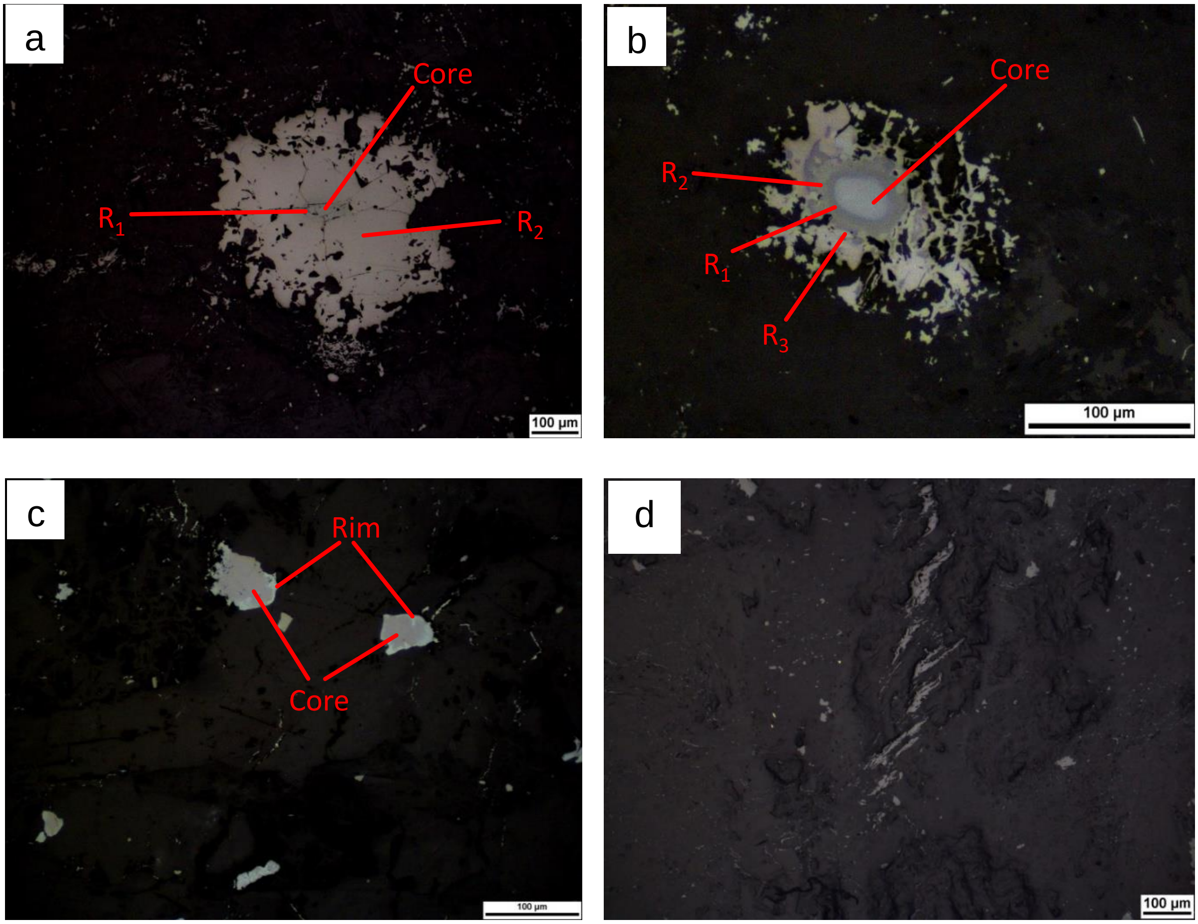
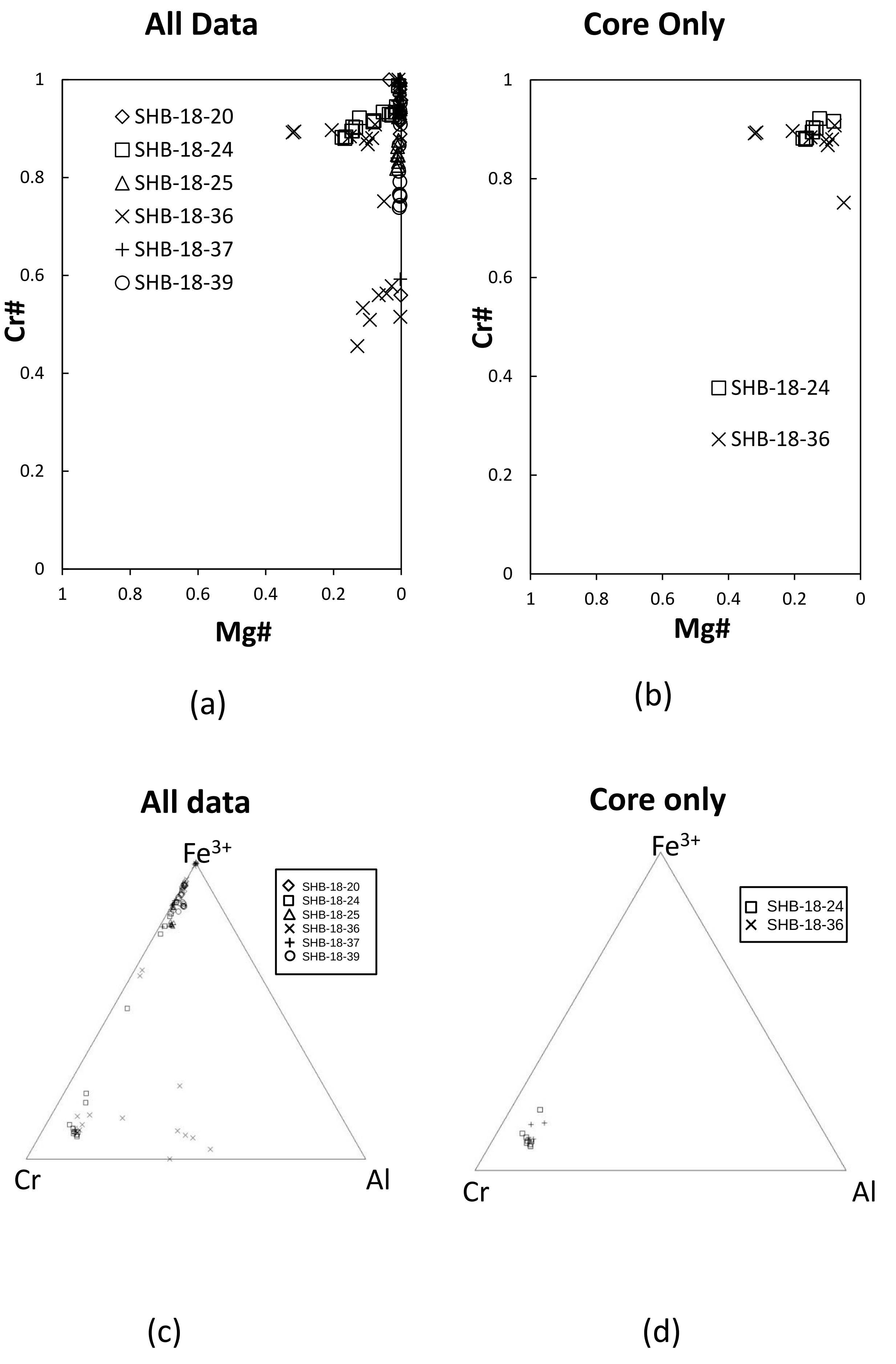
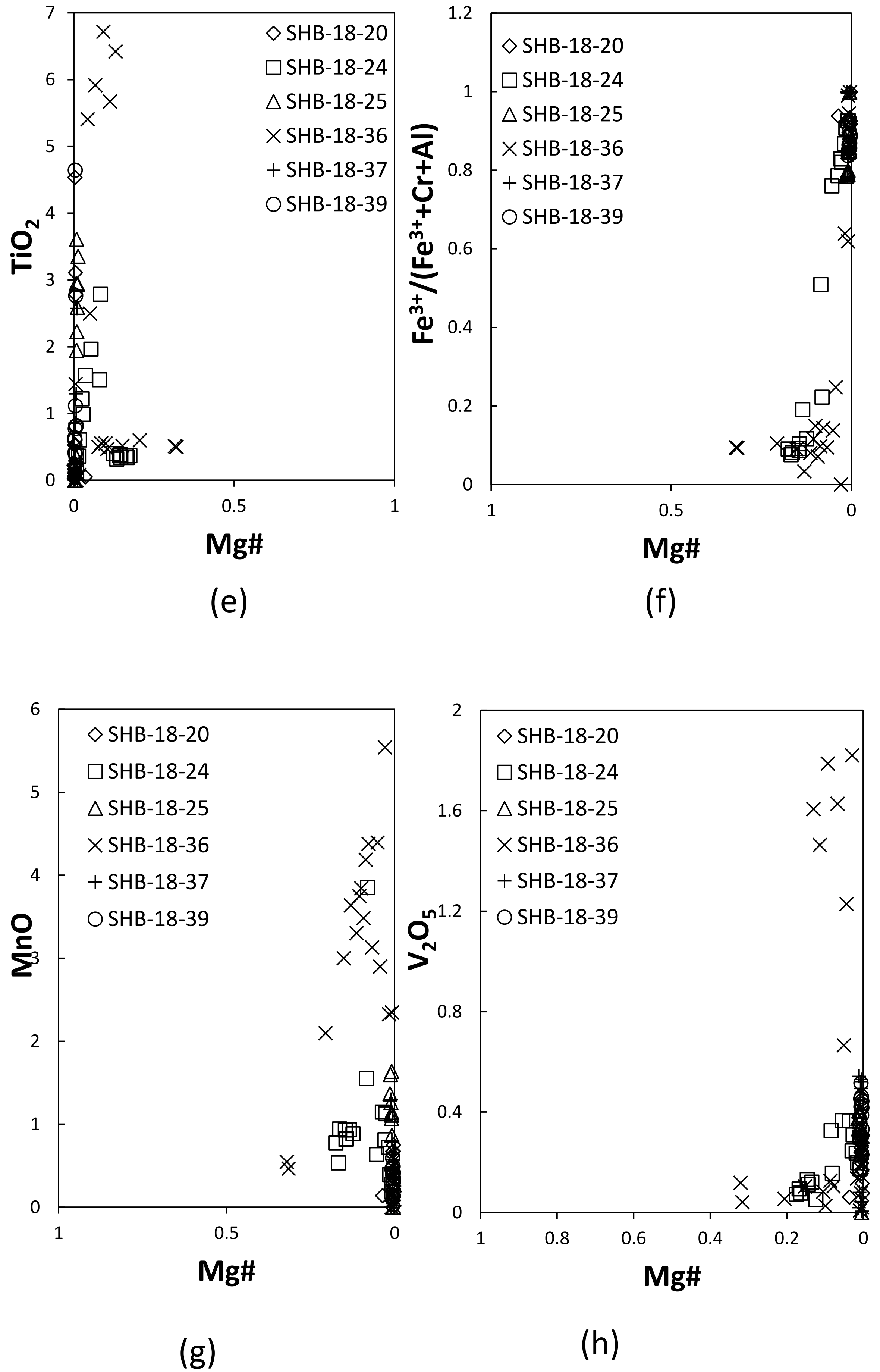
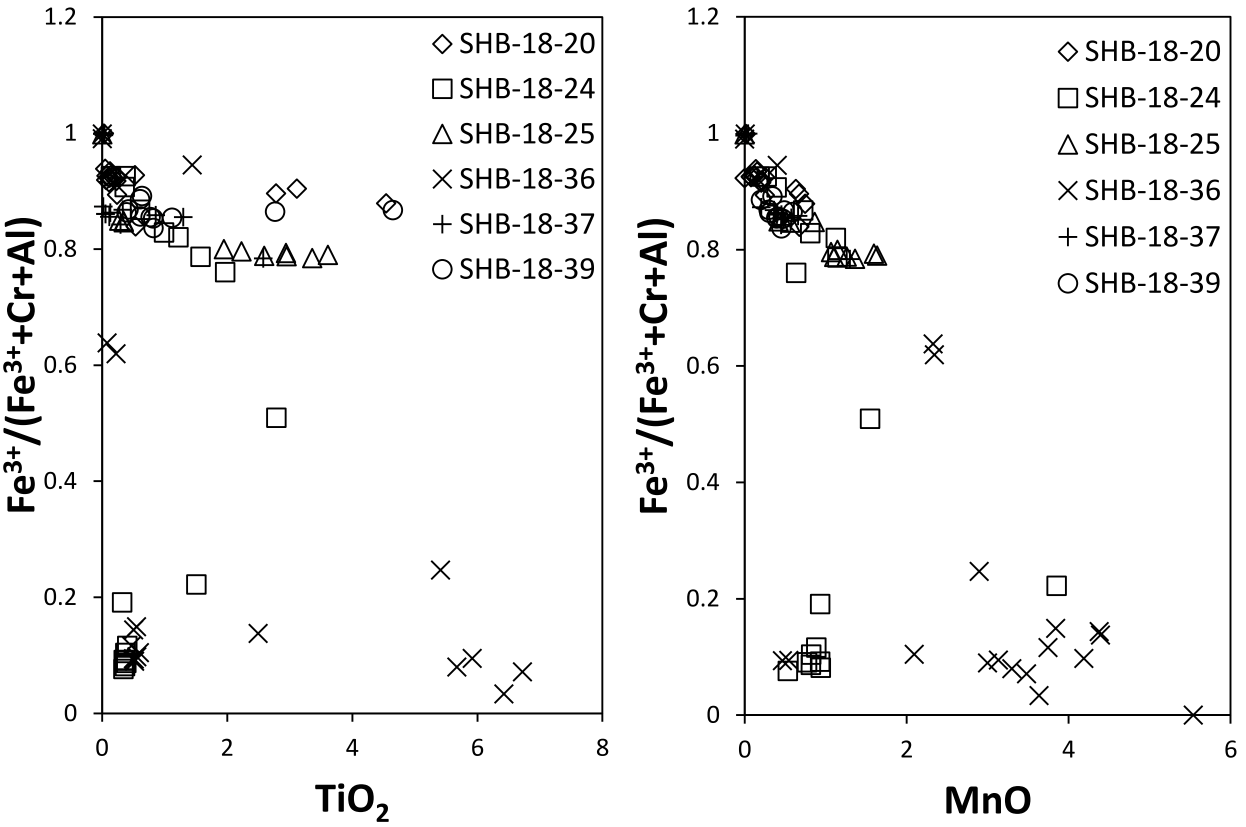


Fig 8: Photomicrographs of: (a) Type A chromite; (b) Type B chromite; and (c) Type C chromites; (d) Ilmenite


All Data
Core Only
SHB-18-20
SHB-18-24
SHB-18-25
SHB-18-36
SHB-18-37
SHB-18-39
Cr#
Mg#
(a)
(b)
All data
Core only
Fe3+
Cr
Al
(c)
(d)



TiO2
Mg#
Fe3+/(Fe3++Cr+Al)
MnO
V2O5
SHB-18-20
SHB-18-24
SHB-18-25
SHB-18-36
SHB-18-37
SHB-18-39
(e)
(f)
(g)
(h)



(i) (j)

Fig 9: Variational diagrams for all chromite compositions. (a&b) Cr# vs Mg#: Altered chromites have higher Cr# but lower Mg#. (c&d) Fe^{3+}-Cr-Al ternary : Altered chromites plot on Fe^{3+}-Cr line near Fe^{3+} apex, while core chromites plot near Cr apex. (e, f, g, h) TiO2, Fe^{3+}#, MnO and V2O5 plots against Mg#: TiO2, , Fe^{3+}# and MnO show negative relation with Mg#, and V2O5 show variable relation with Mg#. (i, j) Fe^{3+}# plotted against TiO2 and MnO: Fe^{3+}# shows negative relation with both TiO2 and MnO.

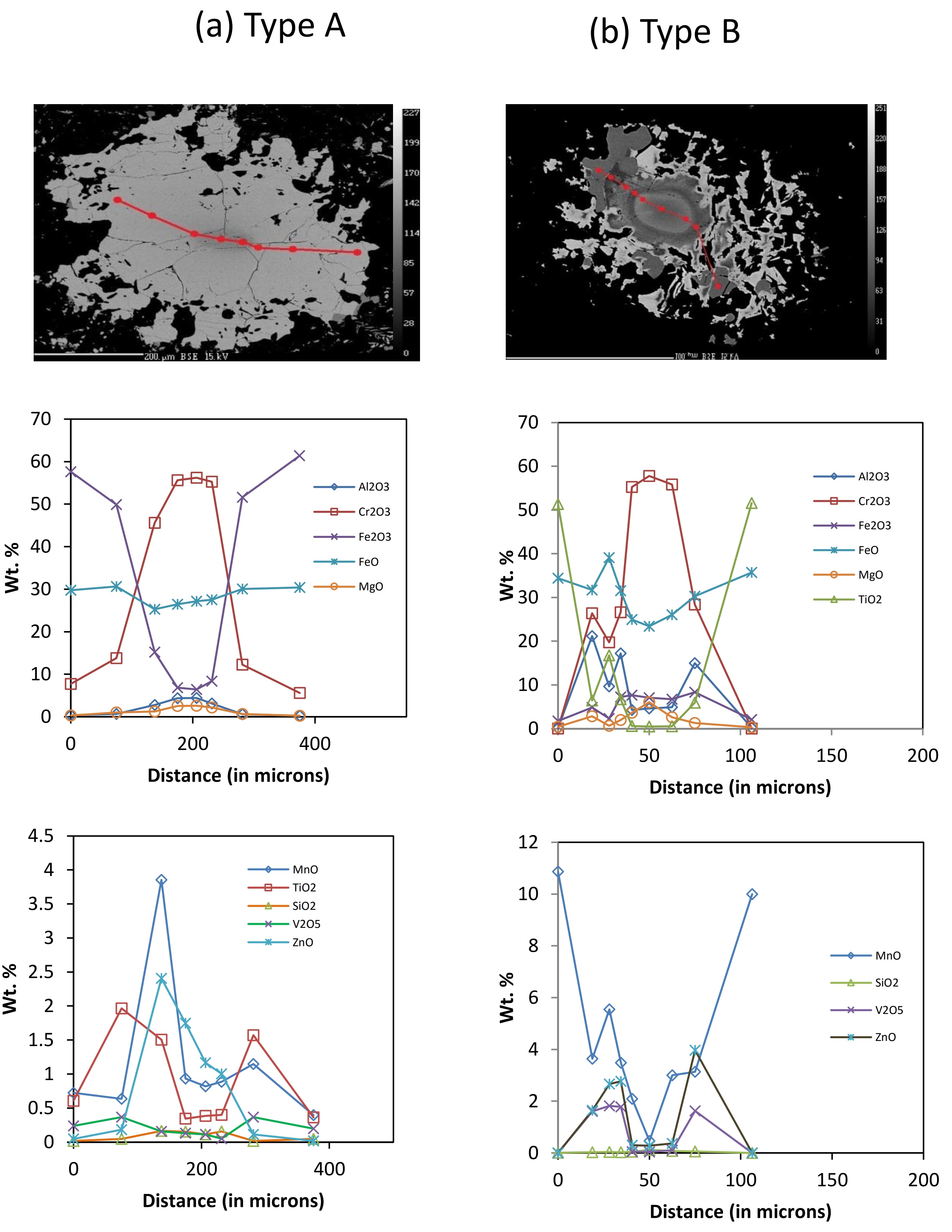


Fig 10: Compositional variations of major and minor elements across rimmed chromites