J. Ind. Geophys. Union (May 2018)
v.22, no.3, pp: 325-332

Petrology, mineral chemistry and geochemistry of the chromian muscovite bearing quartzite in the Neoarchean Veligallu schist belt, eastern Dharwar craton, India

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ABSTRACT

In the present study, we report on the petrography, mineral chemistry and geochemistry of the chromian muscovite bearing quartzite in the Neoarchean Veligallu schist belt (VSB), eastern Dharwar craton, India. The quartzites appear as greenish isolated outcops within the metavolcanic sequences in the north-central part of the VSB. Mineralogically, the rock consists of quartz and subordinate muscovite, while zircon and rutile are noticed as accessory heavy minerals. Mineralogical composition of the muscovite indicates a maximum chrome content upto 4000 ppm. The average (n= 5) bulk-rock geochemical compositions consist of > 85 wt. % SiO_2, ~2.2 wt. % K_2O, ~0.21 wt. % Na_2O, ~6.3 wt. % Al_2O_3, ~0.22 wt. % TiO_2, and ~0.29 wt. % MgO contents. Archean upper continental crust normalized trace element patterns indicate positive Zr and Hf anomalies, consistent with the accumulation of zircon in the rock. Petrographic observations are inconsistent with a metamorphic origin for the enrichment of chrome in these quartzites. Geochemical atttributes involving Ni-V-Th systematics suggest contribution of Ni from ultramafic rocks in the source of the protolith. Alternatively, we infer a hydrothermal origin for the enrichment of chrome in the muscovite bearing Veligallu quartzites. The geochemical compositions, for instance, high silica and the absence of Fe_2O_3 in the rocks indicate that the protolith was derived from the weathering of a felsic source, presumably an archean granite / TTG.

Key words: Cr-muscovite, Quartzite, Neoarchean, Veligallu schist belt, eastern Dharwar craton, India.

INTRODUCTION

Chromian muscovite quartzite "Fuchsite" is known to occur in high and low grade metamorphosed volcano-sedimentary sequences of Meso- and Neo-archean schist belts in the western Dharwar craton, India (e.g. Argast, 1995). The reference to the occurrence of such metasedimentary rocks in the Archean schist belts of the eastern Dharwar craton (EDC) is reported by GSI (Srinivasan et al., 1985). In the present study, we report on the petrography, mineral chemistry, and bulk-rock geochemistry of the chrome bearing muscovite quartzites from the Neoarchean Veligallu schist belt. (Figure 1).

Geological Setting

The VSB is located in the eastern Dharwar craton, and south of the Proterozoic Cuddapah basin (Figure 1A; Srinivasan et al., 1985). The belt broadly exhibits a N-S trend with an approximate strike length of ~ 60 km, and a maximum width of ~ 6 km in the central part (Figure 1B; Srinivasan, 1990). The volcano-sedimentary sequence was subjected to greenschist to lower amphibolite grade metamorphism. The metamorphism of the volcanic units is presumed to be synchronous with the first generation (F1) folds preserved in the rocks (Ramam and Murty, 1997). The metavolcanic lithologies constitute of arc basalt – high Mg-andesite – adakite suite (Khanna et al., 2015) and boninite-type ultramafic arc cumulates (Khanna et al., 2016), associated with banded iron formations (BIFs) and metasediments. The mafic-ultramafic and felsic rocks in the VSB yielded a bulk-rock Lu-Hf isochron age of 2696 ± 54 Ma (Khanna et al., 2016), which is identical to the zircon SIMS U-Pb age derived for the felsic volcanic rocks from elsewhere in the belt (2697 ± 5 Ma; Jayananda et al., 2013). Geochemically an identical suite of metavolcanic sequence is preserved in the Gadwal schist belt, which is located north of the Cuddapah basin. Recently, on the basis of identical geochemical patterns and bulk-rock Lu-Hf isotope systematics, Khanna (2017) has proposed a potential cogenetic link between the Veligallu and Gadwal schist belts. The above studies indicate that the metavolcanic rocks were produced in a subduction-related geodynamic setting in the Neoarchean. The focus of this study is to present a report on the petrological characteristics of chromian muscovite quartzites in the Veligallu schist belt (Figure 1C), eastern Dharwar craton, India.

Sampling and Analytical Techniques

Five representative least altered relatively fresh unweathered quartzite samples were collected from the central part

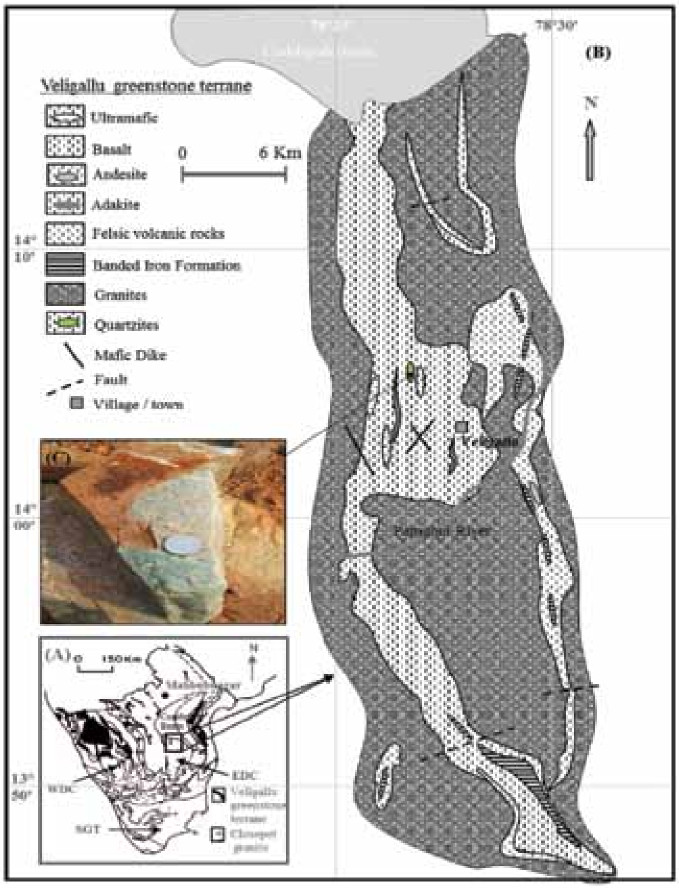

Figure 1. **(A)** Simplified geological map of the southern peninsular India comprising of three major tectonic blocks: the western Dharwar craton (WDC), the eastern Dharwar craton (EDC) and the southern granulite terrane (SGT). Also shown in the box is the location of Veligallu greenstone belt in the eastern Dharwar craton; **(B)** Generalized geological map of the Veligallu greenstone belt, modified after Srinivasan (1990); **(C)** Field photograph of the Veligallu quartzite that exhibits a typical green colour.

of the VSB (Figure 1). Megascopically, the rocks appear fine grained and green in color (Figure 1C). The mineral compositions (Table 1) were determined by electron probe microanalysis on a CAMECA SX-100 at the Petrology Division, Geological Survey of India, Hyderabad, India. A 20 nA beam current and an accelerating voltage of 15 keV were maintained with a focused beam. Certified natural silicate standards supplied by P&H were used for the instrument calibration. The corrections for ZAF were applied online by the instrument software.

Ten major element oxides, Cr, and Ni were analyzed using pressed powder pellets, on a Philips MagiX PRO PW2440; microprocessor controlled, wavelength dispersive sequential XRF (Table 2). The relative standard deviation for the major element oxides is < 3%. Trace elements (Table 2) including large ion lithophile elements (LILE), high field strength elements (HFSE) and rare earth elements (REE) were determined by high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS; Nu Instruments Attom®, UK). The detailed procedures relating to sample dissolution, analytical methodology and instrument parameters are described in Khanna et al. (2015, 2016). In brief, 50 mg of finely ground sample powder was digested in a freshly prepared mixture of ultrapure grade acids (HF $+HNO_3$) taken in 3:1 ratio in screw top Teflon "Savillex" vessels, and heated on a hot plate at 160°C. Certified reference material GSR-4, was dissolved simultaneously following the method described above and analyzed along with the samples. Precision and accuracy are better than RSD 3% for the majority of trace elements.

RESULTS AND DISCUSSION

Field relationship

Field observations indicate that the greenish quartzite occurs as low lying "isolated" outcrops, within the mafic-ultramafic rocks in the north-central part of the VSB. To the west of Tumukunta, the quartzite occurs proximal to the shear zone (Figure 2). Two sets of structural fabric are noticed in the quartzite (i) NNE-SSW foliation is the major structural fabric in the rock, and (ii) E-W

Table 1. Compositions of Cr-muscovite in the Veligallu quartzite, eastern Dharwar craton, India. Compared to Fuchsite and Mariposite in the literature.

							Average	Fuchsite#	Mariposite#
SiO2	46.20	45.81	46.22	46.58	46.42	45.62	46.14	45.97	56.00
TiO2	0.35	0.19	0.46	0.45	0.38	0.15	0.33	-	-
Al2O3	34.97	35.05	34.31	34.86	35.25	34.75	34.87	31.67	23.52
Cr2O3	0.17	0.12	0.13	0.10	0.08	0.39	0.16	4.81	0.78
FeO	0.43	0.33	0.41	0.34	0.36	0.32	0.36	0.53	0.51
MnO	0.00	0.02	0.01	0.01	0.02	0.03	0.01	-	-
MgO	0.67	0.52	0.69	0.58	0.45	0.61	0.59	0.31	2.12
CaO	0.00	0.03	0.00	0.00	0.00	0.04	0.01	0.15	0.37
Na2O	1.27	1.28	1.20	1.32	1.34	1.15	1.26	1.03	2.72
K2O	9.42	9.59	9.43	9.45	9.26	9.43	9.43	9.07	7.03
Total	93.48	92.94	92.86	93.70	93.56	92.49	93.17	93.54	93.05
Number of ions on the basis of 24 oxygens									
Si	6.79	6.77	6.83	6.82	6.80	6.79		7.08	8.15
Al	1.21	1.23	1.17	1.18	1.20	1.21		0.92	-0.15
Al	4.84	4.88	4.81	4.83	4.88	4.88		4.83	4.18
Ti	0.04	0.02	0.05	0.05	0.04	0.02		0.00	0.00
Fe(ii)	0.05	0.04	0.05	0.04	0.04	0.04		0.07	0.09
Mn	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
Mg	0.15	0.12	0.15	0.13	0.10	0.14		0.07	0.46
Ca	0.00	0.00	0.00	0.00	0.00	0.01		0.02	0.06
Na	0.36	0.37	0.34	0.38	0.38	0.33		0.31	0.77
K	1.77	1.81	1.78	1.77	1.73	1.79		1.78	1.31
Total	15.21	15.24	15.19	15.19	15.18	15.21		15.09	14.87

Whitmore et al. (1946)

Table 2. Major and trace element concentrations in the Veligallu Cr-quartzite.

	VDT-25	VDT-26	VDT-27	VDT-28	VDT-30
SiO2	88.34	93.44	85.83	93.20	92.75
TiO2	0.26	0.15	0.34	0.14	0.22
Al2O3	8.0	4.2	9.8	4.6	4.7
Fe2O3	*nd*	*nd*	0.06	*nd*	0.02
MnO	*nd*	*nd*	*nd*	*nd*	*nd*
MgO	0.37	0.26	0.40	0.21	0.21
CaO	0.06	0.05	0.05	0.05	0.05
Na2O	0.25	0.10	0.38	0.14	0.16
K2O	2.7	1.8	3.1	1.7	1.8
P2O5	0.03	0.02	0.03	0.02	0.02
Mg#			0.93		0.95
Cr	311	323	367	344	282
Ni	78	77	90	82	82
Rb	32	19	36	17	23
Sr	23	11	27	12	14
Cs	1.55	0.90	1.22	0.59	0.91
Ba	729	345	1047	534	468
Sc	4.5	1.9	3.3	1.3	2.4
V	38	20	53	23	24
Ta	0.50	0.38	0.65	0.36	0.48
Nb	7.09	4.02	7.33	4.36	5.88
Zr	333	341	404	331	319
Hf	9	10	11	9	9
Th	12.0	9.7	9.9	12.2	11.6
U	1.9	1.7	1.7	1.4	2.0
Y	6.1	5.2	5.4	4.0	5.0
La	33.59	24.89	42.87	34.14	29.15
Ce	54.92	41.04	68.09	56.40	38.34
Pr	5.63	4.20	6.77	5.61	5.19
Nd	17.82	13.52	21.01	17.91	17.15
Sm	2.72	2.13	2.97	2.67	2.68
Eu	0.37	0.26	0.56	0.30	0.32
Gd	1.99	1.58	2.12	1.88	1.88
Tb	0.29	0.24	0.28	0.25	0.26
Dy	1.31	1.08	1.20	1.02	1.09
Ho	0.23	0.19	0.20	0.16	0.19
Er	0.59	0.51	0.51	0.37	0.47
Tm	0.10	0.09	0.08	0.06	0.07
Yb	0.63	0.56	0.53	0.37	0.46
Lu	0.11	0.10	0.10	0.07	0.09

nd = not detected

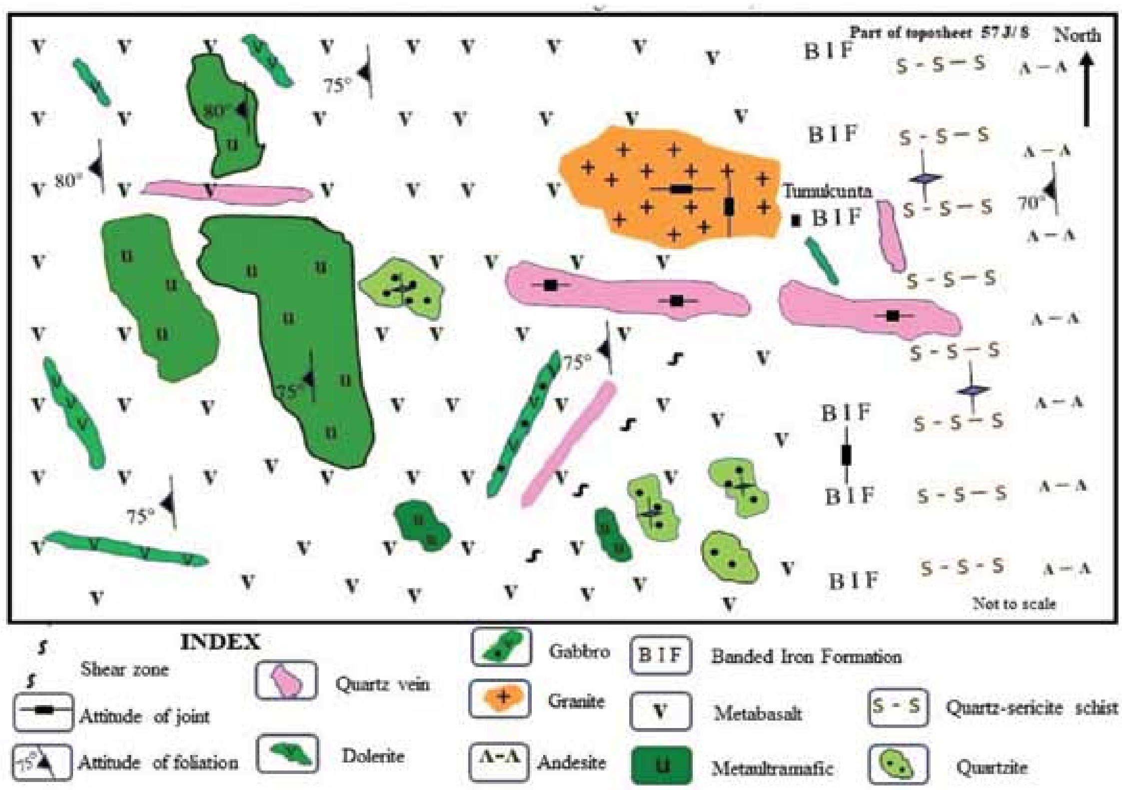

Figure 2. Geological map of the area around Thumkunta showing the disposition of the quartzile and metapelite within the metavolcanics rocks in the neoarchean Veligallu schist belt, eastern Dharwar craton.

warps. The structural fabric noticed in the quartzite has foliation in vertical to subvertical. The field disposition apparently indicates that the quartzites exhibit a discordant relationship with the metavolcanic sequence of the VSB. Incidentally the quartzite outcrops discussed in the present study are located to the north of Bandirevu.

Petrography

The Veligallu quartzite predominantly consisit of quartz with subordinate muscovite. Rutile and zircon are noticed as accessory heavy minrerals. Quartz grains are sub-rounded / sub-angular and exhibit wavy extinction. The rocks exhibit distorted cleavage in muscovite and show serrated grain boundaries in quartz, which indicates deformation. Development of planar fabric is also noticed. Muscovite occurs as large flakes as well as randomly oriented minute aggregates amidst deformed quartz grains. The planar fabric noticed in the quartzite is defined by the orientation of large muscovite flakes. Elongated quartz grains are often aligned parallel to the muscovite flakes. Under plane polarized light, muscovite appears pale green in colour (Figure 3A). It exhibits high order interference colors when observed under crossed nicols (Figure 3B and E). Rutile mostly occurs as minute oval shaped grains that range in size from ~200 μm to ~250 μm, and appears reddish brown in color. It exhibits high relief in plane polarized light (Figure 3C), and displays straight extinction under crossed nicols (Figure 3D). Some of the rutile grains are dismembered due to microscale displacement (Figure 3F). Zircons occur as oval shaped grains (Figure 3G and F) with smooth boundaries, and range in size from 50 μm to 80 μm. It exhibits high relief in plane polarized light (Figure 3G), apart from anisotropy with high order interference colors under the crossed nicols (Figure 3H). Both, rutile and zircon are ultra stable detrital heavy minerals. Perhaps, the euhedral nature of the zircon grains suggests lesser degree of transportation and hence, proximal to the provenance. Zircon is the dominant heavy mineral in the rock with the zircon : rutile ratio of nearly 70 : 30. Morphology of the detrital zircon indicates the preservation of the elongated prismatic nature with by and large smooth grain boundary (Figure 3G, H).

Mineral chemistry and nomenclature of the muscovite

Muscovite in the Veligallu quartzite consists of ~ 46 wt. % SiO_2, ~ 35 wt. % Al_2O_3, ~ 1 wt. % Na_2O, ~ 9 wt. % K_2O and a maximum of ~ 0.4 wt. % (= 4000 ppm) Cr_2O_3 with minor FeO (~ 0.32 wt. %) and MgO (~ 0.6 wt. %) contents (Table 1). As such, muscovite is essentially a potassium-aluminium sheet silicate that does not comonly

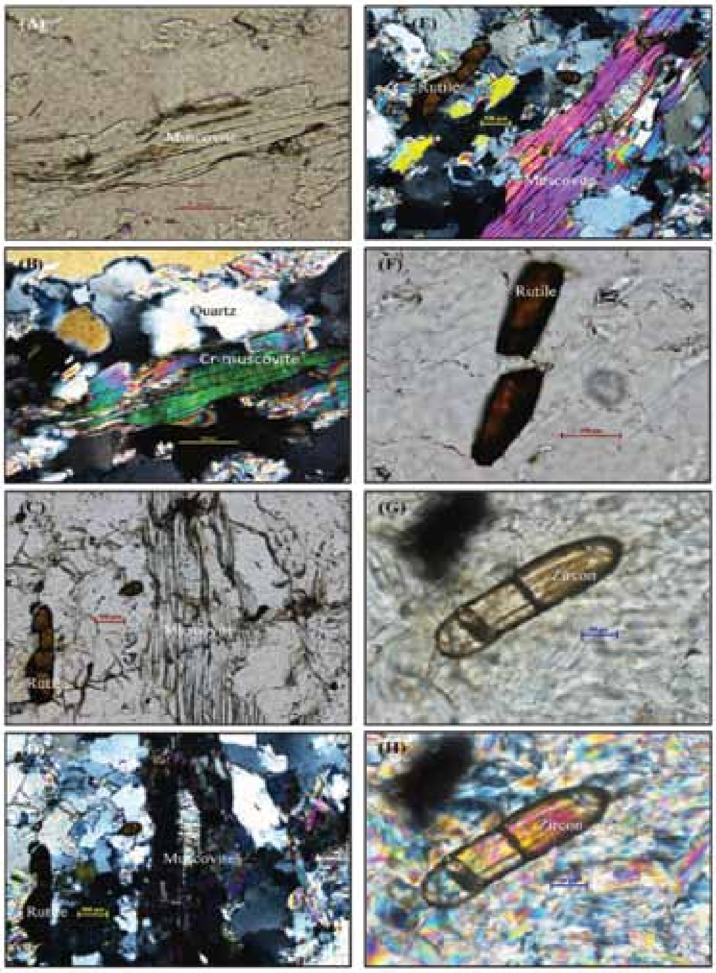

Figure 3. Photomicrograph of the Veligallu quartzite, under **(A)** plane polarized light, and **(B)** crossed nicols, showing quartz and muscovite; **(C)** rutile grains exhibit reddish brown pleochroism, and (**D and E**) straight extinction under crossed nicols; **(F)** dismembered grains of rutile; Oval shaped detrital zircon grains in the quartzite are shown under **(G)** plane polarized light, and **(H)** under crossed nicols. See text for details.

sequester chromium. Chrome bearing micas, where Al is partially replaced by Cr, are recognized as fuchsite and mariposite, although the varietal name "chromian muscovite" is generally preffered (Whitmore et al., 1946). The chromium contents in the fuchsite range from 8400 ppm to about 40000 ppm. Whereas, mariposite consists of relatively low concentrations of chrome ~1800 ppm to 7800 ppm. In comparison to the fuchsite, the green muscovite in the Veligallu quartzite consists of identical SiO_2, Al_2O_3, Na_2O and K_2O contents, but low chromium (Table 1). On the contrary, SiO_2, MgO and Na_2O are considerably high, and Al_2O_3 is typically low in the mariposite compared to the muscovite in the Veligallu quartzite, or a fuchsite (Table 1). On this basis, the muscovite in the veligallu quartzite does not qualify as mariposite. Alternatively, the chromium content in the muscovite is, however, not sufficiently high to be called as fuchsite either. Therefore, we only recognize the muscovite as "chromian muscovite" and hence, the name chromian muscovite quartzite for the bulk-rock samples.

Nature of chrome enrichment in the Veligallu quartzite

As noted by Heinrich et al., (1953), chrome bearing micas occur in either hydrothermal viens and replacement deposits, or regionally metamorphosed rocks e.g. schists, gneisses and quartzites. Leo et al., (1965) suggested that the probable mode of enrichment of chrome in the Serra de Jacobina quartzites, Brazil, may be due to : (1) breaking down of detrital chromite during regional metamorphism of clastic sandstones; and/or (2) hydrothermal leaching of chromium from nearby ultramafic rocks.

As such, we made an attempt to validate the above probable modes of chrome enrichment in the quartzites of VSB. Petrographic observations (Figure 3) indicate that quartz and muscovite are the only major mineral constituents, with zircon, and rutile as the predominant detrital heavy minerals. The quartzites are necessarlily devoid of chromite. Therefore, breaking down of detrital

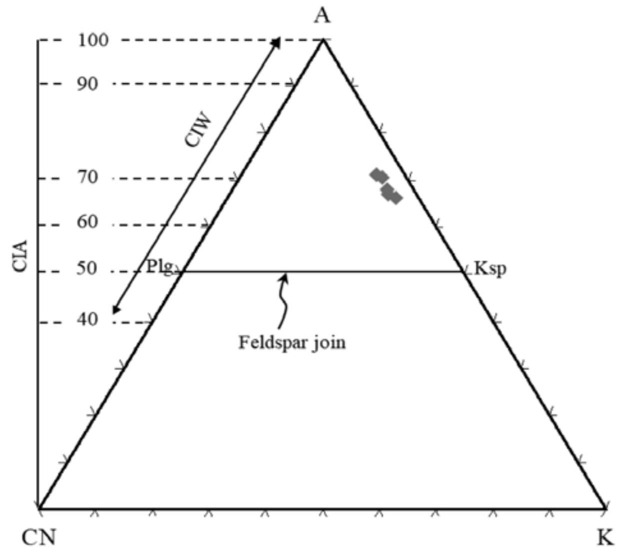

Figure 4. A-CN-K diagram of Fedo et al., (1995) plotted for the Veligallu quartzites. Also shown are the CIA values that are consistent with intermediate degree of weathering of the source rock.

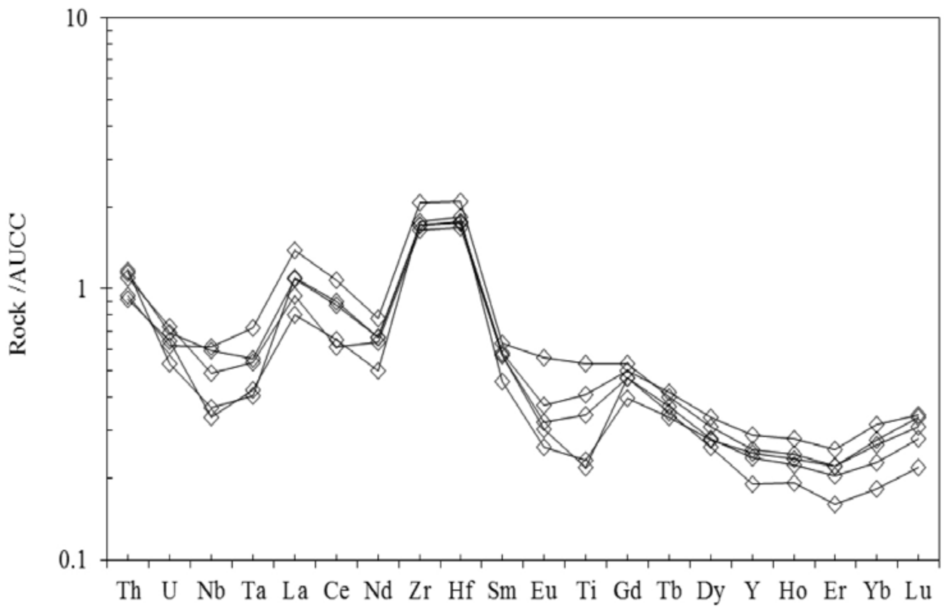

Figure 5. Archean upper continental crust (AUCC; Rudnick and Gao, 2004) normalized trace element variation diagram for the Veligallu quartzites.

chromite during regional metamorphism of the protolith cannot account for the chrome enrichment in the Veligallu quartzite. Moreover, the muscovite flakes are confined to the grain boundaries of quartz, and do not penetrate through the grains as a consequence of metamorphism, which is unlike that observed in the rocks of Montana (Heinrich, 1965), therefore, inconsistent with a metamorphic origin of the chromian muscovite in the Veligallu quartzite. Instead we infer metasomatic origin for the enrichment of chrome in the Veligallu quartzites (discussed below).

Geochemistry

The bulk-rock geochemical composition of the Veligallu quartzites is given in Table 2. The high silica contents (85 to 93 wt. %) in these quartzites indicates that the premetamorphosed rock was a siliciclastic rock. The titanium content is contributed by rutile, and K_2O and Al_2O_3 conentrations essentially reflect the presence of muscovite in these rocks. The chemical index of alteration (CIA = [molar $Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)$] x 100;

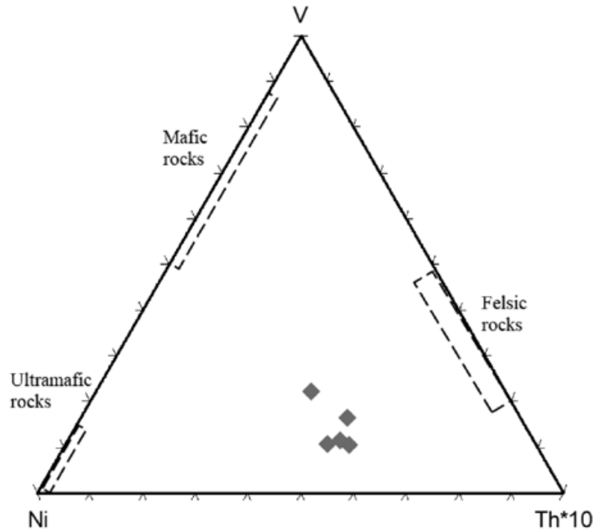

Figure 6. Ni-V-Th diagram of Bracciali et al., (2007) plotted for the Veligallu quartzites. See text for details.

Nesbitt and Young, 1982) values in the Veligallu quartzites range from 66 – 71 with an average value of 68, which indicates intermediate degree of chemical weathering of the source rock (Figure 4; cf. Fedo et al., 1995). The Veligallu quartzites exhibit prominent enrichment in their Zr-Hf relative to the Archean upper continental crust (Figure 5), which is consistent with the accumulation of detrital zircon in these rocks.

On the basis of bulk-rock geochemical concentrations, for instance, high silica contents in combination with extremely low MgO, CaO, Sc, V, and absence of Fe_2O_3, we infer that the weathered source rock must be felsic in nature, which we presume to be an Archean granite / TTG. The quartzites plot in-between the ultramafic and felsic source compositions in a triangular variation diagram involving Ni-V-Th (Figure 6; Bracciali et al., 2007), which is consistent with the regional geological setup wherein the quartzites are spatially associated with the ultramafic rocks, and that the Ni contents observed in the Veligallu quartzites were contributed from the ultramafic rocks. The chrome contents in the Veligallu ultramafics range from 2290 to 3784 ppm (Khanna et al., 2016). Therefore, it is a potential possibility that the chromium and nickel from the ultramafic rocks might have been leached by the hydrothermal solutions that precipated it in the quartzites. Thus, hydrothermal leaching of chrome from the spatially associated ultramafics appears to be a likely hypothesis for the origin of chromian muscovite in the Veligallu quartzite.

CONCLUSION

We make a report on the field occurrence, petrography, mineral chemistry and bulk-rock geochemistry of chromian muscovite bearing quartzite in the Veligallu greenstone belt, eastern Dharwar craton (EDC), India. The quartzites occur as pale grenish coloured isolated low lying outcrops within the Neoarchean mafic-ultramafic sequences in the areas to the west and south of Tumukunta in the Veligallu schist belt. The quartzites are proximally associated with the ultramafics. Petrographucally the rock is composed of quartz, pale greensih muscovite with detrital zircon an rutile. In a Ni-V-Th triangular variation diagram the Veligallu quartzites plot transitional to the ultramafic and felsic sources, thus suggesting the contribution of compatible mafic elements Ni and Cr from the juxtaposed ultramafic rocks in the VSB. Therefore, we infer that leaching of these ultramafic rocks by hydrothermal solutions resulted in the enrichment of chrome in the muscovite bearing Veligallu quartzites.

ACKNOWLEDGEMENTS

We are thankful to Dr. V.M. Tiwari, the Director, NGRI, for permission to publish this work. TCK acknowledges the Department of Science and Technology, Government of India, for funding the project SR/FTP/ES-7/2012 vide letter dated 09.05.2012; in-house classification GAP-682-28 (TCK). Drs. A. Keshav Krishna and M. Satyanarayanan are thankfully acknowledged for extending the XRF and ICP-MS analytial facility, respectively. VVSS is thankful to Shri. S.T. Narahari, Senior Geologist, EPMA lab, GSI Hyderabad, for extending the analytical facility. We express our sincere thanks to Dr. Santanu Bhattacharjee, GSI, for critical review and helpful suggestions.We also thank Prof. U.V.B. Reddy for useful suggestions. Dr. P.R. Reddy, is profusely thanked for continued support, and editorial handling of the manuscript.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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Received on: 29.12.17; Revised on: 21.1.18; Accepted on: 6.2.18