IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 6, Issue 4 Ver. I (Jul. – Aug. 2018), PP 21-27
www.iosrjournals.org

Compositional variation of Spinel from metamorphic rocks of Digapahandi area, Eastern Ghats Belt, India

Sagar Misra[1], Neeraj Vishwakarma[1]*
[1]*(Department of Applied Geology, National Institute of Technology Raipur, Raipur-492001, Chhattisgarh,India)*
** Corresponding Author: Neeraj Vishwakarma1**

Abstract: *Eastern Ghats Belt is a poly-metamorphic terrain, represents high to ultra-high temperature metamorphic condition. The temperature dominant metamorphism has proved by the presence of spinel bearing mineral assemblages like, spinel + quartz, spinel + sillimanite + cordierite, sapphirine + spinel etc. Present paper focus on spinel mineral chemistry, which present as a common phase in both leptynite and khondalite rocks around Digapahandi area of Eastern Ghats Belt. Petrographic observation confirms the presence of two different types of spinel in the rock. Coarse grain anhedral spinels are common in khondalites whereas in leptynites both euhedral and anhedral small spinels are present. EPMA analysis indicates that there is a distinct compositional variation in the spinel from both the rocks, although all the spinel falls under the category of Al-rich spinel series. These evidences clearly reflect that both the rocks have suffered diverse metamorphic history.*
Keywords: *Spinel, leptynite, khondalite, Eastern Ghats Belt, granulite.*

Date of Submission: 30-06-2018 Date of acceptance: 17-07-2018

I. Introduction

Spinel is a characteristic phase in high temperature metamorphic rocks as well as ultra-mafic igneous rocks and exhibits wide range of chemical composition in terms of Al, Cr, Fe and Mg elements. The Mn and Zn content may also present in small proportion. The ionic substitution of these elements are common corresponding to the available temperature-pressure conditions and source of materials (Farahat 2008). For this reason, spinel bearing mineral assemblages has confirmed their successful appliance to know the genesis of rocks. From igneous point of view spinels are Cr-rich whereas Fe-Mg content increases with respect to metamorphism and alterations. There are two types of metamorphic conditions which support the formation of spinel (1) contact metamorphism of Ca-rich rocks (Loomis 1972; Atkin 1978), (2) High grade Regional metamorphism of limestone and pelitic assemblages (Frost 1973; Wagner and Crawford 1975). Hercynite-Spinel solid solution phases are common in regional metamorphic rocks (Navrotsky and Kleppa 1968). In the Eastern Ghats Belt (EGB), spinels commonly occur in khondalites and leptynites. Khondalites are metapelitic rocks having garnet, biotite and sillimanite in its mineral assemblage along with subhedral to anhedral spinels. On the other hand leptynites are quartzo-felspathic rocks, in which small spinels occurs with garnet, biotite, staurolite and plagioclase. Evidence of ultra-high temperature metamorphism in the EGB has marked on the basis of mineral assemblage where sapphirine and Mg-Al spinel are important one.

The present study describes the occurrences of spinel in leptynites as well as khondalite of Digapahandi area of EGB and comparison of their mineral chemistry on the basis of EPMA analysis. Presences of spinel in leptynites with their diverse nature indicate the different metamorphic condition from khondalites.

II. Geology of The Area

The Eastern Ghats Belt is a high-grade, poly-metamorphic belt present in the eastern coast of India, trending in NE-SW direction. The Proterozoic EGB belt is surrounded by three Archean cratons such as, Singbhum in the north, Bastar in the west and Dharwar in the south. The main rock types present in the belt are charnockite, khondalite and migmatites. Migmatites including leptynites, gneiss, and pegmatite veins etc. On the basis of dominant lithology, Ramakrishna et al. (1998) proposed zonal classification for the belt, in which western charnockite zone (WCZ), western khondalite zone (WKZ), central migmatite zone (CMZ) and eastern khondalite zone (EKZ) present from west to east of the belt. Later on three more classification schemes, on the basis of structural and geo-chronological data, came into the existence. These are Terrane classification (Chetty 2001), Domain classification (Rickers et al. 2001) and Province classification (Dobmeier and Raith 2003). Deformation and metamorphism of the EGB is well correlated by Bhowmik (1997). The evidences of ultra-high temperature metamorphism have also been reported form the EGB (Bose et al. 2011; Das et al. 2011).

Digapahandi area of Ganjam district Odisha forms the eastern part of Eastern Ghats Province, where migmatites are present as dominant rocks whereas khondalites and charnockites present in small proportion. Migmatites of the area are classified as leptynites and are most abundant (Figure 1). Charnockites are present as massif bodies. Patchy charnockites are also present with in leptynites as small irregular patches. Khondalites are commonly present as small bodies within the leptynites at several places. The occurrences of spinel are evident in khondalites and leptynites (Figure 2a and 2b).

III. Petrography

In the area under investigations spinels from leptynites are marked as one group whereas spinels from khondalites marked as second group. In the former case, spinels are found to occur as small patches within leptynites, specially in the region where charnockite get in contact with leptynites. Here spinels are euhedral to subhedral in shape, coarse to fine grained with random orientation (Figure 3a). Whereas in the later case i.e khondalites, spinels are randomly distributed throughout. These spinels are coarse grained and anhedral in shape (Figure 3b). Reaction textures suggest that the spinels in khondalites are indicative of peak metamorphic condition that to be prograde in nature.

The common mineral assemblage of leptynites is quartz + feldspar + biotite + garnet $\pm$ spinel. Staurolite and ilmenite are also present at few places. Leptynites of the area generally exhibit inequigranular texture. Feldspars are present as porphyroblats. Garnet varies in size from fine to coarse grain which equally distributed all over the rock. Spinels are infrequently present as small randomly oriented; euhedral to subhedral grains and commonly occur as inclusions within the feldspar. This feature indicates towards the relict nature of the spinel minerals that represent pre-peak metamorphic assemblage. Myrmekitic intergrowth of feldspar is also common in leptynites.

Khondalites are characterized by strong schistosity. The mineral assemblages are sillimanite + biotite + garnet + spinel + feldspar + quartz $\pm$ ilmenite. The parallel arrangement of biotite and sillimanite develop the schistosity in the rock. Spinels are abundant and are found to occur as coarse grained with anhedral shape. Fractures are common in these spinels. At some places early formed quartz grains are present as inclusions within the spinel.

IV. Mineral Chemistry

In order to determine the chemical composition of spinel from both the rock types, EPMA analyses were carried out at Electron Probe Laboratory in IIT Bombay (India) by using Cameca SX Five electron micro probe, operating at 15 keV accelerating voltage and 20na beam current. The beam size of the instrument is 1 µm and dwell time for each analysis around three minutes. EPMA data are represented by the weight percentage of major oxides. Raw data of spinel are processed through the application End-Members Generator (EMG) of Ferracutti et al. (2015). All the calculations including the Fe_2O_3 calculation from FeO (Total), cation proportions and also end-members of spinel group minerals are calculated through the above mentioned application. The results of analysis are shown in the table 1.

The general formula of spinel group of minerals is X Y_2 O_4, where X represent Mg^{+2}, Fe^{+2}, Zn, Mn and Ni and Y represent Al^{+3}, Fe^{+3} and Cr^{+3}. Spinel group further subdivided in to three series as per the trivalent cat-ion in Y site (Deer et al. 1972). These are Spinel series (Al), Magnetite series (Fe^{+3}) and Chromite series (Cr). Among them, the spinels from the rocks of study area of EGB are marked as Al-rich spinel (Figure 4). As per the binary classification diagram (Deer et al. 1972) for spinel group of minerals, the spinel from leptynite falls under the hercynite variety whereas the spinel from khondalite belongs to the pleonaste variety (Figure 5). Hercynite-Spinel solid solution phases are common in the regionally metamorphosed rocks (Navrotsky and Kleppa 1968).

From EPMA analysis it is clear that the Al_2O_3 and MgO contents are higher in spinel from khondalites whereas the FeO^T and ZnO contents are higher in the spinel from leptynite rocks. The other contents are almost similar in spinel from both the rocks. Overall the Cr_2O_3 content is low in spinel from both the rocks and the value ranges from 0.01 to 0.13 wt%. The higher ZnO content of spinel (0.7 - 1.1 wt.%) in leptynites indicates that the substantial gahnite content is present in the spinel from leptynites. Similarly, the presence of high magnesium content in spinels from khondalite indicates towards the higher grade of metamorphism for khondalites as compared to leptynites (Oh et al. 2006). The X_{Mg} ratio is also higher in spinel from khondalite than leptynite. The Fe^{+3} versus Al as well as Fe^{+2} versus Mg binary plots (Figure 6a and 6b) for spinel from the study area indicates that the Al - Fe^{+3} and Mg - Fe^{+2} substitutions are also common in the spinel from both the rocks.

V. Figures and Tables

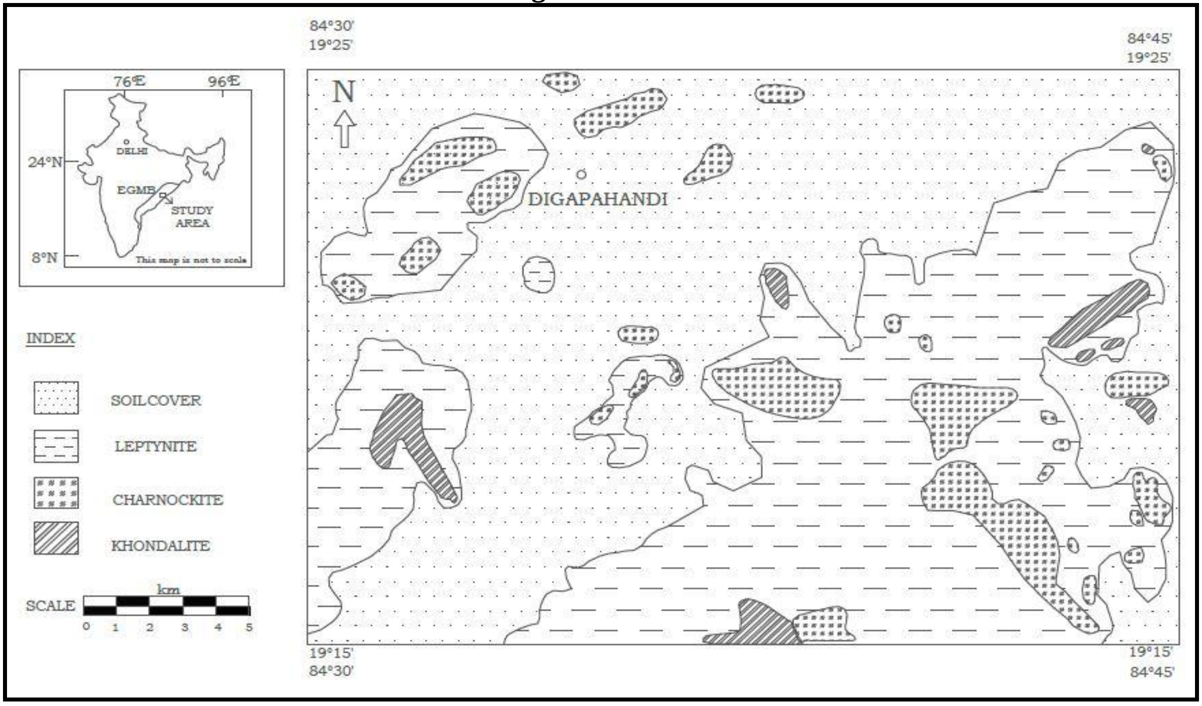

Figure 1 - Geological Map around Digapahandi area, District – Ganjam, Odisha, showing distribution of different rocks.

Figure 2 – Mode of occurrence of spinel. (a) Occurrence of small spinel bearing assemblages within leptynites form Digapahandi area. (b) Alternate layers of spinel bearing assemblages within khondalites form Digapahandi area.

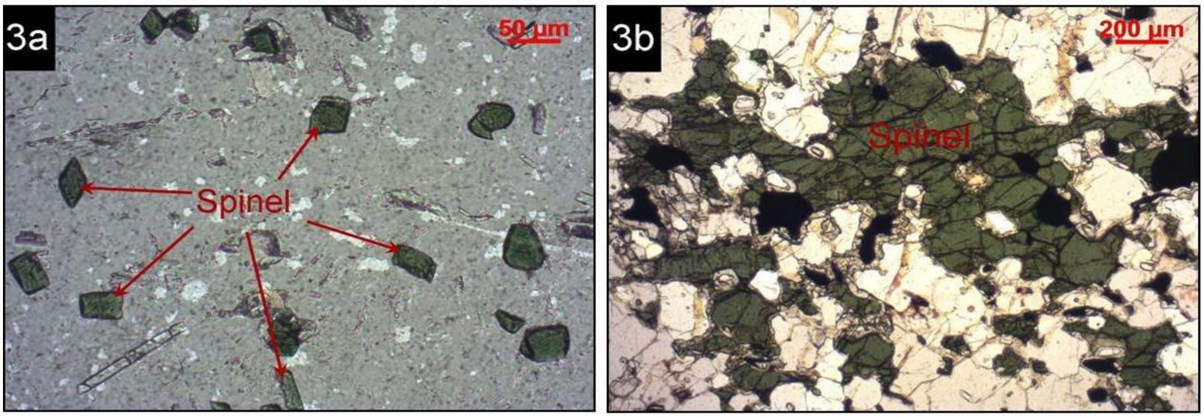

Figure 3 – Photomicrographs of thin section. (a) Fine, euhedral to subhedral, randomly oriented spinel grains within feldspar of leptynites. (b) Coarse grained, anhedral shaped, fractured spinel in khondalites. Also notice the small rim of garnet around spinel.

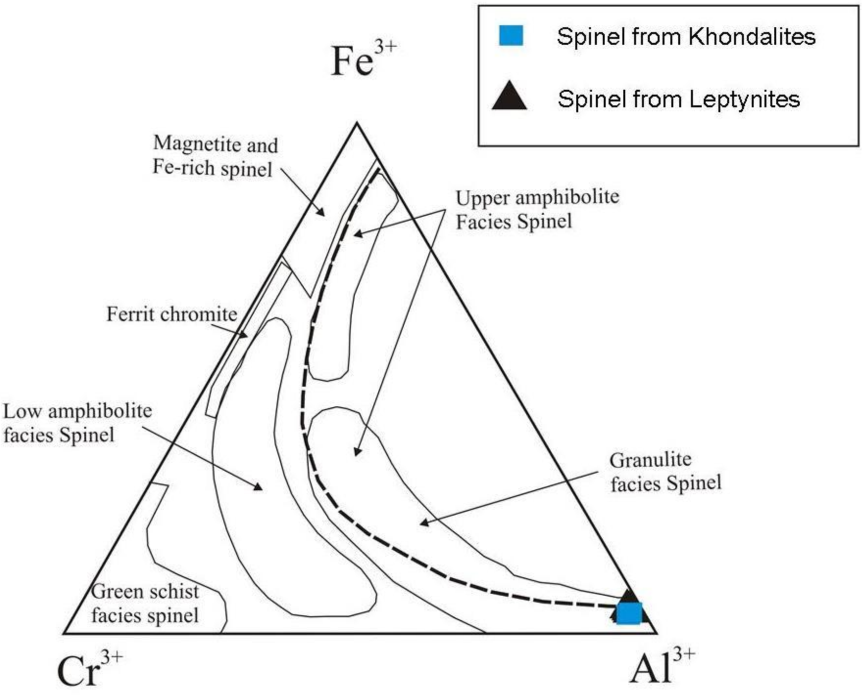

Figure 4 – Fe^{+3} – Cr^{+3} – Al^{+3} triangular plot for spinels from leptynites and khondalites of Digapahandi area, EGB.

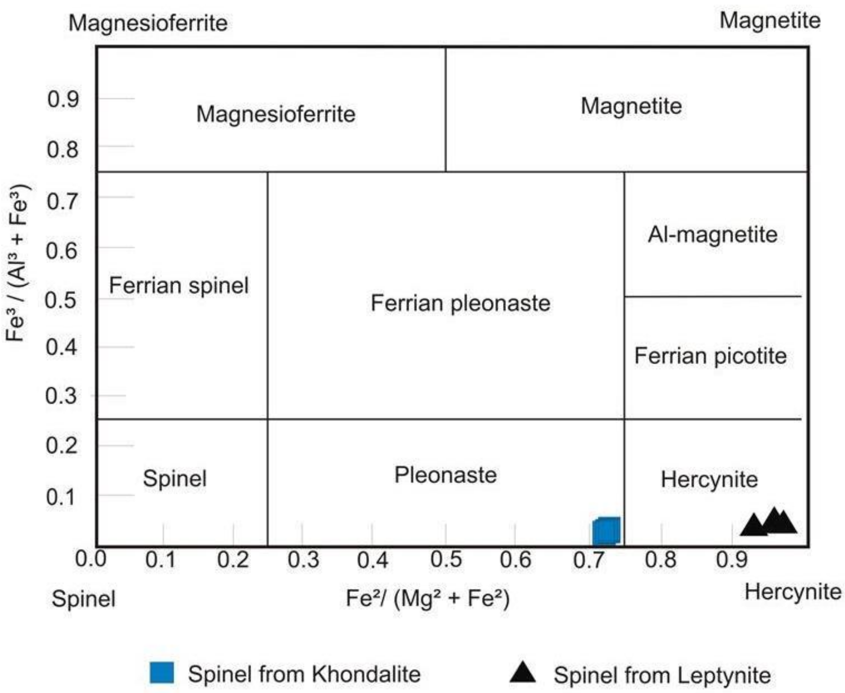

Figure 5 – Classification diagram for spinel group of minerals (after Deer et al. 1972). Spinel from leptynite and khondalite of Digapahandi area falls under hercynite variety and pleonaste variety respectively.

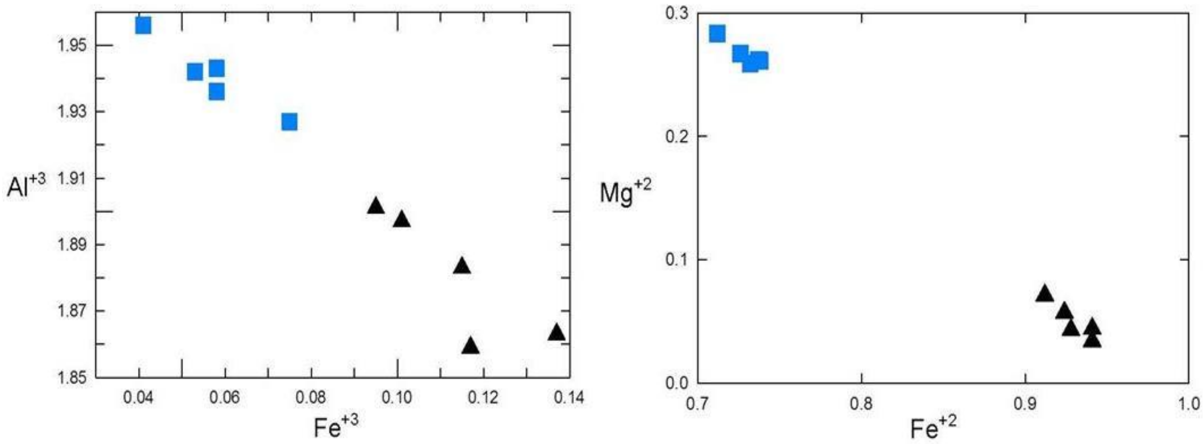

Figure 6 – Binary plot for the spinels from leptynite and khondalite of Digapahandi area. (a) Al^{+3} vs. Fe^{+3} plot (b) Mg^{+2} vs. Fe^{+2} plot. Symbol used: Triangle – Spinels from Leptynites. Square – Spinels from Khondalites.

Table 1. Representative mineral chemistry of spinel from leptynites and khondalites of Digapahandi area.

Rock Type	Leptynite					Khondalite				
Analysis No.	1	2	3	21	22	4	5	13	24	44
SiO2	0.03	0.42	0.01	0.07	0.02	0.03	0.02	0.01	0.00	0.01
TiO2	0.00	0.00	0.06	0.00	0.00	0.01	0.03	0.00	0.00	0.09
Al2O3	54.87	53.89	54.83	56.97	56.75	60.25	58.84	59.15	59.22	58.83
Cr2O3	0.07	0.02	0.06	0.06	0.00	0.11	0.13	0.09	0.07	0.08
FeO^T	44.18	43.21	43.34	43.04	43.41	32.69	33.73	33.63	34.97	34.08
MnO	0.01	0.05	0.04	0.10	0.12	0.07	0.01	0.04	0.08	0.09
MgO	1.01	1.01	0.79	1.36	1.33	6.88	6.28	6.42	6.29	6.26
CaO	0.02	0.01	0.01	0.00	0.03	0.02	0.02	0.01	0.00	0.00
ZnO	1.12	1.03	0.90	0.72	0.72	0.02	0.05	0.00	0.04	0.05
Na2O	0.05	0.03	0.04	0.02	0.05	0.03	0.00	0.05	0.06	0.00
K2O	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.01	0.00	0.00
∑ Oxides	101.35	99.68	100.08	102.36	102.42	100.10	99.10	99.41	100.73	99.49
	Cation calculation									
Si	0.001	0.012	0.000	0.002	0.000	0.001	0.001	0.000	0.000	0.000
Ti	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.002
Al	1.863	1.859	1.883	1.901	1.894	1.956	1.942	1.943	1.927	1.936
Cr	0.002	0.000	0.001	0.001	0.000	0.002	0.003	0.002	0.002	0.002
Fe3	0.137	0.117	0.115	0.095	0.108	0.041	0.053	0.058	0.075	0.058
Fe2	0.928	0.941	0.941	0.924	0.920	0.712	0.737	0.726	0.732	0.738
Mn	0.000	0.001	0.001	0.002	0.003	0.002	0.000	0.001	0.002	0.002
Mg	0.043	0.044	0.034	0.057	0.056	0.283	0.262	0.267	0.259	0.261
Ca	0.001	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000
Zn	0.024	0.022	0.019	0.015	0.015	0.000	0.001	0.000	0.001	0.001
Na	0.003	0.001	0.002	0.001	0.003	0.002	0.000	0.003	0.003	0.000
K	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
∑ Cations	3.002	2.997	2.998	2.998	3.000	3.000	3.001	3.000	3.001	3.000

X_{Mg}	0.039	0.040	0.031	0.053	0.052	0.273	0.249	0.254	0.243	0.247
X_{Zn}	0.021	0.020	0.017	0.014	0.014	0.000	0.001	0.000	0.001	0.001
hercynite	87.29	88.22	89.43	88.60	88.17	70.50	72.24	71.56	71.77	72.25
spinel	4.07	4.15	3.27	5.51	5.37	27.99	25.69	26.30	25.37	25.49
magnetite	6.40	5.54	5.47	4.44	5.02	1.49	1.97	2.13	2.79	2.15
gahnite	2.24	2.09	1.84	1.45	1.43	0.03	0.10	0.00	0.08	0.11
Fe/Fe+Mg	0.96	0.96	0.97	0.94	0.94	0.72	0.74	0.73	0.74	0.74
Fe3/Al+Fe3	0.07	0.06	0.06	0.05	0.05	0.02	0.03	0.03	0.04	0.03

VI. Discussion And Conclusion

The mode of occurrence of spinel from leptynite and khondalite of Digapahandi area of EGB is quite distinct and is evident from field and petrographic study. As per Fe^{+3}, Al^{+3} and Cr^{+3} ternary discrimination plot (after Saumur and Hattori 2013) all the spinel from study area falls under the granulite facies metamorphic zone (Figure 4). According to Cesare (1994) hercynite formed at low pressure high temperature condition of granulite facies or upper amphibolites facies of regional and contact metamorphism, where hercynites are supposed to be formed from Fe-staurolite or Fe-cordierite when they get react with alumina-silicate rocks. The Zn content of spinel thought to be contributed from Zn rich staurolite or biotite or sphalerite (Cesare 1994) as Zn easily substitute the Fe^{+2} during granulite facies metamorphism. Generally the presence of spinel-quartz assemblages advocate towards the temperature dominance metamorphism (Barbosa et al. 2006) and are also an indication to UHT metamorphism (Morimoto et al. 2004). Nichols et al. (1992) pointed out that increasing Zn content in spinel with quartz lowered the stability temperature. Similarly, according to Santosh et al. (2006) low Zn spinels in equilibrium with quartz formed at ultra-high temperature conditions while the high Zn spinels formed during retrograde stage.

Based upon the above study it can be concluded that the diverse mode of occurrence of spinels among leptynite and khondalite of Digapahandi area of EGB is not only due to the difference in the bulk rock composition but also due to the different metamorphic conditions suffered by the rocks. The spinels in khondalite might have been formed during the peek-metamorphic condition whereas spinels in leptynites may be originated during the retrograde metamorphic stage.

Acknowledgements

The Author (SM) is thankful to Director, NIT Raipur for financial support through institute research fellowship. The authors are thankful to the Head, Department of Applied Geology for lab facilities. We are also grateful to Prof. S C Patel and technical staff from EPMA Lab, IIT Bombay for their kind assistance on microprobe analysis.

References

[1]. Barbosa, J., Nicollet, C., Leite, C., Kienast, J.R., Fuck, R.A. and Macedo, E.P. (2006). Hercynite-quartz-bearing granulites from Brejes Dome area, Jequi Block, Bahia, Brazil: Influence of charnockite intrusion on granulite facies metamorphism. Lithos, 92, 537–556, doi: 10.1016/j.lithos.2006.03.064.

[2]. Bhowmik, S.K. (1997). Multiple episodes of tectonothermal processes in the Eastern Ghats granulite belt. Proceedings of the Indian Academy of Sciences - Earth and Planetary Sciences, 106, 131–146, doi: 10.1007/BF02839285.

[3]. Cesare, B. (1994). Hercynite as the product of staurolite decomposition in the contact aureole of Vedrette di Ries, eastern Alps, Italy. Contributions to Mineralogy and Petrology, 116, 239–246, doi: 10.1007/BF00306495.

[4]. Chetty, T.R.K. (2001). The Eastern Ghats Mobile Belt, India: A collage of juxtaposed Terranes. Gondwana Research, 319–328.

[5]. Dobmeier, C.J., and Raith, M. M. (2003). Crustal architecture and evolution of the Eastern Ghats Belt and adjacent regions of India. Geological Society, London, Special Publications, 206(1), 145–168. doi.org/10.1144/GSL.SP.2003.206.01.09

[6]. Farahat, E.S. (2008). Chrome-spinels in serpentinites and talc carbonates of the El Ideid-El Sodmein District, central Eastern Desert, Egypt: their metamorphism and petrogenetic implications. Chemie der Erde - Geochemistry, 68, 193–205, doi: 10.1016/j.chemer.2006.01.003.

[7]. Ferracutti, G.R., Gargiulo, M.F., Ganuza, M.L., Bjerg, E.A. And Castro, S.M. (2015). Determination of the spinel group end-members based on electron microprobe analyses. Mineralogy and Petrology, 109, 153–160, doi: 10.1007/s00710-014-0363-1.

[8]. Saumur, B. M. and Hattori K. (2013). Zoned Cr-spinel and ferritchromite alteration in forearc mantle serpentinites of the Rio San Juan Complex, Dominican Republic. Mineralogical Magazine, 77 (1): 117-136. doi.org/10.1180/minmag.2013.077.1.11

[9]. Morimoto, T., Santosh, M., Tsunogae, T. and Yoshimura, Y. (2004). Spinel + Quartz association from the Kerala khondalites, southern India: evidence for ultrahigh temperature metamorphism. Journal of Mineralogical and Petrological Sciences, 99, 257–278, doi: 10.2465/jmps.99.257.

[10]. Navrotsky, A. and Kleppa, O.J. (1968). Thermodynamics of formation of simple spinels. Journal of Inorganic and Nuclear Chemistry, 30, 479–498, doi.org/10.1016/0022-1902(68)80475-0.

[11]. Nichols, G.T., Berry, R.F. and Green, D.H. (1992). Internally consistent gahanitic spinel-Corderite-Garnet equilibria in the FMASHZN system: Geothermobarometry and applications. Contributions to mineralogy and Petrology, 111: 362-377.

[12]. Oh, C.W., Kim, S.W. and Williams, I.S. (2006). Spinel granulite in Odesan area, South Korea: Tectonic implications for the collision between the North and South China blocks. Lithos, 92, 557–575, doi: 10.1016/j.lithos.2006.03.051.

[13]. Rickers, K., Mezger, K. and Raith, M.M. (2001). Evolution of the continental crust in the Proterozoic Eastern Ghats Belt, India and new constraints for Rodinia reconstruction: Implications from Sm-Nd, Rb-Sr and Pb-Pb isotopes. Precambrian Research, 112, 183–210, doi: 10.1016/S0301-9268(01)00146-2.

[14]. Santosh, M., Sajeev, K. and Li, J.H. (2006). Extreem crustal metamorphism during columbia super continent assembly: Evidence from North China Craton. Gondwana Research, 10 (3-4), 256-266.

[15]. Ramakrishnan, M., Nanda, J.K. and Augustine, P.F. (1998) Geological evolution of the Proterozoic Eastern Ghats Mobile Belt; Geolo. Surv. India. Spec. Publ., v.44, pp.1-21.

[16]. Das, K., Bose, S., Karmakar, S., Dunkley, D.J. and Dasgupta, S. (2011) Multiple tectonometamorphic imprints in the lower crust: first evidence of ca. 950 Ma (zircon U-Pb SHRIMP) compressional reworking of UHT aluminous granulites from the Eastern Ghats Belt, India; Geol. J. v.46, pp.217-239.

[17]. Loomis, T.P. (1972). Contact metamorphism of pelitic rocks by the Ronda ultra-mafic intrusion, Southern Spain, Geol. Soc. Am. Bull., 83, 2449-2474.

[18]. Atkin, B.P. (1978). Hercynite as a breakdown product of staurolite from within the aureole of the Ardara Pluton, Co.Donegal,Eire. Mineral. Mag. 42,237-237.

[19]. Frost, B.R. (1973). Ferroan gahnite from quartz-biotite-almandine schist, Wind River Mountains, Wyo-ming. *Am. Mineral.*, 58, 831-834.

[20]. Wagner, M.E. and Crawford, M. L. (1975). Polymeta-morphism of the Precambrian Baltimore Gneiss in southeastern Pennsylvania. Am. Jour. Sci., 275, 653-682.

[21]. Bose, S., Dunkley, D.J., Dasgupta, S., Das K. and Arima, M. (2011). India – Antarctica – Australia – Laurentia connection in the Paleoproterozoic – Mesoproterozoic revisited: evidence from new zircon U – Pb and monazite chemical age data from the Eastern Ghats Belt, India. *Bulletin of the Geological Society of America*, 123, 2031-2049.

IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) is UGC approved Journal with Sl. No. 5021, Journal no. 49115.

Neeraj Vishwakarma." Compositional variation of Spinel from metamorphic rocks of Digapahandi area, Eastern Ghats Belt, India. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG) 6.4 (2018): 21-27.