Provenance and Tectonic Setting of Late Archaean Greywackes from Dharwar Craton: Karnataka, India

R.Y.Budihal, G.S.Pujar

Department of Geology, Karnatak Science College, Dharwad-580 001, Karnataka State, India.

Abstract- Geochemical characteristics of greywacke and intercalated phyllites from Haveri and Dharwad block (long N 75° 10' to 75° 25' E and lat 15° 30' to 45° 00'S and (long 75° 05'E and lat S 15° 15' to 15° 35') of Shimoga basin have been studied to unravel the provenance and the tectonic setting of the greywackes. The greywackes are medium grained feldspatholithic and show presence of perthitic feldspars, and phyllites are fine grained and show feeble schistocity. Both, greywacke and phyllites are intermediate in composition having high SiO_2/MgO ratio 10.21 to 19.89 and 9.20 to 26. 36 and Al_2O_3/TiO_2 ratio is 21.70 to 80.50 to 23.28 to 84.09, respectively. Greywacke of both the blocks show insignificant enrichment of Si, Fe, Mg, Sc and Co with respect to AUCC. But phyllites show depletion in Cr/Ni (0.52 to 1.9) and in Cu/Zn ratio (0.41 to 1.41). But both greywacke and phyllites have similar REE pattern. The geochemical characters such as negative Eu anomaly and high LREE/HREE (La/Rb)n, suggest granodioritic source for them, whereas, mafic source is indicated by enrichment of Ni, Sc, Sr, & co. The Cu/Zn ratio ranging between 0.48 to 1.20 and 0.41 to 1.41 for greywacke and phyllites respectively. It indicate Komatitic source where as Rb/ Sr content together with presence of perthitic feldspar suggest granitic type source. Based on present studies a mixed provenance dominated by intermediate composition with lesser proportion basic to ultra basic and granitic source is suggested for these greywackes and phyllites. As the source from the lithologic association along with tectonic discriminatory plots, it is concluded that juxtaposition of two tectonic regimes have given rise to the present configuration of outcrop pattern.

Index Terms- Dharwar Craton, Karnataka, Provenance, Tectonic Setting

I. Introduction

Fine grained clastic sediments like greywackes are especially useful for provenance studies as they are least affected by sedimentary fractionation process (Dickinson and Suczek, 1979; Valloni and Mezzardi, 1984; Taylor & McLennan, 1985; Bhatia and Crook, 1986; McLennan *et al.*, 1993; Armstrong-Altrin *et al.*, 2004). Greywacke composition is least affected by sorting process and diagenesis therefore they nearly reflect the composition of early crust (Nesbitt and Young, 1989; Milodowski and Zalasiewicz, 1991). In particular, greywackes from younger greenstone belts are affected by alteration process and metamorphic effect. Hence they are potential in understanding the composition of the early crust (McLennan and Taylor 1991; Naqvi et al, 1988; Manikyamba, 199; Kanerine et al, 1993; and Feng and Kerrich, 1990). It is on the premises that these greywackes are least affected during chemical weathering and rapidly deposited.

Greywackes constitute a major lithology in a younger greenstone belt in Dharwar craton. Provenance studies serve to reconstruct the predepositional history of sediment or sedimentary rocks. This includes the distance and direction, size and setting of the source region, climate and relief in the source area, and the specific type of sedimentary rocks, geochemical features and heavy mineral assemblages (Pettijohn et al., 1987; Mclann, 1998; Bhatia and Crook, 1986; Roser and Korsch, 1988; Chaodong et al., 2005). Therefore in this study an attempt is made to unravel the provenance of the greywackes and apply this knowledge to understand composition of the early crust and crustal evolution process.

II. GEOLOGIC SETTING

In the investigated area, greywackes occurring from Haveri to Dharwad have been considered (Fig 1). Based on the lithological association and petrographic characters they have been conveniently grouped in to Haveri Block and Dharwar Block. The greywacke and intercalated phyllites in the study are constitute Ranebennur formation of Dharwar super group (Swaminath and Ramakrishnan, 1981; Harinand Babu, 1981). General stratigraphy of Shimoga basin given by Swaminath and Ramakrishna (1981) is presented in Table 1. The greywackes to the south and west of Haveri have already been studied by Chavadi and Hegde (1988), (1990) and (2002). The greywackes from the Haveri group are relatively coarse grained and frequent occurrence of BIF and metavolcanics is common in this region. On the contrary, greywackes of Dharwar Block are fine grained and occurrence of BIF within greywackes is a rare feature. Acid volcanic is frequent in the region to the north of the Dharwad. Platformal sediments like BIF's, carbonates are seen in the region (Nagalavi). In both the area intercalation of phyllites with greywackes is a common feature.

III. FIELD AND PETROGRAPHIC FEATURES

Greywackes are medium grained fresh and show intercalations of phyllites, at places mafic flows occur up to the thickness of 15-20 meters. In addition to rhythmic intercalation of phyllites, oxide facies, BIF's occur, which constitute ridges of the hills around Haveri and Shiggaon, phyllites do not exceed 20 cm in thickness where as greywackes show thickness up to 1.5 meter.

Around Dharwad, greywackes are fine grained and show the effect of metamorphism and rude schistocity can be observed with pocket lens. Occurrence of BIF's within greywackes is not seen, on the other hand, platformal facies is seen in the North of Dharwad (intercalation of phyllites is similar to those found in Haveri-Shiggaon Block).

Representative Greywacke and intercalated phyllites samples are selected for the petrographic studies. The selected fresh rock samples of greywacke and phyllites have been subjected to thin section studies for mineral composition and petrographic characters.

Under microscope greywackes exhibit poorly sorted texture consisting of quartz, feldspar and rock fragments. Both monocrystalline and polycrystalline quartz are common. Replacement of feldspars by secondary carbonate is more prominent in greywackes of Haveri block, than in Dharwad block. Rock fragments like cherty, phyllitic and BIF's in Dharwad block, where as large grains of K-feldspar and perthitic feldspars are observed in Haveri block. These rock fragments suggest recycled and granitic provenance for them. Matrix is dominated by chlorite of green variety. Pyrite is a common secondary mineral its diagrammatic origin is indicated by (cubic) well developed crystal faces and replacement of other minerals. Biotite and other minerals are less than 5% in matrix of the greywackes, secondary carbonate replace both matrix as well as clastic grains. The embayment of clastic grains by matrix minerals suggests the role of diagenesis. The metamorphic of low grade green schist facies has not affected the original fabric of the greywackes, whereas rude schistocity can be seen in greywackes of Dharwad block.

IV. ANALYTICAL PROCEDURE

For modal composition of the greywacke sample, thin sections of the area 3-4 Sq Cms have been used with an average of 1,000 grains per rock and the work was carried out with the Lietz Counter Machine.

The selected greywacke and phyllites samples were crushed and powdered to ~200mesh and analyzed for their major, trace and REE composition under ICP-MS at Shiva Analyticals, Bangalore. The analysis for major and minor elements was carried out by preparing samples following the method of Bernas Thomson and Walsh (1989). For normalization, values for Archaean upper continental crust (AUCC) were obtained from Taylor and McLennan (1985). Chondrites normalized ratios are calculated from the values of Sun and McDonough (1989). The Chemical Index of Alteration (CIA) was calculated as [Al2O3/(Al2O3+CaO+Na2O+K2O)]×100, corrected for diagenetic addition of K, following Fedo et al. (1995)

V. RESULTS AND DISCUSION

The data of major, REE and trace elements analysis of the greywackes and phyllites are outlined and listed in Table 2 and 3.

Geochemistry

The greywackes in general are intermediate in composition SiO_2 range from 57.56 to 66.73, whereas phyllites show lesser concentration of SiO_2 53.74 to 65.85. This feature suggests that silica is concentrated in coarser fraction. The distinguishing feature of greywackes of the study area is the dominance of the Na_2O over K_2O. The Al_2O_3/Na_2O ratio which is the Compositional Maturity Index (Pettijohn, 1957) and it is varies between 3.96 to 12.30. The larger range suggests the removal of mobile elements like Na_2O, MgO range in composition from 1.09 to 3.89 and 3.36 to 5.57 and SiO_2/MgO ratio is high 19.9 to 11.4, which is an indication of dominance of acidic provenance. The rocks show high content of Fe as 10.4. The rocks under study are high content of Fe along with BIF rock fragments suggest BIF signature (Manikyamba, 1997).

The compositional diagrams after Pettijohn et al., (1973) classify as greywackes and the distinctive difference can be seen (Fig.2). The REE pattern of greywackes show moderately fractionated pattern with significant Eu(La/Yb)n ratio is 1.11, though there is difference in their petrographic characters and lithological association. Greywackes of both the groups do not show any significant difference. The Eu/Eu* range from 0.69 to 0.91. Greywackes of both the blocks in general are intermediate in composition, SiO_2 range from 56.87 to 62.77 in Haveri block and range from 57.74 to 66.73 in Dharwad block, where as phyllites show lesser concentration of SiO_2 in both the blocks. This feature suggests that Si concentration is in coarser fraction. The Al_2O_3/Na_2O ratio varies from 3.96 to 12.34 in compositional plot of Log (SiO_2/Al_2O_3) Vs Log (Na_2O/K_2O) after Pettijohn (1973) (Fig.2). The phyllites occupy field 2 but greywacke confirm to their field, SiO_2/MgO ratio varying from 10.20 to 19.90 which is significant nature of greywackes.

It is pertinent to note that the interbedded greywackes are poorer in MgO compared to the phyllites in Haveri block, where as such a trend is not clear in the case of Dharwar block. The content of CaO is enriched in interbedded phyllites compared to greywackes in Dharwad block (0.87 to 5.150 and in general, the greywackes show enrichment of CaO in both the blocks. The AUCC normalized multi element diagram (Fig.3A,B,C and D) suggest insignificant variation with regard to SiO_2,Rb,Mg,Ni,Cr,Co,Sc in greywacke of both the blocks, contrast to this phyllites show large variation with regard to Sr, Na_2O show depletion in phyllites and K_2O show enrichment with regard to AUCC in phyllites. The Chemical Index of Alteration (CIA) values of greywacke range from 54.8 to 73.9 with an average 63.85, whereas a CIA value of phyllites is high (Nesbitt and Young, 1982). The value of CIA suggests moderate chemical weathering of the source. The La/Yb ratio of greywacke is 1.11 where as for phyllites it is less than 0.33. The REE pattern of greywacke (Fig.4 A and B) show mild Eu anomaly moderately fractionated LREE and flat HREE. Based on REE signature greywacke and phyllites are indistinguishable which suggest that inspite of fractionation of some major elements and grain size sorting. REE is not affected and can be used to understand the provenance of the greywackes (Ruby 1951, Helm bold 1958, Crook 1974, Roger Swart 1990). The greywackes show high concentration of TiO_2 and Cr.

K_2O/Na_2O ratio of the greywackes more than 1 which suggests the quartz intermediate type of greywackes, (Crooke, 1974) suggest, the recycled orogene provenance field, (Dickinson et al, 1983) and relative abundance of plagioclase feldspar, and, feldspar over lithic fragments suggest accumulation of the material in Active Continental Margin. The low (<4) value of Mg/K and Na/K suggest significant K-metasomatism has not taken place for greywackes (Fedo et al., 1995, 1997). The K/Rb ratio is comparable with other Precambrian greywackes.

The Rb/Sr ratio is consistently low as compared to crustal reservoir. Cr/Ni concentration is comparable to other Precambrian greywackes, and Cr/Ni is high. Cu/Zn ratio varies from 0.48 to 1.20 and higher than the sediments of the OIA, CIA and ACM (0.25, 0.15 and 0.15 respectively) (after Bhatia and Crooke, 1986). Cu/Zn ratio suggests the presence of Komatitic in the source, the Komatites have Cu/Zn ratio is 0.959 (Cattel and Arnadet, 1987). The range of Co, Sc and V are high comparable with other Achaean greywackes. Sr ranges from 208 to 753 and Rb 38.5 to106, and their concentration is high compare to AUCC and suggests the granitic source. It is interesting to that the concentration of these in the phyllites show a large variation and the Rb/Sr ratio (0.07 to 0.51) is higher compare to greywackes in the same block. On the other hand, the Cu/Zn (0.41 to 1.41) and Cr/Ni (0.52 to 1.9) ratio is lower in phyllites compare to that of greywackes from the Achaean Green Stone Belts. However, La is enriched 60 to 130 times, Yb 4.5 to 95 times, those of Chondrites in Haveri block. Although in Dharwad block La concentration is up to 150 to 153 times that, of Chondrites. Thus show a narrow range of 86 to 123 times. Even though Yb restricted to 4.5 to 7.5 range, but Yb and La exhibit similar range as that of greywackes, inspite of differences in their trace element composition.

VI. DISCUSSION

The compositions of sedimentary rocks are influenced by weathering, sorting and digenesis. The geochemical characteristics of greywackes suggest that they have not been affected by this sedimentary process. The fine grained intercalated phyllites within greywackes show low value of CIA, high ratio of Al_2O_3/Na_2O and low value of Mg/K and Na/K suggests some degree of sorting. The Si, Fe, Mg, Sc, Co shows insignificant variation between greywackes and phyllites, as well as, with respect to AUCC. Although Al_2O_3 show enrichment in phyllites. Al_2O_3 is comparable for greywackes and phyllites, therefore, these elements can be made to understand the provenance of greywackes. The feldspathic nature and quartz intermediate type suggest recycled orogene provenance for these greywackes. The QFL ratio also confirms this. The presence of K-feldspar and microcline perthitic feldspars do suggests presence of granitic type of source.

High ratio of SiO_2/MgO suggests acidic source, absence of volcanic rock fragments and feldspars precludes acidic volcanic, on the other hand, the cloudy extinction in quartz along with feldspars and chemical characters such as high ratio of Al_2O_3/SiO_2 and SiO_2/MgO, suggest acidic plutons as source. The Cu/Zn ratio suggests presence of Komatitic source (basic) whereas, enrichment of Cr, Ni, V, Co suggest a basic source as provenance for them. Granitic source is indicated by low value of Rb/Sr.

The greywacke and phyllites show fractionated REE pattern with La/Yb characteristic ratio, a feature of intermediate source. The greywackes and phyllites are characterized by mild negative Eu anomaly; according to Jakes and Taylor (1974) negative anomaly suggests development of upper Granodioritic source. La enriched HREE depleted nature is related to the derivation of mixing of bimodal volcanics. The above chemical characters suggest that a mixed provenance consisting of recycled orogene, intermediate to basic and ultra basic source for greywackes.

Roser and Korsch (1986) established a discrimination diagram using K_2O/Na_2O versus SiO_2 (Fig. 5), to determine the tectonic setting of terrigenous sedimentary rocks. Both SiO_2 and K_2O/Na_2O ratio increase from volcanic-arc to active continental margin settings. On this diagram, the greywackes of the area plot exclusively in the field of active continental margin (ACM). Mayanard et al, (1982) used similar plot of K_2O/Na_2O versus SiO_2/Al_2O_3 in their study of modern sediments to discriminate different tectonic settings. In the discriminatory plot SiO_2 vs. K_2O/Na_2O (after Roser and Korsch, 1986), reveal that Continental Island Arc (CIA) source for them. The association of greywackes and phyllites of Dharwad with platformal sediments suggest juxtaposition of two tectonic regimes by a process of subduction.

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REFERENCES

[1] Armstrong-Altrin, J.S., Lee, Y.I., Verma, S.P., Ramasamy, S., 2004, Geochemistry of sandstones from the Upper Miocene Kudankulam Formation, southern India: implication for provenance, weathering and tectonic setting: Journal of Sedimentary Research, 74(2), 285–297.

[2] Bhatia, M.R., Crook, K.A.W., 1986, Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins: Contributions to Mineralogy and Petrology, 92, 181–193.

[3] Chavadi, V.C And Hedge, V.S. (1988) Geology of Greywackes West of Ranebennur, Dharwad District, Karnataka state. Jour.Geol.Soc of India, V.31.pp.337-342.

[4] Crook, K.A.W. (1974). Lithogenesis and Geotectonics: the significance of compositional variations in flysch arenites (greywackes), In R.H.Dott and R.H.Shaver (Eds) Modern and Ancient geosynclinals sedimentation society of Economic Geology, Paleantology and Mineralogy. Spec Publ. V. 19, pp.304-319.

[5] Dickinson, W.R., Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologist, 63, 2164–2182.

[6] Fedo, C.M., Nesbitt, H.W., Young, G.M., 1995. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance. Geology 23 (10), 921–924.

[7] Feng, R., Kerrich, R., 1990. Geochemistry of fine-grained clastic sediments in the Archaean Abitibi greenstone belt, Canada: implications for provenance and tectonic setting. Geochim. Cosmochim. Acta 54, 1061–1081.

[8] Harinandhababu, P.M. And Krishnamurthy,K.(1981). Shimoga belt, in Mem. Geol Survey of India. V.112, pp.199-218.

[9] Jakes, P. And Taylor, S.R.(1974). Excess europium content in Precambrian sedimentary and continental evolution; Geochim. Cosmochim Acta. V.38, pp.739-745.

[10] Manikyamba, C, Naqui, S.M. (1997). Late Archaean mantle fertility; constraints from metavolcanics of Sandur Schist belt, India. Gond. Res. V. 1, pp. 68-89.

[11] Manikyamba, C, Naqui, S.M., Moen, S., Ganwshwara Rao, Balaram V., Ramesh, S.L. And Reddy, G.L.N. (1997) Geochemical heterogeneities of metagreyackes from the Sandur schist belt: implication for active plate margin processes, Precambrian Res., v, 84, pp.117-138.

[12] McLennan, S.M., Hemming, S., McDaniel, D.K., Hanson, G.N., 1993, Geochemical approaches to sedimentation, provenance and tectonics, *in* Johnsson, M.J., Basu, A. (eds.): Geological Society of America, Special Papers 285**,** 21–40.

[13] Milodowski A.E, Zalasiewicz J.A, 1991, Redistribution of rare earth elements during diagenesis of turbidite/hemipelagic mudrock sequences of Llandovery age from central Wales, *in* Morton,A.C., Todd, S.P., Haughton, P.D.W. (eds.), Developments in Sedimentary Provenance Studies: Geological Society of London, Special Publication, 57, 101–124.

[14] Naqvi, S.M., Sawarkar,R.H., Subbarao, D.V., Govil, P.K. And Ganeshwra Rao, T. (1988). Geology, geochemistry and tectonic setting of Archaean greywackes from Karnatka nucleus, India. Precamb. Res. V. 39, pp.193-216.

[15] Nesbitt, H.W., Young, G.M., 1989, Formation and diagenesis of weathering profi le: Journal of Geology, 97, 129–147.

[16] Pettijohn, F.J., Potter, P.E And Siever, R. (1973). Sand and Sandstone. Springer-Verlag, Newyork, 616 p.

[17] Taylor, S.R And Mc Lennan, S.M. (1985). The continental crust: its composition and evolution, Blackwell, Oxford. 312p

[18] Valloni, R., Mezzardi, G., 1984, Compositional suites of terrigenous deepsea sands of the present continental margins: Sedimentology,31, 353–364.

AUTHORS

First Author – Mr.Rajendrakumar.Y.Budihal, M.Sc In Geology, Assistant Professor, Department of Geology, Karnatak Science College, Dharwad-580 001, Karnataka , India., Email-rybudihal@gmail.com
Second Author – Dr.G.S.Pujar, M.Sc in (Appl) Geology, PhD, Associate Professor, Department of Geology, Karnatak Science College, Dharwad-580 001, Karnataka, India., Email-ganapathipuajar@gamil.com

Correspondence Author – Mr.Rajendrakumar.Y.Budihal, Email- rybudihal@gmail.com rybudihal@yahoo.com
Mobile No-8762334251

Table 1: Generalized Lithostratigraphy 0f Dharwar Super group.

GENERALISED LITHOSTRATIGRAPHY OF DHARWAR SUPERGROUP

Swami Nath and Ramakrishnan, (1981)

Group assemblage **Formation** **Litho-**

(as in the type area)

Hiriyur
Predominantly greywacke with Fe-Mn chert;
polymict
conglomerate

Chitradurga Ingaldhal Quartz-chlorite schist, argillite with Fe-Mn
chert and metabasalt
Group of Chitradurga belt

Vanivilas Fe-Mn
formations, carbonates, phyllite and
quartzite with
conglomerate at the base
Dharwar ------- Unconformity -------
Super group

Mulaingeri
Fine clastics, predominantly with
chemical sedimentation
Bababudan Group Santaveri Bimodal volcanics,
of
quartzite in subordinate amounts
Bababudan belt
Allampur Quartzite with
basic igneous rocks

Kalasapura
Basic volcanics with quartzite and
conglomerate at the base

Table 2: Chemical composition of Greywackes of the study area.

	Haveri Block-Greywackes						Dharwad Block-Greywackes					
Sample	**SG-7G**	**SG-2a**	**SG-5**	**SG-3**	**SN-15**	**S-15**	**107-c**	**111-G**	**119-D**	**B-4a**	**52-D**	**84-G**
SiO2	62.22	57.56	58.9	56.87	62.77	59.5	57.74	58.77	58.62	63.61	61.5	66.7
TiO2	0.63	0.22	0.6	0.21	0.23	0.22	0.68	0.58	0.56	0.38	0.61	0.43
Al2O3	13.73	10.37	16.2	16.91	14.59	15.4	16.2	18.16	16.29	15.54	15.3	13.5
FeOT	9.86	8.49	9.75	10.4	6.59	8.99	9.5	6.8	8.12	6.71	9.13	6.94
MnO	0.17	0.18	0.16	0.14	0.1	0.16	0.17	0.07	0.14	0.13	0.15	0.07
MgO	3.85	4.48	4.23	5.57	4.18	5.21	3.98	3.38	3.75	3.5	4.26	3.36
CaO	2.09	2.77	1.37	2.03	3.46	1.99	2.27	2.89	4.54	4.77	4.92	1.38
Na2O	2.24	3.4	2.7	2.27	3.23	3.89	3.59	2.71	2.51	2.2	2.87	1.09
K2O	1.93	2.37	2.43	1.67	1.25	1.5	2.63	3.55	1.9	1.86	1.26	2.4
P2O5	0.14	0.22	0.14	0.17	0.16	0.18	0.24	0.24	0.23	0.13	0.16	0.11
LOI	3.19	3.9	3.52	3.73	3.42	2.89	2.75	2.75	3.3	3.1	2.81	3.98
Total	**100**	**94**	**100**	**100**	**99.98**	**99.9**	**99.8**	**99.9**	**99.96**	**102**	**103**	**99.9**
CIA	68.7	54.8	71.4	73.9	64.76	67.6	65.6	66.5	64.54	63.8	62.8	73.4
SiO2/MgO	16.2	12.8	13.9	10.2	15.02	11.4	14.5	17.39	15.63	18.2	14.4	19.9
K2O/Na2O	0.86	0.7	0.9	0.74	0.387	0.39	0.73	1.31	0.757	0.85	0.44	2.2
SiO2/Al2O3	4.53	5.55	3.63	3.36	4.302	3.86	3.56	3.236	3.599	4.09	4.01	4.96
Al2O3/Na2O	6.13	3.05	6.01	7.45	4.517	3.96	4.51	6.701	6.49	7.06	5.33	12.3
K2O/Al2O3	0.14	0.23	0.15	0.1	0.086	0.1	0.16	0.195	0.117	0.12	0.08	0.18
Al2O3/TiO2	21.8	47.1	27	80.5	63.43	70.1	23.8	31.31	29.09	40.9	25.1	31.3
Rb	52.3	87	55.2	85.9	42.4	38.5	50.7	62.9	51.1	63.1	43.9	106
Pb	19	71	22	9	22	5	9	14	16	21	24	17
Cd	0.4	0.4	0.3	0.2	1	1.4	0.3	0.1	0.6	0.2	1.9	1.3
Cu	103	58	83	127	58	25	86	41	73	59	45	61
Cr	152	77	165	261	97	89	117	54	125	133	142	56
Zn	102	111	85	126	60	52	84	127	113	54	70	51
Ni	74	34	72	126	50	27	66	35	53	48	64	34
Sr	264	305	225	178	353	306	428	306	753	284	238	208
Zr	31	20	31	38	20	20	27	20	22	20	24	20
V	109	75	116	220	96	76	98	78	101	89	118	63
Co	28	14	30	39	27	16	27	20	24	23	27	17
Sc	13	9	15	29	12	12	13	9	13	17	14	24
La	31	28	34	40	21	19	26	27	37	26	33	25
Ce	46.4	50.3	53.4	55.2	45	42	38.4	40.7	45.7	32.3	59.4	95.5
Pr	7.5	8.6	8.5	9.4	5.4	5.1	6.3	6.5	7.4	5	6.9	10
Nd	19.9	21.8	22.6	26.3	19.4	18.4	18.9	18.3	21.2	14.1	23.8	35.4
Sm	4.6	4.7	5.1	6.6	3.8	3.4	4.2	4.1	5	3.2	4.2	6.8
Eu	1.1	1.2	1.26	1.49	1.04	0.91	1.03	1.07	1.32	0.8	0.98	1.55
Gd	4.4	3.4	6	4.5	3.5	2.8	3.7	3.4	3.9	2.5	3.7	5.5
Tb	0.6	0.4	0.5	0.5	0.8	0.7	0.4	0.4	0.5	0.3	0.9	0.7
Dy	3.5	2.2	2.8	2.5	2	1.5	2.9	2.7	2.3	1.7	2.6	2.8
Ho	0.7	0.4	0.6	0.4	0.9	0.8	0.5	0.5	0.4	0.3	1	0.8
Er	2.2	1.3	2.2	1.2	0.8	0.8	1.6	1.4	1.3	1.1	1.3	1.1
Tm	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Yb	1.9	1	1.2	1.3	1.1	0.9	1.4	1.2	1.1	0.9	1.5	1.5
Lu	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
ΣREE	**124**	**124**	**138**	**150**	**104.9**	**96.5**	**106**	**107.5**	**127.3**	**88.4**	**139**	**187**
Cu/Zn	1.01	0.52	0.98	1.01	0.967	0.48	1.02	0.323	0.646	1.09	0.64	1.2
Cr/Ni	2.05	2.26	2.29	2.07	1.94	3.3	1.77	1.543	2.358	2.77	2.22	1.65
Rb/Sr	0.2	0.29	0.25	0.48	0.12	0.13	0.12	0.206	0.068	0.22	0.18	0.51
Eu/Eu*	0.74	0.91	0.69	0.83	0.87	0.76	0.79	0.87	0.87	0.86	0.76	0.77
Eu*	0.24	0.30	0.23	0.27	0.29	0.29	0.26	0.29	0.30	0.28	0.25	0.25

Table 3: Chemical composition of Phyllites of the study area.

	Haveri Block -Phyllites					Dharwad Block-Phyllites				
Sl.No/Sample	SG-7P	SG-2B	S-11	S-4	TH-2	60-D	84-P	98-P	108-P	111-P
SiO_2	55.2	53.7	57.8	63.7	65.9	63.1	52.4	56.6	59.8	61.9
TiO_2	0.35	0.47	0.66	0.61	0.42	0.62	0.56	0.35	0.22	0.66
Al_2O_3	18.6	18.9	16.8	14.2	13.8	16.1	18.6	18.9	18.5	16.1
FeO	12.16	11.41	9.45	7.75	6.85	7.57	7.49	9.12	8.29	7.39
MnO	0.10	0.10	0.14	0.12	0.16	0.10	0.08	0.11	0.08	0.08
MgO	5.88	5.78	5.95	3.18	2.50	2.61	3.84	4.64	4.90	4.51
CaO	0.60	0.76	1.90	2.70	2.76	1.07	5.15	2.10	0.85	2.15
Na_2O	1.40	1.54	1.36	2.98	2.84	3.04	0.86	1.84	1.10	1.05
K2O	2.66	3.84	3.44	3.66	3.80	2.66	3.84	3.44	3.66	2.80
P_2O_5	0.14	0.19	0.19	0.18	0.14	0.16	0.18	0.14	0.14	0.20
LOI	2.45	3.65	2.88	2.85	3.00	2.90	2.98	2.98	2.48	3.12
Total	**99.48**	**100.37**	**100.55**	**101.94**	**102.13**	**99.90**	**95.95**	**100.24**	**99.98**	**99.94**
CIA	79.94	75.47	71.49	60.36	59.50	70.33	65.37	71.90	76.72	72.80
K_2O/Na_2O	1.90	2.49	2.53	1.23	1.34	0.88	4.47	1.87	3.33	2.67
SiO_2/Al_2O_3	2.97	2.84	3.44	4.48	4.77	3.93	2.82	3.00	3.23	3.86
SiO_2/MgO	9.38	9.30	9.71	20.03	26.34	24.18	13.64	12.21	12.20	13.73
Al_2O_3/Na_2O	13.26	12.27	12.35	4.77	4.86	5.28	21.62	10.26	16.81	15.30
K_2O/CaO	4.43	5.05	1.81	1.36	1.38	2.49	0.75	1.64	4.31	1.30
TiO_2/Al_2O_3	0.02	0.02	0.04	0.04	0.03	0.04	0.03	0.02	0.01	0.04
Na_2O/MgO	0.24	0.27	0.23	0.94	1.14	1.16	0.22	0.40	0.22	0.23
Rb	71.5	94.1	156.0	113.9	89.7	52.7	61.1	44	87.2	88.6
Pb	13.0	28.0	20.0	13.0	5.0	6.0	12.0	106.0	31.0	20.0
Cd	0.2	1.4	3.1	2.3	0.1	0.1	0.1	0	0	0
Cu	52.0	90.0	68.0	61.0	93.0	70.0	53.0	124.0	56.0	69.0
Cr	110.0	107.0	54.0	119.0	152.0	198.0	73.0	115.0	115.0	121.0
Zn	127.0	89.0	57.0	59.0	96.0	128.0	95.0	88.0	66.0	129.0
Ni	74.0	88.0	32.0	65.0	78.0	97.0	46.0	74.0	57.0	65.0
Sr	115.0	208.0	1192.0	108.0	75.0	85.0	141.0	155.0	215.0	158.0
Zr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V	145.0	150.0	67.0	125.0	125.0	173.0	104.0	0.0	0.0	0.0
Co	31.0	38.0	17.0	27.0	20.0	32.0	23.0	0.0	0.0	0.0
Sc	17.0	19.0	8.0	17.0	16.0	24.0	15.0	0.0	0.0	0.0
La	31.00	26.00	48.00	31.00	40.00	29.00	27.00	26.00	32.00	29.00
Ce	50.70	56.00	84.00	58.00	55.00	45.00	48.00	35.00	60.00	60.00
Pr	8.20	7.00	9.40	6.80	8.90	7.30	7.90	3.50	7.70	5.70
Nd	22.70	25.00	31.00	23.00	25.00	22.00	23.00	14.00	25.00	21.00
Sm	5.00	5.00	5.20	4.40	5.30	5.60	5.10	2.80	5.30	5.10
Eu	1.26	1.30	1.20	1.00	1.20	1.20	1.20	0.80	1.30	1.40
Gd	4.50	4.40	4.40	4.00	4.30	4.00	4.50	0.00	0.00	0.00
Tb	0.50	1.00	1.00	0.90	0.50	0.50	0.60	0.00	0.00	0.00
Dy	3.00	3.30	3.50	3.00	2.90	2.10	4.00	1.40	2.60	3.20
Ho	0.50	1.10	1.10	1.10	0.50	0.30	0.70	0.00	0.00	0.00
Er	2.10	1.50	1.80	1.60	1.80	0.90	2.00	1.40	2.20	3.20
Tm	0.10	0.10	0.10	0.10	0.20	0.10	0.20	0.10	0.10	0.10
Yb	1.50	1.90	1.70	1.80	1.70	0.90	1.60	0.80	1.90	2.20
Lu	0.10	0.20	0.10	0.20	0.10	0.10	0.10	0.25	0.42	0.39
ΣREE	**131**	**134**	**193**	**137**	**147**	**119**	**126**	**86**	**139**	**131**
La/Yb	20.67	13.68	28.24	17.22	23.53	32.22	16.88	32.50	16.84	13.18
Cu/Zn	0.41	1.01	1.19	1.03	0.97	0.55	0.56	1.41	0.85	0.53
Cr/Ni	1.49	1.22	1.69	1.83	1.95	2.04	1.59	1.55	2.02	1.86
Rb/Sr	0.62	0.45	0.13	1.05	1.20	0.62	0.43	0.28	0.41	0.56

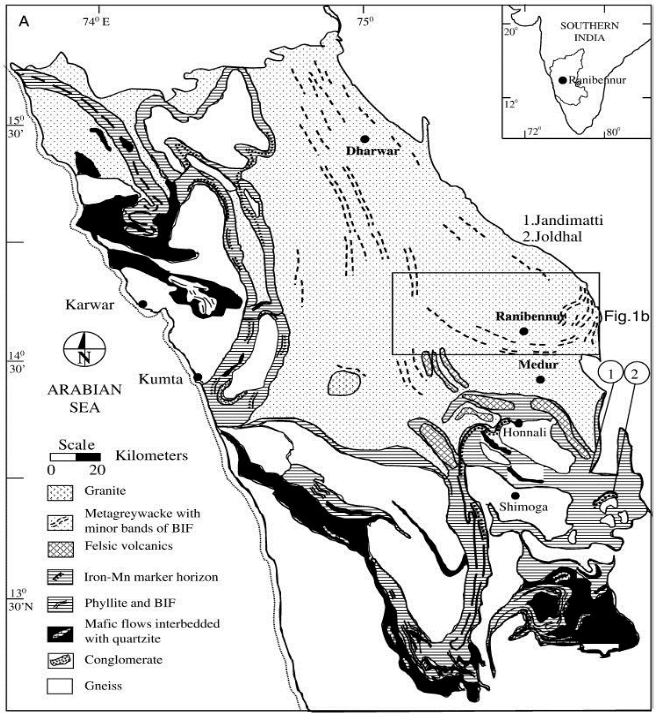

Figure 1: Regional geological map of the Shimoga basin (source Swaminath and Ramakrishnan, 1981).

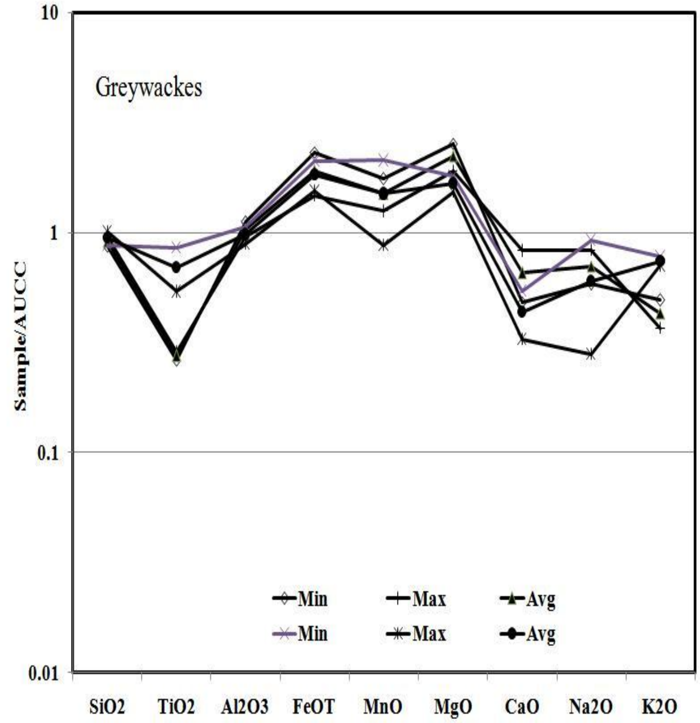

Figure 3 (A): Multi-elements normalized diagram for the Greywackes of the study area, normalized against AUCC (after Taylor and McLennan, 1985).

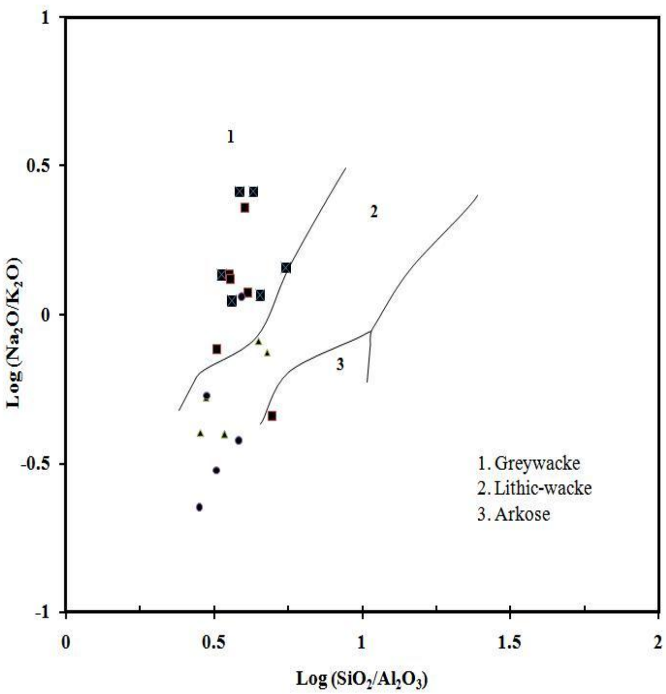

Figure 2: Chemical classification scheme of Greywackes based on major elements Log (Na_2O/K_2O) vs. Log (SiO_2/Al_2O_3) diagram after Pettijohn et al., 1973).

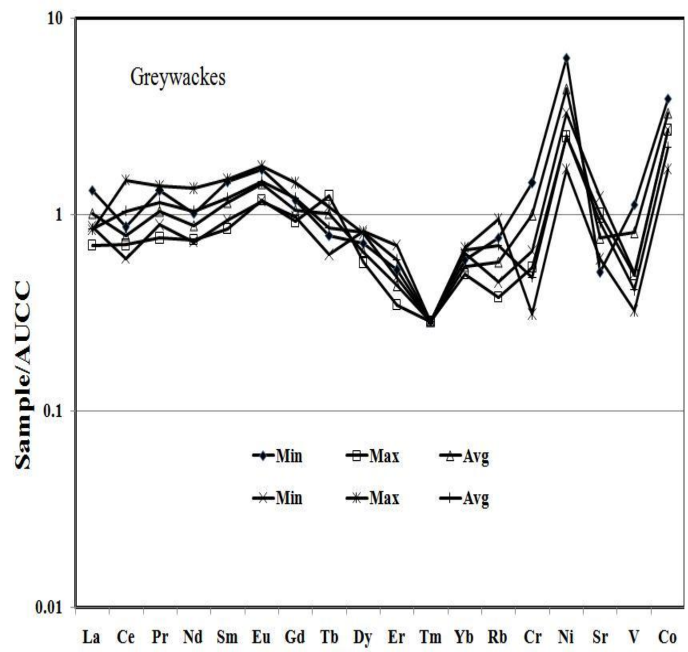

Figure 3(B): Multi-elements diagram for the Greywackes, normalized against AUCC (after Taylor and McLennan, 1985).

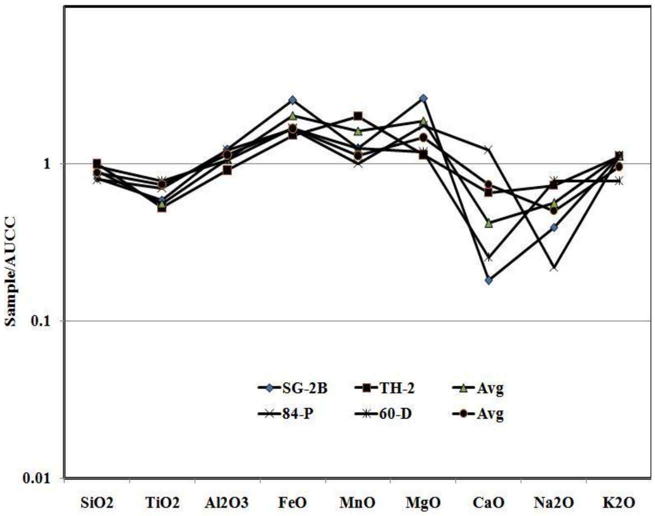

Figure 3(C): Multi-elements diagram for the Phyllites, normalized against AUCC (after Taylor and McLennan, 1985).

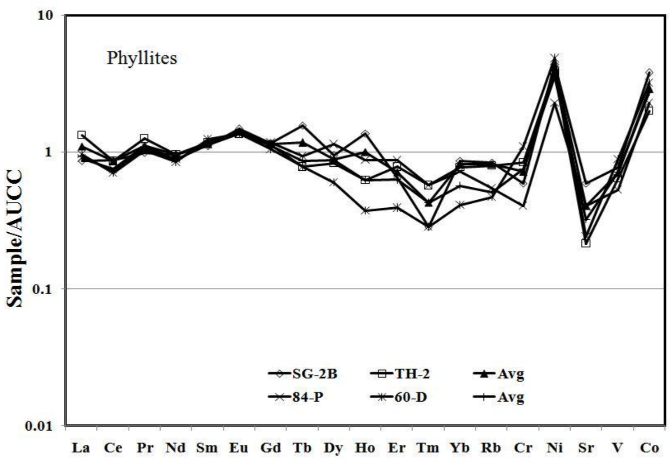

Figure 3(D): Multi-elements diagram for the Phyllites, normalized against AUCC (after Taylor and McLennan, 1985).

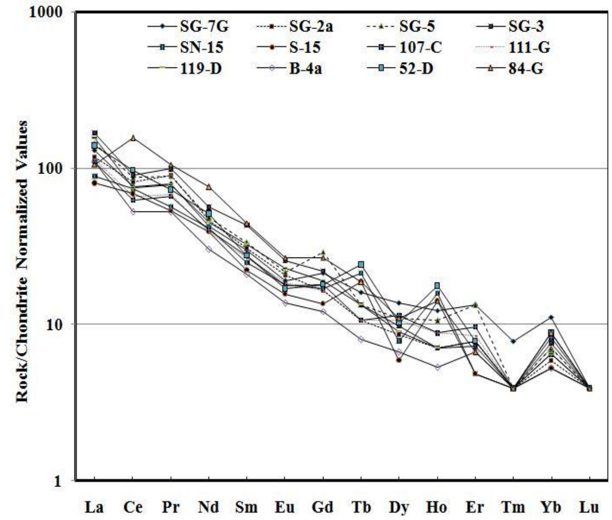

Figure 4(A): Chondrites normalized rare earth element (REE) patterns for Greywackes of the study area (after Sun and McDonough, 1989).

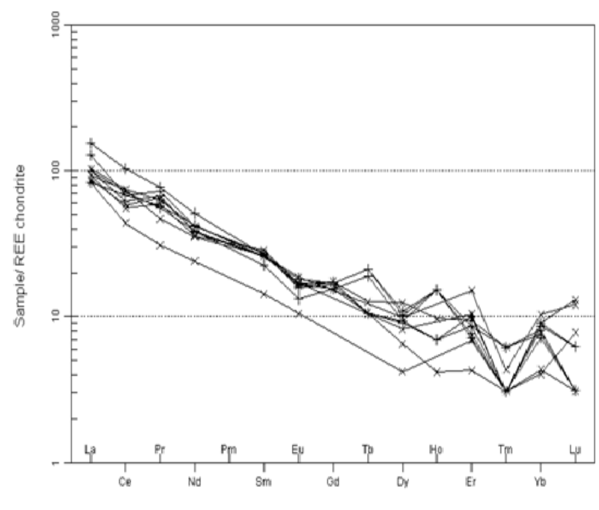

Figure 4(B): Chondrites normalized rare earth element (REE) patterns for Greywackes of the study area (after Sun and McDonough, 1989).

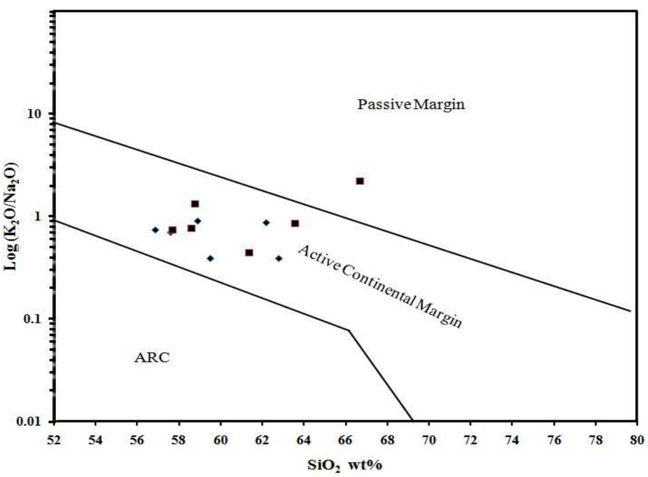

Figure 5: Geochemical tectonic discrimination plot for Greywackes (after Roser and Korsch, 1986).