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Petrology and Geochemistry of the Quartz-White Mica Schists in the Luk Ulo Melange Complex, Central Java.

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Abstract - The quartz-white mica schist cropped excellently out in Sadang Area, north Kebumen and in Kaliwiro area, south Wonosobo Central Java. It contains bulk of quartz; white mica, albite, garnet, chlorite, epidote with or without subordinate rutile, titanite, calcite, graphite, opaque, and sometime biotite. Its appearance shows medium-coarse grained, foliated, North-Northwest gently inclined rock. Rutile and garnet in the assemblage indicated high pressure minerals present in the rock. High Mg, Fe, Si together with Al content of white mica represent phengitic mica while garnet shows average xAlm: xPrp : xSps : xGrs = 0.59:0.05:0.03:0.33 with average xFe =1.14, of amandine garnet. Geo-thermometry calculation using Fe-Mg exchange on garnet and biotit and geo-barometry calculation using garnet-biotit-white mica-albite yield temperature 380°C, pressure 15-16 Kbar, and gradient geothermal was about 7,3° C km^{-1} during metamorphism. It was occurred in about 50 km depth. This gradient geothermal is consistent with prevailing gradient geothermal on eclogite of this complex.

Sari - Sekis kuarsa-mika putih tersingkap sangat baik di Daerah Sadang, Kebumen Utara dan di Kaliwiro, Wonosobo selatan, Jawa Tengah. Batuan tersebut mengandung kuarsa, mika putih, albit, garnet, klorit, epidot yang kadang dengan sejumlah rutil, titanit, kalsit, grafit, opak dan biotit. Kenampakannya memperlihatkan nerbutir kasar, berfoliasi, miring ke Utara-Barat Laut. Kehadiran rutil dan garnet dalam himpunannya mengindikasikan mineral tekanan tinggi hadir di dalam batuan. Kandungan Mg, Fe, Si bersama dengan Al pada mika putih mewakili mika fenjit sedangkan garnet cenderung berupa almandine dengan komposisi xAlm: xPrp : xSps : xGrs = 0.59:0.05:0.03:0.33dengan rata-rata rasio Fe sebesar 1,14. Perhitungan geo-termometri menggunakan pertukaran Fe-Mg pada garnet dan biotit serta perhitungan geo-barometri menggunakan garnet-biotit-fenjit-albit menghasilkan suhu 380°C, tekanan 15-16 Kbar dengan gradient geothermal sekitar 7,3° C km^{-1}terjadi selama metamorfisme. Hal tersebut terjadi pada kedalaman sekitar 50 km. Nilai gradien geothermalyang berpengaruh sangat konsisten dengan gradien geothermal yang berpengaruh pada eklogit pada komplek ini.

INTRODUCTION

The Luk Ulo is a river located in Kebumen district, Central Java that its upper course is come from the northern subdistrict, called Sadang area which formerly part of Karangsambung area. This area is one of the three areas in Java where pre-Tertiary rocks cropped out; other areas include Ciletuh in West Java and the Jiwo hills in Central Java. The area is underlain by a complex of Late Mesozoic to Paleocene tectono-stratigraphic terrain to the north and Tertiary sedimentary terrain to the south. The regions are separated by a fault zone running approximately ENE-WSW (Asikin, 1991). To the south of the fault the rock association consists mainly of olistostromal and turbidity deposits indicating sedimentation in tectonically active basins. To the north, tectonic mixtures of various kinds of metamorphic, dismembered ophiolites and sedimentary rocks dominate the area which is generally separated by tectonites. The latest northern part belongs to the Luk Ulo Melange Complex (Asikin, 1974).

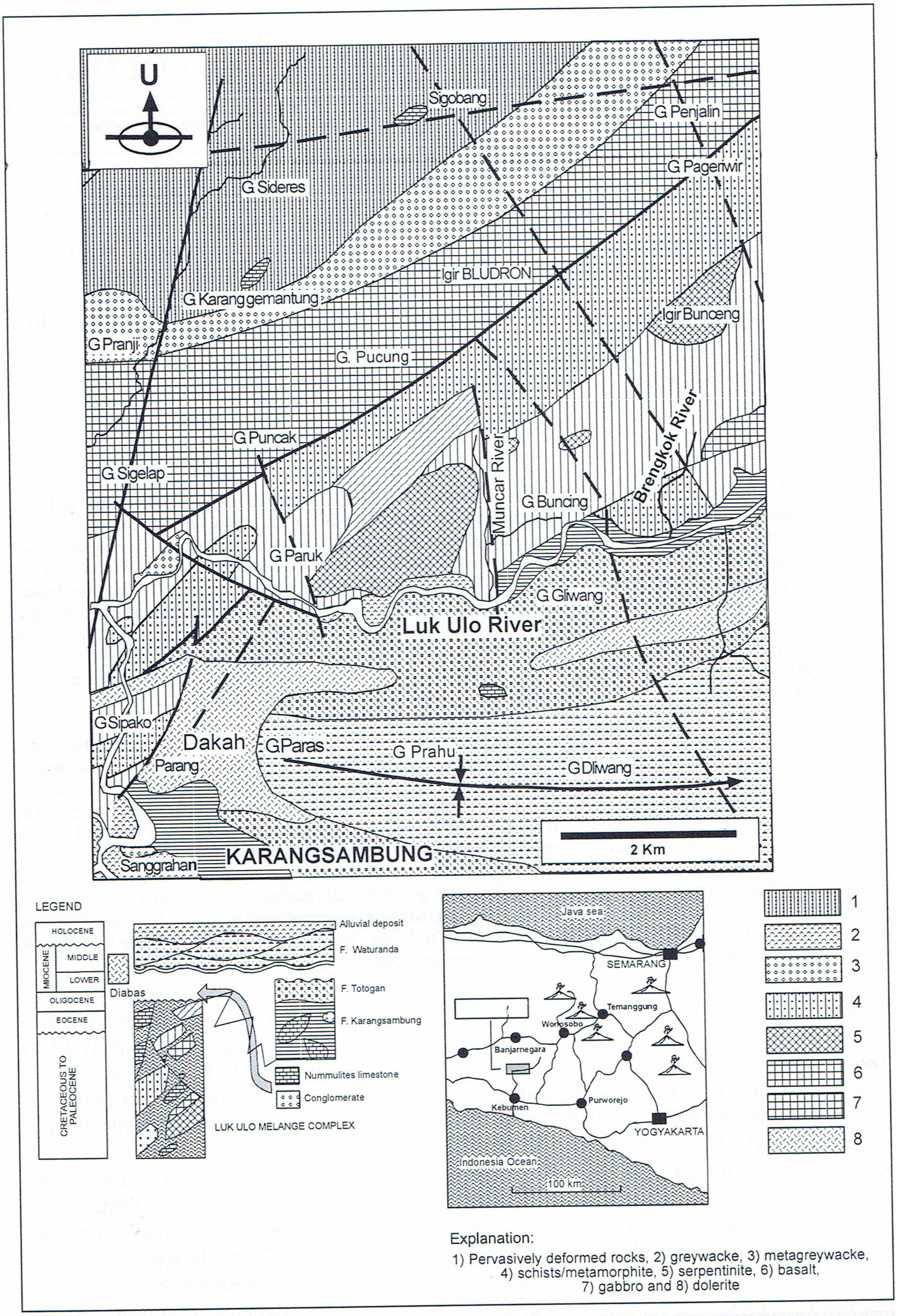

Figure 1. Geological map of the Luk Ulo Area, Kebumen Central java (Modified from Asikin, 1991)

Dismembered ophiolites is common in the area. The pillow basalt, gabbro and the serpentinized ultramafic rocks are never found in complete sequence. The pillows are commonly fresh and unmetamorphosed while high pressure metamorphites of ophiolite protolites and metagreywacke are sliced among it. In the other hand mica-schist is disrupted and incorporated in the melange. If dismembered ophiolites and meta-turbidity rocks are native block in the subduction zone it should be seems exotic for mica-schist.

The authors traversed along Brengkok River in Sadang Kulon area where the mica schist cropped out, collected samples and made structural measurements along mica schist–metabasite detachment. The purpose of the report is to discuss provenance, emplacement of mica schist based on petrology and structural geology of the detachment and to infer its tectonic history.

GEOLOGIC SETTING

Pre-Tertiary accretionary complexes of SE Sundaland are distributed in SW-NE trending. It is started from Ciletuh, West Java, to east at Karangsambung area, Central Java and extends to Meratus, Island of Laut, and Mangkalihat, Kalimantan. Cross over Makasar strait to Bantimala, South Sulawesi and extends to north and north east to Pompangeo, Central Sulawesi and Mengkoka, SE Sulawesi respectively. Some outcrops exhibit UHP metamorphic rocks such as in Karangsambung, Meratus and Bantimala (Sikumbang N dan Heryanto.R, 1994, Miyazaki et al,1996, 1998; Parkinson et al, 1998) while some others exhibit very low-low metamorphic grade (Parkinson et al, 1998, Soesilo et al, 2000)

The SE Sundaland accretionary complexes consist of para schists, HP-VHP metabasites, alternating of limestone, chert and greywacke

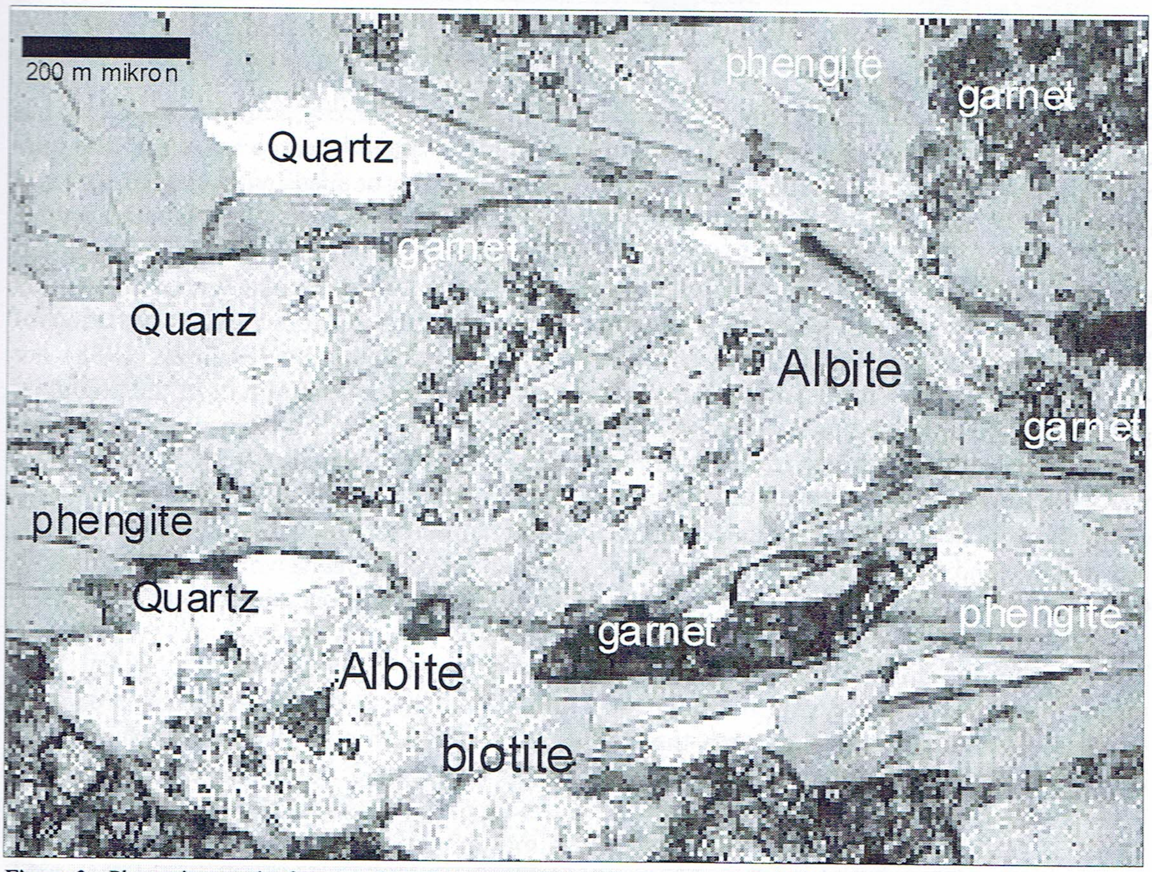

Figure 2. Photomicrograph of quartz-whitemica-garnet-albite schist from the LUMC. Garnet presents as inclusions in other minerals including albite, phengite.

Table 1. Petrographic description on samples taken from the LUMC.

Sample number	KSb2	KSb2B1	KSb2B2	KSb2B3	KSb2B4	KSb4	KSb 5	KSb 5b	KSb 7a	KSb 7b	KSb 8	KSb 9	KSb 10	KSb 11a	KSb 11b	KSb 12	KSb 14	KSb 20	KSb 24	KSb 24a	KSb 38
Rock names	quartz-phengite-garnet schist	quartz-phengite schist	quartz-phengite schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	actinolite rocks	quartz-phengite schist	quartz-phengite schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	quartz-phengite-garnet schist	tremolit-garnet-quartz rock	quartz-phengite-garnet schist	quartz-tremolite-garnet schist	quartz-phengite-garnet schist
Texture																					
cataclastic				■							■	■	■								
schistosity	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Mineralogy																					
Calcite	■	■			■						■	■					■		■		
Quartz	■	■		■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
Epidote	■	■	■		■		■	■			■							■	■	■	
Zoisite		■		■													■				
Clinozoisite	■		■		■	■	■	■	■	■	■		■	■		■	■	■	■	■	
Opaque		■					■					■				■	■		■		
White mica	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■		■		■
Biotite											■	■									
Rutile								■								■	■				
Titanite	■						■	■		■	■					■	■			■	
Chlorite	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	
Garnet	■			■	■	■	■				■	■	■	■	■	■	■	■	■	■	■
Tremolite							■											■		■	
Actinolite								■									■	■		■	
Albite/Plagioclase	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■			■
Graphite													■								

of Cretaceous age, serpentinized ophiolite slices, and black shale matrix of melange (Asikin, 1974, Ketner, et al., 1976, Hehuwat, 1986, Suparka, 1988, Sikumbang and Hery-anto, 1994). Commonly, the accretionary complex may combine metabasites, ophiolites and terrigenous derived rocks. In the Pre -Tertiary subduction of SE Sundaland, terrigenous derived rocks may obtain sources from Sundaland or may come from northward shuttled micro continental slices accompanying The Thethian oceanic plate in the middle- end of Mesozoic time (Audley-Charles,M.G.1976).

The Cretaceous-Early Paleogene tectonic melange and Tertiary olistostromal and turbidity sediments (figure 1) overlay the Sadang-Karangsambung area, Kebumen district. The melange has been known as the Luk Ulo Melange Complex (Asikin, 1974). The rock assemblage consists of a mixture of highly deformed rocks of different environment. They include greywacke, argillite, pillow basalt associated with red cherts and pink colored limestone, dismembered ophiolites and high pressure low temperature greenschist to blueschist facies metamorphite. The large tectonic slabs consisting of dismembered ophiolite (Suparka, 1988) are distributed in the central part of the complex. The Luk Ulo Melange Complex is unconformable overlain by Eocene-Oligocene mass flow sediments of the Karangsambung and Totogan Formations. Then followed by sedimentation of Neogene volcaniclastics that in some sequences intercalated with carbonate-clastics.

Based on the field data, the occurrence of the tectonic melange is considered had been progressed up to the end of Eocene time when the mass flow sediments had simultaneously been deposited inside its inter-flank basins. Unconformable over the mass flow sediments, the volcaniclastic

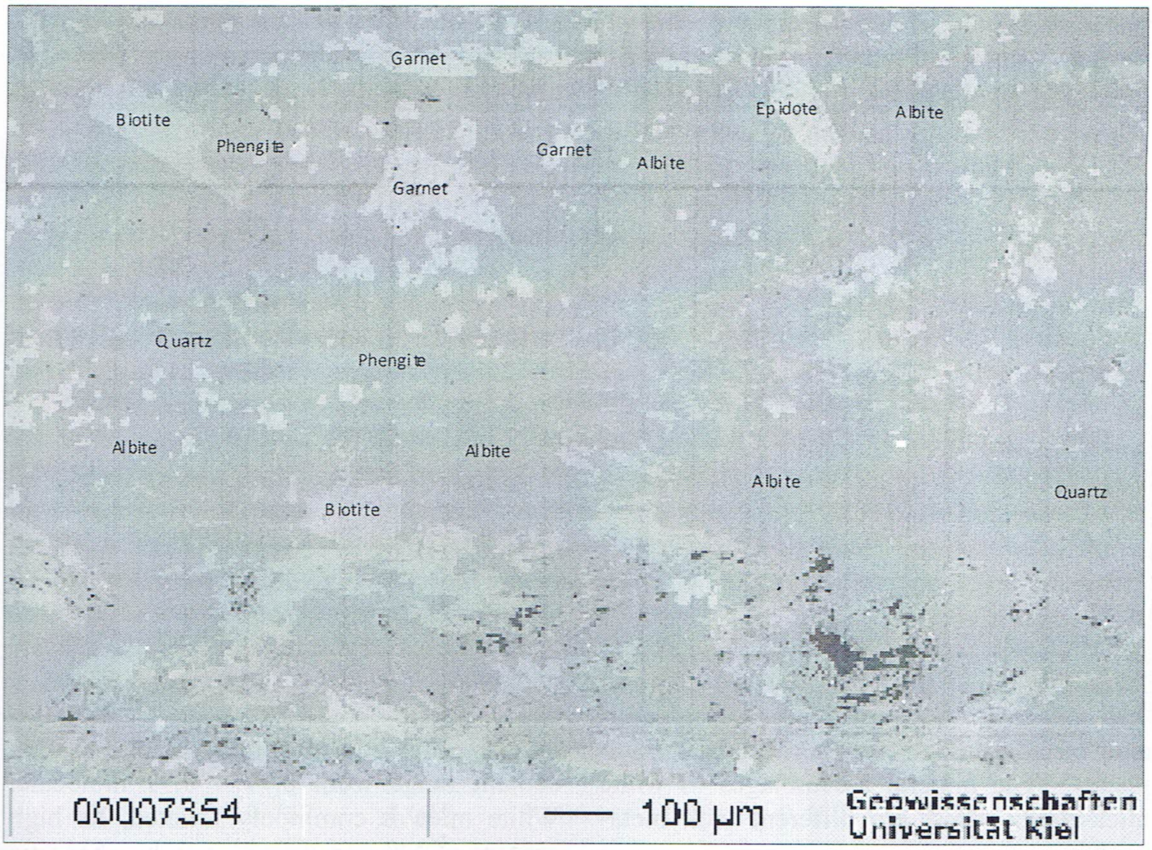

Figure 3. Photomicrograph of backscattered imagery taken from EPMA. High Mg and Si content in white mica classify mica as phengite.

sediments of Waturanda, Panosogan, Halang and Peniron Formations are deposited. It was happened in Early to Middle Neogene time when the area has developed as magmatic arc. The Tertiary sequence is gently folded with an E-W trending vertical axial plane.

METHODS

During research all of the rocks samples have passed some procedures. Initially started from collecting representative rock samples, and then followed with whole rock and mineral chemistry analysis. Collecting rock-sample was done during dry season of 2008 fieldwork in the research area, Sadang subdistrict, Kebumen Central Java. Traverses of relatively N-S in river Loning, Paladadi, Brengkok and Muncar may present some relatively fresh metamorphic rock samples.

Thin sections of the quartz-whitemica schist are polished in a 0.03 mm thick which may enable polarized light emanates through the body of mineral. The thin blade is put in preparative glass and be sticked with Canada balsam adhesive. Whole rock chemistry analysis of Major, Rare Earth and Trace Elements are applied using XRF and ICP-MS methods. All thin sections, XRF and ICP_MS were done in Geolab, Indonesian Centre for Geological Survey (PSG). Mineral chemistry analysis was done in Institut fur Mineralogy and petrography, University of Kiel, Germany. It was preceded by Electron Probe Micro Analyzer, Jeol Superprobe JXA 9800 RL.

PETROLOGY AND GEOCHEMISTRY OF THE QUARTZ-WHITE MICA SCHISTS

Garnet bearing quartz-white mica schist is cropped out in Sadang area, about 8 km northeast of Karangsambung subdistrict. It is distributed to the east over southern Kaliwiro area, Wonosobo district. The schists are amalgamated with serpentinized ophiolites

Table 2. Whole rock chemistry of quatz-white mica schist taken from the LUMC.

Sample no	KSb2	KSb2B2	KSb9	KSb11B	KSb12	KSb24A	KSb38
SiO_2	63.07	58.15	64.24	57.49	54.82	49.7	60.7
TiO_2	0.819	0.678	0.81	1.73	1.04	1.41	0.843
Al_2O_3	17.44	16.2	16.88	19.34	16.96	13.7	17.17
Fe_2O_3	5.15	4.68	4.41	7.1	7.01	12.16	6.41
MnO	0.125	0.125	0.111	0.159	0.162	0.184	0.157
MgO	2.04	2.02	2.23	2.14	3.11	7.94	3.82
CaO	2.55	7.36	2.62	2.66	6.65	10.58	2.99
Na_2O	3.4	5.81	3.23	4.01	2.32	3.27	3.84
K_2O	2.76	0.701	3.02	2.04	2.34	0.0499	1.61
P_2O_5	0.273	0.225	0.313	0.528	0.353	0.219	0.249
LOI	2.14	3.57	1.96	2.64	4.9	0.56	2.07
total	99.767	99.519	99.824	99.837	99.665	99.7729	99.859

and metabasites in the accretionary complexes. The mineral assemblages of white mica-quartz schist are different with metabasites.

It is greysh light, very well foliated and clearly free from S0 bedding. It's mainly composed by abundant of quartz, white mica, albite, chlorite, minute grains of garnet, epidote sometime graphite, titanite, calcite and rutile (table 1). In some area such as in Kali Loning some coarser-grained schists contain biotite. Garnet bearing quartz-mica schist is also found in Kaliwiro, about 15 km far to the northeast of. It is associated with quartz-feldspar porphyry and had intensely been weathered till 25 m thick. There is no age data taken from these samples but from the physical properties it might be similar with the Sadang's schist.

Garnet presents as minute euhedral polygonal mineral which commonly inside other mineral especially white mica and albite. Garnet show high almandine content than three other components: pyrope, spessartine and glossularite (figure 5). Petrographically occurrence of albite in the rock is notified by a lot of inclusions of garnet and quartz inside its polygonal subhedral body. Albite has Na content range from 0.94 – 0.97 molecule. White mica is commonly foliated. Its high content of Mg and Si lead it to be phengitic mica (figure 4). Ten mineral chemistry taken from the body of white mica are consistence show similar content of Mg about 0.54 – 0.8 molecule and Si = 6.73 – 7.1 molecule and Fe = 0.27 – 0.4 molecule.

In the other hand next to the quartz-white mica schist are meta-basite. Sometime inside the schist, there is metabasic intercalation, generally no more than 0.5 m wide. Metabasite rock are recrystallized to epidote amphibolite that contains hornblende, epidote, garnet, albite, biotite and sometime white mica. The K-Ar dating of white mica form quartz-white mica schist yielded ages 117 Ma (Ketner et al. 1976), 115 Ma and 110 Ma (Miyazaki et al. 1998)

Body of schist is gently to steeply folded with an ENE-WSW trending, without S_{X+1} mineral assemblage. Deformation D_{X+1} might seem responsible for the folds. The schist is northward thrusted over metabasite in horizontal to gentle angle. The attitude nearby is intensely disrupted and sometime contained

Table 3. Trace element and Rare Earth Elements taken from quartz-white mica schists

	KSb2	KSb2B2	KSb9	KSb11B	KSb12	KSb24A	KSb38
Rb	58.399	14.184	61.767	45.000	46.038	2.274	40.000
Ba	23.670	8.572	18.962	18.666	25.487	1.866	15.811
Th	91.716	117.905	85.462	78.300	32.443	5.719	50.347
U	89.170	75.668	106.048	75.387	47.398	25.738	47.117
Nb	1.714	2.005	1.873	1.645	0.992	0.673	1.925
K	25.929	6.586	28.372	19.165	21.983	0.469	15.125
La	4.711	5.766	4.655	3.538	3.504	1.566	3.481
Ce	3.493	4.457	3.233	2.525	2.305	0.461	2.350
Pr	1.041	2.083	0.955	0.222	0.092	0.005	0.005
Sr	0.885	2.049	0.736	0.913	1.140	0.901	1.140
Nd	1.884	2.515	1.881	1.556	1.557	0.559	1.434
Zr	0.163	0.212	0.122	0.204	0.228	0.195	0.166
Sm	0.994	1.610	1.007	0.874	0.805	0.189	0.656
Eu	0.719	0.936	0.749	0.801	1.034	0.959	0.936
Ti	0.507	0.420	0.502	1.071	0.644	0.873	0.522
Gd	0.680	1.136	0.701	0.723	0.601	0.425	0.565
Tb	0.780	1.040	0.701	0.983	0.644	0.701	0.701
Dy	0.676	0.866	0.590	0.893	0.552	0.692	0.628
Y	0.747	1.048	0.606	1.051	0.589	0.808	0.647
Ho	0.641	0.805	0.537	0.879	0.507	0.708	0.604
Er	0.560	0.693	0.459	0.823	0.473	0.654	0.558
Tm	0.741	0.950	0.628	1.224	0.676	0.918	0.757
Yb	0.715	0.900	0.613	1.238	0.677	0.946	0.759
Lu	0.679	0.849	0.560	1.205	0.679	0.917	0.713

granule size metabasite porphyroclasts in the disrupted schist. The thrusts made the river valley carpeted by metabasit while the infacing walls are garnet bearing quartz-mica schist. Milonites and fault breccias note its contacts the metabasite.

Underlying metabasite is dominantly composed by of tremolite-actinolite. Some samples show high-pressure rock protolith that has been retrograded to tremolite-actinolite rock. Ultra milonite, milonite and fault breccia are common found in the disjoin with mica schist. Jadeite-glaucophane-quartz rock (Parkinson et al. 1998) taken from Muncar river is composed by jadeite, quartz, glaucophane, garnet, phengite and rutile. It shows 124 ± 2 and 119 ± 2 Ma of the K-Ar age dating (Parkinson et al. 1998) and reached the peak PT conditions 20 – 24 kbar and 490-570°C (Miyazaki et al. 1998). Near Brengkok Village, in the reaches of the river, quartz-white mica schist is intruded by basalt. Quartz feldspar veins are also found nearby.

PRESSURE AND TEMPERATURE CALCULATION

Petrographical data of the quartz-white mica schist is not enough encourage showing that the body of rock suffer high pressure metamorphism such as displays by neighbor rock: eclogite which shows high pressure mineral assemblages. Moreover people think that the quartz-white mica schist is tend to suffer high temperature metamorphism except the present of garnet in between the assemblages. Commonly its textute indicates planar structure, gently inclined and event sometime in horizontal. A dif-

Table 4. White mica chemical composition

No.	190	191	192	195	224	225	226	239	241	245
SiO2	51.8	49.5	50.3	50.0	49.9	53.3	50.6	50.6	49.9	49.9
TiO2	0.2	0.4	0.3	0.3	0.4	0.3	0.3	0.0	0.2	0.4
Al2O3	24.7	26.4	26.9	27.0	26.7	24.2	27.0	27.4	28.2	27.4
Cr2O3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FeO	2.6	3.5	2.5	3.6	3.6	2.4	3.2	2.6	3.0	2.9
MnO	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	3.7	3.1	3.1	3.1	3.1	4.2	3.1	3.1	2.7	2.8
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Na2O	0.1	0.1	0.5	0.4	0.2	0.1	0.3	0.2	0.1	0.2
K2O	11.1	11.0	10.8	10.9	11.1	11.4	10.8	11.1	11.2	11.2
Total	94.4	94.1	94.2	95.2	95.0	95.8	95.5	95.0	95.3	94.9

Number of ions on the basis of 22 Oxygen

No.	190	191	192	195	224	225	226	239	241	245
Si	7.000	6.759	6.812	6.745	6.756	7.096	6.786	6.801	6.703	6.734
Ti	0.025	0.038	0.026	0.033	0.040	0.029	0.035	0.004	0.020	0.044
Al	3.900	4.253	4.287	4.286	4.259	3.788	4.272	4.334	4.462	4.368
Cr	0.004	0.004	0.000	0.003	0.003	0.003	0.002	0.002	0.001	0.000
Fe	0.300	0.403	0.281	0.402	0.406	0.268	0.363	0.290	0.334	0.328
Mn	0.004	0.008	0.003	0.004	0.000	0.001	0.002	0.004	0.001	0.003
Mg	0.800	0.630	0.616	0.618	0.616	0.823	0.611	0.613	0.539	0.570
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.000
Na	0.033	0.039	0.123	0.098	0.061	0.021	0.086	0.052	0.039	0.057
K	1.912	1.917	1.866	1.876	1.925	1.927	1.850	1.907	1.923	1.928
Total	14.0	14.1	14.0	14.1	14.1	14.0	14.0	14.0	14.0	14.0

ferent appearance is showed by outcrops in the river of Brengkok which is strongly folded and mix up with metabasite and sometime augen structure appears as well as porphiroclasts of metabasite.

In contrary mineral chemistry data show phengite white mica is present together with almandine garnet which are indicate qualitatively high pressure mineral assemblages. Pressure and temperature calculation using garnet-biotite geothermometry (Ghent and Stout, 1981) and garnet-biotite-muscovite (white mica)- plagioclase geo-barometry (Ferry and Spear, 1978) indicate that the quartz-white mica schist suffered temperature of 380°C and pressure of about 15-16 Kbar during its metamorphism. Gradient geothermal influenced the metamorphism is supposed about 7.3°C/ km which mean cold condition metamorphism.

PROTOLITH

Quartz-white mica schist consists of quartz + white mica + albite + chlorite + garnet + epidote ± titanite ± graphite ± biotite ± rutile ±calcite in vary proportions (table 1). That micaceous assemblage identifies a politic rock protolith. Whole rock chemistry data (table 2) refers to a composition of largely SiO_2-Al_2O_3-Fe_2O_3-MgO-K_2O-Na_2O-H_2O although some amount of MnO, CaO and TiO are also present . According to Spear S, 1993 those composition is also consistent belong to pelitic composition except KSb2B2 and KSb24A. KSb2B2 has high CaO and Na_2O content but lack of K_2O that indicated calcareous politic rock, but KSb24A tends to be resemble with intermediate – basic volcanic which is lack of

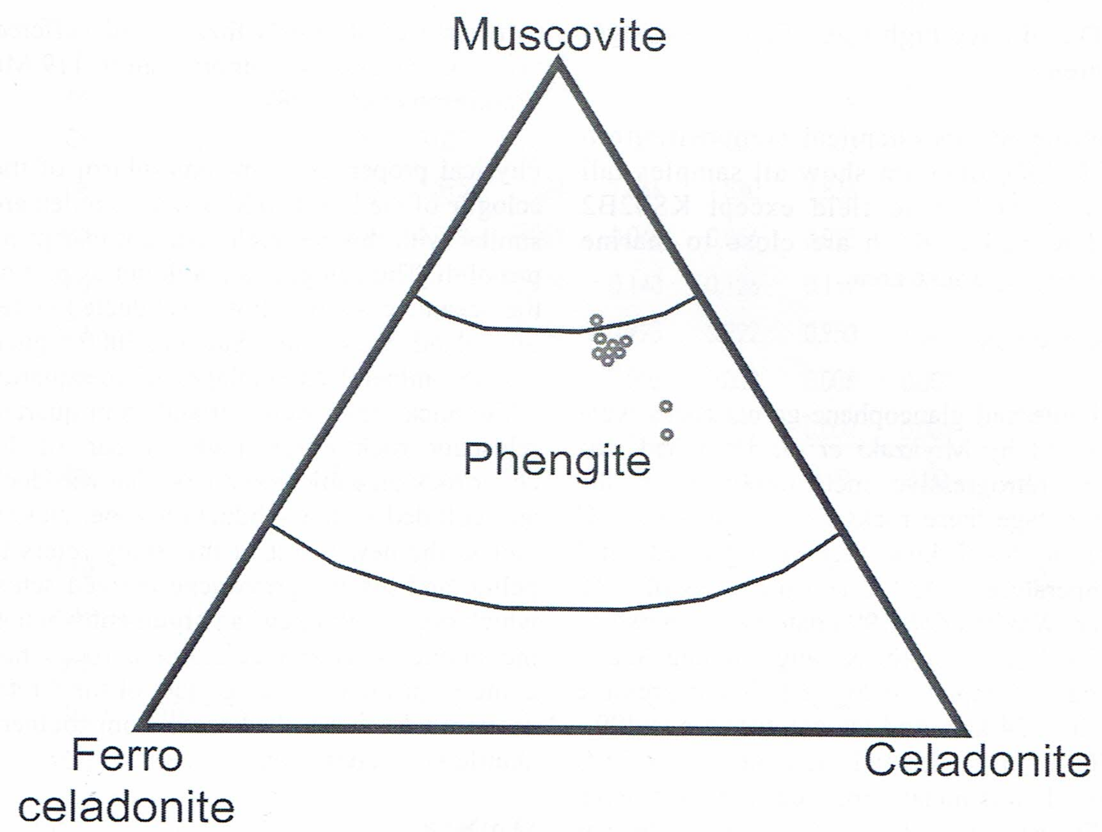

Figure 4. Plotting of composition space of dioctahedral micas of KSb8 which display phengitic white mica.

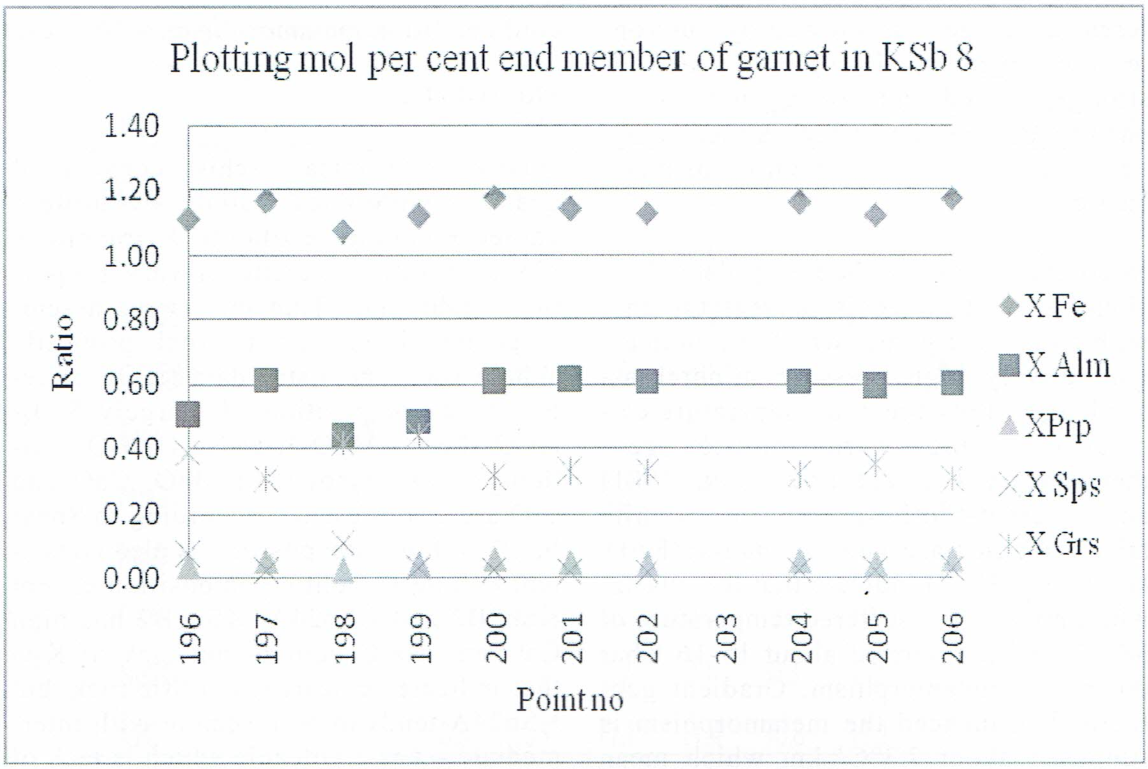

Figure 5. Plotting of mol percent end member of garnet in sample no. KSb 8

K_2O and have high CaO, Fe_2O_3 and MgO contents.

Plotting of its chemical composition on ACF-AKF diagram show all samples fall in clay and shale field except KSb2B2 and KSb24A which are close to marine clay or greywacke area.

DISCUSSION

Eclogite and glaucophane-garnet rocks were reported by Miyazaki *et al*, 1996 had suffered retrogressive metamorphism. In the early stage these rocks got of 580 - 650° C and of 24-27 kbar then retrogressed until temperature of 450°C and pressures of ~ 15 kbar. Wakita *et al*, 1994 date its age between 113 - 132 Ma. In the Karangsambung Accretionary Complex, eclogite suffered pressure of 20 – 24 kbar and temperature range 490 - 570° C in geothermal gradient almost 7° C km^{-1}. It was metamorphosed in 80 km depth (Miyazaki *et al*, 1997). The metabasite was part of the dismembered ophiolite of the Thethian oceanic plate of 120-130 Ma (Miyazaki et al, 1994) then it had suffered very high pressure metamorphism in 119 Ma (Parkinson *et al*, 1998).

Physical properties of metamorphism of the eclogite of the Luk Ulo Melange complex are similar with this research resultant except its protolith. The eclogite is not doubt as part of the oceanic crust which was subducted under Sundaland. Soesilo and Sutanto, 2000 argued that the mineral assemblages of the quartz-white mica schist were derived from quartzo feldspatic rock which might be part of the cover rock on a microcontinent that was dock and collided in the subduction zone. Nevertheless the new result of this study refers to pelitic and marine greywacke derived schist which might still opens an argument whether the pelitic derived metamorphic rocks had come from the overriding plate of the Cretaceous subduction or had come from southern shuttle microcontinent.

SUMMARY

Mineral assemblages of quartz + white mica

No.	196	197	198	199	200	201	202	204	205	206
SiO2	37.89	37.46	37.73	37.64	38.15	38.07	38.10	38.56	38.22	38.50
TiO2	0.51	0.19	0.09	6.14	0.13	0.02	0.24	0.27	0.22	0.08
Al2O3	20.64	20.87	20.93	18.35	21.47	21.22	21.23	21.23	21.11	21.47
Cr2O3	0.04	0.04	0.00	0.03	0.00	0.01	0.05	0.02	0.02	0.08
FeO	23.11	27.95	20.44	21.38	27.75	28.33	27.97	28.08	27.09	27.51
MnO	3.26	0.95	5.05	1.49	0.88	0.71	0.84	0.88	0.85	1.19
MgO	0.93	1.38	0.64	1.02	1.53	1.20	1.08	1.36	1.03	1.48
CaO	13.79	10.93	15.00	15.03	11.17	11.77	11.77	11.34	12.36	10.97
Na2O	0.06	0.06	0.04	0.02	0.00	0.00	0.05	0.04	0.01	0.03
K2O	0.05	0.06	0.06	0.07	0.08	0.01	0.01	0.00	0.05	0.05
Total	100.27	99.90	99.97	101.18	101.16	101.34	101.33	101.78	100.95	101.36

Number of ions on the basis of 12 Oxygen

No.	196	197	198	199	200	201	202	204	205	206
Si	3.003	2.993	2.997	2.936	2.998	2.998	2.997	3.014	3.011	3.015
Ti	0.030	0.011	0.005	0.360	0.008	0.001	0.014	0.016	0.013	0.005
Al	1.928	1.965	1.960	1.687	1.989	1.969	1.969	1.956	1.960	1.982
Cr	0.002	0.002	0.000	0.002	0.000	0.001	0.003	0.001	0.001	0.005
Fe	1.532	1.868	1.358	1.395	1.824	1.866	1.840	1.836	1.785	1.802
Mn	0.219	0.065	0.340	0.098	0.059	0.048	0.056	0.058	0.057	0.079
Mg	0.109	0.165	0.075	0.119	0.179	0.140	0.126	0.159	0.120	0.173
Ca	1.171	0.936	1.277	1.256	0.940	0.993	0.992	0.950	1.043	0.921
Na	0.009	0.009	0.006	0.004	0.000	0.000	0.008	0.006	0.002	0.005
K	0.005	0.006	0.006	0.007	0.008	0.001	0.001	0.000	0.005	0.005
Total	8.01	8.02	8.02	7.86	8.00	8.02	8.01	8.00	8.00	7.99
X Fe	1.11	1.16	1.08	1.12	1.18	1.14	1.13	1.16	1.12	1.17
xAlm	0.51	0.62	0.45	0.49	0.61	0.61	0.61	0.61	0.59	0.61
xPrp	0.04	0.05	0.02	0.04	0.06	0.05	0.04	0.05	0.04	0.06
xSps	0.07	0.02	0.11	0.03	0.02	0.02	0.02	0.02	0.02	0.03
xGrs	0.39	0.31	0.42	0.44	0.31	0.33	0.33	0.32	0.35	0.31

Alm = almandine; Prp = Pyrope; Sps = Spessartite and Grs = Glossularite

xFe = Fe/(Fe+Mg); xAlm = Fe/(Fe+Mg+Mn+Ca); xPrp = Mg/(Fe+Mg+Mn+Ca), xSps = Mn/(Fe+Mg+Mn+Ca), xGrs = Ca/(Fe+Mg+Mn+Ca)

Table 5. Garnet chemical composition

Table 6. Albite (left) and K Feldspar (right) chemical compositions

Albite											K Feldspar
No.	213	214	215	216	217	229	231	233	234	235	240
SiO2	69.0	68.8	69.1	68.7	69.0	68.8	68.7	68.7	68.7	68.9	64.14
TiO2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.07
Al2O3	19.0	19.0	19.2	19.0	18.8	18.7	18.9	18.7	18.8	18.8	17.67
Cr2O3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
FeO	0.2	0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.1	0.1	0.05
MnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.00
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
CaO	0.2	0.1	0.1	0.2	0.0	0.2	0.2	0.1	0.1	0.1	0.00
Na2O	11.2	11.4	11.1	11.3	11.3	11.3	11.4	11.4	11.3	11.4	0.28
K2O	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	16.63
Total	99.62	99.46	99.67	99.59	99.39	99.27	99.41	99.06	99.22	99.43	98.84

Number of ions on the basis of 8 Oxygen

No.	213	214	215	216	217	229	231	233	234	235	240
Si	3.020	3.016	3.018	3.010	3.025	3.024	3.015	3.024	3.018	3.021	3.009
Ti	0.000	0.003	0.000	0.004	0.000	0.001	0.000	0.002	0.000	0.000	0.002
Al	0.979	0.979	0.987	0.983	0.974	0.969	0.978	0.969	0.976	0.973	0.977
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	0.006	0.001	0.003	0.006	0.001	0.002	0.004	0.000	0.002	0.003	0.002
Mn	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.003	0.001	0.000
Mg	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.002	0.001
Ca	0.008	0.004	0.003	0.008	0.002	0.007	0.007	0.003	0.007	0.005	0.000
Na	0.950	0.970	0.944	0.958	0.962	0.962	0.971	0.973	0.966	0.969	0.025
K	0.005	0.006	0.009	0.007	0.008	0.007	0.009	0.006	0.006	0.005	0.995
Total	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.01

Table 7. Biotite chemical composition

No.	187	188	189	221	222	223	232
SiO2	36.78	37.03	37.66	36.76	36.66	36.31	37.21
TiO2	0.879	1.376	1.103	0.842	1.016	1.495	0.835
Al2O3	17.26	16.04	16.34	17.78	17.19	17.54	17.25
Cr2O3	0	0.04	0.034	0.077	0.04	0	0.02
FeO	21.07	20.35	19.9	20.73	20.51	21.26	19.45
MnO	0.424	0.36	0.358	0.341	0.343	0.426	0.37
MgO	9.34	9.75	9.72	8.95	9.57	8.99	10.31
CaO	0	0.01	0	0.019	0.026	0.036	0
Na2O	0.124	0.082	0.085	0.127	0.072	0.131	0.121
K2O	9.73	9.72	9.76	8.64	8.98	8.79	9.71
Total	95.607	94.758	94.959	94.266	94.408	94.977	95.276

Number of ions on the basis of 22 Oxygen

No.	187	188	189	221	222	223	232
Si	5.634	5.709	5.768	5.658	5.647	5.579	5.667
Ti	0.101	0.160	0.127	0.097	0.118	0.173	0.095
Al	3.116	2.915	2.950	3.226	3.121	3.176	3.097
Cr	0.000	0.005	0.004	0.009	0.005	0.000	0.002
Fe	2.699	2.624	2.549	2.668	2.642	2.732	2.477
Mn	0.055	0.047	0.046	0.044	0.045	0.055	0.048
Mg	2.133	2.241	2.219	2.053	2.197	2.059	2.341
Ca	0.000	0.002	0.000	0.003	0.004	0.006	0.000
Na	0.037	0.025	0.025	0.038	0.022	0.039	0.036
K	1.901	1.912	1.907	1.697	1.765	1.723	1.887
Total	15.68	15.64	15.59	15.49	15.57	15.54	15.65

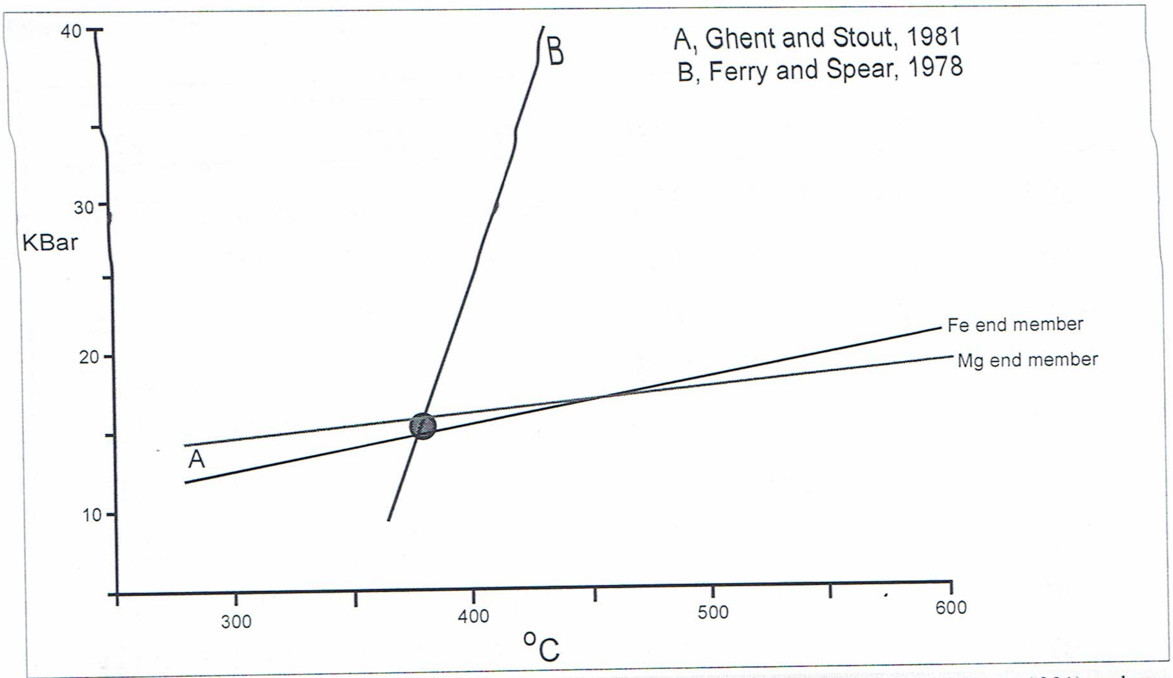

Figure 6. Plot of geo-thermometer based on Fe-Mg exchange of garnet-biotite (Ghent and Stout, 1981) and geo -barometer based on reaction of assemblages of garnet-biotite-muscovite (white mica) and plagioclase (Ferry and Spear, 1978)

+ albite + chlorite + garnet + epidote ± titanite ± graphite ± biotite ± rutile ±calcite in quartz-white mica of the Luk Ulo Melange Complex indicated pelitic derived rocks. It is supported by its whole rock geochemical analysis which are supposed to be pelitic and marine greywacke protolith. Present of rutile and garnet among of the assemblage support an idea that metamorphism occurred under high pressure condition. Its mineral chemistry analysis shows the rocks contain rutile, almandine and phengite. Plotting on garnet-biotite geo-thermometry and garnet-biotite-white mica-albite geo-barometry confine that metamorphism occurred under temperature of about 380°C and pressure between 15 – 16 Kbar with gradient geothermal about 7,3°C/ km. Quartz-white mica schist was metamorphosed in at least 50 km depth. This condition is consistent with pressure and temperature controlled metamorphism of the eclogite in this accretionary complex except it depth. It suggest that the quartz-white mica changed in shallower depth that the eclogite.

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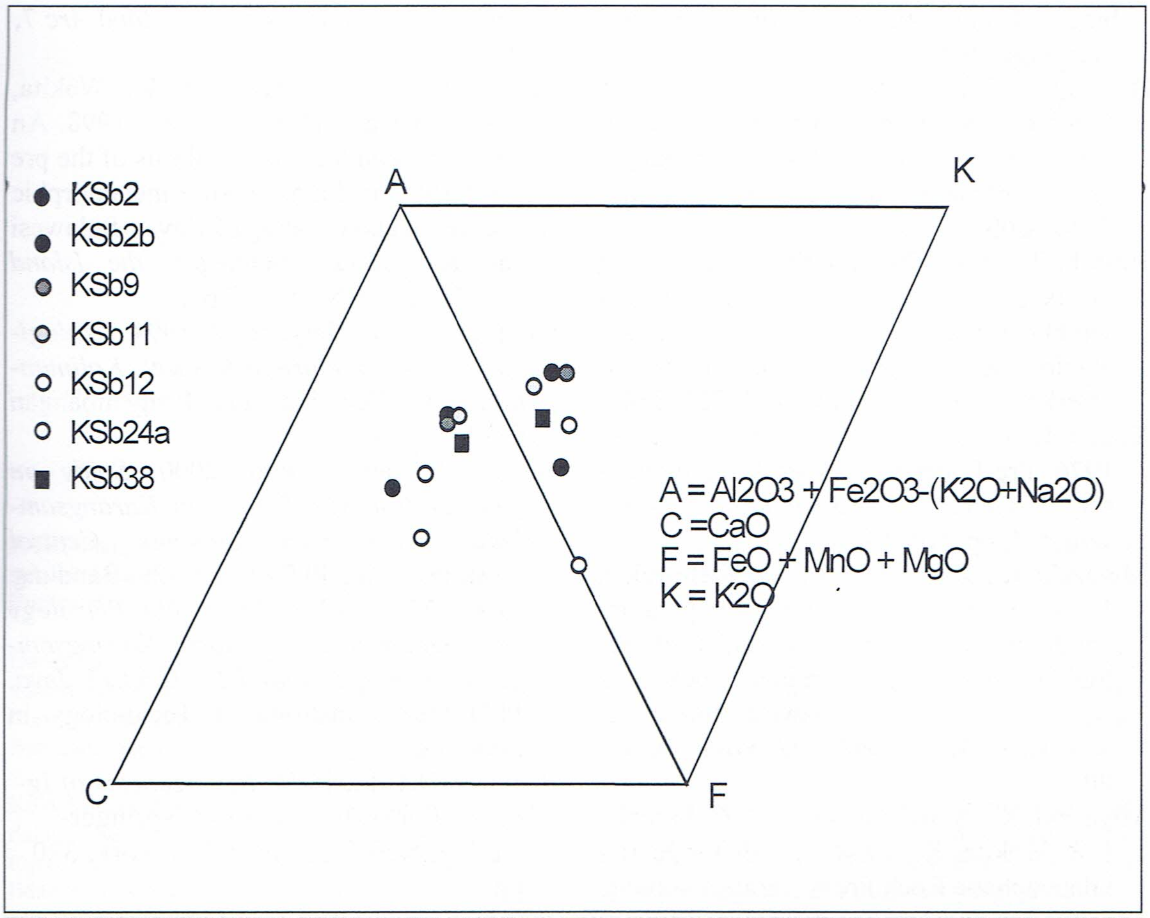

Figure 7. Plotting of quartz-white mica chemical composition on ACF-AKF diagram. A corner on AKF diagram is $A=Al_2O_3+Fe_2O_3-(K_2O+Na_2O+CaO)$

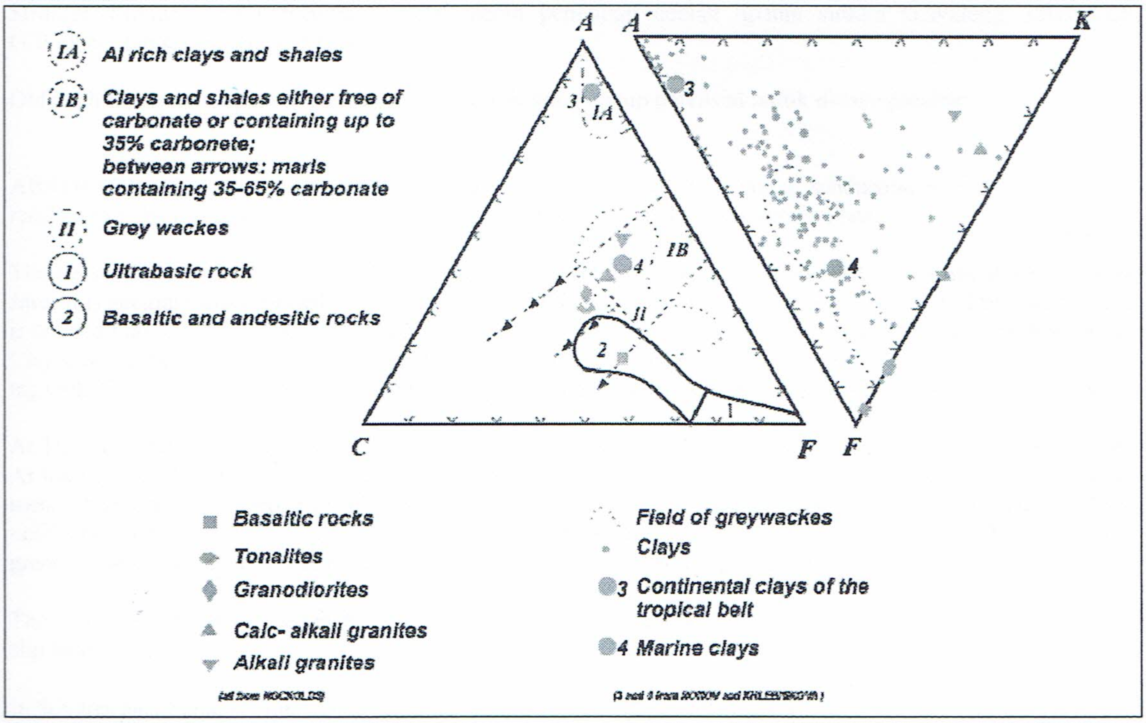

Figure 8. The chemical composition of various rocks plotted on ACF-AKF diagram. (Winkler, HGF, 1974)

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