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METASOMATISM (INFILTRATION, DIFFUSION), BUFERING AND FLUID TRANSPORT IN THE UBO MARBLE AREA WITHIN THE IGARRA SCHIST BELT, SOUTHWEST NIGERIA

F. U. ASHIDI

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ABSTRACT

The processes of metasomatism in the Ubo marble area have been investigated. The evidence available shows there are five isograds formed by the combined effect of diffusion and infiltration metasomatism in prograde.

(i) Wollastonite – Parawollastonite (intergrowth)
(ii) Scapolite – intergrowth (Merwinite – marialite)
(iii) Grossularite – Andradite – intergrowths
(iv) Andradite – Diopside + (Salite – Ferrosilite)

All these occurred to limited extent in contact with felsic dykes in the marble trunks. The mafic ultramafic intrusives while resident underneath the metasediments sourced mobile, and compatible trace elements (N1, Cr, V etc) influx migration, anti gravity roof pendant metasomatism leading to high concentrations of these upper mantle derived elements in the metasediments.

At the northern boundary of the marble (mass A), the pluton emplacement resulted in severe baking, margin chilling and vesiculation of the carbonate rocks leading to recrystallization of existing phases and the fabrication of highly refractory phases – parawollastonite, larnite, spurrite etc, which rules out any buffering effect due to any fluids at peak of metamorphism.

Texturally the emplacement of the intrusives led to uplift of the metasediments at their contacts and shearing with resultant shortening led to local mylonitization and massive poikiloblastic crystallization of wollastonite – scapolite – garnet – vesuvianite as prograde phases with mylonitic crystallites as inclusions.

The mylonitization was accompanied with hydrofracturing which enabled fluid flow either pervasively or in channels to reach through the rocks effecting 22 devolitilization reactions. A few of these reactions are retrograde. The introduction of fluid enhanced diffusion (symplectitic intergrowths) infiltration and buffering (several prograde and retrograde reactions).

The source of fluid could be metamorphic, hydrothermal, meteoric or even magmatic which is mainly undirected but flowed down temperatures.

The volatilization effectively produced mixed – fluids; CO_2 –H_2O which were characteristic in effecting retrograde reaction stabilizing: sillimanite, stilpnomelane, chloritoid, andalusite, staurolite and cordierite. Sharp reaction fronts are not established in the prograde reactions nor in the retrograde phases as well.

KEYWORDS: Metasomatism, infiltration, Diffusion Shortening Channelized

INTRODUCTION

Metasomatism has been defined as the changes in the bulk composition of rocks in the solid state which occurs to some degrees in virtually all contact metamorphic environments, although, the types, scales, and causes vary (Barton et al, 1992). The definition is apparently silent on the changes or constancy in the volume of the affected rocks as the rock is considered only in the solid state. There are two mutually independent end members associated with metasomatism; these are (i) infiltration metasomatism and (ii) diffusion metasomatism. These may occur together but are virtually independent of each other. Diffusion metasomatism (bimetasomatism) is driven by differences in chemical potentials and promoted by temperature and prolonged times, while infiltration metasomatism occurs to some degrees around mot intrusions in the upper crust and even deeper intrusion with widely varying character, (Einaudi et al, 1981; Joesten and Fisher, 1988; Frantz and Mao, 1976, 1979).

The most enduring of the debate is that of direction of fluid flow Ferry (1989, 1991, 1992a,b; Kerrick (1992), Barton et. al. (1992), Symmes and Ferry (1991) and Brenan 1992 propose a fluid flow direction from a lower temperature terrane (the country rock to a higher temperature region (the intrusive) while Hart et al. 1991, Masch and Heuss-arpbchiler 1991 and a host of others posited that fluid in contact metamorphic aureoles and even under hydrothermal conditions move from the hot region along with thermal energy down into the country rocks.

The Ubo marble and other basement metamorphic rocks in the Igarra schist belt area of S.W. Nigeria present the geological setting and features in which the processes of regional and contact metamorphism with attendant magmatic and hydrothermal processes can be carefully investigated and monitored along the concepts of metasomatism (infiltration, diffusion) and buffering outlined above.

Geologic Set Up

The Ubo marble is the carbonate unit of the younger metasedimentary Precambrian rocks in the Ubo area within the Igarra schist belt of S.W. Nigeria. It is underlain by and bordered in the eastern margin by a biotite schist body. A few meters east of the biotite schist body lies a more or less leucocratic gneiss body of parallel orientation with the marble body extending several kilometers in a N.S. direction (Fig 1). The main intrusive body is a single pyroxene gabbro about 1,500m in thickness in the east-west direction and of 1.5 km in the north-south direction. It was violently emplaced lifting the northern margin of the marble several meters above its former level. Massive stopping occurs at the contact though no extensive marble body is found at the northern border of the gabbro. However intrusive plugs north of the gabbro are extensively covered with calcsilicate materials. There were some chilled margins found at the marble contacts with the gabbo.

Several dolerite dykes finger into the marble masses as apophyses of the gabbro. A network of narrow skarn bands are formed at the contact margins between the marble bodies and the gabbro bodies and to a very limited effect between the marble and the felsic intrusives. At dolerite contacts with the schist, which were very abundant in the marble mass B. complex hybrids hornfels and calcsilicates are produced. Mircogranite, aplite, pegmatite (fractional differentiates of the gabbro magma) (Ashidi, 1999b; 2000) occur as swarm

F. U. Ashidi, Applied Geology Department, Federal University of Technology, P.M.B, 704, Akure, Nigeria.

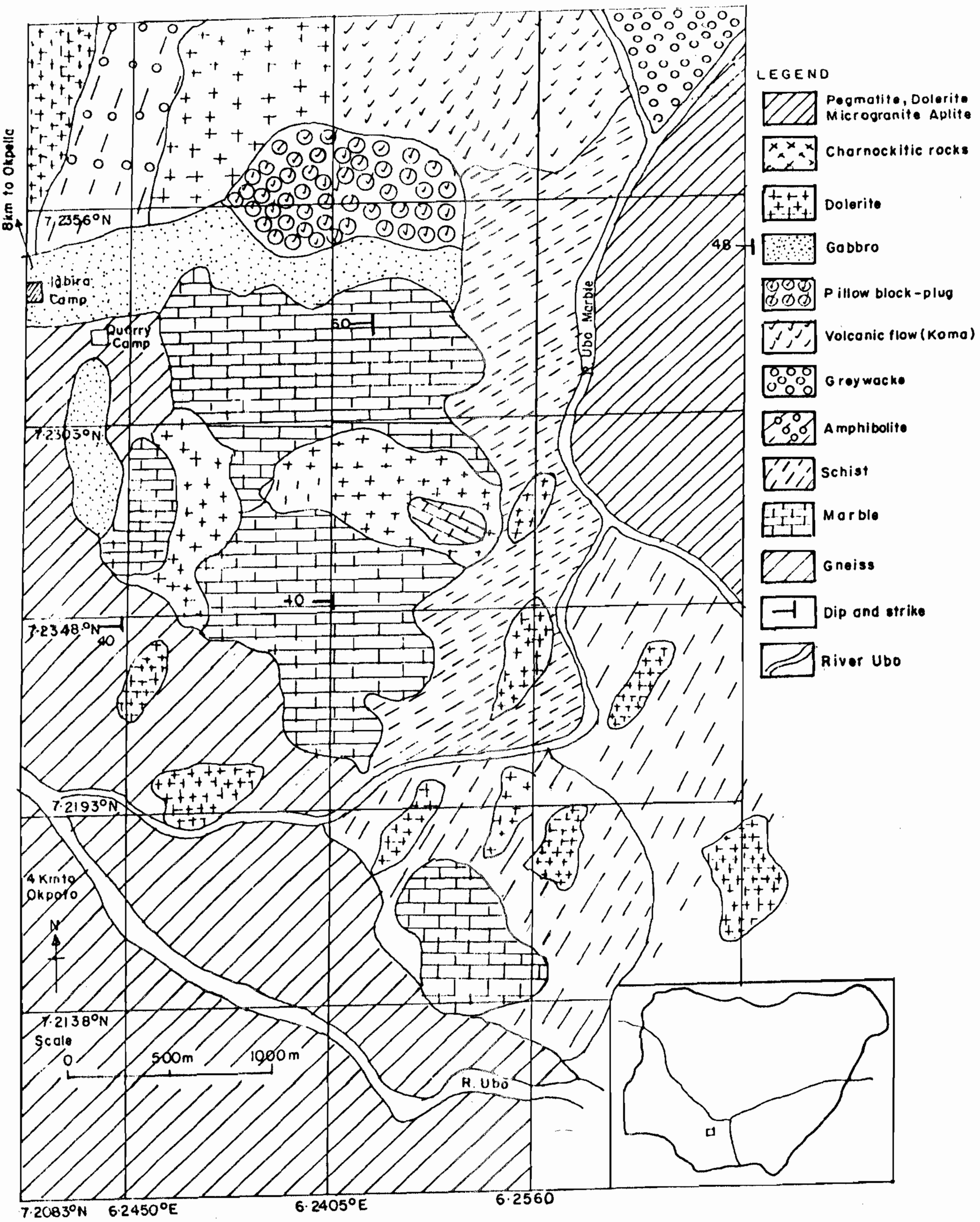

Fig.1: Geological map of Ubo area. Insert map of Nigeria showing Ubo marble area.

outcrops within the marble forming an intrusive network, cross-cutting one another thus making it impossible to know which one is younger or older.

Petrography of the rocks of the Ubo marble area:

The Marble: The marble deposit forms the trunk of a monoclinal series. Arcelloni (1965) gave a comprehensive economic appraisal of the marble describing it as a pure calcitic marble with purity value reaching up to 99.7% $CaCO_3$ in most samples. Calcite crystals at the contact with the gabbro measure above 5cm across and this size diminishes away from the contact to very fine grains in the marble mass C which is about 1,500m; away from the gabbro contact. Ashidi (2000) reports of several impurities in the Ubo marble which include, scapolite, muscovite, zoisite, epidote, quartz and some opaques. Quarry works have exposed the trunks of the marble bodies for closer observation of the several felsic intrusives.

The Gabbro – diorite: The gabbro is a coarse grained single clino pyroxene non-ophitic, andesine – labradorite bearing mafic rock intrusive into the marble at the north. It is extensive and has lifted the marble body several meters up at the its southern border – which has a lot of stopped, calcsilicate boulders. Three apical plugs on top of the gabbro have the appearance of basanitoids which contain apart from plagioclase and pyroxene that were in almost equal proportion in the gabbro, hornblende was present in three forms Ashidi (2000, 2003).

The pyroxenite – basanitoids: These are swarm like plugs hardly measuring above 3-4m high and contain piles of pillows. Here the background looks like a flow material with a bouldery mass at the centre, Clinopyroxene megacryst measure in certain places up to 10cm across (such large crystals are marked with frequent martilization at the edges). With shreds of plagioclase, titanite is a major substitute for the plagiocalse.

The Amphibolite: The amphibolites occur as low lying well foliated massive dykes trending northwards. Klemm et al. 1979, Olade and Elueze 1978 and Bafor 1988 reported amphibolites in the Nigerian schist belts. The mineralogy is mainly hornblende, and minor plagioclase. The amphibolites and the serpentinites occur interspersed among the pyroxenite and diorite plugs.

The Dolerite dykes (Apophyses): The dolerite outcrops as dykes (quite extensive 50m diameter) in two localities. The dyke to the east is fine grained while that to the south is relatively coarser. The mineralogy of the dolerites is same as that of the gabbro except for abundance of modal scapolite, vesuvianite, and other calcsilicate minerals.

The Aplites, Microgranites and Pegmatites: The felsic rocks are intertwined hence it is impossible to determine which of the three rock types is youngest or oldest. The microgranite has more abundant biotite than the aplite. The aplite was not totally devoid of biotite but are of two feldspar kinds – one with predominantly microcline while the other was predominantly Na – feldspar. The two kinds were not mixed in any form. The mineralogy of the aplite and microgranite has a lot of aluminosilicates – profusely characterized by andalusite, sillimanite, staurolite and cordierite.

The Gneiss and the Schist: The gneiss outcrops extensively in the east of the marble bodies. It is more or less leucocratic, often variegated, low lying west wards but gradually rising towards the east away from the marble bodies. The mica content is actually very low – usually less than 10% modal composition (Ashidi 2000). However, it contains K-feldspar, sillimanite, staurolite, plagioclase, quartz, some amphibole and abundant cordierite. The schist is weathered in its exposed outcrop in between the marble and the gneiss. However in the trunk of the marble mass B, several intercalations of the biotite schist are found in the excarvations. The schist has been altered generally to hornfels by the swarm invation of dolerite dykes.

The Skarn Assemblages: The skarn bands are generally narrow between the gabbro and the marble bodies. They are almost imperceptible between the dolerites and the marble while between the felsic rocks and the marble, they are only observable under the microscope. Five conspicuous isograds are mapped (Ashidi, 2000), which represent five stages of progressive calc-silicate reactions:- wollastonite – parawollastonite; - scapolite – grossular, grossular – andradite; - titanite; titanite – diopside – plagioclase.

Analytical Methods

Sample Preparation and analysis

All samples preparation and analyses except Fe_3 + CO_2 and H_2O determinations were carried out at the Department of Petrography/Mineralogy; and Geochemistry/Geology in the University of Munich,Germany. Analysis of H_2O and CO_2 were performed in the University of Belgium.

The preparations include:

1. Thin sectioning of slides for transmitted microscopic studies,
2. Polished-thin sectioning of whole rock samples for reflected microscopy (SEM) and microprobe studies.
3. Fused glass discs of whole rock samples for XRFS studies
4. Whole rock mineral acid digestion for REES.

Whole-rock dilithium –tetra borate fusion glass discs

0.8g powder of whole rock samples and 4.8g of $Li_2B_4O_7$ were thoroughly mixed and fused at 1,200°C in platinum cups for XRFS studies. Whole rock samples finely ground and quartered, later weighed for acid attack were used in solution for ICP-MS analysis of REE values. The polished thin sections were prepared in automatic machine and coated with graphite for microprobe analysis.

Presentation of Results

Skarn Rocks

There are five conspicuous isograds in the skarn bands. They define progressive contact reactions:

1. Wollastonite – Parawollastonite
2. Wollastonite – Scapolite
3. Scapolite – Grossularite
4. Grossularite – Andranite – Diopside
5. Diopside – Titanite – Plagioclase –

Wollastosnite parawollastonite intergrowth is detected on single crystal X-ray diffractometer determination with introduction of pure silicon to the sample as standard calibration (Kayode and Enu 1974).

The prograde reaction was mainly at contacts between the gabbro and the marble and was not conspicuous at other contacts.

General modal composition at the reaction skarns are shown in table 1. In most samples in the endoskarn, diopside and salite range between 10 – 45%, hornblende has values of 10% - 15% usually as exsolved phases. Plagioclase as partially altered material in the endoskarn and as neocrystallites in the exoskarn. (10 – 15%).

Tremolite – actinolite were found only in few locations in the exoskarn. The modal composition is between 5-25%. All actinolite samples have mutilated/altered edges. Garnet is most abundant after scapolite. It is found anastomising around other crystals as poikiloblasts enbosing neocrystallites. Only few well formed euhedral crystals were found in the endoskarn with average modal composition of about 20%. Wollastonite occurs most often as bladed poikiloblasts. In many cases there were exsolved calcite and quartz grains in the matrix of wollastonite. Calcite was abundant as exsolved blebs either in garnets, vesuvianite, wollastonite or scapolite. Epidote-zoisite was found in about ten locations in which the modal range was between 10 and 20%, though it was up to 40% in one sample.

Table 1 : Modal analysis of Skarn minerals.

SKARN MODAL ANALYSIS	4	6	7	9	10	13	14	17	19	20	30	51	52	53	54		
KF=K-Feldspa		Gabbro Skarn				Pyroxenite Fe Skarn	Gb		Gabbro Skarn								
MODAL/MINE	1	2	3	4	5	6	7	8	9	10	11	12		14	15	16	
DIOPSIDE		40		20	15	60	45	20	15		10	10	20		10	10	
SALITE/FAL	5		10	10	10		15		45		35				10		
Hornblende		5						10		10		5					
Plaggiodace				5		5	5	10				5			20		
Scapolite		10	70	25	20	5	20	30	5	10		10	30		20	20	10
Versvvianite											20						
Tremolite Actinolite								20						5		10	
Gernet			5	10	15	5	10		10		20				20	30	20
Wollasitonite		15						30		25				10	10	30	
Calcite		5		5	20	5	5		5	5	10		15		5	10	20
Epidote		10	5	10	5			10									
B-Quartz										5			20				
Zoisite																	
Scheelite									10			10	10		10	10	10
Corrcliente																	
Tourmaline										5		5					
Quartz		5	5	5	5	5	5	5	5		10		5		5	5	
Titante		20		10	10	5	10		10	10	5	10					
Apatite										10		10					

Table 1 continued

SKARN MODAL ANALYSIS	55	57	59	62	63	64	66	71	74	75	76	77	81	82	83	84	85	86	87	88	89	90	141	147	148
KF = K-Felspar			Pyroxenite Skarn			Dorerite Skarn					Gabbro Skarn														
MODA/MINE	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38			
DIOPSIDE	10	30	20						10		20		20	30	20	20					5				
SALITE FAL	5	15	20		40																				
Hornblende																									
Plaggiodace		40	30	5	5	40	35					[illegible]	10		10	20						5			
Scapolite	20			35				50	20	35	10	30	20		10	10	45	30	[illegible]	50	20	40			
Verswianite											20			20											
Tremolite Actinolite											10	10													
Gernet	20		10	15	20	20	10	10	15	20	20		30	10	50	20	20	20	15	15		5			
Wollasitonite		15	5	30	20			20	30	30		20+chl			10		20		20						
Calcite				5	10			10	5	10								20	20	10	40	10			
Epidote				10				10										20	20	10	40	10			
B-Quartz						15										10									
Zoisite	5													40											
Scheelite									20		20	20	30			20									
Corrcliente																						20			
Tourmaline																									
Quartz	20	5				5	5				5		10				5				20	5			
Titante			10		5	5						5	10					5		5	5	5			
Apatite																									

Table 2: Trace element composition of Skarns

	Gabbro skarn																	
	1	4	6	7	9	10	13	14	17	19	20	30	102	103	104	105	106	107
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	14	16	17	18
Rb								13	10	22	Nd	19	10	10	10	14	34	10
Sr								202	192	136	1837	167	223	204	875	89	515	185
Zr								113	165	204	10	62	256	401	82	208	156	96
Ba								116	240	226	68	428	162	179	83	106	624	116
Cr								284	325	503	49	865	528	Nd	475	444	958	450
Mn								952	1087	805	10	217	926	882	528	560	578	522
Ni								1750	1531	2463	1109	2563	2468	313	2230	3822	4056	2176
Zn								16	59	42	Nd	11	50	56	19	55	47	31
V								77	260	146	Nd	10	180	202	34	49	45	20
La								Nd	38	10	Nd	Nd	Nd	Nd	10	Nd	10	10
Nb								Nd	10	Nd	Nd	Nd	10	13	Nd	Nd	10	Nd
Nd								13	60	15	Nd	Nd	13	26	10	10	10	Nd
Th								Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd	Nd
Y								25	25	23	17	20	21	23	21	18	20	19

P-quartz was found in four different locations with an average modal composition of 15%.

Modal Composition of the Gneiss, Aplite, Microgranite, the pegmatite and their skarns.

Aplite is fine grained slightly foliated. Microcline are fractured at their margins with staurolite with minor garnet crystals at deformed edges. Garnets were found as exsolution or inclusions in the cores of staurolite. Garnets in the matrix are identical in shape to those in the cores of staurolite. Cordierite are free of any inclusions. Chloritoid occurred not as fine fresh crystals but altered and deformed. Andalusite crystals occur as fine to medium euhedral rhomb aligned along fracture planes. A few limbs of andalusite are fractured looking less deformed than the chloritoid. While andalusite crystallized along fracture planes, chlorioid had no specific constraint and occurred with no particular orientation, but were evenly distributed in the matrix of the samples. Sillimanite was associated with the sleeves of stilpnomelane which occurs more or less porphyroblastic in the rock. Some of the edges of the stilpnomelane have been altered to kyanite. In the rocks, biotites occurred in two distinct forms (green and brown) Iron dotted sillimanite associated in stable equilibrium with biotite.

The Actinolite-tremolite present in the exoskarn is replaced in the endoskarn assemblage by diopside. Vesuvianite and garnet were anastomising. Diopside coexisted with crystals of epidote. Wollastonite and epidote (all poikiloblastic) contained inclusion of calcite + quartz which did not yield wollastonite. Plagioclase-scapolite contacts yielded faint coronas. The scapolites are exoskarn derived by reaction of calcite + plagioclase. In a typical thin section (sample 137), several monomineralic bands occur along a traverse within thin section range:- calcite quartz vesuvianite epidote and a poikiloblastic scapolite band that contains inclusions of all the previous species, respectively in that order.

The hornfels formed as a result of contact reactions between the aplite and the schist. Calc-silicate poikiloblasts with pelitic inclusions (aluminosilicates and micas) – zoisite, vesuvianite and some lime garnet.

Discussion of Results:

The complex nature of diffusion and infiltration in the field is difficult to determine from their effects. Diffusion of ions definitely occur across ionic potential/chemical gradients, while infiltration is conditioned on the possible movement of both water, gases and solutes. The most conspicuous evidence in the field is the occurrence of prograde isobaric reactions that are termed isograds.

Five isograds are mapped at the contact between the intrusive and the carbonate rock. The isograd closest to the marble is monomineralic – wollastonite, all others are polymineralic. According to Brock (1972) who defined diffusion skarn as those formed under conditions of low metasomatic intensity and normally occurs in sequential monomineralic bands adjacent to the marble body, suggesting that diffusion was the major mechanism involved in the production of wollastonite.

Ashworth et al. (1992) in discussing diffusion coronas around clinopyroxene suggested that wollastonite is formed because of a higher mobility of Si over and above Al. The authors cited an example of Al – saturated phase (hornblende) that has a corona of an aluminium undersaturated phase (actinolite). Since it is an isothermal reaction to transform one phase to the other phase, the authors hinged the occurrence to lack of sufficient diffusion through crystal edges. While infiltration is considered on a megascopic scale, whether it is perverse or channelized, diffusion is usually considered to occur as an intergranular phenomenon..

In the Ubo marble there are two conspicuous sources of heat energy from the intrusives:

i) From roof pendant baking
ii) Post intrusional lateral heating

Roof pendant baking introduced upward thrust, anti-gravity, migration of trace elements to the marble and other felsic lithologies resulting in prolific, unusually high concentrations of elements in these rocks (Ashidi, 2000, 2003).

According to Joesten (1992), grain coarsening involves the transfer of material from smaller grains which are dissolving to larger grains that are growing. The driving force for dissolution, diffusion and precipitation is the chemical potential differences that exists between large and small grains of the same phase due to differences in their surface area and hence surface free energy. Hence the phenomenon of grain coarsening involves a lot of fluid phases in effecting diffusion, dissolution and precipitation.

The implication of porphyroblasts development in the contact areas is perverse fluid flow and fluid generation through multitudes of microfractures. According to Bell et al, (1986) – porphyroblastic minerals cannot nucleate and grow in zones of active progressive shearing as they would be dissolved by the effects of shearing strain on their boundaries but they can nucleate and grow in zones of progressive shortening and this is aided by the propensity for microfracturing in these zones which allows rapid access of fluids – carrying the material presumed to be necessary for nucleation and growth.

From the foregoing, the abundance of porphyroblasts in the contact zone of study area suggests infiltration of fluid through microfractures. The various microclasts contained in poikiloblasts indicate an earlier progressive shearing leading to local mylonitization in the contact zones. The calcsilicates are of various petropgrahic phases which implies, there had been repeated episodes of intrusive emplacements. Kano (1991) report how mylonitization had assisted metasomatic formation of augen gneiss from contact reactions of an intrusive granite with an hornblende gneiss while microfracture healing could have succeeded in sealing microfractures which were fluid transmission channels. Such evidence still abound in cases of andaluite which crystallized along partially healed fractures and cracked limbs of star shaped chloritoid grains. The occurrence of foliations in several directions marked by mineral alignment stands also as good evidence of fluid channel ways and due also to enhanced permeability in such lithologies.

Since the poikiloblasts contain products due to shearing, then shearing occurred much earlier than porphyroblasts formation. The shearing thus enhances pervasive fluid flow into the reaction zones in which several calcsilicates were formed with abundant fluid. This corresponds to what Jamteveit et al (1992) reported that first major fluid infiltration took place at near metamorphic peak conditions in forming stage one skarn in which carbonate layers are frequently completely replaced by skarns. The formation of stage 1 skarn, he stated, cannot be favoured by localized fault controlled brittle deformation but rather pervasive fluid infiltration.

Devolatilization Reaction

The reaction zones were marked with the following decarbonation reactions

1. Calcite + Quartz = Wollastonite + CO_2
2. Anorthite + 2Calcite + SiO_2 = Grossulante + $2CO_2$
3. 3 Anorthite + 2Calcite + H_2O = 2Epidote + $2CO_2$
4. 3 Anorthite + Calcite = Meionite + CO_2
5. 6 Albite+2NaCl = Marialite +CO_2; 6 albite + 2NaCl + Calcite = Marialite + CO_2
6. 3 Calcite + Tremolite + $2SiO_2$ = 5 Diopside + $3CO_2$ + H_2S
7. Calcite + Chloride = Al-actinolite + Zoisite + CO_2 + H_2O
8. Calcite + Chloride = Actinolite + Epidote + Water + CO_2
9. Grossular + Quartz = Anorthite + Wollastonite
10. Zoisite + Quartz = Anorthite + Wollastonite
11. Scapolite + H_2O = Epidote
12. Scap + H_2O = Vesuvianite + CO_2 + O_2
13. Scap + H_2O = Vesuvianite + Cal
14. 5 Dol + 8qtz + H_2O = Trem + 3 Cal + $7CO_2$
15. Cal + 3an ± H_2O 2 Zoisite + CO_2
16. Alpha Qtz = β-Quartz

Athe pelitic association

17. Andalusite:- Musco + qtz = K-fsp + andalusite + H_2O
18. Sillimanite:- Andalusite = Sillimanite
19. Staurolite + Musco + qtz = Sil + gar + bio + H_2O
20. Staurolite:- Chlorite + muscovite + garnet + stau + bio + qtz + H_2O
21. Chloritoid:- St + sil + grt = chloritoid
22. Cordierite:- Bio + musco + Qtz = Kfsp + cord + ilm + H_2O

Reaction 1 is monomineralic, though polymorphic with parawollastonite, is purely diffusional. Grossularite was most often zoned with andradite which also is a state of mobility difference between Fe, and Al. Reactions 4 and 5 are polymorphic. All reactions, except a few that consumed fluid, really produced fluid which are generally regarded as metamorphic fluids.

These stable phases of reaction 1-22 were produced under metasomatic roof pendant heating either by dehydration or decarbonation. Could there have been an external source of fluid, either magmatic, hydrothermal or meteoric besides these fluids generated in the contact aureoles? Besides, could these fluids flow either through channels, or pervasive – permeability controlled or by advection. A more complicating suggestion is the direction of flow of the fluid either along up temperature or down temperature.

Symmes and Ferry (1991), Rice and Ferry (1982), Kerrick (1992), are of the opinion that though magmatic fluid might take part in contact-metasomatic metamorphism, but that, metamorphic fluid in advective-pervasive, channelized, infiltrative up temperature flow occurs in metamorphic terranes.

However the major controversy has been the issue of up temperature or down temperature flow. While there is more or less concensus on the nature of fluid (whether pervasive or channelized) the solution to be considered is the mylonitization, brecciation due to emplacement shearing that affected the contact area which resulted in improved permeability, crack creation, and possible directed flow of fluid in the Ubo area.

Hanson (1992) asserted that the models of contact metamorphism do not account for the release of fluids from the intrusion or influx of fluids from devolitization occurring at depth corresponding to above 4kbars of lithostatic pressure. He asserted that such fluids would further inhibit fluid circulation in the models.

Masch & Heuss Apbichler (1991), Hart et al (1991), do not ascribe to external source of a metamorphic fluid nor a pervasive fluid flow in the contact zone, however agree that fluid could be produced through the intrusive and devolatilization reactions which are very limited in quantity during metamorphic peak.

Fig. 2 is a diagrammatic illustration of the fluid content and composition in the Ubo marble area compared to the stable mineral assemblages with their respective P – T conditions from Motoyoshi et al. (1992) and Schenk (1984). The X H_2O is usually about 2 x CO2 from the inner aureoles to what could be regarded as the innermost skarn rock. (Sample No. 7) where X CO_2 is 0.25, and X H_2O is about 0.18. That sample represents the peak of CO_2 decarbonation. Shortly thereafter X H_2O became more abundant through the skarn into the marble body.

The value of X CO_2 is usually greatly depressed by the abundant presence of X H_2O Ferry (1992). The fluid present in the Ubo marble area is a mixed-fluid X H_2O – X CO_2. The contacts of the intrusive rocks are chilled hence are marked by profuse boiling at metamorphic peak. Although Cartels (1983) suggested significant fluid will not occur through crystalline rock hotter than 400°C, however, Ferry et al. (1987) promptly retorted that contrary to Cathel's (1983) deduction, fluid – rock ratios > 0.5 calculated from oxygen isotope data implies flow of substantial amounts of fluids through the basalts from Skye at temperatures above 400°C, Ferry *et al op cit.* flows were recorded for temperatures hotter than 900°C. The H_2O – CO_2 is determined mainly for prograde reaction, although, even in the intrusives, pyroxene – hornblende, plagioclase – titanite plagioclase – scapolite, transformation and, inversion of Ca –feldspar to K-feldspar are evidence of retrogrades. Pattision and Harte et al (1991) believed in the occurrence of magmatic fluid to be responsible for generation of the mixed fluid, while Kerrick (1986) suggested that water was drawn from the wall rocks during most of the thermal metamorphism, of the roof pendant, but the magma expelled water in the late stage of crystallization. While abundant evidence occurs as to the possible production of water close to the intrusive body, Ferry (1992) remorsed that petrologic data on contact metamorphosed carbonates generally are inconsistent with flow of H_2O fluid out of pluton down temperature into their aureoles.

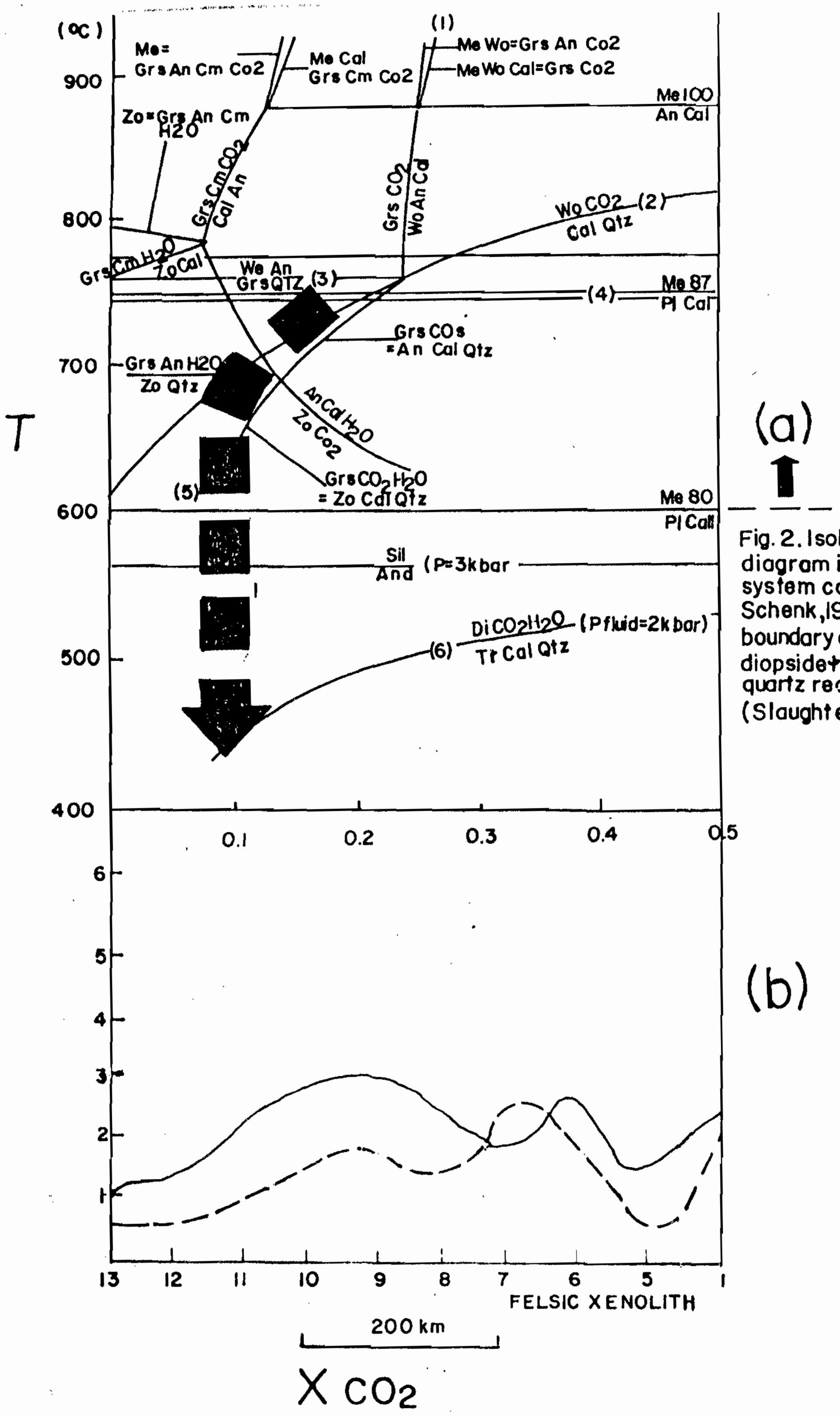

Fig. 2. Isobaric (P_l=6kbar)T-X_{CO_2} diagram illustrating reaction curves in the system CaO-Al_2O_3-SiO_2-CO_2-H_2O (after Schenk, 1984) with sillimanite-andalusite boundary at 3k bar (Holdaway, 1971) and diopside+CO_2+H_2O=tremolite+calcite+quartz reaction curve Pt=2kbar (Slaughter et al, 1975.)

Furthermore a flow during the peak of metamorphism at which wollastonite – pseudo wollastonite and parawollastonite, larnite and spurrite were produced at the vesicular skarns is most unlikely. Fluid that accompanied decarbonation reactions could have been on local basis. That gives much room for components and thermal buffering between samples and fluid.

Another dividing line is the direction of flow of fluid which has usually being hinged on sharp reaction fronts represented by invariant, univariant, divariant assemblages in the contact area.

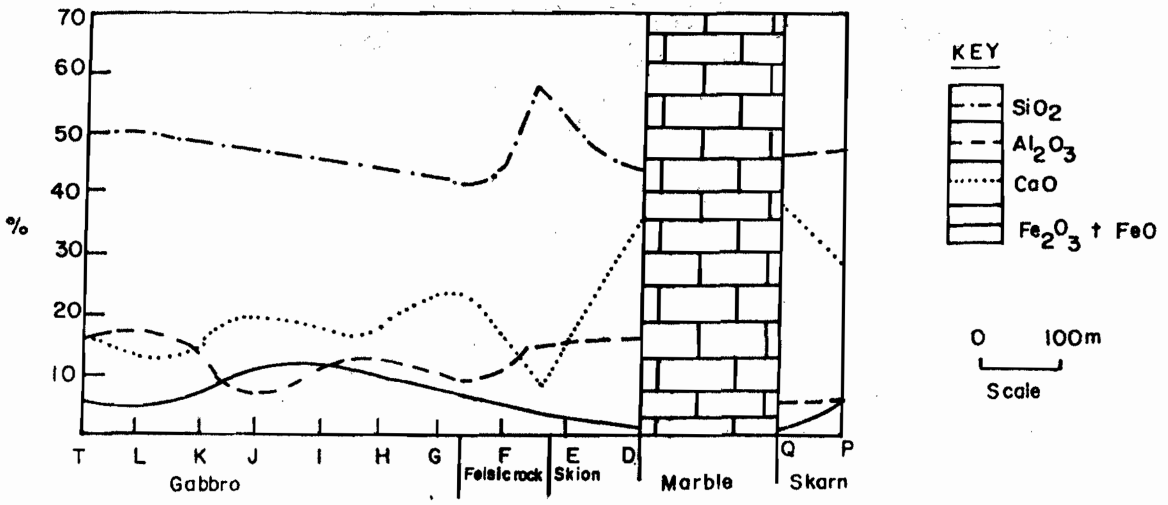

Fig. 3: Chemical distribution of four major elements along a horizontal profile on the Gabbro.

i) Ferry (1992) posited that, fluid flow along down temperature would normally give rise to sharp reaction fronts in which reactants will be far separated from the products. This accordingly will lead to invariant, univariant and divariant assemblages. However, Korzhinski (1970) explained that the influx of a magmatic fluid could lead to simultaneous reaction fronts in which different assemblages (unvariant, divariant, inviariant and multivariant assemblages could be formed. In the Ubo marble area only the diffusion skarn in which (Calcite + Quartz = Wollastonite + CO_2) wollastonite was the monomineralic phase occurred close to the marble. All other rock samples in the reaction zone have multiple phases which are classed as invariant, univariant or divariant.

CONCLUSION

The metasediments in the Ubo marble area experienced a period of roof pendant heating by the mafic-ultramafic magma that subsequently intruded these rocks. This under baking by the intrusive led to very rich mobile-element metasomatism and migration under favourable pH conditions. The under heating was succeeded by an intrusive emplacement at very shallow levels at the northern boundaries of the marble deposits.

There was abundant boiling at emplacement with occurrence of vesicular textures and chilled margins of the mafic rocks. The roof pendant heating had caused recrystallization and reequilibration of metamorphic phases leading to the occurrence of several calcsilicate minerals with severe shearing and shortening. These led to increased permeability, intensive decarbonation, hydrofracturing and subsequently advective fluid flow. Probably by introduction of meteoric fluid and hydrothermal fluid as residual product, after formation of the felsic phases, (microgranite, aplite and pegmatite) there was rapid fluid infiltration, and rapid development of poikiloblast at the waning thermal regime of the emplaced rocks. At the last stage, the mixed fluids H_2O – CO_2 buffered the mineral assemblages and led to the formation of retrograde phases both in the carbonate and schistose rocks.

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