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OPAQUE MINERALS IN SOME TONGONAN GEOTHERMAL WELLS

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ABSTRACT

The majority of hydrothermal minerals in the Tongonan field occur as: 1) partial replacement of groundmass and phenocrysts (disseminated mineralisation) and 2) infilling or lining of vugs, cavities and fractures(vein mineralisation. These minerals exhibit a distinct and systematic distribution with depth and temperature.

The opaque minerals comprise three volume per cent of the rocks, but locally reach fifteen percent in the intrusive contact and in the acid alteration zones. Pyrite dominates in most zones except in the R-silicate zones where a preponderance of magnetite over pyrite has been observed.
Genetically, the opaques can be divided into: magmatic(magnetite, pyrrhotite, ilmenite, chromite, titanomagnetite), sedimentary/diagenetic (pyrite, hematite, maghemite), contact metamorphic/skarn(mainly magnetite), supergene(pyrite, hematite, covellite, maghemite, goethite), and hypogene(sphalerite, galena, chalcopyrite, bornite, pyrite) minerals.

A temperature and distinct zonation of opaque minerals also parallels the calc-silicate alteration zones. Chalcopyrite is the most abundant base-metal sulphide. Minor to trace galena first appears in the inter-layered illite-montmorillonite sub-zone and persists with drilled depths; it is also strongly associated with hematite in acid alteration zones. Sphalerite is more intimately related with the propylitic alteration assemblage. Magnetite and pyrrhotite occur as ubiquitous inclusion in pyrite. In zones peripheral to dykes and in the main transition or "contact" zone, magnetite exhibits a preponderance over pyrite. This local abundance coincides with the K-silicate and advanced propylitic zones.

INTRODUCTION

The volceno-tectonic setting of the Tongonan reservoir shares similarities with fossil hydrothermal system such as epithermal base-metal and some porphyry copper deposits. These fossil systems provide information about the processes that led to the formation of ore deposits and such processes can be identified in various active geothermal systems(Fournier, 1983).

Base-metal mineralisation has been recognised in the Tongonan field (eg. Wood,1977,1980)although, there is a dearth of published information on opaque mineralisation on this system as attention has been paid to silicate alteration and geochemistry through the analysis of cores and cuttings from Tongonan wells. This paper describes the alteration patterns, opaque phases and relationship between these opaques and large scale alteration patterns. Polished mounts were prepared from cores, cuttings, surface samples, well blockage materials, ejecta and precipitates from weir boxes of discharging wells; these were examined under a reflected light microscope and some finely disseminated phases and inclusions verified with electron microprobe.

STRATIGRAPHY, LITHOLOGY AND ALTERATION

The Tongonan wells intersect a thick sequence (2100m max.) of upper Miocene to upper Pliocene lavas, breccias and tuffs interbedded with thin lenses of limestones, shales, calcisiltites which comprise the Bao Volcanic Formation(Table 1); these are intruded by a coarse grained granodioritic to dioritic pluton. The stratigraphy and lithology of the Tongonan field are discussed by Vasquez and Tolentino(1973), Grindley(1973), Wood(1976) and summarised by Ward(1979) and Knox(1983). This work draws mainly from recent unpublished papers of Ablaze (1980) and Reyes(1984).

Hydrothermal alteration in the Tongonan field records an outstanding example of complex fluid/mineral interaction with a wide range of minerals and their variegated textures. These are well documented in various petrological(published and unpublished) reports of Wood(1977-1980), Leach(1981-1983) Reyes(1979-1985), Ferrer (1983) and Knox(1983).

The primary mineralogy of the diorites and the andesites show a decreasing susceptibility to alteration as follows:
glass → pyroxene → hornblende → biotite → plagioclase +magnetite → quartz → apatite → sphene → zircon.
Figure 2 shows the typical replacement products of the Tongonan plagioclase and mafic minerals and their composition readjustments and styles of alteration under hydrothermal conditions.

Mode of formation, sequence and zonation

Majority of the Tongonan hydrothermal minerals occur: 1) as partial or complete replacement of pre-existing phenocrysts and groundmass
2) as filling and lining in vugs, cavities, and fractures formed by direct deposition in open spaces;
3) as scales in well blockage materials;
4) as scales in pipelines and precipitates in weirboxes for discharging wells; and
5) in well ejecta, as sub/euhedral crystals from permeable zones in some wells. These minerals exhibit a distinct and systematic distribution with depth and temperature; a pronounced zonation can be observed particularly with the interlayered clays, zeolites and some calc-silicates and which at increasing temperatures occur in the following sequence:

a) smectite - illite-smectite - illite ($\pm$ chlorite);

b) clinoptilolite - heulandite - stilbite - laumontite - wairakite;

c) epidote - garnet - talc - tremolite - biotite.

Two main types of alteration are recognised, viz: neutral pH and acid alteration.

Table 1 : SUMMARY OF TONGONAN STRATIGRAPHY (Slightly Modified from Reyes, 1984)

FORMATION		SYMBOLS	LITHOLOGICAL UNITS	AGE		THICKNESS DRILLED
North Central Leyte Formation			Algal limestone, andesitic conglomerates volcaniclastics and sandstones	Pleistocene to Recent		570 m (encountered in several shallow Bao 'alley wells
Bao Volcanic Formation	Younger Bao Volcanic Formation (BV1)		Weakly altered hornblende andesites with minor augite, hypersthene and biotite. Intercalated with minor tuff-breccia	Upper Pleistocene	Upper Miocene to Upper Pleistocene	900 - 2100 m (intersected in all the Tongonan wells)
	Post Sambaloran (BV2)		Biocalcarenites, calcisiltite, calcarenites and black carbonaceous calcisiltite/calcarenite with minor andesite volcaniclastics	Pliocene-Pleistocene		
	Sambaloran Sedimentary Sequence (BV3)		Thin calcareous lenses, (2-3m) fine grained volcaniclastic sediment	Upper Miocene-Pliocene		
	Pre- to Syn Sambaloran (BV4)		Lava flows, minor andesitic breccias	Pliocene to Pleistocene		
Tongonan Intrusive Complex			Coarse grained granodioritic to dioritic intrusives; these are cut by younger minor quartz diorite aid dacitic dykes	Pliccene Io Pleistocene		1200 m
Leyte Ultramafic Complex*			Pyroxene-rich, serpentinised ultramafic	Late Cretaceous		Unknown (encountered only in well 402)

*(This Study)

Two major hydrothermal regimes are observed: (a) a relict assemblage comprising biotite, actinolite and garnet indicate ancient temperatures of about 270°C; present temperatures are significantly lower (140°C); (b) a current hydrothermal regime consisting of minerals which formed at temperatures in agreement with those measured at the present time.

Widespread propylitisation of the andesites and diorites occur at around 250°C; epidote, albite, chlorite, illite, calcite, sphene and pyrite typically comprise the propylitic assemblage. A K-silicate zone analogous to the potassic zone in porphyry copper deposits consists of biotite, actinolite! quartz, illite ± K-feldspar, albite and epidote. This alteration zone is related to contact hornfels and dyke intrusions in peripheral wells, e.g., 408, 501, 403. Between 250 and 300°C, epidote, anhydrite, illite, chlorite, adularia, albite, sphene, quartz and wairakite comprise the alteration suite; this appears to be stable in the reservoir and is consistent with that predicted from the fluid chemistry. Garnet and actinolite occur at temperatures above 265°C while talc and tremolite are observed in the propylitic zones at 300°C in wells 401, 404 and 407; no siliceous dolomites nor serpentinised ultramafics were encountered in these wells. A lower temperature ($\leq 270^{\circ}C$) talc alteration (without tremolite) forms from serpentinised ultramafics seen in well 402.

OPAQUE MINERALOGY

Genetic Classification

The distinction between hypogene, contact metamorphic and supergene alteration was not easily discerned in many cases. However, minerals in fractures or open spaces are clearly hydrothermal. Supergene alteration superimposed on pre-viously altered samples posed some difficulties: but textural and mineral association aided classification. Several opaque minerals were identified; all but five or six in only minor to trace amounts. These include pyrite, chalcopyrite! galena, sphalerite, magnetite, titanomagnetite, ilmenite, bornite, pyrrhotite, covellite, fahlore (tetrahedrite-tennantite), sulphosalts, brookite/pseudobrookite, anatase, rutile, hematite, maghemite, goethite, marcasite, ilmenorutile, chromite (?), electrum, Ag-sulphide and trace molybdenite(?).

These minerals are classified as: 1) magmatic = comprising unaltered to variably altered magnetite with inclusions of pyrite; pyrrhotite, ilmenite, titanomagnetite, chromite and rare chalcopyrite; (2) sedimentary/diagenetic - this group consists of pyrite, magnetite, rutile, hematite, pyrrhotite and chalcopyrite occurring in weak to moderately altered sediments; (3) contact metamorphic/skarn - this comprises mainly magnetite; (4) supergene - this consists of pyrite, covellite, hematite, maghemite, goethite and chalcopyrite; (5) &-drothermal/hypogene - most of the other opaques except covellite.

Styles of mineralisation.

The opaque minerals in the altered rocks exhibit recurring patterns on a microscopic scale. The mineralisation observed in the Tongonan wells revealed a close relationship to the mode of formation of the co-existing silicates. These are: 1) Open space filling - this includes a) mainly sulphide and minor oxide veins and veinlets, generally less than 1.0 mm wide; conjugate sets of intersecting microfractures; are also common, b) rare sulphide zones attaining 2-3 mm width in intensely brecciated rock. c) solitary grains (e.g. sphalerite, galena, pyrite) deposited into open, closely spaced

fractures. Epidote is the common calc-silicate alteration minerals associated with these opaques at temperatures above 250°C. d) sulphides deposited into etch voids contiguous with fractures,
2) Disseminated mineralisation, This includes selective alteration of older minerals(e.g. hornblende altering to. pyrite + rutile). On a microscopic scale however, it was seen that 70-80% of the sulphides identified are related or are close to fractures.

Distribution

Table 2 shows the checklist of opaque minerals identified in cuttings and cores from 15 Tongonan wells and some surface samples. The opaque minerals comprise about three volume per cent of the rock (Arevalo, 1985) but these increase to about fifteen volume per cent locally especially in the pyroclastic rocks of the lower Bao Volcanics (Table 1). The largest volume of opaques occur in the contact zone (ave.5-7%) and this usually coincides with propylitic assemblages.

Descriptive Opaque Mineralogy.

Pyrite is the most ubiquitous sulphide in Tongonan's variably altered rocks and comprises nearly 90% of the opaques. It occurs as 1)disseminated grains, 2) mutual intergrowths with non-opaque; and other sulphides, 3) stringers(some) discontinuous, open space filling including vugs, 4) rare ovoid inclusions in opaque and non-opaques, and 5) botryoidal aggregates and framboidal growths in sediments, acid altered and ultramafic rocks,

Pyrite exhibits a wide and complex range of crystal habits, the most common of which are the cube and the pyritohedron. Textures range from massive to coarsely disseminated, idiomorphic to fine-grained colloform, sub-dendritic, skeletal, reniform /reticulate amoeboid, lamellar(interwoven!, poikilitic and framboidal sub/anhedra are not uncommon. Local variations in habit, size, morphology occur, e.g. in tuffs and breccias where clast lithology and permeability vary within one sample. No distinct association or relation was observed between pyrite morphology and alteration style.

Minute inclusions (2-30u) of ilmenite, magnetite, titanoinagnetite pyrrhotite, marcasite, galena, sphalerite, hematite, sulphosalts, Ag-sulphide, rutile, molybdenite (?), and cassiterite(?) occur in some pyrite crystals; their dimensions are similar(3-30 u) to those of exsolution blebs. Anisotropic effects are not noticeable, however in one sample(408/105m) rare intergrown prismatic pyrite crystals are strongly aniaotropic and may pseudomorph(?) primary ilmenite/pyrrhotite.

Zoning is not common but in some samples from wells 402 and 505, it appears to be due to differences in porosity and/or interruption in crystal growth. Chemical zoning between the core and rims of crystals in optically homogeneous pyrite is reflected in slight differences in probe analysis(Table 3). The Tongonan pyrite are mostly stoichiometric; they contain small amounts of nickel(?) and probe scans indicate minor amounts of Cu, Pb, Zn, Ti, and Mn (Table 4) are generally present with trace Mo(?) and Ga(?).

Magnetite (Fe_3O_4) is typically subordinate to pyrite in most samples. However, in the 'contact' zone or in the peripheries of dyke intrusions, a marked increase in the overall abundance of opaques is characterised by the preponderance of magnetite over pyrite, This local predominance of magnetite coincides with the K-silicate zone and some advanced propylitic zones.

Magnetite occurs as: 1)solitary to clustered magmatic grains and deuteric replacement of mafic minerals; 2) ovoid to elongate inclusions/exsolution blebs in pyrite, 3) veinlets, fibrous to dendritic filaments and fracture coating, and; 4) ragged disseminations, mutual intergrowths with pyrite/chalcopyrite and porphyroblasts. Magnetite is one of. the common stable primary minerals in the Tongonan field. It occasionally exhibits lamellar exsolution textures and leucoxinisation; alteration to rutile of these lamellae are common. With pro-

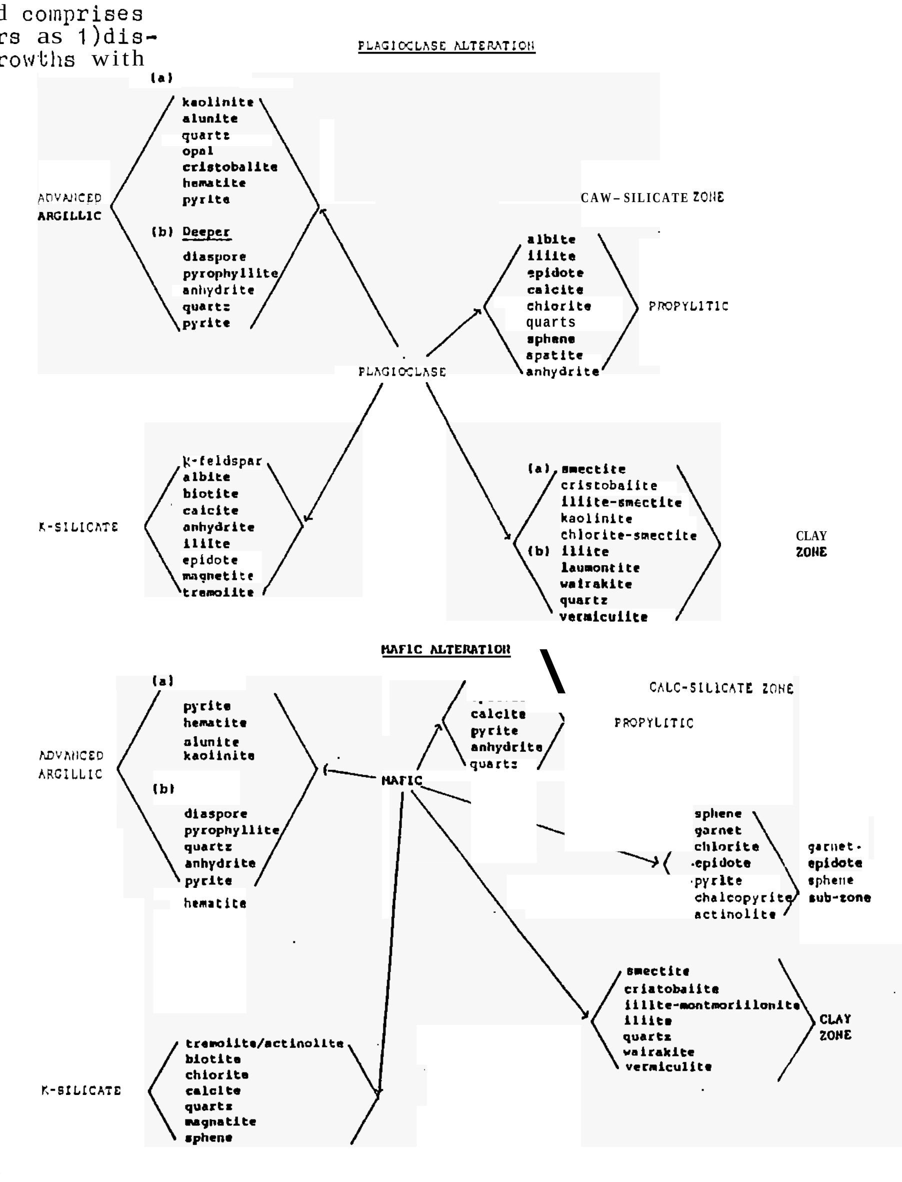


FIGURE 1 : SCHEMATIC DIAGRAM DEPICTING BREAKDOWN OF PLAGIOCLASE AND MAFIC TO FORM VARIOUS HYDROTHERMAL MINERALS AND ALTERATION STYLES IN THE TONGONAN GEOTHERMAL FIELD.

Table 2 : [?] Sol Opaque Min[er]als in So[u]th Tongonan Wells

MINERALS			403	404	405	407	408	202	208	209	213	503	505	MN-1	MG-1	
MAGNETITE			X	X	X	X	X	X	X	X	X	X	X	X	X	
MAGHEMITE							Y						Y	X		
HEMATITE			X	X	X	X	X	X	X			X	X	X	X	X
ILMENITE						X	X	‹		X			Y		Y	X
TITANOMAGNETITE							X									7
RUTILE			Y	X	X	X	X	X	X	X	X	X	X	X	X	X
ANATASE						X							X			
PSEUDOBROOKITE				X												
GOETHITE							Y	X					Y	X		
LIMONITE							X						X	X		
PYRITE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PYRRHOTITE	X	X	Y	X	X	X	X	X	X	X	X	?	X	X	X	
MARCASITE	X	X							1							7
COVELLITE		X														
BORNITE			?												X	
CHALCOPYRITE			X	X	X	X	X	X	X	X	X		X	X	X	
GALENA			X	X	?	X	X	X			X		X	?	X	
SPHALERITE			X	X		X	X	X		/	x				X	
FAHLORE	X	X													X	(
ELECTRUM	X	X	?										X		7	
Ag - SULPHIDE	X							7								
SULPHOSALT	?	X	X			Y							X			
DJURLEITE		..														
ILMENORUTILE							X								X	

OTHERS

~~Loellingite~~ - well 402; Annlite - well 402(?)

*ASR - ALTERED SURFACE ROCKS

gressive alteration intensity, pyrite is formed and rutile plus its correlatives remain. Magnetite inclusions occur in both low and high temperature formed pyrite. It is difficult to determine whether or not, some magnetite(and other inclusions in pyrite are residual or hydrothermal. A comparison between magmatic and vein magnetite chemistry is shown in Table 5. Vein magnetite occurs within the contact hornfels in well 408(-950m and -1198 m) and in a strongly brecciated andesite dyke(?) in well 202.

Chalcopyrite is the most ubiquitous and locally abundant base-metal sulphide. Its shallowest appearance coincides with the montmorillonite-cristobalite zone and it occurs to the bottom of most wells (Fig. 2); it is locally abundant in acid altered rocks and with magnetite. Chalcopyrite occurs as: 1) inclusions in magmatic magnetite(rare), epidote veins, pyrite and sphalerite; 2) discrete, solitary sub/euhedral grains(0.02-0.2mm) in etch voids and microfractures; 3) vein filling and mutual intergrowths with pyrite, quartz, epidote, galena, sphalerite and magnetite; and 4) patchy replacement of mafic silicates,

Where associated with earlier formed pyrite or magnetite, chalcopyrite commonly fills minute fractures attesting to a definite temporal relationship between vein chalcopyrite and pyrite or magnetite. The moot common occurrence of chalcopyrite is at the 'contact' zone and in the pluton, except in well 408 where it occurs in some andesitic breccia cuttings.

Galena occurs as 1) inclusions in pyrite, sphalerite and occasionally with ovoid chalcopyrite; 2) discrete crystals in mineralised open fractures; and 3) rare anhedral patches mutually associated with either pyrite or chalcopyrite (Fig. 2). The shallowest appearance of galena coincides with the lower illite-montmorillonite zone down to the bottom of most wells, except in well MN-1. Galena exhibits a strong preferential association with talc and with the acid alteration assemblages, diaspore-pyrophyllite (e.g. in wells 408,402 and 403).

Sphalerite occurs as: 1) discrete crystals lining mineralised fractures, and scattered in saponite and talc; 2) anhedral patches mutually intergrown with quartz, epidote, chalcopyrite and galena; and 3) inclusions in pyrite and chalcopyrite. The shallowest occurrence of sphalerite shows a strong correlation with the propylitic zones and the lover illite-chlorite sub-zone (Fig. 2), generally below -600m RSL.

Similar to galena, sphalerite occurs mainly in the talc alteration sub-zone(e.g. in wells 401, 402,404) within strongly propylitised intrusives and extrusives and rarely in the biotite-garnet zone. Crystals of yellow sphalerite and rare galena are scattered throughout saponite and intergrown with quartz (Wood, 1377) in core sample 401/-305 m. At deeper levels in well 401, sub-vertical vuggy veins are lined with quartz, epidote, chalcopyrite, galena and sphalerite. Sphalerite occurring in veins and open fracture8 is minor to rare in most of the wells; if was not observed in samples from wells MN-1, 505 and 405 where alteration is low grade and/ or relict,

Pyrrhotite occurs as a) near ubiquitous ovoid inclusions in pyrite in all the wells, except in MN-1 where permeablility is poor and measured temperatures donot exceed 200°C; and in the upper relict zone of well 505D where the actual measured temperatures are significantly lower than that indicated by alteration temperatures.
b) coarse aggregates to rare prismatic disseminations. The inclusions range in size from 0.005 to 0.01 mm long; some exhibit internal

TABLE 3 . VARIATIONS IN FE:S RATIOS ACROSS SINGLE PYRITI CRYSTALS IN SOME TONGONAN ALTERED ROCK SAMPLES.

SAMPLE SO. WELL/CORE NO.	PROBE SCAN NO. (RIM TO RIM)	FE:S RATIO
40815	1	0.54
	4	0.48
	5	0.48
	6	o.48
	7	0.54
40119	1	0.61
	2	. 0.55
	3	0.56
	4	C.5;
209/5	1	0.53
	3	. 0.52
	7	0.57
		0.52

etching. Pyrrhotite does not occur at shallow (mean sea level) depths; it appears to be ubiquitous in pyrite(e.g. in samples froin well 408) spatially related to the illite-montmorillonite zone. The inclusions are typical of peripheral arid epithermal zones in porphyry copper deposits, e.g. east of Thames(Kobe, pers. com.)

Marcasite- this dimorph of pyrite is rare in samples from the Tongonan wells; it is present .in one surface sample and occurs as .inclusion in pyrite and as replacement of pyrrhotite in some portions of well 402. In the Kapakuhan altered ground, Wood(1975) identified marcasite in surficially altered hornblende andesite in an assemblage containing montmorillonite + kaolinite ± pyrite + natroalunite + cristobalite.

Deeper in well 402 (-1540 m RSL), marcasite is present as encrustations in boundaries along fractures of pyrrhotite; it occurs with pyrrhotite + pyrite + chalcopyrite + framboidal pyrite + maghemite + magnetite and as a rare inclusion with pyrrhotite in cube pyrite.

Hematite in trace to minor amounts has been observed in soine samples froin all the wells; its occurrence closely correlates with acid alteration assemblages and fossil hydrothermal zones especially in the upper levels of Malitbog wells and throughout well MN-1(Fig. 2). Hematite occurs as: 1) ovoid to tabular inclusions in pyrite and rare pyrrhotite(?); 2) hydrothermal(?) replacement of magnetite and rare titanomagnetite; 3) exsolution lamellae in magmatic magnetite; 4) veins with chlorite cutting calcite or epidote veins; 5) intergrowth with other opaques and and silicates; 6) retrograde alteration of iron oxides in breccia clasts and matrix particularly in supergene and advanced argillic zones, and; 7) acicular euhedra in rock matrix and as etch void filling.

Hematite is rare in the central Mahiao and Sambaloran wells; it occurs .in minor amount in samples from well MG-1 e.g. in fault breccias and sediments,

Maghemite, a low temperature replacement of magnetite and titanomagnetite was often difficult to distinguish from porous hematite.

Goethite occurs as a low temperature oxidation product of iron bearing phases but ha3 been observed mostly in acid, relict and supergene alteration zones, e.g. in samples from wells MN-1 and 402. Supergene replacement of both pyrite and magnetite result in marginal or complete replacement by goethite often leading to pseudomorphic and colloform textures.

TABLE I . ELECTRON MICROPROBE ANNYSES OF SOME TONGONAN PYRITES

SAMPLE NO. WELL/CORE NO.	ANALYSES (ATOMIC PEP CENT) Fe	S	cu	Zn	Ti
309/5/4	33.85	65.16	0.41	0.0	0.0
209/6/1	31.92	63.38	0.0	0.26	0.0
209/6/4B	33.93	64.86	0.0 .	0.5	0.0
2061616	32.31	61.37	0.0 .	0.0	1.4
MG-1/5/1	31.66	61.51	0.0	0.0	1.33
MG-1/5/3	32.98	63.05	1.22	1.27	0.0
401/6/9	30.71	66.63	0.99	0.0	0.0
401/6/9	36.35	63.76	0.0	0.0	0.0

Bornite has only been identified in three samples; these occur as discrete disseminations, inclusions and intergrowths in both diorite and andesite(with biotite and hornblende) in well MG-1. Samples from well 409 contains finely disseminated bornite ± chalcopyrite in an epidotised, fractured rock.

Titanomagnetite/Ilmenite are common inclusions in Tongonan pyrite (samples from wells 408, 209, 407). Dominant reflectivity appears to be in one direction and many of the light-brownish opaque phases in most Tongonan wells exhibit a bireflectance typical of ilmenite.

Rutile is ubiquitous in Tonqonan and is present mainly as an intermediate phase between pyrite and magmatic opaques during sulphidation. It mimics titaniferous lamellae in these opaque phases and occurs as disseminated, reticulate intergrowths with creamy-brown to transluscent internal reflections. It is identified readily optically, as it is ganerally grey-'cloudy'white with faint lilac tint and distinct pleochroism.

Rare ilmenorutile was observed in one sample from well MG-1 and exhibits ilmenite bireflection but rutile type internal reflection, In the montmorillonite-cristobalite zone (Fig. 2)rutile is uncommon and in the surface zones, anatase, a low temperature TiO_2 polymorph is the dominant titaniferous phase replacement.

Covellite has only been identified in the zone of supergene alteration e.g in well 402, and is accompanied by natrojarosite; detailed discussion on the supergene processes and alteration products is presented in another paper. Stoichiometric and non-stoichiometric covellite are both present in cuttings from well 402/-20m . These replace pyrite and are overgrown by goethite. Covellite occurs is samples from the Southern Negros wells (Philippines) and vas suggested(Leach and Weigel,1983) to indicate advanced argillic alteration adjacent to high temperature zones.

Sulphosalts and Fahlore occur as inclusions in sphalerite. The term sulphosalt is here used to describe a non-descript, soft, white to grey mediun to high reflectivity phase showing similarity to galena. It is restricted in samples from wells 408 and 505. Rlecton microprobe analyses revealed the dominance of lead in the sulphosalts (bournonite-boulangerite(?)). Fahlore(tetrahedrite-tennantite solid solution) occurs as grey inclusions in sphalerite and as overgrowthe, some with Chalcopyrite in the weirbox precipitates.

Pseudobrookite/brookite - these polytypes occur in the upper portions of wells in other Philippine fields(Leach and Weigel,1983). Pseudobrookite is a meta-stable phase that reflects the sluggish alteration reaction of Ti-bearing phases at low temperature, In Tongonan they were observed in wells 404 and 402. The reaction below depicts the formation of pseudobrookite:

Fe–Ti oxides → sphene → leucoxene → pseudobrookite
Fe–Ti oxides → rutile

TABLE- 5

Chemistry of primary and hydrothermal magnetites (probe analyses in atomic %)

	PRIMARY		HYDROTHERMAL							
	TONGONAN		TONGONAN				SOUTHERN NEGROS			
Sample No.	1	2	3	4	5	6	7	8	9	10
Al	3.80	7.46	1.46	0.75	0.63	1.0	0.97	1.014	0.982	0.84
Ti	3.27	1.56	-	-	0.32	1.51	0.46	0.59	1.05	0.32
V	0.264	-	0.34	-	0.43	0.55	0.37	0.39	0.47	0.46
Cr	-	-	-	-	0.00	-	-	-	-	-
Mn	0.58	0.925	-	-	-	-	0.49	0.57	0.77	0.44
Fe	87.37	58.19	91.63	94.79	35.79	90.96	34.58	95.23	93.89	91.11
				Zn -0.79						

	Sample Name/Source	Formula Fe^{2+}	Fe^{3+}	TI	Al	Cr	Mn	V
1.	Mahiao surface sample	1.14	1.75	0.10	0.18	0.0	0.02	0.01
2.	Mahiao surface sample	1.08	1.53	0.06	0.47	0.00	0.04	0.00
3.	Well 408/core 5	1.01	2.03	0.00	0.01	0.00	0.01	0.01
4.	Yell 408/core 5	1.07	2.08	0.01	0.04	0.00	0.00	0.00
5.	Well MG-1/core 78	1.10	2.08	0.01	0.00	0.00	0.00	0.01
6.	Well MG-1/core 7B	1.13	1.96	0.05	0.05	0.00	0.00	0.01
7.	Well SG-3/core 2(a)	1.07	2.04	0.01	0.04	0.00	0.02	0.01
8.	Yell SG 3/core 2(b)	1.01	2.03	0.02	0.05	0.00	0.02	0.01
9.	Well SG 3/core 2(c)	1.08	0.0	1.41	0.02	0.00	0.01	0.01
10.	Well SG 3/core 2(d)	1.08	2.04	0.01	0.04	0.00	0.01	0.01

OTHERS :

Electrum occurs in trace quantities in the peripheral wells 402, 403, 505 and MG-1. Ultra-fine disseminated Au varies from straw to bright yellow in reflected light; it occurs as isolated xenomorphic blebs in the matrix and carbonaceous material in MG-1 sediments.

A rare Ag-sulphide occurs as a bluish-grey inclusion in 401/-305 in pyrite. Several opaque phases co-exist in some of the wairbox precipitates e.g. digenite, djurleite and annilite (discussed in another paper),

DISCUSSION AND SUMMARY

Relationships between opaque minerals and calc-silicate alteration zones

There exists a distict zonation of opaque minerals in Tongonan (Big.), with a definite parallelism and consanguinity between the calc-silicate alteration zones and opaque mineral zones; these also appear to be temperature dependent,

Clay zone. Pyrite dominates the opaques which seldom exceed 1 volume per cent in the clay zones. Here, mafic silicates are weakly altered to pyrite, magnetite, chalcopyrite, rutile, and hematite. The volume of opaque minerals in the illite-smectite sub-zone remains constant at less than 2 volume per cent; trace galena and pyrrhotite inclusions in pyrite appear for the first time. Chalcopyrite increases slightly while pyrite still dominates thio sub-zone.

Propylitic zone. Trace sphalerite first appears: in the propylitic zone; the opaques here range froin 2-7 volume per cent, averaging 2-5%. Pyrite dominates the opaques and occurs with rutile, leucoxene, chalcopyrite, galena, magnetite and ovoid inclusions of magnetite and titanomagnetite. Galena was not identified in samples from wells 209, MN-1 or MGH and sphalerite was absent from sporadic samples collected from wells MHH and 405.

Hematite sub-zones.

Hematite occurrence falls in to three categories, viz:

1) within acid alteration zones- the opaques within this zone comprise 3-15 volume per cent and accompanied by a local increase in chalcopyrite content. The strong association of galena with hematite in the advanced argillic asaemblages is conspicuous in well 408.

2) montmorillonite-cristobalite sub-zone - hematite consistently occurs at this level in weakly altered rocks containing criatobalite, smectite, pyrite, calcite, ankerite and kaolinite, Pyrite. dominates the opaques in this zone.

3) fossil alteration zone - particularly in the upper Malitbog wells. Opaques range from 3-5 volume per cent and contain hematite. Galena occurs in the hematite sub-zone in well 505D. Hematite appears consistently throughout well MH-1 where the opaques comprise less than 2 volume per cent and these do not contain galena. The paucity of sulphides in this well is accompanied by the absence of pyrrhotite inclusions in the pyrite in contrast to those of well 505D.

IC-silicate zone,

Magnetite occurrences are more closely related to a) K-silicate zona and b) intrusive'contacts', including peripheral areas of dyke intrusionn. The 1:-silicate zone contains finely disseminated and vein magnetite, pyrite, rutile, pyrrhotite, chalcopyrite, rare hematite and galena. The preponderance of magnetite over pyrite in this zone is accompanied by a decrease of the opaques in the lower transition zone and on the carapace of the pluton.

Talc$^{\pm}$ tremolite sub-zone

Talc has only been identified in three wells: 401, 402 and 404; it may also be present in 108. An interesting and unusual feature of the talc zone in the strong base metal mineralisation associated with it.The talc base metal

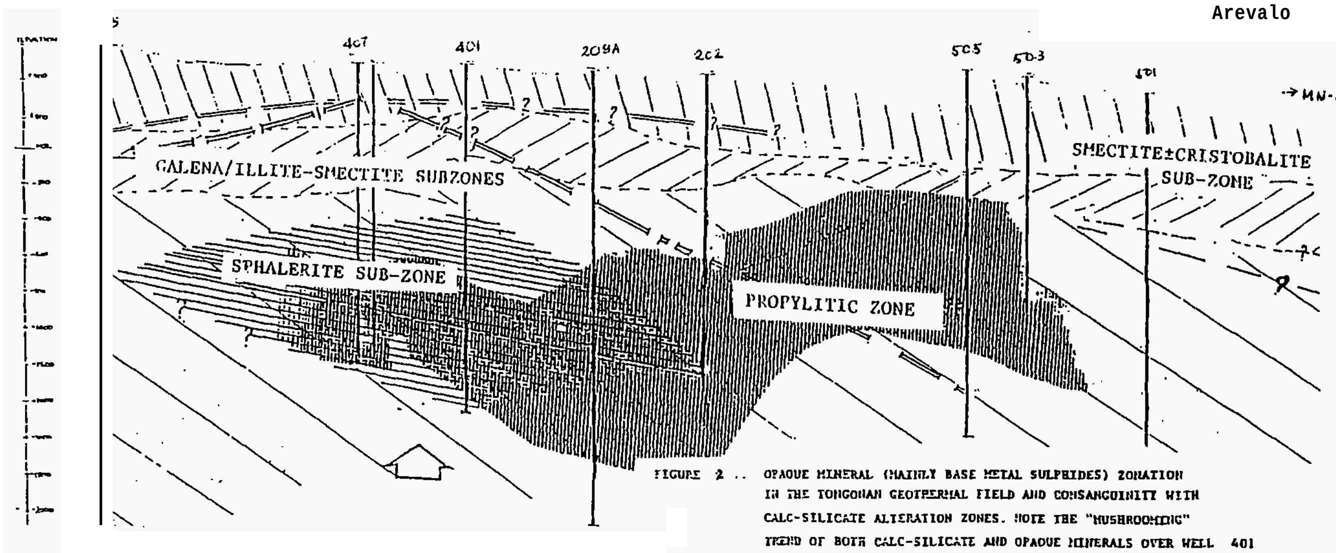
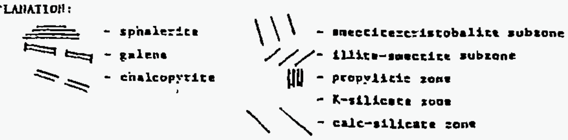


FIGURE 2 .. OPAQUE MINERAL (MAINLY BASE METAL SULPHIDES) ZONATION IN THE TONGONAN GEOTHERMAL FIELD AND CONSANGUINITY WITH CALC-SILICATE ALTERATION ZONES. NOTE THE "MUSHROOMING" TREND OF BOTH CALC-SILICATE AND OPAQUE MINERALS OVER WELL 401

EXPLANATION:



association occurs within propylitic assemblages except in well 402 which is an acid and peripheral. ne 11. Pyrite still dominates the opaques .in this zone and is accompanied by galena, sphalerite, chalcopyrite, rutile, pyrrhotite and,rare marcasite.

The lateral extent and distribution of the sulphides reflect relative permeabilities in the host rocks and the geometry of the thermal reservoir. Hydraulic fracturing and tectonic movements, particularly along the splays of the Philippine Fault are thought to be responsible for intense fracturing and brecciation - inferred mechanisms for pressure release within isolated fluid pockets in the reservoir which initiated boiling and subsequent precipitation of metal sulphides, quartz and K-feldspar.The factors affecting and physico-chemical conditions of alteration and mineralisation in Tongonan will be discussed in 'another paper.

The Tongonan hydrothermal fluids are up to 2 orders of magnitude undersaturated with respect to the base-metals which appear to have precipitated in the reservoir rocks as sulphides (Arevalo, 1985). These fluids currently deposit a significant amount (10,000 ppm total Cu, Yb, Zn) of base-metals within an amorphous silica base in artificial. drains and channels. A variety of opaque minerals occur in these scales. Their textures closely compare with advanced argillic/supra porphyry breccia bodies; such textures are apparently preserved in nature as they are apparently preserved in nature as they are observed in some hydrothermal ore deposits.

The results of this study demonstrate that Tongonan is an active metal depositing system. The metalliferous precipitates(discussed in a separate paper) further demonstrate the ability of the Tongonan waters to transport and deposit base and precious metals,

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