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MINERALISATION ASSOCIATED WITH TONGONAN WELL EJECTA, BLOCKAGE MATERIALS AND DISCHARGE LINE PRECIPITATES

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ABSTRACT

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. These fluids currently deposit a significant amount (10,000 ppm total Cu, Pb, Zn) of base-metals within an amorphous silica base in artificial drains and channels. A variety of opaque minerals occur in these scales, vis: base-metal eulphides, pyrite, marcasite, silver sulphide, sulphosalt, electrum, dignite-chalcocite, djurleite-annilite(?), fahlore, pyrrhotite, bornite, hematite and goethite. Their textures closely compare with advanced argillic/supra porphyry breccia bodies; such textures are apparently preserved in nature as they are observed in some hydrothermal ore deposits.

Two important implications of this study are:

a) Research on mineral deposition is highly relevant to the environmental and utilisation problems associated with the discharge of geothermal effluents, particularly the high arsenic and lead that are dumped into and pollute surface waters and blockage of production and reinjection wells and surface equipment by silica;
b) The precipitates containing variable amounts of metals represent the last phase deposited by the most recent geothermal water reequilibration attempt in the wells; the high metal content of these materials demonstrate the ability of the metal and sulphur deficient Tongonan geothermal fluids to transport and deposit 'ore' metals.

1. INTRODUCTION

Several physical and chemical processes occur as hot water. ascends through wells and pipeline; a steam phase forms in increasing proportion with large proportion of the gases, especially, H_2S and CO_2 originally dissolved in the deep water. The cooled water is depleted in these gases while non-volatile constituents concentrate; mineral deposition may be initiated by these changes (Ellis and Mahon, 1977).

Increasing exploitation of hot (200-340°C) water reservoirs during the last 15 years has brought about environmental and utilisation problems associated with mineral deposition; this (deposition) occurs along artificial flow channels e.g. steam line, turbine blades, well casing, weirbox, drainage channels, etc. in most utilisation schemes such as those at Wairakei and Broadlands (Tulloch, 1984; Rea, 1983), Weissberg, 1969, Tongonan and Southern Negros (Glover, 1975; Wood, 1975; Reyes, pers. com.), Bacon Manito (Reyes, pers. com.), Salton Sea (Skinner et.al., 1967; Miller et.al., 1977; Maimoni, 1982), Reykjanes and Krafla (Arnorsson, 1981), Svartsengi (Kristmansdottir, 1980), Matsao (Chen, 1970), Cheleken (Lebedev, 1967).

Table 1 summarises the scales deposited by well discharges from some of these geothermal areas. Appreciable near-surface concentration of heavy metals are also contained and deposited by highly mineralised and/or highly acid, hot waters such as those in Tatun (Chen, 1970). Silica and calcium carbonate (mainly calcite and minor aragonite) are the most common deposits formed in hot water systems; very hot and/or very acid systems may also form sulphide deposits. Ellis and Mahon (1977) attribute sulphide deposition in artificial flow channels as due to changes in temperature and pressure.

Removal of steam from geothermal discharge initially saturated with quartz at the aquifer temperature increases the silica concentration in the residual water so that where it exceeds that of amorphous silica, a silica scale may deposit; this is the case in the Tongonan pipes and drains.

2. MINERAL DEPOSITION IN TONGONAN

In Tongonan, scaling was early recognised as a problem in the shallow (~500 m) exploration wells in the Bao Valley (Figure 1). Glover (1975) reported aragonite scaling in well TGE-7 which was drilled in the outflow region. During 1977, the geothermal effluents from 401 discharge test passed through a conditioning/holding pond and treated with slaked lime to remove toxic elements (such as boron and arsenic) by precipitation with the calcium silicates. (Rothbaum, 1975). In a matter of hours a grey flocculant, essentially hydrated Ca- silicates, mantled the surface of the holding pond and the effluent discharge channel (writer's pers. observation); no chemical analyses of these precipitatesare available.

Opal, cristobalite, pyrite, hematite, magnetite occur on layered brittle scales from the Tongonan scheme (at the separation station and bypass line) and reinjection pipe (Zaide, 1984); scales recovered with well blockage materials consist of banded opal and iron oxides, The present writer examined some of these samples in reflected light including precipitates from the weirbox and drains of discharge wells and discovered base-metals in most samples. Figure 1 shows the location of the wells and springs where precipitates were collected. This paper discusses the mineralogy of these Tongonan scales which represent the latest products of fluid/rock reequilibration attempts in the wells.

3. MINERALOGY OF THE SCALES

Table 2 describes these scales and ejecta. A variety of opaque minerals occur in the opaline scale; these are: base-metal sulphides, pyrite, marcasite, silver sulphide/sulphosalts, electrum, chalcocite group minerals = digenite-chalcocite, djurleite-annilite(?), fahlores, pyrrhotite and bornite hematite, in rythmic, colloform hydrated iron oxides and sulphides. The non-opaque phases consist of the silica polymorphs, sulphates and carbonates.

Brecciation and shrinkage cracks characterise many of the sulphides; however etching is uncommon in contrast to the sulphides in the core. In most cases, the scales comprised less than 0.3 volume per cent opaques except sample 404 DC where they exceed 0.5 volume per cent.

Samples CV3 RI is one of the most interesting scales in terms of mineralogy and textures (Figure 2).

Initial laboratory examinations (Bagamasbad, 1984) showed a dark grey brownish material composed of predominantly hard amorphous silica with minor Fe-oxide. Further petrographic and XRD examination (Zaide, 1984) revealed 30% cristobalite fringing on 30% opal, 15%hematite, 15%magnetite and 5% pyrite. Reflected light examination however disclosed a more complex and varied mineralisation.

Scheme	Occurrences	Deposits	Reference
Brwdlands	in pipes discharge areas of holes Br 2, 6, 14	aragonite, dolomite, talc Mg-calcite, amrphous Sb - Hg - Cu - Tl - Ag - Au	Ellis, and Mahon, 1977 Browns, 1971; Weissberg et al., 1979
Kawerau	in pipes	dolomite, talc, pyrrhotite, galena sphalerite, covellite, vaterite, chalcopyrite silica, amorphous As - Sb - Hg	Tulloch, 1904
Southern-Negros	in pipes in well casing	aragonite, pyrrhotite, anhydrite, calcite, hematite and pyrite	Wood, 1976 A. Reyes (pers. con.)
Bacon-Manito	in drains	Fe oxides, silica, Cu, Pb, Zn, Au', Ag (AAS)*	A. Reyes (pers. com.)
Matsao	discharge pipe	galena, Pb', As - Sb - Ge- Ag - Cu - Ba	Ellis, 1972
Salton Sea	in pipes and plant	silica, manganese, hydrated Fa oxides, metal bornite, chalcocite, stromeyerite, tetrahedrite, pyrite, Ag°	Skinner et al., 1967
The Geysers	in pipes and plant	siliceous material, rock dust.	
Steamboat Springs	in pipes	CaCO (aragonite?)	Ellis and Uahon, 1977
Reykjavik	in pipes, plant	Mg, Fe oxides, silica	
Namafjall		amorphous silica, chalcedony, talc, Mg silicates	Kristmansdottir, 1980
Krafla	pipes	pyrite, pyrrhotite, magnetite, goethite, chalcopyrite, iron oxides, silica	Arnorsson, 1982
Matsukawa	drain pipes	Fe oxides, S, Fe, $FeSO_4$ silica	Ozawa end Fujii, 1970 in Ellis and Mahon, 1977
Otake	drain pipes	calcite, silica	Ellis and Mahon, 1977
Cheleken	in reservoir tank	sphalerite, pyrite, galena, sulphate, silica, carbonate	Lebedev, 1967; 1972

(*Atomic absorption spectrophometric analysis)

Table .1 :

OCCURRENCE OF OPAQUE AND NON-OPAQUE PHASES IN SURFACE PRECIPITATES DEPOSITED BY WELL DISCHARGE WATERS IN SOME ACTIVE GEOTHERMAL SYSTEMS.

The following sequence was observed:

early ————————→ late

chalcopyrite+ galena+ sphalerite+ fahlore→ marcasite+- 'digenite-djurleite'

in a maghemite-goethite hematite base. Chalcopyrite often is intergrown with sphalerite and fills shrinkage cracks in pyrite (Figure 2) attesting to a definite temporal relationship. Rare phases include pink-brown sulphosalts, white-yellow marcasite and discrete bornite-digenite-djurleite(?). A unique feature of these samples is a dendritic growth with similar optical characteristics to tetrahedrite but this has not been observed in hydrothermal ore deposits elsewhere (Kobe, pers. com.).

4. FEATURES OF THE SILICEOUS OPALINE BASE

The precipitates from the weirbox and drains are generally green to ash-grey and to the unaided eye appear to be devoid of opaque phases. The well blockage scales (e.g. sample 105D) are almost black with rusty tints; these appear to be made up mainly of iron oxides and amorphous silica. Their opaline base shows a higher index of refraction (1.5+) than ordinary amorphous silica; a similar feature was observed in the Salton Sea scales (Skinner et.al., 1967). XRD analyses of samples MG-1, 209, 404,401 and 108 reveal subtle variations in the peak locations despite a similar rise to 4.2Å typical of broad amorphous opaline silica. Figure 3 (a to g) show the x-ray diffractograms of precipitates from weirboxes and discharge channels; these are compared with those precipitated from hot spring waters in Kapakuhan.

Except for minor to trace cristobalite and quartz, calcite, illite-montmorillonite, halite and sulphates were also identified and no other peak belonging to a silicate phase was observed.

5. CHEMISTRY OF PRECIPITATES

Bulk compositional data for some of the scales are presented in Table 3; these analyses were obtained by x-ray flourescence and compared with those obtained from scales from other active geothermal systems. The XRF analyses show the opaline base to be made up of 80 - 90% silica and a very high concentration of base-metals (10,000 ppm) these confirm the results of polished mount examination (i.e. the occurence of base-metal concentration in 209 range from one to almost twice the magnitude found in the other sample. This higher mineralisation trend of scales from sample 209 is accom ied by its lower SiO_2 and higher total Fe (aa Fe_2O_3) content. The higher Cr (and Ba) content of sample 108DC probably reflects its proximity to well 402 which intersected an ultramafic rock. The high As content is consistent with that of the discharge fluids; trace Sb and Ag are present in the subsurface rocks (Arevalo, 1986) and were also identified in the precipitates by electron microprobe. However, no stibnite, orpiment or realgar were identified in the cores, cuttings and scales; silver sulphides and sulphosalts however, are present in trace amounts in both samples.

Drill cores and cuttings recovered from well 401 are by far the most mineralised, containing variable amounts of base-metal sulphides; however, the precipitates show that the strongest (> 10,000 ppm total Cu, Pb, Zn) base-metal concentration occurs in the Sambaloran sector (209 Samples). This trend appears to be consistent as sample 108DC is also more mineralised than the two samples from the upflow (320°C) center, 401 and 404. There also seem to be a correlation between the output and the metal concentration: the measured injectivity of 50 l/s-MPa indicate the well has good permeability and this is further confirmed by a large (80 kg/s) mass flow.

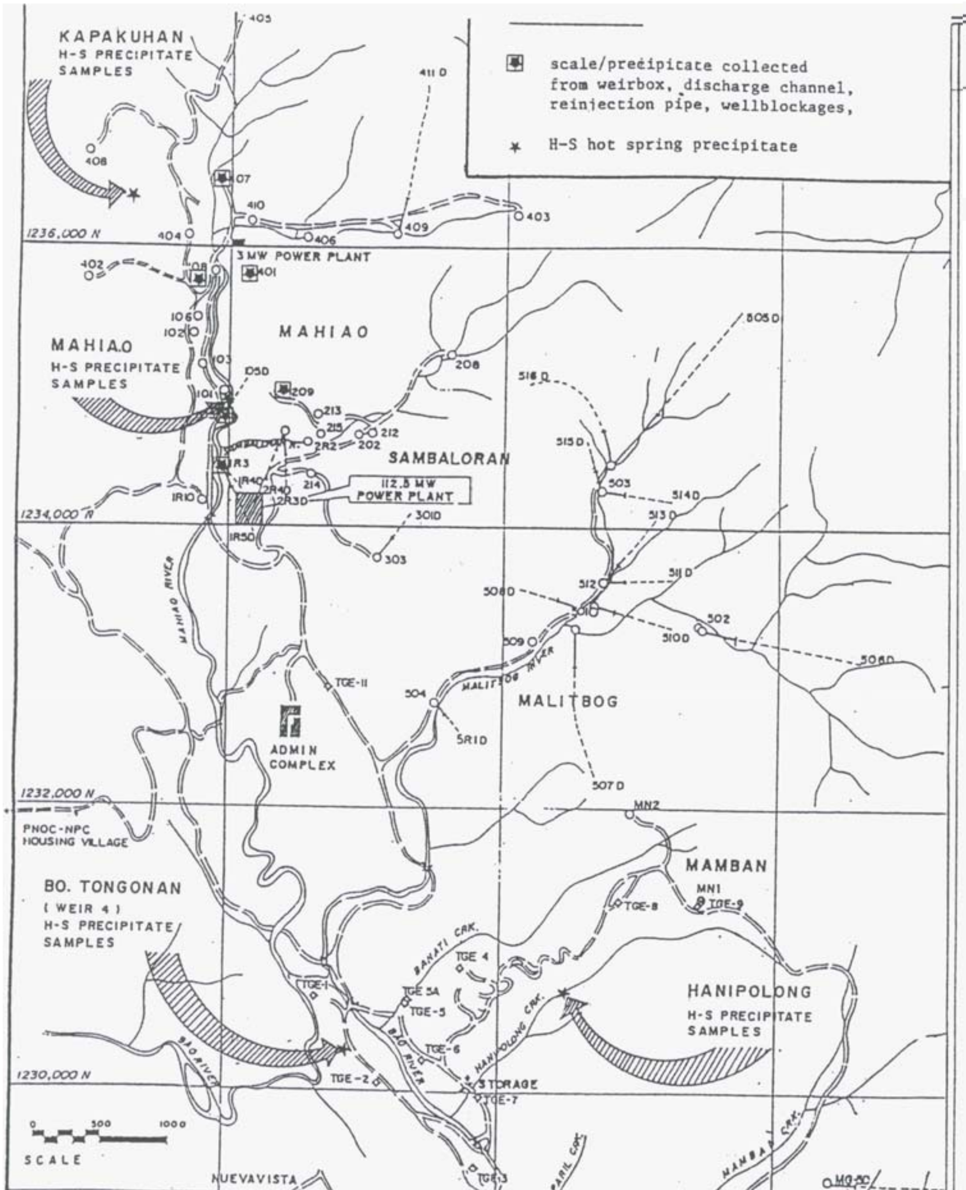

FIGURE 1

MAP OF THE TONGONAN GEOTHERMAL FIELD SHOWING LOCATIONS OF WELLS AND HOT SPRINGS WHERE SCALES/PRECIPITATES, EJECTA AND BLOCKAGE MATERIALS WERE COLLECTED. (Map courtesy of PNOC-EDC; prepared by Palma/Labajo 1982/83)

Well/Sample No.	Sample Source or Location	Description of Scale/Ejecta	Mineralogy	
			Non-Metals	Opaque Phases
1 5D	Blockage material collected during scraper run at 210 m	Rust coloured to black scales showing sequential colloform growth; shrinkage cracks	anhydrite chlorite opal prismatic and equant gangue	pyrite-subhedra and colloform rhythmic phases; chalcopyrite, rutile, fahlore, galena and sphalerite(?), hematite
108DC	Discharge channel past the weirbox	Cream-grey precipitate with typical colloform sequential rhythmic texture	opal, apatite halite quartz	pyrite, rare chalcopyrite-sphalerite, bornite-chalcopyrite intergrowths, ultrafine Au (electrum), yellow marcasite allochthonous magnetite-hematite
09WB	Weirbox	Typical colloform, rhythmic Fe oxides	opal apatite(?)	hydrated iron oxides, chalcopyrite-bornite pyrite intergrowth, brownish fahlore, etched chalcopyrite, sphalerite-galena and sphalerite chalcopyrite intergrowths, rare framboidal pyrite, electrum(?), sulphosalts
DC	Drains	Green grey scales; colloform rhythmic hydrated iron oxide	opal	allochthonous titanomagnetite pink grey phase (Fahlore), rare chalcopyrite-pyrite intergrowth, bornite-sphalerite
0 RP	Reinjection pipe	Cream-grey, more coherent sample, base contains colloform rhythmic grey Fe oxides	opal, sulphates	pyrite, maghemite, rutile, chalcopyrite, sphalerite, rare electrum, Ag(?) sulphides and sulphosalts, chalcocite unidentified high reflectivity white to yellow white phase mimics marcasite
404DC	Discharge channel	Green grey scales, fragmented crustiform	opal	pyrite, pink-yellow marcasite overgrowth on oxide, rare sphalerite, fahlore and/or electrum inclusions in sphalerite-chalcopyrite, galena pyrrhotite, chalcopyrite group (digenite-chalcocite or anilite-djurleite, silver(?) sulphide unidentified rare light bluish grey phase
MG-1WB	Weirbox	Cream-grey precipitate with typical rhythmic colloform texture Fragmented dissemination similar to supra porphyry breccia zones	quartz, opal illite smectite, calcite	chalcopyrite, hematite, pyrite, fahlore, rutile
CV-3 RI	Reinjection line	Dark grey to almost black vesicular precipitate; more coherent and harder than all other samples; crustiform banded texture shrinkage cracks .	cristobalite sulphate	chalcopyrite, pyrite, galena sphalerite, white-yellow marcasite, sulphosalts, fahlore, bornite, digenite, djurleite(?), rutile, maghemite-goethite-hematite base, unidentified phase (As-Sb sulphides), pink-grey
I 3/1 S	Well blockage collected at 661 m CHF during scrapes run	Typical colloform/sequential precipitate	amorphous silica	discrete pyrite, chalcopyrite rutile, iron oxides
0 E	Ejecta collected during initial clearing discharge	Pale green rock fragment at 3% disseminated opaques	quartz	pyrite, magnetite, hematite, chalcopyrite pyrrhotite, rutile leucoxene

TABLE . 2

SUMMARY OF MINERALISATION IN TONGONAN WELL EJECTA AND SCALES/PRECIPITATES FROM WELL BLOCKAGE MATERIALS , WEIRBOX AND DISCHARGE CHANNELS.

AREVALO

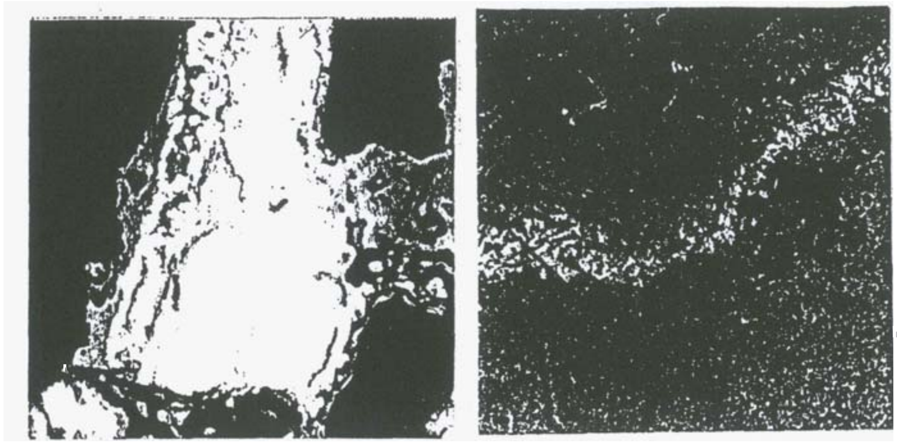

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FIGURE 7.2 Photomicrographs of Opaque Minerals in Tongonan Precipitates.

A. Sequential colloform texture is a common feature of the scales/precipitates from Tongonan. An amorphous silica and hydrated iron oxide base hosts base metal mineralisation in sample CV-3 RI. in

B. Scales in well blockage materials exhibit sequential colloform texture and shrinkage cracks as shown by this sample from well 105D.

6. SIGNIFICANCE OF THE METALS IN THE PRECIPITATES DEPOSITED BY THE TONGONAN GEOTHERMAL WATERS

The Tongonan geothermal wells discharge near neutral pH sodium chloride waters (up to 10,000 mg/kg; Lovelock, et.al., 1982) with variable amounts of Na, K, SiO_2, Ca and significant amount of B and As and perhaps Pb based on high concentration in precipitate. These waters deposit high (~10,000ppm) concentration of base-metals and are precipitated with amorphous silica in artificial flow channels. It is not known whether the hot spring precipitates are mineralised but iron sulphides have been observed in the Kapakuhan and Hanipolong samples. Trace amounts of Au, Ag and Sb are probably transported by the fluids based on the occurrence of electrum, silver sulphides, sulphosalts and fahlores. These precipitates represent the latest phase deposited by the fluids after attempting to reequilibrate in the wells; they also indicate that sulphides observed in drill cures arid cuttings collected from the wells are currently depositing. However, only a fraction of the metals are apparently precipitated as sulphides since they comprise a very small volume of the amorphous/opaline silica base compared to the high metal content. The high (5,000 ppm) Pb content of tlie sample 209 precipitates is riot reflected in the little galena mineralisation in the reservoir rocks suggesting the fluid is undersaturated with respect to this mineral.

The Cu-Pb-Zn-As in amorphous silica precipitates deposited by tlie Tongonan fluids do not constitute an ore deposit; however, their textures closely compare with advanced argillic/supra porphyry type breccia bodies; such textures are apparently preserved in nature as they occur in hydrothermal ore deposits. Rapid ascent, cooling and 'de-gassing' of the fluids and limited time for them to react with reservoir rocks and descending cooler fluids characterise the deposition of these metal rich precipitates. Skinner et.al.,(1967) similarly suggested that a hole drilled into a deep brine reservoir, such as well No.1 IID (Salton Sea) does not constitute a reasonable facsimile of an ore depositing system. As the brine is erupted at high velocity, through a nearly straight, smooth walled channel, it has nil to little time to react with wall rocks or to mix with the cooler surface waters of different composition. Furthermore, as the fluid flow is adiabatic, cooling occurs with great rapidity and the opal-sulphide assemblage is deposited rapidly under conditions that favour disequilibrium.

Mineral deposition is attributed to (a) cooling of the fluids; elements such as As, Sb(?), Yb, Zn as precipitate with silica. Browne (1984) suggested that this process is moot effective at or close to the surface

TABLE . 3 A . QUANTITATIVE MAJOR ELEMENT ANALYSES OY X-RAY FLUORESCENCE OF SOME SELECTED TONGONAN PRECIPITATES.

Analyst: Or. R. Parker

Sample No.	108 DC	208 RP	209 WB	209 DC	401 RP	404 DC	MG-1 WB
SiO_2	. 89.03	91.14	84.61	82.58	92.82	90.67	85.45
TiO_2	0.04	0.02	0.05	0.07	0.01	0.01	0.07
Al_2O	1.30	0.57	1.42	1.07	0.19	0.51	1.61
Fe_2O	1.20	0.28	4.15	3.52	0.09	0.62	3.77
MnO	0.05	0.02	0.08	0.07	0.01	0.04	0.03
MgO	0.22	0.03	0.25	0.25	0.03	0.12	0.10
CaO	0.24	0.09	0.21	1.29	0.06	0.17	1.15
Na_2O	0.46	0.23	0.35	0.51	0.10	0.19	0.36
K_2O	0.61	0.30	0.62	0.58	0.17	0.31	0.39
	0.03	0.02	0.04	0.05	0.02	0.03	0.06
TOTAL(%)	99.99	100.22	99.05	98.71	100.13	.99.50	99.90

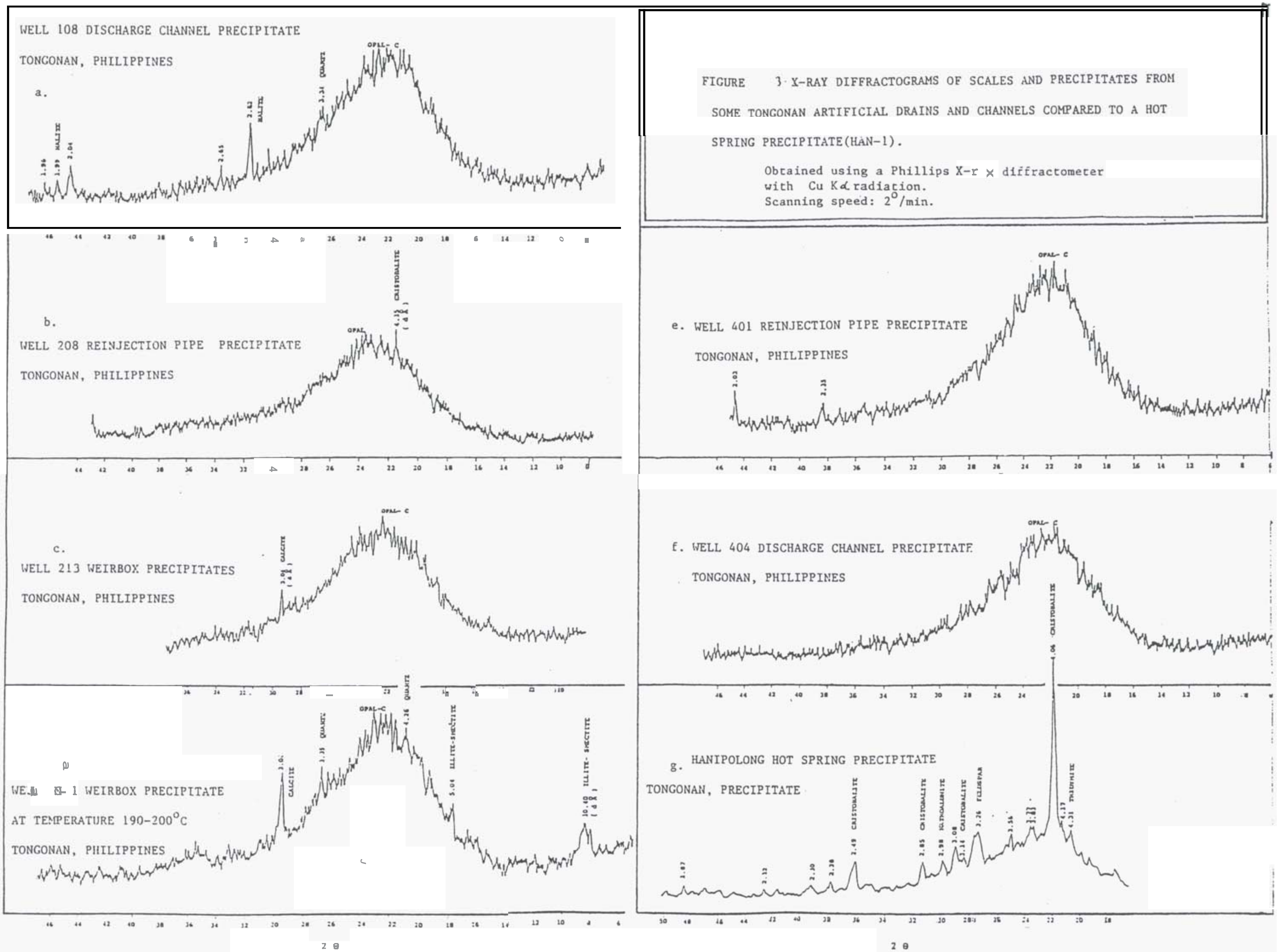

FIGURE 3 X-RAY DIFFRACTOGRAMS OF SCALES AND PRECIPITATES FROM SOME TONGONAN ARTIFICIAL DRAINS AND CHANNELS COMPARED TO A HOT SPRING PRECIPITATE(HAN-1).

Obtained using a Phillips X-r x diffractometer with Cu Kα radiation. Scanning speed: 2^{o}/min.

~~TABLE 7.3B.~~ QUANTITATIVE X-RAY FLUORESCENCE ANALYSES OF SOME TONGONAN BASE-METAL BEARING PRECIPITATES (TRACE ELEMENTS) . These are compared with metal content of precipitates from Broadlands and Imperial Valley.(after Weissberg,1969 and Maimoni, 1982 in Henley,et al,1984)

Element	108 DC	208 RP	209 WB	209 DC	401 RP	404 DC	MG-1 WB	Broadlands (+)	Broadlands (++)	Imperial Valley** **	Imperial Valley** ****
Nb		1.1									
Zr	9.0	4.2	17.S	21.1	1.4	3.9	12.2	not available	not available	not available	not available
Y	1.4		1.5			0.2	1.2				
Sr	30.0	10.3	24.0	48.4	5.0	15.9	37.7				
Rb	30.7	17.8	31.4	34.8	16.9	22.1	18.8				
Th											
Pb	454.5	34.0	5260.2	4754.2	52.9	180.7	121.0	25	400	16%	1.3%
A	82.1	31.1	382.2	316.4	40.3	75.0	36.1	400	50	na	1500
Zn	373.0	57.4	3867.2	2330.9	62.2	256.7	790.3	70	50	700	1100
Cu	118.1	57.7	1109.0	701.2	57.5	117.2	233.9			0.02%	1.0%
Ni	4.1		7.3	4.6(?)							
Cr	24.9		17.1	2.9(?)		5.8	9.8				
Ba	149.4			114.5	18.5(?)	27.0(?)	51.1	not available	not available	not available	not available
V	15.5	7.2	22.2	29.3		11.8	36.8				
Ti	0	0	0	0	0.	0	0				
La	4.4(?)	3.3(?)	4.5(?)				3.0(?)				
Sb	na	na	na	na	na	na	na	10%	1000	trace	190
Ag	na	na	no	na	na	na	na	500	2000	3400	80
Au	na	na	no	na	na	na	na	85	50	na	na
Tl	na	na	na	na	na	na	na	630	150	na	na
Hg	na	na	na	na	na	na	na	2000	600	na	na

Analyst: Dr. R. J. Parker
- below the detection limit
nu–not analysed

Broadlands(+)-Ohaaki Pool (Weissberg,1969)
Broadlands(++)- Sample from inside the silencer,well BR2
***Magmamax well No. 1
**** Separator
** after Maimoni,1982

where the temperature gradient is steepest, (b) boiling of the geothermal fluids; dissolved gases like CO_2, H_2S and NH_3(?) strongly partition in to the vapour phase accompanying boiling causing the residual liquid to become more alkaline and slightly concentrated.

IMPLICATIONS AND SUMMARY

There is dearth of information on base metal ocourrences in precipitates deposited by the Tongonan waters. Some geologists did not believe that these amorphous silica would show any mineralieation. Reflected light microscopy proved useful in this study. There are several implications recogenised from the study of these deposits. The two important ones are:

a) Research on mineral deposition is valuable to an understanding of the environmental and utilisation problems associated with the discharge of geothermal effluents, particularly, the high level of toxic elements that are dumped into and pollute surface waters; and blockage of production and reinjection wells and surface equipment by silica;

b) the precipitates containing variable amounts of metals represent the latest phase deposited by the fluids during the re-equilibration attempt of these geothermal waters within the wells. The high metal content of these materials demonstrate the ability of the metal and sulphur deficient Tongonan geothermal fluids to transport and deposit 'ore' metals.

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