THE GEOLOGY OF THE TONGONAN GEOTHERMAL FIELD

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ABSTRACT

The geology of the Tongonan geothermal field on the island of Leyte, Philippines is described.

Alteration mineral aesemblages are discussed and related to measured subsurface temperature and pressure conditions.

INTRODUCTION

The Philippines consists of a typical island arc system with an active subduction zone lying off the eastern coast. A major fault system, the Philippine Fault, strikes north to north-westward through the islands and it appears that some of the major geothermal areas are associated with this feature. Active subduction took place along the Philippine Trench approximately 60 million years ago, resulting in emplacement of the oldest known intermediate intrusives. There was then a period of relative quiescence until late Miocene when subduction again became active, accounting for many of the intrusives dated 15 million years to the present associated with the Philippine fault (Wolfe 1973). It is to this later activity that the Tongonan geothermal activity is related.

GEOLOGY

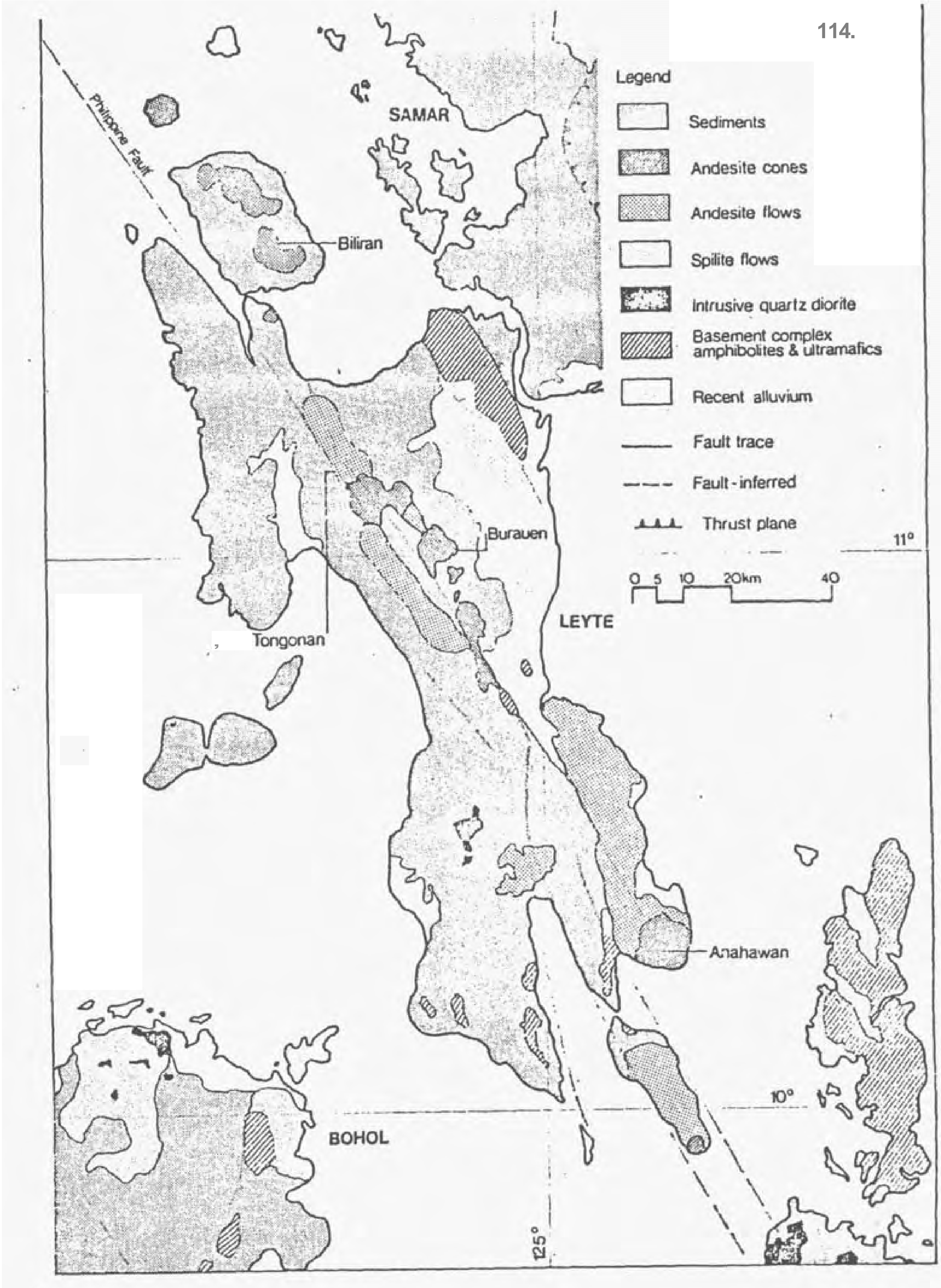
During the late Miocene the eruptive development of island arc volcanoes gave rise to flows and cones of andesitic material which now form the central mountain spine of the island of Leyte and lie alonq the approximate strike of the Philippine Fault (Figure 1).

The Tongonan geothermal area lies in one such andesitic region within a bifurcation of the Philippine Fault, Three major branches with approximately northwest-southeast strike dominate the Tongonan area. These have been designated the West Philippine Fault, to the west of the Bao Valley; the Central Philippine Fault, cutting the flank of the ranges to the east of the Bao River, and the less precisely defined East Philippine Fault along the crest of the central ranges (Grindley 1973) (Figure 2).

A general stratigraphy for the area has been constructed based on surface investigations (Vasquez and Tolentino 1973) and drilling observations (Figure 3).

North Central Leyte Formation (N.C.L.F.)

This formation crops out in the Bao gorge and the middle reaches of the Bao River and consists of coarse, massive pebble and boulder conglomerate with thin interbedded volcanic sandstone, ash layers and river silts. The majority of the boulders are of hornblende-andesite similar to flows in the Bao Volcanics. The intervening matrix is a Coarse sandstona containing angular fragments of quartz, feldspars, augite, hornblende and minor clay and glass.

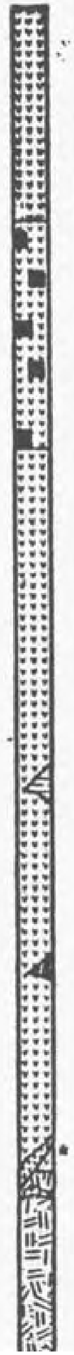


GENERALISED GEOLOGY OF LEYTE WITH MAIN THERMAL AREAS INDICATED.

Figure 1

Figure 2

... STRUCTURAL GEOLOGY.



Unit and Description	Thickness	Age
JANAGDAN ANDESITE Volcanics and flows comprising a 2 pyroxene andesite. Does not extend into area drilled	Unknown	Quaternary
NORTH CENTRAL LEYTE FORMATION Andesitic conglomerates and laharic breccias encountered in several Bao Valley wells.	580 m in TGE 3	Upper Miocene to Mid Phis ——
BAO VOLCANICS Crystal rich, hornblende andesite lavas and associated breccias and tuffs, encountered in all wells to date. Clay Horizon: Extensive clay development sometimes accompanied by calcarenites and conglomerates. loran Shale: Dense, fine grained, black rock with minor organic content.	1860 m max logged	
MAHIAO PLUTONIC COMPLEX Medium to fine grained, massive rock of diorite to quartz diorite composition. Granites have been identified in two holes.	Unknown	Not certain but believ-ed younger

The boulder conglomerates appear to be of lahar origin from active andesite volcanoes to the east and southeast. The similarity of their constituent fragments to the flows in the Bao Volcanics suggests that the formation may be contemporaneous with the later flows of the Bao Volcanics (Grindley 1973).

Rocks of the N.C.L.F. have not been intersected in the later Mahiao drilling and the unit has no importance with respect to the geothermal system.

Bao Volcanics

These are predominantly hornblende andesites with phenocrysts of oxyhornblende and andesine-labradorite up to 1 cm in a microcrystalline base of plagioclase, hornblendes, iron oxides and glass.

All wells drilled during the latest and deepest stage of exploration (i.e. wells assigned 3 digit numbers) have penetrated extensive sections of hornblende andesite lavas, breccias and tuffs, in the order of 1500 m thick. These rocks are chaotic, interfingered and probably of limited areal extent. No unequivocal marker horizons have been established, but for working purposes two horizons have been selected as offering possible subsurface well to well correlations. These are a zone of intense clay development and a thin shale comprised of organic and volcaniclastic sediments.

Clay Horizon

A zone of intense clay development has been noted in the Mahiao wells at a depth which, with the exception of well 1R10, ranges from 100 m to 260 m above mean sea level. This clay horizon is coincident with the overpressured, gas producing zones encountered in wells 103, 105 and 209.

A conglomeratic bed was observed to overlie the clay horizon in wells 209 and 213. Shales and pebbles underlie the clay in well 406. That marine conditions existed is demonstrated by the presence of calcarenites in wells 401, 404 and 406. In well 401 these were found to contain echinoid spines and shallow water marine foraminifera and in well 406 foraminifera of the genus Rotalia were identified (Hornibrook 1979). The calcarenites encountered in well 406 occur within the clay horizon and appear to be partly reworked.

This association of the clay horizbn with marine and erosional products indicates a marine incursion over the Tongonan area. It is postulated that this horizon would originally have had significantly better permeability than the enclosing rocks. Thus it may have acted as a channel for hydrothermal fluids resulting in degradation of the original minerals to form the clay assemblages now present. Alternatively the clay may have formed as a result of the marine transgression, but since the original volcanic texture is often well preserved this explanation is considered unlikely.

Sambaloran Shale

A unit of dense, fine grained black volcaniclastic sediment 2 to 3 m thick has been recorded in the southern and northern Mahiao wells.

Palynological investigations using low temperature ashing techniques on samples from well 407 have determined the organic content to be 2.9%. Most of the organic residue was in the fonn of amorphous fragments, but some still retained cellular morphology and a few fungal or algal cells were present (Raine 1978).

In section there is an obvious disruption to the shale unit between wells 209 and 213, and similarly 401 and 4R1 (Figure 4). This has been interpreted as evidence of a normal fault striking N.W. to S.E. and dipping westward with an apparent vertical displacement varying between 75 m and 125 m.

Well to well correlations suggest that the Sambaloran shale forms an antiform, closing and plunging to the west. It is possible that the crest of this antifonn was removed by erosion during the marine incursion previously described. This may account for the absence of Sambaloran shale from well 406 (Figure 5).

Mahiao Plutonic Complex

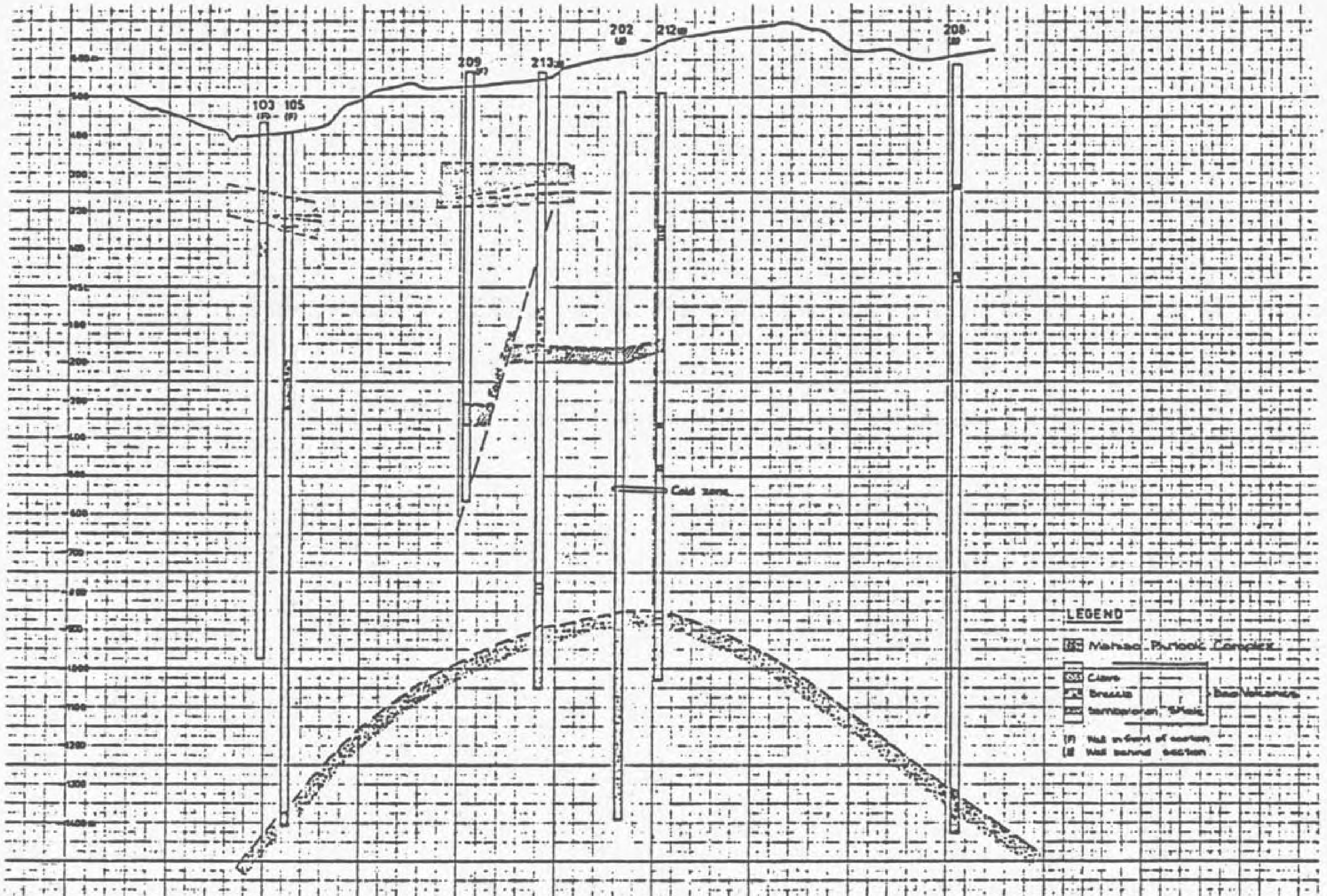
The eruptive rocks comprising the Bao Volcanics are underlain by a body of plutonic rock of diorite to quartz diorite composition. The diorite is a coarse, even-grained rock exhibiting propylitic alteration. The originally abundant plagioclase is now entirely replaced by cloudy, sericitic, hydrothermal albite, though primary apatite included in feldspar crystals has not been altered. Primary mafics were not abundant, and are represented by irregular concentrations of hydrothermal chlorite, epidote and pyrite. Magnetite has been altered to patches of leucoxene. Quartz occurs interstitially to feldspar to form patches with serrated edges. Possibly these are composed of original igneous quartz overgrown by hydrothermal quartz. The rock is cut by a network of fine veinlets and strings in which epidote and pyrite are the most obvious minerals in hand specimens. In thin section these are also seen to contain quartz and adularia (Wood 1977).

The contact between the plutonic rocks and overlying volcanics is not clearly defined but frequently takes the form of a transitional zone in which magnetite and epidote become abundant. This zone frequently corresponds to circulation losses during drilling and is an important production horizon. Magnetite content declines rapidly once the plutonics proper are intersected. The absence of any sharp contact or sedimentary unit: between the Bao Volcanics and the Mahiao Plutonics is believed to indicate that the intrusion of the Mahiao Plutonics postdates, or is contemporaneous with, the extrusion of the Bao Volcanics.

The plutonic rock mass forms a ridge-like feature, trending and plunging to the northwest beneath well 407 and rising toward well 202 (Figure 5).

Hornblende Dacite

This rock occurs in a number of short intervals (less than 3 m) in walls in the Mahiao area at a depth of approximately 1000 m below mean sea level and coincides with the incoming of quartz diorite. The dacite contains much perfectly fresh hornblende of magmatic origin. This is inconsistent with the general alteration sequence observed in the Bao Volcanics in which hornblende appears to be the most unstable mineral. It is possible that ths hornblende in the dacite is of a different composition and more resistant to alteration than the andesitic hornblende. Since the dacite and andesite are petrographically very similar, this would seem improbable. It is interpreted that the dacite represents a relatively young dyke system and that there has been insufficient time to allow complete mineral reaction with the hydrothermal fluids. Assuming that the intrusion of the dacite postdates the faulting then it is likely to have relatively poorer permeability as a consequence of baing less fractured. This would further reduce mineral reaction with the hydrothermal fluids.

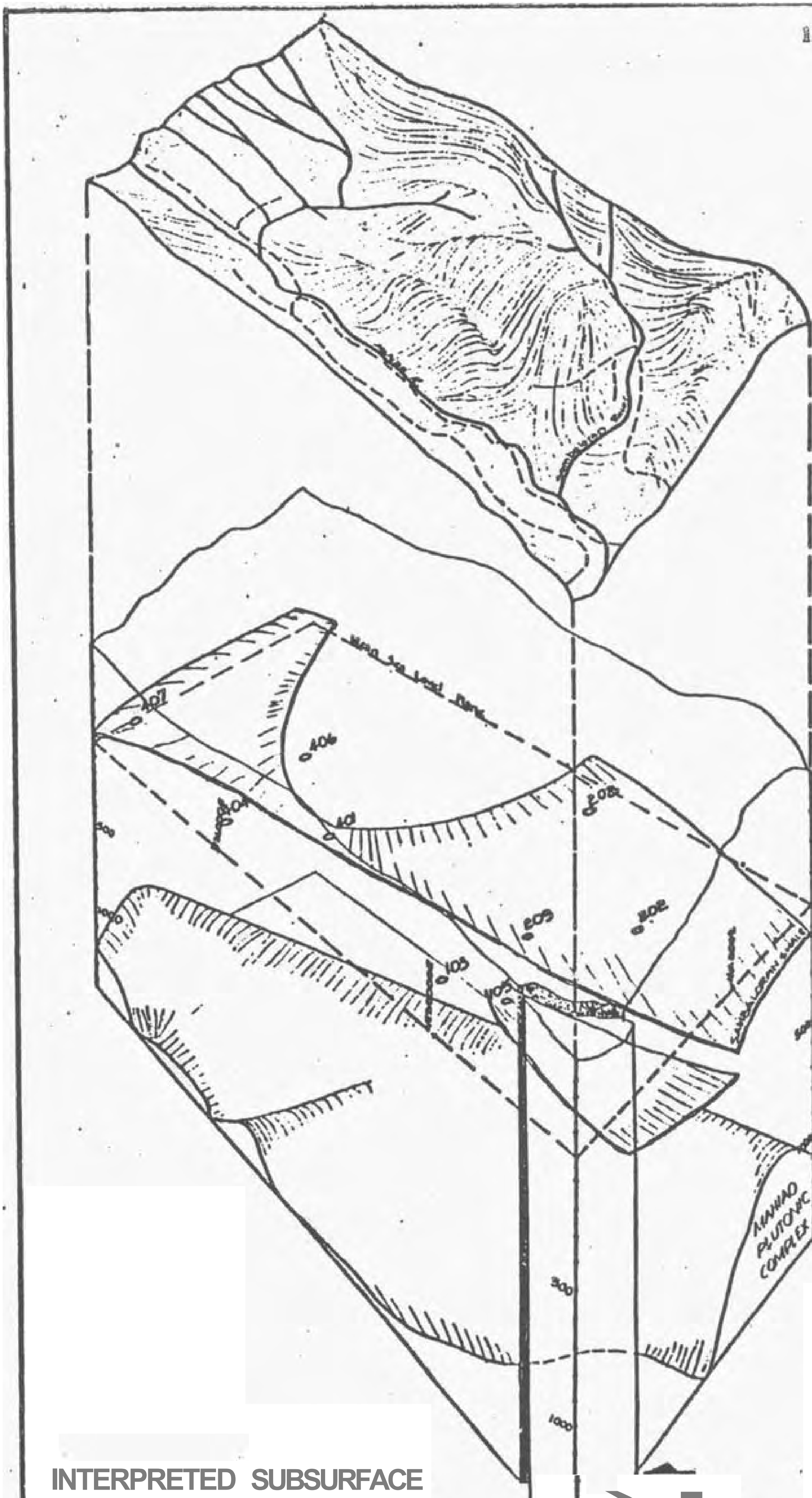


CROSS SECTION THROUGH TONGONAN FIELD

Figure 4

Figure 7

CROSS SECTION THROUGH TONGONAN FIELD



INTERPRETED SUBSURFACE GEOLOGY OF THE MAHIAO SECTOR–TONGONAN FIELD-

GEOLOGICAL HISTORY

From the above observations and interpretations the following sequence of events is proposed in order of decreasing age:

1. Eruption of lavas and tuffs from Bao Volcanoes onto continental crust.

2. Marine transgression resulting in deposition of Sambaloran shale.

3. Folding.

4. Uplift and erosion. Marine incursion to the north east resulting in formation of calcarenites.

5. Faulting accanpanied by the intrusion of Mahiao Plutonic Complex.

6. Development of hydrothermal system.

HYDROTHERMAL ALTERATION

Throughout the area drilled the entire volcanic sequence has undergone hydrothermal alteration, the intensity of which increases with depth. Generally speaking, wells exhibit similar alteration assemblages at corresponding depths relative to sea level (Figure 6).

Temperature Estimates

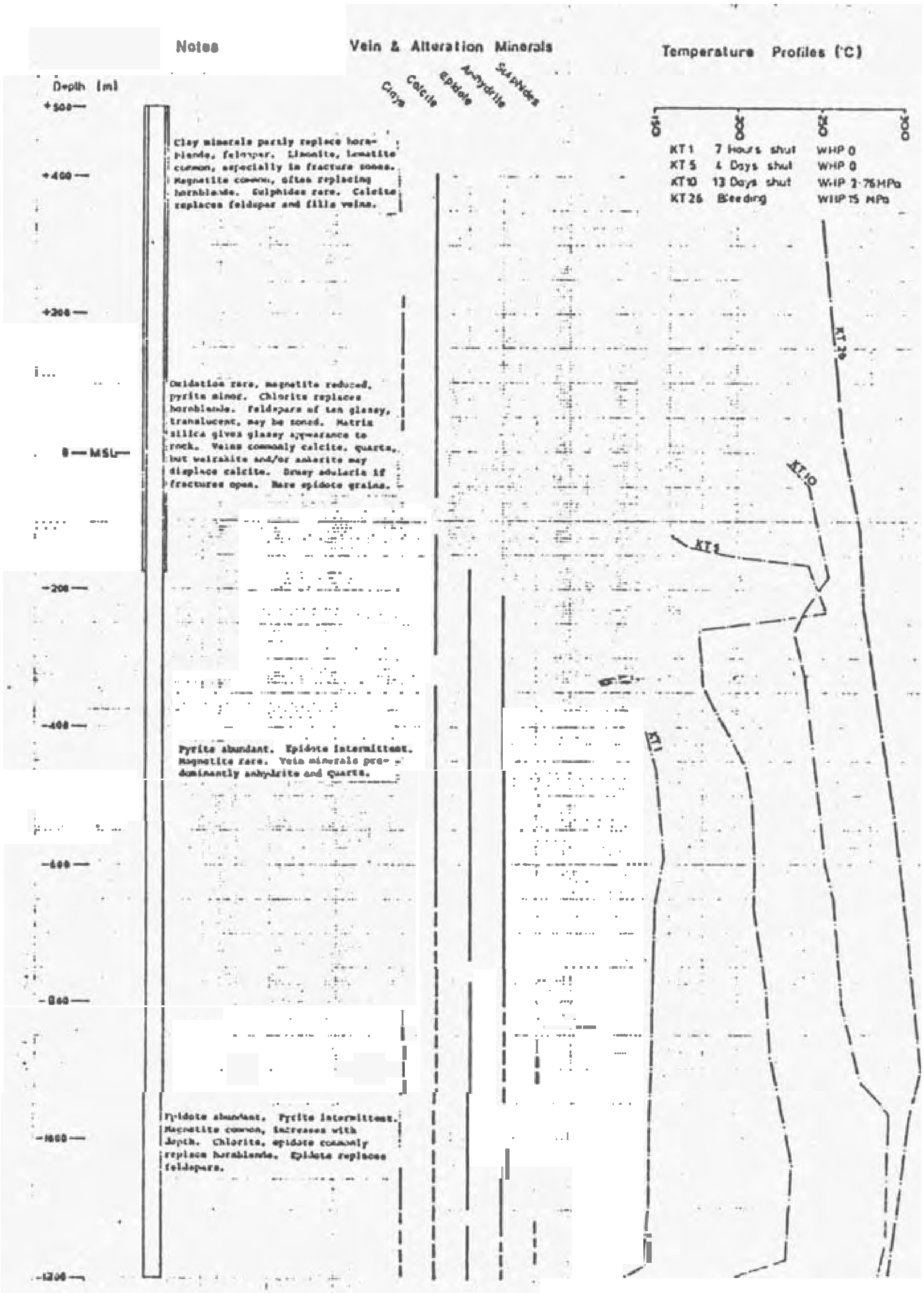
Since the mineral assemblages change in response to the hydrothermal conditions, estimates of subsurface temperatures existing at the time of mineral fornation can be attemptad. Thus movements of the hydrothermal system through space and time may be recorded.

Generally, at Tongonan, good agreement has been found between predicted temperatures and measured results. Important indicator minerals used are the hydrothermal clays, epidote and garnet.

The hydrothermal clay minerals

Interstratified expanding clays of montmorillonite and illite compositions reflect increasing temperature by an increase in the relative amount of illite at the expense of the lower temperature montmorillonite. The general sequence is as follows:

Depth M.S.L.	Clay Mineralogy	Temp°C
+500 m to +300 m	Montmorillonite rich with illite interlayering	140-180
+300 m to -400 m	Random I.M. (d001=10.4 to 11.6°A) some layers regular I.H.	180-230
Below -400 m	Illite (+ epidote)	> 250



ALTERATION IN A TYPICAL MAHIAO WELL.

Figure 6

Epidote

Epidote is present in all the deep wells and is usually first observed at approximately 100 m below mean sea level, From this depth to 900 m below HSL the occurrences are intermittent and minor. Below -900 m M.S.L. where measured downhole temperature exceeds 250°C all lithologies are propylitic and epidote is abundant as a vein mineral and replacing feldspar.

Carbonates, in the form of calcite, ankerite or wairakite may coexist vfth epidote but generally are restricted to the section from surface to -100 m HSL, that is, above any epidote occurrences.

This change in the alteration assemblage has been used as a marker tor the setting of production casing in order to preclude the possibility of calcite deposition in the well.

Garnet

Garnets of the grossular-hydrogrossular or grossular-andradite series haw been observed at various depths below -100 m H.S.L. in W31 and at -460 m M.S.L. in well 209. Andradite has been found in the Salton Sea field where temperatures reach 360%. Other estimates of the temperature prevailing during hydrothermal garnet crystallisation come from fluid inclusion studies of garnet-bearing skarns associated with porphyry copper and other ore deposita. Theodore & Blake (1978) have summarised such data and record temperatures in the range 350-550°C for garnet growth.

DISCUSSION

Although in general there is good agreement between measured subsurface temperatures and those predicted fran the hydrothennal mineral assemblage, some intereating exceptions Occur.

In the western wells 103 and 105, assemblages indicative of disequilibrium have been encountered. In well 103 epidote (250°C) occurs along with random IH clay (230°C) at depths between 600 m and 720 m. Xn well 105 an assortment of clay-rich, variegated andesite tuff/lava chips were recovered froa 1665 m and 1755 m approximate depths. The clays are all interlayered illite-montmorillonite with relatively high montmorillonite component. (d001 = 10.7-12.1). Such clay normally indicates temperatures in the 140°C - 200°C region which is completely at variance with the recorded stable downhole temperature of 300% at these depths.

The assemblages encountered in wells 103 and 105 are believed to be reliat alteration from a lower temperature boundary area which is in the process of re-equilibrating to the higher temperature conditions now present. A westward or south westward shift of the hydrothermal system boundary within geologically recent times is postulated. Such an explanation is in accord with the south westward flow direction of the hydrothermal fluid proposed by my colleagues in another paper (Whittome & Smith 1979).

To the south-east of the Mahiao area in the Malitbog and Mamban areas, Wells MB1, TGE-8 and TGE-9 indicate past hydrothermal activity with higher temperature than those now measured. In TGE-9 I.M. clays indicative of temperatures of formation in the 180-230°C range occur where the measured temperature is only 60-75°C. In well MB1, epidote was first noted at 400 m depth where the measured stable temperature is now 120°C. A temperature of 250°C is not reached until a depth of 1100 m but there is no increase in epidote abundance at this depth. The presence of garnet at 580 m in MB1 is further evidence of mineral disequilibrium in this area.

Also worthy of note is the presence of diaspore at 675 m in well MB1. Experimental work *(Roy & Osborn, 1954)* on hydrothennal synthesis of diaspore suggests that it will fora only at pressures greater than 13.8 MPa and at temperatures between 275°C and 415°C. Present measured temperature is 180°C at 675 a depth, and 600 m to 1000 m of extra overburden would have been required to maintain the necessary hydrostatic pressure. This relict alteration may represent a dying hydrothermal system which still supplies the hot water tapped by well MB1 and whose centre may have aigrated north westward to the Mahiao area. But in the light of the flow directions postulated earlier, this explanation is considered unlikely. It is suggested that the hot vater encountered in well MB1 comes from the active Mahiao area and is penetrating and flowing south into the alteration zones of a long extinct systen.

CONCLUSIONS

The Tongonan geothermal field lies in a centre of andesitic volcanism which was active during upper Miocene to mid Pleistocene times.

Permeability is predominantly derived fran fractures but appears in part to be stratigraphically controlled, that is changes in lithology have become the foci for the production of permeable fractured Zones. Particularly important is the contact between the Bao Volcanics and nahiao Plutonics.

The hydrothermal alteration mineral assemblage recorda the temperature and pressure conditions existing at the time of mineral formation. These generally correspond to measured, present day conditions. The mineral assemblage may provide a record of past conditions and thus indicate movements of the hydrothermal system through space and time.

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