STRATIGRAPHIC CORRELATION IN MT. LABO, MT. CANLAON AND MT. CABALIAN GEOTHERMAL AREAS USING FISSION-TRACK, THERMOLUMINESCENCE AND ZIRCON MORPHOLOGY

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Abstract

The absolute ages of selected volcanic rocks were determined in order to refine the working stratigraphy of three Philippine geothermal areas - Mt. Canlaon,. Labo and Cabalian. The rock dating methods used are fission-track (FT) and thermoluminescence (TL) which are suitable for measuring the ages not only of young, fresh volcanic rocks but also **of** *hydrothermal events in altered rocks Zircon morphology was utilized to correlate various lithologic units that might be derived from the same magmatic source and to deduce the probable temperature of the magmatic reservoir.*

Fission-track dating yielded ages of 0.27 Ma for dacites in well LB-2D in Mt. Labo and 1.81 Ma for dacites in well PT-ID in Mt. Canlaon which are both consistent with the Pleistocene ages **of** *the Labo and Canlaon Volcanics, respectively. It also gave a 1.62 Ma age for silicic andesites in MC-2 indicating that these volcanic rocks should be correlated with Pleistocene Canlaon Volcanics,* **and** *not with Pliocene Caliiing Formation. The latest hydrothermal regime in Mt.* ***Labo*** *was estimated to be 0.32* ***Ma from*** *FT age of altered dacites in LB-1D. Results of fission-track dating and zircon morphology analysis revised the working stratigraphy of Mt. Canlaon but validated that of Mt. Labo. Using zircon data, the source magma temperature of Pleistocene volcanics was estimated to be ~845°C in Mt. Labo, and ~680°C in Mt. Canlaon.*

In Mt. Cabalian, thermoluminescence data suggest a Pleistocene age (490-670 ka) for Tamar Volcanics, initially postulated to be Late Pliocene. TL also confirmed the Pleistocene ages of Cantodoc **(510** *ka) and Cabalian (17 ka) Volcanics, and implied the age of the latest hydrothermal event (5-6* **ka)** *in the area.*

1.0 INTRODUCTION

Two dating methods were **used** in determining the absolute ages of selected volcanic **rocks** in three geothermal exploration areas of PNOC EDC (Fig. 1). These methods **are** fission-track (FT), and thermoluminescence (TL). Another method, zircon morphology analysis was utilized to estimate the probable temperature of the magmatic source of the rocks. It was **also** used to correlate various lithologic **units based** on the morphology of their zircons. The results of these three methodologies were subsequently applied to refine the working stratigraphy of Mt. Canlaon, Mt. **Labo** and Mt. Cabalian.

Fission-track **and** zircon morphology studies utilize the accessory mineral zircon **($ZrSiO_4$)** while the TL **method** is based on primary quartz (SiO_2). Thus, these methods have wide applications in silicic and intermediate rocks where both minerals are common constituents. The

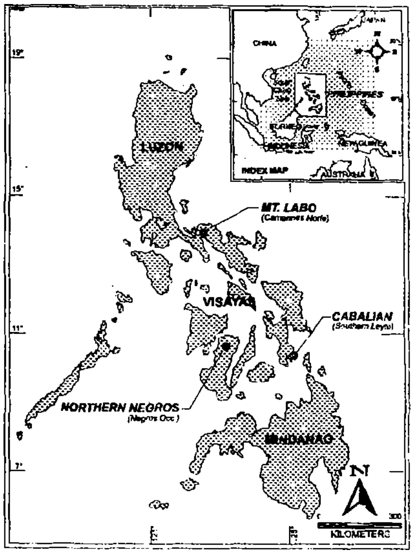

Figure **1.** *Location map of Mt. Labo, Canlaon and Cabalian geothermal areas.*

density of spontaneous fission tracks is proportional to the age of the rock. However, the tracks decrease in length and disappear when the rock is subjected to temperatures of more than 250°C. A similar case holds true for the TL method where the TL clock is reset if the rock is subjected to temperatures as low as 100°C (Hayashi, 19%). For hydrothermally altered rocks, these methods will provide the age of the latest thermal event which is younger than the true age of the volcanic rock. FT dating method can determine rock ages from Pre-Cambrian (>570 Ma) to Quaternary (0.1 Ma). TL dating technique, on the other hand, is most effective for volcanic rocks with ages ranging from a few thousand years to a few million years. The most reliable TL ages can be obtained for those younger than 300 ka (Takashima and Watanabe, 1994).

2.0 PRINCIPLES OF THE THREE DATING METHODS

2.1 Fission-Track

Radioactive uranium is present in zircon in appreciable amounts. Of the two isotopes, ^{238}U produces natural or spontaneous fission tracks which is a record of the path traversed by fission fragments within the crystal lattices of zircon. Upon chemical etching, these paths become visible under a microscope of high magnification (Hayashi, 1996). The number of spontaneous fission-tracks per unit area in zircon is a function of age, and uranium concentration of the zircon. The ^{238}U concentration is determined by irradiating zircon with thermal neutrons to induce fission of ^{235}U; and then multiplying by the constant value of 138 which is the ratio of ^{238}U to ^{235}U (Wagner and Van Den Haute, 1992 in Zaide-Delfin, 1997).

The external detector method was used for the present study. The fission-track age of zircon for samples younger than 100 million years can be calculated using the equation

$$\text{Age} = (Ds * Dd/Di) * Z$$

where Ds = density of spontaneous tracks produced by ^{238}U in the zircon sample of unknown age
Di = density of induced tracks in the attached mica sheet produced by ^{235}U in the zircon
Dd = density of induced tracks in the mica sheet produced by ^{235}U in the standard glass of known U content

The zeta value (Z), a calibration factor, is derived empirically by measuring the Ds and Di values of a standard zircon sample of known age which was irradiated together with the zircon samples of unknown age. The standard zircons used for the present study came from the Fish Canyon Tuff which has an age of 27.8 Ma by argon isotope method. The uranium standard glass is the NBS-SRM962 (Zaide-Delfin, 1997).

2.2 Thermoluminescence

Minerals absorb radiation from surrounding radioactive materials at a fixed rate called annual dose (AD), and display TL resulting from an accumulated dose known as equivalent dose (ED). AD is calculated from the chemical content of radiogenic elements U, Th. K: while ED is derived from the TL glow curves (Fig. 2) of both natural and artificially irradiated samples (Takashima and Watanabe, 1994). The TL age is given in the equation ED/AD; age is in ka where 1 ka=1,000 years. Quartz is used for the TL dating method since its TL intensity is stable over a million years and its AD varies within a narrow range (Hayashi, 1996).

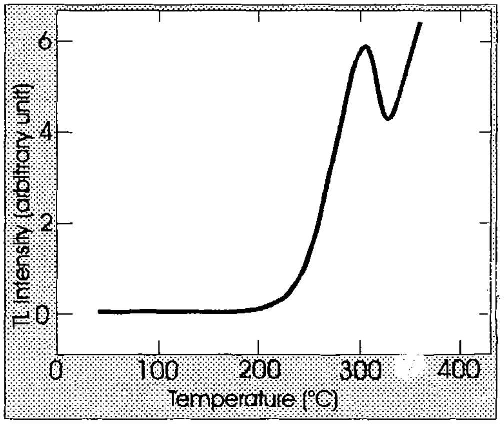

Figure 2. TL Glow Curve of Quartz in MC-32A, Cabalian.

A simpler approach to this dating technique is the TL intensity index (TI) where the TL age is calculated using a standard of known age and is shown in the equation of Hayashi and Shinno (1996, in Hayashi, 1997) as follows:

$$TI = \frac{Tn}{wt} * \frac{Tst}{Yst}$$

Tn = TL intensity of sample
wt = Weight of sample (mg)
Tst = Age of standard = 1000 ka (Yabekei tuff)
Yst = TL intensity of standard = 2.00

2.3 Zircon Morphology

A zircon crystal may be described using four indices - prism, pyramid, elongation and flatness (Hayashi. 1991). These indices are calculated in a computer program of Daishi and Hayashi (1989) by using measured data from zircon photomicrographs. These data are the middle prism type (100 or 110), dimensions of the middle prism, and dimensions of the crystal.

The flatness index (FI) is a measure of the thickness of zircon relative to its width and ranges from very thin (<0.2) to very thick (>0.8). The elongation index (EI) shows the degree of prism development along the c-axis and may be classified from very short-prismatic (<0.2) to very long-prismatic (>0.8). The prism index (PI) indicates the relative development of the two tetragonal prisms (100) or (110), and ranges from <0.2 for welldeveloped 110 prisms, and >0.8 for well-developed 100 prisms. The pyramid index (PY) shows the relative development of the pyramid faces by comparing their heights to that of the hghest ideal pyramid (301) and classified from very low (<0.2) to very high (>0.8). These data are plotted on a prism-pyramid elongation-flatness or PPEF diagram (Fig. 3). An ideal crystal form is drawn based on the means of each index of the 30 grains (Hayashi, 1997). Thus, similarity of these parameters in the zircon content of two rock units suggests that these rocks likely originated from a common magmatic reservoir.

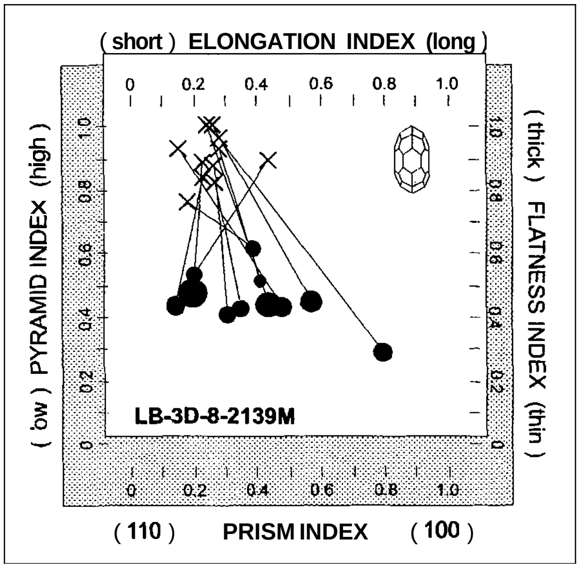

Figure 3. ***PPEF diagram of Zircons from well LB-3D, Mt. Labo.***

The prism index (PI) is the most understood among these four indices. Zircons with high PI have well developed (100) prism faces and are formed in intermediate igneous rocks which crystallize at about 900°C (Pupin, 1980, in Zaide-Delfin, 1997). In contrast, low PI zircons have well developed (110) prisms and are found in silicic rocks which form at lower temperatures of ~600°C. Based on zircon synthesis experiments, Hayashi (1990) formulated the equation T(°C) = 400(PI) + 600 to estimate the possible temperature of the volcanic magma reservoir.

3.0 APPLICATIONS OF THE THREE DATING METHODS

3.1 Mt. Labo Geothermal Area

The Mt. Labo geothermal project is located in Bicol peninsula in southeastern Luzon (Fig. 1). Mt. Labo is an inactive volcano and is part of a 200-km long chain of Quaternary stratovolcanoes in the region. Eight deep exploratory wells have been drilled in the area since 1990.

The subsurface stratigraphy of the Mt. Labo area is comprised of the Upper Miocene Susung Dalaga Formation (Sdf) and the Pleistocene Labo Volcanics (Lbv). The Sdf is made up of submarine deposited fine-grained, conglomerates and limestones with interbedded andesiticdacitic lava flows while the Lbv consists of silicic andesiticdacitic breccias and lavas. The Lbv is further subdivided into the thick Labo basal unit (Lbu) and the central cone deposits (Lcc), a –100 m-thick cap over Lbu.

All Mt. Labo samples analyzed for both fission-track dating and zircon morphology are rock cuttings from the 6 geothermal wells drilled as deep as -1800 mRL (Figs. 4, 5, and 6)

3.1.1 Fission-Track. Two samples were analyzed using the fission-track dating method. The first sample is an Lbu dacite taken at +680 mRL in well LB-2D which gave an age of 0.27 Ma. This age confirms the Pleistocene age of the Lbu. It is also very close to the K-Ar age of 0.24 Ma of an Lcc dacite outcrop (Gillot, 1983; Mouret and Pasquare, 1982). Thus, based on the close similarity of their ages, the Lbu and the Lcc should no longer be distinguished as separate member units, and should instead be termed collectively as the Labo volcanics.

The second sample, a dacite lava flow within the Upper Miocene Sdf taken at -1000 mRL in LB-1D, yielded a very young FT age of 0.32 Ma. The age discrepancy is likely caused by the fading of fission tracks upon reheating of the rocks to temperatures >250°C. Although present subsurface temperature at this depth is only ~200-220°C, the presence of relict high temperature alteration minerals like epidote, and fluid inclusion data in nearby LB-5D suggest that high temperature (>250°C) conditions existed in the past in this sector. Hence, fission-track dating will not yield the true age of rocks altered by fluids hotter than 250°C. Instead, their FT ages could probably approximate the age of the latest hydrothermal regime in the area. The fission-track age of the first sample, on the other hand, reflects the true age since temperatures never exceeded 100°C at +680 mRL in LB-2D.

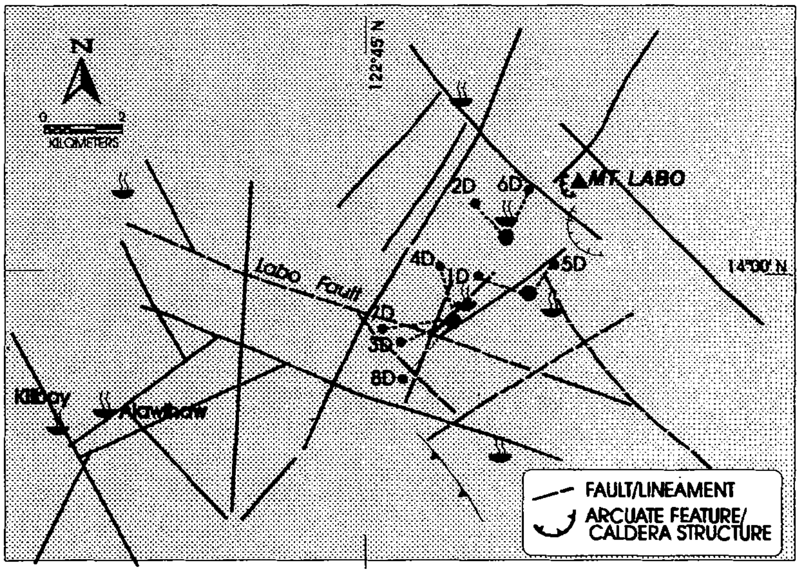

Figure 4. Location maps of wells in Mt. Labo.

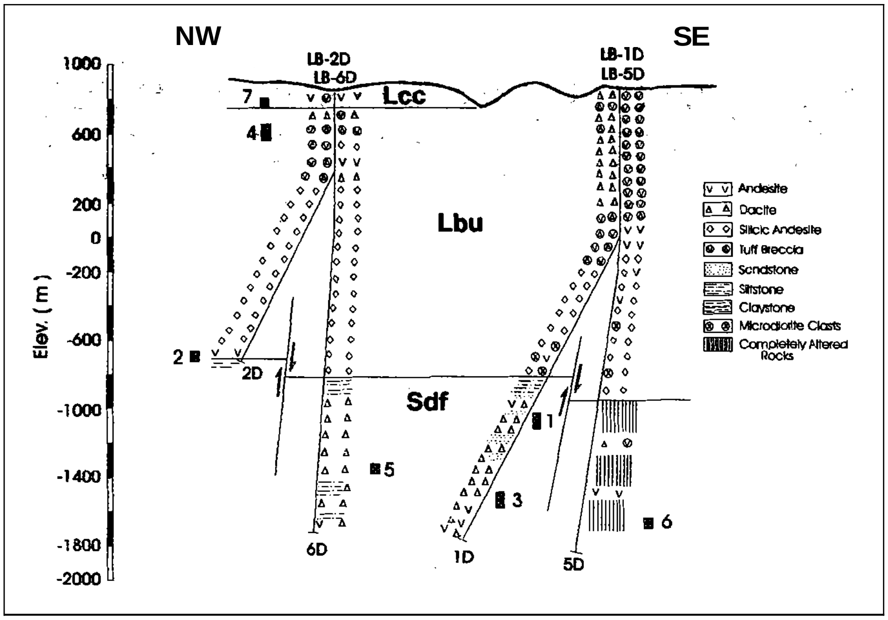

Figure 5. Subsurface stratigraphy of Mt. Labo showing wells LB-ID, LB-2D, LB-5D and LB-6D.

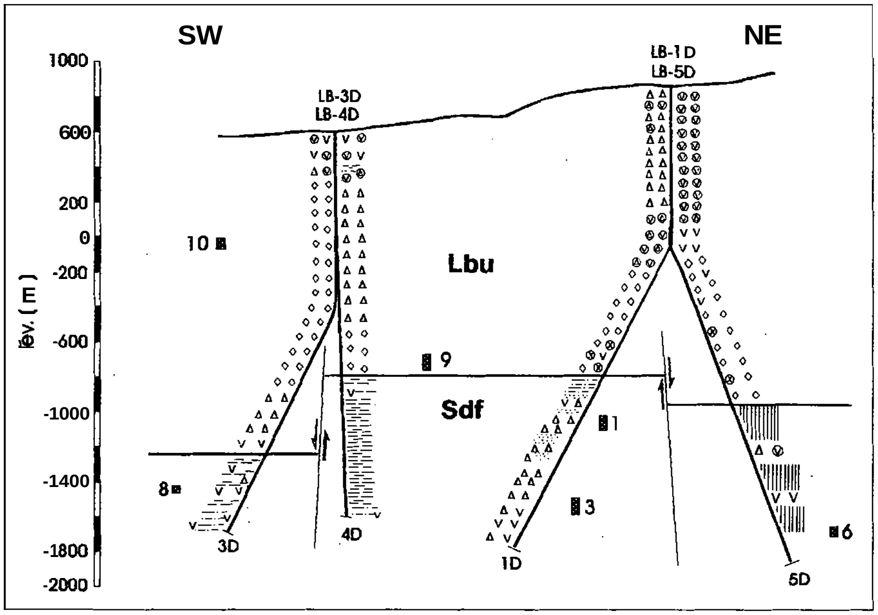

Figure 6. Subsurface stratigraphy of Mt. Labo showing wells LB-ID, LB-3D, LB-4D and LB-5D.

3.1.2 Zircon Morphology. **Ten samples from six wells (LB-ID, 2D, 3D, 4D, 5D and 6D) were analyzed for zircon morphology (Figs. 5 and 6, Table 1). The results of zircon morphology (Table 2) validated the present subsurface stratigraphy of Mt.** Labo, **and resolved problems in stratigraphic correlation and lithologic identification.**

Table 1. Mt. Labo Well Samples Analyzed for Zircon Morphology.

Sample No.	Well	Depth (m RL)	Rock Type	Formation
1	LB-1D	-997-1068	HbDa	Sdf
2	LB-2D	-635-678	HbPxAn	Lbu
3	LB-1D	-1460-1564	Da	Sdf
4	LB-2D	+680-+590	BtHbDa	Lbu
5	LB-6D	-1316-1353	Da	Sdf
6	LB-5D	-1620-1670	Completely altered rock	Sdf (?)
7	LB-2D	+818-+770	OxyHbAn	Lcc
8	LB-3D	-1423-1453	An	Sdf
9	LB-4D	-648-738	HbDa/SilicicAn	Lbu
10	LB-3D	-33-63	Da/SilicicAn	Lbu

Hb:hornblende; Px:pyroxene; Bt:biotite; Da:dacite; An:andesite

Table 2. Average Values of Zircon Morphology Data of Mt. Labo Volcanic Rocks.

Sample No.	Width (mm)	Length (mm)	PI	PY	EI	FI
1	0.073	0.152	0.28	0.52	0.23	0.80
2	0.040	0.105	0.31	0.53	0.32	0.90
3	0.070	0.176	0.28	0.51	0.30	0.93
4	0.067	0.173	0.24	0.50	0.37	0.83
5	0.062	0.175	0.34	0.54	0.33	0.89
6	0.064	0.153	0.33	0.48	0.31	0.83
7	0.049	0.117	0.32	0.48	0.30	0.89
8	0.057	0.114	0.38	0.46	0.25	0.90
9	0.044	0.142	0.33	0.55	0.40	0.89
10	0.047	0.104	0.33	0.53	0.25	0.86

The strong resemblance of zircons in four lavas (2, 7, 9, 10) proved that the thick pile of volcanic rocks termed as Labo Volcanics truly constitute a single stratigraphic unit. Their zircons exhibit identical grain size and crystal indices suggesting that these lavas were derived from a common magma source. Based on their young age (0.27 Ma), their source magma probably drives the present hydrothermal system in Mt. Labo. Its temperature is estimated to be ~845°C using prism index.

Zircon analysis also confirmed that the dacite lavas *(5)* at -1316 mRL in LB-6D truly belong to the Sdf, and are not Lbv lavas displaced by Hagdan fault. The zircons in LB-6D dacite *(5)* show identical coarse grain size and crystal indices with those contained in Sdf dacite (3) in LB-ID. In contrast, their zircons differ sharply from those found in Lbv lavas 9 and 10 in terms of grain size (fine) and prism index distribution.

The original lithology of completely altered rock units was also deduced using zircon morphology. Based on the high and intermediate prism indices of their zircons, the completely altered Sdf volcanic rock (6) in LB-5D at -1620 mRL has been identified as an andesite.

32 Mt. Canlaon Geothermal Area

The Mt. Canlaon geothermal area is located in the northern part of Negros island, central Philippines (Fig. 1). The geothermal system is postulated to be related to Mt. Canlaon, a Pleistocene-Recent volcanic complex consisting of various eruptive vents including the active Canlaon Crater (Pamatian et al., 1992). The first two exploratory wells were drilled in the northern sector of the field in 1978. Six deep wells were subsequently drilled between 1994-1997 (Fig. 7).

Two stratigraphic units were encountered by the 8 deep wells drilled in Mt. Canlaon (Fig. 8). These are the Pliocene Caliling Formation (Cf) composed of limestones with interbedded microdiorite breccia, sandstone, fine-grained clastics and andesite lava flows; and the Pleistocene-Recent Canlaon Volcanics (CnV) made up of a thin layer of andesite lava and an underlying thicker pile of tuff breccia, dacite and silicic andesite lavas (Zaide-Delfin, 1996).

*3.2.1. **Fission-Track**.* Two samples from two wells were analyzed using this dating method. Though they exhibit slight hydrothermal alteration, the FT ages obtained from these rocks represent their true ages since they were never subjected to temperatures hotter than 180°C.

The first sample is a dacite lava at 48 mRL in PT-1D which lies within the Pleistocene CnV. Its inclusion within the CnV is correct based on its FT age of 1.81 Ma or Early Pleistocene. The second sample is a coarse silicic andesite at -576 mRL in MC-2 which was previously grouped with the Pliocene Caliling sedimentary formation underlying the CnV. Results of fission-track dating, however, indicate that it should be classified under the Pleistocene CnV based on its age of 1.62 Ma or Early Pleistocene.

*3.2.2 **Zircon Morphology**.* Nineteen samples from 6 wells in Mt. Canlaon were analyzed for zircon morphology (Fig. 8, Table 3) to validate their classification as either CnV or Cf. The results of zircon analysis are shown in Table 4.

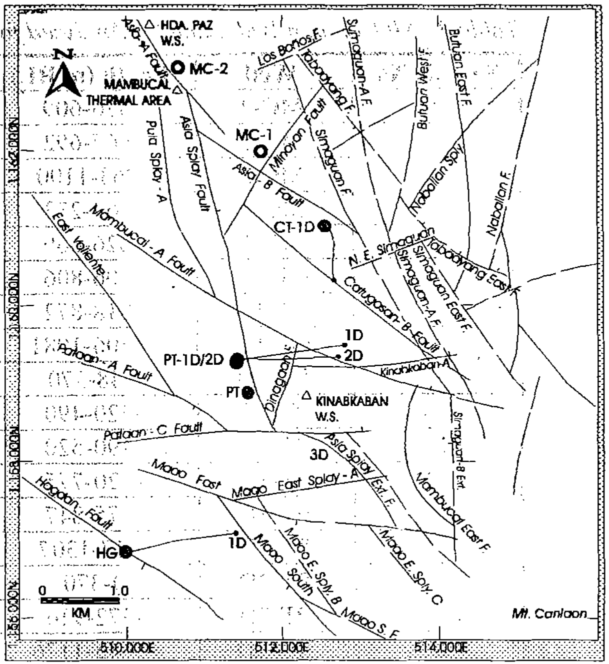

Figure 7: Location map of wells in Mt. Canlaon.

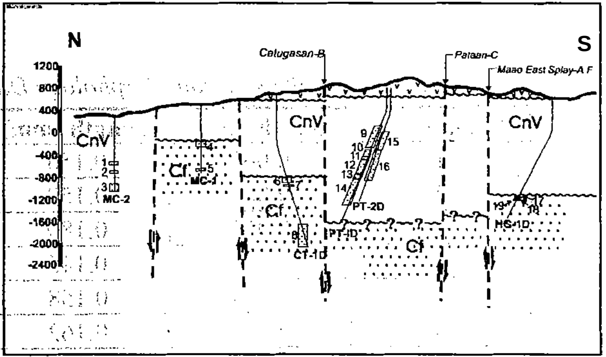

Figure 8: Subsurface stratigraphy of Mt. Canlaon.

All CnV dacite lavas in PT-1D (9, 10, 11, 12, 13) and **PT-2D (15, 16)** contain zircons which exhibit identical grain size and crystal form suggesting that they originate from the same magma reservoir. Fission-track dating confirmed that these dacite lavas are truly Pleistocene in age (**1.81** Ma), The probable temperature of the source magma of these Pleistocene CnV dacites is ~680°C using zircon prism index.

The coarse dacites near the bottom of PT-1D (14) and the coarse silicic andesites in MC-2 (1, 2, 3) were previously correlated with the Pliocene Cf. However, their zircons show the same grain size and crystal structure as the zircons in the Pleistocene CnV dacites. The identical morphology of their zircons suggests that the coarse dacites and silicic andesites were derived from the same CnV source magma. Thus, they should still be grouped with the Pleistocene CnV, and not with the Pliocene Cf.

Based on zircon studies and fission-track dating, MC-2, **PT-1D** and PT-2D encountered only one stratigraphic unit, the Canlaon Volcanics, in contrast to previous interpretations that the Pliocene Cf is present near their well bottoms

Table 3. Mt.Canlaon Well Samples Analyzed for Zircon Morphology.

Sample No.	Well	Depth (m RL)	Rock Type	Formation
1	MC-2	-576-609	Sil *An*	CnV
2	MC-2	-667-692	Sil *An*	CnV
3	MC-2	-963-1100	Sil *An*	CnV
4	MC-1	-163-233	Ls/Minor *An*	Cf
5	MC-1	-626-669	Ls/An/Cs	Cf
6	CT-1D	-706-806	Ls/An	Cf
7	CT-1D	-818-872	Ls/Tuff	Cf
8	CT-1D	-1606-1981	Ls/Minor An/Tuff	Cf
9	PT-1D	+48-370	Da (fine)	CnV
10	PT-ID	-420-490	Da (fine)	CnV
11	PT-1D	-490-520	Da (fine)	CnV
12	PT-1D	-520-775	Da (fine)	CnV
13	PT-1D	-775-847	Da (fine)	CnV
14	PT-1D	-847-1307	Da (fine to coarse)	CnV
15	PT-2D	0-370	Da (fine)	CnV
16	PT-2D	-372-916	Da (fine)	CnV
19	HG-ID	-1237-1250	Ls/Rare *An*	Cf

Table 4. Average Values Zircon Morphology Data of Mt.Canlaon Rocks.

Sample No.	Width (mm)	Length (mm)	PI	PY	EI	FI
1	0.063	0.150	0.16	0.45	0.34	0.88
2	0.065	0.158	0.16	0.44	0.35	0.88
3	0.072	0.180	0.16	0.48	0.35	0.87
4	0.048	0.145	0.50	0.47	0.42	0.88
5	0.064	0.158	0.43	0.46	0.35	0.89
6	0.077	0.162	0.75	0.45	0.26	0.95
7	0.060	0.162	0.22	0.48	0.36	0.89
9	0.067	0.179	0.13	0.49	0.37	0.86
10	0.070	0.160	0.16	0.46	0.32	0.87
11	0.073	0.181	0.21	0.44	0.35	0.88
12	0.066	0.171	0.17	0.49	0.34	0.88
13	0.077	0.179	0.16	0.45	0.33	0.85
14	0.063	0.164	0.15	0.48	0.37	0.87
15	0.070	0.169	0.16	0.47	0.33	0.89
16	0.062	0.161	0.13	0.46	0.38	0.87
17	0.065	0.153	0.28	0.46	0.35	0.85

Only minor amounts of zircons were recovered from the sedimentary units of Caliling Formation in MC-1 (4, 5), in CT-ID (6, 7) and in HG-ID (17). No zircons were found in the Cf limestones in CT-1D (8) and in HG-ID (18, 19). These zircons were likely hosted in the igneous clasts of the clastic facies of the Cf. The zircons in these 3 wells have well- to moderately developed (100) prism faces in contrast to the welldeveloped (110) prism in the CnV. These marked morphological variations indicate that the zircons in the epiclastic rocks were derived from a magma different from the CnV dacite magma. Thus, results of the zircon morphological studies confirm that the Caliling Formation is a separate stratigraphic unit distinct from the Pleistocene Canlaon Volcanics.

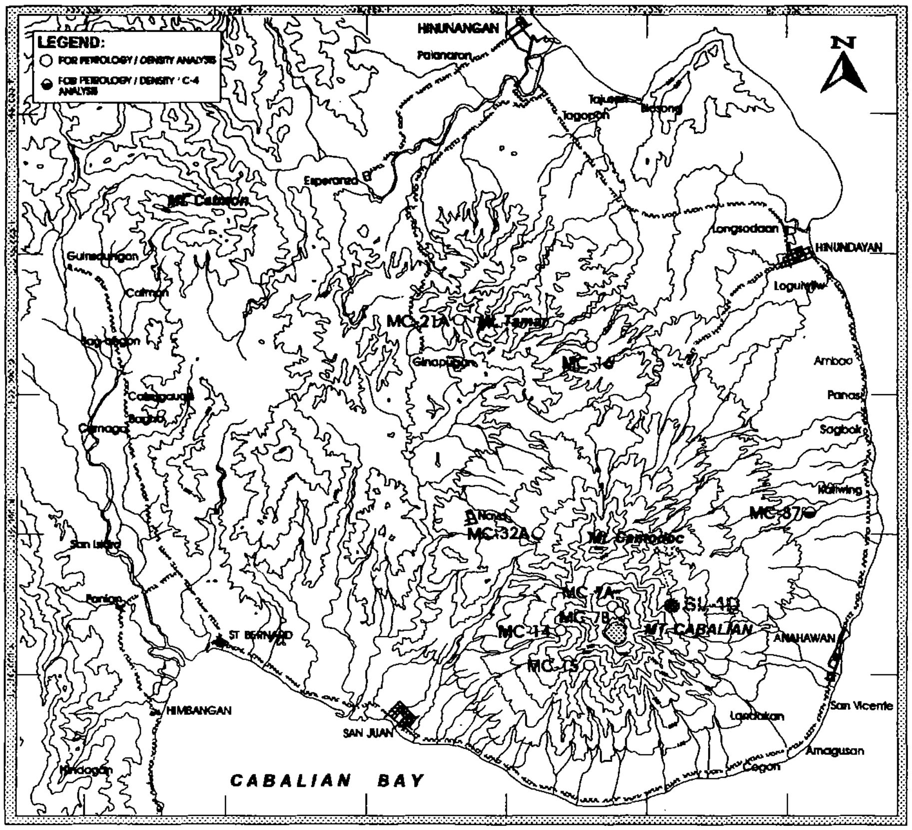

Figure 9. Sample location of Cabalian.

3.3 Mt. Cabalian Geothermal Area

The Mt. Cabalian geothermal area is situated in the southeastern tip of Leyte island, central Philippines (Fig. 1). Semidetailed geologic mapping together with geochemical, gravity and magnetotelluric surveys were conducted in 1996. One deep exploratory well, SL-1D, was subsequently drilled in 1997 (Fig. 9) to test the presence of hot geothermal fluids postulated to be upflowing beneath the Quaternary Mt. Cabalian.

TL ages were obtained for 7 Mt. Cabalian surface samples (Fig. 9, Table 5) using the TL intensity index (TI) approach (Ramos, 1997).

Table 5. TL Ages of Mt. Cabalian Surface Rocks.

Sample No	Rock Name	Rock Unit	TL Age (ka)
MC-7B	PxHbAn	Cabalian	5 ± 1
MC-14	HbPxAn	Cabalian	6 ± 1
MC-15	HbPxAn	Cabalian	6 ± 1
MC-7A	PxHbAn	Cabalian	17 ± 3
MC-16	HbDa	Tamar	490 ± 30
MC-32A	HbPxAn	Cantodoc	510 ± 30
MC-21	HbAn	Tamar	670 ± 30

The TL ages of the Mt. Cabalian rocks may be roughly grouped into three: 490-670 ka, 17 ka and 5-6 ka. Two of the oldest dated samples, MC-16 and MC-21 were taken from the northern sector of the area and mapped as Tamar Volcanics. In the absence of radiometric dating, this volcanic Unit was postulated to be of

Late Pliocene age based on stratigraphic position. In surface outcrops, Tamar Volcanics overlie Tertiary limestones, and underlie Quaternary volcanics (Leynes, pers. comm.). The TL age data of 670 ka (MC-21) and 490 ka (MC-16) instead suggests that the Tamar Volcanics is still part of Quaternary deposits.

MC-32A, sampled on the western flank of Mt. Cantodoc, a Quaternary volcano in the south gave a TL age of 510 ka. K-Ar dating of rocks in the vicinity (Leynes, 1997) yielded a comparable age of 450 ka.

Samples representing the 2 younger age groups were taken in the vicinity of Mt. Cabalian, another Quaternary volcano dated 180-190 ka by K-Ar method. MC-7A gave a younger TL age of 17 ka which is comparable to the C-14 age of 25 ka of charred wood sample (MC-37) within a pyroclastic flow deposit northeast of Mt. Cabalian. Hence, both TL and C-14 dating indicate that the youngest deposits of Mt. Cabalian were erupted from ~17-25 ka.

On the other hand, the youngest ages of 5-6 ka of MC-7B, 14 and 15 are not likely the true age of the rocks based on the K-Ar age of 190 ka of nearby MC-7B sample. The younger TL ages relative to the K-Ar age could be due to the annealing of the TL signals as a result of reheating of the host rocks by hydrothermal fluids. TL signals are sensitive to temperatures as low as 100°C (Hayashi, 1996). The presence of cristobalite in the matrix of the three samples manifests the passage of thermal waters whose temperature may reach ~120°C. Hence, the 5-6 ka TL ages likely represent the latest hydrothermal event in Mt. Cabalian.

4.0 SUMMARY AND CONCLUSIONS

The fission-track dating method gave an age of 0.27 Ma for dacites in well LB-2D in Mt. Labo confirming the Pleistocene age of the Labo Volcanics. It estimated the age of the latest hydrothermal regime in the area to be 0.32 Ma based on FT age of dacites in LB-1D which were altered above 250°C.

In Mt. Canlaon. this dating method gave a 1.81 Ma age for dacites in well PT-ID likewise validating the Pleistocene age of the Canlaon Volcanics. It also yielded an age of 1.62 Ma for silicic dacites in well MC-2 indicating that these volcanic rocks should be grouped with the Pleistocene Canlaon Volcanics, instead of with the Pliocene Caliling Formation.

Fission-track dating and zircon morphology studies revised the stratigraphy of Mt. Canlaon and validated that of Mt. Labo. Using zircon data, the approximate temperature of the source magma of the Pleistocene volcanics was estimated to be ~845°C in Mt. Labo and ~680°C in Mt. Canlaon.

The thermoluminescence dating method gave a Pleistocene age (490-670 ka) for Tamar Volcanics. initially postulated to be Late Pliocene. It confirmed the Pleistocene ages of Cantodoc Volcanics (510 ka) and Cabalian Volcanics (17 ka). It also estimated the age of the latest hydrothermal event in the area to be 5-6 ka based on the TL age of Cabalian andesites reheated above 100°C.

The fission-track and thermoluminescence dating methods are both reliable in determining the ages of young volcanic rocks based on their agreement with previous K-Ar and C-14 dating results. They can also provide estimates of the ages of the latest hydrothermal events for altered rocks heated above 100°C for TL, and above 250°C for FT.

Zircon morphology studies are useful for stratigraphic correlation of lithologic units which were likely derived from a commom magma source. The original lithology of altered rocks as well as the probable temperature of the volcanic magma reservoir may also be deduced from the zircon contents of rocks.

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