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THERMOLUMINESCENCE DATING IN MT. LABO AND NORTH DAVAO, PHILIPPINES: IMPLICATIONS ON GEOTHERMAL MODELS

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ABSTRACT

Thermoluminescence dating was used to obtain absolute ages for volcanic rocks in two geothermal exploration areas in the Philippines: Mt. Labo and North Davao. In Mt. Labo, eleven samples gave ages ranging from ~197-142 ka for the dacitic lava domes in the southwestern sector to ~27 ka for an andesitic pyroclastic flow at the Mt. Labo summit. These TL ages support the volcanic history of the area which was inferred earlier based on existing K-Ar and fission track dating. The youngest deposits (~27 ka) were likely derived from the same source being tapped by the present hot but partly acidic Mt. Labo geothermal system. The lava domes in the southwest (~197-142 ka) may be correlated with an older, neutral-pH but probably cooler system.

In North Davao, twelve samples from Quaternary domes gave ages of ~0.21-238 ka. The youngest domes (<10 ka) are found in the western and southern sectors of Lake Leonard. Five of the six Paloc Pyroclastics gave Recent ages of < 1 ka while a Pleistocene age (~13 ka) was obtained for one sample. The TL ages for most of the pyroclastics are younger compared to the ^{14}C dates (1,800-25,000 years BP) for this unit. These variations may be due to differences in TL accumulation process between younger and older rocks. The ages of the youngest domes and Paloc (<10 ka) likely represent the latest volcanism in the area. This activity probably provides the heat source for the Amacan-Ugos-Leonard geothermal system. The oldest dated rock (~933 ka) is hydrothermally altered and belongs to a fossil hydrothermal system in Masara.

1. INTRODUCTION

The thermoluminescence (TL) dating method was used to obtain absolute ages for volcanic rocks in two geothermal exploration areas in the Philippines: Mt. Labo and North Davao (Fig. 1).

Mt. Labo, an inactive volcano in southwestern Luzon has been a geothermal exploration interest since 1982 (Delfin and Alincastre, 1988). Deep exploration drilling of 8 wells from 1990-1997 revealed a high temperature, but partly acidic geothermal resource centered beneath well LB-1D in the southwestern flank of Mt. Labo. A 1995 magnetotelluric survey and VES data review suggested a separate hydrothermal system further southwest of the drilled sector (West JEC, 1995).

In North Davao, southern Philippines, initial exploration work was done in the 1980's (PNOC EDC, 1985). The upflow zone of the geothermal resource is postulated to lie beneath the Ugos-Amacan-Leonard sector. Lake Leonard is a caldera and is believed to be related to the latest volcanism. Deep drilling of well AM-1in Amacan in 1985 encountered a high temperature, neutral resource within a diorite of low permeability (PNOC EDC, 1985). Exploration focus then shifted to more prospective areas in the region until 1997 when renewed interest prompted additional structural geological and geochemical work.

Numerous Quaternary domes which probably represent local heat sources are found in both areas. TL dating was used to obtain absolute ages for these domes. In North Davao, TL data were also needed for the widely distributed Paloc Pyroclastics to determine their relationship with the domes. TL data were also integrated with other radiocarbon dates to refine the geochronology of the various volcanic units and define their role in the evolution of the geothermal systems in Mt. Labo and North Davao.

2. METHODOLOGY

The TL dating method is suitable for rocks with ages ranging from a few thousand years to a million years. Quartz is separated from the 300-400 g rock sample by crushing and initial sieving using a 20 mesh. A 290 g portion is set aside for analysis of radiometric elements U, Th, and K by gamma ray spectrometry to obtain the annual dose (AD). The remaining samples are further crushed and sieved through a 80-200 mesh. All grains bigger than 200 mesh are washed, dried below 50° C and separated into magnetic and non-magnetic fractions. The latter is treated with 24% HF and 1:1 HCl to obtain pure quartz. TL emission was then measured for both natural and gamma ray irradiated samples to obtain the equivalent dose (ED). All TL measurements were done in Akita University. The TL age is calculated by the equation t (ka) = ED/AD.

A more detailed discussion of the procedure and instrumentation is found in Takashima and Watanabe (1994).

3. RESULTS OF TL DATING

3.1 Mt. Labo

Eleven samples from Labo Volcanics consisting of eight domes, two central cone deposits and one pyroclastic flow were dated by the TL technique (Table 1).

The lava domes located south-southwest of Mt. Labo gave the oldest ages (Fig. 2, Table 1). These are Susung Malaki (190-197 ka), Small Baguio (169 ka), Almasigahan (158 ka), Tukang Kalo (143 ka) and Bakilid (142 ka). Most of these lava domes are hornblende dacites except Tukang Kalo which is a hornblende andesite.

The two Labo Volcanics central cone (Lcc) samples gave ages of 88 ka and 129 ka. These relatively younger samples were taken south of the Mt. Labo edifice. The two other lava dome samples are younger than Lcc. These are Banga-banga (94 ka), a hornblende andesite collected southeast of Mt. Labo, and Cogon (42 ka), a hornblende dacite found west of Mt. Labo.

The youngest rock unit is a pyroclastic flow which gave an age of 27 ka. It is a fresh andesite taken near the peak of Mt. Labo.

3.2 North Davao

Quaternary Domes

The twelve Quaternary dome samples yielded Recent-Pleistocene ages (Table 2, Fig. 3) These domes may be categorized into three age groups based on their TL ages: young, intermediate and old. The four young domes have Recent ages of <10 ka . Among the Pleistocene domes, five belong to the intermediate group with ages ranging from 10-100 ka, while three bear the oldest ages of >100 ka. Most of the dome samples are porphyritic biotite and clinopyroxene-bearing hornblende andesites. Three are porphyritic dacites (Table 2).

The young Quaternary domes are confined in the southern and western sectors of Lake Leonard. Kniazeff 2 (0.75 ka) and Kniazeff (3.93 ka) domes are located proximal to the southern periphery of the lake. The two other domes, Mamaon (0.24 ka) and Teresa (8.49 ka) are situated farther west.

Among the intermediate Quaternary domes, the youngest is Katumbuan (56 ± 7 ka), the northernmost dome mapped in the area. Paloc (76 ± 10 ka) and Tandic (74 ± 9 ka) domes are situated northeast of the lake. The oldest in this group bear identical ages of ~90 ka. These are Camogon, found in the southeastern periphery of the area, and Ugos located farther down south.

The oldest Quaternary domes range in TL ages between ~101-238 ka. In contrast to the young domes, two of the oldest domes are found at the other side of Lake Leonard, i.e., directly to the north and east of the lake. These are Leonard North (101 ± 15 ka) and Leonard East (238 ± 55 ka) domes. The other dome, SW of Leonard Mt. Range (136 ± 20 ka.) lies to the southeast of the lake.

Paloc Pyroclastics

The six Paloc Pyroclastic samples are scattered in the northern, eastern and southern sectors of the field. They are made up of tuff, lapilli tuff and pumiceous breccia. Only Sample 19, taken farther east, yielded a Pleistocene age (~13 ka). The rest of the pyroclastics gave very young Recent ages of 0.24-0.49 ka (Table 2, Fig. 3).

Amacan Volcanics

The two hydrothermally altered samples of the Miocene Amacan Volcanics are located north and farther southwest of Lake Leonard (Fig. 3). Their TL ages, based on secondary quartz, yielded Pleistocene ages of 933 ± 195 ka and 217 ± 38 ka (Table 2).

4. DISCUSSION

4.1 Mt. Labo

Known Ages and Geochronology

The absolute ages of rock units of the Labo Volcanics based on potassium-argon (K-Ar) dating (Gillot, 1983), fission-track (FT) method (Zaide-Delfin, 1996), and TL analysis are discussed. The results of the present TL dating are generally consistent with earlier interpretations on the volcanic history of the area (Delfin and Alincastre, 1988; PNOC-EDC, 1991).

Volcanism in Mt. Labo may be subdivided into at least three stages using all available data. These are the deposition of Labo basal unit (Lbu), Labo central cone (Lcc) and Labo pyroclastic flows (Lpf) with dome building phases in the first two stages.

The Lbu stage, occurring ~580-440 ka is closely associated with the eruption of Bayabas Dome (560 ka) in the northwest and Nadugdugan Dome (430 ka) in the northeast. The Lcc stage lasted between ~270-88 ka and characterized by central vent-cone forming eruptions including the present edifice of Mt. Labo. During this stage, dome building was active southwest of Mt. Labo producing Susung Malaki (190-197 ka), Small Baguio (169 ka), Almasigahan (158 ka) and Tukang Kalo (143 ka) domes. The youngest domes were later erupted in the northeast (San Vicente - 129 ka), in the southeast (Banga-banga - 94 ka) and in the west (Cogon - 42 ka).

The final stage occurred ~27 ka and consisted mostly of pyroclastic-flows.

Implications on Geothermal Model

The TL ages confirmed that the latest volcanic activity in Mt. Labo is characterized by pyroclastic flows-from the summit cone and dated ~27,000 years. The source magma of these deposits is probably driving the present hydrothermal system in the area. The center of this system apparently lies near the bottom of well LB-1D which tapped acidic fluids with temperatures of ~270-280°C at -1600 mRL (PNOC-EDC, 1995).

VES surveys defined a 5 ohm-m low-resistivity contour within the 10 ohm-m low anomaly in the southwestern portion of Mt. Labo (West JEC, 1995). This contour coincides with the steep resistivity boundary delineated by magnetotelluric surveys which could represent upflowing geothermal fluids (WEST JEC, 1995). This possible separate system lies in the vicinity of the southwestern domes erupted during the second stage of Labo volcanism.

The older system in the southwest may be more mature and more evolved than the younger, acidic reservoir in the LB-1D

sector. However, this older system may also have temperatures lower than ~270-280°C found in the younger system.

4.2 North Davao

Comparison with ^{14}C Ages and Geochronology

The ^{14}C ages of charred wood from six Paloc Pyroclastics range from 1,800-25,144 years BP (Sajjad, 1998; Wood, 1980) (Fig. 3, Table 3).

Both the TL and ^{14}C dating methods confirm the Recent-Pleistocene ages of the Paloc Pyroclastic samples collected from various outcrops of the unit. However, ^{14}C ages gave relatively older Recent ages of 1,800-6,042 years in contrast to the TL data which are mostly of <1000 years. The TL technique is most reliable for rocks with ages <300 ka (Takashima, 1991 in Takashima and Watanabe, 1994). For rocks with ages of a few thousand years, the applications of the TL dating method is constrained by less understood parameters such as differences in TL accumulation process between younger and older rocks.

For the Pleistocene rocks, ^{14}C method yielded ages of ~12,144-25,714 years BP while TL gave an age of ~13,500 years for a pyroclastic sample taken further west-southwest of the area. Both methods gave comparable ages for the upper limit of the Pleistocene age of Paloc Pyroclastics.

Pleistocene volcanism in North Davao may be grouped into two hydrothermal events based on TL ages and ^{14}C ages. These are the Masara and Leonard stages.

The Masara stage which prevailed at ~1100-700 ka is represented by the older, hydrothermally altered rock. This stage is related to the Masara collapse, a prominent volcanic feature in the southwest. This is considered a fossil hydrothermal system.

The Leonard stage, started at ~290 ka and lasted until Recent times at ≤ 2 ka. The Leonard sector was a consistent volcanic foci throughout this stage. The initial event was a pre-caldera dome building phase giving rise to Leonard East, the oldest dome in the eastern periphery of the lake. The altered Amacan Volcanics (~260 ka) north of the lake is probably related to this phase. Between ~160-110 ka, dome effusion SW of Leonard Mountain Range, Leonard North and Camogon was concentrated southeast and north of the lake. At ~100 ka, activities shifted farther south in Ugos.

The Paloc and Tandic domes were erupted northeast of the lake between ~80-90 ka. Volcanism was also evident farther north in the Manat sector at ~60 ka where a dome, collapse feature and thermal manifestations are found.

Renewed volcanic activities prevailed in the Leonard sector between ~26 ka and ≤ 2 ka, based both on TL and ^{14}C ages. This younger phase was characterized by voluminous extrusion and widespread deposition of Paloc pyroclastics and subsequent collapse of the Leonard caldera. Attendant effusion of Kniazeff, Kniazeff 2, Mamaon and Teresa domes occurred at ~9-≤ 2 ka in the southern and western sectors of Lake Leonard. The TL data are thus consistent with current interpretations (Pioquinto et al., 1997) that the youngest volcanic center is located in the vicinity of Lake Leonard. This magmatic source drives the present geothermal system in North Davao.

Implications on Geothermal Model

The geothermal system in North Davao is postulated to be upflowing in the Ugos-Amacan-Leonard sector (Pioquinto, et al., 1997; PNOC EDC, 1985). Active solfatara is found in the southwest rim of Lake Leonard, while in the south, the Amacan-Gopod thermal area consists of solfataras, fumaroles and hotsprings (Maturgo, 1997). This system is correlated with dome effusion, pyroclastic eruption and caldera collapse in the vicinity of Lake Leonard. TL and ^{14}C data suggest that its age may be as young as ~≤ 2 ka.

The Ugos-Amacan sector is considered the southern extension of this geothermal system but the TL ages obtained for Ugos and the nearby Camogon domes are ~90-100 ka. While Ugos dome itself is old compared to some of the Recent domes in Leonard, the Amacan-Gopod thermal area is diagnostic of proximity to the upflow zone. The only deep exploratory well AM-1 which was drilled in Amacan, tapped neutral, hot fluids (~265°C) within an impermeable intrusive complex. The emplacement of older (12-18 Ma), dioritic intrusives (PNOC-EDC, 1985; Sajona et al., 1994 in Pioquinto et al., 1997) including Ugos dome has effectively reduced the permeability in this sector. Apparently, the deep structural connection vis-a-vis the north-south-trending Amacan-B fault between the Lake Leonard and Ugos-Amacan sectors paved the way for later (<100 ka) magmatic ascent and extrusion towards the north in the more permeable Leonard sector.

Further north of Lake Leonard, the Manat thermal area was previously shown as seepages of outflowing geothermal fluids from Amacan which was channeled along Manat fault (Maturgo, 1997; PNOC EDC, 1985). The TL age of Katumbuan dome (~62 ka) suggests that volcanism in this sector is still part of the Leonard stage thus supporting a single resource model for North Davao.

5. CONCLUSIONS

The TL data provided absolute ages for the various volcanic units in Mt. Labo and North Davao critical in refining their geochronologies. These data are generally consistent with previous interpretations on the volcanic history for both areas. In Mt. Labo, the present geothermal system is associated with volcanism that is ~27,000 years old. The system is hot (~270-280°C) but partly acidic as evidenced by the discharge of well LB-1D. An older, more evolved, likely neutral but probably cooler system correlates with older domes in the southwest. In North Davao, the Ugos-Amacan-Leonard geothermal system is relatively younger at ~2 ka. The fluids tapped by well AM-1 is neutral and hot (~265°C) but hosted by a poorly permeable diorite. Future drilling targets may thus be refocused towards the Leonard sector where higher temperature and permeability are expected.

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REFERENCES

Delfin, F.G. and Alincastre (1988). Geology of the Del Gallego (Mt. Labo) geothermal prospect, southeastern Luzon. PNOC EDC internal report.

Gillot, P. (1983). Report on K-Ar Dating of Volcanic Rocks from Mt. Labo area, island of Luzon, the Philippines. TOTAL/Pogei report no. 4-4.3, 7 pp.

Maturgo, O.O. (1997). Geochemical Evaluation of North Davao Geothermal Prospect: Review and Update. PNOC EDC internal report.

Pioquinto, W.C., Caranto, J.A., Leynes, R.D., Rosell, J.B. (1997). North Davao Geothermal Prospect. Geologic Framework and Fault Set Analysis. PNOC-EDC Internal Report.

PNOC-EDC (1985). A Review of Surface Prospecting and Exploratory Drilling. North Davao Geothermal Prospect. PNOC-EDC Internal Report.

PNOC-EDC (1991). Post-Drilling Geoscientific Evaluation of the Mt. Labo Geothermal Project, Camarines Norte. PNOC-EDC Internal Report.

PNOC-EDC (1995). Mt. Labo Geothermal Project Resource Assessment Update. PNOC-EDC Internal Report.

Sajjad, I. (1998). Results of C-14 Samples. PNOC-EDC Internal Report.

Takashima, I. and Watanabe, K. (1994). Thermoluminescence Age Determination of Lava Flows/Domes and Collapsed Materials at Unzen Volcano, SW Japan. Bull. Volcanol. Soc. Japan, v. 39, no. 1. pp. 1-12.

West JEC (1995). Final Report of Magnetotelluric Survey in Mt. Labo Geothermal Area for PNOC Energy Development Corporation.

Wood, P. (1980). A Report on a visit to the Philippines. February 1980. Unpublished report. NZ DSIR, 1980.

Zaide-Delfin, M.C. (1997). Zircon Analysis of Mt. Labo Volcanic Rocks – Implications on Stratigraphy and Geologic Model of Mt. Labo Geothermal Field.

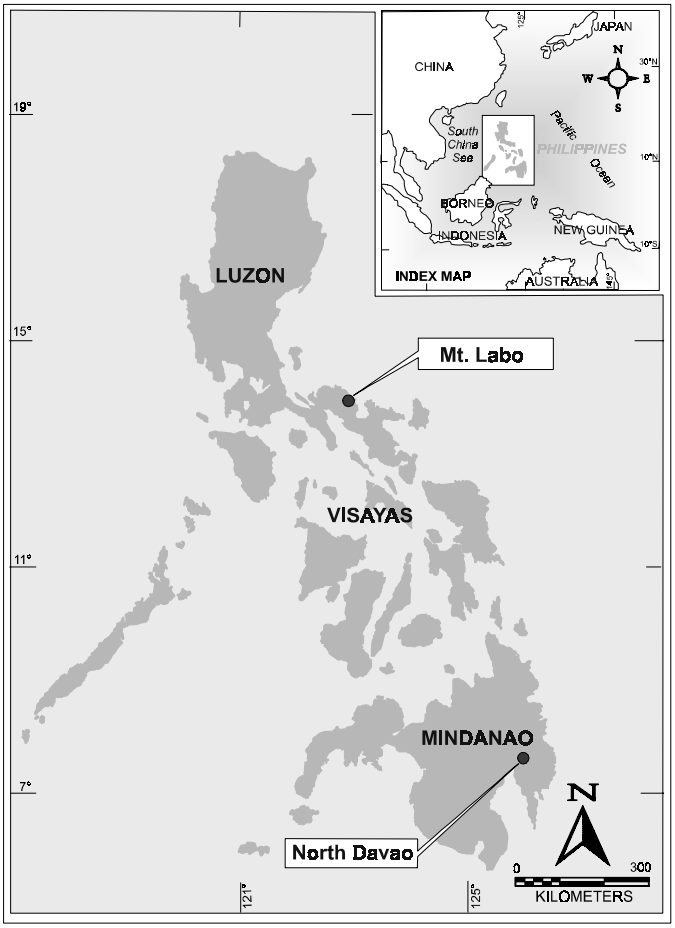

Figure 1. Location of Mt. Labo and North Davao Geothermal Areas.

Table 1. TL Ages of Mt. Labo Rocks

Spl No.	TL Age (ka)	Rock Unit	Rock Name
4	94 ± 21	Banga-banga Dome	Bt-bearing hb an
5	169 ± 70	Small Baguio Dome	Bt hb da
6	142 ± 36	Bakilid Dome	Bt hb da
7	129 ± 28	Central cone (Lcc)	Hb an
8	42 ± 7	Cogon Dome	Cpx-bt hb da
10	197 ± 62	Susung Malaki Dome	Bt hb da
11	190 ± 32	Susung Malaki Dome	Bt hb da
13	27 ± 6	Pyroclastic flow (Lpf)	Px bt hb an
14	143 ± 28	Tukang Kalo Dome	Px-bt hb an
16	158 ± 27	Almasigahan Dome	Px bt hb da
17	88 ± 21	Central cone (Lcc)	Bt-cpx hb an

an=andesite, da=dacite, bt=biotite, cpx=clinopyroxene, hb=hornblende, px=pyroxene

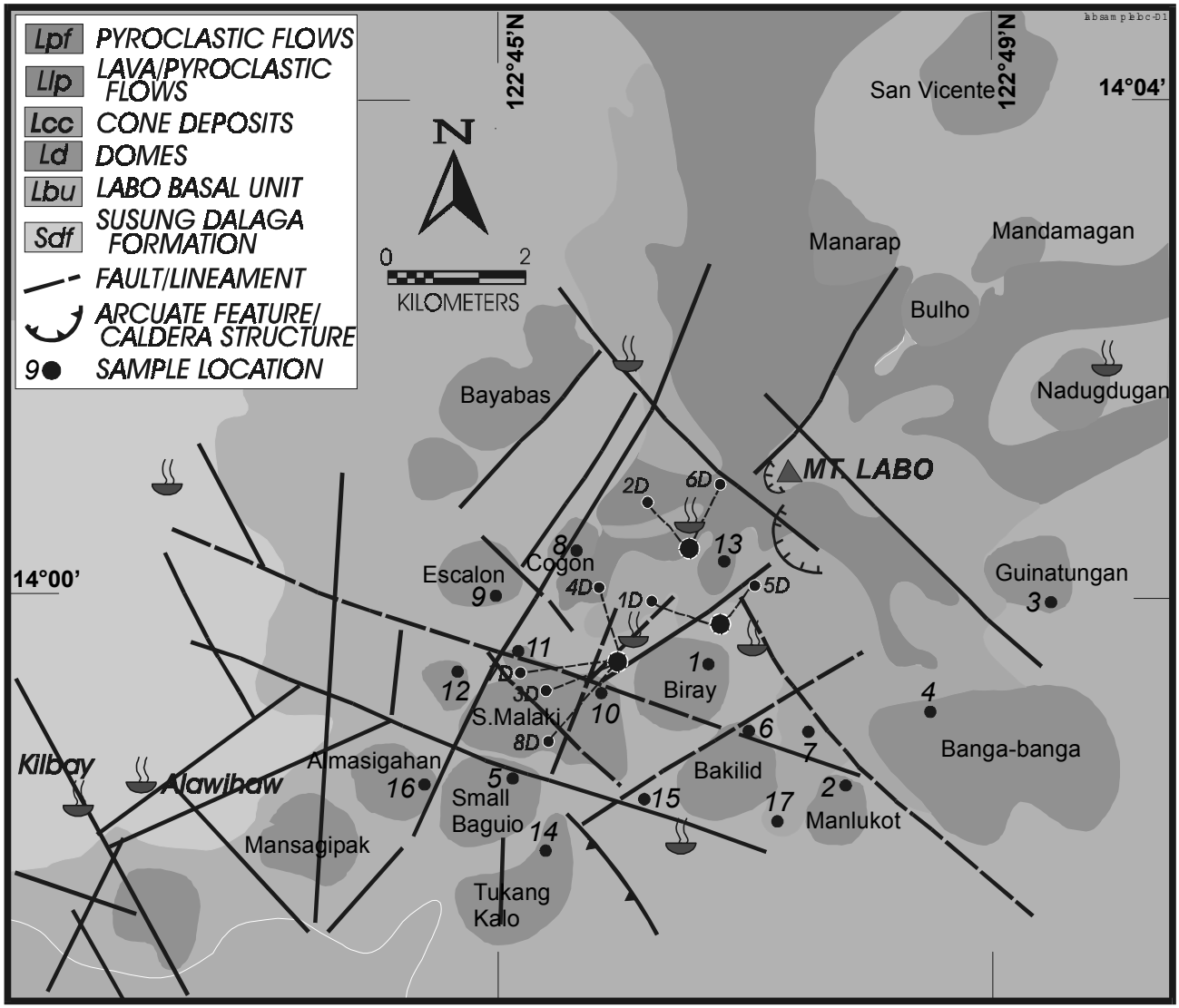

Figure 2. Rock sample location map, Mt. Labo.

Table 2 TL Ages of North Davao Rocks.

Spl No.	TL Age (ka)	Rock Unit	Rock Name
2	0.75	Kniazeff 2 Dome	Bt cpx hb an
3	0.21	Mamaon Dome	Bt hb an
3a	8.49	Teresa Dome	Bt cpx hb an
4a	76 ± 10	Paloc Dome	Hb Bt an
5	101 ± 15	Leonard North Dome	Cpx bt hb an
5a	3.93	Kniazeff Dome	Cpx hb an
6a	90 ± 10	Ugos Dome	Bt cpx hb an
8	74 ± 9	Tandic Dome	Bt cpx hb da
9	0.24	Paloc Pyroclastics	Lithic lapilli tuff
11	238 ± 55	Leonard East Dome	Bt an
12	56 ± 7	Katumbuan Dome	Bt cpx hb da
14	136 ± 20	SW of Leonard Range Dome	Bt hb da
15	90 ± 18	Camogon Dome	Cpx hb an
18	0.43	Paloc Pyroclastics	Lithic crystal vitric tuff
19	13.5 ± 2	Paloc Pyroclastics	Crystal tuff
20	0.49	Paloc Pyroclastics	Lithic crystal vitric lapilli tuff
22	0.48	Paloc Pyroclastics	Pumiceous breccia
25	933 ± 195	Hydrothermally altered rocks	Completely altered to quartz, illite and opaques
29	0.43	Paloc Pyroclastics	Lithic vitric crystal tuff
37	217 ± 38	Hydrothermally altered rocks	Completely altered to quartz, illite, pyrophyllite and dickite

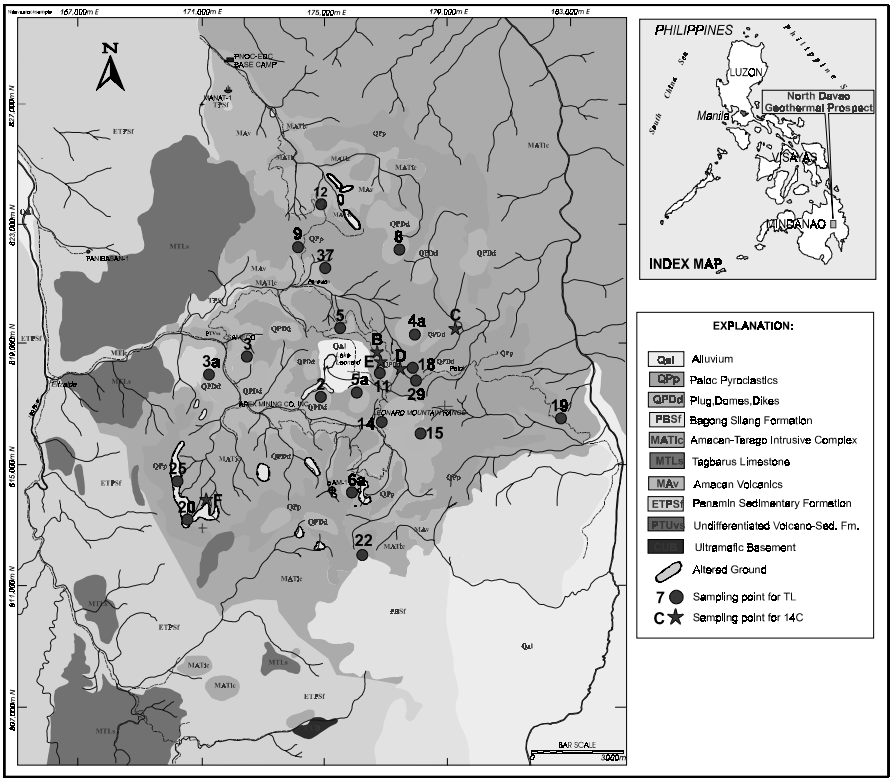

Figure 3. Rock sample location map, North Davao.

Table 3. ^{14}C Ages of Paloc Pyroclastics.

Spl No.	^{14}C Age (years BP)
A	1,800
B	25,714 ± 422
C	2,027 ± 54
D	1,870 ± 60
E	12,144 ± 234
F	6,042 ± 122