

Characteristics of Surface Manifestation, Cisolok, Sukabumi, West Java: With Relation to Cisolok Geothermal System

Wulandari Mandradewi and Niniek Rina Herdianita

Jalan Ganesha 10, Bandung, West Java

wulandari.mandradewi@avocet.co.id, herdianita@gc.itb.ac.id

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ABSTRACT

Cisolok is one of the geothermal prospects at Sukabumi, West Java. Geothermal surface manifestations at Cisolok occurs along 300 m of the Cisolok River consisting of spouting springs, surface alteration, and deposits, such as prophyritic zone, argillic zone, silica sinter and dominated by travertine deposits. Temperature within the reservoir area range about 170-200 °C, with the composition of hot fluids typically is bicarbonate (HCO_3). The travertine deposit exhibits from the top to the bottom of the following characteristics: 1. Crustiform and colloform, 2. Comb, saccharoidal and dogteeth, 3. Crustiform and stromalitic, and 4. Brecciated. Comparison of the characteristics of hot spring, surface alteration and deposits in the area will improve our understanding of the evolution of the Cisolok Geothermal System

1. INTRODUCTION

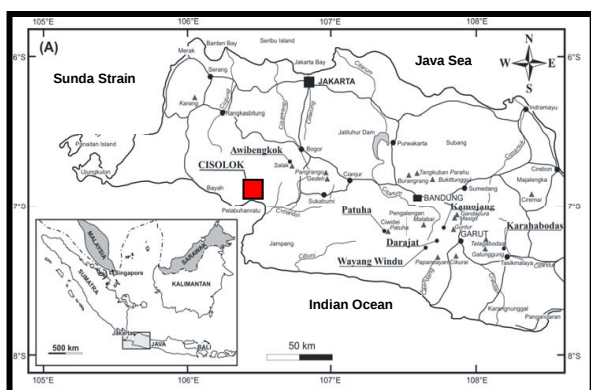


Figure 1: West Java and Banten Map shows location Cisolok on Sukabumi District.

West Java is one area with many geothermal prospects. This area has many geothermal manifestations, such as hot spring, fumaroles, and steaming ground. We can predict geothermal systems by these surface manifestations (Herdianita and Browne, 2000 and Browne, 1978).

Cisolok is one of geothermal prospect at western Sukabumi, and 170 km from Bandung (Figure 1). This area has surface manifestations such as spouting springs, silica sinter, and travertine deposits. The temperature of hot springs is near boiling and neutral pH on the surface. Hot springs through Citarete Formation, are described as carbonate dominant.

2. GEOLOGY OF CISOLOK AREA

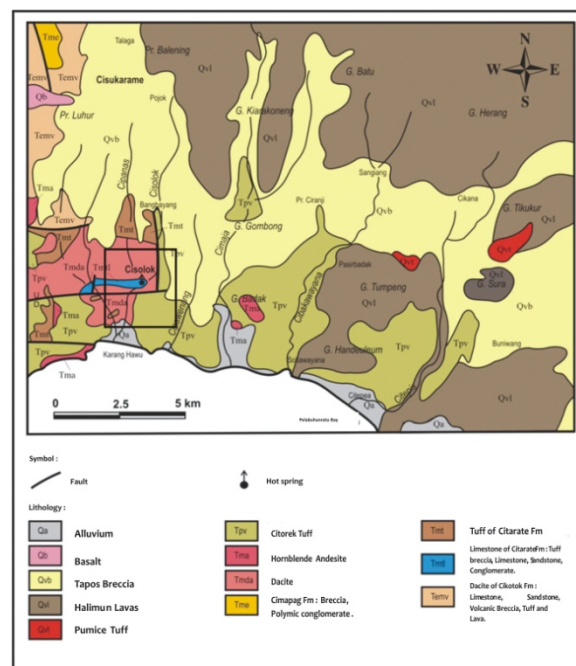


Figure 2: Geology Map of Cisolok area (modified from Sujatmiko and Santosa, 1992).

The Cisolok area is a part of the Bayah Dome (Bemmelen, 1949). The Bayah Dome formed by Cikotok Formation as oldest formation. This formation is Oligocene age with units comprised of volcanic breccias, tuff and lava deposits exposed west of Cisolok (Sujatmiko and Santosa, 1992). Then Early Miocene units consist of Citarete and Cimapiag Formation. The Andesite and Dacite intrusion of Late Miocene is exposed South of this area (Sujatmiko and Santosa, 1992). Finally, the area covered by Citrek Tuff, breccias of Tapos Formation and basaltic lava of Quaternary age (Figure 2).

The Cisolok area is controlled by main structure of NNE-SSW to NE-SW, the thermal features in this area is controlled by normal fault of NE-SW.

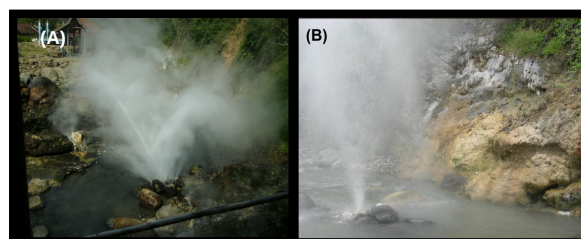


Figure 3: Hot spring manifestation at CSL-01 (A) and surface alteration on wall of Cisolok River (B).

3. GEOTHERMAL SURFACE MANIFESTATION OF CISOLOK

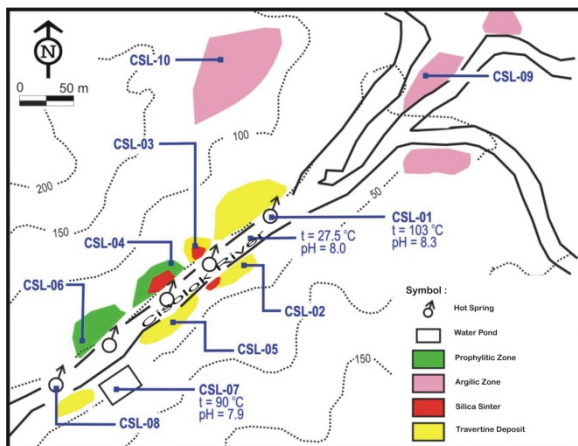


Figure 4: Sketch of surface manifestation along Cisolok River showing travertine deposits, silica sinter, propylitics zone and argillic zone.

Geothermal surface manifestations at Cisolok River occur along 300 m consisting of spouting springs, surface alteration and deposits, such as propylitic zone, argillic zone and silica sinter and dominated by travertine deposits (Figure 4). The large hot spring has a height about 3-4 m, flow rate 10 L/s, temperature 90° C and pH 7.3 (Figure 3A). Hot springs along the river have smaller flow rates than large hot spring with temperature 90°-100° C and pH 8. The Cisolok hot springs is an artesian spouting spring (Hochstein, 1994), because the condition near the boiling point.

Surface alteration occurs along the wall of Cisolok River and around the hot springs. Surface alteration are dominated by silica sinter (SiO_2) and travertine (CaCO_3). Propylitic zone distributed at NNW of the river covered by silica sinter and argillic zone was exposed at upper of the river predict as fossil of early hot spring activity.

Table 1: Chemistry analysis results of hot fluids at Cisolok River for CSL-01 and CSL-07

Parameter		No. Sample	
		CSL-01	CSL-07
Temperature	°C	103	90
pH	-	8.3	7.9
Debit	L/minutes	10	-
Conductivity	MeV	-61.2	45.2
pH (lab.25 °C)	-	7.24	8.32
TDS	mg/L	3360	1510
DHL	µS/c	4800	2160
CaCO_3	mg/L	287.36	159.21
Ca^{2+}	mg/L	68.82	50.05
Mg^{2+}	mg/L	28.10	8.34
Cl	mg/L	369.86	369.86
F	mg/L	1.033	1.033
SO_4^{2-}	mg/L	268.04	187.45
Na^+	mg/L	1022.59	325.37
K^+	mg/L	77.33	24.92
Fe	mg/L	0.144	0.093
Mn	mg/L	0.00	0.00
B	mg/L	0.000	0.072
NH_4	mg/L	0.475	0.673
SiO_2	mg/L	12.22	13.55
CO_3^{2-}	mg/L	28.64	6.51
HCO_3^-	mg/L	1416.36	201.20
As^{3+}	mg/L	0.0414	0.0476
Li^+	mg/L	0.179	0.175
Anion	-	39.23	17.63
Kation	-	52.20	17.97
$\Delta_{\text{anion-kation}}$	(%)	14.19	0.96

3.1 Cisolok Hot Spring Manifestations

Chemical analysis using Atomic Absorption Spectrometer (AAS) indicated 2 types of hot fluids in Cisolok area. Table 1 and Figure 2 show AAS results of CSL-01 and CSL-07 and the result is very significant.

CSL-01 is a sample from direct outflow of large geyser. The mainly anion CSL-01 is HCO_3 and type of hot fluids is bicarbonate. CSL-07 is a sample from hot spring pond shows Cl as main anion with type of hot fluids is chloride (Figure 5).

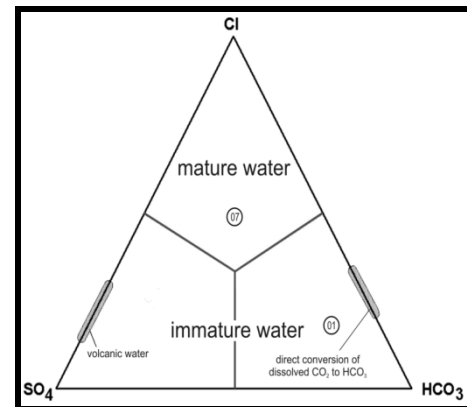


Figure 5: Compositions of Cl-SO₄-HCO₃ for Cisolok hot spring. Point 01 for CSL-01 sample and 07 for CSL-07.

Figure 6 shows composition of Cl higher than Li and B. It is shows that Cisolok hot spring is result of volcano-magmatic activity.

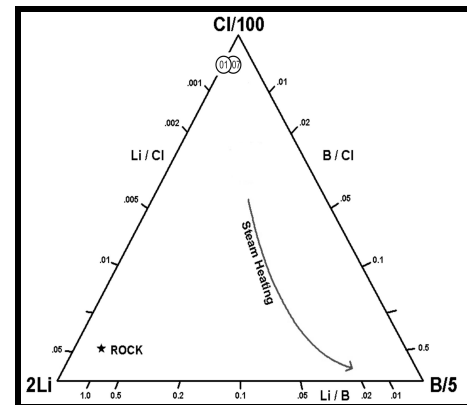


Figure 6: Compositions of Cl-Li-B (mg/L) of Cisolok hot springs. 01 for CSL-01 sample and 07 for CSL-07 sample.

Range of Cisolok reservoir temperature using K-Na geothermometry is 190° until 200°C and decreasing until 170°C using Na-K-Ca geothermometry. Equations of K-Na geothermometry are:

$$t^{\circ}\text{C} = 1217 / [\log (\text{Na/K}) + 1.483] - 273 \text{ (Fournier, 1979)}$$

$$t^{\circ}\text{C} = 1390 / [\log (\text{Na/K}) + 1.750] - 273 \text{ (Giggenbach, 1988)}$$

And the equation of Na-K-Ca geothermometry (Fournier and Truesdell, 1973) is:

$$t^{\circ}\text{C} = 1647 / \{ \log (\text{Na/K}) + b[\log (\text{Ca}^{1/2}/\text{Na}) + 2.06] + 2.47 \} - 273$$

Figure 7 shows the consideration of B/Cl, Li/Cl and B/Li is very low. This result indicated that Cisolok hot spring has a lateral flow.

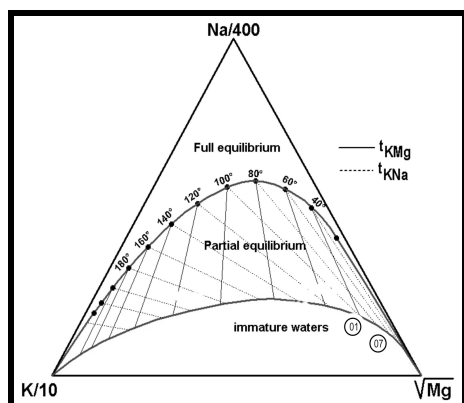


Figure 7: Compositions of Na-K-Mg of Cisolok hot spring. Triangle diagram is showing subsurface temperature, result of K-Na and K-Mg geothermometer. Point 01 for CSL-01 and 07 for CSL-07.

Reservoir system predicted at North of this area and relationship with Halimun volcanic activity.

3.2 Surface Alteration Manifestations

CSL-01 is a large hot spring at upper of Cisolok River. Alluvial surrounding CSL-01 covered by travertine deposits. The comprising stratified travertine deposit at CSL-01 exhibit from the upper to the bottom of the following: 1. Crustiform and colloform with 10-50 cm in thickness, 2. Comb, saccharoidal and dogteeth with 5-40 cm, 3. Crustiform and stromalitic, 4. Brecciated (Figure 8).

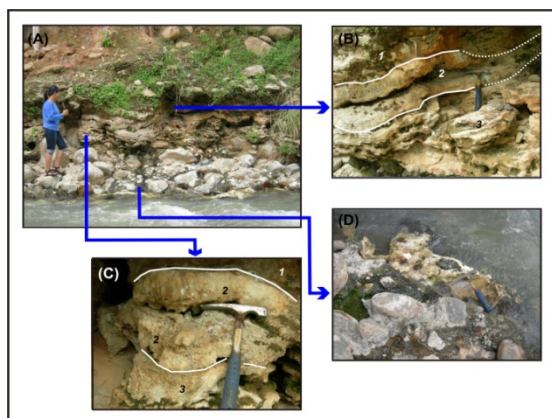


Figure 8: Textures of surface alteration manifestation at CSL-01.

Travertine deposit has exposed at CSL-08. At this point, travertine deposit associated with silica sinter as old sinter and deposit, but not as stratified. This is a massive deposit with some fractures as lithofacies lithoclast travertine (Özkul et al., 2002).

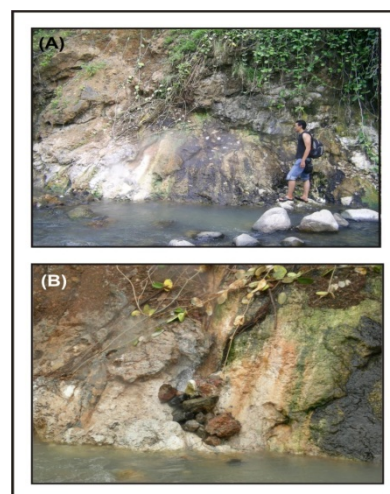


Figure 9: (A) The figure above is Propylitic zone at CSL-04. (B) The outcrop covered by travertine and silica sinter.

Propylitic zone (Figure 9) cropped out at CSL-04 shows by altered dacite with disseminated pyrite, quartz veins, and calcite with crustiform and colloform textures. Silica amorph covered walls of the river with thickness is 3 cm and suggested as recent sinter from the geothermal activities

CSL-05 (Figure 10) has pebbly travertine lithofacies (Özkul et al., 2002) association with silica sinter. Travertine deposit and silica sinter filling porosity of alluvial with some texture such as comb, crustiform and colloform. Calcite formed as microcrystalline calcite with bladed and saccharoidal textures. Some textures such as comb, crustiform and colloform are commonly for calcite deposit, but bladed texture caused by subsurface boiling zone (Simmons and Christenson, 1994).

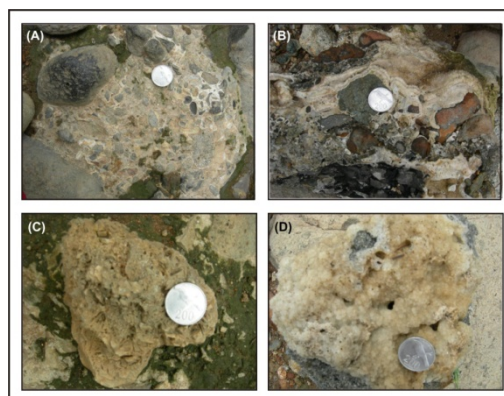


Figure 10: The figure is travertine deposits associated with silica sinter at CSL-05

Argillic zone are cropped out at CSL-09 and CSL-10 (Figure 11). Thickness this zone is about 10-30 m. This zone composed by chlorite with kaolinite and smectite.



Figure 11: The figure is showing argillic zone at CSL-09 dominated by clay minerals such as chlorite, kaolinite and smectite.

4. MINERALOGY

Mineralogy analysis using petrography and XRD also performed for suggestion the mineral has been formed in this area. The result for this analysis shows by XRD graphics and petrography

The XRD results show that in this area dominant by calcite (Figure 12). From thin sections, travertine deposit was changed from amorphous calcite to microcrystalline calcite (0.01-0.03 mm). This deposit is massive micritic travertine (Sant' Anna, 1994). The gangue minerals are aragonite, arsenic, and sulfur, but from XRD analysis, other hydrothermal minerals are pyrite, goethite, and hematite. Based on hydrothermal mineral, type of this deposit is impure micritic travertine (San't Anna, 2004).

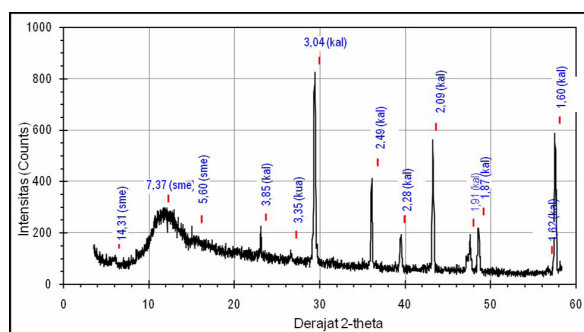


Figure 12: The figure is showing XRD result for CSL-03

Silica sinter has been formed at some point (Figure 13) such as CSL-03, CSL-04, CSL-05 and CSL-07. From XRD result is silica presence as quartz, not as amorphous silica. This is because amorphous silica was changed to be a stable form as quartz. This condition shows this sinter is an old sinter.

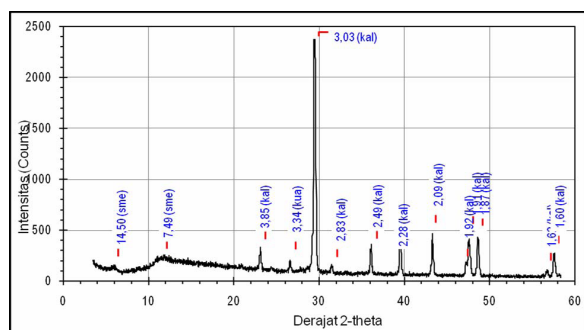


Figure 13: The figure is showing XRD result for CSL-05

Argillic zone cropped out at CSL-09 and CSL-10. XRD analysis shows that in this zone quartz is dominant than calcite and quartz presence with chlorite, smectite and kaolinite (see Figure 14). Argillic zone is not result surface geothermal activity but from interaction between hydrothermal fluids on subsurface.

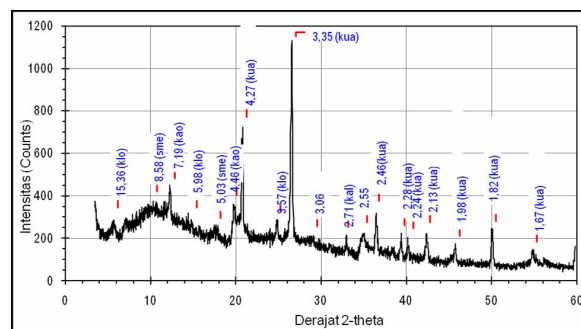


Figure 14: The figure is showing XRD result for CSL-10

5. ENVIRONMENT AND AGE

Hot water in this area richest with SiO_2 and CaCO_3 , this is caused by interaction of dacite and limestone. Hot water has migrated through limestone with a good permeability and has been cooled as travertine deposits on surface. Silica sinter is mainly formed as amorphous silica (opal-A) and travertine deposit as amorphous calcium carbonate.

Recent deposits and old deposits have different formed. Recent deposits formed as amorphous silica sinter and travertine deposits and old deposits presence as microcrystalline quartz and calcite as stratified deposits. Silica needs 10000 until 50000 years for changing from amorf to microcrystalline (Herdianita et al., 2000). Based on age of silica, age of old travertine deposit in this area is 10000 years.

6. EVOLUTION OF CISOLOK GEOTHERMAL SYSTEM

Geothermal manifestations of Cisolok are spouting spring and surface alteration dominated by travertine deposits. Both of manifestations have been indicating evolution of Cisolok geothermal system.

Cisolok reservoir is higher than 200°C based on presence of prophylic zone and silica sinter. The direction of outflow is lateral flow, but steam is up flow (see Figure 15). Argillic zone caused by oxidation process ($\text{H}_2\text{S} \rightarrow \text{H}_2\text{SO}_4$). This zone dominated by clay mineral, such as kaolinite and smectite associated with chlorite and quartz are formed by acid pH environment with temperature less than 120°C . These conditions was happened over 10000 years ago, shown by silica sinter has changed from amorphous silica become quartz crystalline (stable form).

Characteristic of hot spring have been changing caused by interaction of hydrothermal and wall rock. Hot spring has been changing from chloride to bicarbonate water and the evidence is presence of travertine deposit on surface. Travertine deposit is filling alluvial and basement of river as pebbly travertine (Özkul et al., 2002). Continued by crystalline crust and lithoclast (Özkul et al., 2002). This is shows temperature of reservoir more than 200°C . Travertine deposit was happened at CSL-01, CSL-02, and CSL-03 as geothermal manifestation at upper of Cisolok River.

The condition reservoir of Cislok has been cooling than before, it is shows by the temperature less than 200° C. Geothermal activity in this area still active with evidence are travertine deposits and silica sinter around the hot springs.

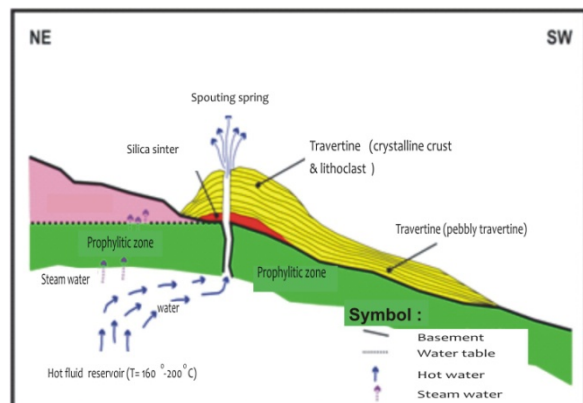


Figure 15: Sketch of NE-SW sections of geothermal manifestations along Cislok Rivers (without scale)

CONCLUSION AND DISCUSSION

1. Surface manifestation of Cislok area consisting of hot springs (spouting spring) and surface alteration such as phreatic zone, argillic zone, silica sinter and travertine deposits.
2. Hot spring of Cislok has temperature 90°-100° C, pH 8 and s 10 L/detik. Fluids of Cislok hot springs are bicarbonate and chloride. And temperature of reservoir above 170°-200° C.
3. Travertine deposits were formed as stratified with some texture, such as: colloform and crustiform, comb, dogteeth, saccharoidal, and brecciated.
4. Alteration surface manifestations occur along ±300 m of Cislok River. This manifestation is dominated by travertine deposits and silica sinter. Characteristics of travertine shows the deposits were occurred 10000 years ago.
5. The temperature of Cislok reservoir less than 200°C, and it shows that the temperature of reservoir has changed and is decreasing.

REFERENCE

- Browne, P.R.L. (1978), Hydrothermal alteration in active geothermal fields, *Annual Reviews in Earth Planet Science*, 6, 229-250.
- van Bemmelen, R.W. 1949, *The Geology of Indonesia*. Vol.1A, The Hague, Government Printing Office, -.
- Fournier, R.O., and Truesdell, A.H., 1973, An Empirical Na-C-K geothermometer for natural waters, *Geochimica et Cosmochimica Acta*, 37, 1255-1275.
- Fournier, R.O., 1979, A revised equation for the Na/K geothermometer. *Geothermal Resources Council Transactions*, 3, 221-224.
- Giggenbach, W.F., 1988, Geothermal solute equilibria. Derivation of Na-Mg-Ca geoinicator, *Geochimica et Cosmochimica Acta*, 52, 2749-2765.
- Hochstein, M.P., 1994, Classification of surface discharge features, dalam *Teaching the Teacher: Geothermal*

Technology, D.H. Freeston and P.R.L. Browne (eds.), Course Notes, Geothermal Institute, University of Auckland – Institut Teknologi Bandung.

Herdianita, N.R., Browne, P.R.L., Rodgers, K.A. and Campbell, K.A. 2000, Mineralogical and textural changes accompanying ageing of silica sinter, *Mineralium Deposita*, 35, 48-62.

Özkul, M., Varol, B. and Alçiçek, M.C., 2002, Depositional environments and petrography of Denizli travertines, *Mineral Resources Exploration Bulletin*, 125, 13-29.

Sant'Anna, L., Riccomini, C., Rodrigues-Francisco, B.H., Sial, A.N., Carvalho, M.D. and Moura, C.A.V., 2004, The Paleocene travertine system of the Itaboraí basin, Southeastern Brazil, *Journal of South American Earth Sciences*, 18, 11-25.

Simmons, S.F. and Christenson, B.W., 1994, Origins of calcite in a boiling geothermal system, *American Journal of Science*, 294, 361-400.

Sujatmiko and Santosa, S., 1992, *Leuwidamar Map*, Skala 1 : 25.000, Pusat Penelitian and Pengembangan Geologi (P3G), Bandung, -.

