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Distribution of the Gunungsewu karstic aquifers based on fractal analysis — case study: Semanu and surrounding area, Yogyakarta, Indonesia

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Abstract: In the Semanu Subdistrict, apart of the Gunungsewu Region, Southern Mountains of Central Java, Indonesia, the lithologic formation comprises carbonate rocks, which are composed of four lithofacies namely *boundstone, packstone, wackestone, and marl*. All of the carbonates except marl, are very prospective aquifers in the study area. Using conventional mapping method, determining the distribution of these aquifers, is not easy to do, due to their almost similar physical characteristics in the field. Fractal analysis, in this study, can be utilized to help outline the distribution of the carbonate aquifers mentioned above. The delineation is executed by unifying the fractal dimension values of the topography on the study area, and then drawing their boundaries. It can be done because the topographic irregularity degree of a particular place, which represents the performing geologic formation, is actually specified by its fractal dimension.

INTRODUCTION

Semanu and surrounding area is apart of the Gunungsewu Region, a chain of karst terrain in the Southern Mountains of Central Java, Indonesia. It belongs to the Yogyakarta Special Province, and is situated about 50 km southeast of Yogyakarta town (Fig. 1).

Discussing karst hydrogeology is always interesting owing to the very unique hydraulic characteristics of the limestone as a conduit aquifer (White, 1988). To map the distribution of carbonate aquifers in a karstic area, generally one faces difficulty due to the similar physical features of the lithology under naked eyes, and the almost similar topography of the terrain either in the field or on aerial photograph. This paper reports on how fractal analysis can be applied to help determine the boundary distributions of such lithology especially carbonate rock.

METHOD

To determine boundary distributions of the carbonate aquifers in the study area, topographic map of 1:50,000 scale is sliced into cells with 1 km (2 cm) width each. The fractal dimension of the surface topography in every four cells of the grids was determined by the box counting method. The surface topography being analysed was represented by the surface erosional valley pattern on that site, derived from topographic map and aerial photograph of 1:50,000 scale. The determination of fractal dimensions was done four cells by four cells, following the brickstack system. Delineation of the boundaries of aquifers dispersion was determined based upon the distribution of the similar topographical fractal dimensions and secondary porosity fractal dimensions derived from microscopic petrography analysis. It is executed by unifying the fractal dimension values of the topography on

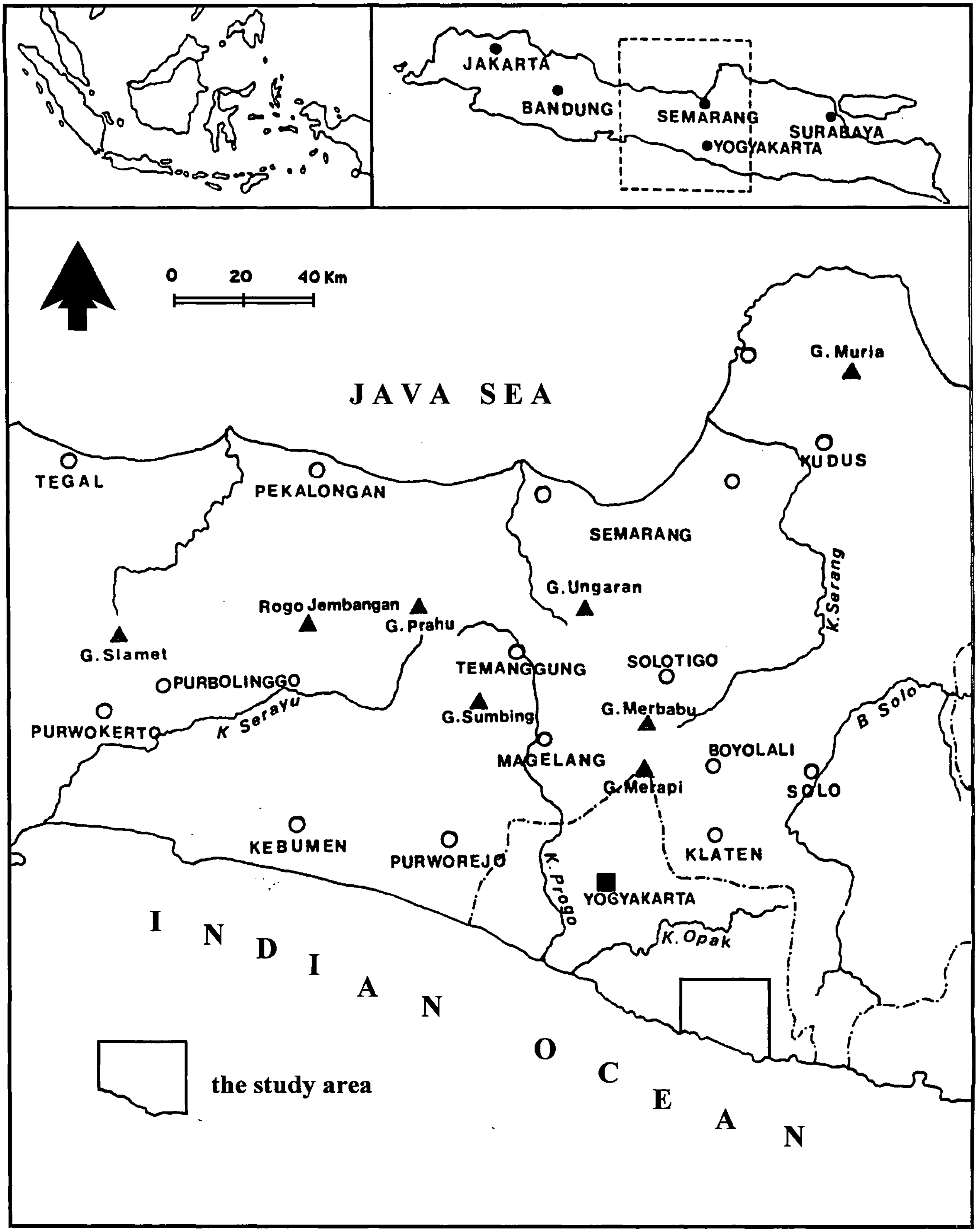

Figure 1. The location map of the study area.

the study area, and then drawing their boundaries. It can be done because the topographic irregularity degree of a particular place, which represents the performing geologic formation, is actually specified by its fractal dimension.

Despite using petrography analysis, lithofacies determination was also done by etching 50 samples.

FRACTAL REVIEW

Mandelbrot (1982) use the word *fractal* to describe objects, which display repetition of the similar shape on various scales. There is a formula that creates simple shapes, which grow more complex as the shape is being repeated in miniature around the edges of the first shape (Xie, 1993). Smaller versions of the shape grows out of these smaller shapes and so on to infinitesimal infinity. The surprising end result is a field of infinite, swirling, and complexity. So fractal is simplicity yielding such complexity through the simple repetition of its own shape. In nature, the repetition of shapes and angles at every scale is everywhere (Korvin, 1992; Turcotte, 1993).

Fractals are non-Euclidean objects, with non-integer dimension. A fractal has Hausdorf-Besicovitch dimension larger than its topological dimension (Mandelbrot, 1982). The important character of fractal geometry is the part is reminiscent of the whole. In other words, the part of the set is the small scale of the entire fractal set object (Sahimi and Yortsos, 1990). This includes other important fractal characteristics of self-similarity, self-affinity, and scale invariant (statistical, general). Within these properties, fractal is able to unravel the geometry of such a natural object into its initial elements (Peitgen *et al.*, 1992).

The fractal scaling system is specified by non-integer numbers, so called fractal dimension (Mandeldrot, 1982; Xie, 1993). Determining fractal dimension is very important in dealing with practical quantification problems, because fractal dimension is generally correlated to origin or process acting on the fractal object. Conventional box counting fractal dimension method can be used for statistical self-similar fractal or statistical self-affine fractal (Fig. 2). The fractal dimension then is determined using equation (Tricot, 1995):

$$D = \lim_{r \to 0} \frac{\log Nr\ (F)}{-\log r}$$

Nr(F) is the number of boxes covering fractal set (F).

Nr(F) is repeatedly executed by changing the value of r so that r approaches 0. The variation of Nr(F) values and r are plotted into a log-log graph to derive fractal dimension, e.g. the slope of the plot result (Fig. 3).

HYDROGEOLOGIC SETTING OF THE GUNUNGSEWU AREA

The tropical karst terrain of Gunungsewu, Indonesia, is characterised by the existence of

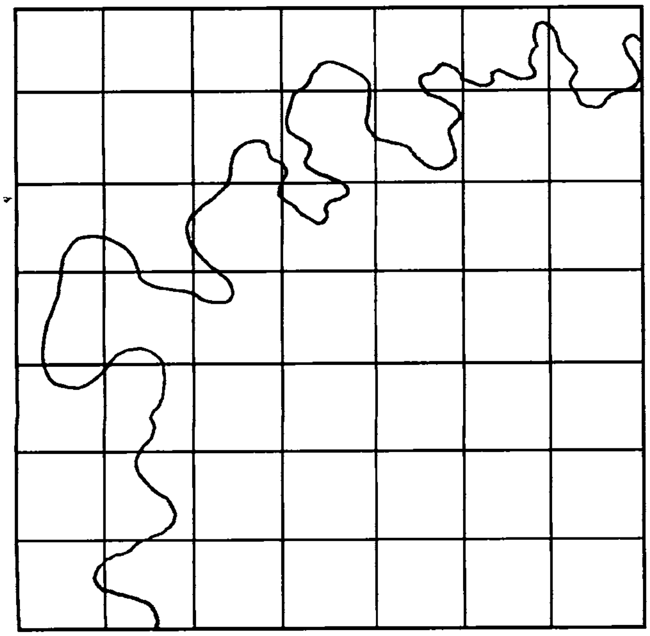

Figure 2. Box counting method for the flow of River Oyo.

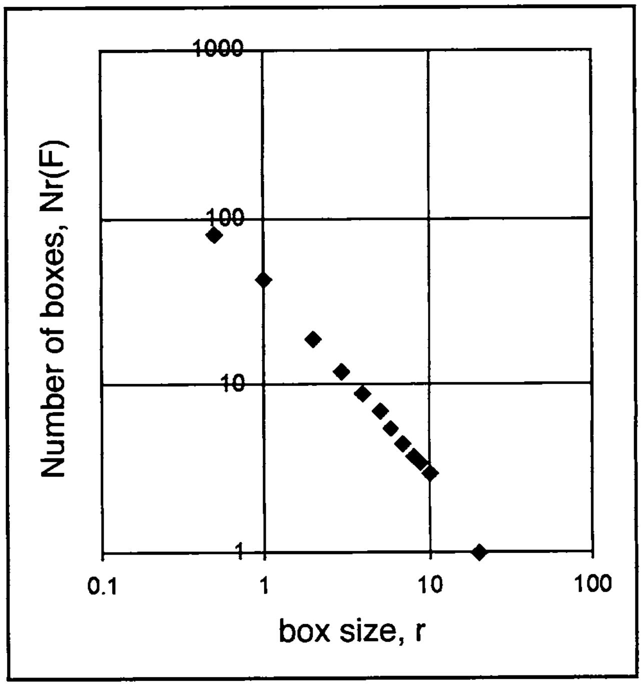

Figure 3. Plot result of Nr(F) vs r.

thousands of conical hills, closed depressions of various largeness and composition, surficial flow disturbance, caves, and subsurface drainage system. This area physiographically belongs to the Zone of Southern Mountains, Central Java (Van Bemmelen, 1949), is occupied by reefs, massive and bedded limestones of middle to late Miocene age of the Wonosari Formation which is underlain by a unit of volcanic sediments called Besole Group (Suyoto, 1994). Besole Group are composed of tuffaceous sandstone, sandstone, calcareous sandstone, calcareous claystone, tuffaceous marl, tuffaceous shale, agglomerate, andesitic breccia, and lava deposits of Oligocene to middle Miocene age. Wonosari Formation is of different facies from Oyo Formation which consists of bedded sandy limestone, calcarenites, calcareous sandstones, and tuffaceous sandstone of middle to late Miocene age. In the middle part of the Gunungsewu Area, the carbonate of Wonosari Formation is covered by globigerina marl and calcareous limestone of the Kepek Formation. Suyoto (1994) unified the formations of Oyo, Wonosari and Kepek into *the Carbonates of Gunungsewu Group*. Although all members of the group are carbonates, the most prospective water bearing formation in the study area is, however, the limestones of the Wonosari Formation.

Carbonate rocks in the Gunungsewu region are composed of four lithofacies namely *boundstone*, *packstone*, *wackestone*, and *marl*. There are two different physical outcrop features of the Gunungsewu limestones in the field, i.e. karstic and calichic. The karstic limestone expresses the very specific characteristic of massive texture, fresh, hard with conduit networks, whereas the calichic shows nodular, brittle, even chalky texture, relatively soft with intergrain porosity. Limestone, which is calichic, is called caliche. Due to the existences of karstic and calichic, the limestones can be divided into karstic aquifers with conduit flow, and calichic aquifer with diffuse flow.

Geologic structure of the Gunungsewu area is homocline regionally dipping southward. The area is also dissected by faults of northwest-southeast and northeast-southwest strikes. In the northern part of the study area, there is a syncline with almost west-east axis (Fig. 4). These structures enable the groundwater to discharge enormously into Indian Ocean in the south. One of the discharges is Baron, the largest coastal spring in the Gunungsewu.

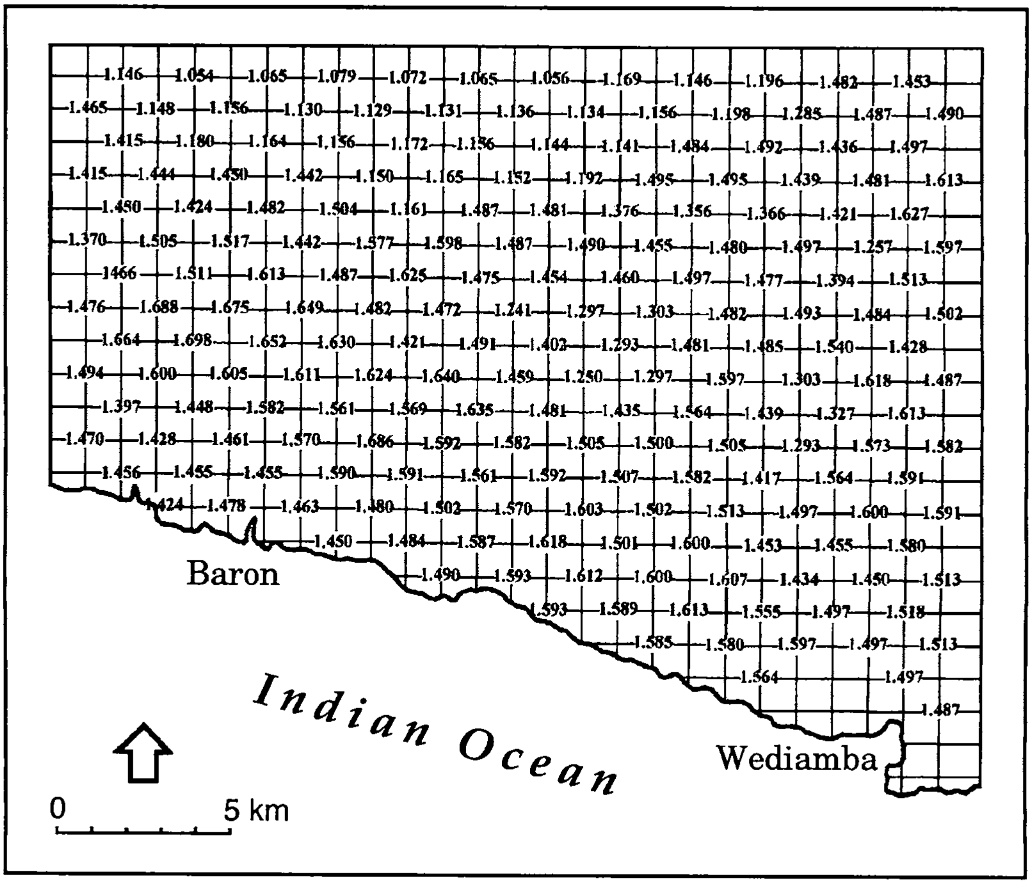

Figure 4. Grids and fractal dimensions of topography of the study area.

FRACTAL DIMENSION AND CARBONATE ROCKS

Fractal dimension is the quantitative factor of the irregularity of such geometry. However, irregularity reflects how complicated the processes are acting on the object being identified. The distribution of a formation, or rock facies, if is subjected to exogenic processes will bring about a specific morphology, the results of interaction between the process and the rock materials. The topographic expression will be depend on the physical properties and reactability of the rocks. Different formations even though subjected to the same exogenic process, will create distinctive surface topography (Kusumayudha *et al.*, 1997a, 1997b; Kusumayudha, 1997).

The four carbonate facies of *boundstone*, *packstone*, *wackestone*, and *marl* in Semanu and surrounding area, even though difficult to be distinguished between one another in the field, display different fractal dimensions of surficial topography. The fractal dimension values of the topography can be unified into five, i.e. Unit A with fractal dimensions D_t ranging 1.054–1.079, unit B with fractal dimensions varying from 1.129 to 1.192, unit C with fractal dimensions, D_t ranging 1.411–1.507, unit D with D_t varying from 1.551 to 1.698, and group E with D_t ranging 1.241–1.376. Unit A is occupied by marl, unit B is occupied by *bioclastic* or *bedded limestone* (*wackestone*), unit C is occupied by *packstone* (dominant) and *boundstone*, unit D is occupied by *boundstone* (dominant) and *packstone*, and unit E is occupied by *chalky limestone* (*caliche*). The map derived from this fractal application is displayed in Figure 5.

The fractal characteristics of secondary porosity of the Gunungsewu aquifers in the Semanu Area are shown in Table 1. The five-fractal topography units also represent distributions of different physical pore characteristics of the carbonates. Unit A represents carbonate with no secondary porosity, Unit B represents carbonate with average secondary porosity of 14.29%, fractal dimension of pore topology, $D_p = 2.075$; Unit C represents carbonate with average secondary porosity of 20.56%, $D_p = 2.017$; Unit D represents carbonate with secondary porosity of 12.85, $D_p = 2.109$; and Unit E represents carbonate with secondary porosity of 7.92%, $D_p = 2.234$.

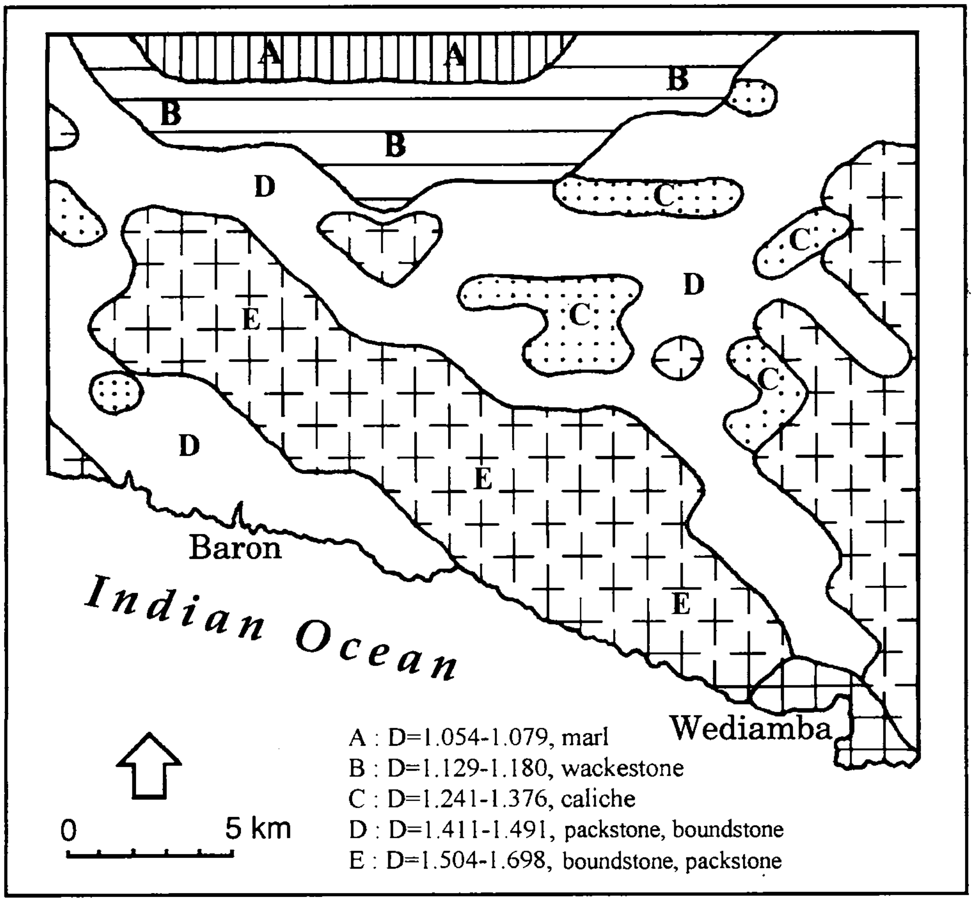

Figure 5. The distribution of carbonate aquifers in Semanu area based on fractal analysis.

Table 1. Fractal characteristics of secondary porosity of the Gunungsewu carbonates from tin section.

SURFACIAL VALLEY PATTERN	LITHOLOGY (FACIES)	PORE CHARACTERISTICS	
		SECONDARY POROSITY 2D (%)	PORES TOPOLOGY
D_t = 1.054–1.079	Marl	–	–
D_t = 1.129–1.180	Wackestone	4–23.49 Average: 14.29	Dp = 2.00–2.192 Average: 2.075
D_t = 1.241–1.376	Chalky limestone (caliche)	10–25.25 Average: 20.56	Dp = 2.00–2.110 Average: 2.017
D_t = 1.421–1.491	Packstone (dominant) Boundstone	5.15–23.81 Average: 12.85	Dp = 2.070–2.192 Average: 2.109
D_t = 1.504–1.698	Boundstone (dominant) Packstone	2.9–22 Average: 7.92	Dp = 2.140–2.257 Average: 2.234

CONCLUSIONS

Surficial valley pattern of the Semanu area and surrounding can be divided into five units, i.e. Unit A, D_t = 1.054–1.079, which is occupied by marl without secondary porosity; Unit B, D_t = 1.129–1.1180, which is occupied by *wackestone / bioclastic limestone* or *bedded limestone* with average secondary porosity, n_s = 14.29%, fractal dimension of pore topology, D_p = 2.075; Unit C, Dt = 1.241–1.376, which is occupied by *chalky limestone* (*caliche*) with ns = 20.56%, D_p = 2.017: Unit D, Dt = 1.421–1.491, which is occupied by *packstone* (dominant) and *boundstone* with ns = 12.85%, D_p = 2.109; Unit E, D_t = 1.504–1.698, which is occupied by *boundstone* (dominant) and *packstone* with ns = 7.92%, D_p = 2.234.

Fractal analysis can be utilized to help trace the boundary distribution of the Gunungsewu carbonate aquifers in Semanu and surrounding area. This is drawn by delineating places with similar topographical fractal dimension values.

REFERENCES

KORVIN, G., 1992. *Fractal Models in the Earth Sciences.* Elsevier Science Publishers, 396p.

KUSUMAYUDHA, S.B., ZEN, M.T., NOTOSISWOYO, S. AND GAUTAMA, R.S., 1997a. Identifikasi Pola Fraktal Sungai Bawah Tanah dan Topografi Permukaan Batuan Karst Gunungsewu Pegunungan Selatan DIY. *Proc. PIT HAGI XXII*, 176–179.

KUSUMAYUDHA, S.B., ZEN, M.T., NOTOSISWOYO, S. AND GAUTAMA, R.S., 1997b. Analisis Fraktal Aliran Kali Oyo di Pegunungan Selatan, Kendali Lithologi dan Struktur Geologi. *Jurnal Teknologi Mineral*, IV(2), 71–86.

KUSUMAYUDHA, S.B., 1997. Application of Fractal Geometry To Hydrogeology: Hydraulic Characteristics of A Karstic Aquifer in Fractal Models. *Proc. National Seminar of Human Resources of Indonesian Geologists*, UPN "Veteran" Yogyakarta, 237–245.

MANDELBROT, 1982. *The Fractal of Nature.* Springer-Verlag, 406p.

PEITGEN, H.O., JURGENS, AND SAUPE, D., 1992. *Fractals for the Classroom, Part One: Introduction to Fractals and Chaos.* National Council of Teachers of Mathematics, Springer Verlag, 450p.

SAHIMI, M. AND YORTSOS, Y.C., 1990. *Applications of Fractal Geometry to Porous Media: A Review.* SPE 20476.

SUYOTO, 1994. Sikuen Stratigrafi Karbonat Gunungsewu, *Proc. PIT IAGI XXIII, Vol 1*, 67–76.

TRICOT, C., 1995. *Curves and Fractal Dimension.* Springer-Verlag, 323p.

TURCOTTE, D.L., 1993. *Fractals and Chaos in Geology and Geophysics.* Cambridge University Press, 221p.

VAN BEMMELEN, 1949. *The Geology of Indonesia, Vol 1A.* Martinus Nijhoff, The Hague, 732p.

WHITE, W.B., 1988. *Geomorphology and Hydrology of Karst Terranes.* Oxford University Press, New York, 464p.

XIE, H., 1993. *Fractals in rock Mechanics.* A.A. Balkema, Rotterdam, 453p.

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