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Hydrogeology of the Gunungsewu karstic area, Central Java, Indonesia: a conceptual model

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Abstract: The Gunungsewu Area in Central Java, Indonesia, has been suffering from water shortage since time immemorial, although the precipitation in the region concerned and surroundings is known to be adequate (2,000 mm/year average). This region is controlled by a karstic geology with conduits, dolines, caves, and subterraneous rivers, and very permeable rock formation, causing most of the rainwater in this area to be directly absorbed into the ground. There is a homoclinal structure dipping southward that conducts groundwater to discharge enormously into the Indian Ocean. The Gunungsewu limestone is composed of reefs and bioclastics, which based on their different physical characteristics in the field, can be classified into chalky limestone called caliche and karstic limestone. Groundwater level in the bioclastic limestone is at 5–10 m depth, whereas in the reef limestone it is able to reach 150 m depth or more. The existence of caliche and karst in Gunungsewu enable the rock formation to be divided into non-karstic aquifer with diffuse flow and karstic aquifer with conduit flow.

INTRODUCTION

Gunungsewu, *The One Thousand Hills*, a very specific tropical cone karst area in Yogyakarta Special Province, Central Java, Indonesia (Fig. 1), is located about 50 km south-eastward of the Yogyakarta town. The entire area is about 1,500 km^2, bounded by the Bantul and Yogyakarta basins in the West, Wonosari Plateau in the North, Wonogiri High in the East, and the Indian Ocean in the South. Although the average annual precipitation in the area is 2,000 mm, Gunungsewu is known to be the most barren area of Central Java, with approximately 200,000 people in six subdistricts of Panggang, Paliyan, Semanu, Ponjong, Tepus, and Rongkop, suffering from water deficiency every dry season.

Plenty of hydrogeologic studies have been and often done for this area, but the existence and dynamics of groundwater in Gunungsewu remains mysterious. This study is to conceptually model the hydrogeologic condition of the area of dryness, Gunungsewu. This model is expected at least to be able to explain the causes of water problems in that area.

GEOLOGIC SETTING

Gunungsewu physiographically belongs to the Zone of Southern Mountains of Central Java (Van Bemmelen, 1949). The axis of this mountain is relatively parallel to the southern coastlines of Java, from the Parangtritis area to the Pacitan Bay. The Southern Mountains of Central Java can be divided into three physiographic subzones, that is:

- Baturagung Range, Panggung Massive, and Plopoh Range in the North
- Wonosari Plateau, in the middle
- Gunungsewu subzone in the South and East

The stratigraphy of the Southern Mountains from the oldest to the youngest is briefly figured as the following (Suyoto, 1994):

- **The Besole Group**. In the study area, this group is a unification of Semilir formation and Nglanggran formation consisting of dacitic tuff, sandstone, tuffaceous sandstone, pumice, claystones, siltstones, shale, andesitic breccia, polymixed breccia, lava deposits, agglomerates, and sandstone of Oligocene to early Miocene age.
- **Sambipitu Formation**. This formation comprises calcareous siltstone, marl, tuff, and

polymixed breccia of middle Miocene age.

- **The Gunungsewu Group**. The group of carbonate rocks of **Oyo Formation, Wonosari Formation**, and **Kepek Formation**. The group consists of bedded limestone, calcarenite, calcareous sandstone, tuffaceous sandstone, massive-reefs and *bedded-bioclastic-limestone* forming karst topography of the Gunungsewu, interbedded with calcareous claystone and marl. The age of these carbonates is middle to late Miocene.
- **Terrarosa**. These Quaternary red-color deposits partly occupy the basepart of interhills basins or dolines of the Gunungsewu.
- **Alluvium deposits** are composed of black clay, silt, sand, pebbles, and boulders.

Suyoto (1994) discovered the indications of at least four times of sea level changes that brought about the existence of four stratigraphic sequences, since the formation of carbonates of the Gunungsewu. The first and the second sea level rise occurred in the arid atmosphere, causing calichification to form calichified limestone (caliche). Whereas the third and the last sea level rise occurred in tropic environment creating karst topography in the Gunungsewu area.

The main geologic structure of the Gunungsewu Area is a homocline regionally dipping southward. Gunungsewu is also dissected by faults of northwest-southeast and northeast-southwest strikes. There is a syncline in the middle part of the Southern Mountains of Central Java, with the axis of almost west-east (Fig. 2).

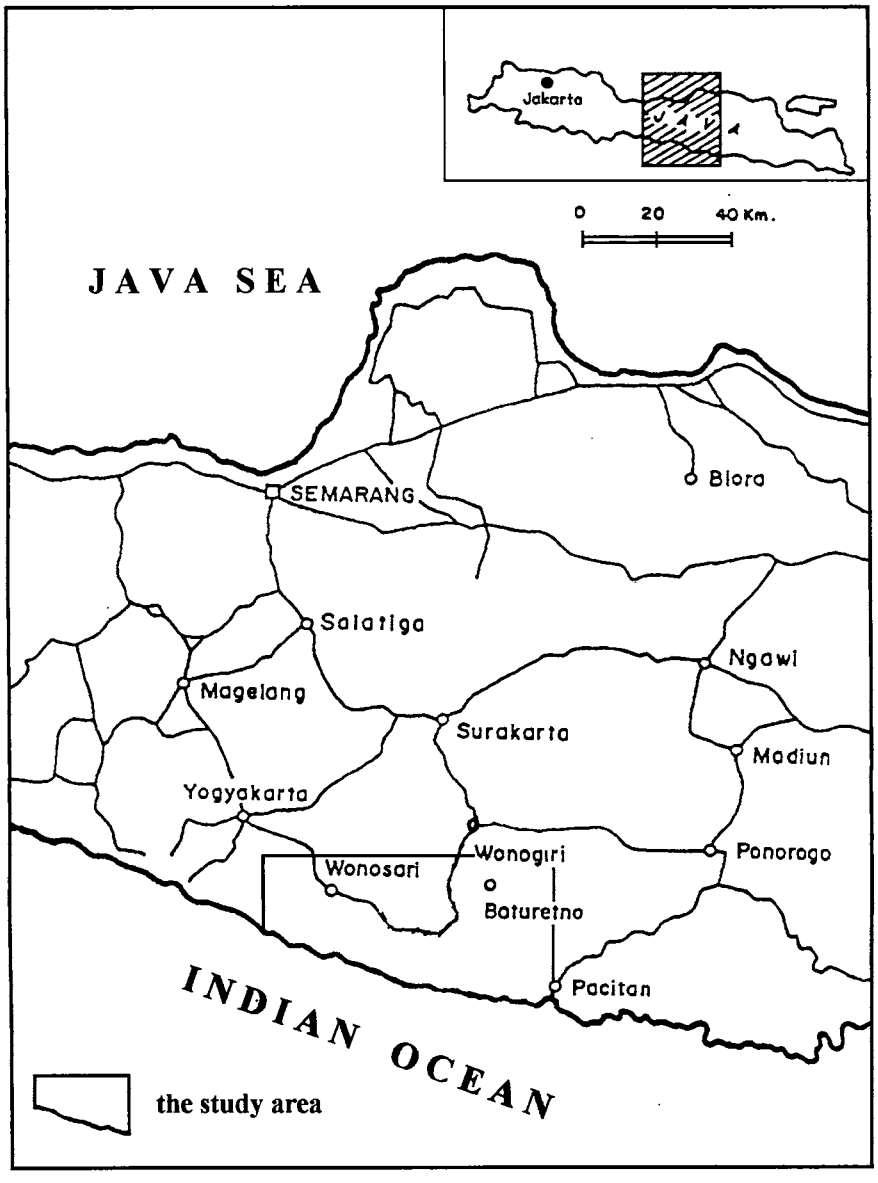

Figure 1. Location map of the Gunungsewu area.

HYDROGEOLOGY

Based on water dynamic divides in this area, the Gunungsewu can be separated into three hydrogeologic sub-systems, i.e. Panggang sub-system in the west, Wonosari-Baron sub-system in the middle, and Sadeng sub-system in the east (Fig. 3). The water divides are controlled by the configuration of the basement of the Gunungsewu aquifers. Basement position in the Panggang sub-system is in general high (above sea level); the limestone is relatively not thick (< 150 m). There is a valley of basement splitting subsurficially Wonosari-Baron sub-system in the middle part. This basement configuration makes the Wonosari-Baron sub-system, which this study especially concentrates on, the most unique one, because the waterflows commonly initiate from surface runoff, sink under ground, move along subterraneous tunnels, and terminate throughout coastal springs into the sea. Sadeng sub-system is bounded by the paleo valley of the Solo River.

In the northern part of the area occupied by bioclastic limestone, groundwater is found at 5–10 m depth, while in the south occupied by reef limestone, the water level abruptly drops reaching 150–200 m depth. Despite lithofacies differentiation, these two portions are separated from one another by faults. In this case faults are interpreted as being able to function as seals for groundwater motion. When the fault zone is well cemented by calcite, the fault will act as seals, on the other hand, if the ruptured zone is poorly cemented, the fault will play as leaks.

Aquifer System

Based on their qualitative-ability to transfer groundwater, rock formations in the Gunungsewu Area can be classified into aquitard which is composed of marl of the Kepek Formation, aquifer is composed of limestone of the Wonosari Formation, and aquiclude consisting of volcanic rocks of the Semilir-Nglanggran Formation. There are genetically in general two types of aquifer in the Gunungsewu area, i.e. karst aquifer and non-karst aquifer. The karst aquifer comprises karstified bedded, massive, bioclastic and reef limestones, whereas non-karst aquifer comprises chalky and

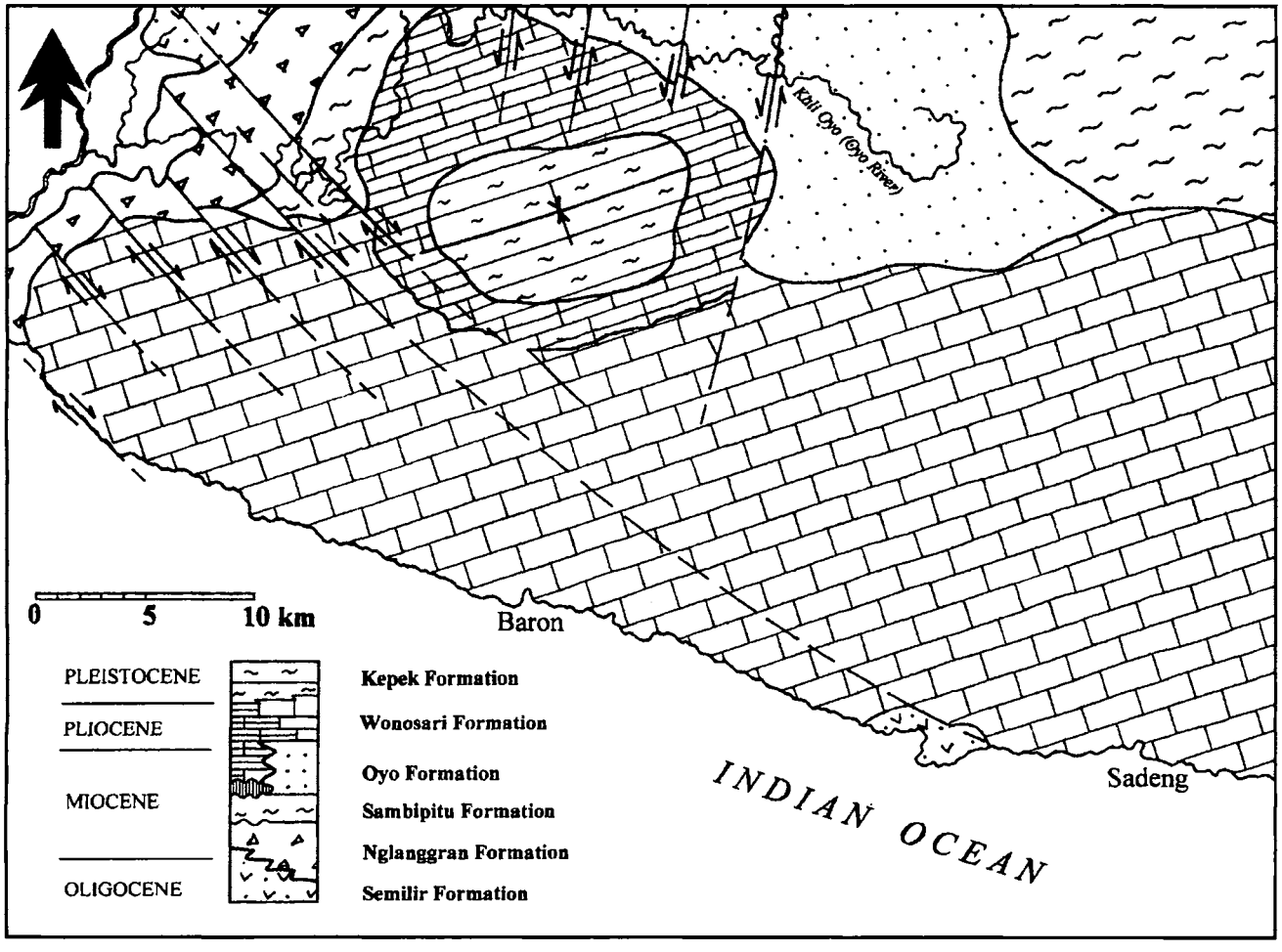

Figure 2. Geologic map of the Gunungsewu area.

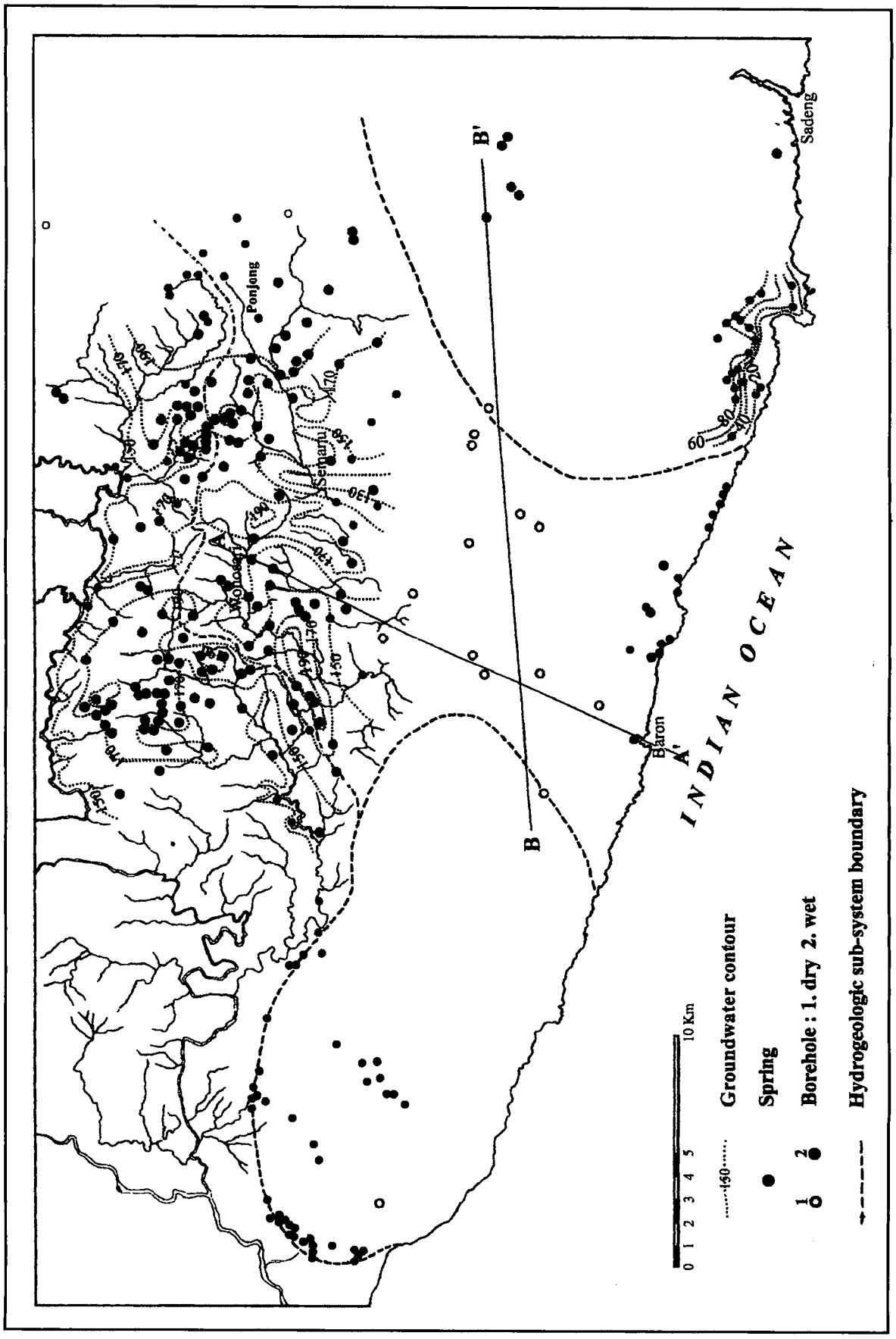

Figure 3. Divisions in the Gunungsewu hydrogeologic system.

nodular calichified limestone. The two aquifers have several differences in their physical properties and hydraulic characteristics. Non karst aquifer is relatively soft, brittle, having intergrain porous-medium characteristics, while karst aquifer, is hard to very hard, massive, and is specified by the existence of macro pores, conduits or caves.

The prevalent, non-karst aquifer is stratigrahically overlain by karst aquifer. Based on bore-log data analyses, the thickness of the Gunungsewu karst aquifer varies from 50 to 200 m, while the thickness of the non-karst aquifer is at least 150 m. It is interpreted that in some locations, the non-karst aquifer can be karstified by tropical climate exposure in recent time. Therefore it is always found that the surface part of this rock formation shows karstic morphology, such as lapies, karren, etc.

A complete sequence of such calichified limestone in the study area from the upper part is usually hardpan, platy caliche, nodular caliche, and chalky caliche respectively. In the eastern parts of the Gunungsewu Area, a sequence of caliche commonly exists without platy caliche. Hardpan, the most hard portion of a caliche, and the top part of the sequence is often subjected to karstification when exposed. The existence of hardpan that occasionally disjoin karst aquifer at the top, and non-karst aquifer at the bottom, and such impermeable sediments on the base of some caves, enable the Gunungsewu limestones to perform as many perched aquifers especially in the rainy season.

Groundwater Flow System

Flow in a non-karst aquifer is diffused through intergrain pores, while flow in a karst aquifer is tending to turbulent through conduits, called conduit flow. Flow mechanics in a non-karst aquifer is governed by Darcy's law, whereas flow mechanics in a karst aquifer is following Bernoulli's law.

In the study area, there are at least three surficial flows that sink into the subsurface. Tegoan River sinks into Sumurup Cave, Serpeng River enters into Serpeng Shaft, and Suci River disappears under Suci Cave. The three surface-rivers flow through underground passages to discharge into the Indian Ocean at Baron Bay with an average flow-rate reaching 5,000 l/sec (Bambang Soenarto, 1997). The largest well-known subsurface flow in the Gunungsewu is Bribin River with the average flow-rate of 850 l/sec in the dry season, and 1,500 l/sec in the rainy season (P.A.B, 1997, unpublished). Some surficial small springs are found in the west and east of Baron, and in the north of Wediamba coastal area. Other coastal-outflows of underground rivers of the Gunungsewu can be found at Ngrenean, Ngobaran, and Ngungap. Plenty of surficial springs, due to either the relatively high basement position or the closeness of the location to the base level of seawater are found in Panggang sub-system.

Fresh water from underground rivers in the Gunungsewu area is already made use of by pumping up to tanks, and then distributing it to villages which suffer from water-scarcity. Some of the underground-water exploitations are located in Bribin, Seropan, Ngobaran, Ngungap, and Baron.

CONCEPTUAL MODEL

Aquifers of the Gunungsewu Area can be divided into non-karst intergrain aquifer composed of caliche or chalky limestone and karst aquifer of conduit limestone. Water movement through non-karst aquifer is diffuse flow conducted by Darcy's law, whereas in karst aquifer is Bernoulli's law conduit flow. Non karst aquifer is generally found overlain by karst whether it is thick (> 5 m) or thin (< 2 m). At some places like Ngaglik, Dadapayu and Semanu, non-karst aquifer is exposed displaying interfingering contact with karst aquifer. In this case, as can be obtained at Seropan-Semuluh cave area, the non-karst aquifer acts as the catchment area of the karst aquifer. All of the Gununungsewu aquifers are underlain by volcanic clastics of tuffaceous sandstone, breccia, lava deposits, and tuffaceous marl of the Besole Group and Sambipitu Formation.

As it has been mentioned above, geologic structures play a very substantial role in groundwater dynamics in the Gunungsewu. The northwest-southeast strike and northeast-southwest striking faults in the Wonosari-Baron Hydrogeologic Subzone disconnect the section of shallow groundwater of bioclastic limestone aquifer from the section of deep groundwater of reef aquifer. Homoclinal structure causes groundwater to flow enormously southward under hydraulic gradient into the Indian Ocean. The existence of four stratigraphic sequences in Gunungsewu carbonate group enables this formation to form many perched aquifers in the rainy season, although in the dry season these aquifers are drained.

The two dimensional conceptual model of hydrogeology of the Gunungsewu Area can be summarized as shown in Figure 4 and Figure 5.

CONCLUSIONS

Rock formations of the Gunungsewu Area can be classified into aquitard, aquifer, and aquiclude. The Gunungsewu limestones form two types of aquifers, i.e. non-karst intergrain aquifer with

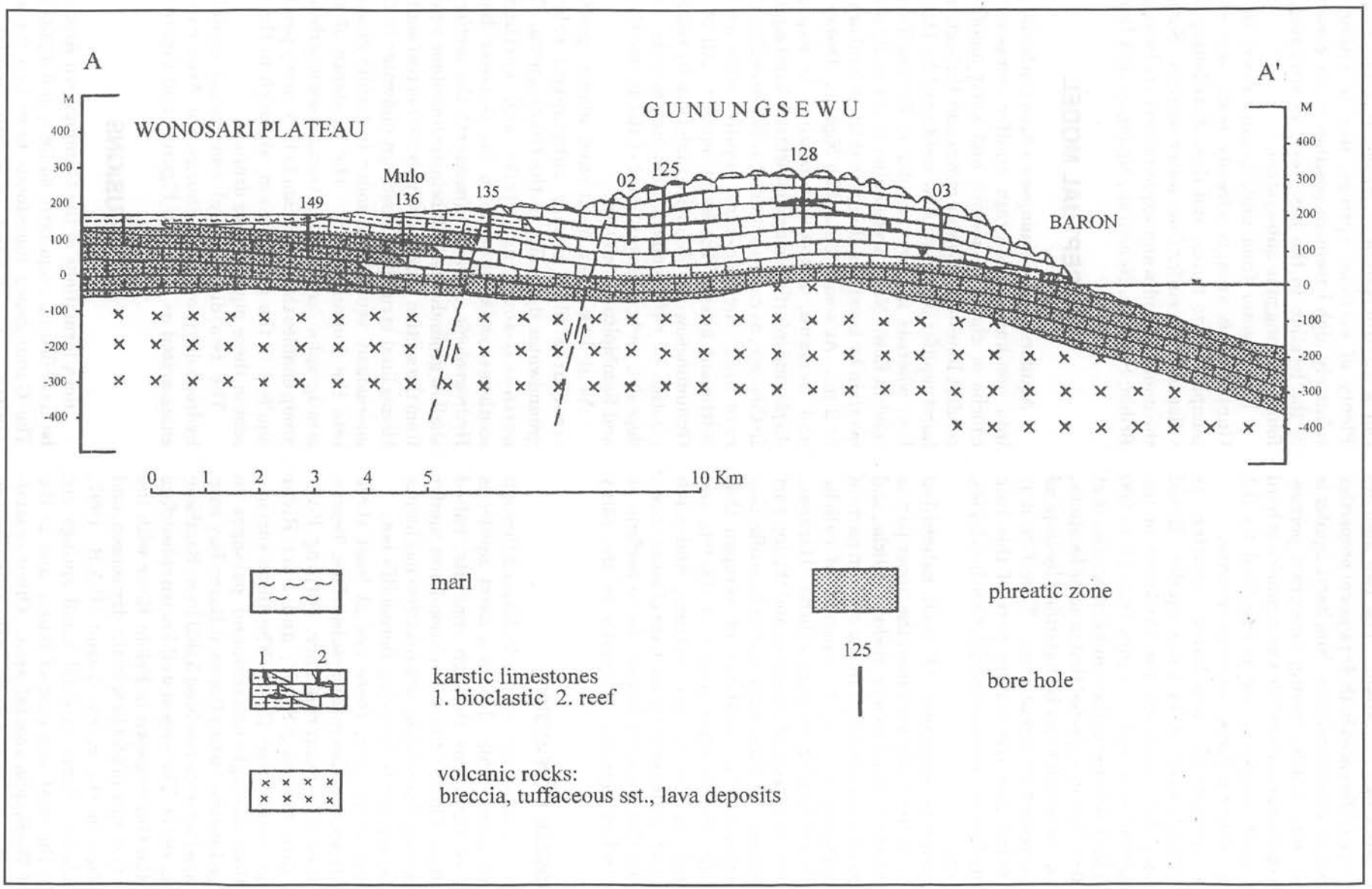

Figure 4. A-A' cross sectional conceptual hydrogeologic model of the Gunungsewu.

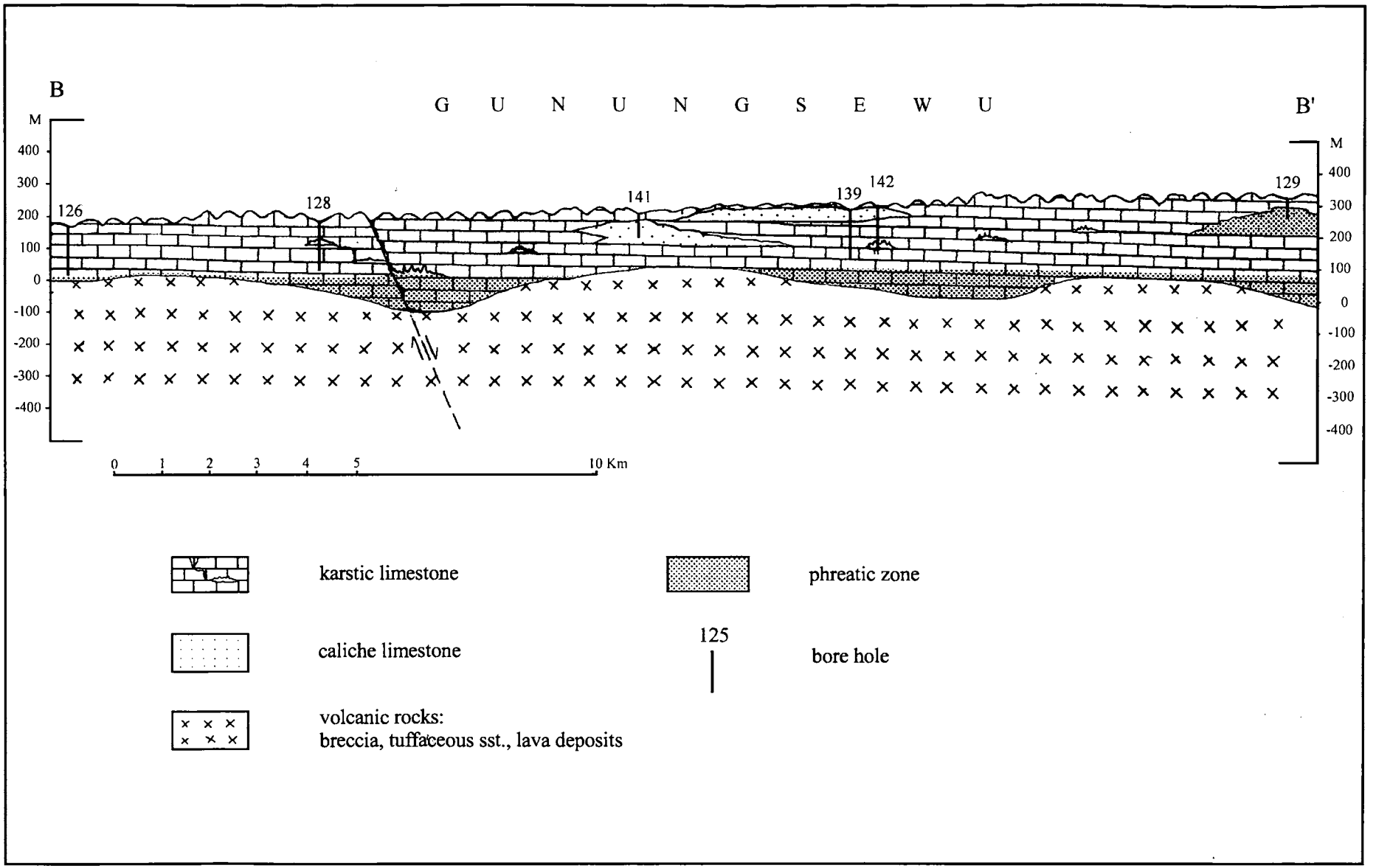

Figure 5. B-B' cross sectional conceptual hydrogeologic model of the Gunungsewu.

diffuse flow, and karst aquifer with conduit flow.

The non-karst aquifer is stratigraphically overlain or interfingered by karst aquifer. If the non-karst aquifer is exposed with interfingering contact with the karst-aquifer, it will act as the catchment of the karst-aquifer.

Faults of northwest-southeast and northeast-southwest strikes divide Wonosari-Baron Hydrogeologic Subzone into two sections, i.e. the section of shallow groundwater of bioclastic aquifer in the north, and the section of deep groundwater of reef aquifer in the south. The homoclinal structure lead groundwater to flow enormously southward into the sea.

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