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EXPLORATION OF CAVES FOR RURAL WATER SUPPLIES IN THE GUNUNG SEWU KARST, JAVA

by

Antony C. WALTHAM [1], Peter L. SMART [2], Hans FRIEDERICH [3] & Timothy C. ATKINSON [4]

(4 figures)

RESUME. - Prospection spéléologique et recherche de ressources en eau pour les villages du karst de Gunung Sewu, Java.
L'exploration spéléologique a été employée comme moyen principal pour établir une carte du niveau hydrostatique et estimer le potentiel aquifère d'un karst non développé. En même temps, des cours d'eau souterrains, des nappes d'eau et des rivières ont été localisés et ont été l'objet d'une évaluation en vue de leur utilisation directe pour l'approvisionnement en eau.

ABSTRACT. - Conventional cave exploration was used as the primary means of constructing a water table map and assessing the aquifer potential in an undeveloped karst. At the same time, underground streams, pools and rivers were located and evaluated for direct abstraction schemes.

Gunung Sewu consists of over 1000 km^2 of cone karst (fig. 1) developed in massive Miocene limestone. Overall relief rises to a central ridge around 300 m high. The landscape is an endless repetition of small rounded conical hills with thin soils, separated by dendritic valley systems mostly floored by a few metres of clay soils. All drainage goes underground into hundreds of valley floor sinkholes. The climate is uniformly warm, but with a marked annual dry season between three and eight months long.

Over a quarter of a million people live in the karst, farming the valley floor soils by rainfed cropping. During the dry season agriculture is impossible and the people suffer from acute shortages of water for drinking, washing and basic survival. The main resources are widely spaced telagas; these are shallow pools where wet season runoff collects on the clay soils, mostly retained by low hand-built earth dams. Water is also taken from streams and pools in a number of walk-in caves, and is carried from sinks and springs round the karst margins.

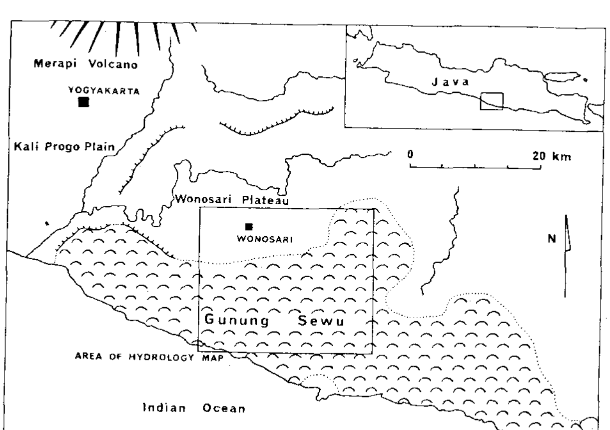

Figure 1. - The Gunung Sewu karst.
Figure 1.- Le karst de Gunung Sewu.

A Government scheme for water supply improvements is in progress. It has concentrated on telaga development with new sites or raised dams, but there is a severe lack of suitable sites; failures have also been experienced where new sinkholes have instantly drained reservoirs into the underlying limestone. Piped supplies from marginal springs are generally not favoured because of the pumping heads involved and the inadequate financial and maintenance infrastructure. A number of deep boreholes were drilled but none yielded usable flows; most were dry, as their design had been based on an incorrect assumption that the water table was domed beneath the main upland axis.

As the water supply improvement scheme met increasing problems, the need was recognised for a comprehensive aquifer assessment together with an evaluation of any resources existing within the caves which were inaccessible due to vertical shafts. Conventional cave exploration methods were employed by a team of

1 *Civil Engineering Dept, Trent Polytechnic, Nottingham, U.K.*

2 *Geography Dept, University, Bristol, U.K.*

3. *P.O. Box 39, Tutume, Botswana.*

4. *Environmental Sciences Dept, University of East Anglia, Norwich, U.K.*

hydrologists/geologists/surveyors experienced in caving techniques. The caves were systematically explored during the 1982 dry season, all those containing water were mapped, abstraction potential was evaluated and measurements were made of both water flow and water quality. During six weeks in the field, 160 sinkholes were examined (Waltham *et al.,* 1983), essentially by two two-man teams; surface back-up was provided and there was follow-up in 1983.

THE CAVES

More than 250 open sinkholes are known in Gunung Sewu, all sited in the valley floors between the conical hills. Most have vertical entrances, which had precluded exploration by the local people. The majority of sinkhole caves descend rapidly in a series of shafts through the almost structureless limestone; 27 of them have been followed to depths of over 100 m, but none beyond 200 m. They act as major wet season drains and many are therefore choked with mud and debris; during the wet season, backing up of water to depths of 50 m is not uncommon. A proportion of the sinkhole caves can be followed down to sumps, some of which are static in the dry season and some of which are clearly perched.

A few of the sinkholes reach sub-horizontal conduits at depth; these gather increasing flows of water, are commonly on some geological control and also eventually reach sumps. Ten caves have been mapped with more than a kilometre of passage; but it is clear that the great majority of the horizontal caves are below the water table. A remarkable anomaly is the Bribin cave river, flowing at high level in an ancient phreatic tunnel.

Draining from the Wonosari Plateau, a number of rivers sink along the northern edge of Gunung Sewu. These have formed cave passages mostly larger than those beneath the sinkholes of the karst interior, but otherwise of similar morphology. There are also some dry fossil caves within the conical hills, largely irrelevant to the modern hydrology.

AQUIFER ASSESSMENT

It is recognised that fissure flow and conduit flow, in a mature karst aquifer, may be at least partly independant; it is therefore often difficult to identify a meaningful water table in karst areas. In Gunung Sewu, conduits do not form at the water table but are geologically guided above or below it, though once created their high transmissivity bears a strong influence on the water table topography. While an individual conduit may be above the water table, standing water levels within them can be interpreted as the water table in a karst of adequate maturity, though local perched ponding may have to be identified using subjective evidence.

Within Gunung Sewu, over 40 sinkholes have been explored and mapped to standing water, and this has been used as primary data to construct a contoured water table map (part of which forms figure 2). Additional data on water table altitudes has come from marginal risings and some boreholes, and also from dry caves and bores interpreted as ending above the water table. A programme of dye tracing in central Gunung Sewu proved that all the main underground flows, of both stream sink and percolation origin, drain to a single coastal resurgence at Baron. These results were incorporated in construction of the map to identify the main water table troughs and regional gradients; further detail was provided by short mapped lengths of major cave conduits.

The main feature of the water table is its slope to the coast, passing beneath the central ridge of Gunung Sewu. This regional trend is disturbed by a water table trough, along the direct line between the major input and output, namely from the Wonosari Plateau marginal sinks to the Baron resurgence. The trough is deflected along the edge of the karst (fig. 2) in response to the multiple input sinkholes which have created a zone of maximum erosion. It is suggested that flow along the main trough is largely in a single master conduit, which lies within a zone of fissures and conduits representing an axis of enhanced secondary permeability. It appears that the major conduits of Gunung Sewu are phreatic. The efficiency of their flow accounts for the very low water table gradient (fig. 3) extending right through the base of the upland karst.

Waters pours into the main water table trough from both sides, as is clear from direct observation and flow measurements in the sinkhole caves within its upper end. There is a major flow input from the north, through the inclined, interdigitated facies boundary against the Wonosari Plateau aquifer of chalky limestone. This creates a marked step in the water table profile which is a direct response to the contrasting permeabilities. The trough also draws percolation water northwards from the karst interior, deflecting the overall drainage towards the south coast.

A deep water table is therefore a feature beneath much of Gunung Sewu. Most sinkholes are simply vertical or steeply inclined conduits transmitting flow rapidly through the vadose zone. In the dry season they merely gather percolation water from fissure storage, but in the wet season they carry major flows which cause significant fluctuations of water table level.

Major lateral conduits in the vadose zone are rare. In the Sodong sinkhole the long meandering vadose conduit is guided by locally well developed bedding planes, and drains against the regional water table gradient until it meets the phreas (fig. 2). The Bribin cave river collects a large proportion of the percolation water in north-eastern Sewu, as indicated by the dye tracing and di-

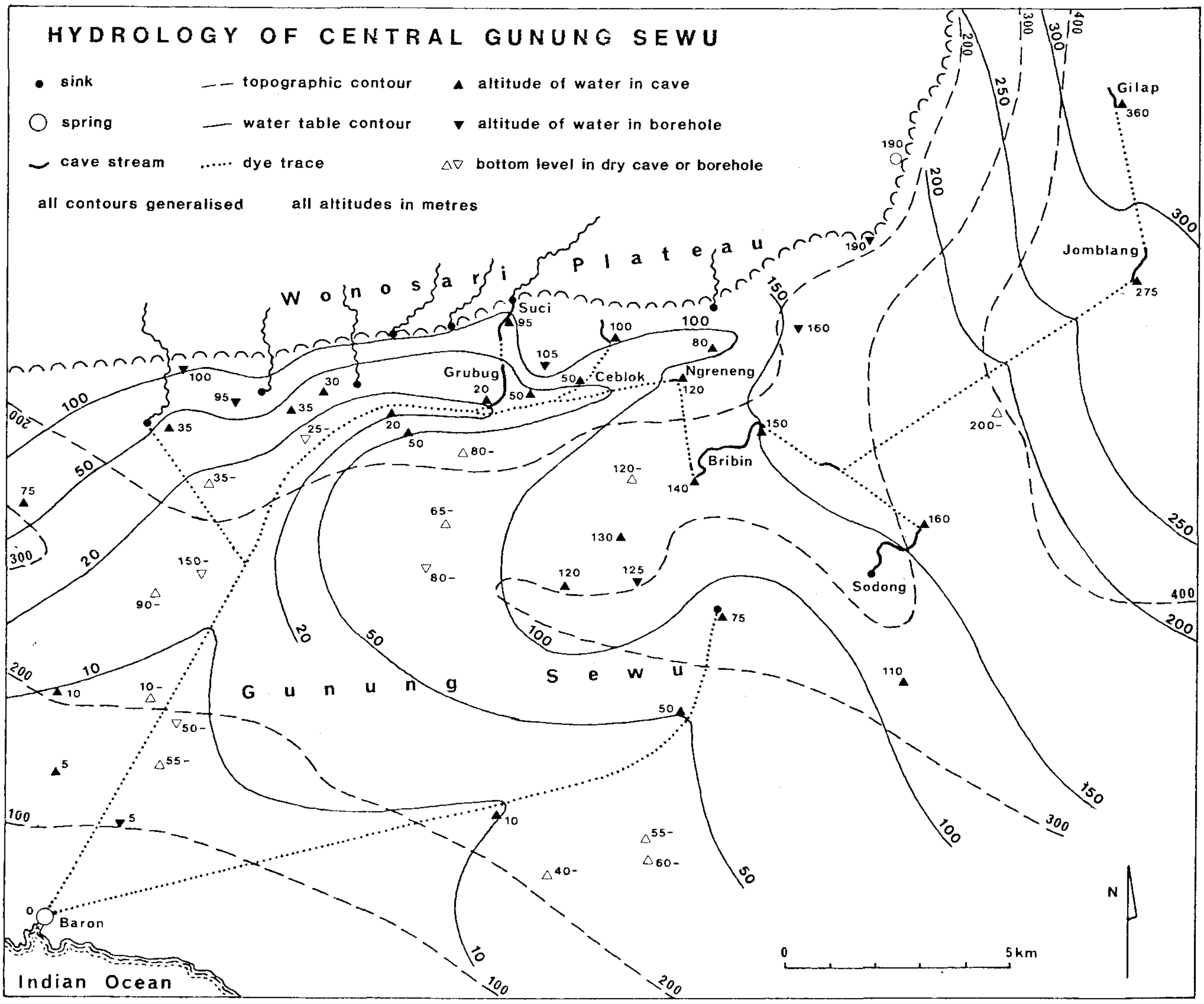

Figure 2.- Water table map of central Gunung Sewu.

Figure 2.- Carte du niveau hydrostatique du centre de Gunung Sewu.

rect mapping of its major tributaries (fig. 2). Its flow is through ancient, partly drained, phreatic caves, and its survival at high level may be due to volcanic ash horizons more commonly interbedded in the limestone towards the east. Though therefore perched, its presence dictates the local level of the water table. Only downstream of the Bribin cave does the water escape to greater depths as it drops into the main water table trough.

CAVE WATER RESOURCES

The prime purpose of the cave exploration was the direct examination of any water resources, and the evaluation of the potential for abstraction schemes on either small or large scales. All sinkhole entrances are dry in the dry season, and prediction of the water situation within the caves is totally impossible without exploration. Resources fall into shallow and deep groupings, separable on the basis of the scale and sophistication of abstraction schemes required. Many caves were found to contain no water in the dry season.

Shallow resources consist of pools or streams at depths of less than 30 m, and were found in 12 °/o of sinkholes examined. Some passages have static pools, perched well above the water table, retaining wet season input; these can suffer from the same disadvantages of leakage, depletion and contamination as surface telagas, but without evaporation loss, though their volumes are mostly small. A pool in the Sodong cave contains over 700 cubic metres of water and is heavily used by local people as it is accessible through only 200 m of passage. This resource may be improved by a small dam at the downstream end of the cave pool. Mapping of the cave has also identified the location for a hand-dug well into the pool to eliminate the arduous carrying of water out of the cave and the associated pollution from both the parafin lighting and on-site washing.

Shallow resources with flowing water, mainly of good quality percolation from high level inlets, are

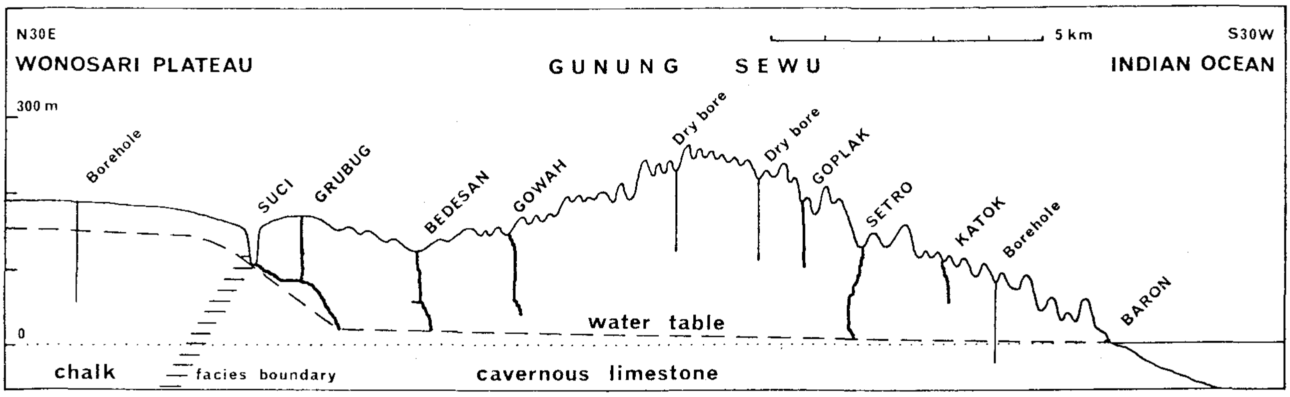

Figure 3.- Projected cross section through central Gunung Sewu.
Figure 3.- Coupe à travers le centre de Gunung Sewu.

particularly valuable. In the Ceblok sinkhole (fig. 4) a deep pool has a throughflow of good water adequate to yield a rope and bucket well supply; it lies at the foot of a natural shaft and will require only a short hand-dug well. In the Jomblang sinkhole, a pool just beyond daylight is already utilized by villagers. The small overflow passage from the pool was found to have, only a short way along it, a tributary with a much higher flow. Diversion of this, through a pipe laid in the passage, will vastly increase the potential abstraction rate from the entrance pool.

Various methods of abstraction were found to be applicable to sites of contrasting character. The basic choice at the shallow sites is between hand-dug wells, creation of direct access, and diversion of flow to accessible points. All these have the benefit of almost no maintenance requirements, but small pump schemes are appropriate in some cases. Detailed cave surveys allowed optimum selection, and well sites were accurately identified by using the Molephone radio location technique.

The Bribin cave river is a shallow resource of anomalous size, and, as it appears to be unique within Gunung Sewu, is of prime importance. It already has a small dam within the cave, pumps and a pipeline to the surface; however, the supply via the overland pipelines to nearby villages is seriously limited by lack of operating finance and inadequate maintenance.

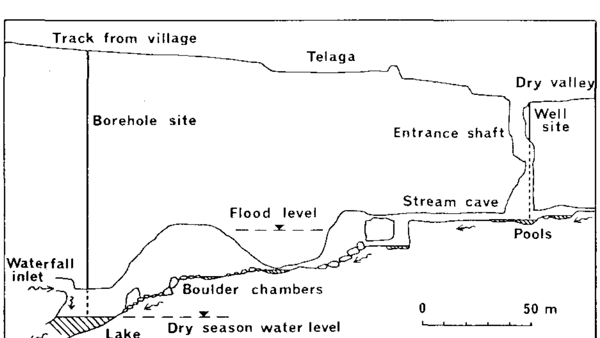

Figure 4.- Simplified cross section of the Ceblok sinkhole, with potential abstraction sites.
Figure 4.- Coupe simplifiée dans le ponor de Ceblok, avec sites potentiels de prélèvement d'eau.

Deep resources consist of underground streams, rivers and water table lakes of sizes large enough to be economically exploitable from their depths; they were found in 5 °/o of the sinkholes examined. The Grubug cave river, with a base flow of over 600 litres/second, is fed partly by the sinking Suci river and largely by groundwater flow from beneath the Wonosari Plateau. It could support a large scale abstraction scheme, which will however need to be able to overcome the depth of nearly 100 m, the enormous annual flooding, and its relatively isolated location. Other sites have streams feeding large pools which make excellent borehole targets and ready-made sumps for submersible pumps; the lower end of the Ceblok sinkhole (fig. 4) is one such example. A maintenance-free alternative to a deep borehole from a hilltop may be an inclined adit from a nearby valley. Where, as in the Sodong cave, the passage is tall and narrow the large adit target compares favourably with the small borehole target, and can overcome the difficulties of accurate survey through long, tortuous cave passages.

There is a clear correlation of percolation inflow and depth in the deeper sinkhole caves. All caves explored to over 150 m contain some dry season flow. This indicates the importance of fissure storage within the vadose zone; it appears to account for about 20 °/o of dry season flow from the karst, most of the rest deriving from phreatic drawdown. But unless a major lateral conduit is intersected, this percolation flow rarely exceeds a few litres per second, so is not economically exploitable from the depths of over 100 m.

CONCLUSIONS

The cave exploration programme provided an economical method of assessing the Gunung Sewu karst aquifer. The overall hydrology was established, proving to be similar to that expected based on previous work in karsts; it is in marked contrast to the previous incorrect interpretation based on a conventional, non-karstic, approach. Cave mapping permitted the identification of water table altitudes, and the form of the major water table trough was revealed. Based on this data, well depths can now be predicted and evaluated, and placement of them in the water table trough should provide higher yields from zones of increased fissure development.

Underground explorations did reveal some water resources, but, excluding the marginal zones, these were thinly distributed. This is to be expected in any mature karst aquifer. With individual passages having an almost random choice of patterns, few can offer accessible resource sites, but discovery of these is impossible without direct exploration; and further explorations may well yield more resources.

For most of the villages within the Gunung Sewu karst, there is therefore little long-term alternative to adequate water supplies being piped from a distance. There is however no overall water shortage. The Baron rising has a base flow of about 5 m^3/s. The Bribin cave river (also located in the Ngreneng sinkhole) is a valuable high altitude resource with a minimum flow of over 1 m^3/s. Pipelines from these two sites will therefore have to be the core of the future water supply for Gunung Sewu, but economical planning can now procede firmly based on a true assessment of the karst hydrology. In this context, the value of the cave exploration programme is easily justified; its overall cost could be roughly equated with that of four deep boreholes.

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