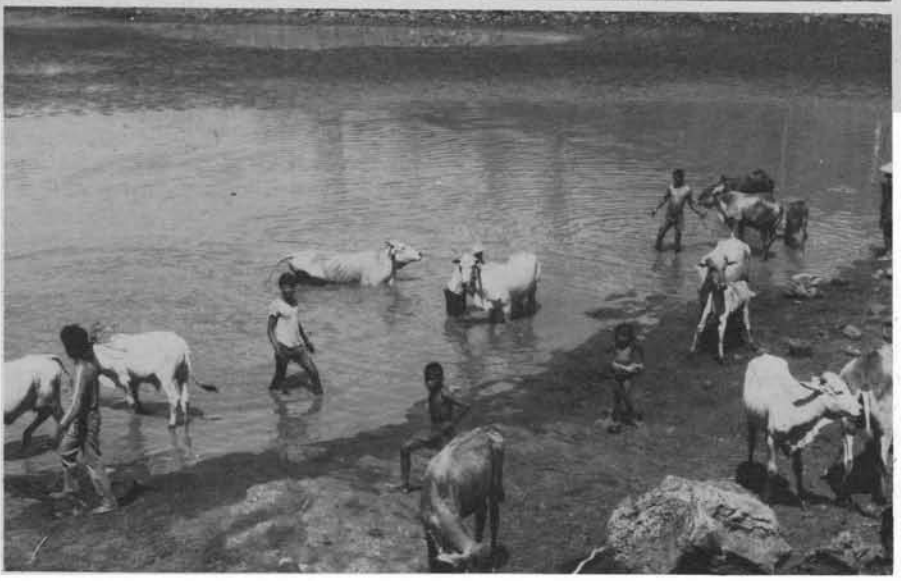
(Above) in the wet season the conical hills of Gunung Sewu rise from a sea of green cassava. (Right) sufficient water accumulates in the shallow *telagas* or lakes to meet the needs of the people and their livestock



(Above) the dry season sees a transformation to dry-stone terrace walls and barren red soil and for months nothing is grown. The farmers toil to break the clay soil ready for the first rain (right)

(Bottom right) carrying water becomes a regular task with the men of the households usually going twice a day to fetch supplies from a telaga or cave, often many kilometres away

Deep cave waters for Gunung Sewu

by Dr A. C. Waltham and A. J. Eavis

Drought and water shortages are unusual conditions in tropical Java. But during the dry season in the limestone area of Gunung Sewu vital water escapes deep underground. Dr A. C. Waltham and A. J. Eavis explored a vast network of caves and passages for new sources of water

JAVA IS the most densely populated of the Indonesian islands and it survives largely on intensive agriculture. Lush rice paddies on rich soils, terraced up the footslopes of massive volcanoes, typify the Javanese countryside. With irrigation the land supports three rice crops per year. However, in the Sewu hills (Gunung Sewu) which lie against the south coast of central Java the local farmers are less fortunate, for Gunung Sewu is different. It is cone karst. For a thousand square kilometres its limestone is unbroken, supporting an almost monotonous landscape of low conical hills which are a textbook example of tropical karst. The name Gunung Sewu translates as Thousand Hills, but there are many times that number.

Each hill is around 200 m in diameter and 50 m high, and they are remarkably consistent. Their surfaces are a mixture of bare, solutionally fretted rock and thin patchy soils. Winding between them, dendritic valley systems, with floors of superficial clay, almost all end in open sinkholes. The chaotic relief of the karst surface is complemented by an integrated drainage system which is entirely underground.

Rice paddies cannot exist on the limestone. The annual dry season lasts between three and eight months, and the almost total lack of surface water makes irrigation impossible. The people have to survive from only rain-fed cropping of dry rice, beans and cassava, and then the land lies baked and useless through the dry season. Even this agriculture is only possible on the 25 per cent of land area which is clay-lined valley floor between the limestone cones. Consequently the people of Gunung Sewu are among the poorest in Java. The seasons dictate their farming and ensure their poverty, but, in addition, the limestone bedrock means that during the dry seasons there is a desperate shortage of water even for drinking.

In the main part of the karst only about 20 survive even a normal dry season, and they are very unevenly distributed. Most telaga water is seriously polluted, and it all has to be boiled for drinking.

Alternatives to telaga supplies are sparse. Springs exist only around the edge of the karst, and surface rivers from the Wonosari Plateau sink underground as soon as they meet the cavernous limestone. Shallow wells in the valley clays have extremely low yields, and roof-fed rainwater tanks have almost negligible storage. Water deliveries by road tanker are expensive and only possible for a few of the larger villages. Caves provide a number of supplies. In their search for water, villagers have entered many of the caves, but only a handful contain pools or streams accessible to men carrying a pair of heavy cans on a bamboo yoke. At a few sites, small pumps and pipelines have been installed to lift the water to daylight, but all are in a nearly permanent state of disrepair. Frustratingly, the majority of the sinkholes have vertical shafts which effectively stop the local people exploring them. The very uneven distribution of all these sources mean that a large proportion of the people have to carry all their drinking, cooking and washing water for considerable distances. Overall, perhaps half the people have to carry water for distances greater than three kilometres, and in a long dry season the situation becomes progressively worse. Carrying water during the dry season is an awful burden on the people of Gunung Sewu.

Improvements to rural water supplies have become a social priority in many parts of Java, and Gunung Sewu falls into the area covered by the Gunung Kidul Groundwater Project. This is a large operation funded jointly by the Government of Indonesia and the Overseas Development Administration in Britain. Being karst, Gunung Sewu obviously needed special treatment. Considerable progress was made with a programme of telaga improvements and renovations and even new telaga construction, but there is a shortage of sites suitable for development.

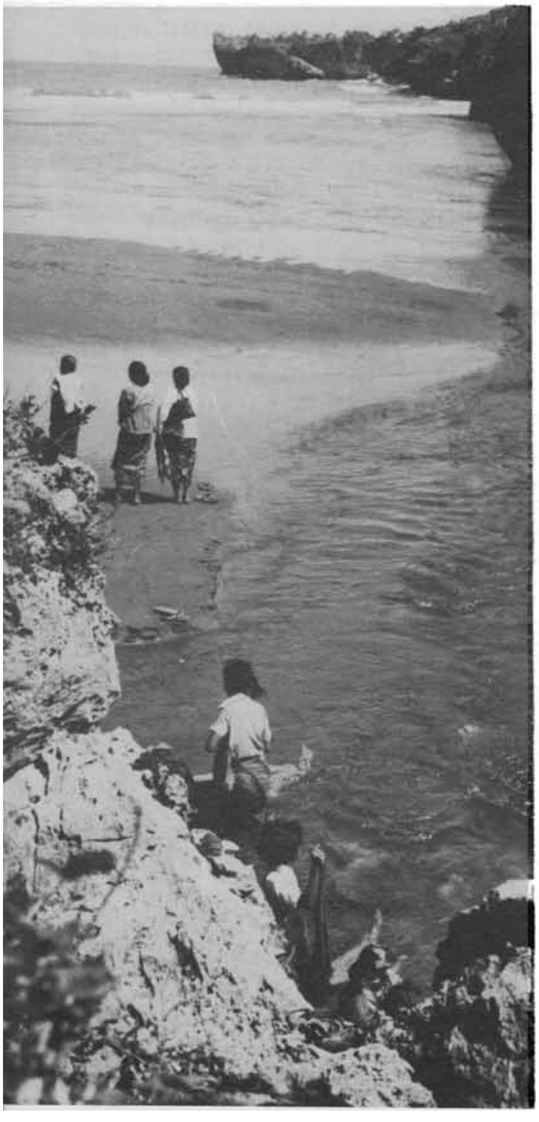
Nearly a quarter of a million people live in the karst, mostly in villages with populations of less than a thousand. They have immaculate houses of timber and split bamboo with clay tile roofs, and during the wet season, village life has a routine repeated almost throughout the tropics – warm rain, fast-growing crops and local trade determine repetitive days of work on the land, all in an environment which can seem like a paradise to visitors from colder countries. But the good life stops in the dry season and is replaced by an endless struggle to obtain water.

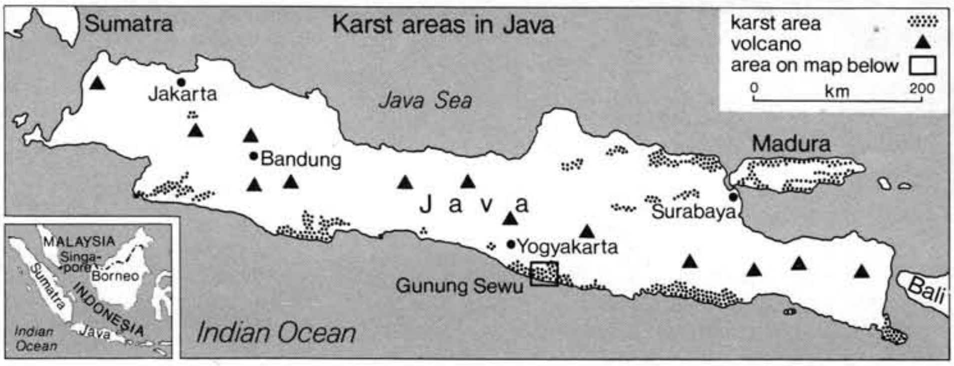
Surface water is almost totally non-existent. *Telagas* are small shallow lakes which survive on the thicker clays of the valley floors, though nearly all have been created by the construction of low earth dams. Their input is wet season surface flow, and during the dry season they slowly dry up due to evaporation, leakage and abstraction.

Groundwater resources provide the alternative to telagas. The water is of much higher quality, and there is far greater potential – as witnessed by the Baron resurgence on the coast which has eight m^3 per second of water flowing out of the limestone and straight into the sea even late in the dry season. The disadvantage of the groundwater is the difficulty of its exploitation. A number of boreholes were drilled into the limestone but nearly all were dry, partly due to the very uneven flow of water within the aquifer. In such a cavernous karst limestone a well only produces a significant yield if it intersects a cave or conduit, and the chances of that are very low where mature caves are so widely spaced. In addition, piecemeal development of pump schemes at accessible caves was impossible to evaluate while the regional aquifer properties were totally unknown.

The numerous open sinkholes provided the means to explore the resources of the limestone aquifer, except that the dominantly vertical entrance shafts posed a severe access problem. Adrian Young, the field engineer in Gunung Sewu, therefore proposed that a team of experienced cavers were contracted to explore the sinkholes and caves. With expertise in both surveying and hydrology, they could not only locate individual water resources in the caves but could also make a comprehensive assessment of the limestone aquifer. Consequently a team of five (Peter Smart, Hans Friederich, Tim Atkinson and the authors) worked in Gunung Sewu through the dry season of summer 1982. In preparation, Javanese staff of the Groundwater Project had compiled a register of sinkhole entrances, all of which were known to the nearest local villagers, and the cavers eventually investigated over 150 sites.

Freshwater pours into the sea from the Baron resurgence after flowing in underground rivers beneath Gunung Sewu from the edge of the Wonosari Plateau

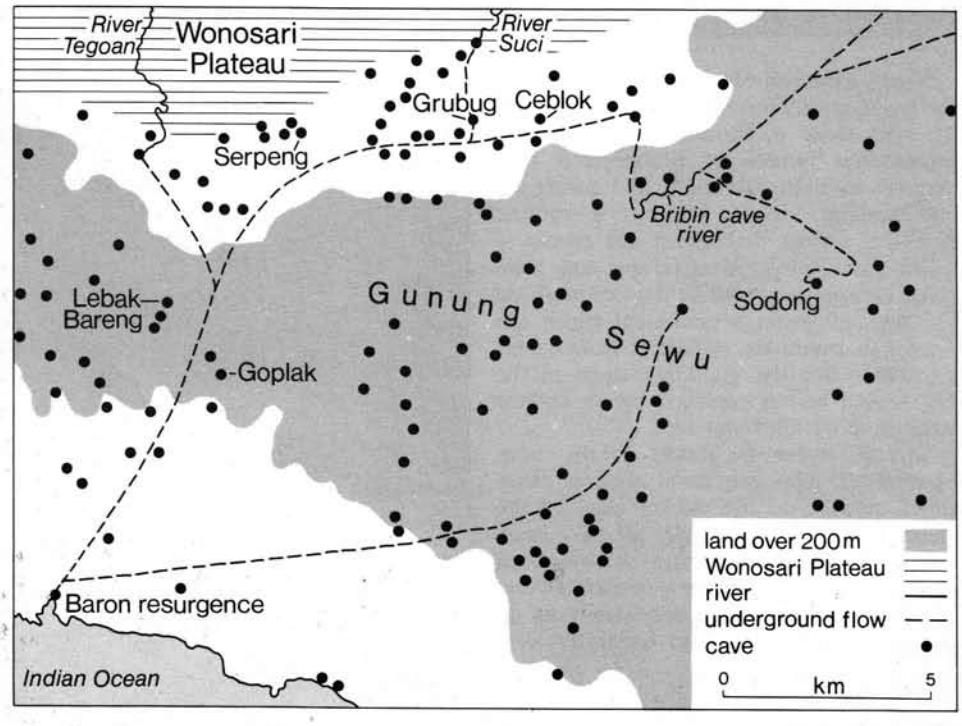


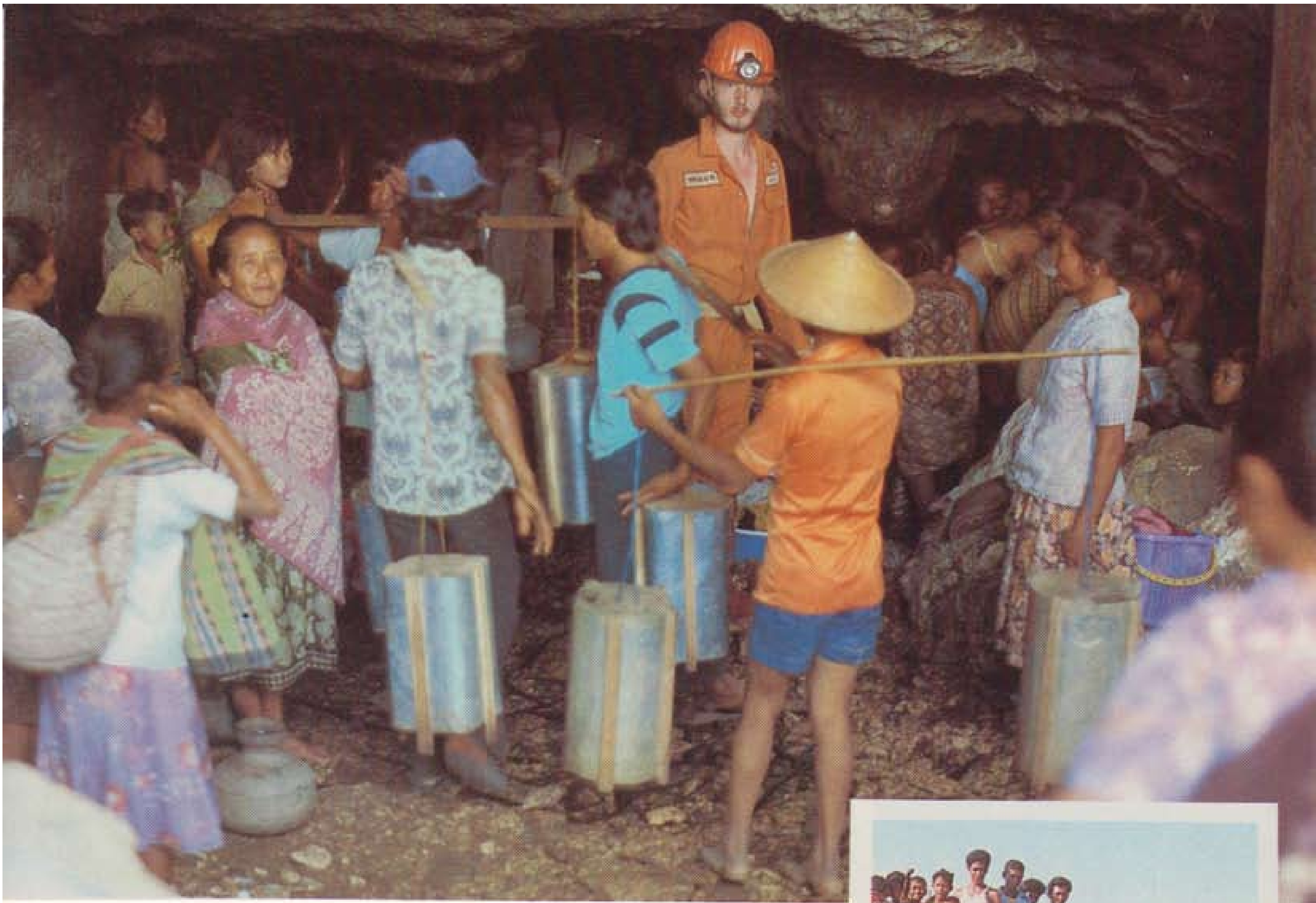


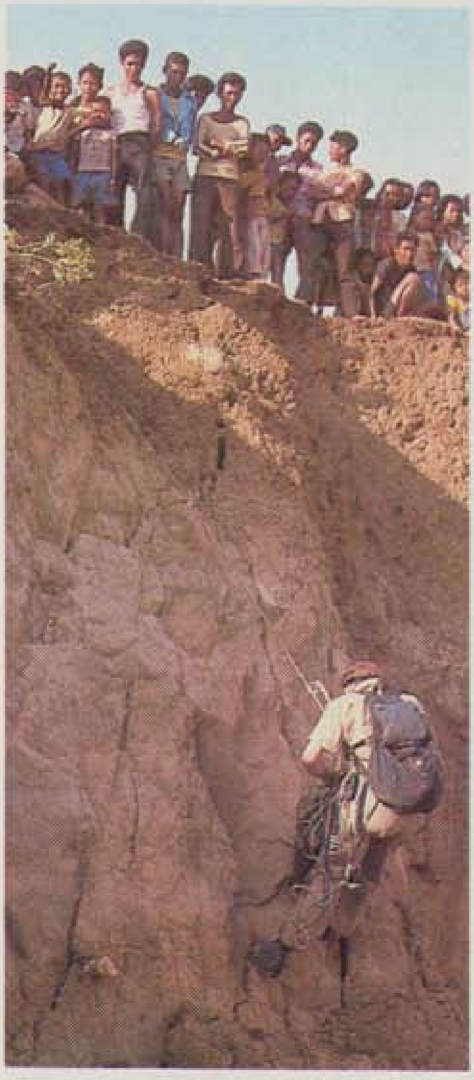
Exploration of the sinkholes revealed a typical mature karst. The majority of the cave passages consist of a succession of vertical shafts descending rapidly to a deep water table. Storage above the water table provides small flows of water from the microfissure systems into the caves even late in the dry season. There is a good correlation between depth and flow in the sinkholes; while all the entrances were dry in August, every cave had at least some flow in it at depths greater than 100 m.

The general pattern of steep shaft systems was soon recognized, but the practical problem was to determine the amounts of water in individual sinkholes. Most have negligibly small flows, of no economic potential, or just descend to small static pools at great depth. But others contain usable pools or cave lakes, or exploitable large flows at acceptably shallow depths. It was totally impossible to predict the resources of an individual sinkhole without directly exploring it. Luwang Goplak (the Goplak sinkhole) has a magnificent bell-shaped entrance shaft 70 m deep, but at its foot boulder slopes lead only to blank walls; the debris floors absorb wet season floods with ease but in August the sinkhole is dry and useless. Luwang Serpeng has a 50 m entrance shaft, but this drops into a large passage which continues down a series of giant steps to the edge of a huge underground lake; thousands of cubic metres of clear cool water, continually replenished by seepage, constitute a valuable resource. With predictions being impossible, the cavers spent most of the summer descending the multitude of sinkhole shafts just looking for underground streams and lakes – a method of aquifer exploration which depends on chance, but is infinitely faster and cheaper than a programme of deep boreholes.

Luwang Ceblok proved to be one of the good sites. From the floor of a shallow dry valley a dry 23 m deep shaft descends to a clean rock floor, where just a few metres to one side a second shaft drops as far again to a deep pool of clean water. It is almost a natural well. Villagers will be able to dig by hand a shaft from the surface less than 15 m deep to meet the roof of the second natural shaft directly above the pool. A hand-hauled rope and bucket system can then provide a maintenance-free supply of good quality water. Inlets in the cave feed over a litre per second through the pool; it is a small resource but enough for local needs. The







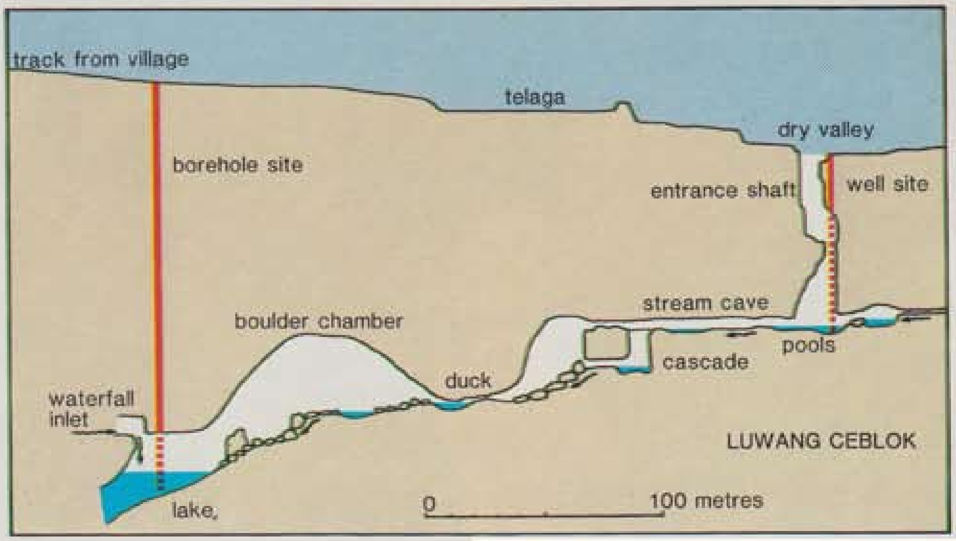
(Above) some caves with short passages to water have been heavily used by successive generations of villagers. (Right) vertical shafts are not easily descended and crowds of hopeful local people come to watch the British cavers explore them

cave passage continues downstream, then down another shaft and through a couple of chambers to a deep sump pool over 20 m across. A waterfall cascades from a slot in the roof straight into the lake, and there is a total dry season flow of 100 litres per second. Even though it is 110 m below the surface the lake makes an ideal target for a borehole which can be equipped with a submersible pump to feed a regional supply scheme. The cave was surveyed to a high accuracy, and the borehole site was located on the surface.

With nearly all the sinkholes located near villages, the arrival of a team of cavers became an instant centre of attraction. Crowds of people frequently numbered over a hundred, and usually contained a good proportion of children but also the village headman. They gathered at the entrance, and patiently awaited the return of the cavers, sometimes long after sunset. They realized the water potential of the shafts inaccessible to them, and they yearned for news of what lay down their local sinkhole. At Ceblok the news was good. But more often than not, it was disappointing; it was sometimes heart-breaking to have to announce to the villagers that their sinkhole was dry and that they would still have to walk to a distant telaga.

It was even worse when the cavers returned to daylight with their clothes and ropes soaking wet but could still not promise a water supply. At the Lebak Bareng sinkhole the entrance passage is horizontal, but soon ends at the lip of a deep shaft. Fluted walls of vertical limestone plunge for 140 m, unbroken except for a few ledges on one side. There is a single deep pool at the bottom which drains off into a roomy stream passage extending 100 m to a terminal sump pool. Unfortunately the combined flow of various little inlets is only a few litres per second, which cannot be economically exploited from a depth of over 160 m

The short length of explored conduit at the bottom of Lebak Bareng is an indication of the pattern of groundwater flow at depth. In the phreatic zone, beneath the water table, the flow is dominantly horizontal, in total contrast to the vertical flow above. The Lebak Bareng passage has been rejuvenated, as it was originally totally flooded until the water table fell slightly in response to regional evolution. Only a few fossil galleries like this are known. The great majority of horizontal conduits are permanently flooded, and virtually inaccessible. The pattern of the major conduits was partly deduced from a series of dye tests which showed that all the cave streams from a very large area flow to the single coastal resurgence at Baron. The maturity and

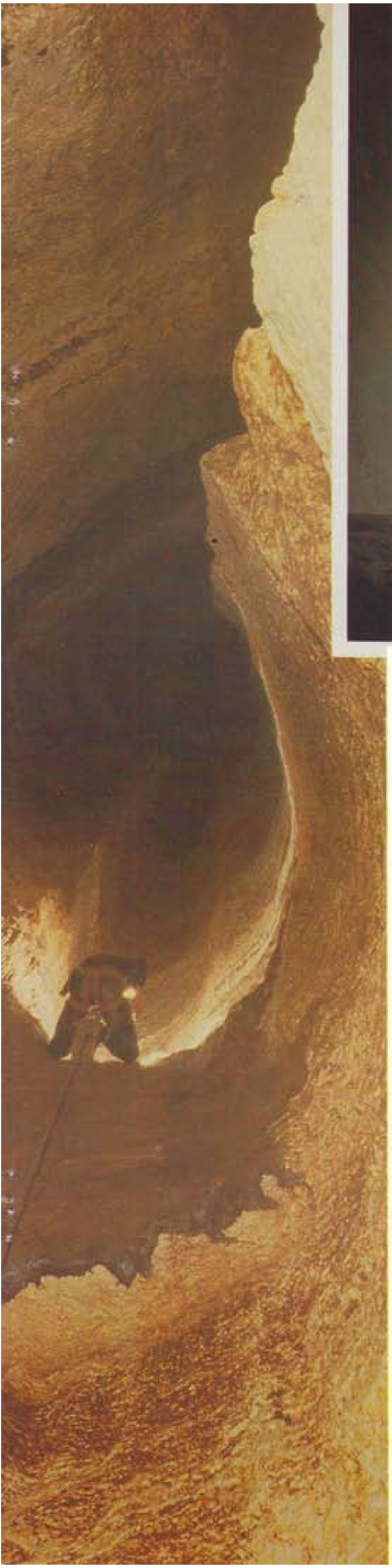


Some of the cavers' explorations brought new hopes for local people; a potential site for a borehole water supply was found 100 m underground where the passage of Luwang Ceblok breaks into a large chamber

efficiency of the phreatic conduits accounts for a very gently graded water table beneath Gunung Sewu. Rivers flowing from the Wonosari Plateau sink into large caves where they meet the limestone at altitudes around 175 m; underground they descend very steeply till they enter totally flooded conduits at altitudes of around 30 m even though they are still 12 kms or more from the Baron resurgence. The main conduits pass right beneath the axis of the Sewu hills and consequently the water table is commonly more than 200 m down; even where a water table dome does exist it is no match for the topography.

The mainly low level, phreatic flow beneath Gunung Sewu does not simplify abstraction from the aquifer. Even the very large flows draining towards the Baron resurgence cannot be exploited where they are confined to flooded conduits which are inaccessible. A successful abstraction scheme can only be based on a located, and therefore accessible, resource, which must then be either large or shallow. Small flows at great depth, as in Lebak Bareng, are uneconomic. A large cave river at shallow depth is a bonus.

The Bribin cave is a magnificent anomaly in the heart of Gunung Sewu. A dry, gently descending, passage leads to the bank of a powerful underground river. With a minimum flow of slightly more than one m^3 per second, of very good quality water, it is a valuable resource. It was found many years ago by local people and the cave river now boasts a small dam with pumps feeding pipelines to the surface and nearby villages. Even when the dam was built the cave was unexplored both upstream and downstream. The cavers hoped to follow the river and perhaps locate further abstraction sites, but it could only be followed for 3 kms before sumps were met, and dye tracing suggested that downstream it quickly descends to much greater depths. There were also hopes that other cave rivers comparable to the Bribin could be found. But the Bribin appears to be unique in Gunung Sewu; it owes its existence at least partly to perching on layers of volcanic ash within the limestone, and the geology offers little prospect of a carbon-copy existing elsewhere.



(Left) the deep shaft of the Lebak Bareng sinkhole is a typical vertical conduit dropping to the deep water table in the limestone. It carries a torrent in the wet season but only dripwater in the dry season. (Above) the dramatic entrance of Luwang Grubug has a daylight shaft 64 m deep – to the sloping boulder floor of a wide chamber crossed by the underground River Suci

When it was recognized that major conduits like the Bribin were rarities in Gunung Sewu, the systematic exploration of the sinkholes was directed more to finding smaller sources for local supplies. Even resources already utilized proved to have scope for improvement. At one of the many sinkholes named Jomblang, villagers already take water from a pool only just out of daylight. It suffers from only having a tiny flow into it, and the overflow drains into a low passage. Exploration downstream proved to be easy, and, less than 100 m along, a substantial tributary stream was found. Furthermore, this enters down a small cascade from a passage at a level higher than the entrance supply pool; it will require a minimum of work to build a small masonry dam to divert this flow back to the entrance pool and increase the yield of the resource ten-fold.

Not far to the south, the Sodong cave has been used for a dry season water supply since time immemorial. The local villagers have a long walk on a rough road, but then have to scramble through nearly 300 m of the cave. Their only lights are paraffin flares which create far more smoke than light and coat the cave walls with black soot. They take water from a single pool, but the water is badly contaminated, both organically from the presence of the water collectors and also by a scum of paraffin oil. The men bring out 40 kg of water at a time, stumbling through the thick stinking smoke on a slippery floor and even up a short climb. Conditions are appalling: smoke, soot, inky darkness, pollution – but the villagers keep on coming purely for lack of an alternative. Even with no inflow the pool level drops extremely slowly with continued abstraction. The cavers provided the explanation for this when they dived beneath a section of submerged roof and found a long lake with a very large surface area. But they also mapped the cave, only to find that the supply pool lies directly below the road from the village. The exact spot on the surface was pin-pointed using a Molephone, a means of radio-surveying, newly developed by Lancaster University, based on a directional transmitter in the cave and a mobile search receiver on the surface. A concrete marker post now stands at the roadside, and later this year a well can be dug straight into the cave roof. It will not increase the water supply, but it will vastly improve the access for the long-suffering villagers and will eliminate the sources of pollution.

The cave survey project revealed a number of supply sites like Sodong and Ceblok. But it also showed that Gunung Sewu is a typical karst with most water far beneath the surface. The importance of the Bribin cave river and the Baron resurgence has been recognized, and there is in the long term little alternative to expensive surface pipelines from these and just a few other sources and cave boreholes. Exploration of the sinkholes allowed a true assessment of the hydrology, and progress can now be made with a cost-effective development of small and large resources.

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