

Limestone Karsts of the Annapurna Region, Nepal Himalayas

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Abstract: The Annapurna region contains three units of limestone and karst — the Nilgiri Limestones of the high summits, the Jomosom Limestones further north with the famous holy springs of Muktinath, and the Holocene Pokhara limestone further south with its substantial cave development. The Pokhara caves are formed in limestones little more than 500 years old. Brief new observations add to the data documented by the British expedition in 1970.

Annapurna and Dhaulagiri are two of the world's 14 summits which reach over 8000m high. They are both formed of a very thick sequence of Ordovician carbonates, known as the Nilgiri Limestone after the 7061m summit lying between them. Except for a slice of limestone forming the summit pyramid of Mount Everest, the Nilgiri Limestone has the highest altitude carbonate outcrop in the world. Furthermore they can be traced down to the floor of the Kali Gandaki Valley, between Dhaulagiri and Nilgiri, providing a vertical range of about 5500m in the outcrops. This situation was enough to attract a British expedition to the Kali Gandaki Valley in 1970 (Waltham, 1971), but they found only impure limestones, limited karst and almost no caves.

There are also other limestones in the Annapurna region. North of the main range, Jurassic limestones form a series of ridges and outcrops around Muktinath, and south of the range there are Holocene limestones in the floor of the Pokhara Valley. Both these have been found to exhibit karstic features, with substantial caves in the latter (Waltham, 1971).

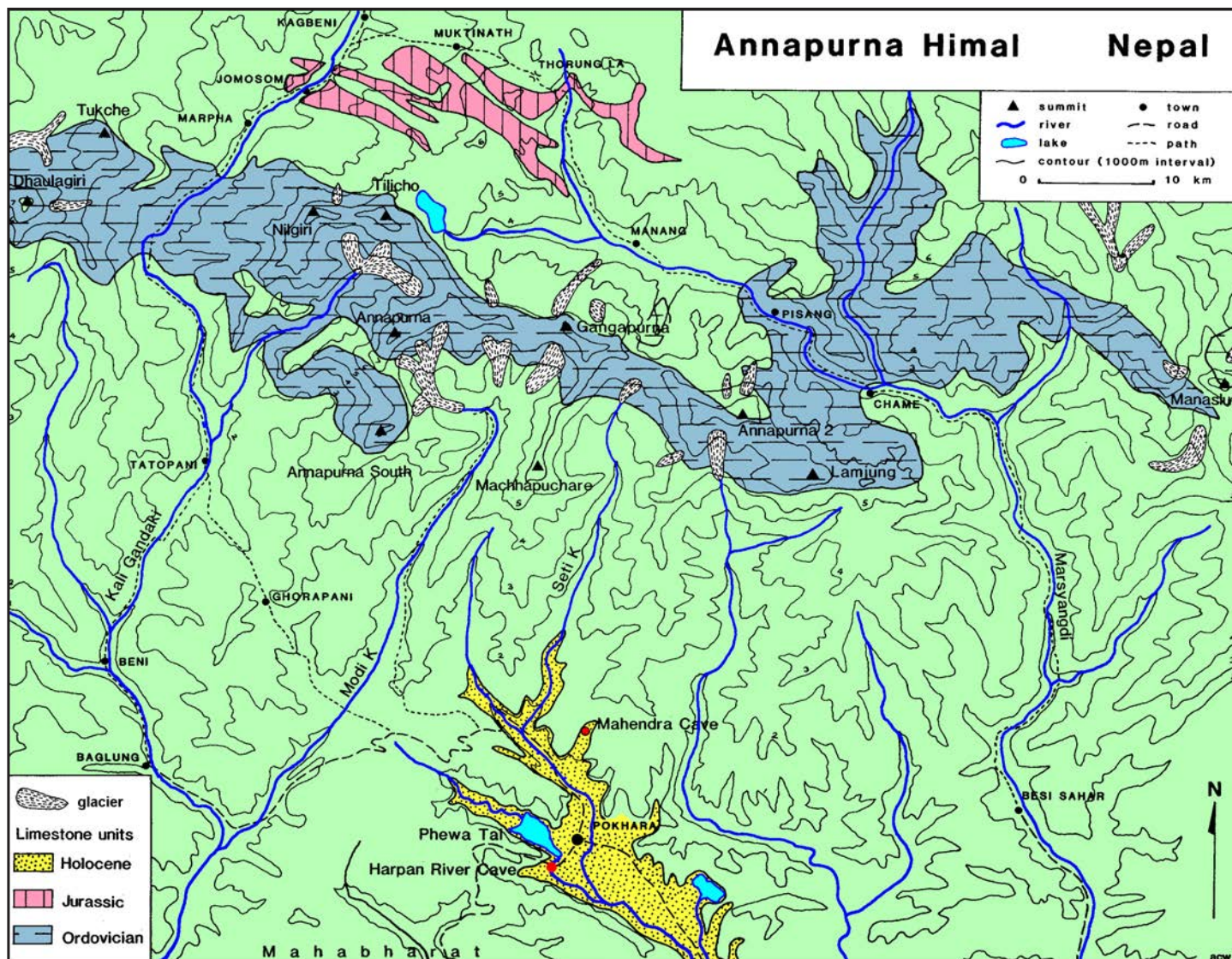
A recent walk round the Annapurna massif provided a further opportunity for brief observations of the limestones and karsts, including the outcrops in the Marsyangdi Valley and around Muktinath which were politically inaccessible in 1970.

THE NILGIRI LIMESTONES

The Nilgiri Limestone is a 2000m thick unit of dominantly carbonate rocks, largely impure limestones and dolomitic limestones; it is of Ordovician age, and has been lightly metamorphosed with some recrystallisation. It is underlain by another 1000m of Lower Paleozoic rocks which are largely limestone but with thicker bands of reddish sandstone and more slaty facies; these were known partly as the Larjung Limestone (Bordet *et al*, 1967), but are later referred to as the Yellow Formation of Annapurna (Bordet *et al*, 1981). The boundary is not easily recognised in the field, and the two units are grouped together on the map (figure 1).

The main outcrops dip steeply north with massive recumbent folding; this repeats the strong limestones by stacking, to form huge thicknesses in the mountains of Dhaulagiri, Tukche Peak, Annapurna and Annapurna South (Waltham, 1972). These outcrops are breached by the graben faults of the Kali Gandaki, whose effect on the outcrop patterns is barely distinguishable at the scale of the geological map in figure 1. Further east, the limestones form the high ridge including the peaks of Gangapurna, Annapurna 2 and Lamjung, before a downfolded

Figure 1. Geological map of the Annapurna limestones. Topography largely after Mandalla trekking maps; geology largely after Bordet *et al*, 1981.





View across the Kali Gandaki Valley, looking north and east, with Nilgiri (centre) and Annapurna (right) seen from the southeast shoulder of Dhaulagiri. Most of the viewed area is located on the Nilgiri limestones — except the lower right slopes on the underlying gneisses, and the far distant sandstones of the Mustang basin just left of the distant snow peak formed of the Jomosom Limestone.

zone is breached by the Marsyangdi River just above Chame. East of the Marsyangdi, the limestone outcrops are more convoluted as they reach to the summit of Manaslu (another over 8000m high) where they are cut out by a Tertiary intrusion of granite. The map (figure 1) is largely based on the published work of the French geological mapping programme (Bordet *et al*, 1981).

Karst features on the Ordovician limestones (both the Nilgiri and the Annapurna) are severely restricted for three main reasons: the carbonates are mostly impure with insolubles ranging from 15 to 35%; there is minimal vegetation on the high altitude outcrops, so that both carbon dioxide levels in percolation and run-off waters and also solutional activity are reduced; and, perhaps most importantly, the Pleistocene tectonic history of the Nepal Himalayas leaves outcrops only recently exposed in areas of extremely high surface erosion rates. These facts were all recognised in 1970 from field data collected in the Kali Gandaki Valley, and observations in the Marsyangdi Valley serve to confirm the concepts.

Between Chame and Pisang the limestones form high buttresses and steep walls along the Marsyangdi Valley. The tributary Nar Khola emerges from a limestone gorge of impressive dimensions, but no signs of karst are visible from the main valley. The limestone is massive but impure, and no karren were seen on the steep rock outcrops. Some Quaternary valley infills do have a tufa cement. One substantial resurgence was seen across the valley below Pisang; water pours from a small exit in the valley fill and probably emerges from a tufa cave similar to those at Kursangmo above the Kali Gandaki (Waltham, 1971). The likelihood of finding caves in the eastern outcrops of the Nilgiri and associated

limestones seems to be as remote as it is in the Kali Gandaki Valley.

THE MUKTINATH LIMESTONES

North of, and stratigraphically above, the Nilgiri limestones, the Tibetan facies of various Mesozoic rocks are complexly folded and faulted behind the wedge of older rocks rising along the convergent plate boundary. The most conspicuous carbonates are the Lower Jurassic Jomosom Limestones, mapped by the French teams, forming a series of high rocky ridges rising to nearly 6500m just south of the Thorung Pass (figure 1).

Except for a few small fossil phreatic rifts exposed on the ridges above Jomosom (Waltham, 1971), no caves have yet been found in these limestones. Very small karren occur on the same outcrops, and microkarren were observed at an elevation of 5000m on the eastern slope of the Thorung Pass. The microkarren have rills, or solution grooves, only about 1mm wide; some are closely spaced with sinuous courses downslope, but others form more open networks at various angles across inclined surfaces cut in undisturbed bedrock. They may form largely by capillary tension related to evaporating water fronts; they characterise karst with minimal rates of solutional activity at high altitude or in arid zones, though they have been found in a wide range of climates (Ford and Lundberg, 1987). The Muktinath area is essentially a cold desert, almost devoid of natural vegetation or organic soils, in the rain shadow of the Himalayas.

Muktinath Temple stands below the end of a limestone ridge. At its heart lies the famous burning spring — a karst fissure issues



Intersecting sets of microrills on a sloping bedrock surface of the Jomosom limestone high on the Thorung Pass.

The karst rising from the limestone scree behind the temple at Muktinath; the resurgent water is channelled into the 108 carved spouts around the temple.



a small but steady flow of water (less than a litre per second), and from the same fissure natural jets of methane support small but perpetual flames. The water drains from the limestone ridge behind the spring, and the gas originates from carbonaceous animal remains in the adjacent Upper Jurassic black shales. The emergence of gas and water together is a coincidence guided by the rock permeabilities. Not surprisingly, the combination of earth, fire and water is held in some regard, and a small temple now sits on top of the spring (which is still visible below an image of Shiva). This is a major Hindu shrine attracting pilgrims from all over India, and the site also holds on adjacent Buddhist gompa. The common occurrence in shale nodules of golden (pyritised) fossil ammonites, known as saligrams, adds to the reverence accorded Muktinath.

Just 100m north of the burning spring, a larger spring supplies the water trickling from 108 carved spouts around the temple of Jiwalā Mayi; with a flow of around 50 litres per second, this is also karstic, but no cave is visible, as the water emerges from an extensive scree at the foot of the limestone cliff.

The many cave openings in the valley sides around Muktinath, Kagbeni and Marpha, and further south in the Kali Gandaki Valley, are all only artificial excavations in the Quaternary valley sediments.

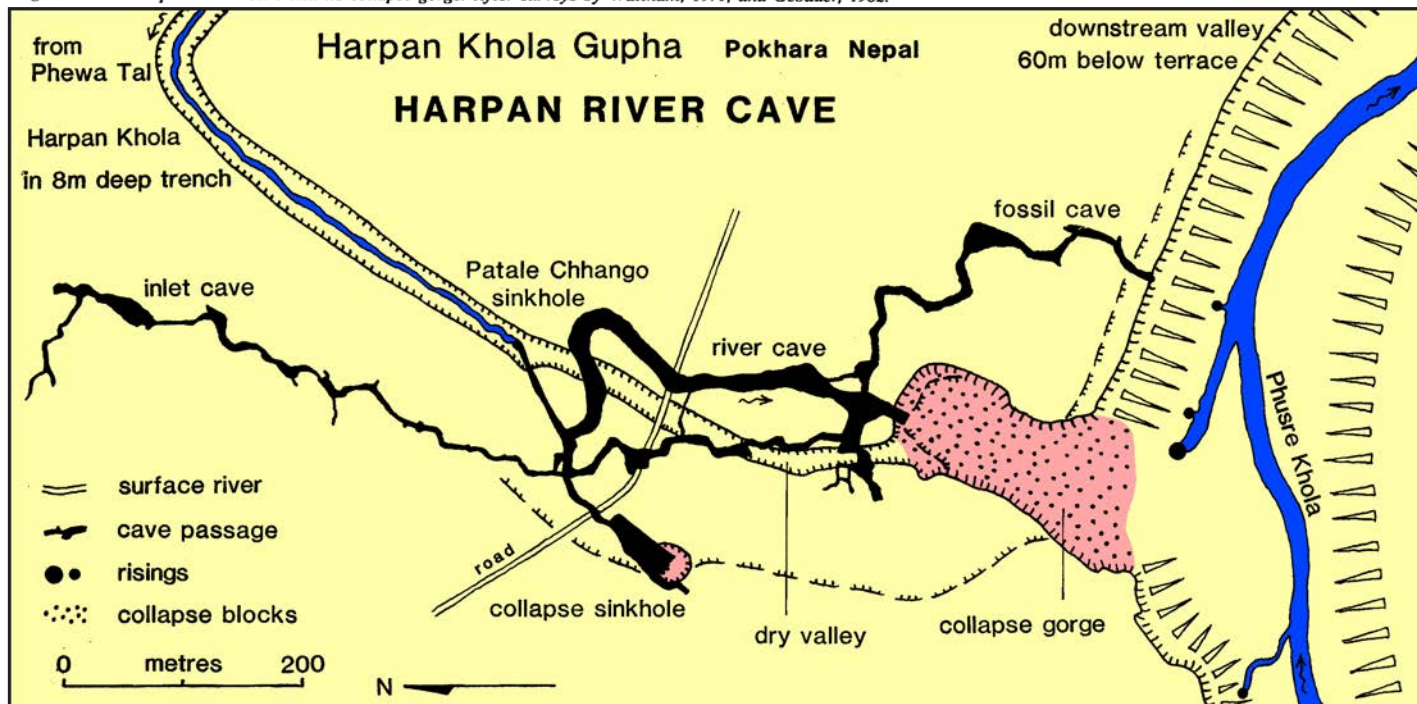
THE POKHARA LIMESTONES

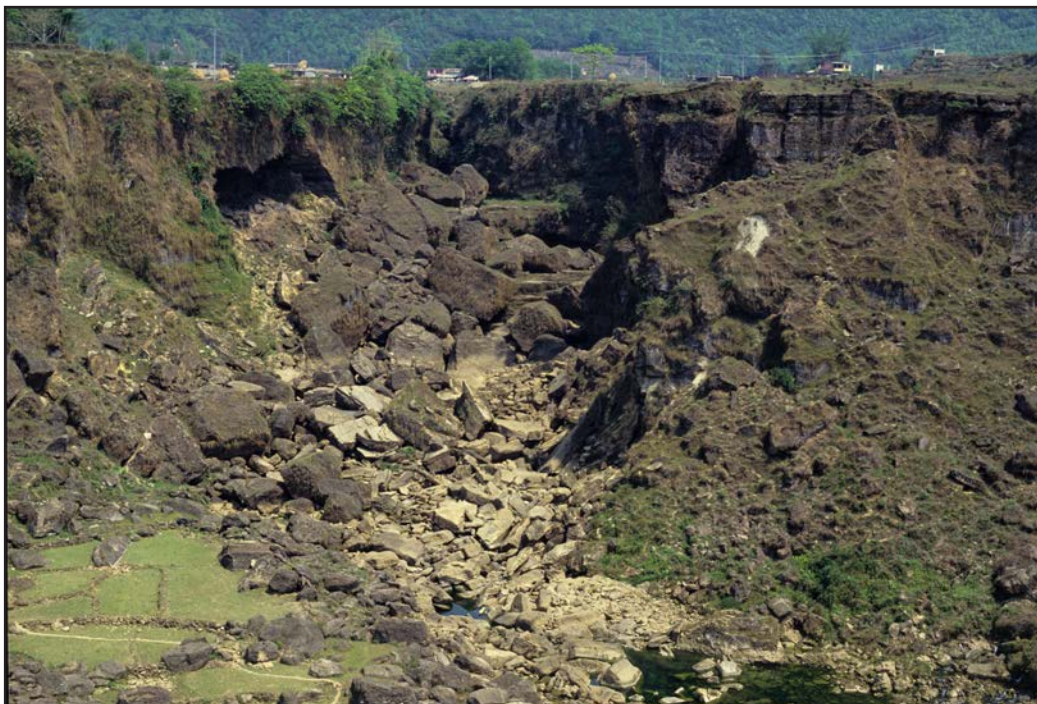
South of the Nilgiri limestones, bedrock is a complex series of metamorphic rocks, dominated by gneisses and schists but including bands of quartzite, marble and limestone. A small tourist cave is now advertised in an area of limestone crags along the Pokhara to Kathmandu road just south of Dumre; the Hinko Cave on the trail up the Modi Khola is however just a shelter beneath a massive boulder. The karst interest of the area is largely within the youngest sediments.

Quaternary sediments are features of most of the Himalayan valleys. Locally great thicknesses have accumulated behind Pleistocene moraines and later landslides. The greatest accumulations of all are behind the Quaternary uplift zone of the Mahabharat ranges, which the main rivers have to traverse between the Himalayas and the Ganges plain. The Pokhara basin was infilled by sediments from the Seti Khola and its tributaries. Subsequent incision and rejuvenation has left broad terraces in the Pokhara valley; the most extensive of these is the youngest and highest — the Pokhara Terrace, on top of the Pokhara Formation, which includes the Pokhara limestones (figure 1).

The detrital limestones of the Pokhara Formation have the visual appearance of sandstones, along with ripple-marking and

Figure 2. The Harpan River Cave and its collapse gorge. After surveys by Waltham, 1971, and Gebauer, 1982.



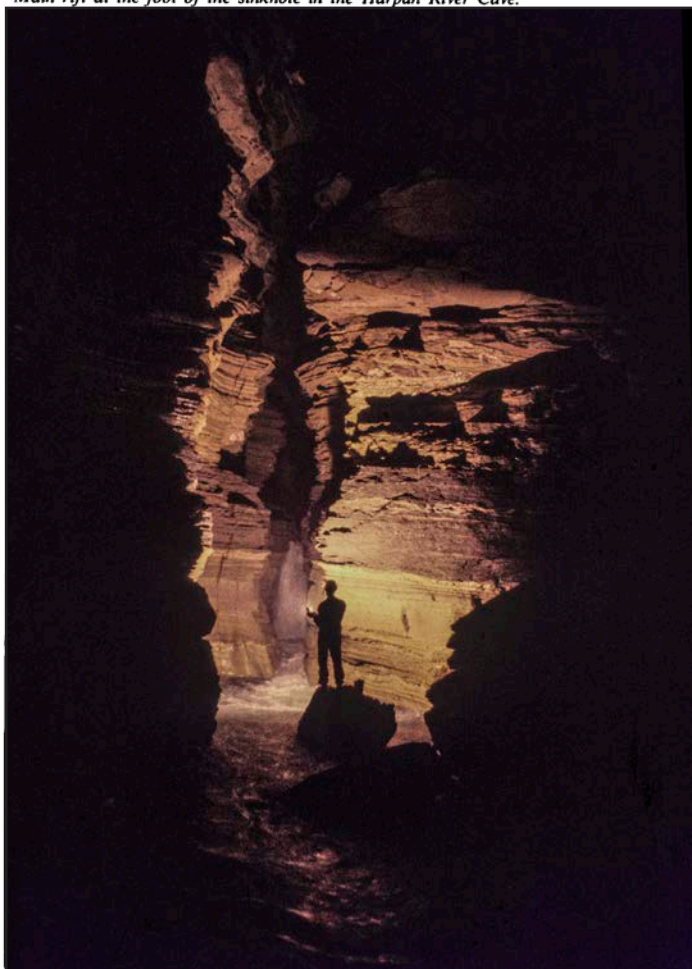


The collapsed cavern forming the downstream gorge at the Harpan River Cave, with the risings in the lower foreground.

cross-bedding and conspicuous conglomerate horizons. Though of very variable grain size and often poorly sorted their calcite contents are 45-80% (Waltham, 1971; Sharma, 1975) with little variation across the size ranges of the components. They are lightly lithified with secondary calcite cement, but are still very porous. The Pokhara limestones have an exposed thickness of at least 60m, and lie almost horizontally.

The Pokhara Formation appears to represent a fanglomerate of torrential debris flows, derived from the outcrops of the Ordovician limestones in the upper basin of the Seti Khola between Machhapuchare and Annapurna 2. Radiocarbon dating (eight analyses in three different laboratories) has yielded ages of 400-1100 years B.P. from included wood and peat (Fort, 1987).

Main rift at the foot of the sinkhole in the Harpan River Cave.



There is no recognisable age contrast between top and bottom of the bed, and it appears that the Pokhara limestones were formed in a catastrophic event. A seismically induced failure of a debris dam upstream of the Seti Khola gorges, perhaps during a recorded 1464 earthquake, could have released huge volumes of saturated landslide and morainic material originally derived from the steep limestone slopes of the Annapurna range (Fort, 1987). Rapid filling of the Seti Khola valley would have impounded lakes in the tributary valleys around Pokhara; and this matches the historical legends of drowned villages now beneath Phewa Lake.

The Harpan River Cave

The largest cave in the Pokhara limestone is the Harpan River Cave, located just downstream of the spectacularly beautiful Phewa Lake, now fringed by the Pokhara tourist quarter (figure 1). The lake outlet flows for two kilometres through a shallow ravine cut in the upper conglomeratic limestone of the Pokhara Formation, and then plunges into a deep sinkhole beside the main road south out of Pokhara. The sinkhole is a tremendous sight when the river is in flood during the monsoon, but has only a small cascade down it for most of the year, since the lake water has been diverted through the Pokhara hydro-electric power station. It is now a tourist site, with an admission fee of three rupees, entered between lines of Tibetan craft stalls.

Down the sinkhole, the cave was explored and mapped for 1480m in 1970 by the British expedition (Waltham, 1971), and was subsequently extended to 2960m in much drier conditions largely by a German expedition (Gebauer, 1983). It is still the longest known cave in the Indian sub-continent. The sinkhole is known to the locals as Patale Chhango or Devi's Fall, and both the river and the cave have several different names; perhaps the cave should be known by its Nepali translation, Harpan Khola Gupha, or even maybe as Patale Chhango Gupha.

Despite local rumours, the sinkhole is 45m deep; the river passage below (only passable in dry conditions) is mostly 10m wide and 5m high, with a parallel loop to the south only of slightly lesser size (figure 2). The main resurgence is through the extensive collapse blocks forming the floor of the downstream gorge, and the water emerges at various extra points at times of higher flow. The gorge is cut back into the edge of the terrace, and is one of the few karst gorges in the world which can conclusively be demonstrated to have an origin as a collapsed cavern (or as the coalesced collapse of a series of caves); the blocks on its floor are of the strong conglomeratic limestone which lies well above the main cave passages and forms the terrace caprock. High level cave passages, tributaries and distributaries, and other smaller resurgences, all indicate the considerable extent of cave development in the Pokhara limestones; undiscovered passages almost certainly exist, but will not be easily explored beyond zones of collapse.

Perhaps the most remarkable feature of the Harpan River Cave is the speed of its formation. The host limestone appears to be

little more than 500 years old; the minimal lithification was probably almost immediate. Erosion started very soon after, concurrent with drainage and runoff into the open valley downstream of the debris mass in the Pokhara basin. Water in the Phewa valley ponded until it filled the lake, which survives until today, and then overflowed onto the limestone surface. Underground flow was initiated due to the very high primary permeability of the fanglomeratic limestone, perhaps aided by vertical desiccation or landslide fissures. The poor sorting of the granular limestone would also have permitted piping to take place, with fines washed out from between coarser particles. Solution of the limestone appears to have played no more than a subsidiary role in both the initiation and development of the cave.

Passage enlargement, within this time-scale, to diameters in excess of five metres, must have been largely mechanical. It is commensurate with the mean incision rates of over 100mm/year exhibited by the nearby Seti Khola over the 500 years of erosion in the debris flow limestone. The multiple levels and parallel passages within the cave system were probably formed almost contemporaneously. Incision of the Phusre Khola gorge downstream of the cave was initially rapid; once the cave outlet was close to its present level, the river passage would have taken the great majority of the flow, and is hence so much larger than the higher loops and distributaries. The relative depths of the surface trench above and below the Patale Chhango sinkhole suggest that continuous surface flow was maintained for only about half the erosional history; the cave appears to have reached maturity within 200-300 years of its initiation.

For both the extent of the cave system and the size of the main passage, the Harpan River Cave is probably the youngest limestone cave in the world. However, although the cave passages are of conventional morphology, both the limestone geology and the erosional environment are notably untypical of limestone karsts worldwide.

Other caves in the Pokhara valley

Caves are recorded elsewhere in the Pokhara limestones (Gebauer, 1983); all are only fossil passage fragments. Mahendra Gupha, located north of Pokhara (figure 1), has 240m of passage largely accessible as a showcave, and the Power Station Caves, east of the Harpan River Cave, have a total passage length of about 400m.

East of Pokhara, a series of rivers cross the main terrace and all are incised to various depths in the detrital and conglomeratic limestones. The Seti Khola is the largest river, and has cut a gorge 3km long just east of the airport. This increases in depth from about 30 to 60m, and is a remarkably narrow karstic slot gorge; a footbridge only 8m long spans it over 50m above the river. Sections of the river are invisible beneath huge blocks of fallen caprock conglomeratic limestone, and the lower end (seen only from the air) is very narrow, almost certainly with the river in a



Air view of the downstream end of the Seti Khola gorge, where the river appears to go underground for at least a short distance.

cave with a bedrock roof for about 100m. By analogy with the Harpan River, caves may well exist in the deeper recesses of the gorge, but none has yet been seen from the rim. Any exploration would be suicidal during the summer monsoon, and, being downstream of the town, could be medically hazardous in the dry season; there must be better caving elsewhere. Near the footbridge, the conglomeratic limestone along the gorge rim has been carved into a heavily dissected karst pavement, with some remnant clints and pinnacles standing up to 5m high. All the gorges further east appear to be much smaller, and certainly have less depth where crossed by the Kathmandu road; more caves may exist, but outward signs offer little encouragement.

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Dissected clints and pinnacles in the conglomeratic limestone of the Pokhara terrace; the men are on a footbridge 50 metres above the Seti Khola.