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CAVE SCIENCE

IMPERIAL COLLEGE EXPEDITION TO THE KARST OF PERU

Number 52 November 1973

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Imperial College Karst Research Expedition to the Peruvian Andes, 1972

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The Palcamayo Area

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GEOLOGY AND TOPOGRAPHY

Only two rock types crop out in this area. The main part of the area consists of limestones of the Pucará group, locally of Triassic age. This overlies volcanic rocks of the Mitu group which crop out to the north west.

The main structures of the area are generally NW-SE trending. The predominant structure of the area appears to be a syncline in this orientation, the axis of which forms the valley of the Rio Shaca. To the north of the syncline there are two parallel monoclines, which trend roughly NNW-SSE. These monoclines appear on aerial photographs as vertically dipping beds. They may follow faults in the basement and may be faulted in places themselves. The structure and geology as interpreted from the aerial photographs is presented on figure 3.2.

Although the area is generally underlain by limestone, a karst landscape such as found in North-west England is not developed. The country is mountainous and the rivers have been overdeveloped, forming steep sided gorges in some places. Typical karst features such as limestone pavements and dolines are generally absent, though occasional rare shakeholes are found. A little way from Shaca Marca up the valley towards Antacocha, there is a small polje, a dry flat bottomed valley with underground drainage.

The drainage area of the Huagapo cave system would appear to lie on the north eastern limb of the Shaca syncline and to be cut by one of the monoclines. The area is bounded by the Shaca valley, the Ushto gorge and the Antacocha valley. The Shaca valley is overdeepened and gorge-like, especially lower down where the Ushto gorge enters. The Antacocha valley is also generally steep-sided and gorge-like. Both of these valleys are permanent water courses. The Ushto gorge is exceptionally steep-sided and the almost vertical sides are very high. This valley is dry except in times of flood, the water being taken by the sinks entering La Sima de Milpo.

Valley elevations around the Huagapo cave are around 3,500m and the mountains rise to over 4,500m.

To the northeast, the limestone is bounded by the contact with the volcanic rocks. This contact zone is characterised by a low lying area with numerous lakes. The volcanic rocks themselves form a completely contrasting landscape which is almost "badlands", consisting of very steep sided hills with bare red rock slopes.

(L.W.T.)

HYDROLOGY

The limestone has a marked effect on the local hydrology. There is virtually no surface run-off on the outcrops, as all rainfall sinks as soon as it hits the ground.

The infiltrated water resurges at a number of springs, generally at valley level. There are three major springs, Huagapo cave and two risings along the Rio Shaca, as well as a number of smaller springs. Huagapo cave is described in another section of this report. The Rio Shaca has its source on the Mitu volcanics, but sinks as soon

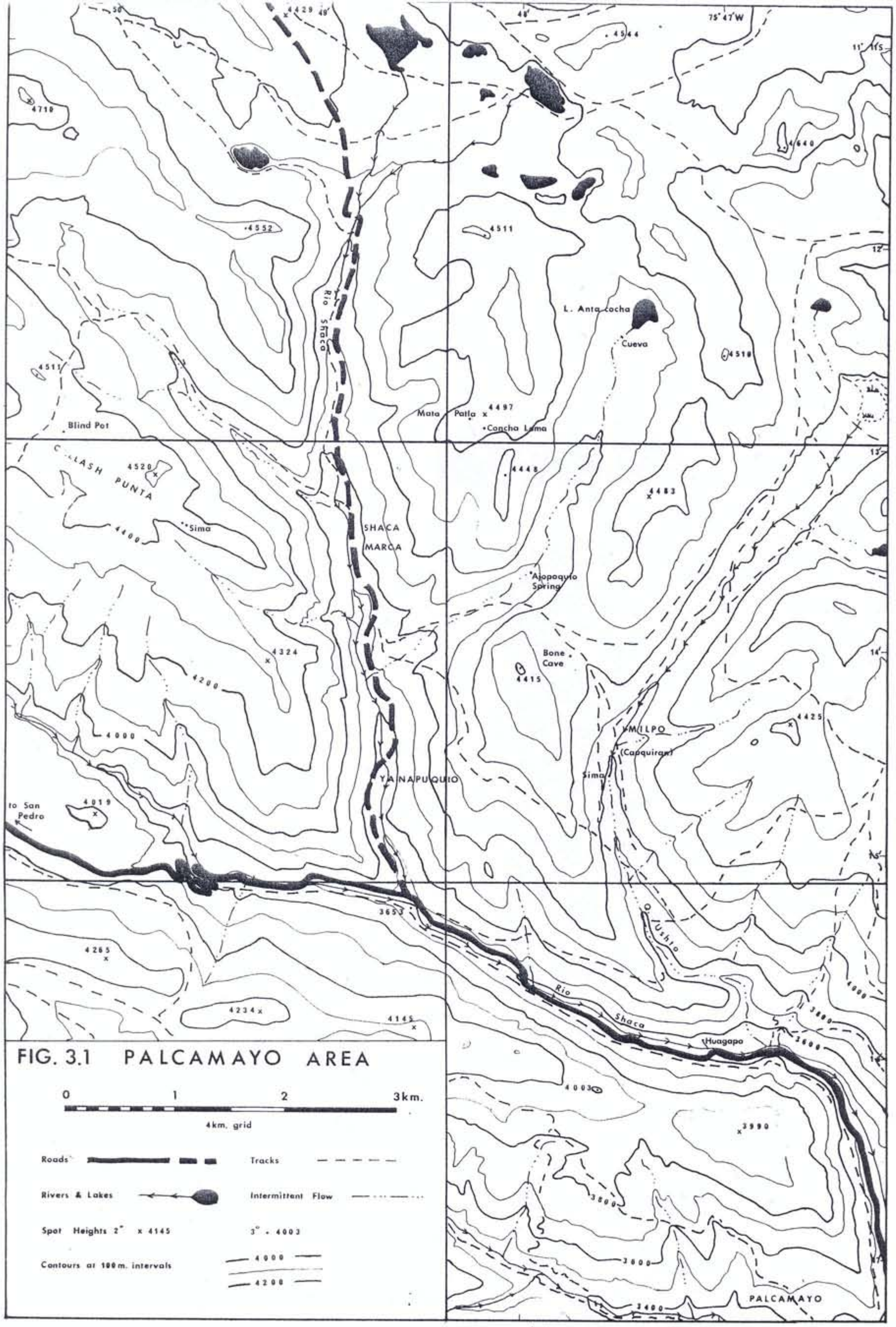

FIG. 3.1 PALCAMAYO AREA

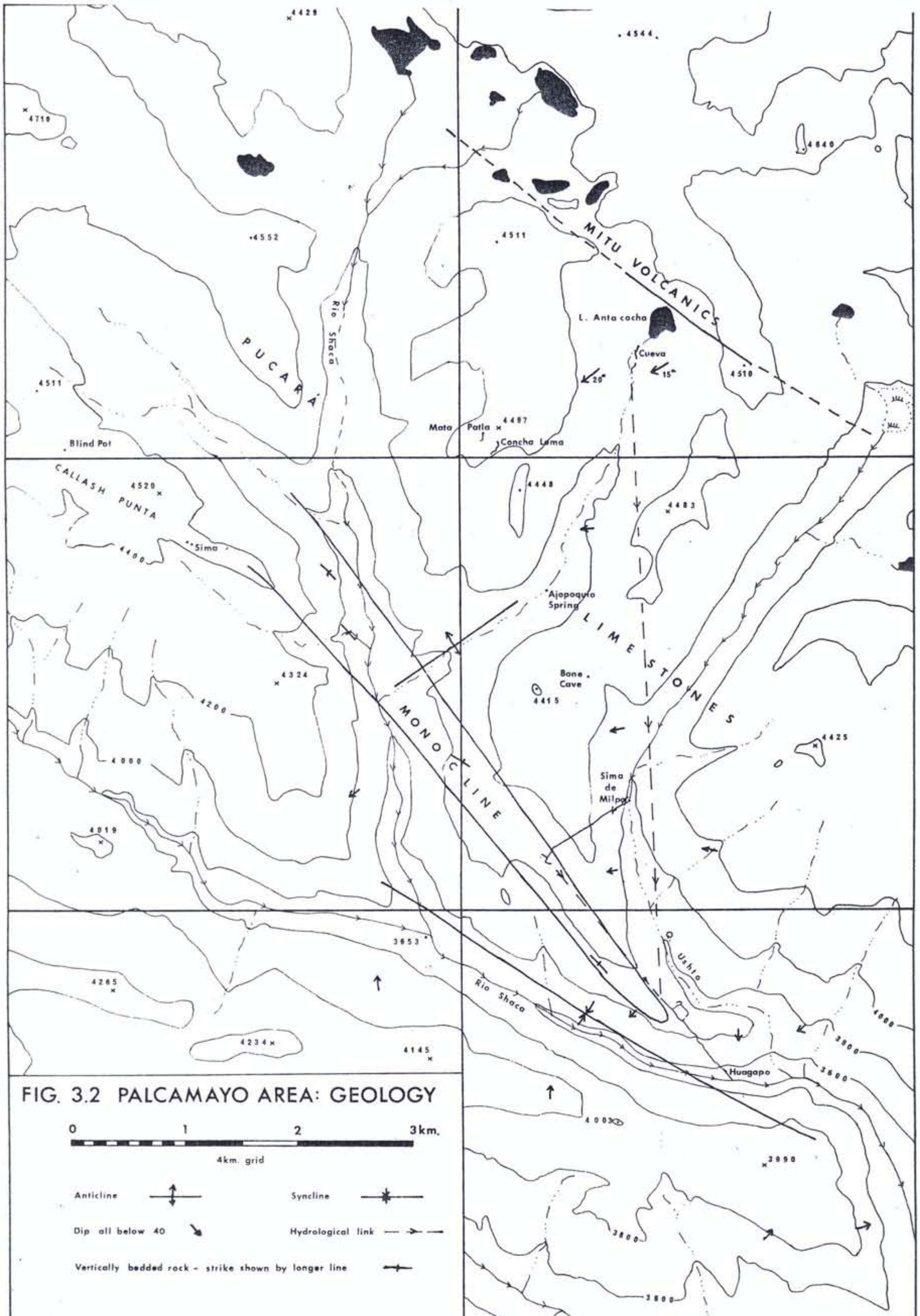

FIG. 3.2 PALCAMAYO AREA: GEOLOGY

0 1 2 3km.

4km. grid

Anticline

Syncline

Dip all below 40

Hydrological link

Vertically bedded rock - strike shown by longer line as it reaches the limestone five kilometres north of Shaca Marca. The sink is in boulders and cannot be entered; the river flows underground for four kilometres to resurge, again through boulders, just north of Shaca Marca. In the village of Shaca Marca part of the river sinks again to reappear 400m downstream. It appears that more water resurges than sinks. The Rio Shaca then flows on the surface to finally join the Amazon and flow out to the Atlantic.

Near Huagapo there are several areas where extensive travertine has been deposited. The travertine has not been laid down evenly and has often been re-eroded giving rise to a number of shallow rock shelters. The travertine also occurs along the valley floor and forms several natural bridges across the Rio Shaca. One of these bridges has been used for the main road.

Climate

The prevailing winds are the south east trades, which give rise to the extreme differences in climate across the Andes, from the wet tropical climate in the Amazon jungle in the east, to the desert near the coast. The climate near Huagapo is a high mountain type. Daily temperature variations are large, but, also due to the low latitude, seasonal temperature variations are not large.

The precipitation is very variable in this part of the Andes, and there is a marked rainshadow effect to the west of the mountains. Elevation also effects precipitation and at this altitude (3,500m) precipitation will tend to decrease with elevation rise.

Precipitation at Huagapo was estimated by taking a weighted mean from three nearby stations, as in table 3.1 (weights were: Oroya 0.5, Cerro de Pasco and Juaja 0.25), although the figures could be considerably in error. The potential evaporation

TABLE 3.1 PRECIPITATION IN PERU

Station	Cerro de Pasco		Oroya		Jauja		Huagapo (assumed)		
Location	10°45'S 76°15'W		11°31'S 75°56'W		11°44'S 75°27'W		11°16'S 75°47'W		
Altitude m.	4401		3773		3387		3572		
	P	PE	P	PE	P	PE	P	PE	P-PE
Jan.	117	53	81	56	113	59	98	56	42
Feb.	114	45	79	49	107	53	95	49	46
March	91	52	71	54	93	58	82	55	27
April	86	49	38	49	36	52	50	50	0
May	58	46	17	44	13	50	26	46	–20
June	23	37	14	36	4	45	14	39	–25
July	28	36	14	33	3	45	15	37	–22
August	31	39	11	38	3	49	14	41	–27
Sep.	70	39	28	45	31	53	40	46	–6
Oct.	85	45	44	53	53	60	56	53	3
Nov.	87	46	54	53	58	63	63	54	9
Dec.	94	48	81	56	98	62	89	56	33

P = precipitation mm. PE = potential evaporation mm.

From: C. W. Thornthwaite et al, 1965, Average water balance data of the continents: South America; Laboratory of Climatology XVIII,2.

Plate 3.1. Callash Punta with the moniclinally folded, vertically bedded limestones.

Plate 3.2. The upper Ushto gorge showing limestone in the foreground and the volcanics in the distance.

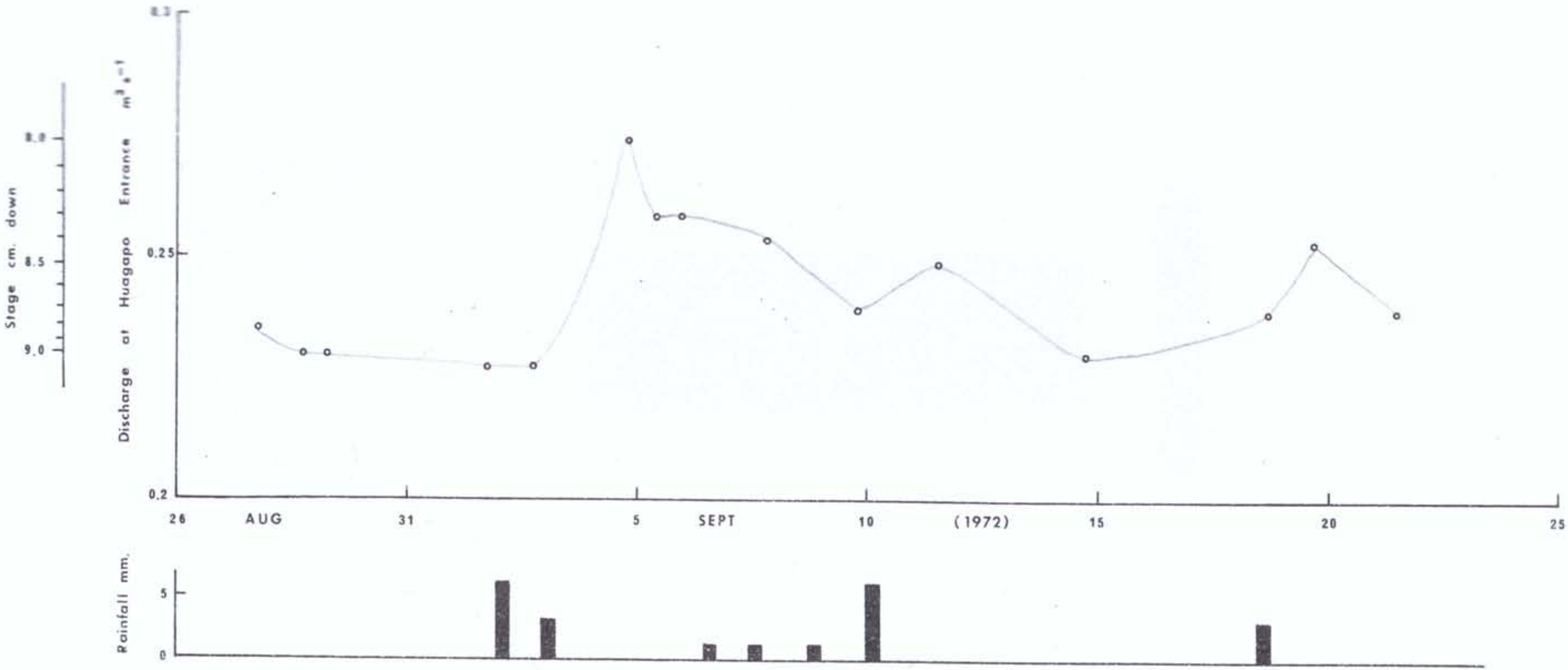

Fig. 3.3 Discharge at Huagapo and Precipitation from Aug 28 to Sept 22 1972

was similarly estimated. The average annual precipitation is about 650mm. Snow is uncommon in the valleys but occurs more frequently in the mountains during the dry winter from June to August. The precipitation is seasonal with May to September being the dry season when potential evaporation exceeds rainfall. Throughout the rest of the year the rainfall exceeds evaporation and run-off is larger. During our stay from 27th August to 21st September, 1972, 21mm of rain fell, which is less than the average.

Dye Test at Antacocha Cave

About four kilogrammes of Rhodamine 6G powedered dye was inserted into the stream entering Upper Antacocha Cave at 3.00pm. on the 8th September. Two hours later no dye was visible in the stream in Lower Antacocha Cave. Detectors were placed in the entrance to Huagapo, in the Rio Shaca near camp and near Shaca Marca, and in the Ajopoquio spring (see fig. 3.1.). The detectors were put in on 8-9th September, changed on 15-16th September and removed on 22nd September. The detectors were eluted with potassium hydroxide in alcohol and tested visually and on a fluorimeter.

The Huagapo detectors removed on 22nd September were positive and all the other detecors were negative. The dye therefore came through the system in more than seven days and less than fourteen days.

The other caves in the area were not dye tested. However it seems very likely that La Sima de Milpo does drain to Huagapo. It is not known where the caves of Concha Loma and Mata Patla drain; these could drain to Huagapo, or, more likely, to the risings on the Rio Shaca near Shaca Marca.

The Huagapo Cave Catchment

The water level running over a bedrock lip in the entrance to Huagapo was measured. The lip was rated by measuring the discharge by the velocity head method at two stages and estimating a rating curve according to the sharp-crested rectangular weir formula.

$Q=AH^{3/2}$ where A = a constant
H = the head over the weir
Q = the discharge

A plot of the discharge from 28th August to 22nd September is shown in figure 3.3 with the precipitation also shown. It is seen that the discharge increases about one day after more than 3mm of rainfall. The response to rain is not instantaneous. The source of the water effecting Huagapo probably comes from a variety of sinks, such as Antacocha and Sima de Milpo, together with direct infiltration into the limestone.

Huagapo drains a large area of at least 30 square kilometres. The discharge in September 1972 was about 0.25 cumec, but increases considerably during the wet season. Antacocha Cave and probably Sima de Milpo drain to Huagapo and the floodpulse, from rainfall, takes approximately a day to get through to Huagapo (during flow of 0.25 cumec) while the dye pulse takes from between seven and fourteen days to get through from Antacocha cave. (J.M.H.C.)

TABLE 3.2 HIGH ALTITUDE KARST

Area	Altitude	Limestone Geology	Dip Magnitude	Annual Precipitation	Predominant Weathering	Cave Develpmnt	Solute Load (ppm Calcium) Sinks	Risings
Pirhuacocha, Peru	4,500m	Close jointed, thin bedded, locally heavily folded, pure (up to 97% $CaCO_3$)	0°	550mm little snow	Solutional	None	—	96
Palcamayo, Peru	3,500—4,500m	Massive, moderate joint density, fairly pure	25°	650mm little snow	Solutional	Extensive	12-28	96
Sind Valley, Kashmir	2,900m	Massive,moderate joint density, dolomitic	80°	500mm 6 months snow	Mechanical	None	—	32-86
Achabal, Kashmir	1,700—1,900m	Massive, moderate joint density, dolomitic	30°	500mm 4 months snow	Solutional some mechanical	Restricted	16	31-71
Dhaulagiri, Nepal	3,700—5,200m	Massive, very low joint density, impure, slightly dolomitic	40°	1,000mm 6 months snow permanent above 5,000m	Mechanical at high altitude grading to solutional at low altitude	None	—	20-62
East Mendip, England	150m	Massive, moderate joint density, pure	45°	700mm little snow	Solutional	Extensive	36-72	72-135

A NOTE ON KARST DEVELOPMENT AT HIGH ALTITUDE

The study of karst on the high sierras of Peru offered a useful opportunity to examine karst development at high altitude and to compare Peru with other regions of the world. The areas chosen for comparison, by reason of the writer's familiarity, are in Kashmir, Nepal and England. Relevant information on each area is compared in table 3.2.

One conclusion can immediately be drawn, and that is that high altitude does not prevent extensive cave development. The geology and, to a lesser extent, the climate appear to be the controlling factors. Altitude will have a direct effect on the amount of carbon dioxide taken up by the water from the atmosphere, and hence the amount of calcium that can be dissolved. This varies from 15ppm (of ionic calcium) at 4,500m, to 30ppm at sea level. The figures in table 3.2 show that these solute loads are invariably exceeded — due to enrichment from the soil atmospheres. Solute loads at the sinks are mainly related to the geology of the surface catchment areas. Calcium concentrations at the risings exhibit distinctly similar ranges of values, which bear almost no relationship to altitude. However these solute loads do relate to degree of vegetation cover — in turn interdependant with climate; and the climate is dependant both on latitude and on altitude. The comparison between Peru and England best reveals this contrast, and does indicate how latitude, and other local features, are more important than altitude.

Climate has a significant effect on weathering processes and solution sculpture. Weathering varies from purely mechanical under extensive snow cover, through minor solution forms under temparate climates, to cockpit karst development under tropical conditions. Cave development does not appear to depend on climate, as long as there is sufficient precipitation.

The overall factor controlling cave development is the detailed geology of the limestone. Inspection of table 3.2 leads to the conclusion that the limestone must be fairly pure, non dolomitic, massive with a moderate joint density, and not heavily folded locally. Failure to fulfill any one of these conditions seems to rule out cave development. (R.J.B.)

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