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Imperial College Karst Research Expedition to the Peruvian Andes, 1972

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The Pirhuacocha Area

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GEOLOGY

The area mapped by the expedition covers some 200 square kilometres of mountain and plateau country just east of the continental divide of the Andes (map 2.1). The terrain is at an average altitude of around 4,500m, and consists of dissected plateau country typical of the Andean "altiplano".

Geologically too, the Andean watershed almost divides the country; the huge coastal batholith and associated volcanics lie to the west with the mainly sedimentary sequence to the east. The Pirhuacocha area lies some 20km to the east of this dividing line at a relatively low point in the occidental range of the Andes. Most of the rocks are of Mesozoic age and structurally form part of the "Oroya syclinal complex" of Harrison (1944), the type area of which lies some 10km east in the Mantaro valley.

Most of the area was a geological blank on the map for all except reconnaissance work, but the formation terminology of other workers in this part of the world has been applied wherever correlation has been possible.

An attempt has been made in figure 2.1 to display the geological succession of the region as far as that is possible over such an area. As can be seen here, and from the map (map 2.2), the geology is best divided into three parts — the Pucará group, consisting mainly of limestone, the Goyllarisquizga sandstone group and the overlying pile of basaltic lavas and associated sediments. The succession described is about 1,800m thick.

The Pucará Group

This group of rocks, mainly carbonates of Triassic and Liassic age, form the most distinctive outcrops and landforms of this part of the central Andean altiplano. The stratigraphy is as well documented as any in this part of the Andes, and can be traced continuously from Cerro de Pasco in the north west to Huancayo in the south east. The rocks of the Pucará group constitute about 40% of the area mapped and have not been studied in the most recent stratigraphic appraisal of the Pucará group by Szekely and Grose (1972). However, there is a studied succession at Malpasso, just north of the area, which can be used for correlation.

There is only one small exposure of the base of the Pucará at a small inlier of fine, red, altered basalts in a one kilometre stream-section, just west of Saco in the south east (plate 2.1). The base is interpreted as a disconformable contact with the Mitu volcanics of Permian age, but the contact and exposure is not good enough for certainty in the matter.

The full Pucará group succession comprises three formations; ranging in age from Upper Triassic to Lower Jurassic — or 202 to 172 million years before present. The sequence of formations is as follows:-

CONDORSINGA — Massive and thin bioclastic limestones,
some cherty and bituminious horizons. — LOWER JURASSIC
ARAMACHAY — Black bituminous shales and cherts,

grading up into phosphatic mudstones and limestones. — LOWER JURASSIC
CHAMBARA — Limestones, often bituminous and cherty. — UPPER TRIASSIC

If the Saco inlier does in fact represent the base of the Pucará then it seems that the Aramachay and Chambara formations are both missing in the southern part, if not all, of the region. There are certainly none of the bituminous shales and phosphatic rocks, characteristic of the Aramachay formation. As the Malpasso section is reported to display some 106m of Chambara and 453m of Aramachay, their apparent absence from the area to the south is something of a puzzling problem. Szekely and Grose consider the Chambara beds at Malpasso to be only a partial succession and they probably do disappear quite rapidly to the south; hoever, the few metres of thin dolomites immediately above the Saco lavas may represent a remnant Chambara.

The succession west of Saco is about 720m thick and forms probably the best exposure in the area, as the rocks are relatively little folded. The limestones of the Condorsinga are very varied, some beds being massive light-grey biosparites and oosparites whilst others, often much more thinly bedded, are dark-grey micrites and bituminous dismicrites.

There is in addition a peculiar gypsiferous facies of the Condorsinga, not seen elsewhere, which greatly complicates the picture. It is most obvious on the western side of the outcrop, probably fairly close to the top of the succession, and is the source of several small gypsum workings in the Chacpay area. The attempt to map the outcrop of this facies was probably not too successful, as it has suffered preferential tectonic deformation and the structure is none too obvious.

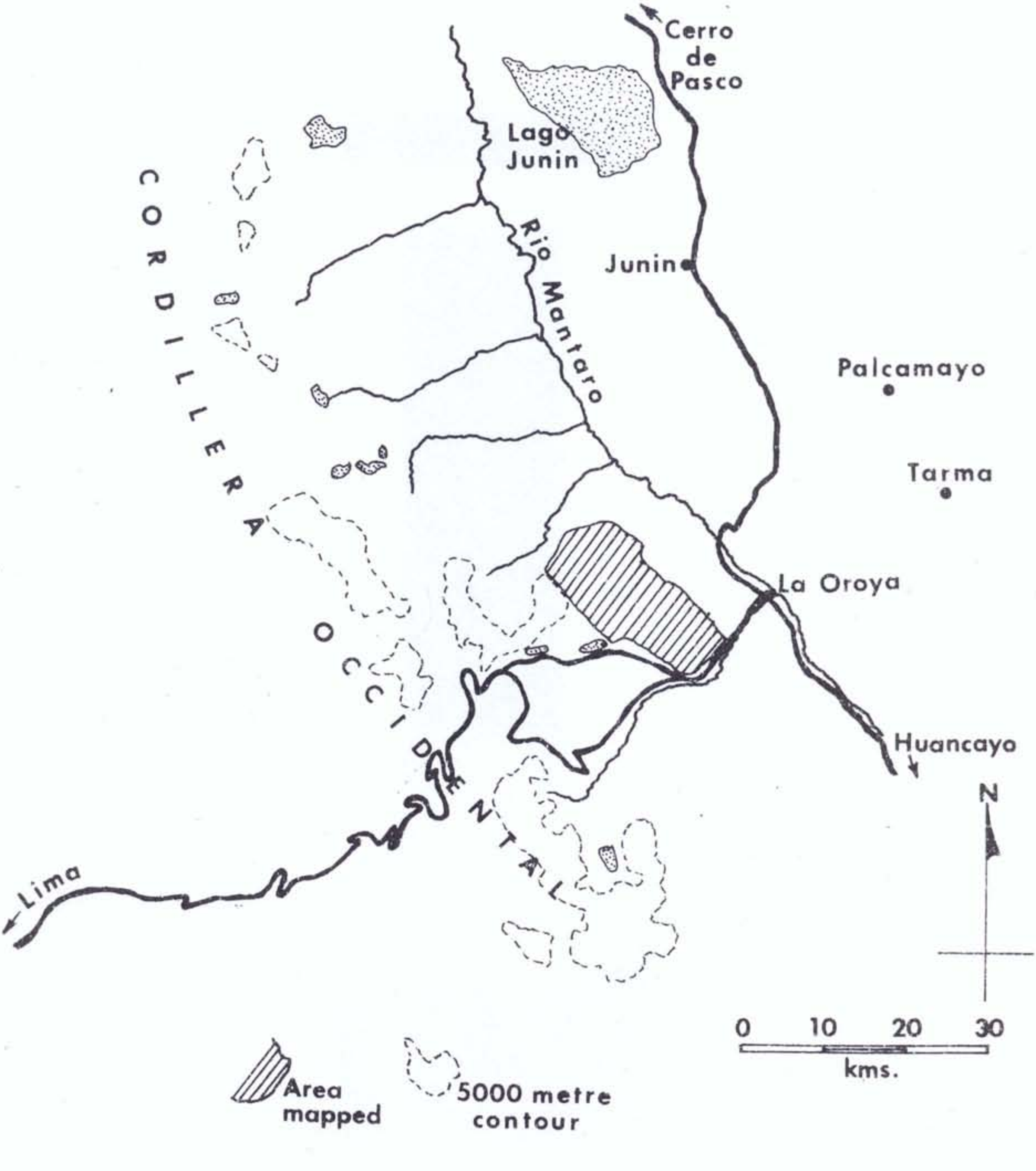
The rocks of this facies are characterised by the occurence of quite thick (up to two metres) beds of gypsum with associated red and green marls, and similarly the non-gypsiferous rocks tend to be more dolomitic in these areas (map 2.2) than elsewhere. In fact, chemical analysis of these rocks shows them to be mainly quartzose dolomites and quartzose dolomitic limestones. Further east, around Saco, there are no gypsiferous beds but the lowermost facies are otherwise similar to the uppermost facies in the west. This does hint that a facies transgression occured, but more detailed work would be needed to prove this.

The Goyllarisquizga Group

At the top of the Condorsinga limestone is a slight unconformity, which is not obvious as the contact is rarely exposed. Upon this rests the sandstones of the Goyllorisquizga group, about 500m of clastic rocks of lower Cretaceous age, most of which are very well exposed in the area. The group is split into two fairly distinct formations; the lower one comprises quartz conglomerates and various ferruginous sandstones, whilst the upper one contains a thick coarse white sandstone and flaggy dolomitic sandstones. Over much of the area the two are separated by a lava flow (map 2.2).

The lower group begins with a typical transgressive facies grit or conglomerate, with clasts of chert and limestone up to ten centimetres across, succeeded by a few metres of a remarkable tree bearing sandstone. One locality, opposite the valley from Pirhuacocha contains in situ trunks up to ten metres long and a metre in diameter. The vast number of these trees in a fairly restricted horizon points to flood deposition on a deltaic environment, and as such is probably of little use as a marker horizon.

Most of the remainder of the lower group is comprised of a thick series of fine to medium grained (0.1—1.0mm) sandstones, commonly with small brown spots of



Map 2.1 Regional setting of the Pirhuacocha area

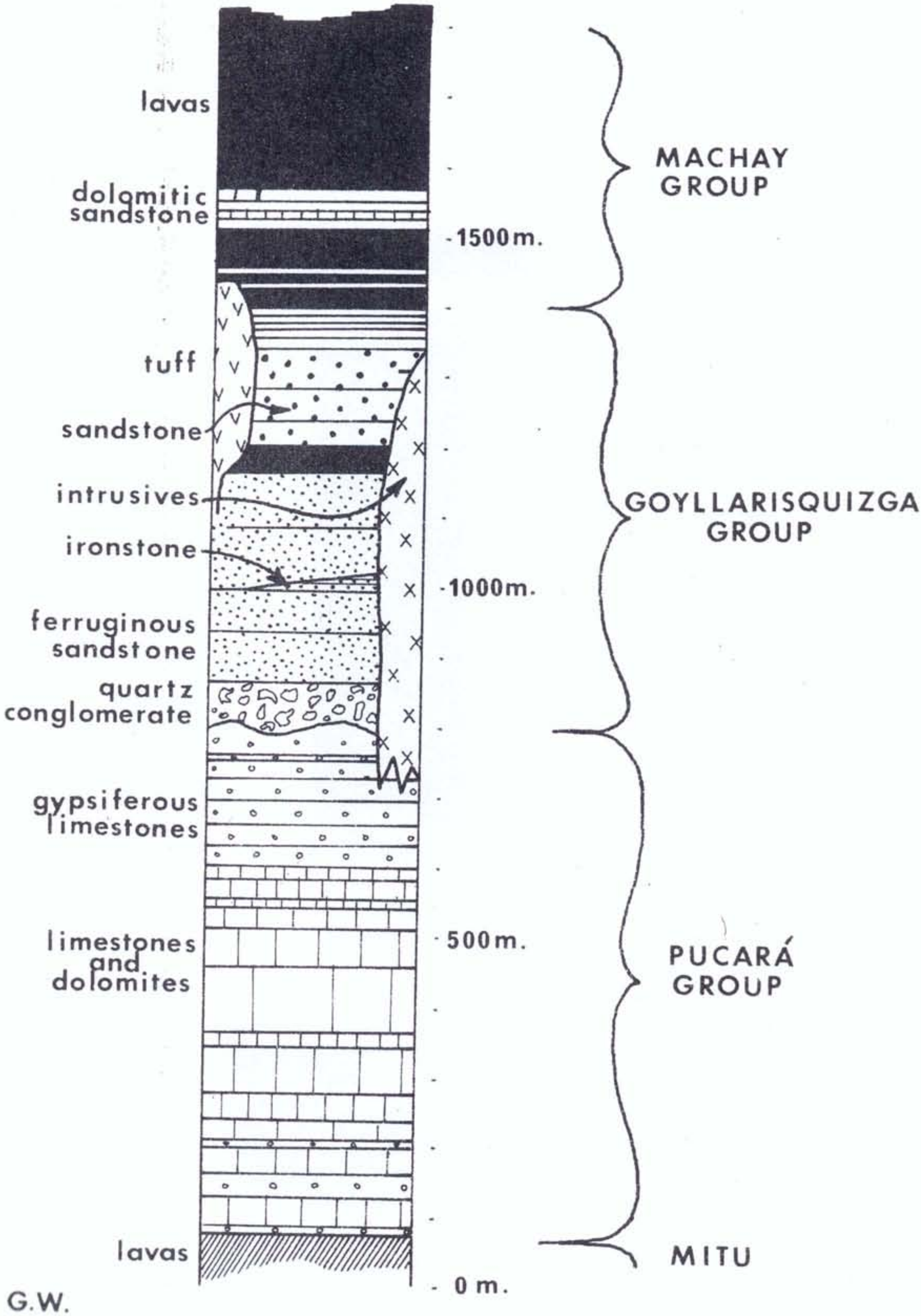


Fig. 2.1 Generalised geological succession

iron-stained grains. The amount of iron-staining is very variable and indeed in one place the whole nature of the rock changes quite rapidly to a flaggy purple ironstone. Though not very well exposed its occurence has given rise to some spectacular landslipping of the massive overlaying sandstones.

The upper group begins with 30m or so of a coarse, white, cross-bedded grit with no iron-staining in the body of the rock, though the joint planes are sometimes iron rich, presumably due to solutional migration from the rocks below. This bed seems to be of near constant thickness over the whole area, unlike the sandstones above, which are very variable in thickness, lithology, and lateral extent. These uppermost sandstones are thickest and best exposed in the section by Punabamba, where fine, white, cross-bedded sandstones alternate with yellow, flaggy, dolomitic sandstones, partly bioclastic and sometimes burrowed. The sequence here is about 50m thick. This is reduced to five metres of flaggy dolomitic sandstones at Pirhuacocha, and near the top of the upper group above Saco a peculiar, thin, orange, iron-rich sandstone occurs.

The Volcanics and Associated Sedimentary Rocks

The rocks overlying the Goyllarisquizga sandstones are the most difficult rocks in the region to assess. This is mainly because the lava horizons are of smaller surface extent than the sedimentary rocks and so it could be said that the lavas intercalate the sedimentary sequence. These late lower and middle Cretaceous lavas are considerably thicker and more numerous in the west, and it seems highly likely that they flowed from a source to the west-north-west of this area.

In the best exposures of this sequence at Pirhuacocha there are about 20 major flow units of an average thickness of ten metres, and approximately six significant sedimentary units constituting some 400m at the top of the studied succession (plate 2.2). The facies of each sedimentary cycle changes, quite markedly in some cases, from one cycle to the next. This, in addition to the lack of sub-aquatic features of the volcanic rocks points to repeated uplift and depression before and after each volcanic episode. As the sediments were probably lagoonal or very shallow-water this movement need not have been great.

A common collection of sedimentary rocks in any section contains fine (0.1mm) buff quartzose dolomites, coarser dolomitic sandstones, dark shaley bituminous dolomites and some thin limestones, mainly biosparites and biomicrites with abundant gastropod, lamellibranch and echinoid assemblages. These are the only consistently fossiliferous horizons in the whole region, though no ammonites were found. The chemistry of the rocks indicates a decrease of dolomitisation and quartz content up the succession indicating perhaps a gradual long term facies change in addition to the individual changes already noted.

The lavas, not surprisingly, show little change of chemistry through the succession. They are mainly basalts and basaltic andesites, typically non-porphyritic. Most of the lavas are fairly coarse-grained (1mm) and the odd phenocryst is of plagioclase, though olivine and augite were also found. Alteration of the lavas is ubiquitous, though it varies tremendously in degree from flow to flow. The common alteration is to a dark-green propylitisation colour with red spots of altered clinopyroxene, and many lavas have obviously been the playground of many mineralising solutions. Bright green secondary copper oxides are common, and there is an abundance of ore mineralisation including pyrite, chalcopyrite, bornite and sphalerite. The accompanying gangue quartz has produced some beautiful crystalline cavity specimens, particularly in the upper lavas which tend to be more quartz rich.

In addition to these relatively straightforward lavas this period produced some volcanic tuffs of a rather remarkable nature. They are typically cross-cutting in relation to the surrounding rocks, and take the form of large pods up to 500m across usually with their bases in the Goyllarisquizga and their tops in the third or fourth lava up. The pyroclastics themselves vary enormously from fine-grained green tuffs to massive flow-breccias with huge clasts of andesite several metres across; significantly, the fragmental rocks appear to be more andesitic than the lavas. There also seems to have been a close relationship between these tuffs and a coarse, white, bioclastic limestone, not seen elsewhere in the region. In places the rock is a carbonate breccia of bedding-plane fragments up to a metre across, set in a green tuff matrix. In one other notable locality behind Pucamachay this situation is reversed and blocks of andesite and tuff rest in a highly fossiliferous limestone matrix (plate 2.2).

These tuff deposits are envisaged as representing monogenetic vent infillings and flow breccias close to their volcanic origin and neighbouring lagoonal environments.

The Instrusive Rocks

There are three small intrusive bodies of a composition probably very close to the olivine-augite basalts of the lava pile, at Punabamba, below Pucamachay, and two kilometres south of Pirhuacocha. The texture is coarsely doleritic except for the southernmost one which is fine. There are no clear cross-cutting instrusive relationships and the bodies are most probably laccoliths with slight up-doming of the overlying country rocks. As has been noted by Harrison (1940), these Mesozoic intrusions have a characteristic lack of any aureole.

In addition to these dolerites there are two other bodies related to one another in the extreme north west of the area. The first forms the body of Cerro Mio, the summit mass of which is an andesitic plug and the whole southern flank of the mountain is the resulting flow (plate 2.3). This is, in all probability, the topmost expression of the same magma body which is exposed further east, to the north of the Punabamba dolerite. The Cerro Mio andesite is a fresh grey-green rock with one-millimetre phenocrysts of feldspar and biotite, whilst the easterly intrusion is twice as coarse and has quartz phenocrysts as well as feldspar and biotite.

It is difficult to accurately assess the age of the intrusions but they are probably of late lower Cretaceous age and belong to the same phase of igneous activity which produced the lava pile, which stratigraphically are best assigned to the Machay group. If anything, the Punabamba dolerite appears younger than the grandiorite intrusion.

Structural Geology

In many ways the structure of the area is very simple compared to the neighbouring region to the east, the type area of the Oroya synclinal complex, the dominant structural feature of this part of the Andes. The major structure of the area is a large anticline which exposes the Pucará limestones in its core; its strike, which swings round from N.W. in the south to N.N.W. in the north, is typical of the tectonic and morphologic trend of the Cordillera Occidental (fig. 2.2 and map 2.2). The western limb of the anticline is steeper than the eastern but the dip varies from place to place from about 5° (in a monocline structure, fig 2.2), to 40°.

Plate 2.1. Mitu lavas at the base of the Pucará Group, Saco.

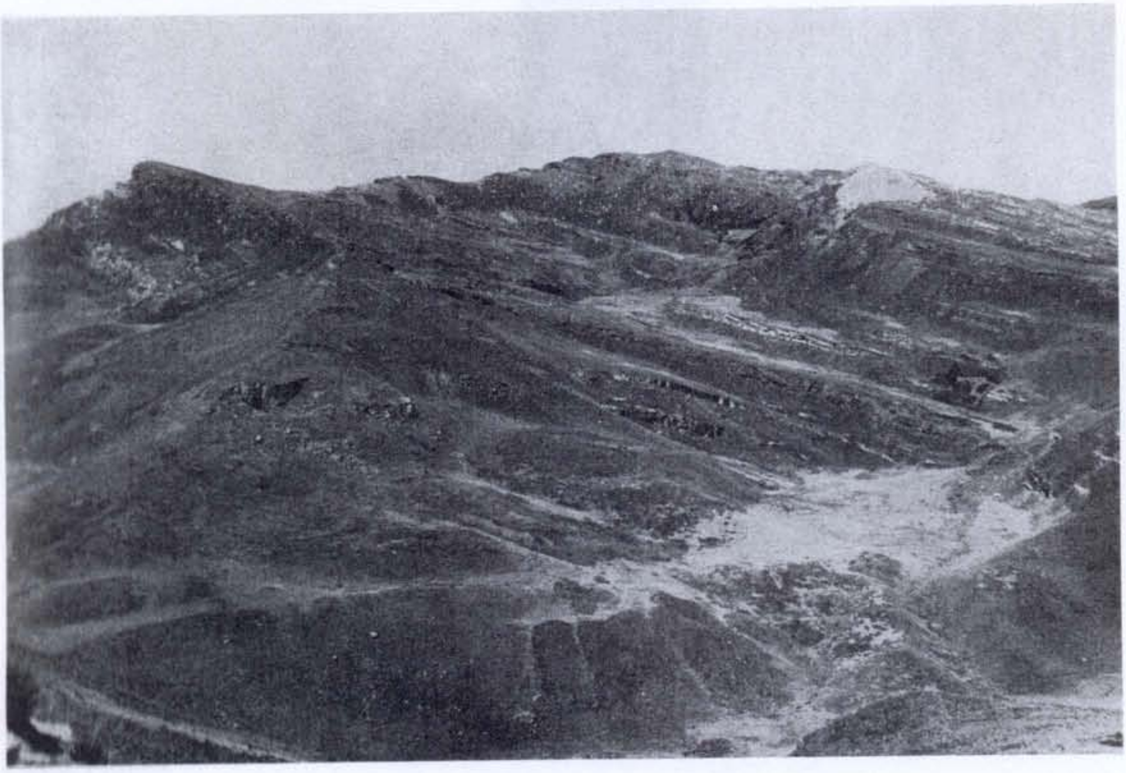


Plate 2.2. The Goyllarisquizga and lava succession, viewed south from Cerro Mio, with a tuff on the left horizon.

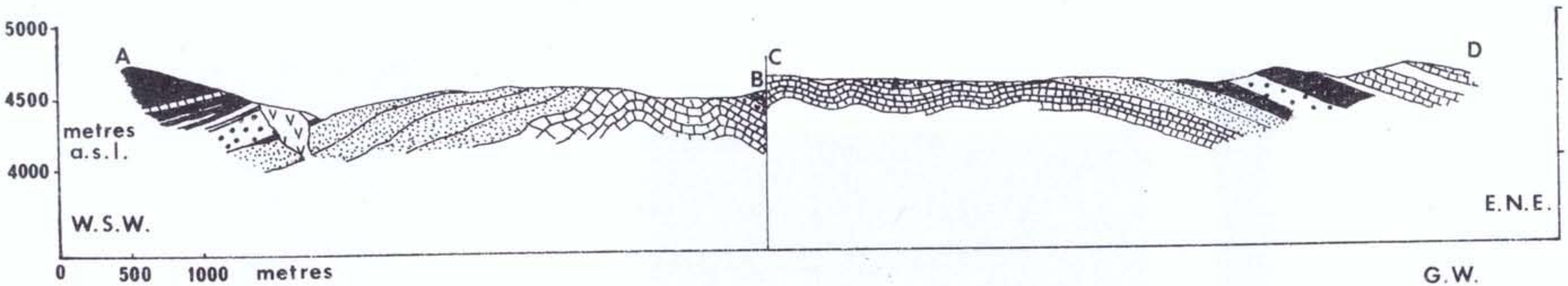


Fig. 2.2 Geological section — AB – CD on Map 2

The Pucará limestones have produced a completely different style of folding to the overlaying Goyllarisquizga and lava sequence (plate 2.4). The main tectonic episode which probably occured in the Tertiary obviously found the limestones much less competent than the sandstones and has produced a wealth of minor folds usually of a fairly open nature, though tight isoclinal folding does occur, usually in specifically "weak" areas. Not surprisingly the gypsiferous limestone is particularly susceptible to folding and several areas of small scale thrusting decollement structures were noted. Unfortunately, the state of affairs is even more confused by the karstic collapse features which abound in the gypsiferous areas and make many of the dips structurally spurious.

The Goyllarisquizga rocks on the other hand display only gentle flexuring on the small scale and weak dome-like structures on the large scale (except the above-mentioned monocline). This is particularly evident in the south where many of the hills have outliers of sandstone capping their summits. This dome structure indicates another major phase of folding in addition to the main N.W. — S.E. phase. This is seen also on a smaller scale in the Pucará limestones where several minor fold axes trend slightly north of east, obviously subsidiary to the main phase of folding, but significant nonetheless.

There seem to be very few faults at all in the area and none of any major proportions. The ones of any size are confined to the Pucará limestones, but, due to the rather repetitous stratigraphy, the faults are difficult to follow. Mainly normal with throws of a few tens of metres, they trend with the major direction of folding either north or north westwards. The Goyllarisquizga and overlying rocks are normally completely free of significant faulting — with a few notable exceptions.

The dolerite intrusion at Pucamachay seems to have chosen a most unlikely place for its laccolith-like emplacement, at a horizon a few metres below the top of the lower massive Goyllarisquizga sandstones and the overlying highly altered lava horizon which separates the upper from the lower sandstone beds. The fact that the lava horizon is cut over the intrusion itself can be explained by thrust faulting along the lower sandstone-lava contact in response to the intrusive pressure below (fig. 2.3).

Some of the cross-cutting tuff deposits seem to have been the focal points of stress within the succession and the complicated tuff/lava mass behind Lago Pirhuacocha is probably fault-bounded on its north-eastern side. The Goyllarisquizga sandstone country rocks of the tuffs are commonly buckled downwards at the contact, as if on lithification the more dense pyroclastics compacted more, and in effect moved downwards, relative to the lighter, more competent sandstones. (G.W.)

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GEOMORPHOLOGY

This part of Peru is essentially a dissected plateau uplifted by three kilometres or more in Pliocene and Pleistocene times. The large scale geomorphologic pattern is in the main controlled by the dominant N.W. — S.E. trend of the geological structures except for the large intrusive/volcanic complexes to the west which form the summit chain of the occidental range.

The annual precipitation probably just exceeds 600mm, with the highest rainfalls coming from December to March. Snow is common during the relatively dry winter of June to August. There is a fairly constant diurnal temperature range of 10°C either side of freezing, so that erosion rates are quite high; this is particularly evident on the large sandstone scarp faces. Glaciation has played a noticeable but not dominant role in the area. Drift is rather scarce but there are some excellent valley glacier deposits, particularly around Punabamba.

The Pucará limestones display some typical karst features. Small karren are abundant and very varied but there are no clint and grike pavements probably because the joint pattern is too complex and closely spaced. Similarly, dolines abound, particularly in the gypsiferous regions where they are due to differential solution of specific horizons. There are some very large collapse-type dolines, but as there is virtually no surface drainage they are almost all impossibly choked. Caves do exist in the area, but the possibility of major cave systems ocurring is effectively ruled out by the impurity of parts of the limestone sequence, its locally very thin bedded nature and the combination of relatively strong folding and high joint density. (G.W.)

HYDROLOGY

On the Pirhuacocha plateau there are many sinkholes, shakeholes and collapse features, some being over 20m deep and several hundred metres across. A number of the smaller depressions have perennial lakes in them. The lake levels are not at base level and are being ponded due to inadequate drainage beneath the shakehole.

In August no streams were seen on the plateau and all drainage was underground. However in the wet season it is evident that some streams form and run into a number of sinkholes. The sinkholes were boulder filled and could not be entered.

Just to the west of the village of Saco is a large resurgence in limestone. A large cave mouth can be entered to a pool, and discharge (in August) flows through boulders near the entrance. The water level varies and under very dry conditions it is possible that a cave could be explored behind the spring. During wet periods water flows out of the main cave entrance, with discharges of several cumecs, judging by the size of the stones in the sump. The source of the water is the limestone hills behind Saco, but no study was made of the extent of the catchment.

Around Saco there are a number of extensive deposits of travertine. These are active and travertine is being deposited today. It forms in the valley bottoms, and the small stream draining the area west of Saco has cut a 20m deep gorge through the travertine, and flows under a number of natural bridges. (J.M.H.C.)

Plate 2.3. Andesite plug and flow, Cerro Mio.

Plate 2.4. Syncline and disharmonic folding in the Pucará Limestones at Saco.

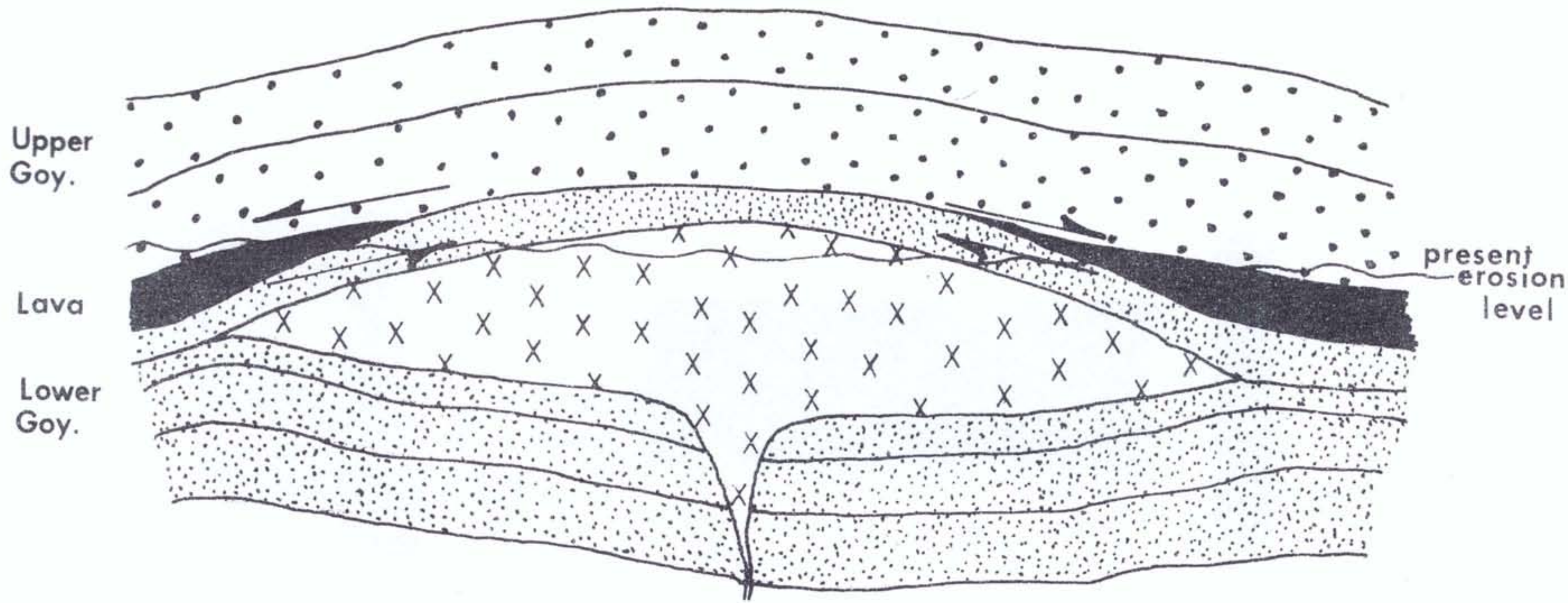
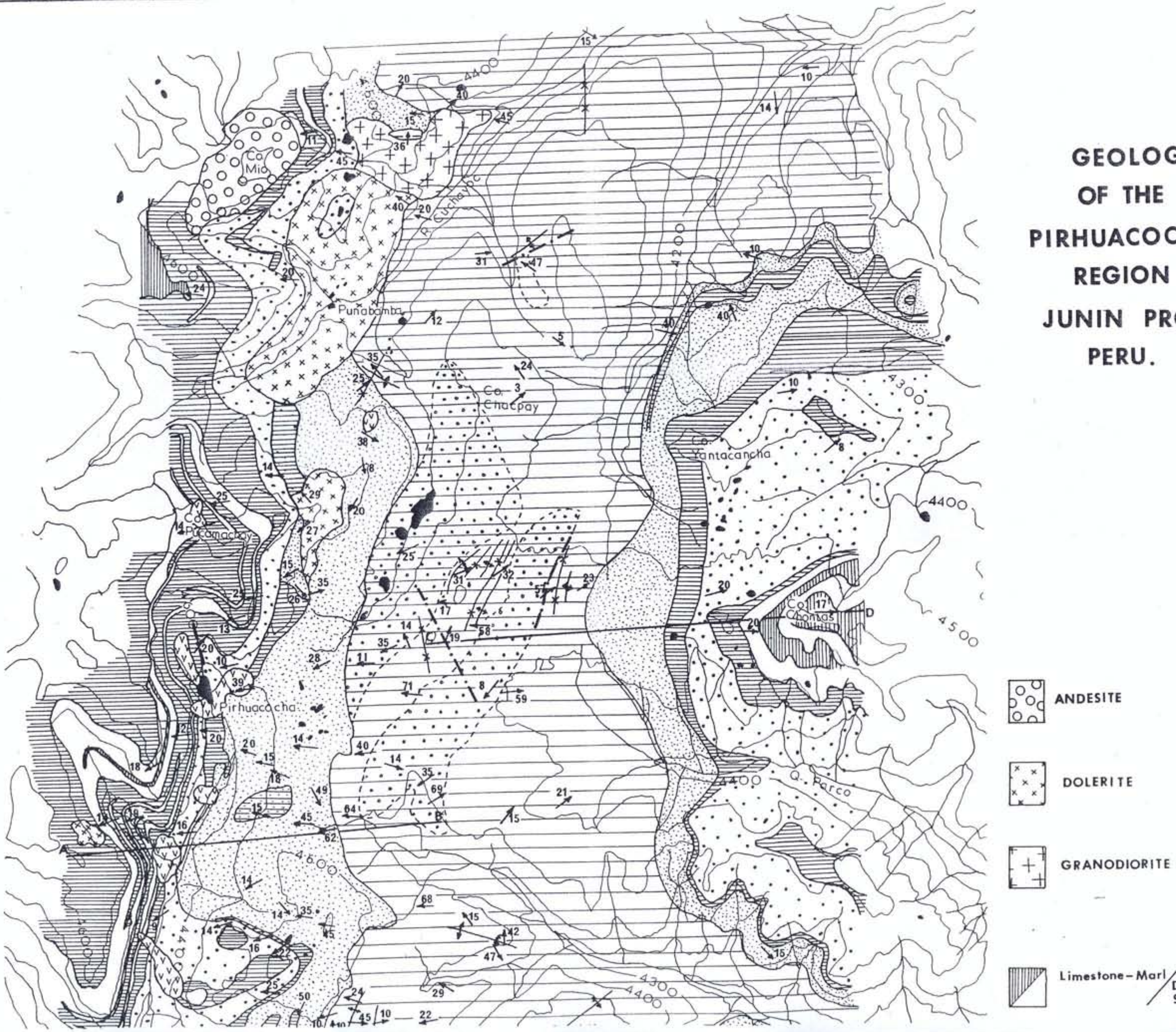
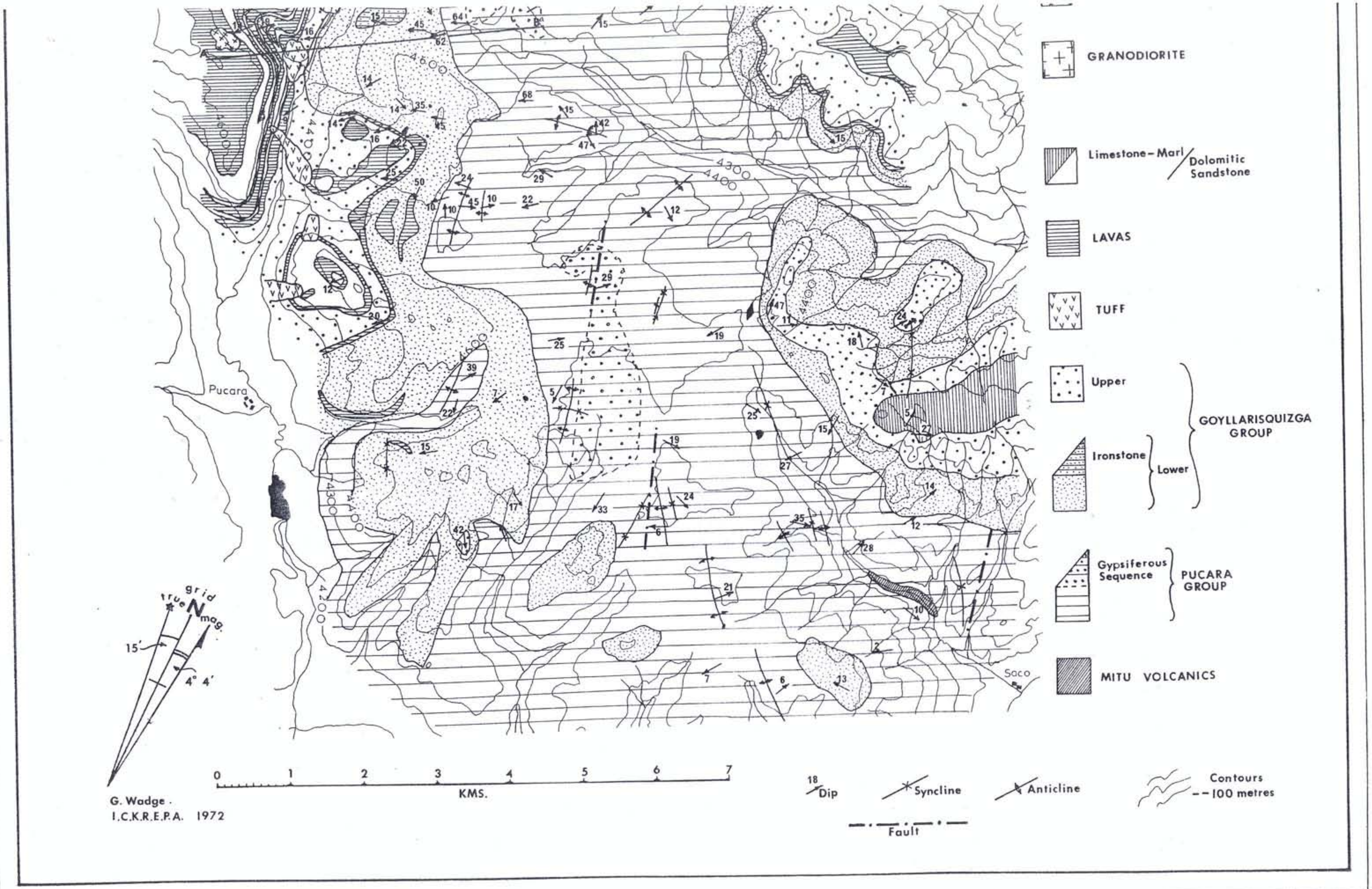


Fig. 2.3 Possible emplacement mechanism for the Pucamachay dolerite

GEOLOGY OF THE PIRHUACOCHA REGION, JUNIN PROVINCE, PERU.




GRANODIORITE
Limestone-Marl / Dolomitic Sandstone
LAVAS
TUFF
Upper
Ironstone
Lower
GOYLLARISQUIZGA GROUP
Gypsiferous Sequence
PUCARA GROUP
MITU VOLCANICS
Pucara
Saco
true grid N mag.
15'
4° 4'
0 1 2 3 4 5 6 7
KMS.
Dip
Syncline
Anticline
Fault
Contours --100 metres
G. Wadge.
I.C.K.R.E.P.A. 1972