

NEOGENE EROSION SURFACES IN THE CENTRAL ANDES OF PERU

SUPERFICIES NEOGENAS DE EROSION EN LOS ANDES CENTRALES DEL PERU

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ABSTRACT

Following the Quechua I orogeny, the Puna Surface was developed regionally as a mature erosional feature. Subsequent episodes of vertical uplift were separated by intervals which were long enough to permit the development of a sequence of individual erosion surfaces. The surfaces established in the study area, and their elevations, are :

Puna Surface 4600 – 5000m
Punrun Surface 4400 – 4700m
Junin Surface 4100 – 4400m
La Oroya Surface 3800 – 4100m
Jauja Surface 3400 – 3700m

There is also a further sequence of surfaces at lower elevations which will be the subject of a separate study.

The surfaces named above occur across the whole width of the Andes, from the Pacific Flank of the W. Cordillera to the vicinity of the Sub-Andean Fault System (SAFS) in the east. There is no sign of significant deformation of the surfaces within the study area, even close to the SAFS, and the whole Andean Block appears to have been uplifted as a single rigid unit.

The fact that the erosion surfaces occur in the same sequence and at the same general elevations on both flanks of the Andes is interpreted as an indication of the synchronicity and uniformity of the episodes of uplift across the region. It appears, therefore, that the same mechanism of uplift was active across the whole Andean Block. A possible explanation is that the brief episodes of uplift may represent the periodic release of pressure which had accumulated across the whole width of the Andean Block as a result of plate convergence. The relationship between the episodic uplifts and the development of the pronounced root beneath the W. Cordillera remains to be resolved.

Keywords: Peru, Andes, erosion surfaces, Neogene, episodic uplift.

RESUMEN

Después de la fase orogénica Quechua I, la Superficie Puna se desarrolló regionalmente como una superficie madura de erosión. Episodios subsecuentes de levantamiento estaban separados por intervalos suficientemente prolongados para permitir la formación de una secuencia de superficies de erosión. Las superficies establecidas dentro del área de estudio, y sus elevaciones, son :

Superficie Puna 4600 – 5000m
Superficie Punrun 4400 – 4700m
Superficie Junin 4100 – 4400m
Superficie La Oroya 3800 – 4100m
Superficie Jauja 3400 – 3700m

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También se ha reconocido una secuencia de superficies a elevaciones menores, las cuales serán el objeto de un estudio separado.

Se encuentran las superficies nombradas arriba a través del ancho completo de los Andes, desde el Flanco Pacífico de la Cordillera Occidental hasta la vecindad del Sistema de Fallas Subandinas (SAFS) al Este. Falta evidencia de deformación significativa de las superficies dentro del área de estudio, aún cerca al SAFS, y parece que el Bloque Andino se levanta como una sola unidad rígida.

El hecho que las superficies de erosión ocurren en la misma secuencia y a las mismas elevaciones generales en ambos flancos de los Andes se interpreta como una indicación que los episodios individuales de levantamiento fueron simultáneas e uniformes a través de la región. Parece, entonces, que el mismo mecanismo de levantamiento estaba activo a través de todo el Bloque Andino. Una explicación posible es que los episodios breves de levantamiento representan el relajamiento periódico de la presión que había acumulado a través de todo el Bloque Andino como resultado de la convergencia de placas. Falta resolver la relación entre los levantamientos episódicos y el desarrollo de la raíz pronunciada debajo de la Cordillera Occidental.

Palabras clave: Peru, Andes, superficies de erosión, Neogeno, levantamiento episódico.

INTRODUCTION

McLaughlin (1924), in his seminal study of the central Andes, recognised the presence of a sequence of erosion surfaces, the highest being the Puna Surface, into which were incised progressively lower features which he named as the Junin, Chacra and Canyon Stages. Nevertheless, the Puna Surface as defined by McLaughlin (op. cit.) in fact includes more than one erosional feature, as was recognised by Dollfus (1973) and Benavides (1999). Over the decades the term Puna Surface has been applied to any reasonably mature surface at elevations of 4000m or more, and has ceased to have a clearly defined meaning. Fortunately, the good quality maps now available permit a more detailed and comprehensive study of Andean geomorphology than was previously possible, such that in central Peru at least the Puna Surface can be defined and mapped as a specific feature. It is also clear that beneath the Puna Surface there occurs a whole sequence of individual erosional features which can be recognised throughout much of the central Andes. The objectives of the present study are therefore as follows :

- a) examine the general area studied by McLaughlin (op. cit.) plus its extension into the E. Cordillera (Fig. 1).
- b) define and map the high level erosion surfaces, establishing a sequence which can be traced along strike to the NW and SE along the Andean chain. The lower erosion surfaces will be covered in a separate study focusing specifically on the Subandean Fault System (SAFS) and the Subandean Belt.

- c) relate the development of the erosion surfaces to the Neogene uplift of the Andes.

WORK METHODS

The work method used in this study was the same as described in Wilson (2009), being mainly an office based examination of the 1:100,000 topographic and geologic maps, with a significant amount of field checking. A careful examination of the 1:100,000 topographic and geologic maps was made with the objective of identifying flat or gently sloping areas on the interfluvies. These subhorizontal ridge tops were then noted on a base map, along with their elevations. The ridge tops were found to cluster around specific elevations. Thus, for example, in a particular area there may be abundant subhorizontal ridge tops at 4100 – 4300m, but none which span the range 4300 – 4500m. Similarly, in an adjacent area there may be ridge tops at 4400 – 4600m, but none which span a greater range. Moreover, field work and careful examination of the topographic maps reveal places where in a single interfluvie the subhorizontal ridges at e.g. 4100 – 4300m are separated by a defined scarp from ridge tops at e.g. 4400 – 4600m. The groups of subhorizontal ridge tops are here interpreted as the remnants of erosion surfaces, the scarps representing the limits achieved by a specific surface prior to the initiation of the next phase of uplift and erosion.

A complicating factor in mapping the individual surfaces is that their upper and lower limits vary slightly across the study area. This is a feature of the two highest surfaces. Thus while in some

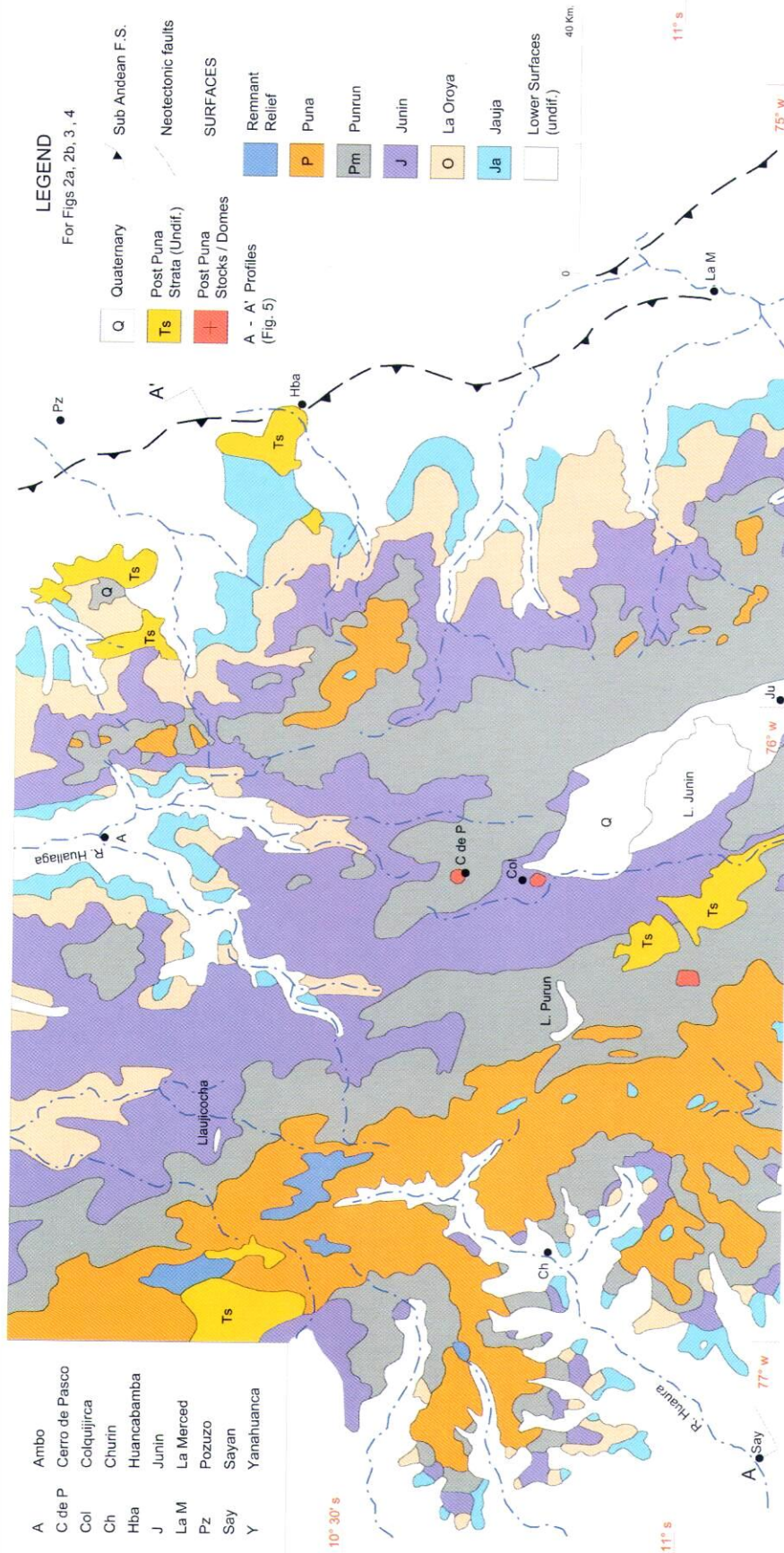


Figure 2a. Distribution of erosion surfaces - northern sector

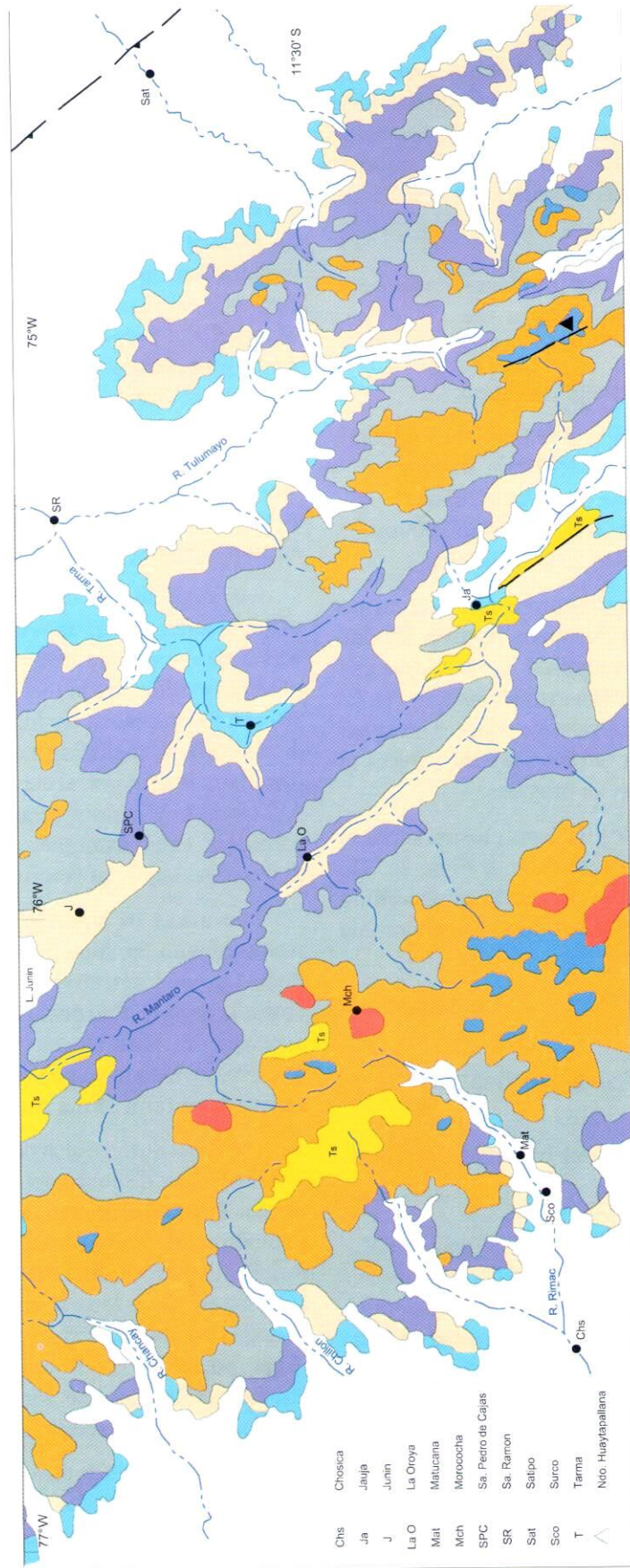


Figure 2b. Distribution of erosion surfaces - southern sector

areas a surface at 4700m corresponds to the Punrun Surface, surfaces at that same elevation elsewhere are clearly part of the Puna Surface. It is not therefore a question of identifying surfaces simply on the basis of elevation. The situation requires an objective study focusing particularly on the distribution of the scarps which form the boundaries to the individual surfaces.

EROSION SURFACES

The following erosion surfaces have been recognised in the study area at the elevations indicated:

Elevation Range	Average Elevation
Puna Surface 4600 – 5000m	4700 – 4800m
Punrun Surface 4400 – 4700m	4500m
Junin Surface 4100 – 4400m	4200m
La Oroya Surface 3800 – 4100m	3900m
Jauja Surface 3400 – 3700m	3600m

The study also revealed the presence of a sequence of surfaces occurring at elevations beneath 3500m. These surfaces can be recognised in the middle and lower sectors of both the Eastern and Western Flanks and appear to represent correlative features on either side of the Andes. These surfaces are the subject of a separate study currently in progress.

The distribution of the high level erosion surfaces can be appreciated with reference to Figs. 2a, 2b. It is proposed to describe the surfaces according to their development in the following geographic subdivisions:

Sierra, including the W. and E. Cordilleras and the intervening area.

East Flank, comprising the flank of the E. Cordillera.

West Flank, being the flank of the W. Cordillera.

Sierra

Puna Surface.— The Puna Surface was initially recognised by McLaughlin (1924) in the higher reaches of the W. Cordillera within the study area, where it occupies a width of up to 60km and extends to within 60km of the coast (Figs. 2a, 2b).

The surface is characterised by concordant ridge tops at 4800–5000m separated by valleys of mainly glacial origin. There are, however, areas where the surface has suffered little subsequent modification. Thus in the western sector of the Oyon Quad., north of Churin (Fig. 4a), the surface occurs as a poorly

drained plateau-like feature with little internal relief. It is clear that the Puna Surface developed by fluvial erosion at a low elevation prior to being uplifted to its present position.

The Puna Surface maintains a more or less constant elevation throughout the W. Cordillera in the study area. Its lower limit occurs at c.4800m and the surface does not generally rise above 5000m. Its western limit is formed by a marked scarp leading down to lower surfaces (Fig. 4a, 4c) There is no hint of any SW dip down towards the coast even in the westernmost occurrences of the surface. In the east the surface is limited by a scarp separating it from the Punrun Surface (Figs. 3a, 5). While McLaughlin (*op. cit.*) considered this scarp to be a fault downthrowing the Puna Surface to the east, the writer interprets it as an erosional feature forming the back scarp of the Punrun Surface (see below).

McLaughlin (*op. cit.*) noted that there are areas of high relief rising above the Puna Surface, and which he interpreted as monadnocks. These areas of remnant relief are in fact quite common (Figs. 2a, 2b) and form some of the high snow capped peaks of the Cordillera, including La Viuda and parts of the Cordillera Huayhuash at elevations of 5100–5700m. Although they mainly occur along the crest of the cordillera, small examples occur tens of kilometres to the west, e.g. N of Churin (Fig. 4a).

The areas of remnant relief should not be confused with the high peaks associated with post-Puna igneous activity. The latter include both volcanic units resting on the Puna Surface, e.g. in the area west of L. Lauricocha (Fig. 2a), and subvolcanic intrusives which have penetrated the surface, e.g. in the southern limit of the study area (Fig. 2b).

The Puna Surface also occurs in the E. Cordillera as isolated or discontinuous areas ranging in size from a few kilometres in diameter to a few tens of kilometres of current areal extent. (Figs. 2a, 2b). Regardless of extent, they are characterised by concordant ridge tops in the range 4600–4900m bounded by the back scarps of the Punrun Surface (Figs. 3d, 4b, 4d). Locally the Puna Surface is directly abutted by the Junin Surface, the Punrun Surface having been completely destroyed (Fig. 4d).

In some areas, e.g. the central sector of the Jauja Quad., the Puna Surface occurs as a poorly drained feature at c.4700m reminiscent of the areas mentioned above in the W. Cordillera to the N of Churin.

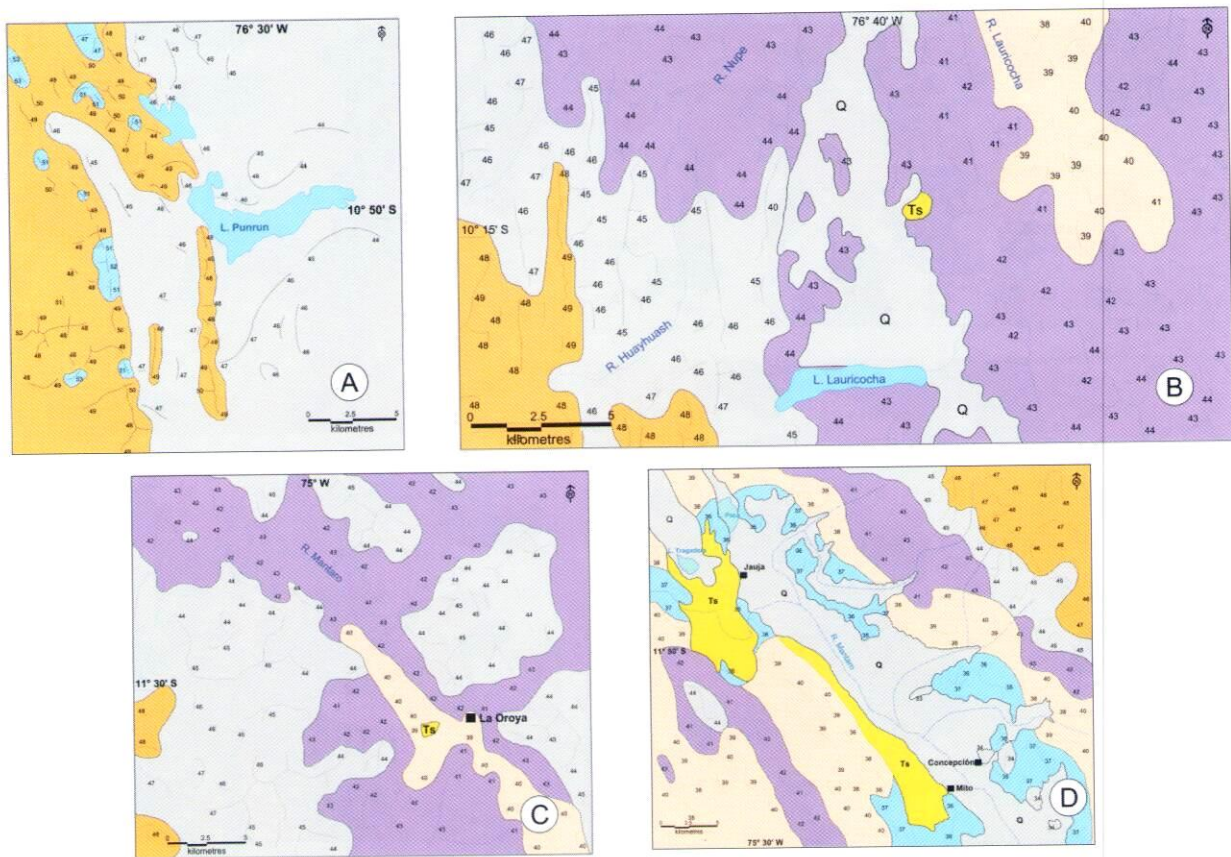


Figure 3. Detailed maps of erosion surfaces - Intermontane Area.

The Puna Surface in the E. Cordillera is slightly lower than in the W. Cordillera. Thus it occurs at 4600–4800m in the area east of Ambo (Fig. 4b) and to the east of Jauja (Fig. 3d), though in other areas it does not occur beneath 4700m (Fig. 4d). The slightly lower altitude of the Puna Surface in the E. Cordillera is the result of differential warping during the Andean uplift, and is discussed in the section on Structure.

The Puna Surface maintains a fairly constant elevation in the E. Cordillera and at its eastern limit it still lies at c.4700–4900m at only 35–40km from the SAFS, e.g. in the range to the west of Satipo (Fig. 2b, 4d). There is no indication of any dip down towards the SAFS.

There are two substantial areas in the E. Cordillera which reach altitudes of well over 5000m. They are the Huaytapallana range (5500m+) east of Jauja and the Huagaruncho range (5700m) in the Ulcumayo Quad. The Huaytapallana range is associated with modern seismic activity and some neotectonic faulting (Philip and Megard, 1977; Doorbath et al.,

1991), and Wise (2007) interpreted the range as comprising a Neogene uplift. On the other hand, the area lying above 5000m has a quite irregular shape and is bounded on all sides by subhorizontal ridge tops at 4600–4800m representing the Puna Surface (Fig. 7). The pattern suggests an erosional limit between the Puna Surface and the range rather than a structural contact. In addition, the Puna Surface is not displaced by the main fault systems, which are therefore interpreted as pre-Puna structures. Thus while not denying the neotectonic activity in the area, the writer suggests that the Huaytapallana range may be largely remnant relief and it is provisionally mapped as such in Fig. 2b. The Huagaruncho range is interpreted similarly.

Punrun Surface.- The Punrun Surface is one of the most widespread geomorphological features of the region, being found across virtually the whole width of the central Andes (Figs. 2a, 2b), forming a mature, almost planar, feature at altitudes of 4400–4700m.

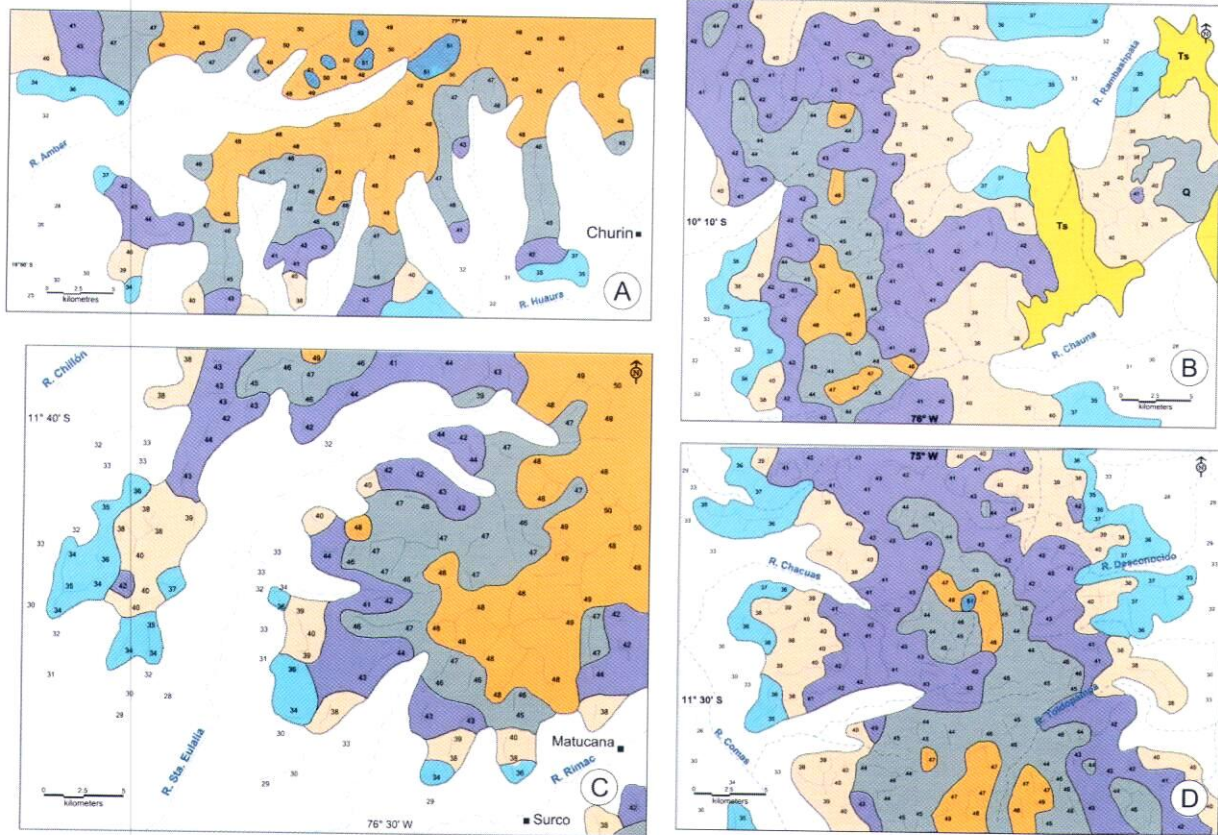


Figure 4. Detailed maps of erosion surfaces - Intermontane Area.

The surface is characteristically developed in the neighbourhood of L. Punrun, where it occurs as high level pampas and concordant ridge tops at 4500 – 4700m (Fig. 3a). It is bounded to the west by a well defined scarp leading up to the concordant summits of the Puna Surface at 4800 – 5000m. As mentioned above, McLaughlin (1924) considered the scarp to be a post-Puna fault. Nevertheless, while the scarp is locally rectilinear, it more generally shows an irregular pattern typical of an erosional feature (Fig. 3a). The tongue of Punrun Surface penetrating the Puna Surface west of L. Punrun (Fig. 5) is clearly an erosional feature. The occurrence of outliers of Puna Surface surrounded by the Punrun Surface (Fig. 3a) confirms this interpretation. A similar relationship can be observed along strike from L. Punrun (Figs. 3b, 3c), where the back scarp of the Punrun Surface has an irregular trace, again precluding the possibility of its being a young fault feature.

The surface can be followed along the flank of the cordillera to the NE and SW of L. Punrun (Figs.

2a, 2b). It maintains the same general characteristics throughout this area, forming a mature surface with little internal relief and bounded to both E and W by scarp features. The boundary between the Punrun Surface and the Junin Surface is variably defined. In the south the two surfaces are separated by a distinct scarp (Fig. 3d). Nevertheless, in the area between Cerro de Pasco and L. Junin the scarp is poorly defined, probably as a result of having been developed in relatively soft strata which has facilitated its subsequent degradation.

While the Punrun Surface is well represented in the flank of the W. Cordillera, it has an even greater development in the E. Cordillera, where it achieves a width of up to 60km (Fig 2b). Throughout this area it maintains the same general characteristics as already described, comprising a mature, almost planar, feature. The surface occurs at slightly lower altitudes than in the W. Cordillera, being found mainly at 4400 – 4500m and not occurring above 4600m.

The surface is represented in the Cerro de Pasco area by concordant ridge tops at c. 4400m, where it bevels the stocks and associated mineralisation (Fig. 8). The Punrun Surface is also well developed in the area immediately east of Junin town, where there are abundant subhorizontal ridge tops at 4400 – 4600m. Similarly, the surface is represented by the high ground at 4400 – 4500m found immediately east of the R. Mantaro in the vicinity of La Oroya (Fig. 3c).

There is a separate area east of Jauja which is characterised by concordant summits at 4400 – 4500m, separated by scarps from the Puna Surface at 4600 – 4900m (Fig. 3d). This area is also ascribed to the Punrun Surface. A similar situation occurs in the far SE of the study area, in the range west of Satipo, where once more concordant summits at 4400 – 4600m are attributed to the Punrun Surface (Fig. 4d).

It may be noted that there are significant differences in the altitude of the Punrun Surface across the area, from a maximum of 4700m in the W. Cordillera to 4400 – 4500m along the upper R. Mantaro, though the surface possibly rises slightly in the E. Cordillera. It is suspected that these variations are the result of slight post-Punrun differential warping.

Junin Surface.— McLaughlin (1924) gave the name Junin Stage to the area of low relief lying between the E. and W. Cordilleras in the vicinity of L. Junin, characterised by “a series of broad valleys with flat gradients and gentle side slopes”. The feature is extensively developed in the study area (Figs. 2a, 2b), being represented by a series of pampas and associated ridge tops at elevations of 4100 – 4400m. It is proposed that the feature be renamed the Junin Surface to conform with current terminology.

The surface occupies a substantial part of the intermontane sector within the study area. Beginning in the north it forms an extensive plateau-like feature at 4100 – 4400m to the N and E of L. Lauricocha (Fig. 3b), into which the rivers have incised their courses. Its western boundary is marked by scarps which separate it from concordant ridge tops at 4500 – 4600m ascribed to the Punrun Surface (Fig. 3b). The divide between the Marañon headwaters and the Huallaga drainage (Figs. 2a, 3b) is formed by the Junin Surface. Similarly, the area east of Ambo, forming the divide between the R. Huallaga and the R. Pozuzo drainage (Figs. 2a, 4b) is formed by the Junin Surface.

Coming south from the Ambo area along the E. Cordillera the Junin Surface is represented by ridge tops at 4100 – 4300m which are generally separated by a distinct scarp from the Punrun Surface. Similarly, in the area N of Cerro de Pasco there is an extensive area of concordant summits at 4100 – 4300m.

In the area of Cerro de Pasco itself, there is a reasonably clear separation of the Junin and Punrun Surfaces. The Junin Surface surrounds the Marcapunta Dome (Fig. 8) and presumably forms the base upon which the dome was built up.

While the Junin Surface in the northern part of the study area occupies a width of c.60km, there is an abrupt narrowing southwards in the latitude of Cerro de Pasco (Fig. 2a), where it is reduced to a 10 – 15 km belt of pampas at 4200 – 4300m. Continuing to the south, the Junin Surface divides into two lobes (Fig. 2a). The eastern lobe is represented by ridge tops at 4200 – 4300m found around the margins of L. Junin. This lobe narrows southeastwards near Junin town, but in the vicinity of San Pedro de Cajas appears to coalesce with the Junin Surface associated with the headwaters of the R. Tarma. (Figs. 2a, 2b).

The western lobe is occupied by the R. Mantaro and forms a generally narrow feature which extends southeastwards to La Oroya and Jauja (Figs. 2a, 2b). In this area the Junin Surface is represented by a bench at 4100 – 4300m separated by a scarp from the Punrun Surface (Fig. 3c)

The palaeovalley was locally blocked by the Huayday ignimbrites, through which the R. Mantaro has subsequently cut its channel.

The surface widens abruptly in the latitude of Jauja, where its distribution indicates a palaeovalley c.50k in width. (Fig. 2b). The surface occurs as a discontinuous belt in the NE flank of the Mantaro valley and also as a narrow NW – SE ridge in the SW flank (Fig. 3d).

The surface is extensively developed north of Jauja, where it forms the divide with the R. Tarma drainage (Fig. 2b). It appears that separate lobes of the Junin Surface advanced up the Mantaro and Tarma palaeodrainage systems and coalesced in this area.

It may be noted that as in the case of the Punrun Surface, the Junin Surface commonly reaches greater altitudes in the W. Cordillera than in areas further east. Thus while the surface commonly reaches elevations of 4400m in the L. Lauricocha area, it is

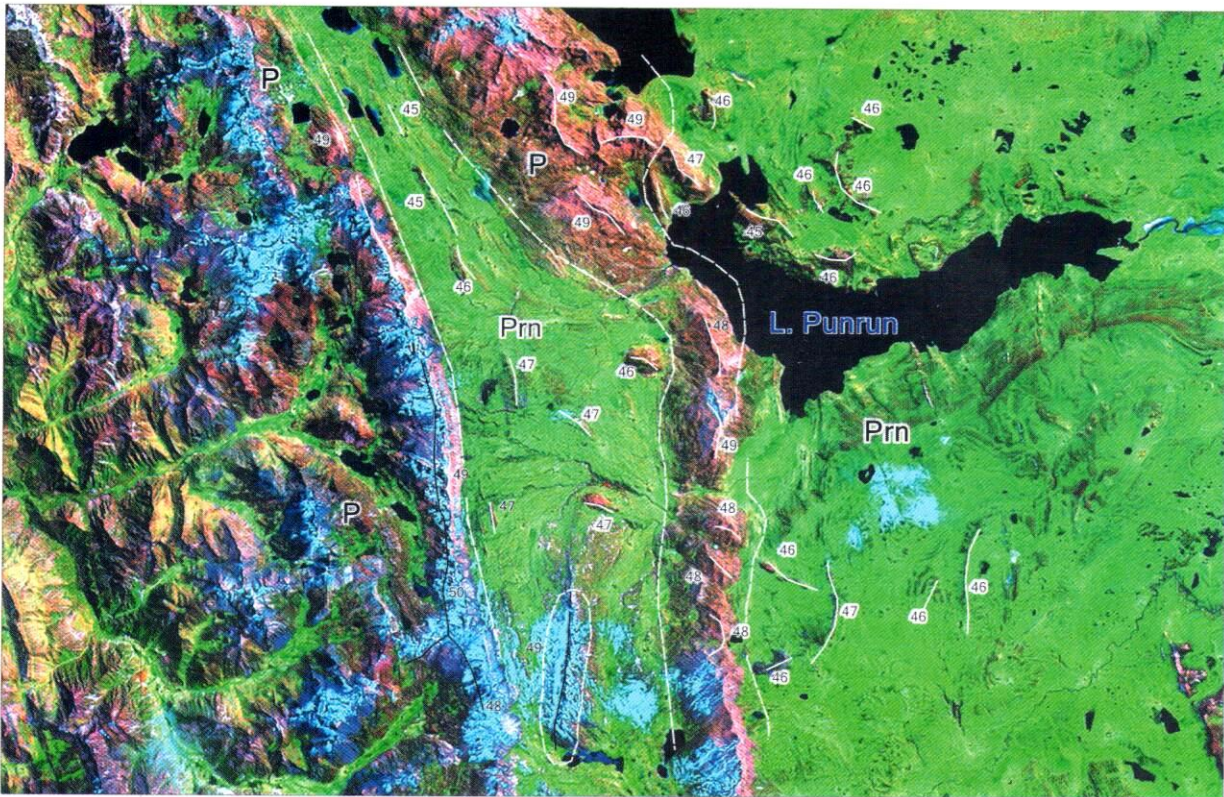


Figure 5. Punrun area - vertical image from Google Earth (symbols as in Fig. 2a)

not found above 4300m in the Mantaro valley. The apparent slight slope down to the NE may be the result of post-Junin differential warping.

La Oroya Surface.- The La Oroya Surface has not hitherto been recognised but nevertheless occurs throughout much of the Andean Belt of central and northern Peru as an erosional bench found at 3800–4000m. The surface is named after the town of La Oroya, where it occurs as a narrow but well defined bench at c.3900m, lying about 100m above the current course of the R. Mantaro, and locally mantled by young sediments of the Mataule Gp. The surface is separated by a prominent scarp from subhorizontal ridges at c.4200m representing the Junin Surface, but locally abuts the Punrun Surface (Fig. 3c). The surface can be traced upstream from La Oroya, forming the remains of a narrow, c.3km wide, valley which terminates c. 15km NW of the town (Fig. 3c).

Downstream from La Oroya the surface occurs on both sides of the R. Mantaro (Fig. 2b) and indicates an incised palaeovalley gradually widening to the S. However, c.15km west of Jauja the palaeovalley

abruptly broadens to 20km and forms the crests at 3800–4000m of the numerous low hills surrounding the towns of Marco and Concho (La Oroya Quad.). The distribution of the La Oroya Surface in the Jauja area (Fig. 3d) indicates a palaeovalley about 25km wide, with a flat floor and bounded by 100–300m scarps separating it from the Junin Surface. The surface is well displayed in a flat topped feature about 6km wide in the SW flank of the Mantaro valley (Fig. 3d). The La Oroya Surface is also present on the NE flank of the valley, though in the latter area it has been partially disrupted by later erosion. The distribution of the La Oroya Surface in this area suggests that the main palaeovalley extended into the area north of Jauja, and that the finger-like feature extending towards La Oroya was occupied by a subsidiary tributary.

The La Oroya Surface is also well represented in the Marañon and Huallaga valleys (Fig. 2a). In the case of the R. Huallaga, the surface is preserved on the flanks of the main valley and its tributaries as erosional benches at 3800–4000m incised into the

Junin Surface and partially destroyed by later erosion. The distribution of the benches indicates that the palaeovalley was 25 – 40km wide (Fig. 2a), being a relatively broad, flat bottomed feature bounded by hills rising about 600m above the valley floor. The palaeovalley extended southwards as narrow finger-like features which, as in the case of the R. Mantaro, failed to reach the central intermontane area (Fig. 2a).

In the case of the R. Tingo, the tributary originating north of Cerro de Pasco, the surface occurs at 4000 – 4100m and is clearly separated by a scarp from the Junin Surface at 4200 – 4300m. The fact that the La Oroya Surface reaches as high as 4100m probably reflects the increase in elevation to be expected in the higher reaches of the tributary valleys.

The La Oroya Surface also extends along the Marañon valley into the northern sector of the study area (Fig. 2a), where its remnants indicate a palaeovalley up to 15km wide and reaching almost as far south as L. Lauricocha (Fig. 3b). The surface occurs in the range 3800 – 4100m, the slightly higher elevation being achieved for the same reasons as in the case of the R. Tingo. The feature is incised into the plateau-like Junin Surface and has itself been partially dissected by later erosion.

Northwards, beyond the limit of the study area, the La Oroya Surface is well developed in the La Union Quad., where it is represented by the concordant hilltops at 3800 – 4000m found immediately south of the Huanuco Viejo ruins and in the surroundings of the town of Llata.

The distribution of the La Oroya Surface indicates that the current drainage pattern was already well established by that stage in the Andean uplift. Nevertheless, the surface failed to penetrate the central portion of the intermontane area, presumably because its advance was halted by the next phase of uplift and the initiation of the phase of erosion which produced the Jauja Surface.

Jauja Surface.— The Jauja Surface forms a well defined feature at 3400 – 3700m in the valleys of the Mantaro and Huallaga rivers (Figs. 2a, 2b) and probably corresponds to the upper part of the Chacra Stage of McLaughlin (1924).

The surface is characteristically developed in the area surrounding the town of Jauja (Fig. 2b). North of the town it is preserved in the concordant summits

found at 3500 – 3600m on either side of L. Paca (Fig. 3d), and which are separated by scarps from the La Oroya Surface to the north. The same general relationship is observed in the lower NE flank of the Mantaro valley downstream from Jauja, where the surface is represented by concordant summits at 3500 – 3700m (Fig. 3d). It may be noted that in the same area there are isolated ridge tops at 3300 – 3400m (Fig. 3d) which indicate a separate, lower, feature which lies outside the scope of the present study.

The situation on the SW flank of the valley is as follows. Behind the town of Mito the Jauja Surface is represented by a bench eroded into Devonian strata at 3500 – 3600m (Fig. 3d). Towards the NW the surface is mantled by tuffs of the Mataule Fm., dated at 5.39Ma by Wise (2007). Wise (op. cit.) has mapped a NE verging high angle reverse fault juxtaposing Mesozoic carbonates and the Neogene tuffs, and interpreted the fault as a major feature forming the margin of the basin. As the La Oroya Surface and Jauja Surface are found at their normal elevations on either side of the fault, it appears that the fault has in fact produced limited vertical displacement.

The distribution of the Jauja Surface in this part of the Mantaro valley indicates a more or less flat bottomed palaeovalley c.10km wide and which had been incised into the La Oroya Surface (Fig. 3d). The palaeovalley narrowed abruptly about 10km west of Jauja, beyond which it ceased to exist as a recognisable geomorphological unit.

The Jauja Surface is also developed in the Huallaga valley (Fig. 2a). East and west of Ambo are found erosional benches represented by concordant ridge tops at 3400 – 3700m and which are ascribed to the Jauja Surface. The surface was undoubtedly much more extensive in the past but has been reduced to discontinuous and commonly small remnants by subsequent erosion. It has been largely destroyed in the upper reaches of the Huallaga and tributary valleys, but is more extensively preserved north of the study area in the Huanuco Quad.

The Jauja Surface in this area has generally similar characteristics to those described in the upper Mantaro valley, being represented by ridge tops at 3400 – 3700m which abut features ascribed to the La Oroya Surface or, locally, the Junin Surface (Fig. 4b). The lower limit of the surface is marked by the back scarps of a variety of younger features.

Eastern Flank

This section addresses the upper portion of the Eastern Flank of the Andes from the Puna Surface at 4600 – 5000m to the Jauja Surface at 3400 – 3700m.

The erosion surfaces recognised in the Eastern Flank occur in the same sequence and at the same general elevations as those already described in the Sierra, and it is on this basis that the surfaces are correlated. The correlation is confirmed by the fact that in some areas the E. Flank surfaces can be observed to merge into their Sierran equivalents.

The distribution of the various surfaces is illustrated in Figs. 2a and 2b, while Figs. 3b and 3d illustrate the relationships of the surfaces in greater detail. Fig. 10 demonstrates the step-like profile of the portion of the E. Flank addressed in this study. It will be noted that towards the north the individual erosion surfaces are preserved in strips 5 – 15km wide, while further south they are much narrower, with the whole sequence of surfaces being compressed into a width of about 15km (Fig. 10). The significance of this change is not yet clear and will require the study of other areas along the flank.

The individual surfaces in the Eastern Flank may be described briefly as follows.

Puna Surface.-The distribution and characteristics of the Puna Surface in the E. Cordillera have already been described in the section on the Sierra. Briefly, the surface occurs mainly as remnants, though more extensive areas occur in the SE sector of the study area (Fig. 2b). The surface maintains a fairly constant elevation in the range 4600 – 4900m in the E. Cordillera, with an average altitude of c.4700m.

The Puna Surface extends eastwards for some distance from the axial area of the E. Cordillera and reaches to within c.40km of the SAFS (Figs. 2a, 2b), maintaining its elevation, and without showing any indication of a downward tilt towards the latter.

Punrun Surface.- The Punrun Surface forms the crest of the E. Cordillera in many areas (Figs. 2a, 2b). It forms a more or less planar feature at 4400 – 4500m, locally rising to 4600m. The surface is bounded by defined scarps which separate it from the Puna Surface and lower features.

The Punrun Surface has been preserved along some of the main interfluves which extend into the E. Flank area, and reaches to within 30 – 40km of the

SAFS (Figs. 2a, 2b). It is also well represented in the crestral portion of the ridge between San Ramon and Satipo (Figs. 2b, 4d), where it again reaches to within about 40km of the SAFS. The surface maintains its characteristics even at its most eastern developments, and shows no sign of any tilt down towards the SAFS.

Junin Surface.- The Junin Surface is well displayed in the main interfluves of the E. Flank area, where it commonly forms a belt 5 – 10km wide, characterised by concordant ridge tops at 4100 – 4300m., and which are separated from the Punrun Surface by a distinct scarp. These characteristics are displayed in the northernmost part of the E. Flank (Fig. 4b), where the Junin Surface locally forms the crest of the E. Cordillera (Fig. 2a).

The surface is particularly well developed in the R. Tarma drainage (Fig. 2b), where it reaches a width of 40km, having destroyed much of the Punrun Surface in that area. The Junin Surface extends without interruption from the Tarma area into the Sierra, particularly near Jauja, suggesting that it comprises features formed by the ancestral Tarma and Mantaro river systems and which coalesced near the present drainage divide. Regardless of this, the continuity of the Jauja Surface from the Sierra into the E. Flank confirms the correlations being made in this report.

The Junin Surface is also preserved in the range lying between San Ramon and Satipo, where it forms the summit over large areas (Fig. 2b), maintaining its general characteristics, being represented by concordant summits at 4100 – 4300m separated by scarps from the Punrun and La Oroya Surfaces (Fig. 4d).

La Oroya Surface.- In the E. Flank sector the La Oroya Surface is represented by a clearly defined belt characterised by concordant ridge tops at 3800 – 4000m (Figs. 3b, 3d). The surface reaches a width of more than 10km in some areas (Fig. 2a), but in others has been largely destroyed by later erosion (Fig. 2b).

As in the Sierra, the La Oroya Surface of this sector has finger-like extensions which penetrate up the main modern valleys. This pattern can be seen in the case of the R. Comas (Figs. 2b, 4d), and also in the upper reaches of the R. Tarma system (Fig. 2b), so confirming that the main river systems had been established by the time that the La Oroya Surface was formed.

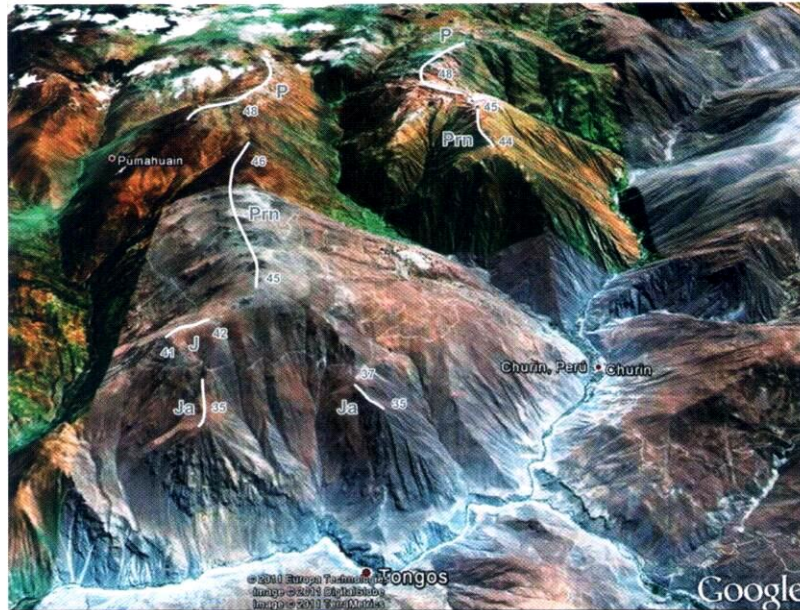


Figure 6. Churin area - oblique image from Google Earth (symbols as in Fig. 2a).

Jauja Surface.- The Jauja Surface is found in the E. Flank as a bench c.10km wide with ridge tops at 3400 – 3700m, and separated from the La Oroya Surface by a defined back scarp (Figs. 4b, 4d). The surface is quite well preserved in the main interfluves, but also penetrates up the major valleys. Good examples of the latter occur in the Tarma valley (Fig.2b).

Western Flank

The distribution of the erosion surfaces in the upper portion of the Western Flank is illustrated in Figs.2a and 2b, while their characteristics can be appreciated by reference to Figs. 4a and 4c. The surfaces occur at the same general elevations and in the same sequence as found in the Sierra and Eastern Flank, and it is on this basis that the individual surfaces are correlated.

While the interfluves in the W. Flank show the same step-like profile as recognised in the E. Flank (Fig. 10), there are significant differences between the two areas. Thus although the Puna and Punrun Surfaces are well preserved throughout the W. Flank, the Junin, La Oroya and Jauja Surfaces commonly occur as discontinuous fragments, and one or more of them may be absent in some areas. It appears that, for whatever reason, there was less preservation of the surfaces than in the E. Flank.

The following brief comments can be made on the individual surfaces.

Puna Surface.- The Puna Surface occurs as an almost planar feature represented by ridge tops at 4800 – 5000m. As mentioned above, there is no indication of any incipient tilt down to the west.

The previously greater extent of the surface is confirmed by the occurrence of small outliers of the surface to the west of the main Puna area, as occurs in the Sta. Eulalia valley (Fig. 4c).

Punrun Surface.- The Punrun Surface is also well preserved in the W. Flank (Figs.2a, 2b), being represented by concordant ridge tops at 4500 – 4700m. An excellent example occurs a few kilometres NW of Churin (Fig. 4a), where a ridge 6km in length has a subhorizontal crest at 4500 – 4600m. The feature is terminated by a well defined scarp separating it from the Puna Surface. The relationship is clearly illustrated in Fig. 6. Similar situations can be observed elsewhere in the Churin area, and indicate that the Punrun Surface developed as a palaeovalley incised into the Puna Surface, and thus formed part of the ancestral Huaura drainage.

The Punrun Surface is also quite well preserved in the Sta. Eulalia area, where it is up to 15km wide (Fig. 4c), and shows the same relationship to the Puna Surface as described above.

Junin Surface.- The Junin Surface occurs mainly as isolated remnants in the W. Flank (Figs. 2a, 2b), where it is represented by concordant ridge tops at

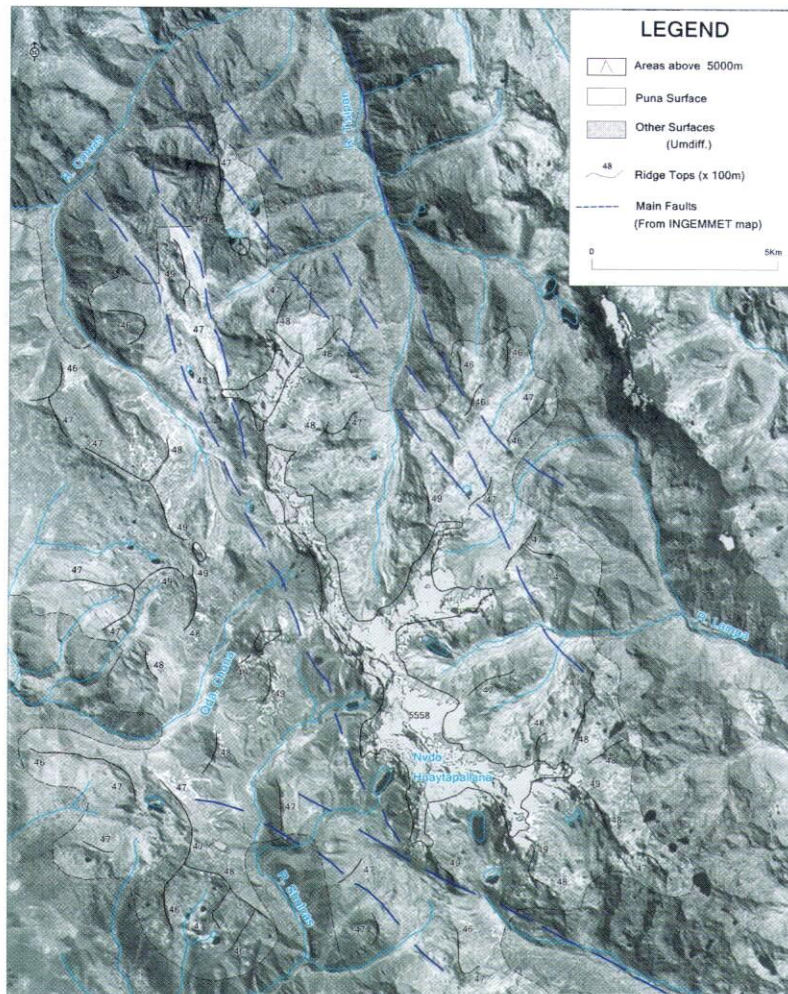


Figure 7. Huaytapallana area - distribution of erosion surfaces

410–4300m (Fig. 4c). The surface is quite well represented in the Churin area (Fig. 4a). In both the Churin and Sta. Eulalia areas the distribution of the Junin Surface indicates that it was incised into the palaeovalleys of the Punrun Surface, exerting further control on the development of the current drainage system.

La Oroya Surface.— The La Oroya Surface in the W. Flank is mainly associated with the existing valley systems (Figs. 2a, 2b). It is found on the flanks of the Rimac valley in the Surco-Matucana area (Fig. 4c) and also in the Sta. Eulalia valley. A similar relationship can also be observed in the R. Huaura area (Fig. 4a).

Jauja Surface.— The Jauja Surface is preserved as discontinuous fragments in the W. flank, represented

by areas of concordant summits at 3400–3700m, and found mainly in the valleys (Figs. 2a, 2b). It is clear that by this stage in the development of the W. Flank, the rivers in the mid-flank area were flowing in valleys 10–15km wide and 1000–1500m deep. This pattern is illustrated in Figs. 4a and 4c, but is common throughout the W. Flank.

The area around Surco in the Rimac valley (Fig. 4c), is worth a mention. Noble et al. (2009) recognised an erosion surface at c.3300m separating the Surco tuff (16.5Ma) from the underlying Surco stock, and argued that the Rimac valley was therefore already in existence at that time. The Surco tuff is, however, eroded by the Jauja Surface at c.3600m. It seems possible that the Surco tuff filled a pre-Puna depression which was progressively re-excavated during the Andean uplift.

Ages of the Erosion Surfaces

Despite the relative abundance of radiometric dates for igneous rocks within the study area (Bissig et al., 2008), they do not bracket the individual surfaces, and commonly provide only a general indication of the ages of the surfaces. Information from outside the study area has also been taken into consideration. Nevertheless, the ages assigned below should for the most part be considered preliminary and subject to further study.

Puna Surface.- The Puna Surface is considered to have developed as a result of erosion of the uplifts produced by the Quechua I orogenic phase, dated at c.17Ma, and is ascribed an age of c.16Ma by Benavides (1999). This age is consistent with the fact that within the study area the Marcapomacocha stock, dated at c.15Ma (Bissig, op. cit.), appears to penetrate the Puna Surface. A similar situation occurs in the southern limit of the study area, where the Cerro Tunsho stock, dated at c.14Ma by Bissig (op. cit.) also penetrates the surface. It is assumed that in these cases the volcanic material originally associated with the stocks has been completely removed by erosion.

Punrun Surface.- Within the study area the Punrun Surface bevels the Cerro de Pasco stock, dated at c.15Ma (Bissig, op.cit.).

In the Castrovirreyna area of southern Peru, the Choclococha Tuff is dated at 12 – 13.9Ma (McKee and Noble, 1982), and is overlain by the sediments and volcanics of the Caudalosa Fm. The base of the sequence locally reaches 4800 – 4900m, but mainly lies at 4400 – 4600m. The writer's provisional interpretation is that the unit was deposited on the Punrun Surface, overlapping locally onto the Puna Surface. If correct, this would suggest an age of c.14Ma for the Punrun Surface, which would be consistent with the surface eroding the Cerro de Pasco stock.

Junin and La Oroya Surfaces.- Both surfaces are mantled by the Huayllay ignimbrite, dated at 5.2Ma (Bissig, op.cit), but are undoubtedly much older than that age suggests. Vidal (pers. comm.) has found that the Marcapunta Dome (dated at c.11Ma) lies on an erosion surface. The current study shows the dome to be surrounded by ridge tops at c.4300m, corresponding to the Junin Surface (Fig. 8), and it therefore appears reasonable to suppose that it is this surface which underlies the Marcapunta Dome. An

age of c.12Ma can therefore be provisionally assigned to the Junin Surface.

Although there are no relevant dates associated with the La Oroya Surface in the study area, useful information is available from the Cajamarca area, where a widespread erosion surface is found at 3800 – 4000m (Wilson, unpublished data). This feature is correlated with the La Oroya Surface on the basis of its elevation and position in a sequence of surfaces. The surface in question bevels the Hualgayoc stock, dated at c.13Ma (Macfarlane et al., 1994), and the Cajamarca ignimbrite, dated at 11.2Ma (Noble et al. 1990). Nevertheless, it is older than the Bambamarca ignimbrite / Frailes Fm., dated at 8.4Ma (Noble et al., op. cit.), which mantles lower erosion surfaces in the area. On this basis the La Oroya Surface can be provisionally assigned an age of c.10Ma.

Jauja Surface.- Although the Jauja Surface is locally mantled by the Mataule Fm., dated at c.5.4Ma by Wise (2007), the surface is probably much older than that date.

The surface is also developed in the Mariscal Cáceres area of the Huancavelica Quad., south of Huancayo (Wilson, unpublished data). Tuffs and travertines variously known as the Huando Fm. or Rumihuasi Fm. overlie the surface in the western flank of the R. Ichu valley south of Mariscal Cáceres, and have been dated at 7.3Ma (Megard, 1984). On this basis the Jauja Surface is assigned a provisional age of c.8Ma, though it may prove to be older than that figure.

DRAINAGE DEVELOPMENT

Prior to the initiation of the Andean uplift the Puna Surface extended across the whole of the Andean Belt. As recognised by McLaughlin (1924), there was a divide corresponding to the crest of the W. Cordillera, where a number of monadnocks still stand proud above the Puna Surface. From this divide river systems flowed to both the Atlantic and Pacific Oceans.

With the initiation of uplift, the Puna Surface began to be destroyed as a result of erosion by these river systems. The process was repeated in the pauses between the various episodes of uplift, giving rise to the sequence of erosion surfaces now found across the Andes and to the establishment of the existing river systems. The present study has confirmed the

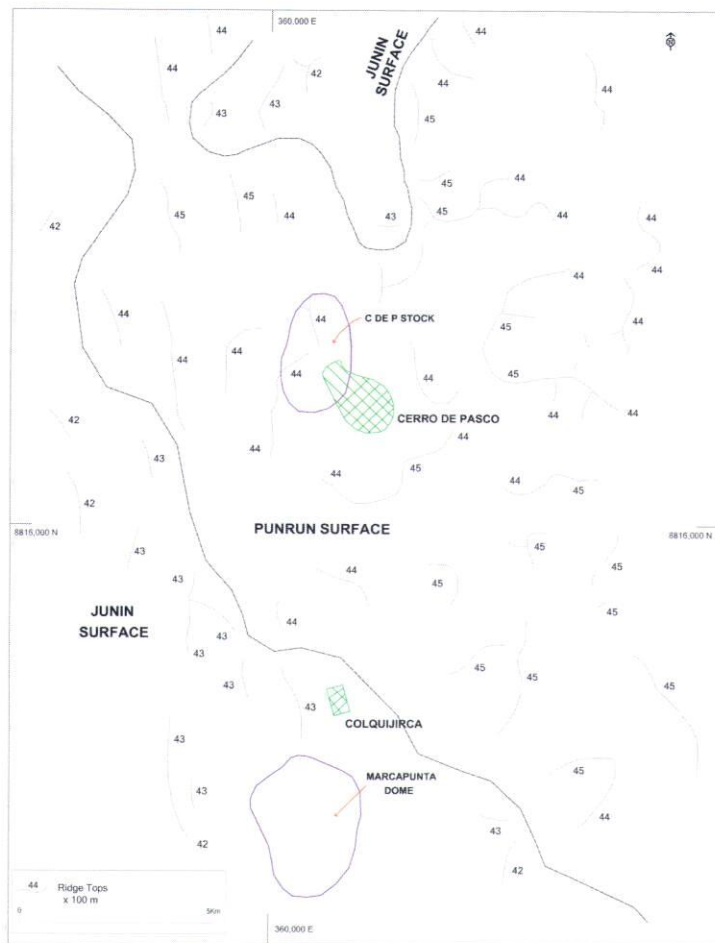


Figure 8. Cerro de Pasco area - distribution of erosion surfaces

antiquity of the main river systems and suggests some degree of structural control, as explained below.

Antiquity of the river systems

The distribution of the erosion surfaces in the study area indicated that the main river systems probably began to become established in their current positions at a time corresponding to the development of the Punrun Surface, which was associated with the early stages of development of the Huaura, Chillón and Rimac valleys (Figs. 2a, 2b). Similarly, the distribution of the Junin Surface indicates that the Tarma and Mantaro valleys also became established at least by the time of development of that feature (Fig. 2b). Finally, the main rivers were essentially in their present locations by the time the La Oroya Surface was formed. Subsequent events largely led to the progressive incision of the valleys in positions which were already well established.

Structural Controls

While there are no obvious structural features affecting the development of the river systems draining the Andean flanks, the strike streams of the intermontane area appear to owe their positions partly to structural controls. Thus the location of the R. Mantaro more or less coincides with the axis of a downwarp defined by the Punrun Surface (see below). The headwaters of the R. Marañón show a similar relationship to the downwarp, though it is best displayed in the La Unión Quad., beyond the northern limit of this study.

The Mantaro drainage upstream from La Oroya presents certain anomalies which merit consideration. Thus the palaeovalley west of Cerro de Pasco comprises a 10km wide belt of Junin Surface at an average elevation of c.4200m and which is currently drained to the SE by a quite small river characterised by abundant meanders and a low gradient. It is

difficult to envisage this river having had the power to erode a substantial valley. It is clear that there is a misfit relationship between the river and the valley.

This misfit may be the result of river capture. A possible scenario is illustrated diagrammatically in Fig. 9, where it is postulated that in Junin Surface time the current upper Mantaro was a northward flowing tributary of the R. Huallaga. It is envisaged that the L. Junin area also drained into the R. Huallaga at that time. Meanwhile, the Mantaro system was advancing from the SE by headward erosion, and captured some of the Huallaga headwaters, probably at the time of formation of the La Oroya Surface. The point of capture may lie in one of the areas upstream from La Oroya where the Junin Surface narrows appreciably.

The L. Junin basin thus possibly occupies what was initially a tributary valley to the Huallaga drainage. The basin was, however, deepened beneath the general level of the Junin Surface prior to its being infilled by Quaternary deposits to an altitude of c.4100m. It is not clear whether the deepening of the basin was the result of local subsidence, or erosion by glaciers descending from the nearby cordilleras.

STRUCTURAL CONSIDERATIONS

An important outcome of the current study is an appreciation of the geometry of the Andean uplift in central Peru, which itself may provide pointers in regard to the mechanics of that uplift. These aspects are considered below.

Geometry of the Andean Uplift

The general geometry of the Andean uplift in the study area can be appreciated by reference to Figs. 10 and 11, which illustrate the following features.

- 1.- While other areas of the Peruvian Andes contain narrow intermontane basins associated with both tensional faulting and compressive deformation, e.g. the Ayacucho Basin (Wise et al., 2008), the Andean Belt comprises a plateau-like feature more than 200km wide which was uplifted essentially as a single unit without significant internal deformation. Thus, although the uplift occurred within a compressive regime at the edge of the South American Plate, there is no indication of significant post-Puna deformation or crustal shortening within the study area.
- 2.- The NE boundary of the Andean uplift is marked by the SAFS, beyond which lie the largely

Neogene basins which developed on the flank of the Brazilian Shield. The high level erosion surfaces extend to within a short distance of the SAFS without showing any sign of a downward tilt or deformation, suggesting that this part of the Andean Block was uplifted more or less vertically along the SAFS. Rivers associated with the Amazon drainage eroded the edge of the uplift, leading to the development of the surfaces found in the E. Flank area. The relationship between the lower surfaces and the uplift will be the subject of a separate study.

- 3.- The situation at the SW boundary of the Andean uplift is less clear. In southern Peru both the Nazca and Puna Surfaces are tilted to the SW at 2 - 4° (Wilson, 2009). McLaughlin (1924) and Myers (1975) assumed that a similar situation prevailed in central Peru prior to the erosion of the Andean Flank. The present study shows that the Puna Surface extended to within 60km of the coast without any sign of a tilt, and it is possible that in central Peru the uplift of the western edge of the Andean Block was achieved by faulting rather than by flexuring. The change from flexure in southern Peru to a possible fault boundary in central Peru could be caused by the switch from normal subduction in the south to flat slab subduction in the central region. Both flexuring and faulting are shown as possibilities in Fig. 11. Regardless of their relative importance, the net effect was to produce a vertical uplift of c.5km across a belt not wider than a few tens of kilometres.
- 4.- Separating the two cordilleras is an elongate depression occupied by the headwaters of the R. Mantaro and R. Marañón. As explained above, the Punrun Surface slopes gradually down towards the R. Mantaro, and it appears that the intermontane depression was initiated as a structural downwarp (Fig. 11) which was subsequently enhanced by fluvial erosion (Fig. 10).

Mechanics of the Andean Uplift

The conventional view of the factors controlling the Neogene Andean uplift can be summarised as follows.

A gravity traverse across the W. Cordillera within the study area (Fukao and Yamamoto, 1988) revealed a gravity anomaly of up to -400mgal

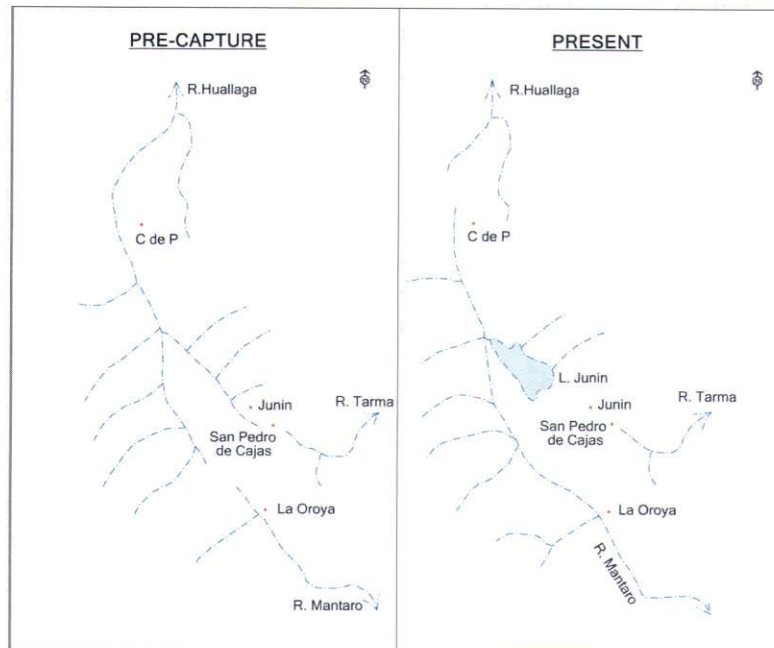


Figure 9. Possible drainage capture by R. Mantaro.

(Fig. 9), indicating a crustal thickness of c.55km. It is therefore assumed that the W. Cordillera is in isostatic equilibrium, the mass of the cordillera being supported by the thickened root.

Although there are no gravity data for the E. Cordillera within the study area, data from elsewhere (Fukao and Yamamoto, 1988) suggest a gradual thinning of the crust across the E. Cordillera, with an average gravity anomaly of c.-200 mgal. The E. Cordillera is therefore not in isostatic equilibrium. Fukao and Yamamoto (op. cit.) concluded that the E. Cordillera was supported either by underthrusting by the Brazilian Shield or by the pressure exerted by the Shield.

While this study does not resolve the precise mechanics of the Andean uplift, it can offer some potentially useful pointers, which are summarised below.

1. While the W. Cordillera is in general isostatic equilibrium, the mechanism of its uplift may prove more complicated than a simple response to crustal thickening. Thus if the uplift is directly related to the development of the root, it would be reasonable to expect the geometry of the uplift to mirror the shape of that root. However, the Puna Surface in the W. Cordillera is essentially flat over a width of 60 km and does not show any obvious

relationship to the gravity anomaly associated with the root (Fig. 11). The mechanics of the uplift may therefore be more complicated than conventionally thought.

2. It is now clear that there is no significant post-Puna deformation of the Andean Block of the study area. In the time frame covered by the erosion surfaces established in this report, i.e. c.16–8Ma, the Andean Block appears to have been uplifted as a rigid unit bounded on the east by the SAFS.
3. The deformation of the Subandean Belt is ascribed to the Quechua II orogeny (Benavides, 1999) and dated at 8.7Ma (Wise et al. 2008). The Andean Block had thus undergone 1000m or more of uplift prior to that orogeny. The uplift appears to have been achieved by movement along the SAFS in response to the pressure being exerted by the Brazilian Shield.
4. The Andean uplift during the 16–8Ma interval resulted from episodic movements which were simultaneous and of the same magnitude across the whole Andean Block. Thus, despite the differences in their crustal makeup, the same mechanism appears to have been involved in the uplift of both the E. and W. Cordilleras.
5. Preliminary work in the Subandean Belt indicates the presence of a sequence of erosion surfaces

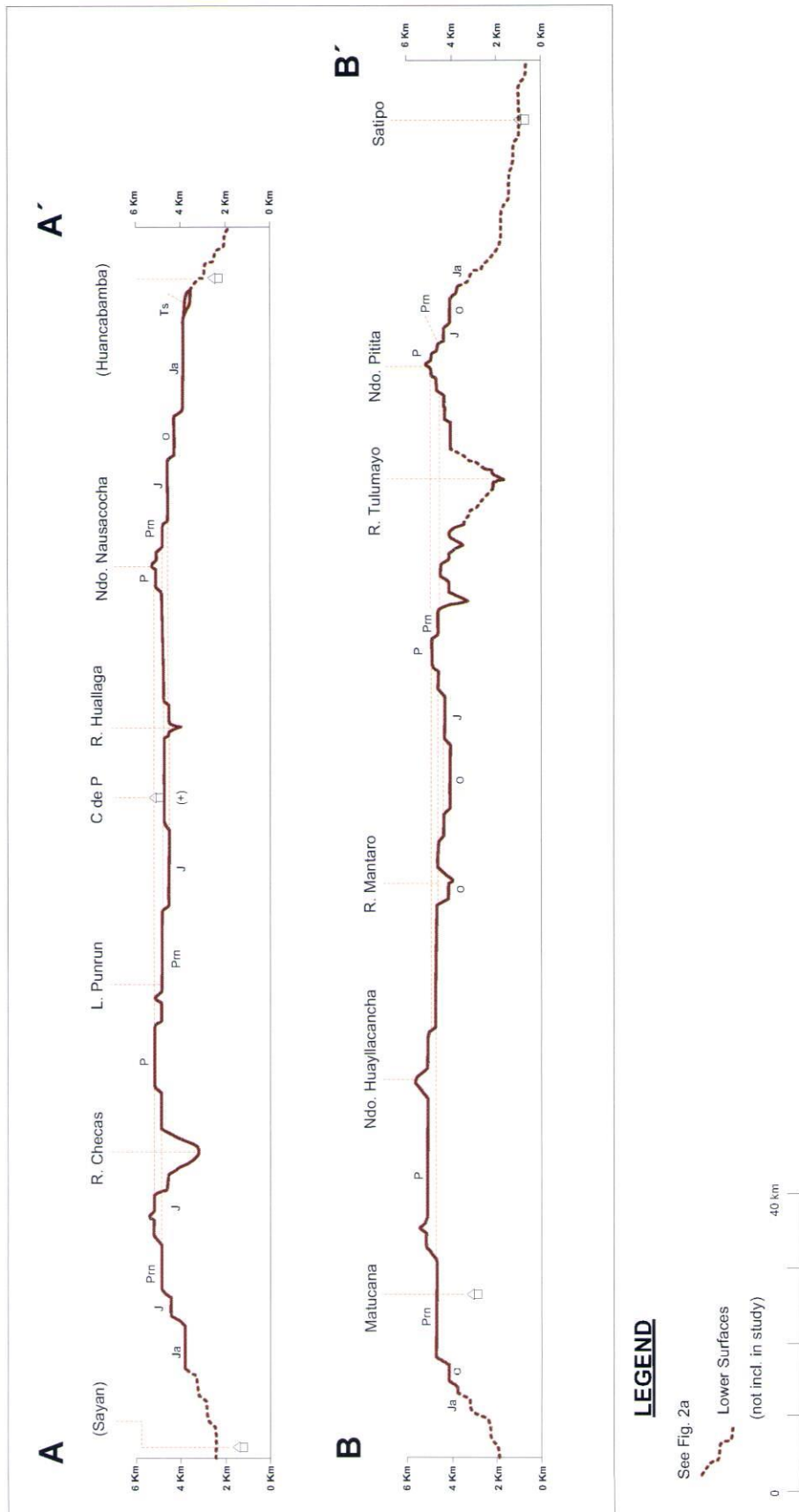


Figure 10. Topographic Profiles.

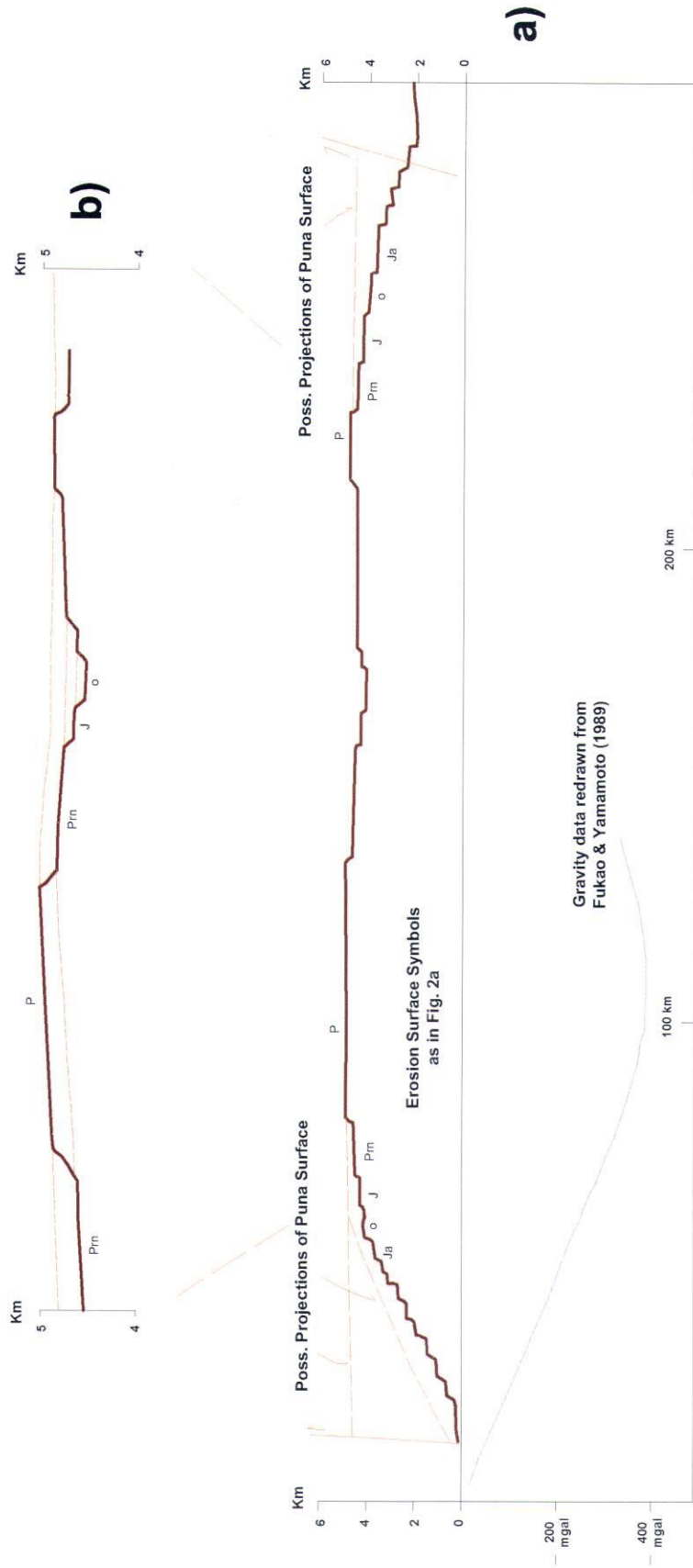


Figure 11. Schematic Structure.

bevelled both the folded Mesozoic units of that area and the eastern edge of the Andean Block. It therefore appears that after Quechua II, uplift of the Andean Block and the Subandean Belt continued in the same episodic manner as before the orogeny.

6. It may be speculated that the relatively brief episodes of uplift may represent the periodic release of pressure which had accumulated across the whole width of the Andean Block as a result of plate convergence.
7. There remains the issue of the relationship between the relatively frequent episodes of uplift demonstrated in this report and the infrequent compressive pulses ascribed to the phases of the Quechuan orogeny. Thus, following the Quechua I orogeny in c.17Ma, further phases have been postulated, the current dating of these phases being as follows (Wise et al., 2008).

QIVc.2Ma

QIIIc.5Ma

Unnamedc.8Ma

QII c.8.7Ma

Despite the fact that dating of the erosion surfaces recognised in this report remains uncertain, it is clear that there have been more episodes of uplift/erosion than can be explained by the conventional concept of the Quechua orogeny. It is therefore concluded that while the Andean uplift took place in a broad compressive regime which produced episodic vertical movements, it was a much more continuous process than is implied by the concept of specific orogenic phases. This conclusion supports the ideas of Sempere (2004), who questioned the validity of using orogenic phases in the Peruvian Andes.

CONCLUSIONS

1. Following development of the Puna Surface in c.16Ma, the Andean Belt of central Peru underwent a series of episodic uplifts which were separated by time intervals long enough to permit the development of reasonably mature erosion surfaces.
2. The high level surfaces in central Peru include the Puna Surface (4600 – 5000m), the Punrun Surface (4400 – 4700m), the Junin Surface (4100 – 4400m), the La Oroya Surface (3800 – 4100m) and the Jauja Surface (3400 – 3700m).
3. The surfaces occur in the same sequence and at the same general elevations across the whole Andean Block. This indicates that the episodic uplifts were simultaneous and uniform across the region, which in turn suggests that the same mechanism was at work throughout the whole Andean Block.
4. Although not formally described in the study, reconnaissance work indicates a sequence of mid and low level erosion surfaces which appear to occur on both sides of the Andes. If confirmed, this would further strengthen the concept of episodic uplifts affecting the whole region.
5. Although the Andean uplift occurred in a regionally compressive regime, there is no evidence of significant crustal shortening in the study area. The Andean Block appears to have acted as a single, more or less rigid, unit.
6. The episodes of uplift may be related to the periodic release of pressure accumulated within the Andean Block as a result of plate convergence.
7. In the W. Cordillera the relative importance of the above process and that of a progressive thickening of the root system remains to be resolved.
- 8.- Only very approximate ages can at present be given to the individual erosion surfaces, ranging from c.16Ma for the Puna Surface to c.8Ma for the Jauja Surface.
9. The episodic vertical movements which led to the development of the erosion surfaces were part of a continuous process different from that implied in the concept of specific and occasional orogenic phases.
- 10.- The current study will be extended into the Subandean Belt in order to formally establish the sequence of features occurring beneath the Jauja Surface, with the objective of obtaining further data on the mechanics of the Andean uplift.

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BIBLIOGRAPHY

- Benavides, V. (1999).- Orogenic Evolution of the Peruvian Andes: The Andean Cycle. In: *Geology and Ore Deposits of the Central Andes*; P.J. Skinner (Ed.), Soc. Econ. Geol., Special Public. No. 7. 61 – 107.
- Bissig, T., Ullrich, T.D., Tosdal, R.M., Friedman, R. & Ebert, S. (2008).- The time- space distribution of Eocene to Miocene magmatism in the central Peruvian polymetallic province and its metallogenic implications. *Jour. S. Amer. Earth Sci.*, 26, 16 – 35.
- Dollfus, O.(1973).- La cordillère des Andes : Présentation des problèmes géomorphologiques: *Revue de Géographie Physique et de Géologie Dynamique*, 15, 157 – 176.
- Dorbath, L., Dorbath C., Cisternas, A., Deverchère, J. & Sebrier, M. (1990).- Seismicity of the Huancayo Basin (central Peru) and the Huaytapallana Fault. *Jour. S. Amer. Earth Sci.*, 3, 21 – 29.
- Fukao, Y. & Yamamoto, A.(1989).- Gravity anomaly across the Peruvian Andes. *Jour. Geophys. Res.*, 94, 3867 – 3890.
- Macfarlane, A.W., Prol-Ledesma, R-M. & Conrad, M.E. (1994).- Isotope and fluid inclusion studies of geological and hydrothermal processes, northern Peru. *Internat. Geol. Review*, 36, 645 – 677.
- McKee, E.H. & Noble, D.C. (1982).- Miocene volcanism and deformation in the western cordillera and high plateaus of south-central Peru. *Geol. Soc. Amer.* 93, 657 – 662.
- Megard, F. (1984).- The Andean orogenic period and its major structures in central and northern Peru. *Journ. Geol. Soc. London*, 141, 893 – 900.
- Myers, J.S. (1976).- Erosion surfaces and ignimbrite eruption, measures of Andean uplift in northern Peru. *Geol. Journ.* 11, 29 – 44.
- Noble, D.C., McKee, E.H., Mourier, T. & Megard, F. (1990).- Cenozoic stratigraphy, magmatic activity, compressive deformation and uplift in northern Peru. *Bull. Geol. Soc. Amer.*, 102, 1105 – 1113.
- Noble, D.C., & McKee, E.H. (1999).- The Miocene Metallogenic Belt of Central and Northern Peru. In: *Geology and Ore Deposits of the Central Andes*: B.J. Skinner (Ed.), Soc. Econ. Geol., Special Publication No. 7, 155 – 193.
- Noble, D.C., Wise, J.M., Vidal, C., Zanetti, K.A. & Spell, T.L. (2009).- Existence and Nature of the Rio Rimac Drainage in Early to Middle Miocene Time. *Geol. Soc. Peru*, Vol. Especial No. 7, 163 – 170.
- Philip, H. & Megard, F. (1977).- Structural analysis of the superficial deformation of the 1969 Pariahuanca earthquake (central Peru). *Tectonophysics*, 38, 259 – 278.
- Sempere, T. (2004).- Las “Fases Tectónicas” en los Andes Centrales: Esplendor y Decadencia de un Paradigma Geológico. Soc. Geol. Peru, Public. Especial No.5, 203 – 216.
- Wilson, J.J. (2009).- Erosion Surfaces in the Andean Flank, Department of Ica. *Geol. Soc. Peru*, Vol. Especial No. 7, 151 – 162
- Wise, J.M. (2007).- Tectono – stratigraphic history of the Huancayo intermontane basin, central Peru. *Soc. Geol. Peru*, 102, 63 – 78.
- Wise, J.M., Noble, D.C., Spell, T.E. & Zanetti, K. (2008).- Quechu II contraction in the Ayacucho intermontane basin: Evidence for rapid and intense deformation in the Andes of central Peru. *Jour. S. Amer. Earth Sci.* 26, 383 - 396.