

# ANDEAN UPLIFT AND EROSION SURFACES NEAR UNCIA, BOLIVIA

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**ABSTRACT.** Such knowledge of the physiographic development of the central Bolivian Andes as exists has been gained from a few rapid reconnaissances. Detailed studies in the region around Llallagua reveal a set of four erosion surfaces that show the stages of intermittent uplift of the Cordillera. Physiographic and paleontologic evidence lead to the conclusion that the area was relatively low-lying toward the end of the Pliocene and that most of the uplift to the present elevations occurred during the Pleistocene. There was slight mountain glaciation during the Pleistocene, but two terraces and stream bed alluvium suggest two stages of glacial climate. The region is now experiencing an increase in aridity.

## INTRODUCTION

**A**LONG a section drawn east-west through central Bolivia (fig. 1) the Andes attain their greatest width, about 435 miles. This broad belt is composed of an eastern and a western cordillera separated by the Altiplano Basin. The rudiments of the geology of the Eastern Cordillera are known, for mining has been carried on at many widely separated points since the discovery of the Potosi silver deposit in 1545. Relatively little is known of the physiographic history. Moon (1939) gathered the scattered observations of many travellers and students but their data varies greatly in age and reliability. Gregory (1913) and Ahlfeld (1945) have discussed the origin of the spectacular gorge cut directly across the backbone of the Eastern Cordillera by the Rio La Paz. Bowman (1909, 1914) first noted the high level surface that truncates the Andean structures, and described the high shorelines that indicate the past higher levels of the Altiplano lakes, Poopo and Titicaca. Heald and Mather (1922), and Mather (1922) briefly mentioned a high erosion surface in the eastern part of the Eastern Cordillera. More recently Newell (1945, 1946) in the course of stratigraphic and structural work in the Lake Titicaca region, has clarified some of the events of the Tertiary.

With the intention of tracing the steps in the development of the Andean landforms the writer carried on field studies intermittently during the years 1942-45 in the region around Llallagua, where he was employed by the Patino tin mining interests. It is a pleasure to acknowledge here the aid given by

Marcelino Medrano of Cochabamba, Bolivia, who acted as muleteer, interpreter and guide on many a trip in canyon and high puna. In another sphere, the writer acknowledges his

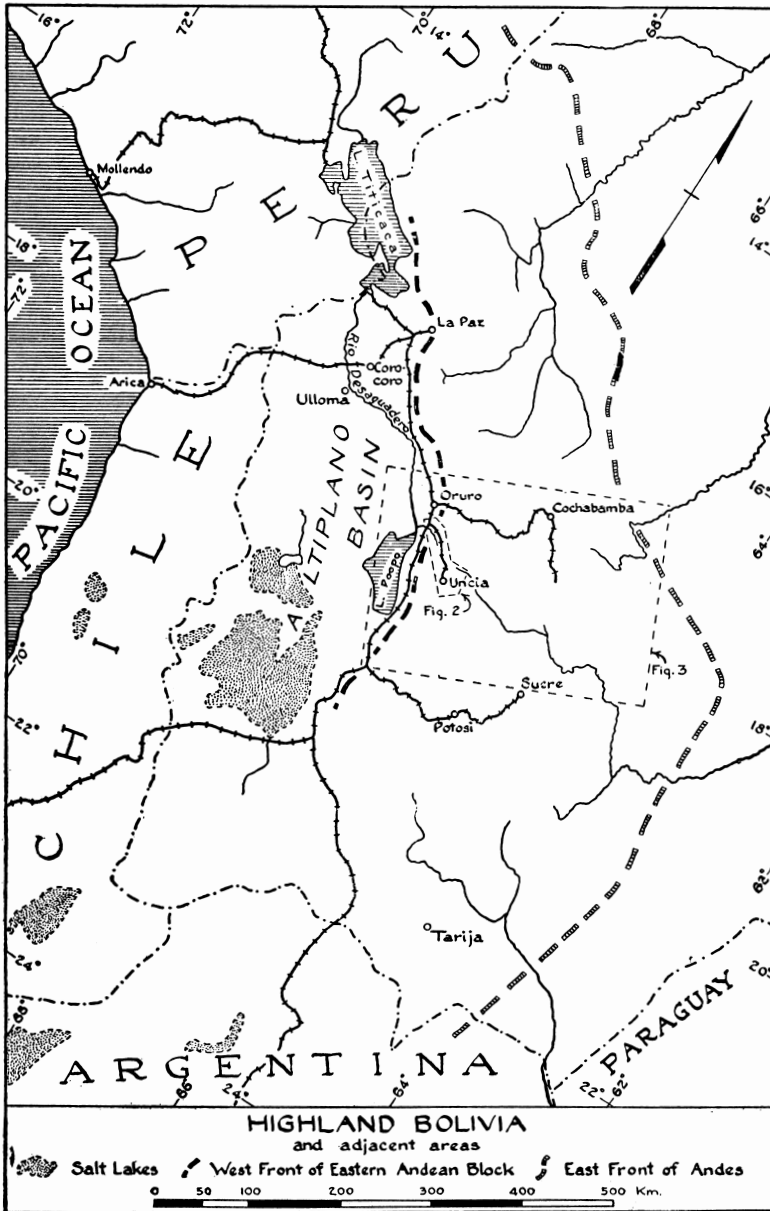


Fig. 1. Index map of Highland Bolivia.

indebtedness to Prof. Kirk Bryan of Harvard University for helpful criticisms and suggestions during the writing of this study. He also owes thanks to Prof. A. J. Eardley of the University of Michigan for his critical review of the manuscript.

#### GEOGRAPHY

The area studied lies a few miles east of the crest of the Eastern Cordillera, near Uncia (fig. 1), capital of the province of Bustillo. Llallagua and Catavi, the mine and mill settlements of the Patino Corporation, are nearby, and these towns are served by a railroad branching from the main line at Machacamarca (fig. 2). Machacamarca lies on a level plain which is an old lake bed, and a mile to the east the front of the Eastern Cordillera rises abruptly. The railroad climbs up the valley of the Rio Huanuni to the Paso del Bombo at 14,435 feet, where an extensive view is obtained of broad uplands of moderate relief, crowned by a few monadnock peaks. The total relief is somewhat more than 3000 feet, mainly due to deep valleys below the upland surface.

The elevation, coolness and semi-aridity of the area provide the steppe type of climate and the Andean bunch grass, *Stipa ichu*, is the strong dominant (pl. 1, fig. 2), though a carpet of shorter grasses usually is present between the clumps of ichu. At higher elevations a sparse growth of curious ground-hugging flowering plants gradually replaces the ichu, and in deep sheltered valleys some tall succulent grasses and a few shrubs appear.

Escobar (1943) shows the mean annual temperature to be about 9°C. (48°F.) and the precipitation about 400 mm. (15.7 inches). The precipitation is mainly as rain, from November to March. The mild winter then comes on and a couple of snowfalls of perhaps half an inch apiece may be expected, but hail is more frequent. Winter nights are frosty. Except during the rainy season the days are brilliant and cloudless.

The sparse vegetation permits rapid runoff so that torrents descend the minor watercourses during rainstorms, and all during the rainy season threads of water run in the braided channels that traverse the flat cobble-choked bottoms of the main valleys. In the succeeding dry season all minor streams

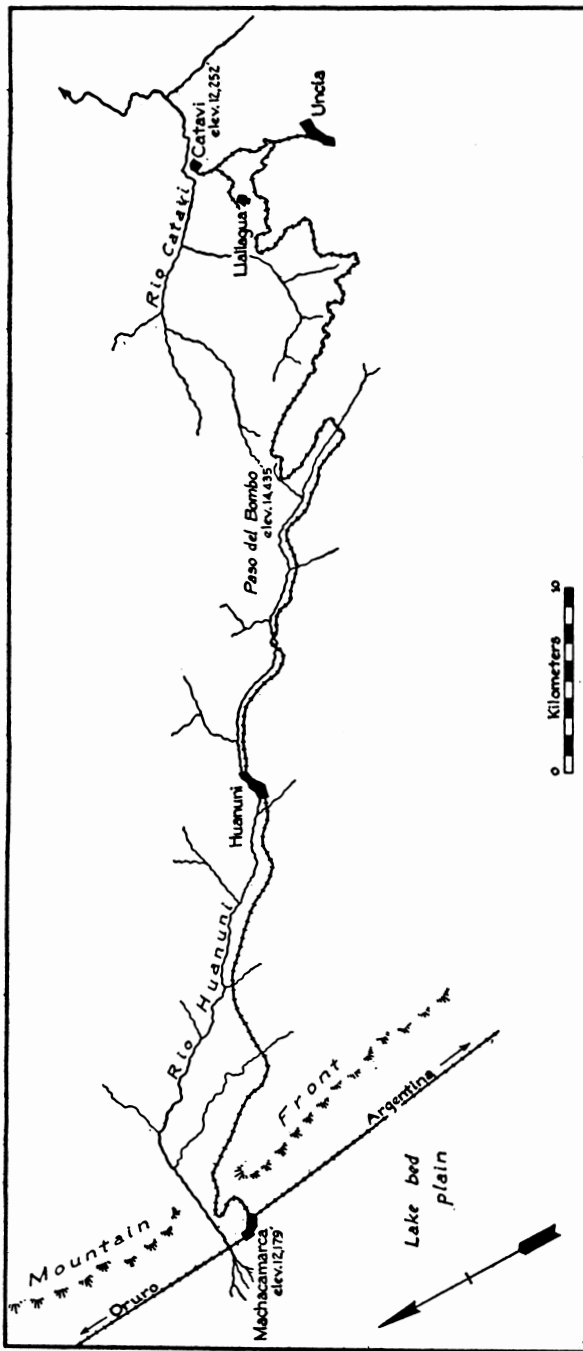


Fig. 2. Location map, Machacamarca-Uncia area.

are dry and the water gradually sinks out of sight beneath the surface of the alluvium in the main valleys.

The region is thinly populated by Aymara and Quechua Indians who have supported themselves since the most remote past by a simple pastoral and farming economy. The mining activity has introduced, more or less in the past 50 years, a town-dwelling population of about 30,000, mainly cholos (mestizos) of dominant Indian blood.

#### BEDROCK GEOLOGY

A section of about 6,000 feet of marine clastics and shales are exposed locally; they were first described by Koeberlin (1919). The strong Llallagua sandstone, about 200 feet thick, is a prominent ridge former. The rest of the sequence consists of greywacke, interbedded thin sandstones, and shales, all of intermediate to weak resistance to erosion. A few ill-preserved brachiopods found in a sandstone midway in the section are of Devonian age. Small patches of red continental sandstone and conglomerates lie with slight erosional unconformity upon the marine strata.

The Andean orogeny here created broad folds which strike northwest. Normally the folds are open, but stresses accumulated locally to cause overturned axial planes and thrust faults, both dipping steeply westward. A set of minor faults run northeast and cause short displacements of the northwesterly striking structures. A large normal fault runs north 30° west through Catavi and dips steeply west; the west side is dropped about 6,000 feet.

A volcanic neck, the Salvadora "stock," occurs along the axis of a large anticline. The cordierite-rhyolite of this body was greatly altered by the solutions that concentrated an enormous wealth of cassiterite locally.

Sheets of light gray tuff mantle broad areas. Though of similar composition to the rock of the volcanic neck, they lie on an erosion surface younger than the neck. The surface upon which they lie is undulating so that their thickness varies from about 150 feet to a feather edge.

The linear outcrops of resistant and non-resistant strata exposed along the fold axes have exerted the major physiographic control. The tuffs are resistant to erosion because of their light and porous nature which permits water to sink in rather than to run off. Thus the volcanics support mesas,

usually bordered by cliffs (pl. 2, fig. 2) which develop because of columnar jointing in the volcanics and undermining the seeps.

## PUNA STAGE

In the vicinity of the Paso del Bombo, the divide between the drainage eastward to the Amazon and that westward to the Altiplano Basin, there are patches of a terrane characterized by broad rounded shoulders with intervening swales and meadow-like expanses. This topography is at elevations from 14,200 to 14,500 feet and is localized upon the rocks of moderate to weak strength, between or near outcrops of the strong Llallagua sandstone which supports long ridges that rise 150 to 350 feet higher (pl. 1, fig. 1). Unfaulted blocks of sandstone cause a few monadnocks to rise still higher; the prominent peak Espiritu Santo has an elevation of 15,364 feet.

This surface is considered the equivalent of the Puna surface that McLaughlin (1924) described in the region near Cerro de Pasco, Peru, where

“In general, the surface truncated the complex structures of the Cordillera with indifference, except here and there, where the course of a particularly resistant stratum is marked by a hog’s-back ridge, or where a mass of intrusive rock forms an isolated hill or prominent group of hills of Monadnock type.”

“Puna” is the Quechuan word for the high and cool grassy uplands throughout the Andes. The presence of this surface in Peru has been verified by all later observers, most recently by Harrison (1943), and Newell (1946).

In the Llallagua region the remnants of the Puna surface decrease in area and practically vanish with increasing distance from the divide. The long hogback ridges on sandstone which stood above the surface persist still and give the even skyline of mid and far distance.

Heald and Mather (1922) recognized remnants of what is probably the Puna surface in the highland southeast of Cochabamba, and wrote that

“During the late Tertiary (?) this area was a low-featured peneplain, which is now represented only by ridgetops and a few undissected remnants.”

Still further south, in the sierras immediately west of Santa Cruz, Mather (1922) saw

“ . . . occasional upland surfaces with gentle slopes which

bevel the upturned sediments and are ordinarily surmounted by slightly higher rounded knobs."

The high mature surface that Bowman (1909) noted on the border between Bolivia and Chile at the crest of the Western Cordillera inland from Iquique, may also be the Puna surface.

Fragmentary as the evidence is, it is apparent that throughout a vast area of the Bolivian and Peruvian Andes a distinct surface bevels structures and intrusives. The surface is probably broadly arched at present. The traces of it are lost in the angular scenery of the Eastern Cordillera before it has declined much in elevation, and it is possible that its remnants end against a line of great faults that Bowman (1909) and Mather (1922) consider to separate the mountainous mass from the Amazon lowland. McLaughlin (1924) states that in western Peru the surface is ". . . obliterated by erosion before it descends much lower than 12,000 feet . . . ." The surface that Bowman (1909) described in the Western Cordillera slopes gently toward the Pacific beneath a thickening cover of late Tertiary sediments and volcanic effusives.

Figure 3 presents the rectangular drainage pattern on the eastern side of the Eastern Cordillera. Lengths of subsequent streams have taken northwesterly courses parallel to the folded structure but long stretches of the major streams run northeast across the regional grain. These transverse links presumably are remnants of the drainage of the Puna stage. It is usual to consider such transverse drainage to have developed by superimposition from a cover such as the coastal plain sediments furnished on the east slope of the Appalachians. Since no traces of such covering sediments exist upon the Puna surface, the relations are most readily explained by assuming superimposition from a cover onto an old age surface which existed above the Puna surface, but which was here wholly destroyed in the making of the Puna surface. Such a surface may eventually be found beneath covering sediments in the subandean foothills to the east of the zone of uplift. The subsequent streams, in any case, testify to a long history of differential erosion and piracy since Puna time.

#### VALLE STAGE

Some 900 to 1,000 feet below the remnants of the Puna surface is a terrane developed broadly across the upturned sediments. Along the main drainage divide massive ridges exist

above this level but elsewhere only occasional monadnock ridges survive along parts of the outcrop of the strong Llallagua sandstone. The landscape at this level is one of valley floors, usually very wide, above which mountains rise 1,000 to 1,400 feet.

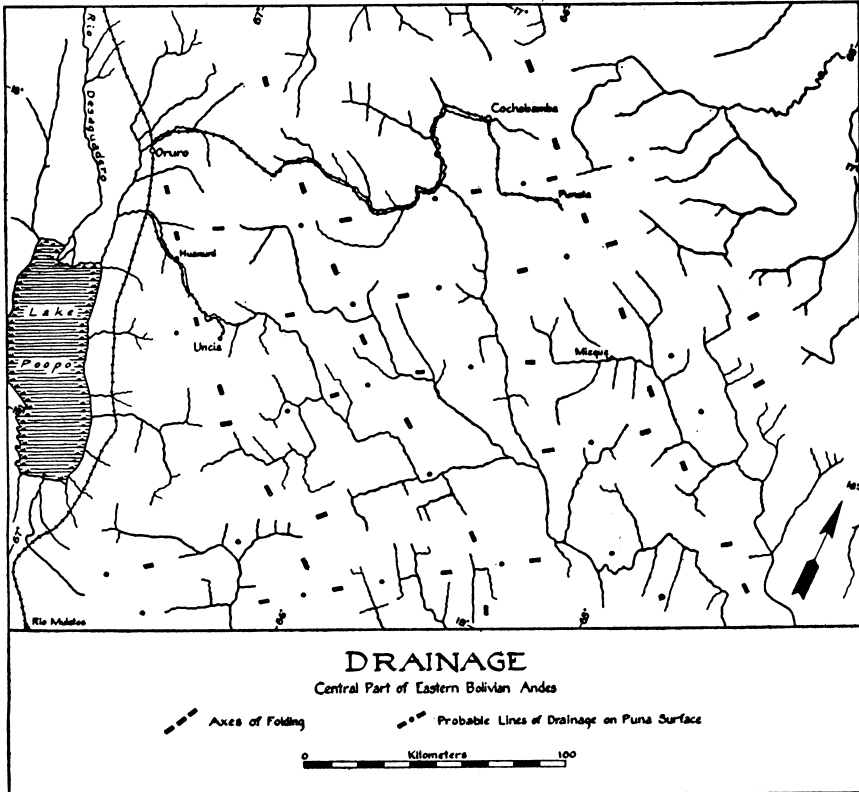


Fig. 3. Drainage of central part of Eastern Andes.

Volcanics, mainly firm tuffs, mantle much of this surface. In old valleys they may be 150 feet thick and they thin out upward on the old slopes. Usually the volcanics lie on bedrock that is weathered to a depth of several feet but in some places one may find stream gravels of quartzite marking buried drainage courses. The volcanics have diminished the local relief to produce the mildly rolling terrane typical of this main upland horizon (pl. 1, fig. 2).

These features record the following sequence of events. The slow course of erosion at the Puna level was interrupted by

uplift (and further west probably by faulting, as will be argued) which caused the streams to lower their courses approximately 1,000 feet before coming to grade. Long stillstand allowed reduction of most of the area to the new level. Weathering of bedrock and the existence of only resistant rock types, mainly quartzite, in stream channels testify to ample chemical weathering at this time.

Probably this interval of valley broadening should be correlated with the Junin stage that McLaughlin (1924) described, for in Peru, after the long stillstand of the Puna stage "An early, rather slight uplift, followed by a long period of quiescence, allowed the development of a series of broad valleys with flat gradients and gentle side slopes." The type locality, the Junin Valley, provided a name for this surface and stage. Since 800 miles separate the localities studied in Peru and Bolivia the correlation is uncertain and the present writer applies the name Valle to the surface in Bolivia. This Spanish word refers to broader and more mature drainage basins than the English word valley, and seems appropriate for the open terrane that resulted from the erosion of this stage.

#### CHACRA STAGE

About 500 feet below the Valle surface, or slightly less than halfway down to the present stream beds, there are traces of a surface. Along the valleys of main streams the vigor of later erosion has left of it only a few flat-topped spurs and occasional gravel-strewn benches. Larger tracts, still little dissected, persist along the courses of those minor streams and headwaters that had the fortune to lie upon the less resistant bedrocks. Such an area is illustrated in plate 2, fig. 1. Another prominent trace of this surface (pl. 2, fig. 2) owes its preservation to a piracy which greatly weakened the stream that crosses it; the stream is now intermittent and so incompetent that even though it crosses soft shales a hanging junction has developed where it joins the main stream.

This surface is important chiefly as evidence of a pause in the major downcutting of post-Valle time. The volcanics that blanket the Valle surface were perhaps the surface manifestation of deep seated disturbances accompanying a regional uplift that brought about renewed downcutting. In some cases the slopes beneath volcanic cover incline gently toward the pres-

ent valleys, indicating that the main streams were able to hold to their courses, though the pattern of the minor streams was effaced. Downcutting continued for about 500 feet, at which point a pause allowed valleys to be broadened upon softer bedrock.

This surface seems likely to correlate with the benches McLaughlin (1924) described in Peru midway between the uplands and the valley floors and is given the same name. "Chacra" signifies a small plot of tilled ground; here in Bolivia as well as in Peru much of the cropland of the Indians is at this level, below the bleak uplands and above the generally stony valley floors.

#### PIEDMONT STAGE

A very obvious surface of planation lies 400 to 500 feet below the Chacra remnants and 150 to 200 feet above the stream beds. Along those portions of the valleys floored with shales and thin-bedded sandstones are expanses as much as several miles wide, the "pampas" of the region. These old valley floors constrict to canyons at the outcrops of the Llallagua sandstone. No counterpart of this surface has been described elsewhere and it will be referred to as the Piedmont surface since it forms so prominent a footslope below most of the local relief.

It is characteristic of this surface that bevelled bedrock inclines toward the valley centers (pl. 3, fig. 1). Where bedrock is mantled with alluvium (pl. 3, fig. 2) the sloping bedrock can be seen in the walls of the quebradas or gulches that trench below the alluvial cover. We have here a rock pediment rather than a surface of lateral planation. The alluvium reaches a thickness of 100 feet in some places but always thins to a frayed edge toward the hill and mountain slopes.

At its base the alluvium is coarse and cobbly, but not badly sorted; low grade placers of cassiterite have encouraged some prospecting. Upward from the base the grain size at first decreases slightly; then a transition sets in and particle size increases till the alluvium becomes even bouldery. Some of the stones are ill-rounded, many of them bear the percussion marks showing handling by torrential streams. This coarse material grades unevenly upward through finer grained zones and at the top of the section there are lenses of sand and silt.

At one locality there is in the upper part of the sequence a thin bed of peat. It is reported that a number of years ago the remains of a mastodon were found in the higher part of the alluvium.

The significant downcutting from the Chacra surface indicates resumption of the spasmodic Andean uplift, and the pediment surface strongly suggests drier conditions than previously. The lower alluvium can probably be considered a normal accumulation on a pediment graded to an incompetent stream, but some explanation must be found for the change midway in the alluvial section.

The coarsening of the alluvium apparently records accelerated erosion of slopes and delivery of excessive loads to lowland streams. The writer believes that this was due to the onset of glaciation in the Andean region. Snowline was high here, for only above 13,500 feet are there striated outcrops and there are no obvious moraines. Waste was not moved down to the valley floors by ice. However the colder climate undoubtedly increased the available supply of waste because of frost breaking of rocks and decreased vegetation cover, and solifluction would hasten material downslope. Valley trains of alluvium were spread.

During the waning stages of glaciation finer sizes of sediments were deposited. The mastodon remains and the patchy peat deposits indicate a cool and damp climate toward the end of this period, with broad marshy valley flats traversed by braided or meandering streams.

#### LATER PLEISTOCENE STAGE

Below the Piedmont surface some 200 feet or less there are flat valley floors strewn with coarse alluvium (pl. 3, fig. 2). West of the divide and downstream from the Huanuni mine the valley of the Rio Huanuni is at places more than a mile wide and the gravels are so thick that a large floating dredge is employed to work them for their cassiterite content. This particular sheet of alluvium was clearly graded to the level of a lake which occupied the Altiplano Basin to the west and which left prominent shoreline features about 115 feet above the basin floor. This was Lake Minchin; lake bed sediments and the delta deposits lain by the Rio Huanuni have been exposed near Machacamamarca by later stream cutting.



REMNANTS OF THE PUNA SURFACE

Foreground elevation about 14,400 feet. Puna surface at (a); monadnock on Puna surface at (b).



VALLE SURFACE MANTLED WITH VOLCANICS

Foreground elevation about 13,500 feet. Puna ridgetop at (a); upland on volcanic mantle at (b); bedrock hills of Valle surface at (c).



## HEAD OF HUANUNI VALLEY

Foreground elevation about 14,300 feet. Level skyline at (a) is Puna surface; at (b) a portion of the Valle surface preserved beneath volcanic cap; the Chacra surface, little dissected is at (c).



## CHACRA VALLEY

Volcanics overlying Valle surface at (a). The light colored zone marks the base of the volcanics. The Chacra surface at (b) has here an elevation of about 12,700 feet.



FIGURE 1. MIDDLE COURSE OF HUANUNI VALLEY

Elevation of immediate foreground is about 13,000 feet. At (a) is a large remnant of the Chacra surface; at (b) the Piedmont benches cut across folded shales and thin sandstones.



FIGURE 2. VALLEY OF RIO CATAVI

At (a), elevation 12,400 feet, the surface of the alluvial fill on the Piedmont surface; at (b), the braided channel of the Rio Catavi. Immediately above (c) is a small patch of the Chacra surface, downstream from a gorge cut across the Llalagua sandstone.

The trenching of streams below the Piedmont surface began after the first glaciation, and locally the streams lowered their courses as much as 100 feet into the bedrock beneath the alluvium. Renewed alluviation seems to have been due to a second period of glacial climate. The deep fill in the lower part of the Huanuni valley evidently is due to the fact that the gradual rise of Lake Minchin lifted the base level of the Rio Huanuni at least 115 feet and caused aggradation far upstream. East of the divide streams are locally graded to strong beds outcropping in their channels and ultimately to the Atlantic, so local aggradation was due to overloading during glacial climate.

#### RECENT EROSION

Due to the disappearance of Lake Minchin, the Rio Huanuni and other streams draining westward to the Altiplano Basin have begun to trench their valley fill. The nickpoint in the Huanuni valley has advanced only about three miles upstream. In general, erosion in main stream beds is taking place very sluggishly due to coarseness of the load to be removed, and small supplies of water. East of the divide, however, the great drainage systems slowly concentrate many trickles of water into single channels, with the result that erosion increases rapidly downstream.

At the present, hill slopes are being gullied, and small arroyos are being cut in the alluvial floors of many tributary streams. Here most of the steep slopes are very thinly covered with bunch grass, others are almost totally barren. Without doubt this erosion is partly due to the land use tactics of the Indians. The search for fuel is intense; hardly a bush survives after its stem attains the thickness of a lead pencil. The bunch grass may be hauled up roots and all for fuel or thatching. The more palatable grasses are cropped closely by sheep and llamas. The marvellous and laboriously built andenes or rock walled terraces built in ancient time still persist on the hill slopes, but the narrow strips of soil they provide are now neglected in favor of larger fields of considerable slope. The accelerated erosion is therefore partly induced by land use.

It is proper, however, to point out the evidence of increasing aridity. The level of Lake Titicaca in the northern part of

the Altiplano has been falling slowly for decades, so that the approaches to steamship wharves have had to be dredged repeatedly. The volume and depth of the Rio Desaguadero, the outlet of Lake Titicaca, have notably decreased with the result that Lake Poopo receives less water and has shrunk greatly. Slope erosion in Bolivia, as in the southwestern United States, is due probably to a combination of climatic change and severe use.

#### SUMMARY OF HISTORY AND DATING OF EVENTS

In the area under discussion paleontologic evidence for dating the surfaces and events is absent so it is necessary to establish correlation with areas where such evidence, scanty as it may be, does exist.

The cutting of the Puna surface is the first event for which a date is required. The surface truncates the folds and intrusives of the Andean region so the date of the orogeny sets a maximum age limit to the surface. Unfortunately the date of the orogeny is still disputed. Berry (1919) assigned the orogeny to the late Pliocene because he dated as Pliocene the plant leaves that are found in the folded sediments at Coro-Coro in the northern Altiplano of Bolivia. At Potosi, sediments with similar leaves are little deformed, but are cut by a volcanic neck.

Near Ulloma, in the broad valley of the Rio Desaguadero south of Lake Titicaca (fig. 1) the slightly consolidated "Puna" beds lie essentially horizontally upon a surface that bevels the older folded sediments. The surface is probably the Puna and in any case it can hardly be older. The Puna beds contain a rich mammalian fauna of *Hippidion*, *Mastodon*, *Scelidotherium*, *Myiodon*, and *Megatherium*, which Philippi (1893) dates as Upper Pliocene. This occurrence suggests that the Puna surface was fully developed at or before the end of the Pliocene.

The evidence from these two localities is conflicting, or at best allows only a fraction of Pliocene time for the folding, intrusions, uplift and long erosion. The recent tendency has been to ignore the date assigned to the fossil leaves and to make the orogeny earlier than Pliocene. Turneure and Welker (1947) believe that the intrusives date from some part of the interval between the Eocene and the Pliocene;

Steinmann (1929) has shown that much if not all the folding in Peru is early Tertiary, and Bruggen (1934) finds a similar date in Chile. Ahlfeld (1941) writes

“Groeber maintains that the principal Andean folding in northern Argentina took place in the interval between the Oligocene and the Miocene. As long as the exact determination of the age of the folding in Bolivia is not possible, we are going to accept that this took place at the same time as in northern Argentina.”

In his recent paper Newell (1946) refers the latest Andean folding to the Miocene.

The evidence is therefore fairly strong that the erosion of the Puna stage took place during a large part of Pliocene time and the surface was completed and locally mantled with the Puna beds before the end of the Pliocene.

The undisturbed Puna beds raise a problem as to their origin and relations to the later erosion surfaces. Patches of these sediments occur throughout the Altiplano Basin. At Ulloma, Ogilvie (1922) reported “. . . reddish and yellowish sands with irregular lenses of gravel and occasional marl and clay bands . . .,” while nearby at Mauri Ahlfeld (1941) mentioned rose colored marls and sands and conglomerates. In the valley of La Paz the writer has seen loose red and white sands interbedded with conglomerates containing pebbles from the Tertiary granites not far to the east.

Similar beds lie in local basins within the Eastern Cordillera, at Cochabamba and at Tarija, according to Oppenheim (1943). In the southernmost part of Peru, just north of Lake Titicaca, Gregory (1914) and Eaton (1914) found and described basin sediments of the same type. Their locality is near Ayusbamba in the Upper Apurimac Basin, where loosely consolidated sands, clays and marls lie with great angular unconformity on folded bedrock. The beds are remarkable for their fauna of *Camelidae*, *Equidae*, *Cervidae*, *Elephantidae*, and *Mylontidae* of late Pliocene or early Pleistocene age.

These occurrences have in common their considerable altitude, ranging from 8,500 feet at Cochabamba to 12,300 feet at Ayusbamba, the great unconformity separating them from the older rocks, and their lithology. They are the clastics deposited in stream channels, on flood plains and deltas, and

the marls and clays of lakes and swamps. Red beds are common. Drainage was to local basins rather than through-going. The climate was warm and the land low-lying if we take the red beds to signify tropical or sub-tropical weathering of the source areas, and clearly the herbivores required abundant vegetation.

The change from the through-going drainage upon the Puna surface to the basin drainage indicated by the Puna beds is most reasonably explained by assuming that block faulting took place. Moon (1939) first suggested faulting as an explanation for the basins, although McLaughlin (1924) had earlier considered that “. . . some warping and possibly block faulting . . .” ended the Puna stage in Peru. Newell (1946) agrees that the Altiplano Basin of Bolivia is probably a broad crustal segment downdropped with respect to the Eastern Cordillera. The relatively straight west front of this Cordillera is the much eroded fault line scarp.

The new relief provided by this faulting set erosion to work upon a weathered terrane. Part of the detritus accumulated in the Altiplano Basin and the smaller intermontane basins to form the Puna beds, part was removed eastward toward the Amazon Basin. The east-running streams gradually opened out the Valle surface, to be dated as Plio-Pleistocene because of contemporaneity with the Puna beds.

As previously mentioned, lithology and fauna of Puna beds indicate low-lying land. The subsequent uplift, which amounts to about ten or twelve thousand feet in some places, must have taken place in the Pleistocene. A similar conclusion as to the recency of the Andean uplift was obtained by Harrison (1943) from his work in Peru. If one million years are allotted to the Pleistocene (Zeuner, 1945), the rate of uplift if steady would have been about 0.01 feet per year. The post-Valle erosion surfaces show that uplift was not continuous, so the rate must have exceeded this figure considerably at times.

The volcanics emitted in the Llallagua region at the close of the Valle stage apparently have their counterparts throughout the Andean region, for vast areas around and east of Potosi are thickly blanketed. To the north volcanics are still widespread, but much thinner. At Mauri the Puna beds are overlain by tuffs, and dacitic ash is mingled with the upper beds at Ayusbamba. It is probable that the great volcanic

piles of the Western Cordillera began to form at this time. The region-wide vulcanism, as well as the climatic change due to uplift, was no doubt a factor contributing to the extinction of the herbivores of the Puna beds.

The Chacra surface is early Pleistocene and significant only as evidence of pause during uplift. The rock-cut floor of the Piedmont surface is a pediment and gives the first evidence of semi-arid climate. This climate may have been due merely to elevation and position far inland; it may also mean that by this time the Western Cordillera had grown high enough to further modify the inland climate.

The nature of the alluvial fill upon the Piedmont surface furnishes evidence of the first of the two glacial stages recorded in the Andes. This stage should be recorded by high shorelines in the Altiplano Basin, but in the southern part of the Basin no such shoreline except that of Lake Minchin is evident. Up to 100 meters or 330 feet above Lake Titicaca are the shorelines of Lake Ballivian described by Bowman (1914) and others (see Moon 1939). Newell (1946) believes that the first lake to occupy the Titicaca basin was pre-glacial, but some of the beaches above the present lake may eventually be shown to illustrate the first and second glacial stages.

In the Llallagua area an interglacial is clearly evident in the interval of erosion that separates the two stages of alluviation, and the second stage of alluviation has, in the case of the streams draining to the Altiplano, been directly correlated with the Lake Minchin beach.

The climate is at present suitable for the formation of pediments and this is the form now developing west of the divide in response to the more or less stationary base level furnished by the Altiplano Basin. East of the divide the slow pace of stream-bed erosion is due to be quickened fairly soon. The Rio Catavi, which may be taken as typical of east-running streams, has an overall gradient of 131 feet per mile in the first 35 miles of its course downstream from Catavi. Canyons will be cut before grade is reached. The divide between east- and west-running drainage is destined to shift westward until ultimately the Altiplano Basin will be drained eastward to the Amazon. This stage of drainage development has already been reached in the northern part of the Altiplano Basin;

the gorge in which La Paz lies is a trench excavated in the soft fill of the Basin by a headwater of the Amazon.

#### CONCLUSION

The principal aim of the writer has been to establish a satisfactory outline of the events of the late Tertiary in the Eastern Cordillera of Bolivia. This has involved reference to other localities about which a meager amount is now known. A framework of reference has been provided, however, for the scattered observations that will slowly accumulate, and perhaps for further systematic studies in small areas. The high Andes offer a practically virgin field for geomorphic study; the stages of glaciation and the glacial lakes are perhaps the most important problems inviting study.

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