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ABSTRACT

An expedition to the Cordillera Huayhuash in the north-central Andes of Peru has shown the range consists of complexly folded and thrust-faulted Cretaceous sedimentary rocks, and less deformed early to middle Tertiary(?) andesitic volcanic rocks, all intruded by granitic plutons thought to be as young as 9 m. y. B.P. A younger sequence of felsic ash flows has escaped folding and intrusion. Unlike the Cordillera Blanca to the north (a batholith), the major 6,000 m summits of the Cordillera Huayhuash are carved from a complex synclinorium of Upper Cretaceous Jumasha Formation carbonates.

The region has suffered two deformations. The first deformation was the most severe, producing tight flexural-slip and flexural-flow folds and east-directed thrust faults between Late Cretaceous and middle(?) Tertiary. During deformation, detachment of the Cretaceous prism from some unexposed "basement" occurred at the horizon of basal Cretaceous Oyon Formation shale. Less severe middle(?) Tertiary deformation warped andesitic volcanic rocks into broad gentle folds, and may have either reactivated or initiated thrust faults.

Field data and hypsometric (area altitude) analysis suggest the middle to late Tertiary Puna erosion surface is represented in the Cordillera Huayhuash by accordant flanking ridgetops and a landmass concentration below 5,000 m. The 6,000 m axial ridge stood above this surface as a residual mass around which ash flows were deposited. Latest Tertiary to Quaternary orogenic uplift, perhaps during the last 6 m.y., incised drainage and represents the most recent deformation of the region.

INTRODUCTION

The Cordillera Huayhuash (Fig. 1) stands in splendid isolation on the crest of the north-central Andes of Peru, 110 km northeast by east of the Pacific coast, and 200 km north of Lima (Fig. 2). The range forms a serrate snow- and ice-clad ridge 40 km long and more than 5,000 m high, extending in a northerly direction close to long. 75°55′ W., between lat 10° 4′ and 10°25′ S. Along its central portion the range is dominated by six peaks more than 6,000 m high, culminating in Nevado Yerupaja (6,634 m), the second highest mountain in Peru. The axial ridge of the Cordillera Huayhuash forms the continental divide drained on the west by tributaries of the Rio Pativilca, and by tributaries of the Rio Maranon on the east. Total relief in the region is about 4,000 m.

The Cordillera Huayhuash is most easily reached by 158 km of dirt road from Paramonga on the Pacific coast to Chiquian (3,400 m), which is 35 km northwest of the range (Fig. 2). From the road-head at Chiquian, travel is on foot or horseback. Trail time to the foot of glaciers is a two- to five-day effort.

No published systematic geologic study of the Cordillera Huayhuash has appeared prior to this report. In 1936, three Austrian geographers explored the range, compiled a topographic map, and wrote a report (Kinzl and others, 1942) including descriptions of orography, glaciology, and cultural geography. Heim (1948) commented on brief geologic observations in the range. Kinzl returned in 1954 and later published a book of photographs (Kinzl, no date). Bodenlos and Ericksen (1955, p. 140-153) published descriptions of several mines in and about Cerro Culebras on the northwest flank of the range.

CRUSTAL CONSTITUTION

General Statement

Rocks of the Cretaceous, Tertiary, Quaternary, and Holocene are exposed in the Cordillera Huayhuash with a total thickness of about 4,500 m (Fig. 3). More than 80 percent of the outcropping rocks are Cretaceous (Fig. 4) and are composed of 3,000 m of marine sediments. Tertiary rocks include minor continental red beds, more than 1,500 m of older intermediate volcanic rocks, and over 750 m of younger felsic volcanic rocks. Cretaceous rocks, continen-

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Figure 1. Cordillera Huayhuash from above Chiquian. View southeasterly from 3,600 m. Rio Pativilca runs left to right in deep canyon (P). Quebrada Llamac (L) is tributary to Rio Pativilca at 2,700 m. Highest summit is Nevado Yerupaja (6,634 m). Snow line is at about 5,000 m. Nevado Yerupaja and summits to left on snow-clad axial ridge are carved from folded Upper Cretaceous limestones. Summits to right on Tsacra Spur are carved from Tertiary volcanics. Ridges and valley walls in foreground, and across Rio Pativilca, are carved from folded Lower Cretaceous sandstone and shale.

tal red beds, and the older volcanic rocks are intruded by scattered late Tertiary granitic plutons. Quaternary and Holocene rocks are glacial deposits, valley alluvium, and talus. Regional considerations suggest the Cretaceous sedimentary prism is floored by a Paleozoic "basement" composed of metamorphic rocks equivalent to the Excelsior Group (Jenks, 1956, p. 222; McLaughlin, 1924, p. 598; Harrison and Wilson, 1960, p. 34-35) of central Peru with the possibility of some Jurassic rocks just below the Cretaceous (Steinmann, 1930, p. 84-86; Bodenlos and Ericksen, 1955, p. 18-21).

Cretaceous Rocks

The 3,000 m of Cretaceous sedimentary rocks in the Cordillera Huayhuash are the pre-Albian Goyllarisquisga Group (Wilson, 1963, p. 9), made up of basal Oyon Formation shale, Chimu Formation orthoquartzite, Santa Formation limestone, Carhuaz Formation sandstone and shale, and the Farrat Formation orthoquartzite. This group is followed above by Albian to Turonian carbonates with interspersed shale made up of the Pariahuanca Formation limestone, Chulec and Pariatambo Formations limestone and shale, and Jumasha Formation limestone. The pre-Albian Goyllarisquisga Group thins just east of the range, loses limestone and shale, and changes facies into the Goyllarisquisga Formation (Wilson, 1963, p. 9-14). West of the range the early Tertiary coastal batholith obscures correlations, but Cretaceous detrital and volcanic rocks of eugeosynclinal aspect crop out along the Pacific coast (Wilson, 1963, p. 6-8). The Cretaceous stratigraphy described by Benevides (1956)

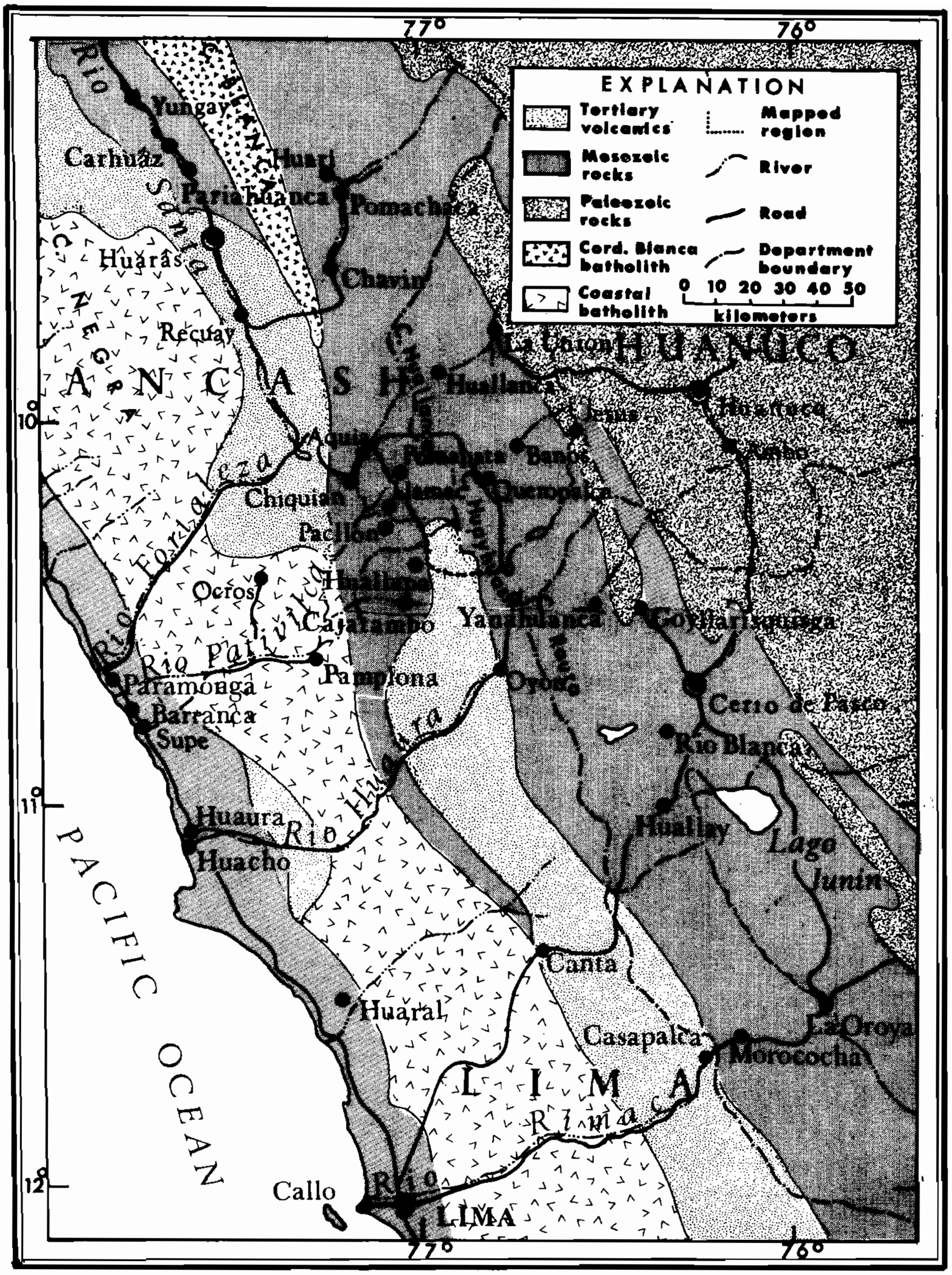


Figure 2. Generalized location and geologic map of the north-central Andes of Peru (geology *after* Bellido and others, 1956).

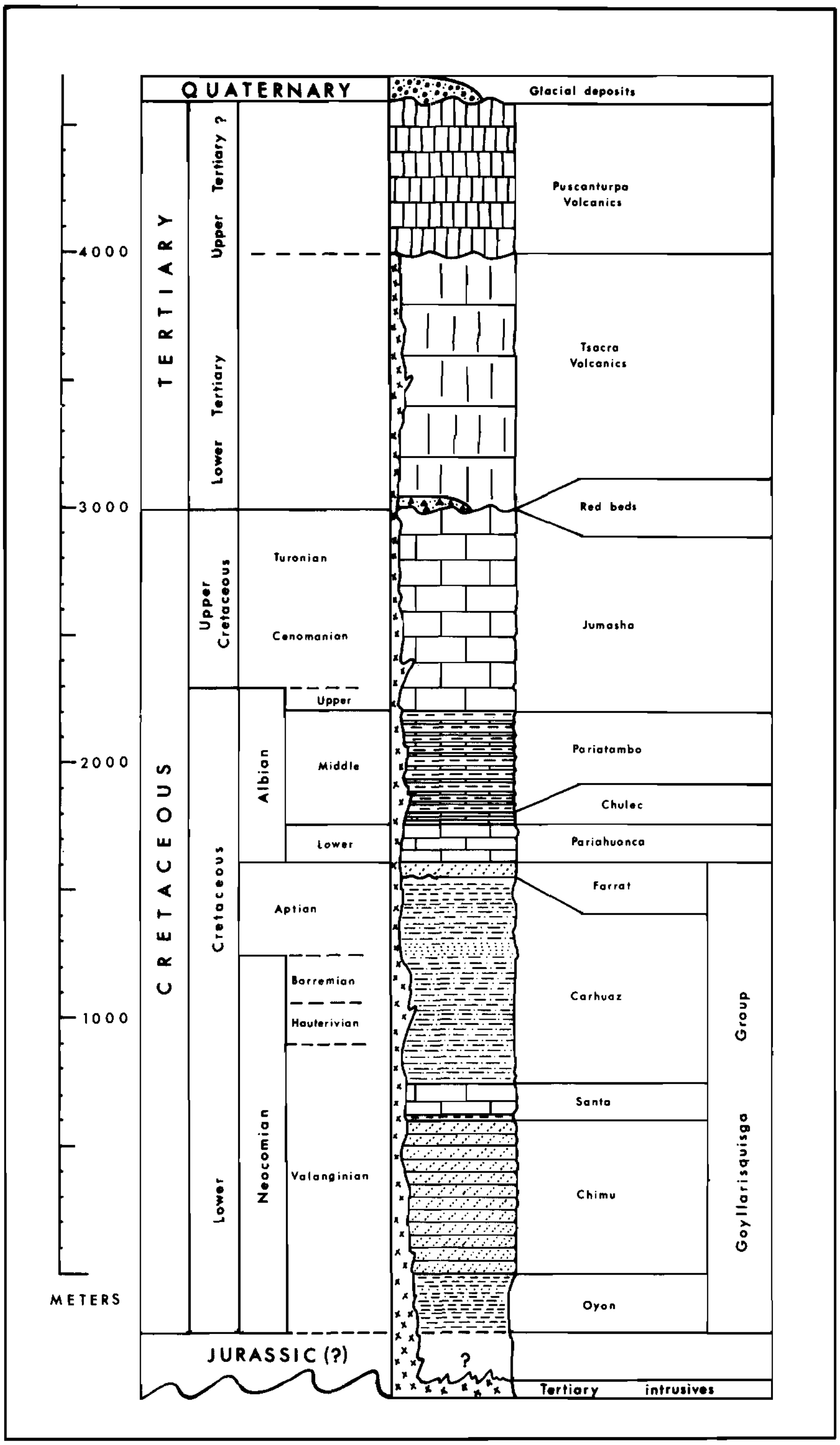
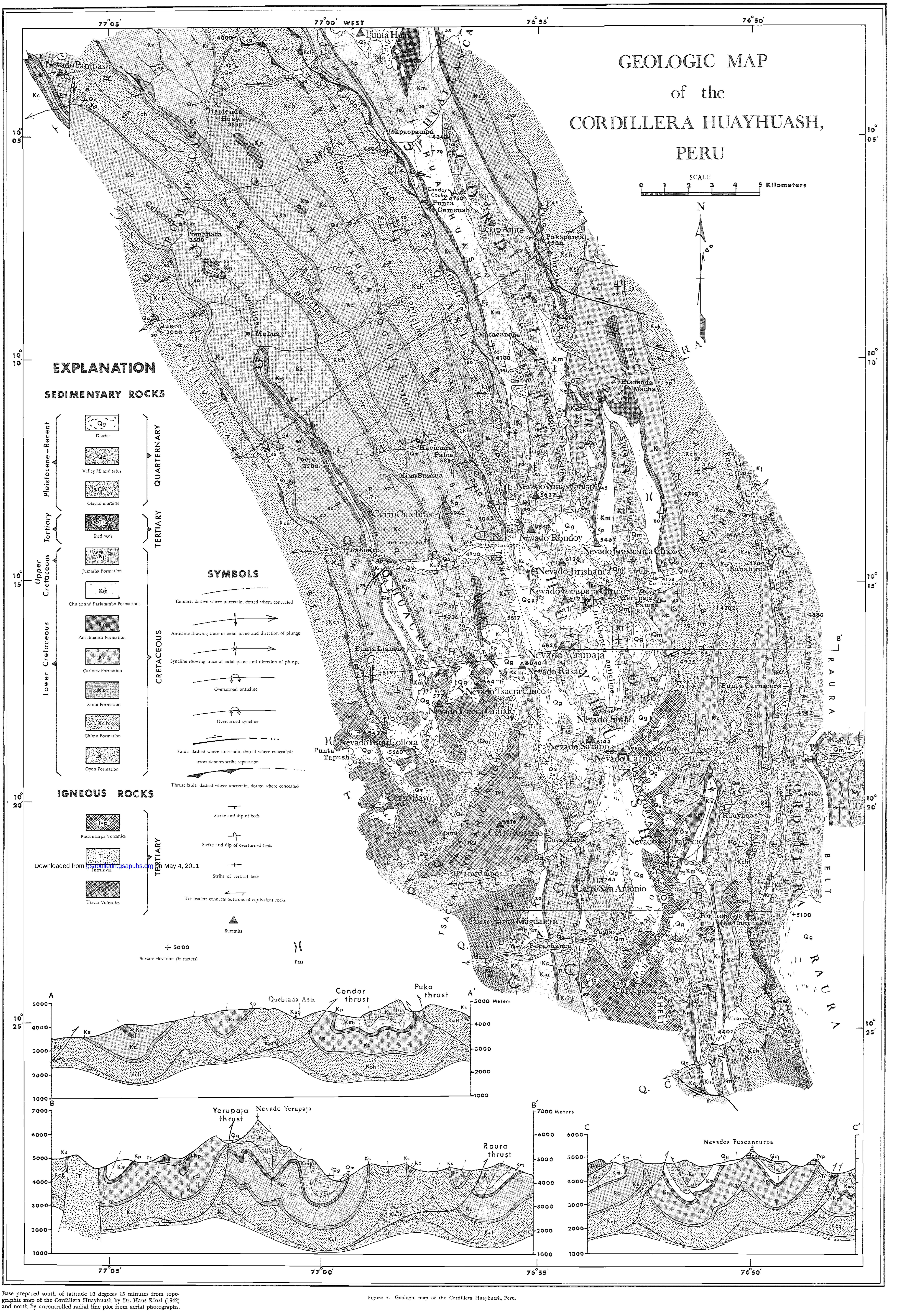


Figure 3. Generalized composite geologic column for the Cordillera Huayhuash.



Base prepared south of latitude 10 degrees 15 minutes from topographic map of the Cordillera Huayhuash by Dr. Hans Kinzl (1942) and north by uncontrolled radial line plot from aerial photographs.

Figure 4. Geologic map of the Cordillera Huayhuash, Peru.

and Wilson (1963) for the central Andes of Peru was found to extend into the Cordillera Huayhuash with only minor variations.

Goyllarisquisga Group. Wilson (1963, p. 12) described the *Oyon Formation* as more than 100 m of thin-bedded, dark, fine-grained sub-graywacke shale interbedded with lenticular seams of coal exposed in the core of a thrusted anticline near Oyon, 30 km south of the Cordillera Huayhuash. In the Cordillera Huayhuash the Oyon Formation is restricted to the core of a complex anticline 1 m east of Carhuacocha, and possibly several other small highly sheared exposures in cores of anticlines in the Chimu Formation in other parts of the range. Neither the base of the Oyon Formation nor any older rock was encountered in the Cordillera Huayhuash.

The *Chimu Formation* (Benevides, 1956, p. 365) is prominent in the Cordillera Huayhuash with a thickness of at least 650 m. It is brought to surface by all anticlines and upthrust belts throughout the range (Fig. 5). The formation is medium- to thick-bedded, occasionally massively bedded, very light gray to white, medium- to coarse-grained, occasionally conglomeratic, orthoquartzite interbedded with subordinate laminated beds of dark gray, silty, carbonaceous shale and scattered seams of coal. The ratio of sandstone to shale beds is about 10:1. Sandstone units exhibit well-developed diagonal and concave cross-bedding indicating current directions toward the southwest.

The *Santa Formation* (Benevides, 1956, p.

Figure 5. Condor thrust fault. View south from 4,810 m on southwest ridge of Punta Huay. Fault (dashed line) lies below cliffs of the Chimu Formation (Kch). Vertical to overturned Pariahaunca Formation (Kp) forms ridge east of overturned Carhuaz Formation (Kc). Somber terrain east of Pariahuanca ridge is in Pariatambo Formation (Km).

367; Wilson, 1963, p. 14) is present throughout the range, flanking the Chimu Formation on all anticlines, with a thickness of about 150 m. The unit is medium-bedded, medium-light to medium-dark gray, very fine-grained to microgranular fossiliferous limestone with minor laminated calcareous shale interbeds. The formation thins and disappears eastward from the range by facies change into the Goyllarisquisga Formation (Wilson, 1963, p. 14). Benavides (1956, p. 368) dates the Santa Formation as Valanginian.

The *Carhuaz Formation* (Benevides, 1956, p. 368) forms subdued grass-covered valley walls and serrate ridge-crests along flanks of folds on both sides of the continental divide (Figs. 5, 6, 7, 8). About 800 m thick, the unit is composed of thin- to medium-bedded, light- to medium-light gray, fine- to medium-grained cross-bedded orthoquartzite with laminated, medium dark gray, silty shale and some light gray siltstone. Sandstone and shale beds are about equally numerous near the divide but the proportion of sandstone increases eastward. Near the top of the unit, 100 m of maroon silty shale is conspicuous. The formation extends several kilometers east of the mapped region, but is reported absent at Lauricocha by Wilson (1963, p. 32), about 20 km east-southeast of the range, passing by facies change into the Goyllarisquisga Formation. Benevides (1956, p. 369) dates the Carhuaz Formation as late Valanginian.

Wilson (1963, p. 15) applied the name *Far-*

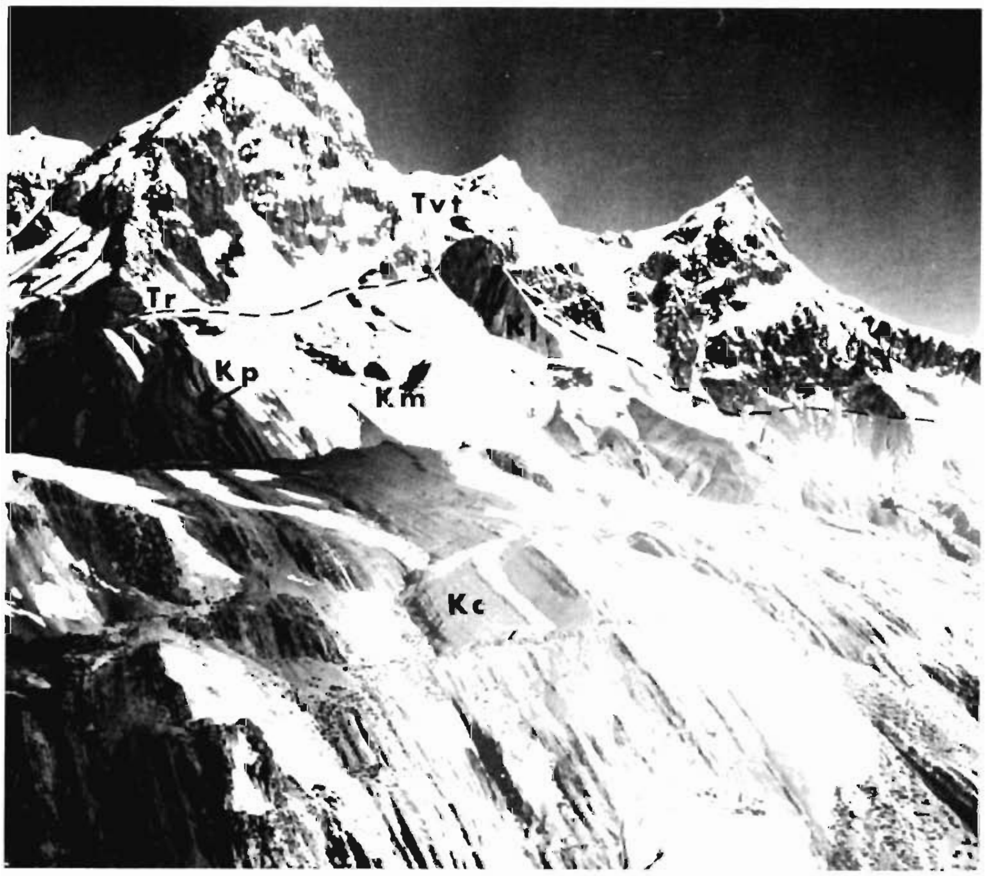


Figure 6. Nevado Tsacra Grande from the north. View from 4,925 m on ridge south of Jahuacocha. Tsacra volcanics (Tvt) and limestone breccia (Tr) overlie upturned Carhuaz (Kc), Pariahuanca (Kp), Pariatambo (Km), and Jumasha (Kj) Formations. Angular unconformity (dashed line), Carhuaz beds, breccia, and volcanics are all cut by hypabyssal quartz monzonite dike (arrow).

rat Formation to a few tens of meters of coarse-grained quartz sandstone of late Aptian age above the Carhuaz Formation and below the Pariahuanca Formation in the north-central Andes of Peru. Benevides (1956, p. 370) considered the unit equivalent to the Goyllarisquisga Formation east of the continental divide. As exposed in the Cordillera Huayhuash the Farrat Formation is 60 m of thin- to medium-bedded, medium gray, medium- to coarse-grained orthoquartzite interbedded with minor silty shale. The formation is not separately mapped on Figure 4 of this report and is included in the Carhuaz Formation.

Pariahuanca Formation. The Pariahuanca Formation (Benevides, 1956, p. 369) is distributed throughout the range in synclines on ridge-tops and quebrada walls (Figs. 5, 7, 8). About 150 m thick, the unit is medium-bedded, medium gray to locally dark gray, very fine-grained fossiliferous limestone. Thick beds are common in the middle part. Fossil hash and abundant megafossils are common in many beds. Benevides (1956, p. 370) dated the Pariahuanca Formation as early Albian. The formation wedges out (Wilson, 1963, p. 15; Benevides, 1956, p. 370) east of the range along a line closely following the facies change of the Goyllarisquisga Group to the Goyllarisquisga Formation.

Chulec and Pariatambo Formations. The Chulec and Pariatambo Formations were originally defined by McLaughlin (1924, p. 608) as members of the Machay Formation for thick

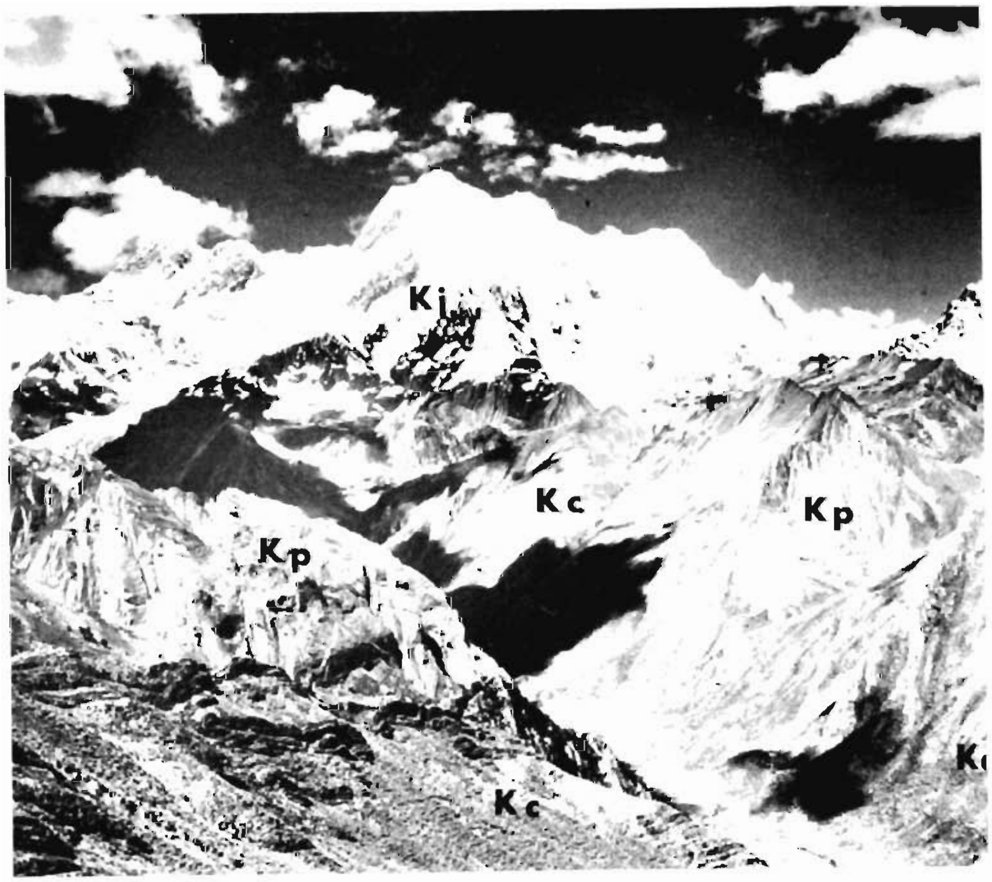


Figure 7. Nevado Yerupaja from the Llamac-Pacllon ridge southwest of Pocpa. View south-southeasterly from 4,700 m. Culebras syncline, outlined by Pariahuanca Formation (Kp), crosses valley. Carhuaz Formation (Kc) forms flanks of fold. Jumasha Formation (Kj) dips east on north face of Nevado Yerupaja. Flat glacial valley is Incahuain in Quebrada Pacllon.

limestone and shale exposed at Oroya, 180 km southeast of the Cordillera Huayhuash. Benavides (1956, p. 373-376) raised both to formation rank, recognizing the basal Chulec Formation limestone and sandy shale, and the Pariatambo Formation dark limestone and shale. He placed both in the Middle Albian. The two formations are mapped as a single unit on the geologic map of this report (Fig. 4), because exposures generally prevent separation. In the Cordillera Huayhuash the Chulec Formation ranges from 10 to 40 m of thin-bedded, nodular, medium-light gray to yellowish-gray, fine-grained fossiliferous limestone in beds 0.1 to 0.5 m thick, interbedded with dark gray calcerous shale in units up to 1 m thick. Limestone beds are usually concretionary. The formation grades upward into platy, laminated, dark gray limestone with less shale interbeds. About 400 m of rocks belonging to the two formations were measured on the ridge south of Calinca.

Jumasha Formation. Orographically, the Jumasha Formation (McLaughlin, 1924, p. 609) is the most important lithologic unit in the Cordillera Huayhuash, since it forms the axial ridge and all 6,000 m summits from Ishpacpampa south to Nevado Carnicero (Figs. 9, 10). The formation is also prominent in the Cordillera Raura southeast of the mapped region and in the Cordillera Huallanca north. Thicknesses of 400 to 600 m or more were accounted for in the Cordillera Huayhuash, but structural complication and difficulties of access

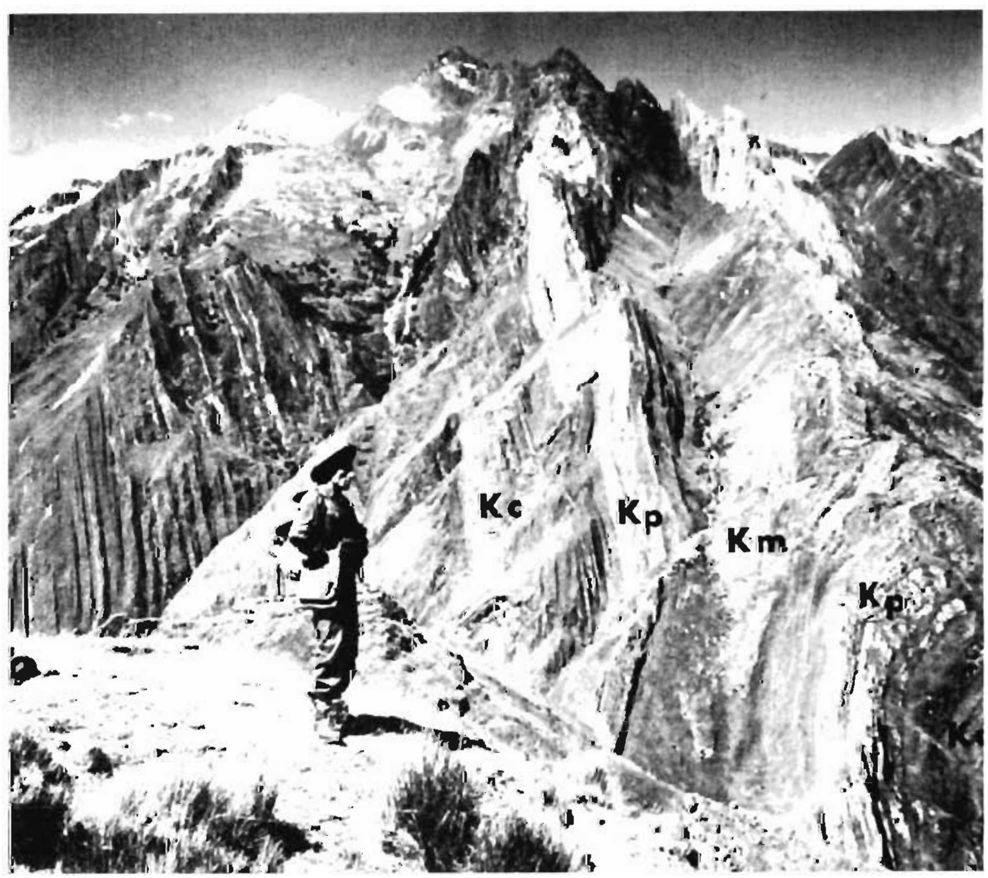


Figure 8. Cerro Culebras and Culebras syncline. View southeast from 3,700 m. Fold is outlined by Pariahuanca Formation (Kp) with Pariatambo Formation (Km) in core. Jumasha Formation is ejected. Carhuaz Formation (Kc) forms flanks of fold.

prevented detailed study. The formation is medium to massively bedded, very fine-grained limestone and dolomite. Benevides (1956, p. 578) dated the formation as Middle Albian to Turonian.

Continental Red Beds

Continental red beds in the Cordillera Huayhuash are of scattered occurrence, are variable in thickness and structural setting, and show several lithologic types. The largest exposure is east of Laguna Viconga in a narrow belt flanking the western edge of the Cordillera Raura. A basal conglomerate 50 m thick, composed of elements of the Chimu Formation, is overlain by about 200 m of red mudstone and siltstone. The conglomerate lies across overturned Jumasha beds and dips 30° westward. The upper mudstone and siltstone are locally dipping up to 60° and the Chimu Formation appears to have been thrust against them. In Quebrada Huacrish a consolidated limestone breccia up to 30 m thick lies across steeply dipping beds of Carhuaz through Pariatambo Formations (Fig. 6). The breccia is overlain by Tsacra volcanic rocks, is intruded by quartz monzonite dikes, and dips up to 50° westward. Elsewhere, red beds are found beneath volcanics near Nevado Puscanturpa and west of Cuyocpunta.

The age of the red beds in the Cordillera Huayhuash is not known, but is presumed Tertiary. The beds lie with angular unconformity over Cretaceous rocks, but are more nearly conformable with overlying Tsacra volcanic

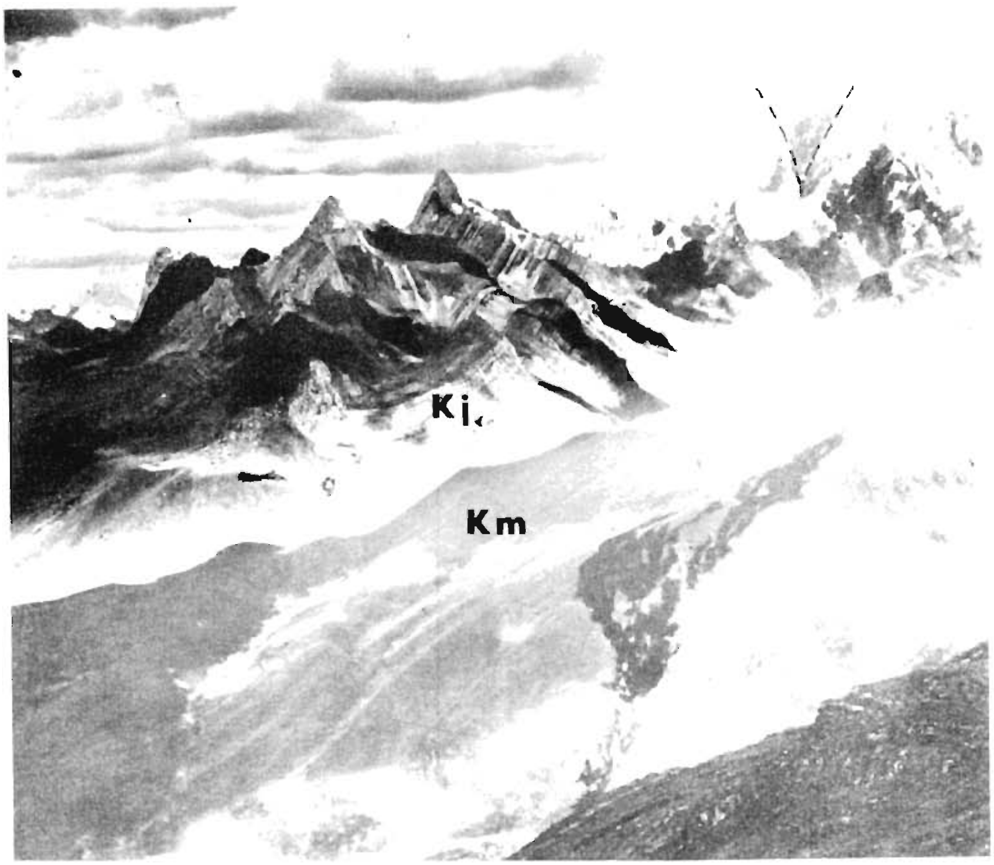


Figure 9. Northern terminus of the Cordillera Huayhuash. View south from 4,600 m on southeast ridge of Punta Huay. Jumasha Formation (Kj) in syncline forms axial ridge with low hills and valleys below of the Pariatambo Formation (Km). Tight chevron Yerupaja syncline (dashed line) over Punta Cumcush.

rocks. They are intruded by quartz monzonite porphyry dikes. Continental red beds are extensive in central Peru (Jenks, 1956, p. 228-230), and most are included in the Casapalca Group (Petersen, 1958, p. 64-65; Mabire, 1961, p. 151-186; Szekeley, 1969, p. 558-559), which lies generally disconformably on Cretaceous marine sediments, attains thicknesses of up to 3,000 m, and is presumed latest Cretaceous to early Tertiary in age. Hosmer (1959, p. 141) states the disconformity between red beds and Cretaceous sediments becomes progressively more angular southwestward as the coastal batholith is approached. Other red beds are at the base of and within an extensive sequence of andesitic volcanics called the Tacaza volcanics (Hosmer, 1959, p. 146). The Tacaza rocks are younger than the Casapalca Group, separated from them by angular unconformity, and presumed early to middle Tertiary in age. There is no definitive evidence in the Cordillera Huayhuash to support correlation of red beds with either the Casapalca or Tacaza sequences, but the strong angular unconformity between red beds and the Cretaceous sequence, and close association with Tsacra volcanic rocks, suggests the Tacaza correlation may be reasonable.

Tertiary Volcanic Rocks

Tsacra Volcanics. The Tsacra volcanics have a wide distribution in the southwestern part of the Cordillera Huayhuash. They underlie the summits along the Tsacra Spur (Fig. 6) and Cerro Rosario, and are also found around Cuyocpunta, north of Nevados Puscanturpa, and east of Laguna Viconga. The re-

Figure 10. Nevado Yerupaja from the south. View from 5,100 m on Cerro Magdalena. Yerupaja thrust (dashed line) passes over col west of the peak bringing up Carhuaz Formation (Kc) against limestones of the Upper Cretaceous (Kj). Nevado Yerupaja is apparently formed from folded Jumasha Formation (*see* structure section B-B′, Fig. 4).

gional extent of these rocks is considerable, and views from high elevations suggest they crop out southwestward from the Cordillera Huayhuash for many kilometers.

The Tsacra volcanics are lithologically variable, but most outcrops show massively bedded, aphanitic-porphyritic textured, greenish-gray, red-purple andesitic flows with chalky phenocrysts of plagioclase. Locally, more felsic maroon crystal tuff and breccia are found. Microscopically, a few specimens have andesine and altered pyroxene, but most rocks show strong propylitic alteration and all vestige of ferromagnesium minerals is altered to chloritic material. Pyrite is ubiquitous and hematite is common.

At last 800 m of Tsacra volcanics are exposed on the Tsacra Spur, and over 1,500 m are exposed from the floor of Quebrada Seria to the top of Cerro Rosario. The basal contact undulates through 800 m of relief cutting across every Cretaceous formation in the Cordillera Huayhuash, with the exception of the Oyon Formation. On the ridge east of Quebrada Seria the volcanics are strongly altered, tourmalinized, and contact metamorphosed by felsic intrusive rocks which crop out just below.

The age of the Tsacra volcanics is not known. They lie in sharp angular unconformity over strongly folded Cretaceous sediments. They have been contact metamorphosed by granodiorite intrusions, intruded by quartz monzonite porphyry dikes, and mineralized. The massive flows and basal contact surface dip as much as 40° in some places where the unit has been warped into broad folds.

Puscanturpa Volcanics. The Puscanturpa volcanics are distinctive felsic ash flows which extend in a narrow belt from Nevado Carnicero southward beyond the mapped region, including the prominent summits of Nevados Puscanturpa for which they are named (Fig. 11). Outliers are found just east of Portachuelo de Huayhuash, and west of Cuyocpunta. The outcrops are restricted to the continental divide and the rock was never seen below 4,800 m in the Cordillera Huayhuash. The total thickness is not known, but at Nevados Puscanturpa the base of the pile is close to 4,900 m and the rocks appear to continue to the summit at 5,652 m. This would indicate a minimum thickness of 750 m.

The Puscanturpa volcanics form light tan to yellow-brown cliffs and spires which exhibit massive beds up to 50 m thick and columnar jointing on a grand scale. Units near the base are gray to tan, aphanitic, very hard, and contain scattered phenocrysts of quartz. Higher units are tuffaceous with lithic, crystal, and pumice fragments. Crystal fragments are embayed quartz, altered oligoclase, and scattered biotite. Limonite stain is prominent both in groundmass and pumice fragments.

The age of the Puscanturpa volcanics is not known. They appear to overlie red beds and Tsacra volcanics with angular unconformity. They are not folded and dips were not noted over about 10°. No contact metamorphism was noted and they were not seen mineralized. They were not seen to be intruded by quartz monzonite dikes. Restricted distribution and difficulties of access prevent definitive conclusions, but they may be very young. Their horizontal attitude and restriction to elevations in excess of 4,800 m suggest they may have been deposited on an extensive surface of erosion in latest Tertiary prior to recent uplift and dissection.

Tertiary Intrusive Rocks

Huacrish Stock. A diorite stock with a circular outcrop of about 1 sq km and an exposed relief of about 600 m forms a prominent peak in Quebrada Huacrish. The body is everywhere in contact with steeply dipping Carhuaz Formation. Outcrops are somber-colored and structureless, and hand specimens away from the aphanitic contact zone exhibit greenish-gray phaneritic altered diorite. Microscopically, distinct phenocrysts of altered andesine are seen in a matrix of feldspathic and chlorotic material. Altered ferromagnsium content makes up 30 percent of the rock. The age of the stock is unknown other than where it has intruded the folded Carhuaz Formation, but its composition, alteration, and setting suggest it may have been a feeder for Tsacra volcanic flows.

Silicic Plutonic and Hypabyssal Rocks. Outcrops of quartz-bearing plutonic rocks are found in Quebrada Seria, and around Sarapococha. The composition of these rocks is mainly granodioritic, grading to quartz monzonite and quartz diorite. The plutons are clearly discordant to structural trends in Cretaceous rocks and contact metamorphism is minor. Outcrops in Quebrada Seria form much of the eastern wall of the upper valley from the glacial headwall southward for about 1.5 km. The outcrops extend upward to near 5,000 m, but contact with overlying Tsacra volcanics which the body must intrude is obscured by talus, or inaccessible. Most exposures are fine- to medium-grained, slightly prophyritic granodiorite grading to quartz diorite. Microscopically, anhedral quartz and orthoclase with scattered biotite and hornblende surround phenocrysts of andesine. On the other side of the ridge, near Sarapococha, outcrops of granodiorite grading to quartz monzonite are found in roches mountonnées west and southwest of the toe of the glacier, and in larger exposures west of the glacier. Most outcrops are gray but some are pinkish, due to potassium feldspar content. The rocks are medium-grained with slight porphyritic development of plagioclase. Both biotite and hornblende are present. Granodiorite debris is found in moraines at the head of Quebrada Rondoy, in moraines of glaciers descending the west side of Nevado Yerupaja and the axial ridge north, and throughout the Sarapococha valley, indicating that soles of glaciers are biting into plutonic bodies at the base of much of the north-central part of the axial ridge of the Cordillera Huayhuash.

Hypabyssal quartz monzonite porphyry bodies include a stock-shaped mass at the south end of the Cordillera Huallanca near the base of Punta Huay intruding the Pariahuanca and Pariatambo Formations, and dikes and sills generally found a short distance west of the continental divide. The dikes and sills follow the strike of Cretaceous sediments and jump in irregular fashion from one bedding plane to another. They are mostly 10 to 50 m wide and some can be traced for as much as 2 km. They appear as white bands in more somber rocks

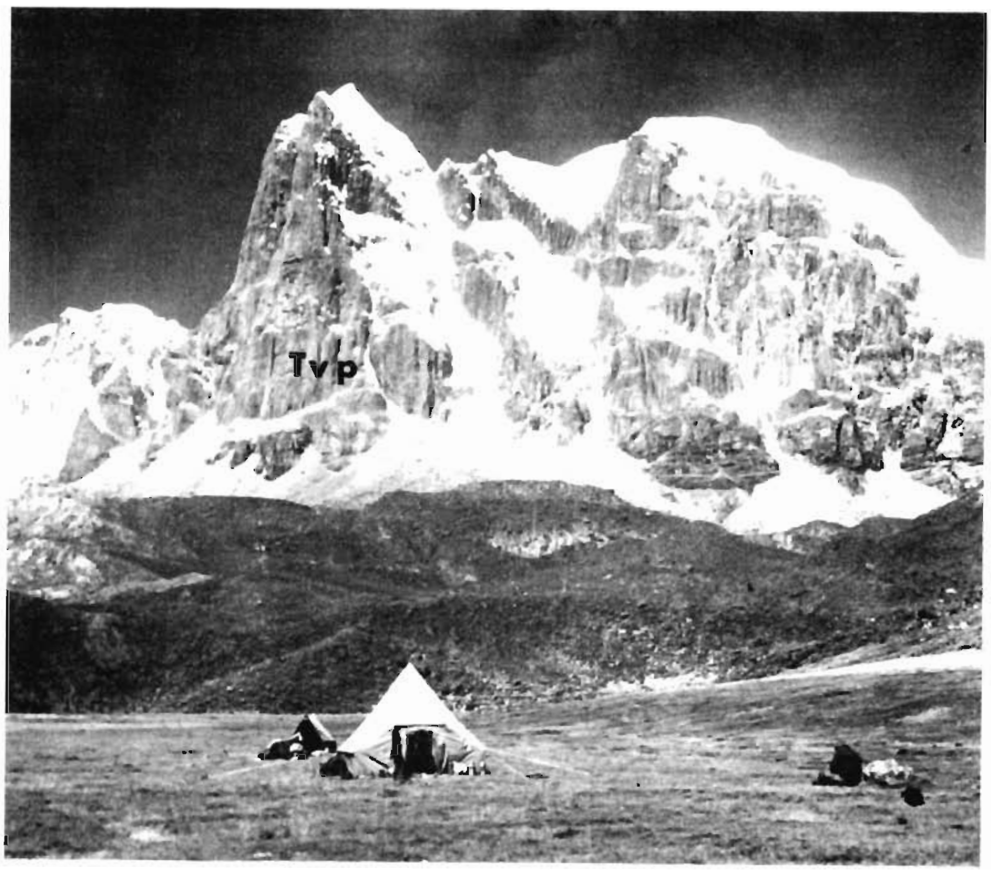


Figure 11. Nevados Puscanturpa from the west. View from 4,500 m at Cuyoc. Puscanturpa volcanics (Tvp) form mountain from peak (5,652 m) to talus cones at base with massive near-horizontal beds and columnar jointing. Field camp in foreground stands on recent lake beds. Low hills beyond are glacial moraine.

slightly asymmetrical, angular anticlines lies along the eastern front. South of Quebrada Llamac these folds are broken by westward dipping thrusts. The thrusts lie in bedding planes of the Chimu Formation and do not appear to have disturbed Tsacra volcanic rocks on the Tsacra Spur as they pass below them.

Jahuacocha Belt. The Jahuacocha belt lies northeast of the Pativilca belt and southwest of the Huayhuash belt extending from the northern to the southern borders of the mapped region over a distance of 40 km. The belt is 10 km wide at the north, narrowing to 7 km between Nevado Rasac and Punta Llanche, and is convex northeastward with a curvature of about 25°. The belt consists of a set of tight to isoclinal, east-vergent, upright to slightly overturned anticlines and synclines that bring rocks from the Chimu to Pariatambo Formations to surface exposure. The eastern boundary of the belt is a zone of east-directed overthrust faulting.

The westernmost fold in the Jahuacocha belt, the Culebras syncline (Fig. 4), is of particular interest, because for much of its length the fold is "strangled," displaying isoclinal geometry in the Pariahuanca Formation with a core of sheared Pariatambo shale and limestone. In Quebrada Llamac the axis of the fold on top of the Pariahuanca Formation is just above the river at 3,500 m. As the fold goes over the Llamac-Pacllon ridge (Fig. 8) the axial surface is vertical and both flanks in the Pariahuanca limestone parallel it to the top of the divide at 5,000 m. No trace of the massive Jumasha Formation remains in the core and one must conclude it has been detached and ejected.

Two anticlines and an intervening syncline follow eastward of the Culebras syncline. The anticlines, particularly in the Chimu Formation, tend to be straight-flanked and angular, reflecting massive brittle struts of quartzite interbedded with ductile carbonaceous shale. The crests in quartzite are commonly broken, and it is from this zone that thrust faults break out along the eastern margin of the belt.

From the western flank of the Cordillera Huallanca southward to Quebrada Rondoy, the eastern margin of the Jahuacocha belt is marked by the west-dipping Condor thrust (Figs. 4, 5). The fault rises out of the core of an anticline in the north, with the Chimu Formation on the upper plate cutting across the eastern flank of the fold southward so that first Chimu, then successively Santa, Carhuaz, and eventually Pariahuanca Formations, are omitted at the surface. The fault appears to dip about 50° west along most of its length. The stratigraphic separation is up to 2,000 m or more at some points.

South of Quebrada Llamac the Yerupaja thrust breaks out of the core of the Paria anticline, placing the Chimu and Santa Formations over Carhuaz rocks to the east. At the pass west of Nevado Rondoy the fault lies on a bedding plane in the upper part of the Chimu Formation and dips 70° southwest. Southward the fault is obscured by the Yerupaja glacier. At the pass between Nevado Yerupaja and Nevado Rasac, close to 5,800 m elevation, the upper part of the Chimu Formation, with overlying Santa and Carhuaz beds, appear to be in discordant contact with Upper Cretaceous limestones. The fault is probably the Yerupaja thrust, here dipping steeply westward (Fig. 10). Southward along the eastern side of Sarapococha to the ridge south of Cuyoc, the Carhuaz Formation, here in a sharply westward inclined anticline, has been thrown against the Jumasha Formation on the east. The break is nearly vertical and is considered to be the southward extension of the Yerupaja thrust. It is to be noted that folds are tighter and faults steeper in the narrow southern part of the Jahuacocha belt compared to the wider northern part.

Huayhuash Belt. Orographically the Huayhuash belt is the most important structure in the Cordillera Huayhuash, because the axial ridge, the continental divide, and the five 6,000 m summits which define the range are carved from it (Figs. 9, 10). As a structure the belt extends from the northern to the southern border of the mapped region over a distance of 45 km and consists of a set of tight folds with the over-all aspect of a synclinorium. Structurally lower and topographically higher than flanking belts to east and west, the belt exposes mainly Jumasha rocks and forms a structural keel for the range.

East of Ishpacpampa a syncline catches the Jumasha Formation plunging southward. South of this point, considered the northern terminus of the Cordillera Huayhuash (Fig. 9), the fold has both flanks dipping 45° to 50° into a slightly eastward-inclined axial surface. Southward, dips pass 60° and the Jumasha limestones are relayed southwestward in a series of right en echelon folds. South of Matacancha to the southern border of the mapped region the principal structure is the Yerupaja syncline, from which Nevados Jirishanca, Yerupaja Chico, Yerupaja, Siula, and Sarapo are carved. On the north face of Nevado Jirishanca the structure has the form of an upright, cuspate fold with both flanks dipping 55° to 70° into the axial surface (Fig. 9). The axial trace appears to pass several hundred meters east of the summit and continues southward along the east face of Nevado Yerupaja. South of Nevado Yerupaja the fold appears to nod westward and the east flank is nearly vertical. South of Nevado Sarapo the fold loses identity and breaks into isoclinal flexures.

Although the gross aspect of the Huayhuash belt is simple, details are complex. Numerous smaller folds flank major flexures and some of the excessive thickness of Jumasha Formation exposed is certainly due to considerable faulting along and across bedding planes. Little detail could be worked out, because much of the belt is confined to elevations over 6,000 m and obscured by glacial ice and snow.

Carhuacocha Belt. The Carhuacocha belt lies east of the Huayhuash belt and enters the mapped region just north of 10° 5′ south. The belt is about 10 km wide and can be traced for 35 km to and beyond the southern boundary of the mapped region. The belt is characterized by south-plunging folds bounded on the east by the east-directed Raura thrust, and bounded on the west in the northern part by the west-directed Puka thrust. The southwestern part of the belt is obscured by Puscanturpa volcanic rocks and glacial cover.

The Puka thrust breaks out of the core and across the western flank of an anticline north of Punta Puka, placing the Chimu Formation quartzite dipping 30° eastward over vertical beds of the Carhuaz Formation. The trace of the fault has a trend about 20° from strike in the Carhuaz beds and eventually cuts out about 600 m of the formation. South of Punta Puka the upper plate plunges southward, taking Chimu and Santa rocks below ground. At the head of Quebrada Ninacocha the fault places upper Carhuaz beds against the Jumasha Formation in the Yerupaja syncline, then dissipates in the core of a slightly westward-inclined Jirishanca anticline.

The folds east of the Puka-Jirishanca axis plunge gently southward, gathering in successively higher Cretaceous rocks from the Chimu Formation in the north to Jumasha rocks in the south. East of these folds is a structural complex bounded on the east by the Raura thrust, which places Chimu, Santa, and Carhuaz beds against westward-dipping overturned Jumasha rocks of the Raura belt to the east. South of Quebrada Nupe the Raura thrust is obscured by glacial debris, but it apparently has no effect on red beds as it passes beneath them. About where the Raura thrust loses its action another thrust breaks out of the Viconga anticline south of Quebrada Nupe, eventually migrating over the eastern flank of the fold. North of Laguna Viconga the fault apparently has disturbed red beds placing Chimu quartzite against them. Farther south, Tsacra volcanics appear to be also disturbed by the fault.

Raura Belt. The Raura belt lies east of the Carhuacocha belt and its western margin forms the eastern border of the mapped region. The part of the belt mapped is an eastward overturned syncline in the Jumasha Formation with overturned dips of 70° west along the western flank.Dips along the eastern flank of the fold are 50°, *more westerly, and right side up.*

Structures in Tertiary Rocks

Tsacra Volcanic Trough. The Tsacra volcanic pile and underlying red beds are warped into a south-plunging trough which extends from the Tsacra Spur southward beyond the mapped region. Along the eastern side of the trough, dips range from 15° to 40° or more westward, while along the western side dips are more gentle southeast and east. These dips place volcanics below 4,000 m in the floor of Quebrada Seria from basal contacts near 5,000 m along the eastern margin of the trough. The western part of the trough laps across the boundary between the Pativilca and Jahuacocha belts, and frontal thrusts do not appear to have disturbed the volcanics on the Tsacra Spur east of Punta Llanche.

Puscanturpa Volcanic Sheet. Where observed in the Cordillera Huayhuash the Puscanturpa volcanics are nearly horizontal, but small warps and a regional southeasterly dip of several degrees are evident. The base of the pile along the west side is always close to 5,000 m, while on the eastern side, near Portachuelo de Huayhuash, it is close to 4,800 m. What remains of the Puscanturpa volcanics has the aspect of a sheet with a regional southeasterly dip of about 5°.

Tectonic Analysis

The Cordillera Huayhuash has suffered two "compressional" deformations. The first deformation was the most severe, involving rocks as young as the Middle Albian to Turonian Jumasha Formation at the top of the Cretaceous prism. Structures produced are tight folds and thrust faults. Later deformation involved rocks as young as the Tsacra volcanics and was much less intense. Structures produced are mainly broad warps or folds, and there was reactivation or initiation of thrusting on some faults.

The mechanism of folding in Cretaceous rocks during the first deformation was dominantly flexural-slip (Donath and Parker, 1964), becoming flexural-flow where thick ductile units such as the Oyon and Pariatambo Formations were involved. Strong intraformation ductility contrast and bedding anisotropy (Donath and Parker, 1964), such as that obtained by massive struts of quartzite and thin ductile shale in the Chimu Formation at the base of the Cretaceous prism, has resulted in sharply angular anticlines by slip between quartzite struts along shale horizons. Synclines in the Chimu Formation tend to be more open (Fig. 4, section B-B′). Breaking at angular anticline crests initiated thrust faulting out of anticlinal cores. Higher in the Cretaceous section, near the top of the folded prism, synclines become sharp and cuspate (Fig. 9). The over-all fold geometry is thus broadly concentric to angular, the angularity occurring in anticlines near the base of the prism and in synclines near the top.

Two stratigraphic units, the Oyon Formation at the base of the Cretaceous prism, and the Pariatambo Formation higher in the section, have behaved in a ductile fashion, relative to overlying formations. This has permitted development of disharmonic fold geometry, in that fold form above these two units can be quite distinct from that found below. In the case of the Pariatambo Formation the effect is local, in that folds such as the Culebras syncline (Figs. 4, 8) display isoclinal geometry in the Pariahuanca Formation with a sheared core of Pariatambo rocks. The massive Jumasha carbonates have apparently become detached from underlying rocks and ejected from the fold. Indeed, much of the detached Jumasha rocks may have glided eastward from the Jahuacocha belt and piled up in the Huayhuash belt. The influence of the Oyon Formation has been more widespread throughout the Cordillera Huayhuash and may have regional significance as well. This is suggested by the fact that in cores of anticlines, as shown on structure sections (Fig. 4), it is difficult to include any considerable volume of rock greater than that to be expected from Oyon shale. The geometric result is that fold amplitude in the cretaceous prism is apparently considerably greater than undulations in the underlying "basement," an interpretation supported by the fact that this "basement" is never brought to surface exposure in the Cordillera Huayhuash. These relations suggest the Oyon Formation has served as a zone of local or regional detachment (Dahlstrom, 1969), or that the "basement" has deformed in a fashion quite distinct from overlying rocks (Compton, 1966). The fact that this "basement" is never exposed anywhere in the Cordillera Huayhuash prevents further speculation.

Margins of structure belts are marked by thrust faults of some magnitude. These faults rise out of cores of anticlines placing one flank over and occasionally omitting the other flank. With the exception of the Puka thrust they are east-directed west-dipping faults with attitudes of 50° to 85° as seen at the surface. The faults often lie parallel to bedding planes in the upper plate, particularly where the Chimu Formation was involved. There is a marked steepening of fault dips southward through the range coincident with a gentle southerly regional plunge, tightening of folds, and narrowing of structural belts.

As shown on structure sections (Fig. 4) the several thrust faults are interpreted as steeply to moderately dipping thrusts which rapidly become low-angle overthrusts within basal Cretaceous Oyon Formation carbonaceous shale. This inference is based mainly on interpretation of the general tectonic style of the region as displayed in fold geometry which suggests local or regional detachment at the level of Oyon shale, and on consideration of fault geometry when projected to depth. It can be noted on section A-A′ (Fig. 4) that the Condor thrust is drawn passing rapidly to a low-angle overthrust under the folded eastern margin of the Jahuacocha belt. The base of the Chimu Formation is well controlled by the Santa Formation exposed in Quebrada Asia on the upper plate west of the fault trace. Dips in the Chimu Formation remain near 50° west up to the fault trace and any reasonable projection of the Santa Formation on the upper plate and on the foot wall indicate a dip separation on the Santa Formation of at least 2,000 m, and it could be much more depending on how far the upper plate has ridden eastward. In an alternate interpretation, if the Condor thrust is projected to depth as a 50° west-dipping upthrust rooting in, and displacing the "basement" (Fig. 12), the dip separation on the base of the Chimu Formation is less than 1,000 m, which is less than one-half that calculated on the Santa Formation. Such disparate dip separation on two strati-

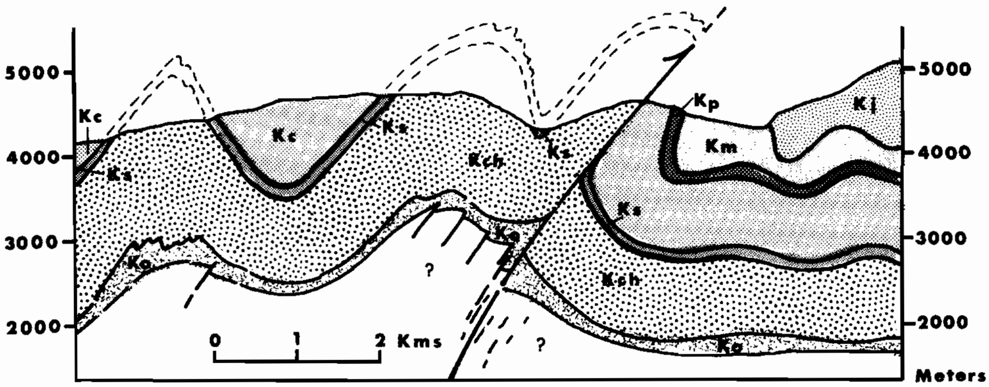


Figure 12. Structure-section across Condor thrust showing alternative "deep seated rooting" of fault (compare with structure-section A-A', Fig. 4).

graphic horizons separated by only 650 m of strata is difficult to explain without undue complication in fault geometry for which there is no surface evidence. Merging the fault surface with the level of detachment in the Oyon shale eliminates all displacement of the basement and seems more reasonable.

Some faults, such as the thrust which breaks from the core of the Viconga anticline (Fig. 4, section C-C'), are more difficult to interpret. Significantly, as well as having generally steeper dips than faults like the Condor thrust, they appear to have disturbed continental red beds and Tsacra volcanics. It seems possible that during post-Tsacra volcanics deformation these thrusts were steepened in dip by rotation during deformation, and perhaps reactivated to cut post-Cretaceous rocks. It is also possible that they may have initiated movement during later deformation, rooting deeper in the "basement," which was broadly folded as well. The wave length of these folds as expressed in the broad fold in the Tsacra volcanic pile in the southwestern part of the range (Fig. 4) is over twice that found in earlier folds in the Cretaceous prism.

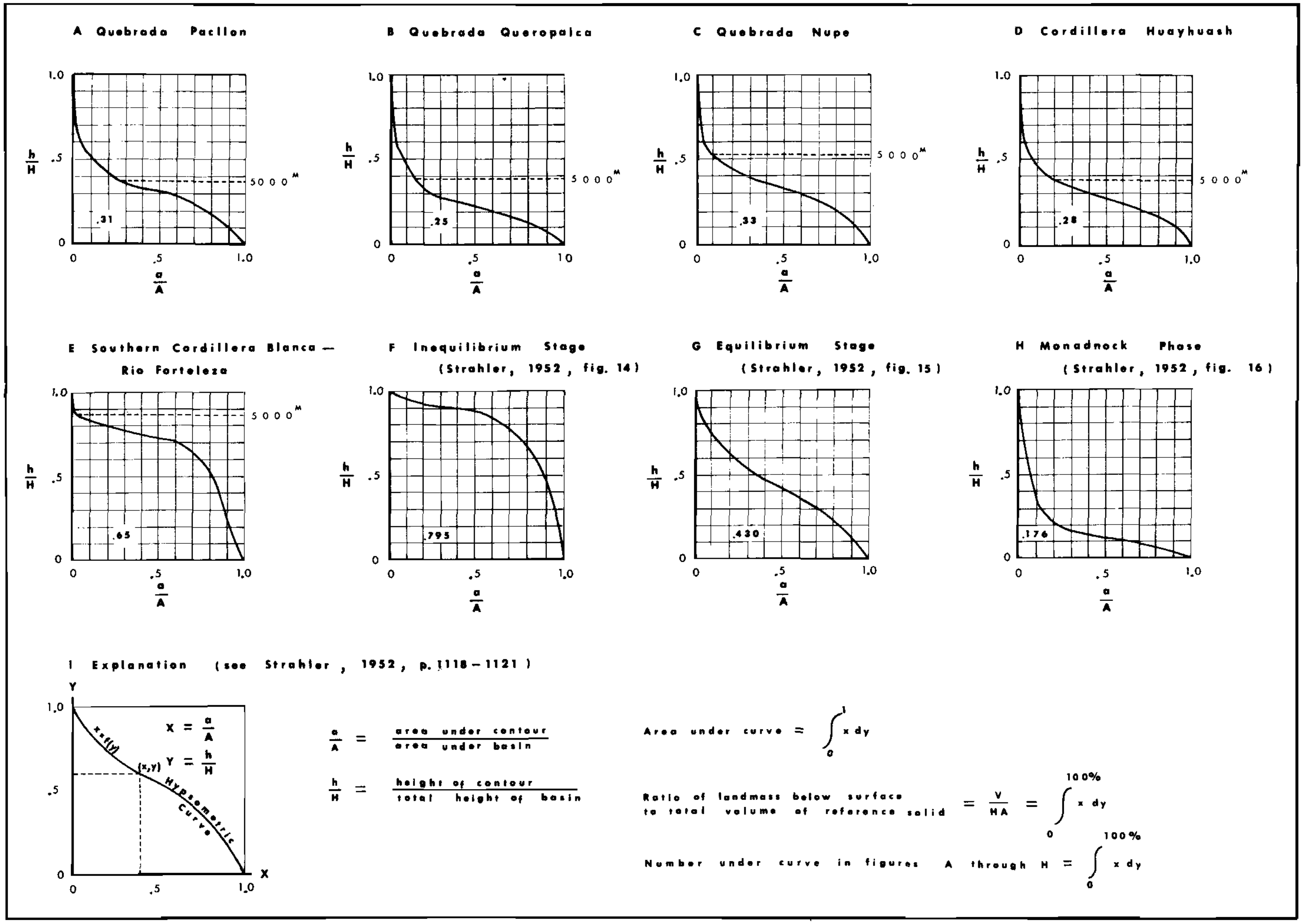
Calculations based on structure sections throughout the range suggest that total shortening in the Cretaceous prism from folding and thrust faulting amounts to about 30 percent in the north, increasing to as high as 40 percent or more south of the deflection to southerly structural trends. These percentages represent up to 15 km of total shortening of the original sedimentary prism now exposed in the mapped region.

Evidence for detachment is often noted in the central and north-central Andes of Peru, particularly in early deformation (Coney, 1968, 1969). At Huallacocha Lakes in central Peru the Pariatambo Formation served as a lubricating horizon for detachment and gravity sliding (Szekely, 1967, p. 1351). Northward from Oroya, particularly from near Oyon northward into the Cordillera Huayhuash, the Oyon is the detachment plane (Wilson, 1963, p. 13). It is significant that east of the line where the Goyllarisquisga Group thins and loses Oyon carbonaceous shale, folding is more open and evidence for imbricate thrusting and detachment of the Cretaceous prism is less obvious. Also, east of this same line the "basement" appears to be involved in deformation along with Tertiary rocks and the Mesozoic sedimentary prism (Harrison and Wilson, 1960, *see their* Fig. 5).

TECTONIC SIGNIFICANCE OF LAND-MASS DISTRIBUTION

General Statement

When one attains a vantage point above 5,000 m in the Cordillera Huayhuash the striking element in the topography of the region is a general accordancy of ridge-tops and interstream divides, and a pronounced flattening of the horizon east and west. The axial ridge and Tsacra Spur stand in isolation up to 1,600 m above this general level (Figs. 1, 7), and deep gorges of flanking valleys are cut up to 1,000 m below this level. The fact that the flat-lying base of the Puscanturpa volcanic sheet lies close to this general accordancy suggests these ash flows may have been erupted upon a relatively subdued erosion surface and around the flanks of residual monadnock massifs of an ancestral ax-


A Quebrada Pacllon
.31
B Quebrada Queropalca
.25
C Quebrada Nupe
.33
D Cordillera Huayhuash
.28
5000 M
E Southern Cordillera Blanca — Rio Forteleza
.65
F Inequilibrium Stage (Strahler, 1952, fig. 14)
.795
G Equilibrium Stage (Strahler, 1952, fig. 15)
.430
H Monadnock Phase (Strahler, 1952, fig. 16)
.176
h/H
a/A
I Explanation (see Strahler, 1952, p. 1118–1121)
X = a/A
Y = h/H
x = f(y)
(x,y)
Hypsometric Curve
a/A = area under contour / area under basin
h/H = height of contour / total height of basin
Area under curve = $\int_0^1 x\,dy$
Ratio of landmass below surface to total volume of reference solid = V/HA = $\int_0^{100\%} x\,dy$
Number under curve in figures A through H = $\int_0^{100\%} x\,dy$

ial ridge of the Cordillera Huayhuash. Recent dissection resulting in flanking valleys subsequently cut into this maturing landscape to produce the deep gorges so characteristic of Andean relief.

Analysis

Hypsometric (area-altitude) analysis (Strahler, 1952, p. 1117-1141) has been carried out on drainage basins in the Cordillera Huayhuash and is presented in Figure 13, A, B, C. The topographic data were taken from the topographic map of Kinzl and others (1942), using the Pacllon, Queropalca, and Nupe drainage basins. Figure 13D is a composite curve for the Cordillera Huayhuash, utilizing the entire topographic map.

It is to be noted that the four curves for the Cordillera Huayhuash have low hypsometric integrals and are characterized by land-mass concentration between 4,000 and 5,000 m, above which is a small mass of considerable relief. Since topographic control in the Cordillera Huayhuash extends down to only 4,000 m above sea level, analysis of flanking valleys beyond the range is not possible. The topographic map of the southern end of the Cordillera Blanca (Kinzl and Schneider, 1950) does permit analysis of lower elevations as it covers topography from the crest of residual massifs in the Cordillera Blanca down western-flanking valleys to within several hundred meters of sea level near the Pacific coast. Figure 13E is the result of hypsometric analysis of the drainage basin of Rio Forteleza, the headwaters of Rio Santa, and the southernmost massifs of the Cordillera Blanca (Fig. 2). The curve is characterized by considerable landmass up to about 4,500 m, above which is a small mass of high relief. It is to be noted that the upper part of the Cordillera Blanca curve strongly resembles the entire curves for the Cordillera Huayhuash, and suggests if similar control existed west of the Cordillera Huayhuash a curve similar to that of the Cordillera Blanca would result.

The hypsometric curves prepared are "two-cycle" in nature. The upper parts strongly resemble the "monadnock phase" of Strahler (1952, *his* Fig. 16; *my* Fig. 13H), and the lower parts resemble the "inequilibrium phase" (Strahler, 1952, *his* Fig. 14; *my* Fig. 13F). In the Cordillera Huayhuash the axial ridge and Tsacra Spur appear to rise as residual "monadnocks" above a land-mass undergoing vigorous dissection in flanking valleys. It is suggested that pronounced flattening near the inflection point of curves represents the effect of accordancy of ridge-tops, and the strong upward concavity above represents the residual massifs of the axial ridge. The pronounced convexity below 4,500 m in the curve for the Cordillera Blanca represents inequilibrium conditions of a youthful incision of drainage. It is proposed that the accordancy of ridge-tops and subdued uplands represented by the flattening of hypsometric curves is all that remains of an extensive surface of subdued topography developed across the region prior to recent orogenic uplift and deep dissection of the Andean Cordillera. This surface may represent the Puna erosion surface (McLaughlin, 1924, p. 623) extensively preserved southeast of the Cordillera Huayhuash in central Peru.

In the Cordillera Huayhuash the Puna erosion surface appears to have beveled all rocks of the Cretaceous, leaving the synclinal structure of the axial ridge as a monadnock in the Jumasha Formation. It would also appear that parts of the Tsacra volcanics were locally residual over the southwestern part of the range. The fact that the base of the Puscanturpa volcanics lies close to the proposed surface suggests these rocks may have been poured out onto it over beveled Cretaceous sediments, red beds, and some Tsacra volcanics, and around the base of residual massifs. The important point is that the age of the Puscanturpa volcanics, which may be very young, puts a lower limit on initiation of dissection and uplift of the Andean Cordillera in the region of the Cordillera Huayhuash.

Figure 13. Hypsometric (area-altitude) curves for the Cordillera Huayhuash.

REGIONAL ASPECTS

Pre-Cretaceous rocks are not exposed in the Cordillera Huayhuash, but facies associations in Cretaceous rocks (Benevides, 1956, p. 363; Wilson, 1963, p. 23-31) suggest the present site of the Cordillera Huayhuash stood near the eastern margin of a transition zone from deeper water continental margin conditions west of the range to miogeoclinal-continental shelf conditions in the range itself. These conditions appear to have prevailed at least from Neocomian through Turonian time.

In the Cordillera Negra, northwest of the Cordillera Huayhuash (Fig. 2), andesite flows and dacite tuffs are separated from steeply folded Cretaceous rocks by an angular unconformity, but have been folded with dips up to 30°. A still younger dacite tuff is undeformed

(Bodenlos and Ericksen, 1957, p. 26-27). In the southern Cordillera Blanca, andesitic Huanstan volcanics (Egeler and DeBooy, 1956, p. 24-27) are gently folded above steeply folded Cretaceous rocks. The Huanstan volcanics are thermally metamorphosed by the batholith of the Cordillera Blanca. The Tsacra volcanics of the Cordillera Huayhuash are presumed equivalent to older folded andesites in the Cordillera Negra, folded Huanstan volcanics in the Cordillera Blanca, and older, generally folded, volcanics found throughout the Andes of Peru, termed the Tacaza volcanics by Hosmer (1959, p. 146-148; *see also* Jenks, 1946, p. 368).

The continental red beds of the Cordillera Huayhuash are more difficult to correlate. If they are equivalent to the Casapalca Group of central Peru, which is generally disconformable on Cretaceous marine sediments and intensely deformed along with them, this suggests an early pre-Casapalca deformation in the Cordillera Huayhuash. An alternate interpretation would be to assume the red beds of the Cordillera Huayhuash are distinctly younger than the Casapalca Group and equivalent to continental red beds at the base of and within Tacaza volcanics. In central Peru the Tacaza sequence is separated from the Casapalca Group by an angular unconformity (Hosmer, 1959, p. 145). Either correlation is possible, but if we assume the latter this suggests major deformation in the Cordillera Huayhuash is post-Casapalca (latest Cretaceous-earliest Tertiary) and pre-Tacaza volcanics, or early to middle Tertiary.

Plutonic and hypabyssal igneous rocks are widespread in the central Andes of Peru (Jenks, 1956, p. 233-235), the most important of which is the coastal Peruvian batholith. It intrudes Cretaceous marine sediments and has been presumed to be Late Cretaceous to very early Tertiary in age (Petersen, 1958, p. 83; Hosmer, 1959, p. 173), apparently confirmed by radiometric dates of 64 m.y. (Giletti and Day, 1968, p. 571). Smaller intrusives along the continental divide and eastward have been considered distinctly younger than the coastal batholith (Petersen, 1958, p. 84-85; Jenks, 1956, p. 234-235; Hosmer, 1959, p. 181). Several of these intrusions have been dated giving ages ranging from 9.1 m.y. for the batholith of the Cordillera Blanca to ages averaging about 6.9 m.y. for smaller stocks south of cordillera Cordillera Huayhaush and east of Lima (Giletti and Day, 1968). The silicic plutons of the Cordillera Huayhuash are correlated with the batholith of the Cordillera Blanca. Younger hypabyssal dikes and sills would perhaps correlate with other smaller intrusives in the central Andes with cooling ages grouping around 6.9 m.y.

The Puscanturpa volcanics, here considered younger than the Tsacra volcanics and silicic plutons, are correlated with younger, mainly silicic, volcanics throughout the central Andes of Peru, grouped as Sillipaca volcanics by Hosmer (1959, p. 149-154; *see also* Jenks, 1946, p. 371). They would also correlate with generally undeformed dacite tuffs in the Cordillera Ericksen, (Bodenlos and Ericksen, 1957, p. 26-27) and the Cordillera Blanca (Egeler and DeBooy, 1956, p. 27-28). If the Puscanturpa volcanics were fed from silicic dikes, sills, and small stocks, such as those in the Cordillera Huayhuash, they may be as young as 6 m.y. old.

STRUCTURAL EVOLUTION

If the above correlations are correct, sometime between Turonian and latest Cretaceous time, marine sedimentation ceased in the Cordillera Huayhuash. Sometime between the Turonian and middle(?) Tertiary the Cordillera Huayhuash must have suffered major deformation, and at this point it is not clear if it was pre-, syn-, or post-Casapalca Group. Regionally it certainly was all of these. By middle(?) Tertiary there was sufficient erosion to remove close to 50 percent of the folded Cretaceous prism, and much of the cover of Casapalca beds. Andesitic volcanism and associated deposition of red beds followed, flooding the region with Tsacra volcanics. The region was again deformed, intruded by batholiths in late Miocene(?), and still further eroded to a region of subdued relief of the Puna surface with residual massifs of an ancestral axial ridge of the Cordillera Huayhuash. Possibly as recently as 6 to 7 m.y. ago, in Pliocene time, Puscanturpa volcanism, fed by silicic intrusives, flooded the region with ash flows. In the last 6 m.y.(?), massive uplift has carried the Andes to present heights, causing deep dissection and eventually permitting onset of Pleistocene glaciation.

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