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GEOLOGY NEAR HUALLACOCHA LAKES, CENTRAL HIGH ANDES, PERÚ[1]

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ABSTRACT

Recent field work near the Huallacocha lakes has defined structural features in a narrow fold-and-fault or thrust belt near the Continental Divide. The rocks deformed include Paleozoic metamorphics, Permian to Cretaceous sedimentary and volcanic formations, and Tertiary terrigenous clastics. There is a large thrust sheet of Upper Cretaceous limestone which was probably formed in latest Cretaceous time and which was thrust from the southwest. Deformation occurred in early or medial Tertiary time and the structures, which strike northwest, include tight folds, reverse faults which change at depth to thrusts directed toward the northeast, and a zone of imbricate thrusts previously recognized by Harrison (1960). Tectonism is considered to be related to the formation of Yauli dome, directly northeast, during Tertiary time.

Introduction and Geologic Setting

In central Perú, Mesozoic rocks of the Andean geosyncline occur in a fold-and-fault belt along or near the Continental Divide. General geology was presented by Jenks (1956) for the Andes and by McLaughlin (1924) for the part of the Cordillera which includes the area of present study. A comprehensive review of Andean geology was given by Petersen (1958). Present interpretations of geologic structure in the region, of which this paper is an example, would be impossible without the study and subdivision of Cretaceous rocks set up by Wilson (1963). Harrison's work in the western Cordillera has contributed most to present understanding of regional geology. He proposes in his recent review (1960) a longitudinal subdivision of the central Peruvian Andes into the following zones, from west to east (Fig. 1): coastal zone, batholith, mountain belt, high plateau, and subandean slopes.

The present work defines the structural pattern between the edge of the mountain belt of Harrison, and the high plateau. The area spans the Continental Divide and, close to it, the zone of thrusts which Harrison described as the eastern edge of the mountain belt (Fig. 2). On the west, his zone of strongly folded Tertiary and Cretaceous beds is represented by the folded Tertiary Casapalca Group. On the northeast, the Chumpe anticline is the western branch of the broad Yauli dome, a "basement uplift" exposing Paleozoic rocks.

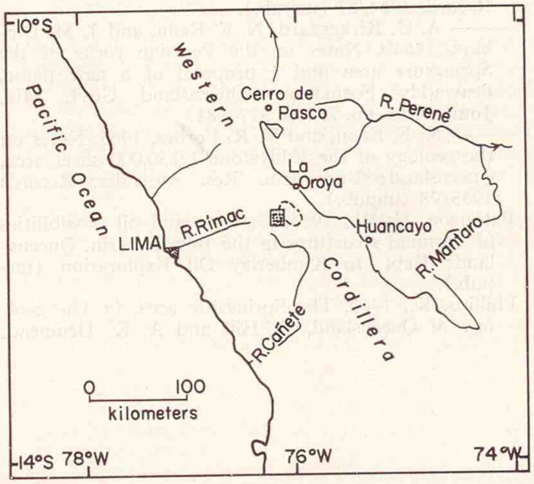

Fig. 1.—Location map, central Perú. Map area, stippled. Dashed line shows Yauli structural dome.

The high plateau, Harrison writes (1960, p. 11):

> . . . is characterized by the frequent and extensive exposure of the basement, a massif of strongly folded rocks of pre-Carboniferous age upon which, in different sections can be seen Lower Carboniferous, Permian, Trias, Jura, Cretaceous and even Tertiary

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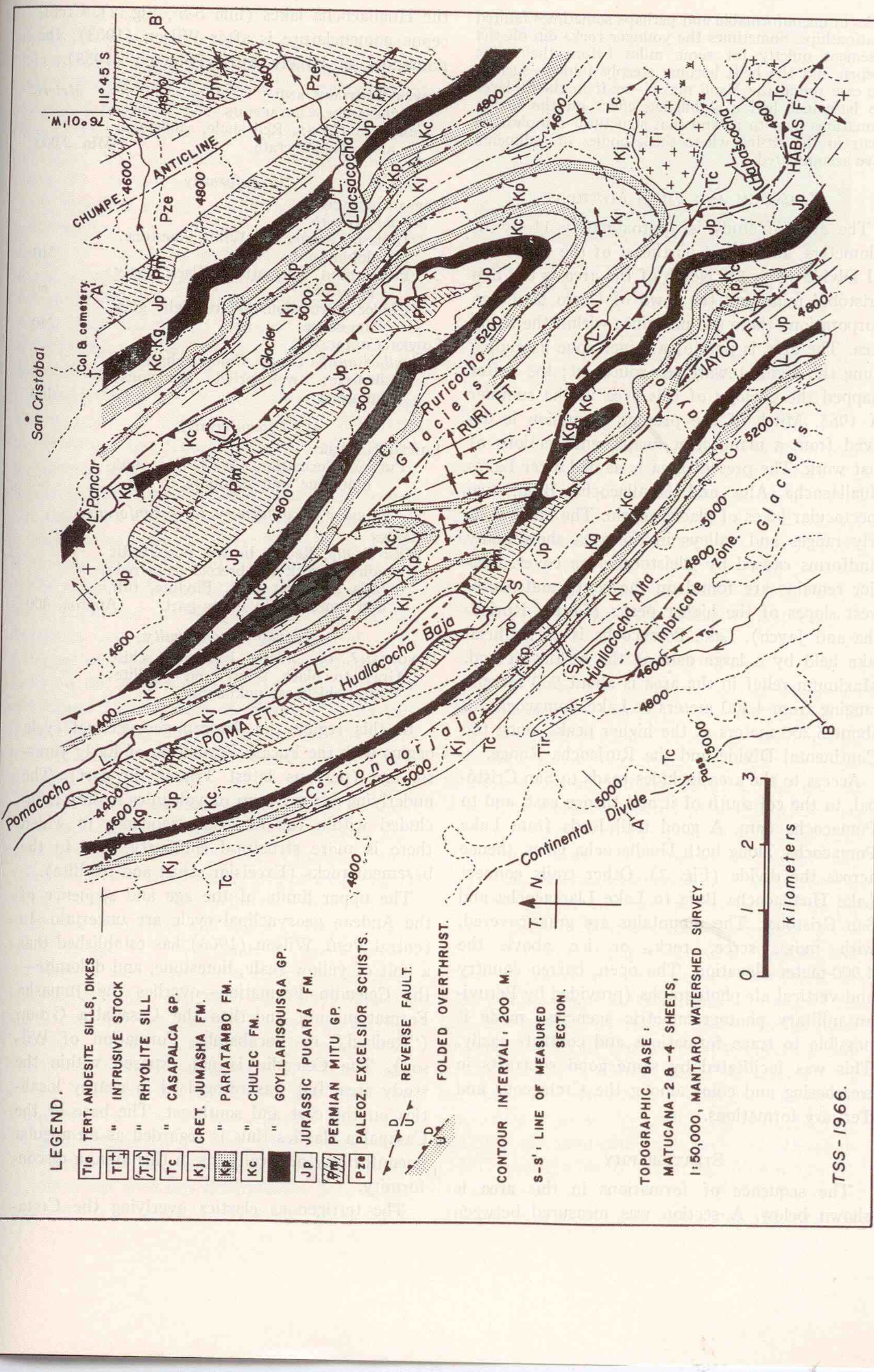

FIG. 2.—Geologic map of Huallacocha lakes area. *A-A′* and *B-B′* are lines of structure sections (Fig. 4).

rocks in unconformable and perhaps sometimes faulted relationships. Sometimes the younger rocks dip off the basement quietly for some miles before their dips steepen and the beds become steeply folded—such is the case round the Yauli massif—as if in these places the basement had a stabilizing effect on the higher formations near to it, and that structural complexities occur in the basins where thick bodies of sediments have accumulated.

Location and Field Methods

The area of study is approximately 11 by 13 kilometers, and is just northeast of the Continental Divide (Fig. 2). North of the area is the San Cristóbal mine and the town of Cerro de Pasco Corporation; there are no mines within the study area. The area is part of a larger zone extending along the divide toward the southeast; the writer mapped the geology of this area in the summer of 1965. Much of the present discussion is derived from a manuscript, maps, and sections of that work. The present area is named after Lakes Huallacocha Alta and Huallacocha Baja, two spectacular lakes of glacial origin. The northwesterly ranges and valleys in the area show many landforms caused by Pleistocene ice cover. Glacier remains are found on the south and southwest slopes of the higher peaks (Cerros Ruricocha and Jayco). Lake Pomacocha is an artificial lake held by a large dam at the northwest end. Maximum relief in the area is about 900 meters, ranging from 4,300 meters at Lake Pomacocha to about 5,200 meters at the higher peaks along the Continental Divide and the Ruricocha Range.

Access to the area includes roads to San Cristóbal, to the col south of it and thence east, and to Pomacocha dam. A good trail leads from Lake Pomacocha, along both Huallacocha lakes, thence across the divide (Fig. 2). Other trails connect Lake Huallacocha Baja to Lake Llacsacocha and San Cristóbal. The mountains are grass-covered, with moss, scree, rock, or ice above the 4,900-meter elevation. The open, barren country and vertical air photographs (provided by Peruvian military photogrammetric agencies) made it possible to trace formations and contacts easily. This was facilitated by some good contrasts in weathering and color among the Cretaceous and Tertiary formations.

Stratigraphy

The sequence of formations in this area is shown below. A section was measured between the Huallacocha lakes (line S-S′, Fig. 2). Cretaceous nomenclature is after Wilson (1963); the remainder is largely after Petersen (1958).

	Meters
LOWER TERTIARY AND UPPERMOST CRETACEOUS	
Casapalca Group. Red shale, sandstone, and conglomerate	Min. 2,000
Disconformity	
UPPER CRETACEOUS	
Machay Group	
Jumasha Formation. White limestone, dolomite	210
Pariatambo Formation. Black shaly limestone	60
Chulec Formation. White, light gray limestone	240
LOWER CRETACEOUS	
Goyllarisquisga Group. Colored shale and siltstone; well-sorted sandstone; limestone	160
Disconformity	
LOWER JURASSIC	
Pucará Formation. White to dark limestone and dolomite	520
Angular unconformity to disconformity	
PERMIAN	
Mitu Group. Red to brown, porphyritic volcanic rock and breccia, some redbeds in upper part. Phyllite, tuff, and limestone in lower part.	Approx. 400
Angular unconformity	
DEVONIAN? or older? Excelsior schist. Gray to black schist and phyllite; total thickness unknown	

In this region the Andean geosynclinal cycle begins with the Pucará Formation of Early Jurassic age (perhaps latest Triassic in part). The underlying Mitu Group of volcanics mainly is included within the Mesozoic sequence to which there is more structural similarity than to the basement rocks (Excelsior schist and phyllite).

The upper limits of the age and sequence of the Andean geosynclinal cycle are uncertain. In central Perú, Wilson (1963) has established that a unit of yellow shale, limestone, and dolomite—the Celendín Formation—overlies the Jumasha Formation and underlies the Casapalca Group ("Redbed," or Pocabamba Formation of Wilson). The Celendín is not exposed within the study area, but was recognized in nearby localities on the east and southeast. The base of the Casapalca clastics thus is regarded as an angular unconformity or locally, as in this area, a disconformity.

The terrigenous clastics overlying the Cretaceous limestone are included in the Casapalca Group (after Petersen, 1958). Approximately 15 kilometers east, the Casapalca Group has an estimated thickness of at least 2,700 meters and is composed predominantly of red shale and sandstone. These rocks have much tectonic significance: they are wedges of clastic sediments deposited in zones where marine sediments were deposited earlier, as the region passed from submergence at the edge of the geosynclinal trough to alternating zones of uplift and subsidence. Insofar as this probably was a gradual development from the earlier conditions, the lower part (lower 400 meters, selected arbitrarily) of the Casapalca Group also is included within the Mesozoic geosynclinal sequence. The age of the Casapalca Group also is uncertain because of the almost complete absence of fossils. Limestone lenses within the redbeds near Huarón, farther northwest, have fossils (Mabire, 1961) which, however, permit an age assignment no more precise than Late Cretaceous. The age of the group is given tentatively as latest Cretaceous (post-Santonian, after Wilson, 1963) to early Tertiary.

The expanded Mesozoic sequence, including the Mitu Group and the 400-meter basal part of the Casapalca Group, has a total thickness of about 2,000 meters and constitutes the deformed cover rocks on the Paleozoic basement. This compares with about 2,100 meters of Mesozoic rocks that form the folded, thrusted cover at the well-studied locality of Grenchenberg, Swiss Juras (Badgley, 1965, p. 77).

Wilson (1963) established the general tectonic framework of the central Peruvian Andean geosynclinal belt for the Cretaceous: a western trough (volcanic) of the geosyncline, with an axis roughly through Lima (Fig. 1); a broad geanticline east of the Marañón River and Cerro de Pasco; and a second trough in the subandean region farther east. Wilson also described a restricted platform that once extended west from La Oroya, from the geanticline into the western trough during the Cretaceous. This platform is here named the *Yauli shelf*. Thinner sequences of Cretaceous and perhaps Jurassic rocks in this area were deposited at and west of the western edge of the Yauli shelf, and the pattern of later deformation seems to be typical of that of a shelf sequence. Probably concurrent with this deformation, part of the Yauli shelf was raised, forming the Yauli dome

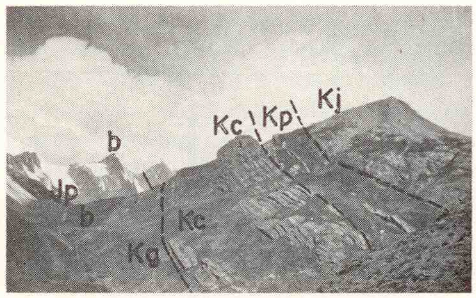

FIG. 3.—Cretaceous section east of Lake Huallacocha Alta, looking southeast. Cerro Jayco in background left. *Jp* = Pucará Formation. *Kg* = Goyllarisquisga Group, with *b* = basaltic interbed. *Kc* = Chulec Formation. *Kp* = Pariatambo Formation. *Kg* = Jumasha Formation with, in higher part, repetition caused by bedding-plane thrust.

(Fig. 1; and northeast corner of map, Fig. 2).

An interesting and useful phenomenon in mapping the Mesozoic rocks is the great contrast in weathering and color between the black Pariatambo Formation and the white, cliff-forming units below and above, the Chulec and Jumasha Formations, respectively (Fig. 3). This contrast, more than any other, facilitated recognition of the structural features, including overthrusting.

STRUCTURAL GEOLOGY

Present structural interpretations are shown on the geologic map (Fig. 2) and structure sections (Fig. 4). To the writer's knowledge, there are no previous published geologic maps of the area. Several structural features shown in the present work have been recognized previously. Harrison (1951), dealing with the geology of a long strip of country from Lake Pomacocha toward the southwest, described the rock units and structure around this lake and first referred to the major reverse fault here named the *Poma fault*. More importantly in that paper, Harrison discussed and described imbricate structure just northwest of Lake Pomacocha, involving strata across the Cretaceous limestone-Casapalca contact. In the present work, imbricate faults within the outcrop belt of the Casapalca Group have been recognized only near Lake Huallacocha Alta and are shown schematically in section B-B′ (Fig. 4). The recognition of imbricate structure by Harrison (1951) and its identification by Wilson (1963) over the crest of the western Cordillera in general have been important guides for the writer's

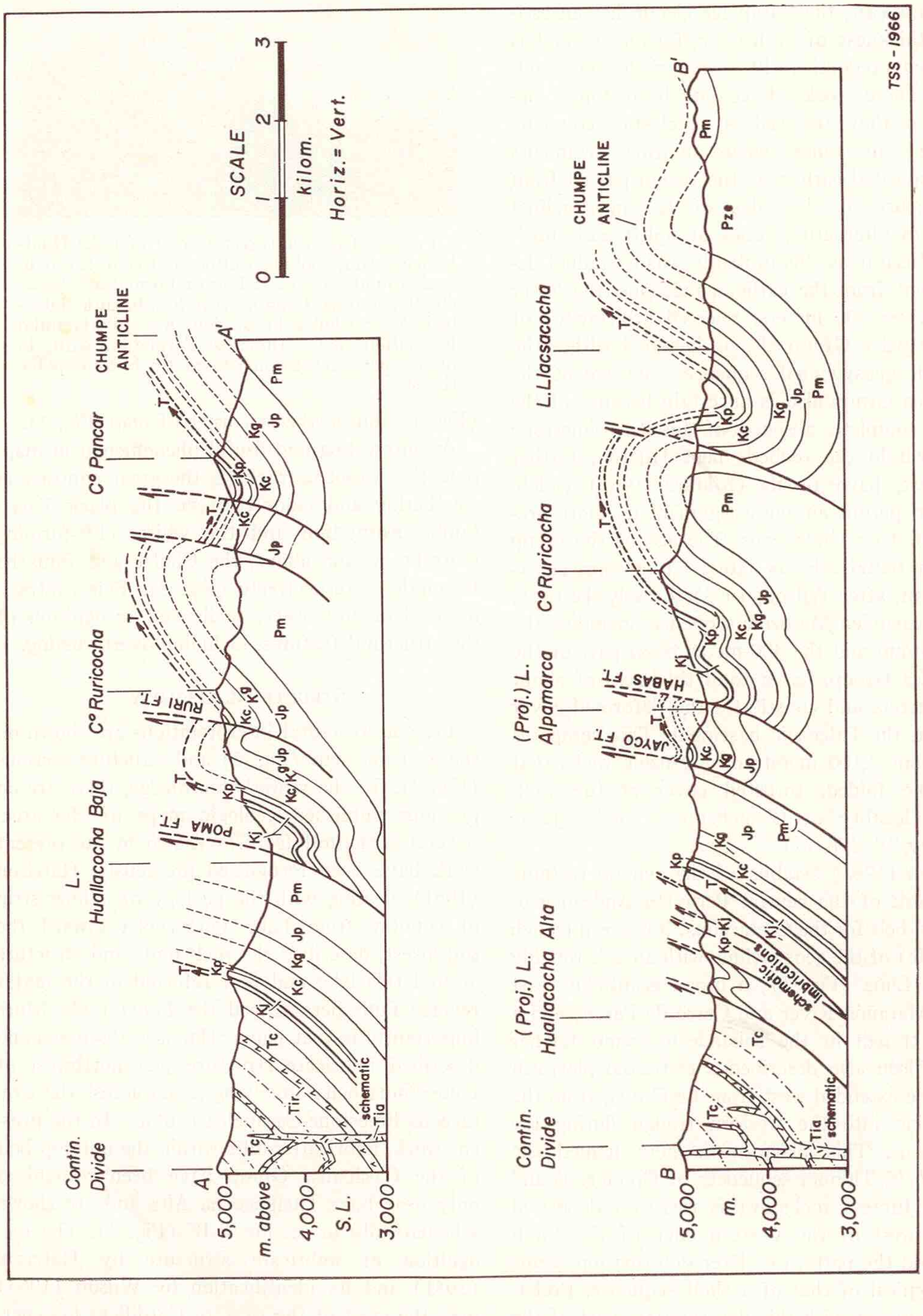

FIG. 4.—Structure sections along lines *A-A'* and *B-B'* of Figure 2, looking northwest. Abbreviations as in Figure 2. T = Ruricocha overthrust.

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recognition of similar structures within Cretaceous limestones south of Cerro Jayco and farther southeast.

Unpublished maps and reports of the Cerro de Pasco Corporation describe several structures in the northeast quadrant of the map (Fig. 2). Among these works are: maps by Harrison which show the large anticline north and east of Cerro Ruricocha; maps and reports on the geology of San Cristóbal Mine and surroundings; and a 1964 map and report by N. Rivera which refer to the reverse faults at Lake Pancar and to the outcrop pattern of the Chumpe anticline.

Within the structural pattern in the map and sections (Figs. 2, 4) are evidences of the following two successive tectonic events: (1) an extensive bedding-plane overthrust of Upper Cretaceous limestone onto the Cretaceous sequence; and (2) tight folding along the northwest-striking axial planes, accompanied by reverse faulting of similar strike.

OVERTHRUSTING

Overthrusting is indicated by repetition of the Pariatambo and Jumasha Formations. Such an occurrence was recorded previously by Wilson (1963, p. 18) as follows:

> A casual survey of the [Jumasha] formation in the strongly folded and faulted region near the Continental Divide suggests considerable thicknesses, but closer examination reveals that many apparently conformable sequences consist of a series of sheets thrust one above the other.

The present work establishes that a broad thrust plate was folded and faulted together with the Mesozoic sequence. Field evidences for this include the following: (1) bedding-plane thrust in the steeply dipping measured section (S-S′) near the Huallacocha lakes; this was traced visually along the strike and on air photos for a minimum total length of 10 kilometers; and (2) twin outcrop bands of the Pariatambo Formation at the nose of the major anticline north of Lake Habascocha and on the fold limbs west and directly south of Lake Llacsacocha, east of Lake Huallacocha Baja, east of Lake Pancar, and east of Cerro Jayco (Fig. 2).

The horizon of detachment and movement was in the soft, black, shaly Pariatambo limestone. A similar structural role has been described by Wilson (1963) and Harrison (1960) for the Oyón Formation, the basal unit of the Cretaceous Goyllarisquisga Group farther northwest. This is a unit approximately 100 meters thick, consisting of thin-bedded sandstone, shale, and coal seams (Lower Cretaceous Coal Measures of Harrison, 1960, p. 10). The Oyón thus has been the zone of *décollement* for numerous overthrusts; Coney's (1964) work in the Cordillera Huayhuash farther northwest along the Continental Divide has shown a well-developed pattern of folding and *décollement* of the Mesozoic rocks above the Oyón Formation.

The thrust plate (or scale) of the study area is named the *Ruricocha thrust plate* (and overthrust) after Cerro Ruricocha on which it is exposed. Approximate dimensions of the thrust plate are estimated as follows (Figs. 2, 4):

Minimum width (breadth of travel), between Cerros Condorjaja and Jayco:	10 km.
Minimum distance of travel (overriding), Lake Huallacocha Alta to Lake Llacsacocha, corrected for folding:	10 km.
Thickness of plate of Jumasha and part of Pariatambo Formations:	220 m.

At Lakes Huallacocha Alta and Habascocha, Casapalca beds overlie the overthrust Mesozoic rocks and are folded and faulted with them. Overthrusting, then, followed deposition of the Jumasha Formation and preceded that of the Casapalca beds. The Celendín Formation of Santonian age (Wilson, 1963) is absent in this area; possibly it might have been present, then eroded prior to overthrusting. The age of the basal Casapalca beds is not clear, but might be expressed as latest Cretaceous. Overthrusting thus occurred sometime between Campanian or Maestrichtian times (Jumasha Formation) and the latest Cretaceous. Thrusting is considered to be from the southwest. This evidence of tectonic denudation is significant. Whereas preceding Cretaceous formations have recorded a former west slope toward the axis of the western geosynclinal trough, by pre-latest Cretaceous time there was a reversal of slope, an indication of uplift toward the southwest (perhaps only local), whence to provide a *décollement* plate. Uplift on the southwest, by latest Cretaceous time, is evidenced better by the fact that Casapalca clastics coarsen in that direction.

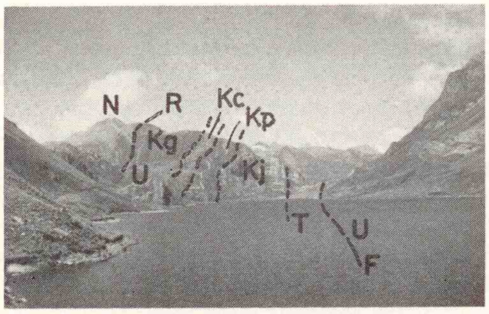

FIG. 5.—View from east shore of Lake Pomacocha looking southeast. *N* = north spur, Cerro Ruricocha. *F* and *R* are approximate traces of Poma and Ruri reverse faults, respectively. *U* marks upthrown fault blocks. Mountainside at right exposes Pucará Formation atop Mitu volcanics. *Kg* = Goyllarisquisga Group. *Kc* = Chulec Formation. *Kp* = Pariatambo Formation. *Kg* = Jumasha Formation. *T* = approximate trace of Ruricocha overthrust.

In areas on the southeast recently mapped by the writer, no folded overthrust plate of Cretaceous limestone was observed.

FOLDING AND REVERSE FAULTING

The pattern of deformation in this area is of tight folds with northwest-striking axial planes, and reverse faults cutting them, with mainly northwest strikes. The overall drag-fold pattern (Fig. 4, sections of overturned anticlines thrust over synclines) strongly suggests that the folding and faulting were partly concurrent.

Actual fault planes were not observed in the field, but the fault contacts could be located fairly well through the contrasting outcrop pattern on opposite fault blocks. The general straightness of the fault traces across this area of much relief suggests mainly steep dips toward the southwest. Nevertheless, the reverse faults are interpreted as flattening with depth, thus being true thrust faults with steepened segments near the surface, as argued by Badgley (1965, chapter 6). The northwest-trending folds and faults are traceable along the Continental Divide for at least 50 kilometers from Lake Pomacocha toward the southeast. The reverse faults are assumed to pass downward into bedding-plane thrusts, but at what depths and within which formations are conjectural (Fig. 4). The Poma fault is of great extent along strike. Within the map area it splits into two branches: the branch here named *Jayco fault* has progressively smaller displacement from Cerro Jayco southeastward; the other branch, named *Habas fault*, increases in displacement in that direction (relay effect). From near the north end of Lake Pomacocha (Fig. 5) to the farthest-traced limit of the Habas fault, the Poma fault system has a length of 22 kilometers. A similar reverse fault, wholly outside the area on the southeast (Tranca fault), was traced for 31 kilometers.

The structural pattern in the area includes tight folds with drag folds, some overturned fold-limbs, and closely spaced reverse faults cutting them. These features are considered to be related to the Yauli structural dome adjoining them on the northeast (northeast edge, Fig. 2). There are no Tertiary plutonic intrusions within the Mesozoic fold-and-fault belt next to this dome; such intrusions occur only within the Paleozoic core of the dome itself (Cerro de Pasco Corporation reports). The small intrusive near Lake Habascocha is opposite the southeast end of Yauli dome, indicated by the southeast-plunging Chumpe anticline. In contrast, on the southeast where the fold-and-fault belt is not opposite a structural dome, the degree of deformation is less; the folds are more open and show smaller overturned limbs; the reverse faults are wider spaced; and there is a fairly regular pattern of Tertiary intrusives. At Morococha, about 40 kilometers north, deformation in the fold-and-fault belt also is different and less severe (Nagell, 1960). The folds are open; gentle cross-folds are present; and there is not an imbricate set of reverse faults, only an overthrust from the southwest and one from the northeast (Gertrudis and Potosi thrust faults, respectively, of Nagell, 1960).

Deformation in the imbricate zone along the Continental Divide is similar to and a part of the main overall fault deformation and is thus indicated on the sections (Fig. 4). Much future field work would be necessary to unravel details in the imbricate zone, but this will be hindered by the jagged terrane and glacier cover. It is notable that the imbricate zone continues from the study area toward the southeast regardless of the structural contrast outlined above.

Diastrophism in this region can not yet be given a definite age. Deformation post-dated deposition of the Casapalca Group and thus is at least post-earliest Tertiary. Field evidences, seen by the writer, indicate that folding and faulting preceded emplacement of plutonic intrusives. Published radiometric ages are as yet lacking for these but tentatively they may be assigned a middle to late Tertiary age. Diastrophism thus dates from the early or middle Tertiary. Petersen (1958) discusses in detail evidences and considerations of ages of diastrophism and plutonic intrusions in the Andean Cordillera.

Conclusions

In the area, structures include tight, overturned folds with drag folds, and closely spaced thrust faults grading to reverse faults. The Mesozoic disturbed belt is narrow, only 8 kilometers across from the edge of the Casapalca outcrop to the Paleozoic rocks in Yauli dome. Imbricate faults slice rocks near the Cretaceous limestone-Casapalca contact; plutonic intrusions are lacking. All of these are considered to be features related to the Yauli structural dome on the northeast. In Cretaceous time at least part of the area was within the Yauli shelf; later, in early Tertiary time, with probably a compressive field oriented in a southwest-northeast direction, part of the Yauli shelf underwent tectonic uplift, and Yauli dome was formed. Concomitantly or later, the shelf may have acted as a buttress causing complex and tight deformation within the rocks along its western part (following the analysis of Harrison, 1960).

The present work extends and defines structural features of which some were established first by Harrison (1960). Parts of this region, in particular zones near the Continental Divide, show complexities similar to those of better studied fold-and-fault belts of the world, such as the Virginia-Tennessee and Jura belts (Badgley, 1965). In these regions and in the Peruvian Cordillera, the fold-and-fault belt is at or near the shelf edge of a former geosyncline. The directions of overthrusting and of reverse faulting are mainly away from the geosynclinal trough axis and toward the continent.

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