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TECTONO-STRATIGRAPHIC HISTORY OF THE HUANCAYO INTERMONTANE BASIN, CENTRAL PERU

HISTORIA TECTÓNICA DE LA CUENCA INTERMONTAÑOSA DE HUANCAYO, PERÚ CENTRAL

James M. Wise

ABSTRACT

Sedimentary sequences of the Huancayo intermontane basin in central Peru provide age constraints on the late Miocene regional Quechua III contractional deformation event, contribute evidence for younger contraction, and record major changes in the canyon and stream network during ongoing uplift of the Cordillera Oriental. A new $^{40}Ar/^{39}Ar$ date of 5.39±0.05 Ma on the Mataula Formation of the Jauja Group combined with a review of regional data indicates the Quechua III contractional event occurred between 4.8 and 5.4 Ma. The Huancayo basin was previously interpreted as a synformal trough, however basin depth and geometry remain unknown. Significantly, basement rock along the western basin margin was thrust over the Jauja Group, defining recent asymmetric basin closure development. Several major facies changes in the Pliocene to Recent basin deposition happened during the exhumation of the Precambrian crystalline rock of the Huaytapallana Massif of the Cordillera Oriental. These include abandonment of the Upper Pliocene (?) Torre Torre conglomerate, widespread deposition of the uppermost Pliocene-Pleistocene (?) Chupaca gravels from integration of the ancestral río Mantaro into the Huancayo basin, and arrival of Precambrian clasts into the Pleistocene to Recent Huancayo alluvial fans. Recent depositional patterns and Pleistocene folding of the gravels illustrate contraction in the basin, distinguishing it from other intermontane basins of Peru. Incisement of the Chupaca gravels and development of at least three stages of river terraces along río Mantaro may represent climate change.

Keywords: *Huancayo intermontane basin, Mataula Formation, Torre Torre conglomerate, Chupaca gravels, Quechua III, Huaytapallana Massif.*

RESUMEN

Las secuencias sedimentarias de la cuenca intermontañosa de Huancayo en el Perú central proporcionan datos bastante aproximados de la edad del último acontecimiento regional miocénico de la deformación conpresional Quechua III, contribuyendo además con evidencia de una compresión más joven, y registrando cambios importantes en el sistema de cañones y drenaje fluvial durante el levantamiento de la Cordillera Oriental. Una nueva datación $^{40}Ar/^{39}Ar$ de 5.39±0.05 Ma en la Formación Mataula del Grupo Jauja combinada con una revisión de datos regionales, indica que el evento compresional Quechua III ocurrió entre 4.8 y 5.4 Ma. La cuenca de Huancayo ha sido previamente interpretada como una depresión sinformal, no obstante, la profundidad y geometría de la cuenca siguen siendo desconocidas. Claramente, la roca del basamento a lo largo del margen occidental de la cuenca fue sobreescurrida sobre el Grupo Jauja, definiendo un reciente desarrollo asimétrico del cierre de la cuenca. Varios cambios importantes de facies en la sedimentación de la cuenca desde el Plioceno hasta épocas recientes sucedieron durante la exhumación del basamento cristalino precámbrico del macizo de Huaytapallana de la Cordillera Oriental. Estos cambios incluyen la extinción del conglomerado Torre Torre del Plioceno superior (?), la deposición extensa de las gravas Chupaca más jóvenes (Plioceno-Pleistoceno superior, ?) producto de la integración del ancestral río Mantaro a la cuenca de Huancayo, y el aporte de clastos precámbricos a los depositos aluviales de edad Pleistoceno a reciente en Huancayo. Patrones deposicionales recientes y plegamiento pleistocénico de las gravas demuestran el régimen compresivo de la cuenca, diferenciándola de otras cuencas intermontañosas del Perú. La erosión de las gravas Chupaca y el desarrollo de por lo menos tres niveles de terrazas fluviales a lo largo del río Mantaro podrían representar un cambio climático.

Palabras claves: *cuenca intermontañosa de Huancayo, Formación Mataula, conglomerado Torre Torre, gravas Chupaca, Quechua III, Macizo de Huaytapallana.*

Newmont Mining Corporation: 337 W. Commercial Street, Elko, NV 89801, U.S.A., jim.wise@newmont.com

INTRODUCTION

The Huancayo intermontane basin preserves sedimentary evidence important for the tectonic history of the Andes, demonstrating multiple contraction events in the late Miocene to present. The basin is 5 to 15 km wide, 70 km elongate in a northwest direction, and lies at 3,200 to 3,300 m elevation (Figs. 1 and 2). The río Mantaro drains the basin to the southeast, and the northern part of the basin is partly occupied by 3-km long Laguna Paca. The Cordillera Oriental, composed mainly of Precambrian and Paleozoic rocks, bounds the east margin of the basin. The Cordillera Oriental is deeply incised by local west-draining canyons that feed active alluvial fans in the Huancayo basin (Fig. 2A).

The intermontane basins of Peru are situated between the Cordilleras Occidental and Oriental (Marocco et al., 1995), defining a belt of discontinuous localized subsidence within the high plateau of the Andes (Fig. 1). The basins formed along major longitudinal fault systems (Mégard, 1973), making NW-elongate depression bordered by mountainous regions. Most of the basins formed during alternating periods of extensional opening and closure during regional contraction. These contraction events were called the Quechua deformation by Steinmann (1929), and then refined into three short and discrete pulses or events by Mégard (1973; 1978). This tectonic style operated throughout the Neogene (Mégard et al., 1984a), and probably during much of the Cenozoic (e.g., Benavides-Cáceres, 1999).

Previous studies interpreted the Huancayo basin to be developed in a large synclinal trough (Dollfus and Mégard, 1968; Dorbath et al., 1991; Benavides-Cáceres, 1999), but the depth and subsurface geometry of the contact between basin fill and basement rock remain unknown. In contrast, this study finds that the western basin margin is mainly fault bounded (Fig. 3). The Huancayo basin shares certain structural and depositional characteristics with the Junín basin, located 75 km to the northwest, based on the western margin being bounded by reverse faults and the eastern basin margins lacking any clear fault boundaries. Unlike the Ayacucho basin 92 km to the southeast, or the Callejón de Huaylas basin situated 260 km to the northwest, both of which are strongly incised, the Mantaro Valley at Huancayo has widespread recent alluvial fans and flood plain deposits of the braided río Mantaro.

Figure 1.- Intermontane basins of Peru (basins marked in white) overlaid on 30-arc second DEM from GLOBE (shades of gray).

Upper Miocene through Recent alluvial, fluvial, and lacustrine deposits are exposed in the basin (Fig. 2). The Upper Miocene-Pliocene Jauja Group is the oldest exposed stratigraphic unit (Blanc, 1984). Pleistocene to modern deposits cover most of the basin, consequently the earlier basin depositional phases are poorly known. These younger, possibly syntectonic, Pleistocene gravels were deformed by the circa 2.5 Ma Quechua IV event (Grose, 1964).

This study reports a new $^{40}Ar/^{39}Ar$ isotopic age for the Mataula Formation of the Jauja Group, which places a refined constraint on the regional Quechua III contractional event (Benavides-Cáceres, 1999). New geographic-based formation names are assigned to emphasize depositional facies over implied climatic conditions. Field observations on the various deposits and structural setting of the basin are presented. Clast compositions in the younger sedimentary deposits are used to demonstrate recent exposure of Precambrian rock along the divide of the Cordillera Oriental. A discussion of the basin evolution is given, exploring variations in the depositional systems as possibly linked to major phases of tectonism.

Upper Miocene-Pliocene Strata

The Upper Miocene-Pliocene Jauja Group, originally called the Jauja Formation by Harrison

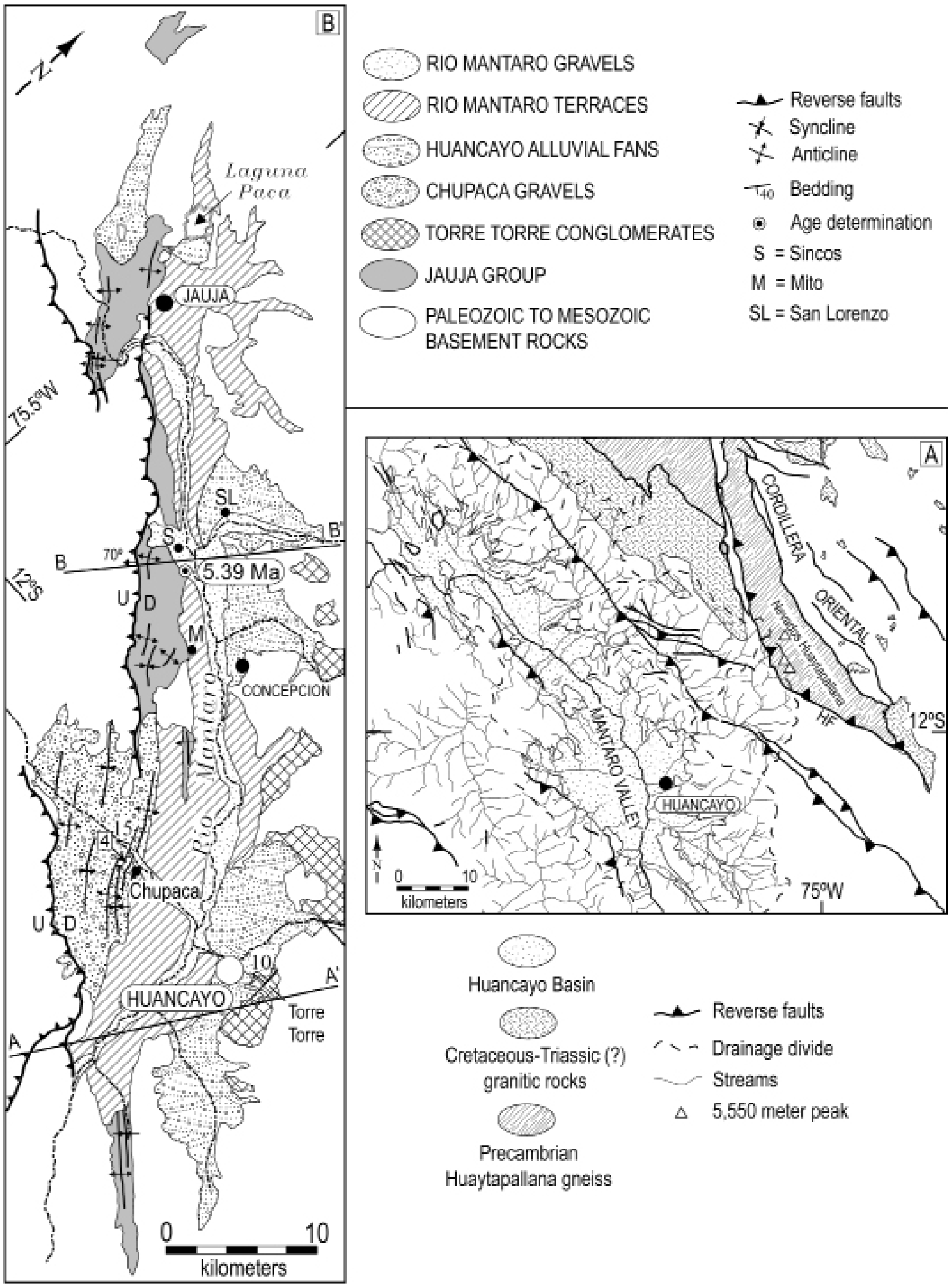

Figure 2.- A. Map showing major faults around the Huancayo basin, exposures of distinct bedrock source areas in the Cordillera Oriental, and pattern of drainages feeding the basin. HF = Huaytapallana reverse fault. B. Geologic map of the Huancayo intermontane basin modified after Dollfus and Mégard (1968), Mégard (1968), Paredes (1972; 1994), Blanc (1984), and Mégard et al. (1996).

(1943), is exposed along the west basin margin and in the northern half of the basin (Figs. 2B and 4). Near Jauja, Blanc (1984) subdivided the Jauja Group into Ushno and Mataula Formations. Overall, these units crop out in 10 to 30 degree east-dipping beds. Dollfus (1965) estimated a maximum thickness of the Jauja Group of 300 m whereas Mégard (1968) reported a combined minimum thickness of 200 m with the base unexposed. Most stratigraphic sections in the basin are incomplete with exposed thicknesses generally less than 100 m and the bases unexposed.

Ushno Formation

The Ushno Formation is composed of thick-bedded pebble to cobble conglomerate and sandstone, some of which were reported by Blanc (1984) as

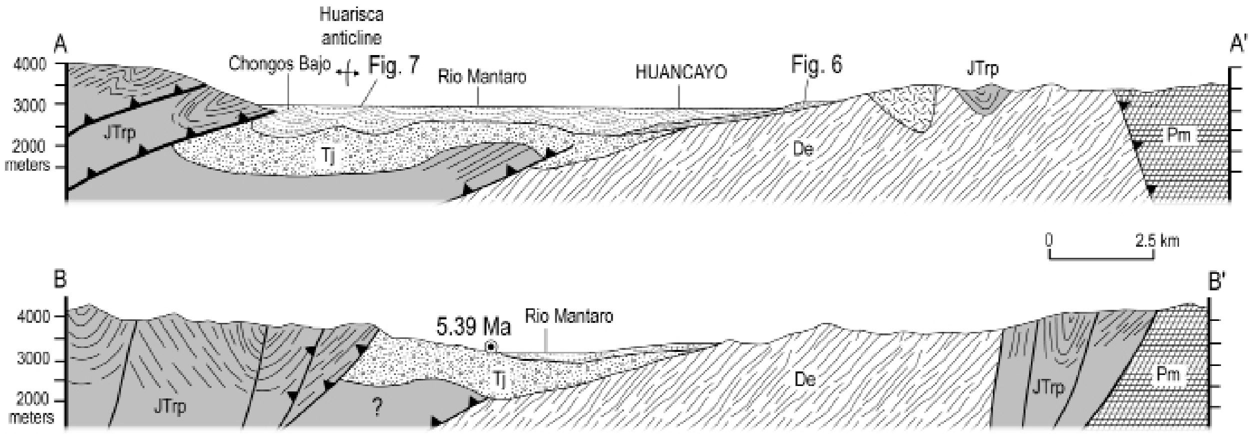

Figure 3.- Geologic cross sections of the Huancayo basin looking toward the northeast. Section locations are marked in Fig. 2. Section A-A' was interpreted from 1:100,000 scale geologic map by Mégard (1968), and section B-B' was based from the map by Paredes (1972) with additional modifications from observing the Pucara Group rocks in the field thrust over the Jauja Group. Depth to basement and thickness of the basin fill is unknown. These sections differ from previous interpretations by showing the basin fill as being thicker, and by having basement rock along the western margin of the basin thrust over the basin fill. Note that this interpretation places basin deposition in a wedge-shape formed between major thrust sheets and does not really fit an ideal piggyback basin setting.

debris flows. Locally these deposits unconformable overlie the dark slates to gray schists of the Devonian Excelsior Formation, limestone of the Triassic-Jurassic Pucará Group, and redbeds of the earliest Cenozoic Casapalca Formation. The Mataula Formation generally concordantly overlies the Ushno Formation, although locally the contact is an angular unconformity (Blanc, 1984).

The Ushno Formation has an overall yellowish- to tan-weathering character. Most of the formation is made of tabular-bedded conglomerate with lesser interbeds of lenticular coarse-grained sandstone. The average clast diameter is about 4 cm, but the clast sizes are very poorly sorted. The conglomerates are mainly framework supported. The conglomerate beds contain subrounded to subangular clasts of well-cemented, brownish-reddish siltstone, possibly derived from either the latest Cretaceous-Paleocene Casapalca Formation or the Permian-Triassic Mitu Group. About half of the clasts are composed of micrite derived from the Triassic-Jurassic Pucurá Group, based on field observation from multiple outcrops and clast compositions reported in Blanc (1984). Source areas for all the clast compositions are located immediately adjacent to the basin margins. Blanc (1984) described several sections in the formation, and repeatedly stated that the most common clast type is limestone. The mountain ranges to the west are mainly composed of limestone of the Pucará Group. Overall, the Ushno Formation represents alluvial fan facies as supported by the presence of debris flow units and local source of detritus.

All previous studies interpreted a Miocene age for the Ushno Formation (Mégard, 1968; Dollfus and Mégard, 1968; Blanc, 1984) as based on the unit underlying the dated Mataula Formation: although the formation is undated and it may be significantly older. Cross cutting relationships show that the formation is younger the uppermost Cretaceous to Paleocene (?) Casapalca Formation, and is older than the Upper Miocene Mataula Formation (see below). Given the large uncertainty in the age of the Ushno Formation, the usefulness of the Jauja Group ranking is questionable. In general, a stratigraphic group should exclude formations of markedly different ages separated by an angular unconformity, particularly when the units are of limited extent.

Mataula Formation

The Mataula Formation is distinctively tan- to white-weathering, composed of tabular bedded cross-stratified sandstone interbedded with tabular-bedded pebble to cobble conglomerates, and includes less common white-weathering lacustrine beds and a few <2-m thick ash beds. Locally the formation is folded and unconformably overlies the Ushno Formation, such as exposed north río Mantaro to the southwest of Jauja (Blanc, 1984).

A lacustrine facies unit, approximately 50-m thick, located near the base of the formation (Fig. 4) provides a prominent white- to gray-weathering marker horizon. This unit mainly contains planar laminated siltstone to fine-grained sandstone. The coarser grained lacustrine facies has tuffaceous sandstone with high concentrations of biotite accompanied with phenocrysts of quartz, plagioclase, and potassium feldspar interpreted as a water lain tuff.

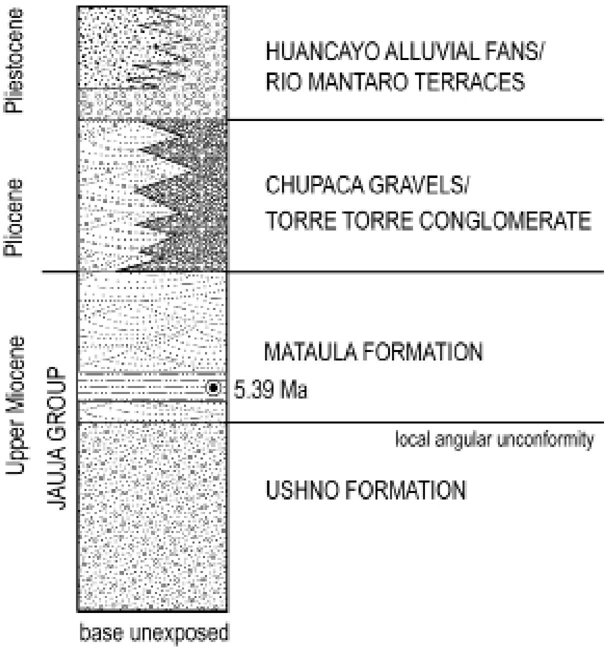

Figure 4.- Generalized stratigraphic section from the Huancayo basin. Thickness of the units is schematic because the bases for many of the formations are unexposed.

Clast compositions of the conglomerates, as reported by Blanc (1984) and observed during this study, include limestone of the Triassic-Jurassic Pucurá Group, material derived from the Permian-Triassic Mitu Group, gray schist from the Devonian Excelsior Formation, and a few intrusive rocks of uncertain age and source location.

Harrison (1943) reported vertebrate fossils, including bone fragments and teeth of both Mastodon and Megatherium, from the section west of Jauja that probably places these fossils in the Mataula Formation. The lacustrine beds are diatom rich, and include fresh water bivalves, gastropods, ostracodes, and plant fossils.

Two kilometers west of Sincos, the upper Mataula Formation is composed of interbedded sandstone and pebble conglomerates and is truncated by the basin boundary fault. These clastic units overlie the above described and dated lacustrine beds. The bedding in the upper section is oriented N65E, 15 SW, which is a direction opposing bedding in the remainder of the formation thereby implying the presence of an open anticline or deformation along the basin boundary. The tabular bedded cross-stratified sandstone has casts of ripple marks on the bed bottoms. This section is interpreted as braided-stream facies as based on bed thickness and sedimentary structures such as low-profile stacked channels and cross-stratification. The bedding thickness, abundance of interbedded sandstone, overall finer-grain size, light tan to white coloration, all distinguish the upper part of the Mataula Formation as having a different deposition setting than the underlying Ushno Formation.

A sample of waterlain tuff within the main lacustrine unit was collected from along the paved road south of pueblo Sincos. The sample was from a large slide block of intact strata that slid basinward. A biotite mineral separate yielded a $^{40}Ar/^{39}Ar$ plateau age of 5.39±0.05 Ma (sample J250, steps 4 to 15 account for 89.8% of the ^{39}Ar released; Table 1, Fig. 5). Steps 1-3 and 16 were excluded because they are significantly older and fail the plateau criteria. These steps yield apparent older ages and probably reflect the inclusion of excess argon, as shown by the U-shaped outer segments of the plateau in Figure 5. Therefore the total gas age of 6.30±0.05 Ma is too old. No isochron was defined by the sample. Previously, the base of the Mataula Formation was dated at 5.64±0.2 Ma by whole rock K-Ar analysis (Blanc, 1984). The exact location of this K-Ar sample is unclear because Blanc (1984) did not report the sample coordinate or indicate the location on a map. Both the K-Ar sample and J250 were probably collected from the same unit of biotite-rich waterlain tuff because it is the only prominent volcanic horizon in the section. Overall, the two samples are in analytical agreement, but the new plateau age better constrains the time of the Mataula Formation.

Upper Pliocene-Pleistocene to Recent deposits

Upper Pliocene to Recent alluvial fan to fluvial deposits cover over 50% of the Huancayo basin. The alluvial fans record at least two phases of deposition, represented by the Torre Torre conglomerate beds

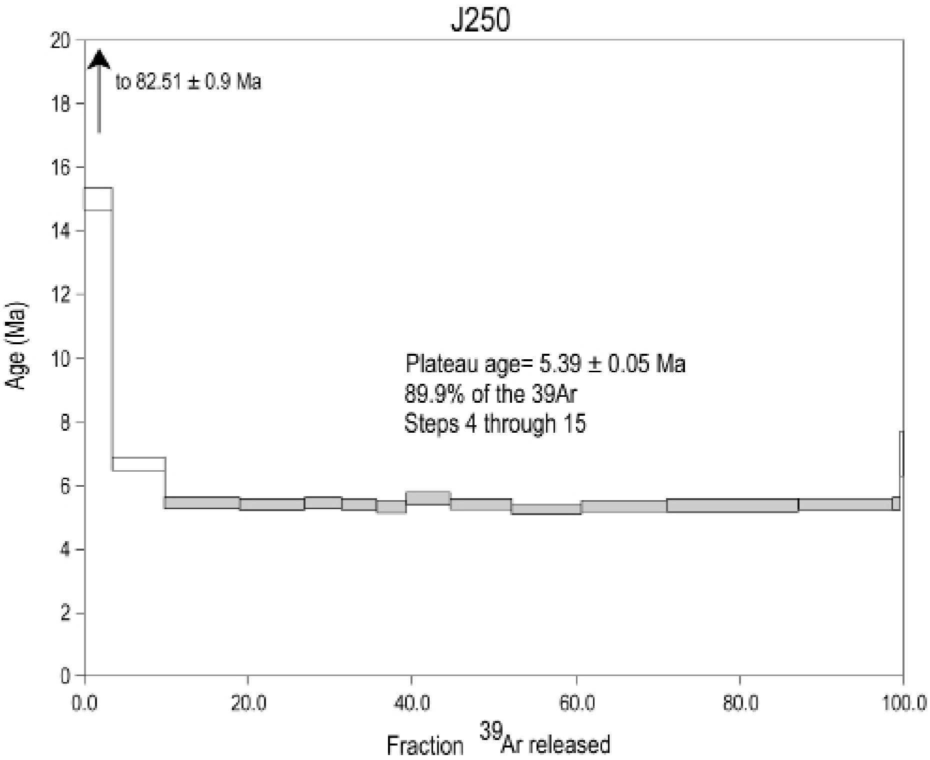

Figure 5.- Incremental step-heating spectra, showing 2-sigma errors, with the steps used in defining the plateau shaded in gray.

and the modern incised Huancayo alluvial fans. Fluvial deposits, including the Chupaca gravels and younger depositional river terraces, are the products of río Mantaro.

Torre Torre conglomerate

Highly dissected remnants of thick-bedded conglomerate and sandstone occur as discontinuous patches on top of bedrock along the east margin of the Huancayo basin. This unit was informally called by a variety of non-geographic or process-based names (Dollfus and Mégard, 1968; Mégard, 1968; Blanc, 1984). Mégard (1968) interpreted these deposits to represent glacial outwash whereas Blanc (1984) correlated them to the Jauja Group. The best exposure of these undated deposits are located at the Torre Torre badlands nearby the city of Huancayo (Fig. 6), which is suggested as the type section and is the basis for the new assigned name. Here the unit is greater than 35-m thick with the base unexposed except for where it thins and onlaps the Paleozoic rocks.

The Torre Torre conglomerate has tabular, 0.5 to 4 m thick, interbedded coarse-grained sandstone and framework-supported conglomerate. Incised channels were not observed in the sections at the Torre Torre badlands formation proper nor in the similar unit to the north of Concepción. The beds dip gently about 10 degrees toward the basin. The reddish- to brown-weathering conglomerate beds contain subangular clasts composed of material derived from the Mitu and Excelsior Groups. Both clast compositions are present in equal amounts, but percentages vary. To the north of Huancayo, at pueblo Cochas, Blanc (1984) reported clasts of granitic rock and suggested that they were derived from the Cordillera Oriental. Largest clasts observed were about 60 cm in diameter.

Blanc (1984) proposed the Torre Torre conglomerate as being correlative with units in the Jauja Group. Possible tilting of the units and the deep incisement of the deposits indicate that they are older than the Chupaca gravels, however, they remain undated. The predominance of alluvial fan deposits makes them somewhat dissimilar from the Jauja Group. The spatial association of the Torre Torre conglomerate with the Huancayo alluvial fans may imply a

Tabla 1

Step 12 min.	T(8C)	$^{37}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	Ca/K (%)	^{39}Ar (%)	^{40}Ar (%)	Age (Ma)	61σ
Sample J250: 481575E, 8536015N (biotite)								
1	600	0.019093	30.8893	0.04391	0.7	8.3	82.51	60.90
2	650	0.008005	5.5088	0.01841	2.7	12.5	14.99	60.17
3	700	0.005157	2.4445	0.01186	6.5	22.5	6.67	60.10
4	760	0.004390	1.9956	0.01009	9.2	50.3	5.45	60.08
5	825	0.005039	1.9790	0.01159	7.7	60.5	5.40	60.08
6	875	0.006891	1.9897	0.01585	4.7	64.3	5.43	60.08
7	925	0.008261	1.9717	0.01899	4.3	67.0	5.38	60.08
8	975	0.009850	1.9493	0.02265	3.6	67.1	5.32	60.09
9	1025	0.008457	2.0484	0.01945	5.3	66.0	5.59	60.08
10	1075	0.007237	1.9717	0.01164	7.7	67.1	5.38	60.08
11	1105	0.008354	1.9181	0.01921	8.1	73.1	5.24	60.08
12	1130	0.009322	1.9636	0.02144	10.7	82.5	5.36	60.08
13	1155	0.013933	1.9710	0.03205	15.6	88.9	5.38	60.08
14	1175	0.036684	1.9721	0.08438	11.5	90.7	5.38	60.08
15	1200	0.169142	1.9816	0.38907	1.2	82.2	5.41	60.09
16	1400	0.872133	2.5643	2.00712	0.2	41.4	7.00	60.35

J = 0.001515 6 0.5%
Plateau = 5.39 ± 0.05 Ma; Steps 4-15, 89.9% ^{39}Ar released.
Total gas age = 6.30 ± 0.05 Ma

relationship with these deposits being earlier then tilted during uplift of the Cordillera Oriental. For these reasons I believe the Torre Torre conglomerate formed in the Upper Pliocene to Pleistocene and are not correlative to the Jauja Group.

Chupaca gravels

The Chupaca gravels make extensive nearly flat-lying clastic deposits along the southwestern part of the Mantaro Valley. The Chupaca gravels are composed of very poorly cemented coarse-grained sandstone, and framework- to matrix-supported thick-bedded conglomerate. Channels are approximately 3 to 4 m deep and filled by stacked 0.5 to 2 m thick beds of cross-stratified sandstone and conglomerate in both lenticular and tabular units (Fig. 7). Multiple stacked channels with cross-stratified channel fill, scours, and imbricated clasts collectively indicate a fluvial facies. Both the size of the channel fills and the abundance of cross-stratified gravels indicate deposition from a highly braided river system with migration of gravel bars, possibly similar to the depositional style of the modern río Mantaro.

Dollfus and Mégard (1968) called the gravels La nappe t'' et les glacis que la recoupent, whereas Mégard (1968) used the map unit name of Q-t1. Both studies estimated the unit to be Pleistocene and interpreted it as river terraces composed of sediments derived from glaciation in the Cordillera Oriental. To the west of pueblo Mito, the Chupaca gravels overlie deposits of the Mataula Formation, forming an elevated plateau 187 m above the río Mantaro, which argues that these deposits are unrelated to the río Mantaro terraces.

Blanc (1984) included some of these gravels into his new map unit called the Terrace of Huacrapuquio. Pueblo Huacrapuquio lies within the map unit Q-t2 of Mégard (1968), and is 6-km southeast of the gravels near Chupaca. Furthermore, Blanc (1984) placed the gravels immediately west of Chupaca in the Mataula Formation. These above correlations are difficult to substantiate. First, the gravels at Huacrapuquio are undeformed whereas Blanc's

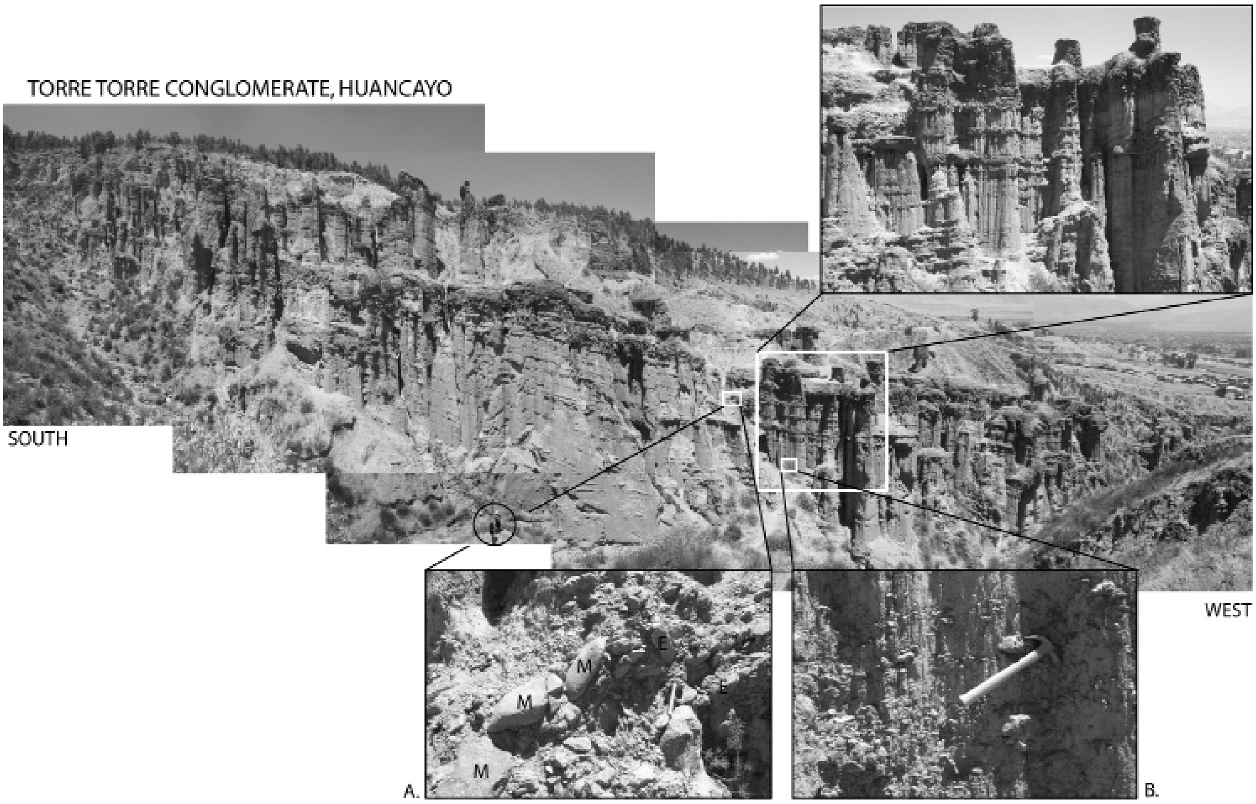

Figure 6.- Photograph mosaic of the Torre Torre conglomerate, as viewed toward the southwest. Circled person in foreground for scale. Beds dip gently northwestward toward the basin. Inset photographs show details of the conglomerate texture, including A). imbricated boulders composed of (M) Mitu Group lava, and (E) clasts of the Excelsior Formation; B). matrix-supported conglomerate.

(1984) unit west of Chupaca lines the cores of very open synclines, marking deposition within these structural depressions. Second, assigning the gravels west and to the north of Chupaca to the Mataula Formation, while possible, needs further field evaluation. The name of Chupaca gravels, called after pueblo Chupaca, is preferred over the previous map unit terminology (Dollfus and Mégard, 1968; Blanc, 1984), which was genetically descriptive rather than being based upon an appropriate geographic area.

To the northwest of pueblo Chupaca, along the crest of the Huarisca anticline, the conglomerate of the Chupaca gravels contain abundant limestone cobbles derived from the Pucará Group. Most of the clasts are subrounded to well rounded in form and commonly imbricated. However, about 5% of the cobbles are made of a distinct very coarse-grained porphyritic felsic intrusive bearing euhedral hornblende and plagioclase up to 5-mm long in a fine-grained light, quartz-bearing, gray aphanitic groundmass. Other sedimentary units in the basin lack this rock type. Furthermore, a source area reflecting this clast composition does not immediately crop out adjacent to the basin, indicating that some of the sediments in the Chupaca gravels were transported greater distances.

The Chupaca gravels are gently folded, distinguishing them as being pre-Huancayo alluvial fans in age. Contact relations are ambiguous because of cover, limited occurrence of continuous outcrop, and extensive agricultural land use. To the west of pueblo Mito, nearly flat-lying gravels overlie the Mataula Formation, and are included in the Chupaca gravels. In addition, surface morphology of the Chupaca gravels does not preserve geometries of the depositional system. The younger terraces of río Mantaro bury the contact between the Chupaca gravels and the Huancayo alluvial fan. Nonetheless, if the estimated relative age of the gravels being younger than the Matuala Formation and older than the río Mantaro terraces is correct, then these older fluvial deposits were probably onlapped by

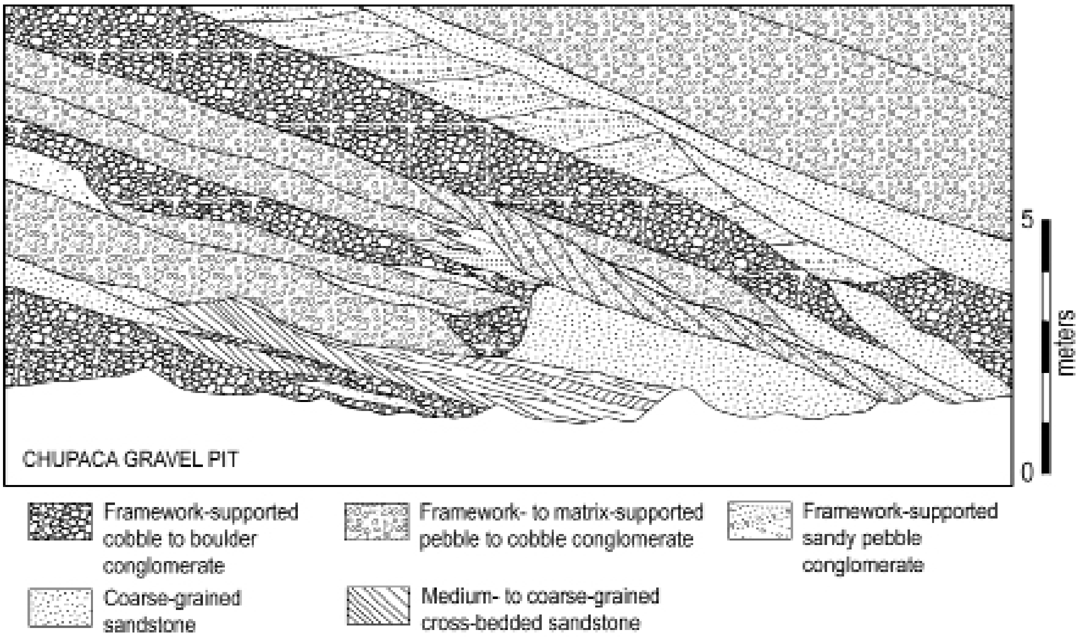

Figure 7.- Sketch of fluvial channels in the Chupaca gravels from a borrow pit near the crest of the Huarisca anticline, near pueblo Chupaca. The outcrop face strikes approximately NS. Channel wall preserved at center of outcrop sketch. Paleoflow directions are variable, and are oblique to view.

progradational advance of the Huancayo alluvial fan. This interpretation is based on the Chupaca gravels being folded whereas the below-described Huancayo alluvial fans have not been deformed.

Huancayo alluvial fans

Huancayo is situated on a low-profile alluvial fan sourced from a major canyon headed in the glacial cirques of the Huaytapallana Massif, which forms an exceptionally high segment of the Cordillera Oriental, containing several summit groups above 5,200 m (Fig. 2). The Huancayo fan proper is one of several that define coalesced alluvial aprons lining the eastern basin margin. Dollfus and Mégard (1968) called these deposits Les nappes alluvials t' and separated alluvial cones and river terraces. Blanc (1984) referred to these same deposits as cone terrasse CT3 and correlated them with his oldest fluvial terrace (T_3). These deposits are undated; however, Blanc (1984) estimated a Pleistocene age. Dollfus and Mégard (1968) and Blanc (1984) mapped the Huancayo fan as being younger than the Chupaca gravels. The Huancayo fan retains well-preserved radial distributary channels (Blanc, 1984), lying on a slope of 2.5% at the midfan position. The canyons along the west flank of the Cordillera Oriental are deeply incised. Some of the modern channels in the fan expose up to 20 m of section, however, the base of the fan is unexposed and the true thickness remains unknown.

Metamorphic clasts occur within the deposits of the fan at Huancayo and in modern gravels lining the incised drainage of río Shullcas. This drainage extends 25 km into the glacial cirques eroding Precambrian crystalline rock of the Huaytapallana Massif. At the midfan position conglomerate clasts of gneiss comprise 15% of the cobbles (Fig. 8, station 1). At stations 2 and 3 (Fig. 8), fine- to medium-grained sandstone in medium- to thick-bedded units infill abandoned channels. At station 2, nearly 15 m of sandstone is exposed along the cut banks of río Shullcas. At station 3, within an abandoned filled channel, is a 3-m thick, laterally lenticular and interfingering, unit composed of medium-grained sandstone and pebbly coarse-grained sandstone. The sandstone contains horizontal planar laminations and cross stratification. Locally, the tops of the sandstone beds grade into several centimeters thick beds of dark brown silty clay.

Overall, the percentage of gneiss clasts increases in the distal fan whereas the less durable clasts of Excelsior Group decrease down slope (Fig. 8). The downstream reduction of grain size of weaker clasts is a function of 1) transport distance, 2) composition and hardness of the clasts, 3) contrasting populations of clasts of different durability (e.g., Abbott and Peterson, 1978), and 4) stream energy which governs clast to clast impacts via transport mechanisms. The clasts of the Excelsior Formation have well-developed schistosity and cleavage that readily cause the attrition in clast size. Likewise, cobbles derived from the Mitu Group are metamorphosed at lower PT conditions than the quartzo-feldspathic gneiss, making the former less durable. Regardless of the relative percentage of the clasts and their distribution, the presence of gneiss in the Huancayo fan system indicates relatively recent inclusion of this source region into the Huancayo basin.

Río Mantaro terraces

Harrison (1943) first mentioned multiple river terraces along the río Mantaro, and called the gravels glacial-fluvial deposits. This interpretation was used in all subsequent studies (e.g., Dollfus, 1965), except there is no direct dating to show that these gravels were formed synchronously with Pleistocene glacial stages. Blanc (1984) mapped three depositional river terraces, the system used in this paper, which are oldest to youngest T_3, T_2, and T_1, along the borders of río Mantaro, and described some aspects of the relative soil development between these terraces. The modern river gravels in the bed of río Mantaro were assigned to unit T_0. Earlier maps by Mégard (1968) and work by Paredes (1972; 1994) used a reverse order of terrace numbering than Blanc (1984). Blanc's (1984) units T_3 and T_2 subdivide the intermediate unit T_2 of Dollfus and Mégard (1968).

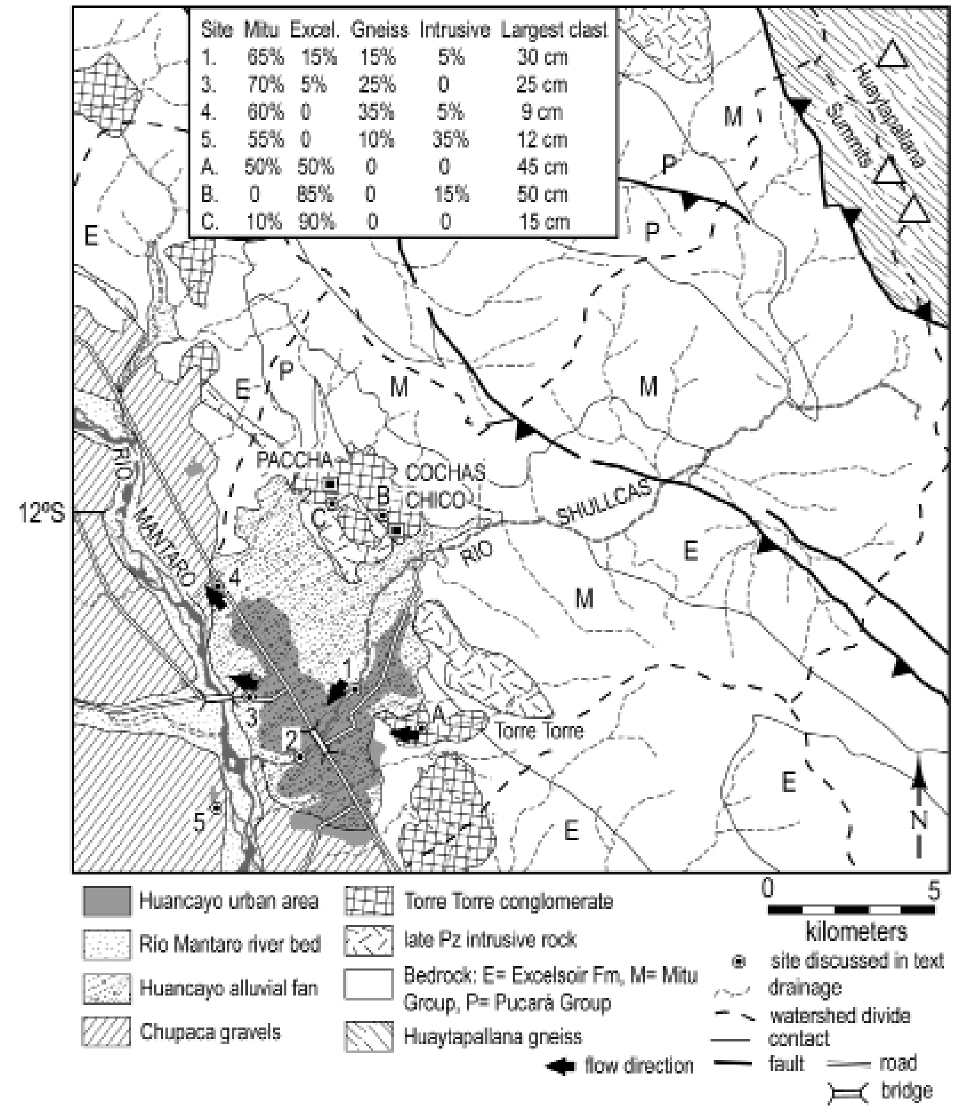

Figure 8.- Map of the Huancayo alluvial fan and watershed, showing basement rock geology and locations of conglomerate compositions discussed in text. Geology after Mégard (1968), Paredes (1972), and new mapping.

Río Mantaro has its headwaters at Lago Junín, 170 km upstream to the northwest, and to the east of Huancayo it flows a sinuous course 470 km through deep canyons to the Amazon flood plain. Terrace heights above the modern río Mantaro channel are as much as 50 m for unit T_3, 14 to 20 m for T_2, and 4 to 8 m for T_1 (Mégard, 1968; Blanc, 1984). The gravels of T_3 may be synchronous and partially overlapped by the Huancayo alluvial fans (Blanc, 1984). Terraces T_2 and T_1 are locally inset into the Huancayo alluvial fans. During development of terraces T_2 and T_1 the Huancayo alluvial fan became entrenched by as much as 20 m, and relocated deposition to the distal portion of the fan, locally onlapping the T_2 and T_1 terraces. The alluvial fans at Santa Rosa de Ocopa and San Lorenzo were assigned to younger unit CT2 by Blanc (1984), but are probably time equivalent to the Huancayo fan. Likewise, channels on these fans have become entrenched, which perhaps is linked with the incisement of the río Mantaro, resulting in units T_2 and T_1. Some of the terraces may correlate to less extensive terrace units downstream where the río Mantaro cross the Ayacucho intermontane basin (Wise, 2004).

All the terrace deposits contain similar clast types as those within the older basin fill units (Blanc, 1984), including material derived from the Cordillera Oriental. Some of the clasts were possibly reworked from these older units. For this study, all the río Mantaro terraces are grouped together as one unit because they represent a single depositional style formed over a relatively short period of time.

Basin boundaries

Previous authors reported that the Huancayo basin deposits as onlapping the basement rock and developed within a gentle synformal depression (Dollfus and Mégard, 1968; Blanc, 1984). In contrast, along the west basin margin near pueblo Sincos, the Triassic-Jurassic Pucará Group limestone was reverse faulted over the Jauja Group, showing the basin geometry to be more complicated than a simple syncline. This fault dips 70 degrees to the southwest. The remainder of the western basin margin may have this geometry, except remain hidden by recent colluvium. The amount of displacement and extent of overriding of the bedrock over the basin sedimentary formations remains unknown. Overall, the Jauja Group has eastward-tilted strata except proximal to the fault where the bedding changes direction to dip 20 degrees toward the southwest. The basement thrust over the basin fill must postdate the 5.39±0.05 Ma Mataula Formation. Dorbath et al. (1991) calculated a reverse earthquake focal mechanism along the western basin margin, demonstrating that this zone has active faulting.

The east side of the basin has no clear structural boundary as shown by the embayed map pattern of gravel deposits accumulated eastward into the canyons of the Cordillera Oriental. About 8-10 km to the east, the canyons cut a regional reverse fault (Fig. 2), but the fault has no geomorphic expression based on the longitudinal stream profiles of major basin-flowing drainages (Fig. 9). The present basin boundaries have recent activity, and therefore need not necessarily reflect the geometry and mode of basin opening during the deposition of the Ushno Formation. Better understanding of the basin depth and shape is needed. Several cross-basin seismic reflection lines could address this problem.

Recent deformation

The folded beds of the Chupaca gravels define a very open, horizontal, upright anticline just northwest of pueblo Chupaca, for which Mégard (1968) gives a clear sketch as viewed from the north. Dollfus (1965), Dollfus and Mégard (1968), and Mégard (1968) described additional details on the folding at the Huarisca anticline. Surface topography follows the crest of the anticline, defining a NW-trending hinge line. The fold interlimb angle is 120 degrees. The deformation of the Chupaca gravels is younger than that in the Mataula Formation, and must pre-date the undeformed río Mantaro river terraces (Blanc, 1984). The Huarisca anticline demonstrates young east-directed contraction that is probably mechanically linked to the west basin marginal fault system. This fold sets the Huancayo basin apart from other intermontante basins in northern and central Peru, which mainly are highly eroded and lack evidence for recent contraction.

DISCUSSION

Timing of the Quechua III event

The Huancayo intermontane basin shows at least three contractional events from the Miocene (?) to present. The first fold event deformed the Ushno Formation by open upright folds before the deposition of the overlying Mataula Formation (Blanc, 1984). The age of the Ushno Formation remains unknown, and consequently this deformation event cannot be directly assigned to the Quechua pulses, although it must pre-date the Quechua III pulse. The Mataula

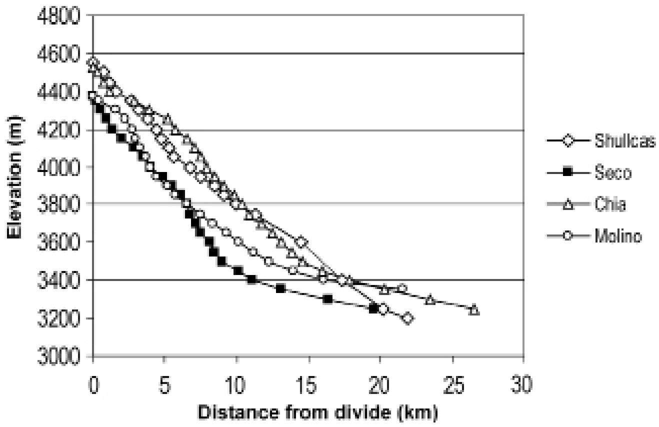

Figure 9.- Longitudinal stream profiles from the west flank of the Cordillera Oriental showing graded profiles with no nick points or steps.

Formation was folded during the Quechua III tectonic pulse because most of the tilting and shortening happened before the deposition of Pleistocene (?) Chupaca gravels.

The regional Quechua III tectonic pulse is generally thought to occur between 4 to 5 Ma (Benavides-Cáceres, 1999), however, review of available age constraints leaves open many possibilities (Fig. 10). Noblet et al. (1996) proposed that all the Quechua events are merely a function of the sampling method in a tectonically continuous orogen. In contrast, data from Huancayo and surrounding regions of central Peru may used to argue otherwise, as explained below.

To the southwest in the Ayacucho intermontane basin, dated volcanic units place both upper and lower limits on folding and formation of angular unconformities, which were interpreted by Mégard et al. (1984a) as an interval between 4.5 to 6 Ma for the Quechua III event. In part, this age assignment relies on inferred age of the Rumihuasi Formation from two imprecise K-Ar dates. The basin records deformation from the Quechua II, which was preceded by extension (Wise, 2004), providing clear evidence that locally compression is discontinuous. Figure 10 shows only the more reliable K-Ar age constraints at the Ayacucho basin reported in Mégard et al. (1984a), illustrating that the deformation there is limited between the youngest determined age on the gently folded Ayacucho Formation of 6.0±0.6 Ma and the overlying unfolded 3.8±0.4 Ma Huari Lavas.

Several NS-striking dacite dikes, 75 km to the south of Huancayo, indicate EW-directed extension that may place an upper limit on the Quechua III event. The dikes have K-Ar ages of 3.3±0.3 Ma just south of Huancavelica, and at Huachocolpa were dated at 4.7±0.2 Ma and 3.9±0.2 Ma (McKee et al., 1975; McKee et al., 1986). These dikes demonstrate that contraction in the region was not everywhere a continuous phenomenon because they intruded during EW-directed extension. Simultaneous contraction in other areas cannot yet be eliminated.

Several EW-striking rhyolite dikes along río Rímac, 94 km west of Huancayo, indicate EW-directed contraction, if formed as Mode I cracks, and were interpreted by Mégard et al. (1984b) as having been emplaced during the Quechua III. K-Ar ages from the dikes are 5.4±0.3 Ma and 6.2±0.6 Ma (Mégard et al., 1984b). Note that their data plotted in Figure 10 shows that this contraction predates formation of the Mataula Formation, and yet is compatible with age constraints at Ayacucho, and do not overlap the dated Huachocolpa dikes that mark EW-directed extension. The río Rímac dikes probably intruded pre-existing fracture sets in the region of Casapalca to Morococha (McKinstry and Noble, 1932; Nagell, 1960; Mégard et al., 1984b), and do not require increased contraction above the background levels of continuous EW-directed late Miocene compressional paleostress. Therefore, the río Rímac dikes do not necessarily constrain the timing of the Quechua III pulse.

To the north in the Callejón de Huaylas basin, minor reverse faults observed in the Upper Miocene Lloclla Formation imply some amount of contractional deformation after 6.4 Ma (Bonnot, 1984; Giovanni, 2003), but an upper limit remains to be established. The contraction was probably short lived because

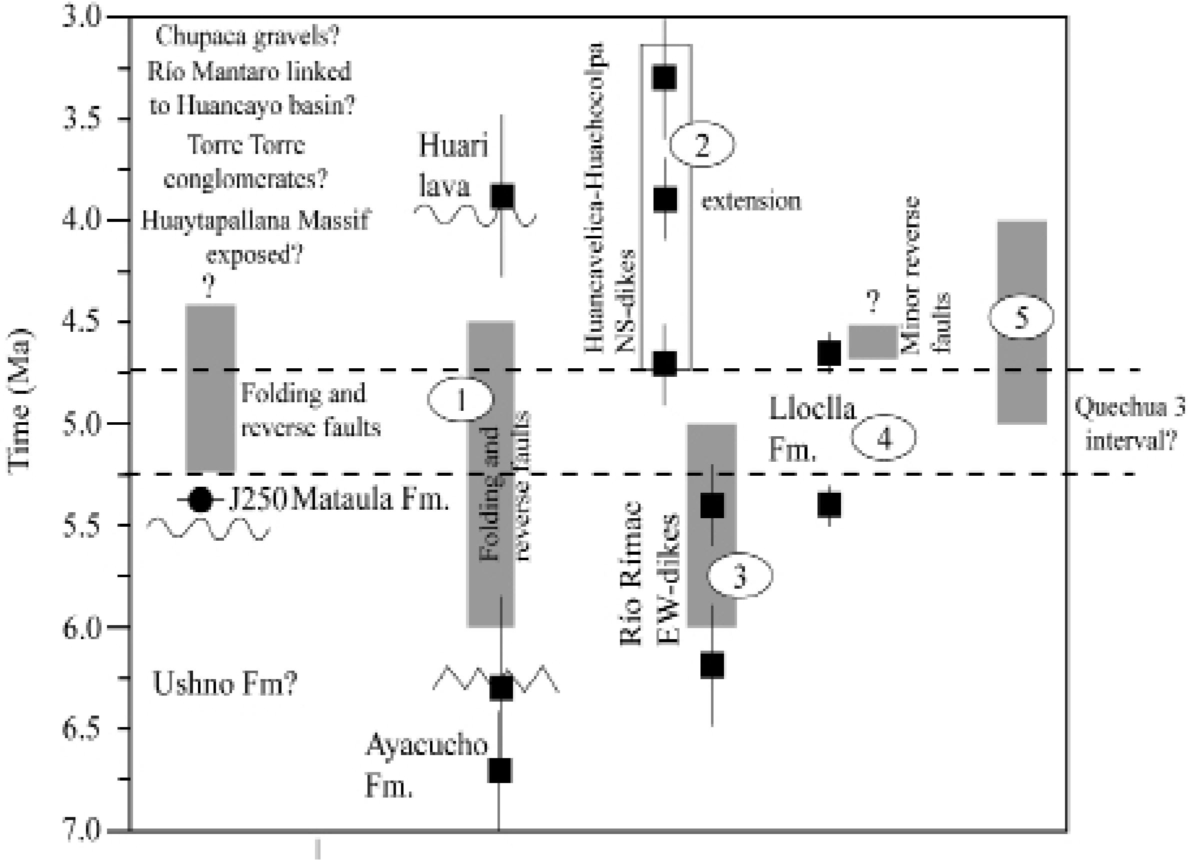

Figure 10.- Age constraints on the Quechua III contractional event. 1. Dated deposits bracketing angular unconformities in the Ayacucho basin (Mégard et al., 1984a). 2. Huachocolpa-Huancavelica dacite dikes (McKee et al., 1975; McKee et al., 1986), which demonstrate EW-directed extension. 3. Río Rímac EW-striking dikes interpreted to be emplaced during contraction (Mégard et al., 1984b). 4. Permissible timing for reverse faults in the Lloclla formation (Bonnot, 1984). 5. Age interval of the Quechua III pulse interpreted by Benavides-Cáceres (1999) from regional stratigraphic data.

this formation lies in the hanging wall of the active Cordillera Blanca normal fault. Overall, the Callejón de Huaylas basin has been one of intermittent extension from about 7 Ma to present (Wise and Noble, 2003).

In summary, all available isotopic age constraints combined with crosscutting relationships of deformation bracket a relatively short interval for the Quechua III from 4.8 to 5.4 Ma in central Peru (if this deformation was synchronous between the various areas considered). In contrast, the work by Sébrier et al. (1988) and Sébrier and Soler (1991) places the Quechua III at 7 Ma as based on dated rocks in Bolivia. This 7 Ma phase of deformation fails to account for geologic relations in central Peru, and here is excluded from the Quechua III. Whether the Quechua III represents a short period as interpreted here or is a manifestation of ongoing deformation as argued by Noblet et al. (1996), the Huancayo intermontane basin certainly underwent a change in depositional style, from intermittent lacustrine to fluvial, following the Quechua III deformation.

Basin evolution

Deposition in the Huancayo intermontane basin has evolved through time. Early deposition in the Ushno Formation was by alluvial fans, which were then deformed, eroded, and overlaid by deposits of a large lake recorded in the Mataula Formation. Within units of the upper Mataula Formation, alluvial fan and braided stream facies deposition continued from locally derived sediments. This pattern was interrupted by tectonic shortening associated with the Quechua III contraction event, deforming the Mataula Formation. Apparently the tectonic event that folded the Mataula Formation resulted in changes in the basin configuration because no subsequent widespread lacustrine deposition occurred. Several mechanisms may explain this extreme shift in deposition styles, including 1) incision of the basin exit or sill to drain the Huancayo basin, or 2) higher sediment influx rate into the Huancayo basin to fill the depression. The Torre Torre conglomerate, shed from the Cordillera Oriental, which contains only clasts derived from the Mitu and Excelsior Groups, may support the second case of increased sedimentation.

After the Quechua III event, the basin deposits were beveled and covered by the Chupaca gravels, which heralds the integration of the río Mantaro into the basin. Fluvial facies of the gravels better fit younger deposition than the predominately alluvial fan and lesser lacustrine facies of the Mataula Formation to which the unit was previously correlated (Blanc, 1984). The Chupaca gravels are interpreted to represent the ancestral río Mantaro, and indicate that the river system was not integrated to the Huancayo basin until after 5.39±0.05 Ma, and probably not until the latest Pliocene time.

The gravels of the río Mantaro terraces and modern bars and in the Huancayo alluvial fans contain the first known appearance of Precambrian rock detritus in the basin. Available data indicate post-Mataula Formation and pre-Pleistocene initial exhumation of the Huaytapallana Massif crystalline rocks. The Huaytapallana Massif was either 1) unexposed until recently, or 2) the position of the drainage divide shifted eastward to tap this unique clast source area. These two processes are not mutually incompatible. For example, unroofing was possibly coincident with or just after the Quechua III event, then breaching of the Huancayo basin by the río Mantaro forced the headwaters of tributary streams to migrate eastward into the newly exposed crystalline rock. These scenarios represent testable hypotheses by the application of fission-track methods on the Huaytapallana Massif. The Huaytapallana Massif is being further uplifted along eastward-dipping reverse faults, as documented by geologic mapping, neotectonic geomorphology, and recent earthquakes that were accompanied by surface rupture (Philip and Mégard, 1977; Blanc et al., 1983; Dorbath et al., 1991). This supports recent unroofing of the gneiss source terrane. Furthermore, the ongoing presence of the Cordillera Oriental is required for the Huancayo basin to develop. The downstream enrichment of the Huaytapallana gneiss in the Huancayo alluvial fan makes the compelling argument that if the gneissic source was present during the deposition of the Miocene formations then clasts of this composition would certainly be preserved. Finally, identification of recently exhumed crystalline rock implies a component of thick-skinned shortening or basement involved thrusting in the Cordillera Oriental, a feature or structural style that is noticeably lacking in the central Andes of Bolivia.

The río Mantaro terraces record an aggradational phase that accumulated gravel beds that were subsequently incised and yet were active at the same time as Huancayo alluvial fans. These deposits represent two events 1) deposition during a period of increased sediment influx, based on the wide spread deposits of the T_3 terraces and volume of the Huancayo alluvial fans, and 2) erosion following either a decrease in sediment influx or an increase in the river discharge and capacity of the river. Schematic cross sections of the basin by Blanc (1984) interpreted the río Mantaro terrace deposits as being deeply inset into the Chupaca gravels, but did not show the stratigraphic position of the Huancayo alluvial fan system. Folding along the west margin of the basin deformed the Chupaca gravels perhaps during the Quechua IV shortening event. This perhaps marks increased uplift in the surrounding ranges and the commencement of greater sediment influx, producing the aggraded río Mantaro terrace deposits and synchronous activity of the Huancayo alluvial fans. Alternatively, previous workers infer a relationship between terrace deposition and glaciation (Harrison, 1943; Dollfus, 1965). Subsequent fan entrenchment and down cutting of río Mantaro is related to post-glacial climate change, as interpreted by Garner (1959) for many canyons throughout the Peruvian Andes.

CONCLUSIONS

The depositional history of the Huancayo basin records first local sedimentation that primarily stripped off the Mesozoic stratigraphic section during ongoing uplift of the Cordillera Oriental, resulting in the relatively recent exposure of the crystalline Precambrian Huaytapallana Massif. The new age determination of 5.39±0.05 Ma provides refined constraints on the deposition of the both Ushno and Mataula Formations. Post 5.39±0.05 Ma deformation was mostly from the regional Quechua III contraction event. After deposition of the Mataula Formation and folding from the Quechua III event, in the latest Pliocene-Pleistocene, the basin underwent a major change in deposition style, going from closed alluvial and lacustrine setting to an open or drained basin dominated by fluvial deposits. This new drainage network, which established the río Mantaro, represents integration of the basin into the Amazon distributaries and may coincide with increased unroofing of the Cordillera Oriental leading to exposure of the Huaytapallana gneiss.

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