Database and Map of Quaternary Faults and Folds in Perú and its Offshore Region

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DATABASE AND MAP OF QUATERNARY FAULTS AND FOLDS IN PERÚ AND ITS OFFSHORE REGION

A project of the International Lithosphere Program Task Group II-2 "Major Active Faults of the World"

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

As part of the International Lithosphere Program's "World Map of Major Active Faults," the U.S. Geological Survey (USGS) is assisting in the compilation of a series of digital maps of Quaternary faults and folds in Western Hemisphere countries. The maps show the locations, ages, and activity rates of major earthquake-related features such as faults and fault-related folds. They are accompanied by databases that describe these features and document current information on their activity in the Quaternary. To date, the project has published fault and fold maps for nine countries (or regions) in Latin America. These include Costa Rica (Montero and others, 1998), Panama (Cowan and others, 1998), Managua (Nicaragua) (Cowan and others, 2000), Venezuela (Audemard and others, 2000), Bolivia/Chile (Lavenu, and others, 2000), Argentina (Costa and others, 2000), Colombia (Paris and others, 2000), Brazil (Saadi and others, 2002), and Ecuador (Eguez and others, 2003). The project is a key part of the Global Seismic Hazards Assessment Program (ILP Project II-0) for the International Decade for Natural Hazard Disaster Reduction.

The project is sponsored by the International Lithosphere Program and funded by the USGS's National Earthquake Hazards Reduction Program. The primary elements of the project are general supervision and interpretation of geologic/tectonic information (Michael N. Machette, Project Chief), data compilation and entry for fault catalog (all personnel), database design and management (Kathleen M. Haller), and digitization and manipulation of data (Richard L. Dart) in [†]ARCINFO. For the compilation of data, we engage experts in Quaternary faulting, neotectonics, paleoseismology, and seismology. These experts are the primary authors of this report, and questions about individual fault descriptions should be directed to them. Questions about the project, its status, and the GIS map should be directed to the USGS authors.

Prior to initiating this project, a digital map of active or Quaternary faults did not exist for Perú or any other country within South America, even though understanding the extent and character of active and older Quaternary faults are critical elements of seismic hazards analysis. Creation of this map and the accompanying database will help extend the relatively short record of instrumental and felt seismicity in Perú by creating a map showing the major active faults of the region.

Although some fault data were available for most of the country, the degree of completeness varies greatly and often is a function of the remoteness and vegetation cover. A few faults have been the subject of detailed investigations involving modern paleoseismic techniques (see for example references by Sébrier and others, 1982, 1985, 1988, 1991; Schwartz and others, 1984; and Schwartz, 1988). Other regions and faults have been studied in some detail, usually in association with concerns about hazards to urban areas or the safety of critical facilities such as mining operations, oil-and-gas pipelines, or power-generating facilities. One notable example is in the southern part of Perú where Fenton and others (1995) of Woodward-Clyde Associates conducted a regional study of Quaternary faulting for the Honda Quebrada tailings impoundment (see inset Map A on the plate). This study generated a significant body of new data on faulting in the region. One should note that the concentration of faults in this area of southern Peru is probably no different than to the north and northwest, but that these areas have not been studied in comparable detail.

[†] Any use of trade names (such as this and others in the report) does not imply endorsement by the U.S. Geological Survey.

The primary author (Jose Macharé) compiled information from a wide variety of sources, but the quality of data and coverage is quite variable across the country. In general, the state of knowledge for faulting in Perú is probably best described as being incomplete and of a reconnaissance nature. With the exception of historic surface faulting events, very little is known about fault chronology and overall rates of fault activity—information that is difficult to acquire but critical to seismic hazard assessments. Hopefully, additional paleoseismic studies will help augment this map and database.

STRATEGY AND PURPOSE

For the map of Perú, we relied on known experts with strong local or regional knowledge of Perú who were willing to participate in this international project. Given the limited time to produce the map (several years), the project was restricted to compilation of just those elements needed for ILP's Global Seismic Hazards Assessment Program (see database). We anticipate that the project will point out the shortcomings of past and current research on Quaternary faulting in Perú in terms of quantity, quality, scope, and regional coverage and should help promote new efforts to collect paleoseismological data in previously neglected or known critical areas.

In many cases, seismicity is used to define some potentially active faults, especially along active plate margins. However, recent faulting events in the Western Hemisphere have shown that much of the faulting away from active plate margins occurs along faults with no significant level of seismicity and that only a fraction of active faults are characterized by ongoing seismicity. Thus, the information on Quaternary faulting included within this database should help extend the modern (past several hundred years) record of seismicity into prehistoric time, and allow better assessments of active and potentially active faults in Perú and other Western Hemisphere countries.

TECTONIC SETTING OF PERÚ

In Perú, Quaternary deformation from the subduction of the Nazca Plate beneath the South American Plate is concentrated at the Andean orogen and related zones, which comprise the western part of the country. This subduction zone is responsible for most of the great (M > 8) earthquakes and tsunamis that have struck the western coast of South America, as well as both north and south of it. This subduction is the driving force for the dramatic and strong uplift of the Andes, which extend from Venezuela in the north, to southern Chile in the south. The Andes of Venezuela and Colombia are known as the Northern Andes, and they form the eastern limit of the North Andean Block. This block is triangular in shape and represents a microplate that is being sheared off the South American Plate along the Bonoco fault (VE-06) and Eastern Frontal fault system (CO-29). The Peruvian Andes are the surface manifestion of the collision of the two plates, which are converging east-west at a rate of about 80 mm/yr (DeMets and others, 1994). The Peruvian Andes belong to the so-called “Central Andes” (Gansser, 1973), which are defined as extending from the Gulf of Guayaquil (4° S, Ecuador) to as far south as the Golfo de Penas (46° 30’ S, Chile). The Peruvian Andes are considered to be a typical Andean-type orogen (mountain chain)—that is, one where mountain building has been driven by subduction processes (Ramos, 1999). Along the Peruvian Andes, two main sectors can be distinguished based mainly on the geometry of the underlying subduction zone: these are referred as the northern and central sectors of the Central Andes.

During early Mesozoic time, the Northern Central Andes (north of 14° S) were dominated by extensional tectonics and subduction (Mégard, 1987). Subsequent migration of deformation toward the foreland (to the east) along the northern sector uplifted the Peruvian Andes as a result of flat-slab (shallow) subduction geometry for the past 5 m.y.(Sébrier and Soler, 1991). The resulting overthickening of the crust gave rise to the Cordillera Blanca (tectonic uplift), which has some of the highest elevations in the Andes and where significant active normal faults are associated with recent episodes of surface faulting (Schwartz, 1988). Also, important shallow seismicity characterizes the Eastern Cordillera and the Sub Andean (lowlands) zone (Suárez and others, 1983, Dorbath and others, 1991) where active deformation is dominated by fault-related fold structures. Atypical characteristic of the shallow-dipping subduction is a lack of active volcanism, such as in this sector.

The central sector of the Central Andes (14°-27°S) is associated with normal subduction angles (30°) and an active volcanic arc. This sector is characterized by a sharp change in the subduction dip angle at its northern end, where the Nazca Ridge is being subducted beneath the South American Plate, and a smooth transition to another flat-slab (shallow) sector of the subduction zone at its southern end in northern Argentina (Ramos, 1999). From west to east, the main morphostructural units of the central sector are the (1) Pacific Coast, which includes the offshore Perú-Chile trench, (2) Pacific Piedmont, (3) Western Cordillera, (4) Altiplano-Puna plateau, (5) Eastern Cordillera, and (6) Sub Andean (lowlands) zone.

The Western Cordillera forms a high plateau (5,000-6,000 m elevation) with active volcanoes along the cordillera's crest. The northern part of the Altiplano-Puna plateau (which is well defined in Bolivia) is included in Peruvian territory. Uplift of this plateau has been thermally induced, has a mean elevation of 4000 m, but lies below the level of the Western and Eastern cordilleras. Faults and folds resulting from Neogene contraction have affected the entire region (Lavenu and others, 2000).

The Eastern Cordillera has been an area of uplift during the entire Cenozoic era (Sébrier and others, 1988), whereas the Sub Andean lowlands that constitute the Amazonian (eastern) piedmont of the Andes are dominated by Neogene contraction in a typical foreland fold-and-thrust belt. Quaternary deformation is present along all these morphostructural units and particularly near the boundaries between them.

Peru has a long history of large damaging earthquakes, mainly related to subduction of the Nazca Plate beneath the South American Plate. However, earthquakes on crustal faults, such as the ones described in this report, are also responsible for substantial damage and loss of life. One of the most devastating earthquakes in recent history struck west-central Perú in on May 31, 1970 (M 7.8 NEIC; Mw 7.9, Beck and Ruff, 1989) and killed about 70,000 people and injured another 50,000. Conversely, the most recent major earthquake along the Nazca subduction zone offshore of Perú occured on June 23, 2001, but was not related to crustal faulting or surface rupturing onshore. This M 8.4 earthquake occurred near the coast of southern Perú, about 110 miles (175 km) west of Arequipa or about 370 miles (595 km) southeast of Lima (http://www.eeri.org/earthquakes/Reconn/Arequipa_Peru/Arequipa.html). At least 102 people were killed, 1,368 were injured and extensive damage occurred in the Arequipa-Camana-Moquega-Tacna areas. At least additional 20 people were killed and some were missing from a tsunami in the Camana-Chala area.

PREPARATION OF THE DATABASE AND MAP

This compilation shows evidence for activity of Quaternary faults and folds in Perú and its offshore regions of the Pacific Ocean. The data compilation and analysis was performed by José Macharé of Newmont Perú Limited (formerly at the Instituto Geofísico del Perú, Lima), and by Clark Fenton of URS Corporation (formerly Woodward-Clyde Consultants, Oakland, CA). Michael Machette edited the text and map data and provided guidance for the project under the International Lithosphere Program's Task Group II-2 "Major Active Faults and Folds of the World," for which he is the Co-chairman (Western Hemisphere). Carlos Costa helped adapt Macharé's information to the Project's standards and guidelines.

Richard Dart used GIS (Geographic Information System) technology to produce the fault and fold maps. The traces of Quaternary faults and folds were digitized, attributed for age, sense of slip, and line type (continuous, discontinuous, and concealed or inferred), and transformed using a Mercator projection. The maps were prepared with ARC/INFO version 7.1.2 running under Solaris version 2.5.1 on a Unix workstation. The GIS data is scale independent but should not be used at scales greater (more detailed) than about 1:1,000,000 (twice the digitized scale). Data for fault length and average strike are from ARC/INFO files.

The base-map information for the enclosed map was taken from the Digital Chart of the World, which was created for use with ARC/INFO (copyright 1993 by the Environmental Systems Research Institute, Inc.). The Digital Chart of the World was compiled at a scale of 1:1,000,000, which is 200 percent of the scale of the digitized fault map (1:2,000,000). The Digital Chart of the World was originally developed for the United States Defense Mapping Agency (DMA) and is primarily derived from the DMA Operational Navigation Chart (ONC) Series.

MAP

The map of Quaternary faults and folds of Perú (see attached plate) was modified by José Macharé from a compilation by Macharé and Leureyro (1991), which in turn was based on a prior compilation by Sébrier and others (1982). Many of the faults shown on the map are considered to be Quaternary, but little or no published information was available to the authors. Both maps used a base map at 1:2,000,000 scale with an unspecified projection (we assumed that it was a Transverse Mercator projection). Thus, the regional data is not very well controlled in terms of their location. Faults in the southern part of Perú came from a rather detailed compilation by Fenton and others (1995) that used 1:200,000-scale Transverse Mercator base maps. Traces shown on this large-scale map were digitized at 1:200,000 scale and redrawn on the enclosed plate (inset Map A) at 1:500,000 scale. The scale of the generalized map of Perú allows output as a single-country map (1:2,000,000 to 1:3,000,000 scale) while retaining all significant digital information, whereas output at provincial and regional scales (1:200,000 to 1:500,000 scale) will greatly magnify errors in the location and depiction of faults and folds (other than in southern Perú, Map A on plate), and should only be done with appropriate caution. In addition to fault location and style, the map shows time of most recent movement and estimates of slip rate (as a proxy for fault activity). Many of the faults Macharé has shown Perú are undocumented, other than being considered as Quaternary on previous maps.

Although as many as five categories of Quaternary faults can be depicted on the Western Hemisphere maps, only three categories were used in Perú:

Historic (generally <400 years in Perú),
Holocene and latest Pleistocene (<15,000 years or <15 ka), and
Quaternary (<1,600,000 years or <1.6 Ma).

Categories for the late Quaternary (<130 ka) and late and middle Quaternary (<750 ka) were not used owing to the general lack of stratigraphic and chronological control needed to make these time differentiations. This categorical time scheme allows some flexibility in reporting between countries owing to the differing levels of investigation and abilities to date prehistoric faulting.

We use three ranges (categories) of slip rates that can be depicted by line thickness on the map in order to differentiate known rates of fault activity. On land in Perú, no faults have been shown to have >5 mm/yr slips rates, and only the Cordillera Blanca fault zone [PE-06] and Eastern Boundary fault [PE-04] fall into the 1-5 mm/yr category. However, the offshore Nazca subduction zone [PE-32] must have cumulative slip rate that greatly exceeds 5 mm/yr as suggested by plate-motion vectors.

>5 mm/yr—Plate-boundary faults and subduction zones (very high slip rates, none in Perú),
1-5 mm/yr—Lesser strike-slip and major extensional faults (medium to high slip rates), and
<1 mm/yr—Most extensional and intraplate faults (medium to very low (<0.2 mm/yr) slip rates)

Actual slip-rate determinations or estimates are sparse in Perú owing to a general lack of paleoseismic data, thus most of the faults have "unknown slip rates." In southern Perú, Fenton and others (1995) report slip rates above and below 0.2 mm/yr, so an additional category (<0.2 mm/yr) is used for faults in this region. Based on the regional geologic setting and information from similarly positioned faults in Ecuador and Chile, these faults with "unknown slip rates" are shown as <1.0 mm/yr on the accompanying plate, although they may well be <0.2 mm/yr.

DATABASE

The purpose of the database is to provide large quantities of fault data that can be readily accessed using a variety of search parameters. For this database, we anticipate that the user would want search-and-retrieve capabilities for parameters as fault name, time of most recent movement (one of three categories), slip rate (one of three categories), sense of movement, or by multiple parameters.

The process of data compilation starts with data acquisition and synthesis. In the case of faults, the compiler must determine if the structure is a simple one, or if it qualifies as having sections (increasing complexity of geometry or fault history). Then using the appropriate form, the compiler tabulates information on the fault's parameters.

After this report is released, we will incorporate suggested changes and additions; then import the data to the computer database. Each of the fields is a potential search object. The use of a computer database program allows us to custom format the reporting of data and to collapse unused fields or notes. The basic fields are restricted to 256 characters, but we use the note option for more explanatory information (shown under comments in this report).

The fault and fold data will be released in several forms. This open-file report for Perú constitutes a traditional hard-copy catalog (database and map) in pdf format. The Perú data will eventually be part of a larger relational computer database for Latin America that should be available on the World Wide Web

(WWW). This interactive WWW product allows the user to browse, sort, and print the data. However, we do not anticipate allowing the database to be altered using by users of the WWW version of the database.

DEFINITION OF DATABASE TERMS

The following terms provide data for specialized fields, most of which will be searchable when the computer database is released. In addition to the searchable fields, more detailed information is provided in the "Comments" section that follows some fields. If a field is empty or has been deleted, no pertinent information was found in the published literature. The following description provides definitions of fields (in alphabetic order) and indicates where various data can be found. Citations of references are in a standard USGS format, although foreign language citations are as provided by the compilers.

Compiler, affiliation and date of compilation: The name and affiliation of the person(s) primarily responsible for compilation or update of data presented for the structure. Also shown is the date when data were compiled for this project (e.g., January 1997).

Dip: General (or average) down-dip direction of the fault where known.

Fault geometry: This includes geographic information pertinent to the fault or fault being described. The data include length, average strike, average dip, and sense of movement.

Fault/fold name (see Name)

Fault/fold number (see Number)

Geomorphic expression: General description of the structure’s geomorphic expression including information on the presence or absence of fault scarps, offset streams, monoclines, shutter-ridges, associated landslides, etc.

Historical surface faulting: When the timing of most recent movement is historic, then this field(s) describes evidence for surface faulting associated with historical earthquakes. Also included is seismological information for the historical earthquake.

Length: This field specifies the end-to-end length of the Quaternary-age fault (or fault section) as measured from the most distal ends of the trace. The ends of overlapping or echelon traces are projected to a line defined by the average strike and the length is then determined from those projected end points. Also shown (in parentheses) is the cumulative length of all surface traces included in the fault, fault zone, or collection of faults. The cumulative length can differ considerably from the end-to-end length.

Name (Fault name or Section name): The earliest referenced name for a structure, fault segment or fault section (where appropriate) generally is given preference, except in cases where a more commonly accepted name is widely used in the recent literature. "Comments" also contains other names and references in which they are used, the geographic limits of the structure, north to south or west to east, as shown in this compilation; various geographic limits that are different in other studies are also included. Minor changes in original name may have been made for reasons of clarity or consistency (such as segment to section) where appropriate. We have found no faults in Perú that justify using the term “segment”, owing to a lack of precise timing information.

Number: Structure number: The structure (fault or fold) is assigned a number that is preceded by a two-character abbreviation (PE, Perú; BO, Bolivia; CH, Chile; etc.) that is unique to each of the countries in the Western Hemisphere. Section number: An alpha character is assigned to the northernmost or westernmost section of a fault (e.g., fault PE-06 has four sections: PE-06a, PE-06b, PE-06c, and PE-06d).

Number of sections: (only used for faults with sections) Numeric value for number of sections (e.g., 4) defined in studies that do not meet the minimum requirements for segments established for this compilation. "Comments" include reference in which sections are discussed; if the term "segment" is used in the literature, an explanation of why "section" is used in the database is provided.

Recurrence interval: Time interval in yr (based on historic data, calendric or calibrated radiocarbon dates), in ^{14}C yr (based on uncalibrated radiocarbon dates), or in k.y. (thousand years, based on less precise dating methods, stratigraphy, or geomorphology). Unknown is shown if there is no published recurrence interval value. Also included is the time interval (in parenthesis) for which this recurrence interval is valid (for example, 10-130 k.y.). Alternative published recurrence intervals, starting with that which applies to the most recent time interval, are included in "Comments. "

References: A bibliographic citation is included for all references pertinent to each structure.

Section: A geographic, geometric, structural portion of a fault or collection of faults that appear(s) to have a different character than adjacent portions of the fault (or fold). Typically, not enough information exists to show that this portion of the fault acts independently of adjacent portions, and thus does not qualify as a bona fide "segment" of a fault in a paleoseismic sense. There are no known faults with proven segments in, although several faults are described as having sections. Further research is needed to document additional faults with sections or those with sections that may be segments.

Section name (see Name)

Section number (see Number)

Sense of movement: Includes thrust, less than 45° dip; reverse, greater than 45° dip; right-lateral strike slip (dextral); left-lateral strike slip (sinistral); or normal. For oblique slip faults, the principle sense of movement is followed by secondary sense.

Slip rate: The primary field shows an actual value or one of several slip-rate categories used for the map part of this compilation: <1 mm/yr, 1-5 mm/yr, or >5 mm/yr. "Unknown" precedes the suspected slip-rate or slip rate category if no published slip rate is known. "Comments" may include a synopsis of published slip rates and pertinent documentation. Generally speaking, there are two types of slip rates. The first type is termed a “Geologic slip rate” and is derived from the age and amount of offset of surficial geologic deposits. These rates are not precise, but allow one to place broad limits on possible slip rates, and hence characterize the fault in one of the above-mentioned categories. The second type of slip rate is termed a “Paleoseismic slip rate” and is derived from times of faulting events and amounts of offset of geologic data or piercing points. This type of slip rate is more precise, but is rare owing to the extensive amount of work involved (*i.e.*, detailed paleoseismologic studies involving trenching and numeric dating).

Strike: The length-weighted average strike of the fault or fold trace is reported in the northwest and northeast quadrants of the compass (*i.e.*, -30° is N. 30° W., versus 30° which is N. 30° E. The value (i.e., ±30°) that follows the strike describes the range for all vectors contained with the trace of that particular fault or collection of faults. These values are included only to provide a general impression of the sinuosity or variability in strike of the mapped structures. Some fault zones include faults with a wide variety of strikes, and thus ± ranges are large.

Synopsis and geologic setting: This field provides a short summary that describes the level of study, provides a snapshot of the scope of data that follows in the database and provides a generalized perspective of the fault in terms of its regional geologic setting, amount of total offset, and general age of offset strata

Timing of most recent event (faulting or folding event): The primary field shows one of the two prehistoric time categories: latest Quaternary (Holocene and latest Pleistocene, <15 ka) or Quaternary (<1.6 Ma). This field may document historic surface faulting, although details of the earthquake related to the faulting will follow.

Type of studies: This field briefly summarizes the types of studies conducted on the fault.

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DATABASE OF FAULTS AND FOLDS

PE-01, AMOTAPE FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PE-01

NOMBRE DE LA FALLA/FAULT NAME: Amotape (fault zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: These structures control the elongated cordillera (ranges) in the coastal border region of northwestern Peru and southwestern Ecuador. The faults involve continental metamorphic basement, and limit the Cenozoic Lancones Basin.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: A. Eguez, A. Alvarado, and H. Yepes; Escuela Politécnica Nacional, Departamento Geología and Instituto Geofísico; March 1997.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Photo interpretation.

GEOMETRY OF THE FAULT:
LENGTH: 104.6 km (194.1 km cumulative)
STRIKE: 38°±21° (N38°E±21°
DIP: Unknown, dipping to northwest
SENSE OF MOVEMENT: Reverse
Comments: The fault has two main strands. The northwestern fault has an unknown sense of movement, whereas the southeastern fault is reverse, northwest side up.

GEOMORPHIC EXPRESSION: The fault has two main strands, both of which form irregular scarps and control drainages.

RECURRENCE INTERVAL: Unknown

SLIP RATE: Unknown probably <1 mm/yr

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: The compiler infer that the last movement was probably Quaternary based on the faults expression on aerial photographs. However, no detailed studies have been made of this fault zone.

PE-02, SHITARI FAULT

FAULT NUMBER: PE-02

FAULT NAME: Shitari

SYNOPSIS AND GEOLOGIC SETTING
The Shitari fault belongs to not a very well known group of faults located in northeastern Perú, at the boundary between the Eastern Cordillera and Subandean Ranges. It is an ancient Andean thrust separating Mesozoic rocks.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Jose Macharé, Newmont Perú, Limited, 1999.

TYPE OF STUDIES: Field studies, interpretation of aerial photos and SLAR radar images.

GEOMETRY OF THE FAULT:
LENGTH: 105.1 km (155.7 km cumulative)
STRIKE: -36°±28° (N36°W±28°)
Comments:
DIP: Unknown. Probably near vertical.

SENSE OF MOVEMENT: Strike-slip
Comments: Strike-slip, apparently left lateral (sinistral).

GEOMORPHIC EXPRESSION: Quite rectilinear scarp, well imposed on the topography. Offset drainages, fault valleys, ridges, and scarps. Poorly affected by erosion. Pressure ridges in modern deposits.

RECURRENCE INTERVAL: Unknown

SLIP RATE: Unknown probably <1 mm/yr

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 k)
Comments: Most of fault appears to be relatively young from its geomorphic expression. The portion near Naranjos may by historic (May 1990 and April 1991), based on the formation of a small historic surface rupture with a normal sense of movement (landslide?). However, the location of this rupture is unknown to the compiler, thus the fault is shown as entirely Holocene or post glacial

NAME OF EARTHQUAKE: Unknown

DATE/FECHA: May 1990 and April 1991

MAGNITUDE OR INTENSITY: Unknown

PE-03, CHAQUILBAMBA FAULT

FAULT NUMBER: PE-03

FAULT NAME: Chaquilbamba

SYNOPSIS AND GEOLOGIC SETTING: Located north of Chaquilbamba, 13 km south-southeast of Cajatambo at the Western Cordillera, and southeast of the Cajamarca deflection. The Quaternarygeology along the fault is dominated by a pediment and glacial deposits from the last glaciation (<15 ka).

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999.

TYPE OF STUDIES: General mapping, morphologic and structural analysis.

GEOMETRY OF THE FAULT:
LENGT: 16.0 km (10.5 km cumulative)
STRIKE: -40°±20° (N40W°±20°)
Comments: NNW–SSE and NW–SE striking strands
DIP: SW
SENSE OF MOVEMENT: Normal
Comments: Size of fault scarp suggests a maximum vertical slip of 8-10 m.

GEOMORPHIC EXPRESSION: The scarp has a well-preserved free face (near vertical) and debris slope, where it has been preserved.   This morphology and the large size of the scarp suggests multiple movements, the most recent of which is quite young (probably historic)

RECURRENCE INTERVAL: Unknown

SLIP RATE: Unknown probably <1 mm/yr

TIME OF MOST RECENT MOVEMENT: Historic (1937)
Comments: Earthquake formed a 1.5 km long rupture.

NAME OF EARTHQUAKE: Unknown

DATE/FECHA: April 8, 1937; April 17, 1937

MAGNITUDE OR INTENSITY: Unknown

PE-04, EASTERN BOUNDARY FAULT

FAULT NUMBER: PE-04

FAULT NAME: Eastern Boundary

SYNOPSIS AND GEOLOGIC SETTING The Eastern Boundary fault is a poorly understood but potentially quite active late Quaternary fault that forms the eastern margin of the Peruvian Andes. To the west, the Cordillera Blanca fault zone forms the western limit of this 120-170 km wide region of active extension. The Eastern Boundary fault was recognized (and named) by Schwartz in 1988 on the basis of an aerial photo reconnaissance. However, no detailed studies have been conducted on this fault, which is in a remote part of northern Perú. The location shown on the map is very approximate, and in need of better mapping.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Michael Machette, U.S. Geological Survey, 2002

TYPE OF STUDIES: Aerial photo interpretation by Schwartz (1988).

GEOMETRY OF THE FAULT:
LENGTH: 217.0 km (225.0 km cumulative)
STRIKE: -50°±15° (N50°W±15°)
DIP: Unknown
SENSE OF MOVEMENT: Normal
Comments: Reported as normal by Schwartz (1988).

GEOMORPHIC EXPRESSION: No information on expression is included in Schwartz (1988).

RECURRENCE INTERVAL: Unknown

SLIP RATE: 1-5 mm/yr
Comments: Schwartz (1988, p. 4729) suggests that the Eastern Boundary fault has a slip rate comparable to or double that of the Cordillera Blanca fault zone [PE-01], which has a slip rate of 1-5 mm/yr. However, the Eastern Boundary fault estimate is based on aerial reconnaissance and regional rates of crestal (Andes) extension, not paleoseismic studies.

TIME OF MOST RECENT MOVEMENT: Late Quaternary? (<15 ka)
Comments: The compiler infers that the last movement was probably in late Quaternary based on the faults clear expression on aerial photographs (Schwartz, 1988) and proximity to the Cordillera Blanca fault zone [PE-01], which has a slip rate of 1-5 mm/yr. However, no field reconnaissance or dating has been conducted on the Eastern Boundary fault.

REFERENCES

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730

PE-05, QUICHES FAULT

FAULT NUMBER: PE-05

FAULT NAME: Quiches
The fault is named for Quiches, a small town that suffered extensive damage (Silgado, 1951) near the south end of the fault.

SYNOPSIS AND GEOLOGIC SETTING: Located north of the Ancash region, between Quiches and Chindalgo, west of the Marañon River, north-northeast of Huaraz, and northeast of the Western Cordillera. This fault was active in the 1946 Ancash earthquake (Ms 7.2). Four distinct scarps formed during the 1946 Ancash earthquake along a 20-km long northwest-striking zone of deformation. The northern and southern fault scarps are the longest (3-5 km) and west-facing, the two central ones are east facing and shorter (<2 km). The northern end of surface rupturing was west of Chingalpo, and south of the Mayas hacienda.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: General studies

FAULT GEOMETRY:
LENGTH: 38.5 km (37.3 km cumulative)
STRIKE: -45°±15° (N45°W±15°)
DIP: 42°-58°
Comments: The main fault dips 58°to southwest at south end, antithetic (minor) faults dip 30° NE (Silgado, 1951). Near Planar hill, Silgado (1951) measured a dip of 42° on a fine-polished bedrock surface.
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: The historic (1946) faulting formed two distinct southwest-facing scarps along an older (preexisting) fault. The southern (5-km long) scarp has a maximum displacement of 3.5 m, whereas the northern scarp (3-km long) shows a maximum displacement of 1 m. These scarps are located about 10-12 km apart, and between them Silgado (1951) mapped a zone of discontinuous NE-dipping antithetic fractures (faults) that have as much as 1 m displacement.
Near Quiches Heights (at the south end of the ruptures), the earthquake reactivated an old fault that Schwartz (1988) suggests had a small preexisting Pleistocene scarp. The fault affects Quaternary glacial and fluvio-glacial deposits and Cretaceous limestones.

RECURRENCE INTERVAL: <12,500±1,500 years
Comments: If the fluvio-glacial deposits that are faulted as shown by Silgado (1951, fig. 3) are latest Pleistocene (11-14 k.y.), then the preexisting scarp shown by Schwartz (1988) would suggest a maximum recurrence of 12.5±1.5 k.y. for the two most recent faulting events.

SLIP RATE: <1.0 mm/yr
Comments: A slip rate of at least 0.25-0.32 mm/yr is suggested on the basis of 3.5 m maximum displacement (Silgado, 1951) in the past 12.5±1.5 k.y.

NAME OF EARTHQUAKE: Ancash (Silgado, 1951)

DATE/FECHA: November 19, 1946

MAGNITUDE OR INTENSITY: Io >IX (Silgado, 1951); Ms 7.2 (Doser, 1987)
Comments: Doser (1987) reevaluated first motion data for the earthquake and concluded that the event formed at 15-17 km depth on a normal fault that flattens from 60° at the surface to 30-38° in the subsurface, suggesting possible reactivation of an existing thrust or reverse fault (Schwartz, 1988).

REFERENCES

Doser, D.I., 1987, The Ancash Peru earthquake of November 19, 1946—Evidence for low-angle normal faulting in the high Andes of northern Peru: Geophysical Journal of Research, v. 91, p. 57-71.

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730.

Silgado, E., 1951, The Ancash, Peru, earthquake of November 10, 1946: Bulletin of the Seismological Society of America, v. 41, p. 83-100.

PE-06, CORDILLERA BLANCA FAULT ZONE

FAULT NUMBER: PE-06

FAULT NAME: Cordillera Blanca fault zone

SYNOPSIS AND GEOLOGIC SETTING: Major active normal fault zone of northern Perú, extending from Corongo through Chiquian (N and S of Huaraz), bounding the western flank of the Cordillera Blanca at the Intracordilleran basin of the Callejón de Huaylas, located between the Cordillera Negra and Cordillera Blanca. The fault zone dips west for much of its length and separates Miocene and Pliocene granite and granodiorite in the footwall from Mesozoic shales in the hanging wall. The range front rises to more than 6000 m at the crest of the Cordillera Blanca. Fission track dating from the central part of the range suggest 5500 m of uplift in the past 2.8 m.y., which equates to a slip rate of 1.9 mm/yr on a 35° fault plane. The fault is about 210-km long and exhibits fairly continuous geomorphic evidence of repeated late Pleistocene and Holocene displacements at vertical rates of about 1 mm/y. Recurrence of surface ruptures (where dated) is roughly 1-3 k.y.The fault has not broken in historic times (since at least 1513 AD).

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: General studies, structural analysis, photointerpretation and paleoseismic studies (on sections a and c).

GEOMETRY OF THE FAULT:
LENGTH: 200.2 km (321.5 km cumulative)
STRIKE: -35°±20° (N35°W±20°)
DIP: Unknown to west.
SENSE OF MOVEMENT: Normal

NUMBER OF SECTIONS: 4
Comments: Four segments (sections herein) were suggested by Schwartz (1988) on the basis of fault geometry and structural features. Schwartz (1988) also suggested an additional (5th) segment boundary that would divide our section PE-06b in two parts.

PE-06A, SECTION A, CORDILLERA BLANCA FAULT ZONE

FAULT SECTION NUMBER: PE-06a

SECTION NAME: Section A
Comments: Section A is about 40 km long and is the northernmost section of the fault zone. It extends from about 10 km south of Huallanca (at Colcas ruins) to about 5 km north of Corongo according to mapping of Schwartz (1988, fig. 1).

GEOMETRY OF THE SECTION:
LENGTH: 42.9 km (52.4 km cumulative)
STRIKE: -17°±28° (N17°W±28°)
Comments: At the southern boundary (with section B) the strike changes from N40°W to N10°W and becomes is characterized by series of complex trenches with individual traces that strike N50-60°W.
DIP: Unknown
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: The fault is generally well defined by a main west-facing scarp along the base of the steep range front. Grabens, back-tilted surfaces and associated antithetic scarps are common and form zones a few tens to several hundres of meters across (Schwartz, 1988). Schwartz (1988) excavated one trench at the Pachma Bajo site, but did not obtain any dates for faulting events. The fault offsets surficial materials such as latest Pleistocene glacial moraines (11-14 ka), glacial and postglacial lacustrine and fluvial deposits, alluvial fans and debris flows.

RECURRENCE INTERVAL: 1,500-3,000 years

Comments: 1,900–2,800 years (Schwartz and others, 1984) and 1,500–3,000 years (Bonnot and Sébrier, 1985). Schwartz (1988) suggested that a general recurrence of 1-3 k.y. is representative of individual sections of the Cordillera Blanca fault zone.

SLIP RATE: Unknown, probably <1 mm/yr

Comments: Schwartz (1988) considers the slip rate determined on Section C at Queroccocha Quebrada (arroyo) (0.86-1.36 mm/yr) to be representative of the entire fault zone. However, since Section A is a distal section of the fault zone, the slip rate is probably is lower (<1 mm/yr) than to the south on Section C.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)

Since there ar eno historical records of surface rupture, the most recent event must have occured before 1513 A.D. (Silgado, 1978).

REFERENCES

Bonnot, D.,1984, Néotectonique et tectonique active de la Cordillère Blanche et du Callejon de Huaylas (Andes nord-péruviennes): Orsay, France, Universityée Paris-Sud, thesis.

Bonnot, D., and Sébrier, M., 1985, Analisis cinematico y sismogenico de un sistema de fallas normales activas—Ejemplo de la Cordillera Blanca, Peru: Caracas, Venezuela, Congreso Geologico Venezolano, Sociedad Venezolana de Geologos, v. 6, no. 3-4, p. 2378-2396

Schwartz, D.P., Salazar, H., Felix, O., Santucci, H., Arnt, A., La Cruz, J., and Farfan, M., 1984, Late Quaternary normal faulting, recurrence intervals, and slip rates along the Cordillera Blanca fault zone, northern Peruvian Andes: Eos, Transactions, American Geophysical Union, v. 65, no. 45, p. 1082.

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730.

Silgado, E., 1978, Historia de los sismos más notables occuridos en el Perú (1513-1974): Lima, Instituto de Geología y Mineralogía, Bol. 3, ser. C, 130 p.

PE-06B, SECTION B, CORDILLERA BLANCA FAULT ZONE

FAULT SECTION NUMBER: PE-06b

SECTION NAME: Section B

Comments: Section B extends from Colcas south to the bedrock salient about 10 km northeast of Huaraz according to Schwartz (1988).

GEOMETRY OF THE SECTION:

LENGTH: 76.8 km (92.1 km cumulative)
STRIKE: -36°±21° (N36°W±21°)
DIP: Unknown
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: The fault is generally well defined by a main west-facing scarp along the base of the steep range front. Grabens, back-tilted surfaces and associated antithetic scarps are common and form zones a few tens to several hundres of meters across (Schwartz, 1988). Scarplets are common from Huaraz to as far north as Colcas ruins. The fault offsets surficial materials such as latest Pleistocene glacial moraines (11-14 ka), glacial and postglacial lacustrine and fluvial deposits, alluvial fans and debris flows. It extends from Huaraz toward the ruins of Colcas.

RECURRENCE INTERVAL: 1,500-3,000 years

Comments: 1,900–2,800 years (Schwartz and others, 1984) and 1,500–3,000 years (Bonnot and Sébrier, 1985). Schwartz (1988) suggests that a general recurrence of 1-3 k.y. is representative of individual sections of the Cordillera Blanca fault zone.

SLIP RATE: Unknown, probably 1-5 mm/yr

Comments: Schwartz (1988) considers the slip rate determined at Queroccocha Quebrada (arroyo) (0.86-1.36 mm/yr) to be representative of the entire fault zone. The median (average?) value (ca. 1.1

mm/yr) suggests a slip rate category of 1-5 mm/yr for the late Quaternary. Fission track dating from the central part of the range suggest 5,500 m of uplift in the past 2.8 m.y., which equates to a long-term vertical slip rate of 1.9 mm/yr on a 35° fault plane (Garver and others, 2002). The dip slip rate would be about 3. 3 mm/yr.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Since there ar eno historical records of surface rupture, the most recent event must have occured before 1513 A.D. (Silgado, 1978). Movement (or multiple movements) during the past 15,000 years is demonstrated by offset of glacial deposits and a relatively high slip rate.

REFERENCES

Bonnot, D.,1984, Néotectonique et tectonique active de la Cordillère Blanche et du Callejon de Huaylas (Andes nord-péruviennes): Orsay, France, Universityée Paris-Sud, thesis.

Bonnot, D., and Sébrier, M., 1985, Analisis cinematico y sismogenico de un sistema de fallas normales activas—Ejemplo de la Cordillera Blanca, Peru: Caracas, Venezuela, Congreso Geologico Venezolano, Sociedad Venezolana de Geologos, v. 6, no. 3-4, p. 2378-2396

Garver, J.I., and Rodbell, D.T., 2002, Fission-track evidence for rapid tectonic exhumation of the Cordillera Blanca, Peru: Geological Society of America Abstracts with Programs, v. 34, no. 6, p. 376.

Schwartz, D.P., Salazar, H., Felix, O., Santucci, H., Arnt, A., La Cruz, J., and Farfan, M., 1984, Late Quaternary normal faulting, recurrence intervals, and slip rates along the Cordillera Blanca fault zone, northern Peruvian Andes: Eos, Transactions, American Geophysical Union, v. 65, no. 45, p. 1082.

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730.

Silgado, E., 1978, Historia de los sismos más notables occuridos en el Perú(1513-1974): Lima, Instituto de Geología y Mineralogía, Bol. 3, ser. C, 130 p.

PE-06c, Section C, Cordillera Blanca fault zone

FAULT SECTION NUMBER: PE-06c

SECTION NAME: Section C
Comments: Section extends from the bedrock salient about 10 km northeast of Huaraz south to a point about midway between Recuay and Chiquan according to Schwartz (1988).

GEOMETRY OF THE SECTION:
LENGTH: 54.4 km (99.7 km cumulative)
STRIKE: -40°±15° (N40°W±15°)
DIP: Unknown.
SENSE OF MOVEMENT: Normal
Comments: Although the majority of slip is normal, Bonnet (1984) measured bedrock striations and slickensides that include a consistent sinistral (left-lateral) component of slip.

GEOMORPHIC EXPRESSION: Fault scarps identified from 15 km south of Queroccoca Quebrada (arroyo) to the about the latitude of Huaraz. The scarps are quite complex and form an overall right-stepping patterm from the section boundary on the south to Huaraz on the north. The westernmost scarps are typically antithetic to the main range-bounding faults. The fault offsets surficial materials such as latest Pleistocene glacial moraines (11-14 ka), glacial and postglacial lacustrine and fluvial deposits, alluvial fans and debris flows. Schwartz (1988) excavated two trenches at the Queroccoca Arroyo site, from which he determined paleoseismic parameters. Section C extends from 15 km south of Huaraz toward the ruins of Colcas (at about the latitude of Huaraz).

RECURRENCE INTERVAL: 2440±1,060 years
Comments: This estimate is based on 5-7 events in the past 11-14 k.y. with 2 to >3 m of vertical displacement per event (Schwartz, 1988).

SLIP RATE: 1-5 mm/yr

Comments: Slip rate for Section C is 0.86-1.36 mm/yr as determined at Queroccocha Quebrada (arroyo) Queroccoca site for the past 11-14 k.y. (Schwartz, 1988). The median value (ca. 1.1 mm/yr) suggests a slip rate category of 1-5 mm/yr for the late Quaternary. Fission track dating from the central part of the range suggest 5,500 m of uplift in the past 2.8 m.y., which equates to a long-term vertical slip rate of 1.9 mm/yr on a 35° fault plane (Garver and others, 2002). The dip slip rate would be about 3. 3 mm/yr.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)

Comments: The most recent faulting was between about 750 and 2500-2700 years ago at the Queroccoca Arroyo site, but it probably occurred closer to the older range (Schwartz, 1988).

REFERENCES

Bonnot, D.,1984, Néotectonique et tectonique active de la Cordillère Blanche et du Callejon de Huaylas (Andes nord-péruviennes): Orsay, France, Université de Paris-Sud, thesis.

Garver, J.I., and Rodbell, D.T., 2002, Fission-track evidence for rapid tectonic exhumation of the Cordillera Blanca, Peru: Geological Society of America Abstracts with Programs, v. 34, no. 6, p. 376.

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730.

PE-06D, SECTION D, CORDILLERA BLANCA FAULT ZONE

FAULT SECTION NUMBER: PE-06d

SECTION NAME: Section D

Comments: Extends from 15 km north of Chiquian, north to as far Quebrada Jeulesh. It is the southernmost section of the fault.

GEOMETRY OF THE SECTION:

LENGTH: 32.4 km (77.2 km cumulative)

STRIKE: -38°±18° (N38°W±18°)

DIP: Unknown.

SENSE OF MOVEMENT: Normal

Comments: Although the majority of slip is normal, Bonnot (1984) measured bedrock striations and slickensides that include a consistent sinistral (left-lateral) component of slip.

GEOMORPHIC EXPRESSION: Well-defined scarps on late Pleistocene and Holocene alluvial-fan and debris-flow deposits; forms small grabens.

RECURRENCE INTERVAL: 1,000-3,000 years

Comments: Schwartz (1988) suggests that a general recurrence of 1-3 k.y. is representative of individual sections of the Cordillera Blanca fault zone.

SLIP RATE: 1-5 mm/yr

Comments: A slip rate of 0.7-1.27 mm/yr was determined at the Quebrada Taco site for the past 11-14 k.y. (Schwartz, 1988). Geologic evidence suggest that the reported 10.2-14 m of vertical slip probably occurred in the past 11 k.y. (rather than 14 k.y.), thus the upper limit (1.27 mm.yr) seems more likely (Schwartz, 1988). A slip rate category of 1-5 mm/yr is considered for late Quaternary movement on Section C.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)

Comments: Schwartz (1988) reports that unfaulted pre-Inca walls (200 B.C.-400 A.D.) near the Quebrada Taco site suggest that surface faulting has not occurred in the past 1600-2000 years.). Movement (or multiple movements) during the past 15,000 years is demonstrated by offset of glacial deposits and a relatively high slip rate.

REFERENCES

Bonnot, D.,1984, Néotectonique et tectonique active de la Cordillère Blanche et du Callejon de Huaylas (Andes nord-péruviennes): Orsay, France, Université de Paris-Sud, thesis.

Schwartz, D.P., 1988, Paleoseismicity and neotectonics of the Cordillera Blanca fault zone, Northern Peruvian Andes: Journal of Geophysical Research, v. 93, p. 4712-4730.

Silgado, E., 1978, Historia de los sismos más notables occuridos en el Perú (1513-1974): Lima, Instituto de Geología y Mineralogía, Bol. 3, ser. C, 130 p.

PE-07, CAYESH FAULT

FAULT NUMBER: PE-07

FAULT NAME: Cayesh

SYNOPSIS AND GEOLOGIC SETTING: Located east of Cayesh, in the Eastern Cordillera of Central Perú, northeast part of the Tarma quadrangle. This fault has a fairly continous trace with a variable orientation to the north and south of Cayesh. Although an early compilation suggested four sections, all of them contain similar attributes and thus are simplied into a single fault for this compilation.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999.

TYPE OF STUDIES: Study of aerial photographs, field reconnaissance.

FAULT GEOMETRY:
LENGTH: 18.0 km (26.1 km cumulative)
STRIKE: -28°±14° (N28°W±14°)
DIP: 70° SW
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: Where exposed, fault is near vertical and affects the diorite basement**.** Between Huaye Creek and Laguna Tingo, the fault offsets late Pleistocene glacial deposits (at Huaye Creek). Between Laguna Tingo and Laguna Capacocha, the fault trace is discontinuous and there are several fault scarplets perpendicular to the main fault trace. Near the faults southern end, south of of Laguna Capacocha, the fault displays a horse-tail geometry.

RECURRENCE INTERVAL: Unknown

SLIP RATE: 0.2-1.0 mm/yr
Comments: Slip rate is estimated to be 0.2-1.0 mm/yr largely on the basis of morphology and offset of glacial deposits.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Affects late Pleistocene glacial deposits at Huaye Creek**.**

PE-08, HUAYTAPALLANA FAULT

FAULT NUMBER: PE-08

FAULT NAME: Huaytapallana

SYNOPSIS AND GEOLOGIC SETTING: Located at the foothills of the Huaytapallana Cordillera, NNE of Huancayo. The fault consists of a 9.5-km-long northern trace and a 5-km-long southern trace that is associated with a linear break about 20 km long. The fault offsets Quaternary moraines and bedrock comprised of volcaniclastic rocks of the Grupo Mitu and Andean granites (to the NW).

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999.

TYPE OF STUDIES: Structural and microtectonic studies.

FAULT GEOMETRY:
LENGTH: 24.4 km (24.7 km cumulative)
STRIKE: -35°±12° (N35°W±12°)
DIP: 60-70° E
Comments: The northern part dips about 60° NE, whereas the southern part dips about 70° NE.
SENSE OF MOVEMENT: Reverse sinistral
Comments:The northern part is reverse sinistral (left-lateral), whereas the southern part is primarily sinistral (left-lateral).

GEOMORPHIC EXPRESSION: The northern trace of the fault has formed landslides in moraine deposits and sag ponds at Antacancha and Chonta arroyos, north of Quebrada de Chusque. The southern trace of the fault is marked by a 5-km-long scarp from the vicinity of Abra arroyo to Anlayaco arroyo. After the 1969 earthquake, scientists observed the following offsets (only part of which was historic?): a vertical displacement of 2 m was observed at Antacama arroyo (northern trace): vertical displacement was 1.8 m and horizontal sinistral displacement was 0.7 m on the southern trace.

RECURRENCE INTERVAL: Unknown

SLIP RATE: Unknown, probably <1 mm/yr

TIME OF MOST RECENT MOVEMENT: Historic (1969)
Comments: Formed historic surface rupture in 1969.

NAME OF EARTHQUAKE: Series of unnamed earthquakes

DATE/FECHA: July 24 to October 1, 1969

MAGNITUDE OR INTENSITY: Unknown

PE-09, CUZCO FAULT ZONE

FAULT NUMBER: PE-09

FAULT NAME: Cuzco (fault zone)

SYNOPSIS AND GEOLOGIC SETTING: Located between the high plateau and the Eastern Cordillera in a region affected by extensional tectonics. The Cuzco fault zone is a historically active seismic source area and is comprised of six discrete faults (Zurie, Tamboray, Qoricocha, Tambomachay, Pachatusan, and Urcos) that appear to have somewhat independent rupture histories (thus, they may be fault sections or segments, although little documentation is available). The entire fault zone is <15 ka, whereas small portions have suffered historic rupturing. The Qoricocha fault was reactivated in 1986 with 1-10 cm of slip, whereas the Urcos fault had an unknown (small?) amount of surface rupture in 1965. The largest and best mapped of the faults, the Tambomachay, strikes north to north-northwest for about 20 km and forms the northern limit of the Cuzco Basin. Six sections were suggested bythe initial compiler, but were not mentioned by Sébrier and others (1995). As such, the fault may be over differentiated based on current understanding of each section’s history. Although we would normally treat the Cuzco fault zone as a sectioned fault (each fault as a section), we do not have maps that show each of the sections. Thus, they are treated together as a single fault zone.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú Limited, 1999; revised by Michael Machette, U.S. Geological Survey, 2003.

TYPE OF STUDIES: General studies.

GEOMETRY OF THE FAULT:
LENGTH: 97.4 km (86.8 km cumulative)
STRIKE: -63°±28° (N63°W±28°)
DIP: 60°

Comments: Average dip reported by Sébrier and others (1985) for the Tambomachay fault.
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: Published remarks about each of the individual faults are noted below:

The Zurie fault is composed of several en échelon strands. It separates the Quaternary deposits of the Anta Basin from the Vilcabamba Cordillera and displaces alluvial deposits and late Pleistocene moraines.

The Tamboray fault has a maximum observed vertical slip of 4 m.

The Chincheros includesa group of faults located around Laguna Qoricocha, about 7 km north of the Tambomachay fault. The Chincheros fault has discontinuous strands affecting the western flank of late Pleistocene glacial moraines. The northernmost part of the Qoricocha fault affects Pliocene-Quaternary volcanic flows.

The Tambomachay fault is located 5 km north and west of Cuzco near the small village of Tambomachay. It forms the northeastern margin of the Cuzco extensional basin (Sebrier and others, 1985, fig. 5a). The most recent faulting is marked by a 2-m high south-facingscarp that vanishes gradually to the north (Sébrier and others, 1985). This small scarp is superposed on a 300-m high scarp with triangular facets on Paleogene red beds that has formed through the Quaternary(?) (Sebrier and others, 1985).

The Pachatusan fault affects volcanic rocks of the Mitu Group and glacial deposits of late Quaternary age. Scarps form echelon patterns and offset U-shaped (glaciated) valleys.

The Urcos fault, which is located east of Tambomachay, offsets the Quaternary Rumicolca volcano to the north. There are sagpondsalong the fault trace, east of Urcos Lake.

RECURRENCE INTERVAL: Unknown

SLIP RATE: Unknown, probably <1 mm/yr .
Comments: Slip rate based on studies of the Tambomachay fault bySébrier and others (1985).

TIME OF MOST RECENT MOVEMENT: Historic (1965 and 1986)
Comments: The entire fault zone is considered to be Holocene or post glacial (<15 ka). However, two of the faults in this zone have evidence of historic rupture. The Urcos fault formed a historic surface rupture on May 8, 1965. The Chincheros fault was reactivated on April 5, 1986 with 1-10 cm of slip.

NAME OF EARTHQUAKE: Series of unnamed earthquakes

DATE/FECHA: May 8, 1965 and April 5, 1986

MAGNITUDE OR INTENSITY: Unknown

REFERENCES

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-10, OCONGATE FAULT ZONE

FAULT NUMBER: PE-10
Comments: Map location is different that than shown by Sébrier and others (1985, fig. 8a).

FAULT NAME: Ocongate (fault zone)

SYNOPSIS AND GEOLOGIC SETTING: Located between the town of Ocongate and Ausangate massif (40 km SE from Cuzco). These faults affect paleosoils developed at the scarp toe, suggesting recent reactivation. The northern set of faults (Ausangate) is Quaternary, but may be as young as the Holocene or post glacial (<15 ka) Uchuycruz faults to the south. The Ocongate fault zone has been interpreted as a high topography compensation (gravitational) effect.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999.

TYPE OF STUDIES
Structural studies and photointerpretation.

FAULT GEOMETRY:
LENGTH: 34.3 km (52.4 km cumulative)
STRIKE: 88°±24° (N88°E±24°)
DIP: N 70°-80° E to SW
SENSE OF MOVEMENT: Normal

GEOMORPHIC EXPRESSION: The northern set of faults (Ausangate) are located close to the Ausangate massif, expressed by north-dipping faults with fresh scarps and south-dipping faults with associated sagponds. The southern set of faults (Uchuycruz) are located 5 km NE of the Ausangate faults, and affect late Pleistocene lateral moraines and recent paleosoil, developed at the toe of the scarp.

RECURRENCE INTERVAL: 5,000 years
Comments: Maximum value

SLIP RATE: Unknown, probably 0.2-1 mm/yr

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
The Ausangate faults may be Holocene or post glacial (<15 ka) based on fresh appearance of scarps, but you movement has not been documented. Conversely, The Uchuycruz faults are clearly Holocene or post glacial (<15 ka) based on their deformation of late Pleistocene glacial deposits.

REFERENCES

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-11, VILCANOTA RIVER FAULT SYSTEM

FAULT NUMBER: PE-11

FAULT NAME: Vilcanota River (fault system)

SYNOPSIS AND GEOLOGIC SETTING: Located southeast of Cuzco, this west- to southwest-dipping fault system strikes generally NW and controls the direction of the Vilcanota River valley (Sébrier and others, 1985, figs. 1). It transfers motion from the east-west striking Cuzco fault zone [PE-09] on the north. Sébrier and others (1985) named this north-trending fault system after the Vilcanota River and included the Pomacanchi Lake fault, the Vilcanota River fault, the Lanqui Layo Lake fault, and several other unnamed known and inferred faults (Sébrier and others, 1985, fig. 8a).

COMPILER, AFFILIATION, & DATE OF COMPILATION: Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: General mapping, morphologic and structural analysis (Sébrier and others, 1985).

GEOMETRY OF THE FAULT:
LENGTH: 93.7 km (151.3 km cumulative)
STRIKE: -35°±23° (N35°W±23°)
DIP: 60-70° SW
Comments: Sébrier and others (1985) report a dip of 60°-70° SW for the northwest-striking Pomacanchi fault.

SENSE OF MOVEMENT: Normal
Comments: However, striated fault planes on the Pomacanchi fault show a combination of normal and sinistral (left-lateral) strike-slip movement, which is compatible with regional N-S extension (Sébrier and others, 1985).

GEOMORPHIC EXPRESSION: The Pomacanchi fault cuts coarse alluvial fan deposits related to the penultimate glaciation (>100 ka) and has about 50 m of Quaternary throw. The last two alluvial terraces do not show evidence of offset, and thus preclude Holocene movement (Sébrier and others, 1985). Some parts of the fault zone appear to be more active as shown by historical seismicity and fresh scarplets on modern topography north of the Lanqui village (at north end of Lanqui Layo Lake).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, plate 5.1) did not report slip rate data, but the fault has a likely rate of <0.2 mm/yr based on rates determined for other similar faults in the Southern High Desert province.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: Quaternary movement is clear from the faulting of >100 ka glacial deposits, and movement may be late Pleistocene, but probably pre Holocene (>10 ka).

REFERENCES

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-12, TRIGAL FAULT

FAULT NUMBER: PE-12

FAULT NAME: Trigal

SYNOPSIS AND GEOLOGIC SETTING: Located to the west of the Andean Cordillera, 100 km north-northwest of Arequipa, between Huambo and Cabana Conde. These east-west trending faults are predominately normal, down to the south and cut volcanic flows as young as Holocene. Older deposits record more offset, showing recurrent movement on the faults.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: General studies.

GEOMETRY OF THE FAULT:
LENGTH: 20.4 km (16.9 km cumulative)
STRIKE: 89°±14° (N89°E±14°) E-W
DIP: 65° S
SENSE OF MOVEMENT: Normal
Comments: Rake measurements vary from 48°-88° for the Trigal [PE-12] and Solarpampa [PE-13] faults, with an average value of 80°. Strike-slip motion is considered to be a minor component that is not visible in the geomorphology (Sébrier and others, 1985).

GEOMORPHIC EXPRESSION: Affects a variety of ages of Quaternary volcanic flows, with more displacement in older flows than younger flows. There are fresh fault scarps on Holocene andesitic flows (Sébrier and others, 1985, fig. 2a). Scarps are mainly south-facing and are 5-12 km long, 5-20 m (max. 30 m) high, and typically oppose the direction of stream flow, thus forming ponds that are filled with young sediment (Sébrier and others, 1985).

RECURRENCE INTERVAL: <10 k.y.
Comments: Sébrier and others (1985) state that the fault has 2 movements in the Holocene (post glacial time). Therefore, the recurrence for faulting is less than 10 k.y.

SLIP RATE: Unknown, probably 0.2-1 mm/yr
Comments: Slip rate based on 4 meters of displacement in <10 k.y.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Vertical displacements during the Holocene of approximately 4 m at Trigal Creek (Sébrier and others, 1985).

REFERENCES

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-13, SOLARPAMPA FAULT

FAULT NUMBER: PE-13

FAULT NAME: Solarpampa

SYNOPSIS AND GEOLOGIC SETTING: Located to the west of the Andean Cordillera, 100 km north-northwest of Arequipa, between Huambo and Cabana Conde. These east-west trending faults are predominately normal, down to the south and cut volcanic flows as young as Holocene. Older deposits record more offset, showing recurrent movement on the faults.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: General studies.

GEOMETRY OF THE FAULT:
LENGTH: 14.4 km (15.8 km cumulative)
STRIKE: 90°±17° (N90°E±17°)
DIP: 65° S
SENSE OF MOVEMENT: Normal
Comments: Rake measurements vary from 48°-88° for the Trigal [PE-12] and Solarpampa [PE-13] faults, with an average value of 80° (Sébrier and others, 1985). Strike-slip motion is considered to be a minor component that is not visible in the geomorphology.

GEOMORPHIC EXPRESSION: Affects a variety of ages of Quaternary volcanic flows, with more displacement in older flows than younger flows. There are fresh fault scarps on Holocene andesitic flows (Sébrier and others, 1985, fig. 2a). Scarps are mainly south-facing and are 5-12 km long, 5-20 m (max. 30 m) high, and typically oppose the direction of stream flow, thus forming ponds that are filled with young sediment (Sébrier and others, 1985).

RECURRENCE INTERVAL: <10 k.y.
Comments: Sébrier and others (1985) state that the fault has 2 movements in the Holocene (post glacial time). Therefore, the recurrence for faulting is less than 10 k.y.

SLIP RATE: Unknown, probably 0.2-1 mm/yr
Comments: Slip rate based on several meters of displacement in <10 k.y.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Could be historic if ground rupture occured during 1979 earthquake.

NAME OF EARTHQUAKE: Unknown

DATE/FECHA: February 1979

MAGNITUDE OR INTENSITY: Unknown

REFERENCES

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-14, MACHADO CHICO FAULT

FAULT NUMBER: PE-14
Comments: Fault 1 on map of Fenton and others (1995).

FAULT NAME: Machado Chico

SYNOPSIS AND GEOLOGIC SETTING: The Machado Chico fault has strong geomorphic expression over its 16 km length. It forms the northwestern base of the Cerro Alto de Meadero and the southeastern margin of the late Miocene-Pliocene peneplain in the Southern Coastal Cordillera province of Noller (1993). Its sense of movement is normal dip slip, down to the northwest. The late Miocene-Pliocene erosion surface is offset as much as 200 m vertically across the Machado Chico fault.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 16.9 km (21.8 km cumulative)
STRIKE: 21°±32° (N21°E±32°)
DIP: 60°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The most recent movement on the fault occurred along its central 6 kilometers, where a northwest-facing scarp about 2-3 m high is developed on colluvial deposits at the base of the Cerro Alto de Meadero and on the late Miocene-Pliocene peneplain. The scarp is poorly developed or absent across active (young) alluvial fans along the mountain front, suggesting that the last movement occurred prior to the Holocene. However, the relatively fresh appearance of the scarp on the peneplain and on colluvial deposits suggests the faulting is relatively young, possibly late Pleistocene in age. The most recent scarps are formed at the base of a series of 60-m-high faceted spurs that record a long history of Pleistocene movement (Fenton and others, 1995).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a very low slip rate of 0.016-0.02 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: Movement occurred prior to the Holocene, but possibly in late Pleistocene time along the central 6 kilometers of the fault (Fenton and others, 1995, table 5.A-1).

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailing Impoundment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-15, PAMPA HUANOCOLLO FAULT

FAULT NUMBER: PE-15

FAULT NAME: Pampa Huanocollo

SYNOPSIS AND GEOLOGIC SETTING The Pampa Huanocollo is a northwest-dipping fault that strikes northeast across the Pampa Huanocollo to the south of the Pan-American Highway in the Southern Coastal Cordillera province of Noller (1993). The fault offsets the late Tertiary erosion surface and Quaternary deposits along its entire length. The poorly developed scarp and lack of significant topographic offset across this fault suggest that is has not had a long history of Neogene movement, perhaps only moving two or three times since the late Tertiary (Fenton and others, 1995).

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 12.3 km (12.2 km cumulative)
STRIKE: 18°±8° (N18°E±8°)
DIP: 40°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault forms a northeast-trending scarp across the Pampa Huanocollo to the south of the Pan-American Highway for about 10.5 km. The scarp is no more than 0.5-1.5 m high and is degraded along its entire length. The most recent movement seems to have been along the central portion of the fault where only a short length of fault scarp remains intact. Even here the scarp is poorly developed on Pleistocene(?) alluvium and is being buried by eolian dune sand.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a very low slip rate of 0.001-0.002 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: Movement occurred prior to Holocene, but possibly in middle to early Pleistocene time (Fenton and others, 1995, table 5.A-1).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailing Impoundment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-16, CERRO CORDILLERAS FAULT

FAULT NUMBER: PE-16

FAULT NAME: Cerro Cordilleras

SYNOPSIS AND GEOLOGIC SETTING: The Cerro Cordilleras fault strikes northeast and has a marked surface expression as a bedrock-alluvium contact for a distance of amore than 20 km. The fault bounds the northwest margin of the Cerro Cordillera in the Southern Coastal Cordillera province of Noller (1993) and dips to the north and northeast. The fault offsets the late Tertiary erosion surface of the Cerro Cordillera a maximum of 300 m in the south, decreasing to less than 100 m in the north.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

FAULT GEOMETRY:
LENGTH: 19.1 km (26.8 km cumulative)
STRIKE: 67°±28° (N67°E±28°)

NUMBER OF SECTIONS: 3
Comments: The fault has three distinct geometric sections: northeast-striking northern and southern sections, and an east-southeast-striking central section.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-16A, NORTHERN SECTION, CERRO CORDILLERAS FAULT

FAULT SECTION NUMBER: PE-16a

SECTION NAME: Northern

GEOMETRY OF THE SECTION:
LENGTH: 7.0 km (10.0 km cumulative)
STRIKE: 56°±12° (N56°E±12°)
DIP: 50°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault scarp is largely buried by colluvial deposits at the bedrock/alluvium contact and by active eolian dunes.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Slip rate estimated at 0.015-0.02 mm/yr for young central section of the fault by Fenton and others (1995). Thus, the rate on the northern section is probably the slower than this owing to decreased amounts of offset (<100 m) of the late Tertiary erosion surface as you go north.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: The last movement along this section is probably no younger than middle Pleistocene based on the preservation of scarps (Fenton and others, 1995).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-16B, CENTRAL SECTION, CERRO CORDILLERAS FAULT

FAULT SECTION NUMBER: PE-16b

SECTION NAME: Central

GEOMETRY OF THE SECTION:
LENGTH: 3.8 km (4.9 km cumulative)
STRIKE: -78°±18° (N78°W±18°)
DIP: 50°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: Along this short (3.7 km long) central section, the fault offsets late Quaternary alluvial and colluvial deposits; however, no scarps were observed across active alluvial fans issuing from the range front. The faults scarps are well preserved, face north and are as much as 2.5 m in height (Fenton and others, 1995).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Slip rate estimated at 0.015-0.02 mm/yr for the young central section of the fault by Fenton and others (1995).

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: The last movement along this section is probably late or latest Pleistocene based on the preservation of scarps (Fenton and others, 1995). However, Holocene movement is excluded on the basis of a lack of scarps on active alluvial fans.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evalualtion, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-16C, SOUTHERN SECTION, CERRO CORDILLERAS FAULT

FAULT SECTION NUMBER: PE-16c

SECTION NAME: Southern

GEOMETRY OF THE SECTION:
LENGTH: 9.2 km (11.9 km cumulative)
STRIKE: 61°±35° (N61°E±35°)
DIP: 50°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault scarp is largely buried by colluvial deposits at the bedrock/alluvium contact by active eolian dunes.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Comments: Slip rate estimated at 0.015-0.02 mm/yr for central section of the fault by Fenton and others (1995). The maxium offset of the late Tertiary erosion surface is about 300 m on this section, but decreases to <100 m along the northern section. Therefore, the long-term rate on the southern section is probably faster than along the the central section of the fault, athough it is probably still below 0.2 mm/yr

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: The last movement along this section is probably no younger than middle Pleistocene based on the state of preservation of the scarps (Fenton and others, 1995).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-17, UNNAMED FAULT WEST OF RIO MOQUEQUA

FAULT NUMBER: PE-17

FAULT NAME: Unnamed fault west of Rio Moquequa

SYNOPSIS AND GEOLOGIC SETTING An unnamed fault strikes east-west for about 10 km west of Rio Moquequa in the Southern High Desert province of Noller (1993). The fault is shown as south dipping and of Quaternary age by Fenton and others (1995), but they did not report any specific data for this structure. It likely has a low slip rate and Pleistocene, not Holocene movement.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES:.

GEOMETRY OF THE FAULT:
LENGTH: 10.4 km (13.0 km cumulative)
STRIKE: -81°±16° (N81°W±16°)
DIP: Unknown
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, plate 5.1) show the fault as south-dipping normal.

GEOMORPHIC EXPRESSION: Fenton and others (1995, Appendix 5.1) did not report geomorphic characteristics for this fault.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, plate 5.1) did not report slip rate data, but the fault has a likely rate of <0.2 mm/yr based on rates determined for other similar faults in the Southern High Desert province.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: Fenton and others (1995, plate 5.1) show the fault as Pleistocene.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impoundment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-18, CHOLOLO FAULT

FAULT NUMBER: PE-18

FAULT NAME: Chololo

SYNOPSIS AND GEOLOGIC SETTING; The Chololo fault zone consists of three sub-parallel faults that form a 1-km-wide zone at the base of the south-facing, 400-m-high range front of the Cerro Chololo in the Southern Coastal Cordillera province of Noller (1993). The southernmost of these fault strands is the youngest and has a prominent 2-m high scarp.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 16.7 km (24.3 km cumulative)
STRIKE: 54°±12° (N54°E±12°)
DIP: 50°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault has a maximum surface trace length of about 17 km and a vertical offset of about 200 m as indicated from scarps on Quaternary alluvium (Narvaez, 1964). The most recent offset on the Chololo fault has produced a southeast-facing scarp as much as 2-m high for about 12 km along the southernmost of its three fault strands. These young scarps are formed on piedmont-alluvial fans and alluvial fans that issue from the range-front canyons. They are less well developed across the active fan surfaces, probably as a result of recent erosion or deposition (Fenton and others, 1995).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) reported a slip rate of 0.016-0.20 mm/yr for the southernmost fault strand (late Quaternary rate) and a long-term (Quaternary) rate of about 0.20 mm/yr . The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: <15 ka
Comments: Fenton and others (1995, table 5.A-1) report that the youngest movement on the fault is probably Holocene or latest Pleistocene for the southernmost strand. Quaternary movement is documented on the remainder of the fault

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Narvaez, S., 1964, Geologia de los cuadrangulos de Ilo y Locumba, Comision Carta Geologica Nacional, Boletin No. 7, 75 p + 2 plates

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-19, CERRO LORETO

FAULT NUMBER: PE-19

FAULT NAME: Cerro Loreto

SYNOPSIS AND GEOLOGIC SETTING: The Cerro Loreto fault is marked by a poorly preserved east-facing scarp that trends north-northeast along the eastern margin of Cerro Loreto in the Southern Coastal Cordillera province of Noller (1993). The fault appears to be relatively immature in that there is a general lack of faceted spurs and other indicators of neotectonic activity along the eastern slopes of Cerro Loreto.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 9.2 km (9.4 km cumulative)
STRIKE: 11°±10° (N11°E±10°)
DIP: 60°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault scarp is partly buried by latest Pleistocene to early Holocene dune sand over much of its length, whereas active dunes bury the northern end of the fault. The scarp is formed across a Pliocene-Pleistocene piedmont-fan surface and forms a prominent topographic step (height not reported).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) reported a very low slip rate of 0.003-0.02 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: The last movement along the fault probably occurred in the late to middle Pleistocene with rupture along the fault's entire 9 km length. Fenton and others (1995) based this conclusion on the degree of preservation of the scarps.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-20, CHASPAYA FAULT

FAULT NUMBER: PE-20

FAULT NAME: Chaspaya

SYNOPSIS AND GEOLOGIC SETTING: The east-northeast-striking Chaspaya fault displays the strongest geomorphic expression of any Quaternary fault in the Southern Coastal Cordillera province of Noller (1993) (Fenton and others, 1995). The fault forms the southwest margin of the Cerro Chaspaya, which is about 5-15 km east and southeast of Pachia. The fault is marked by a series of approximately 200-m-high faceted spurs on the southern slopes of Cerro Chaspaya (see figure 5.A-2, Fenton and others, 1995). The presence of young scarps on eolian sands suggests that the most recent movement of the Chaspaya fault may be less than a few hundred years old.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 10.2 km (10.1 km cumulative)
STRIKE: 61°±8° (N61°E±8°)
DIP: 50°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The young fault has active surface expression over its entire length (ca. 10 km) with the most recent surface rupture breaking along about 8 km of its trace. The most recent scarp is about 3.5-3 m hight and is well developed on Holocene colluvium and eolian deposits. The scarp shows very little degradation, with almost no erosion of the scarp alongs its central portion. The scarp also crosses shallow gullies between triangular faceted spurs (see fig. 5.A-2, Fenton and others, 1995).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a low slip rate of 0.02-0.03 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Fenton and others (1995, table 5.A-1) report Holocene movement on the basis of the morphology and preservation of the fault scarp. The preservation of the scarp on eolian sand further suggests that the most recent movement may have occurred no more than a few hundred years ago, possibly the result of a historical faulting event that is not recorded in the literature.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-21, CERRO CHASCOSO FAULT

FAULT NUMBER: PE-21

FAULT NAME: Cerro Chascoso

SYNOPSIS AND GEOLOGIC SETTING: The Cerro Chascoso fault forms a low bedrock escarpment for almost 10 km along the east margin of Cerro Chascoso in the Southern High Desert province of Noller (1993). The fault strikes north-northeast and dips steeply to the east. The fault bifurcates at its northern end. Although the fault offsets the late Tertiary erosion surface, there is little evidence for offset of Pleistocene materials along much of its length.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 5.8 km (7.8 km cumulative)
STRIKE: 4°±9° (N4°E±9°)
DIP: 70°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: Over much of its length, the fault is expressed as a 1-1.5 m high bedrock scarp or as a bedrock-alluvial contact. Except for the central part of the fault, the scarp is partly buried by recent eolain deposits. The central 5.5 km of the fault appears to be better preserved than the ends, hence it is probably the portion of the fault that most recently moved. There is no offset of alluvial channels or alluvial-fan channels across the scarp.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a very low slip rate of 0.0006-0.005 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)
Comments: The last movement along this section probably occurred in the early to middle Pleistocene with a rupture along the fault's central 5.5 km (Fenton and others, 1995, table 5.A-1).

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-22, ALTOS LOS CHILENOS FAULT

FAULT NUMBER: PE-22

FAULT NAME: Altos los Chilenos

SYNOPSIS AND GEOLOGIC SETTING: The Altos los Chilenos fault is a northeast-striking fault that bounds the northwestern side of a small graben between Altos los Chilenos and Cerro Morrito in the Southern Coastal Cordillera province of Noller (1993). The fault dips steeply to the southeast and extends for about 10 km as marked by a prominent topographic lineament that is formed by a southeast-facing scarp as much as 4 m high. The close association of the Cerro Morrito [PE-20] and Altos los Chilenos faults suggests that they have similar displacement histories. The Cerro Morrito fault is probably antithetic to the Altos los Chilenos fault.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 11.8 km (11.6 km cumulative)
STRIKE: 31°±12° (N31°E±12°)
DIP: 60°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault is characterized by a southeast-facing scarp as much as 4 m high on a late Tertiary peneplain and on Pleistocene alluvial deposits. Over much of its length, the scarp has been highly eroded and is partly buried by colluvium and eolian sand. There appears to be little difference in the morphology or rupture characteristics along the trace of the fault, thus it is assumed that the last event ruptured the entire length of the Altos Los Chilenos fault. The age of alluvial deposits offset along the fault is unknown, but from the surface weathering (color), they are probably no older than middle to early Pleistocene.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) report a low slip rate of 0.003-0.03 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The last movement probably occurred in the late to middle Pleistocene with a rupture along the fault's entire length (Fenton and others, 1995). Holocene movement is excluded based on the poor state of preservation of the scarps.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-23, CERRO MORRITO FAULT

FAULT NUMBER: PE-23

FAULT NAME: Cerro Morrito

SYNOPSIS AND GEOLOGIC SETTING: The Cerro Morrito fault bounds the southern side of the graben between Altos los Chilenos and Cerro Morrito in the Southern Coastal Cordillera province of Noller (1993). The fault strikes east-northeast and has a 5.6-km-long topographic lineament that is formed by a scarp as much as 3-m high. The close association of the Cerro Morrito and Altos los Chilenos [PE-19] faults suggest that they have similar displacement histories. The Cerro Morrito fault is probably antithetic to the Altos los Chilenos fault.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 5.6 km (5.5 km cumulative)

STRIKE: 63°±9° (N63°±9°)

DIP: 60°

Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault is marked by a 2- to 3-m high bedrock scarp along its entire length (5.6 km). Pleistocene alluvial deposits are offset only along several hundred meters of the northern part of the fault, where extensive dune sands cover the end of the fault.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) report a low slip rate of 0.003-0.02 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The last movement probably occurred in the late to middle Pleistocene with a rupture along the fault's entire length (Fenton and others, 1995). Holocene movement is excluded based on burial of the scarp by eolian sand at the northern end of the fault.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-24, PAMPA TRAPICHE FAULT

FAULT NUMBER: PE-24

FAULT NAME: Pampa Trapiche

SYNOPSIS AND GEOLOGIC SETTING The Pampa Trapiche fault is essentially the northwestern extension of the Toquepala fault [PE-23] and Incapuquio fault system, east of Moquegua in the Southern High Desert province of Noller (1993). The fault is expressed as a series of discontinuous south-facing scarps on bedrock and alluvium. These scarps form the bedrock/alluvium contact with the Pampa Trapiche.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 18.5 km (16.4 km cumulative)
STRIKE: -85°±21° (N85°W±21°)
DIP: Unknown
SENSE OF MOVEMENT: Unknown

GEOMORPHIC EXPRESSION: The fault is marked by scarps as much as 4 m high, but which are extensively eroded and have limited lateral continuity, being breached in many places by active alluvial channels on fan surfaces. The scarps are not present on the recent alluvial deposits of the Moquegua Valley. To the west, the fault splits into a number of bedrock fractures as it traverses an area of higher ground that lacks surficial deposits. There is no evidence for late Quaternary movement on the western portion of the fault. Evidence for young (late Quaternary?) movement is restricted to the 7-km-long reach across the Pampa Trapiche above the town of Moquegua. Elsewhere, the scarps on alluvium are discontinuous and greatly eroded, suggesting that they formed sometime prior to the late Pleistocene, and possibly during the early Pleistocene.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) did not report a slip rate for the fault. However, on the basis for rates established for similar nearby faults, the rate is likely to be low (<0.2 mm/yr).

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The last movement probably occurred something prior to the late Pliocene, or possibly during the early Pleistocene (Fenton and others, 1995). Late Quaternary movement is excluded based on late of fault scarps and continuity of the fault trace along much of its length.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-25, TOQUEPALA FAULT

FAULT NUMBER: PE-25

FAULT NAME: Toquepala

SYNOPSIS AND GEOLOGIC SETTING The Toquepala, which is the main fault in the Incapuquio fault system, is the longest, most active fault in the Southern High Desert province of Noller (1993). The Toquepala fault is marked by a strong topographic lineament from about 5 km east of Moquegua east-southeast through Villa Toquepala to as far as the headwaters of the Rio Caplina, below the Cordillera del Barroso, a total distance of about 107 km. The fault is comprised of a number of straight traces joined by a series of jogs and stepovers, suggesting a significant component of lateral motion. The earliest descernable movement on the fault is characterized by as much as 50 m of right-lateral offset of stream channels near Villa Toquepala. Similar evidence of dextral motion is observed all along the fault, but is best displayed in the valley of Quebrada Chintari and below Cerro Nachane at the eastern end of the fault.

The main fault and its splays traverse more that 1,500 m of local topography, revealing a vertical or near-vertical attitude for the fault planes. The Toquepala fault has a complex history of movement during the Quaternary. The fault is herein divided into two geographic sections largely based on an intervening region of poor fault expression (an asperity?). Large portions of both sections display geomorphic and geologic evidence for Holocene movement at rates of 0.2 mm/yr, and longer term rates >0.2 mm/yr.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

FAULT GEOMETRY:
LENGTH: 114.0 km (228.3 km cumulative)
STRIKE: -62°±26° (N62°W±26°)

NUMBER OF SECTIONS: 2
Comments: The fault is herein divided into two geographic sections largely based on an intervening region of poor fault expression (an asperity?).

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-25A, WESTERN SECTION, TOQUEPALA FAULT

FAULT SECTION NUMBER: PE-25a

SECTION NAME: Western
Comments: This section of the fault extends from about 5 km east of Moquegua east-southeast through Villa Toquepala to the interfluve between the Rio Ilabaya and Rio Curibaya. The section boundary is poorly defined owing to poor fault expression.

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE SECTION:
LENGTH: 48.0 km (91.2 km cumulative)
STRIKE: -60°±13° (N60°W±13°)
DIP: 90°
Comments: Dip based on near vertical topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Shown as normal for Holocene movement and right lateral for movement in the middle Pleistocene (Fenton and others, 1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The western section is marked by south-facing, normal fault scarps as much as 3-m high and small associated grabens. Surface rupture along this section of the fault extends for about 40 km from Pampa Lagunas to the Rio Ilabaya. Fenton and others (1995) measured as much as 50 m of right-lateral (dextral) offset of stream channels near Villa Toquepala. As the fault crosses the Pampa Lagunas, it offsets the late Miocene Cochapampa surface and younger alluvial units deposited on this surface. The fault also disrupts alluvial channels of the pampa and a pale grey volcanic ash (Holocene?) found immediately below the modern desert soil. Near Villa Toquepala, recent alluvial terraces, modern colluvium and talus slopes are offset as much as 3 m across the fault. The scarp's morphology and height are relatively continuous in an east-west direction along the fault as far as Rio Ilabaya, near the section boundary.

RECURRENCE INTERVAL: Unknown

SLIP RATE: 0.2-1.0 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a slip rate of 0.15-0.25 mm/yr for the fault during the Holocene, and higher long-term rates of 0.07-0.40 mm/yr since the middle Pleistocene. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Because the fault scarps appear extremely fresh, it is likely that there has been one or more normal surface faulting episodes during the Holocene. The faulted ash deposit along the western section of the fault may be correlative to the ashfall along the Pampa del Purgatorio [PE-24] fault, which is possibly due to a volcanic eruption in A.D. 1600. If so, then the most recent surface rupture on the Toquepala fault may have occurred in the past 400 years. This inference is supported by the apparent destruction of historic stone shelters along the eastern section of the fault.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-25B, EASTERN SECTION, TOQUEPALA FAULT

FAULT SECTION NUMBER: PE-25b

SECTION NAME: Eastern
Comments: This section of the fault extends east-southeast from the interfluve between the Rio Ilabaya and Rio Curibaya to just west of Coropuro and across Quebrada Chero to the headwaters of Rio Caplina, below the Cordillera del Barroso. The section boundary is poorly defined.

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE SECTION:
LENGTH: 65.7 km (137.1 km cumulative)

STRIKE: -64°±31° (N64°W±31°)
DIP: 90°
Comments: Dip based on near vertical topographic expression of the fault (Fenton and

SENSE OF MOVEMENT: Normal
Comments: Shown as normal for Holocene movement and right lateral for earlier movement in the middle Pleistocene (Fenton and others, 1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The eastern section is marked by a simpler rupture pattern than the western section. The most recent faulting event produced a simple linear south-facing scarp as much as 3-m high on bedrock, colluvium, and alluvium where the fault traverses drainage courses. The fault forms a nearly continuous scarp about 25 km long from Coropuro on the Rio Sama, east-southeast to Cerro Palquilla above Quebrada Chero, although none of the numerous splays of the main fault appear to have been reactivated during the most recent event. Unlike the western section, there appears to be no young ash-fall deposits to date the most recent event. There is, however, indirect evidence for historical strong ground motion in the reconstruction history of long-lived stone shelters. The fault scarp maintains a free face about 1 m high along most of this length indicating recent (late Holocene/ movement), whereas the overall scarp can reach 3 m in height.

RECURRENCE INTERVAL: Unknown

SLIP RATE: 0.2-1.0 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a slip rate of 0.15-0.25 mm/yr for the fault during the Holocene, and 0.07-0.40 mm/yr since the middle Pleistocene. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Because the fault scarps appear extremely fresh, it is likely that there has been one or more normal surface fauting episodes during the Holocene. The faulted ashfall along the western section of the fault may be correlative to the ashfall along the Pampa del Purgatorio [PE-24] fault, which is possibly due to a volcanic eruption in A.D. 1600. If so, then the most recent surface rupture on the Toquepala fault may have occurred in the past 400 years. This inference is supported by the apparent destruction of historic stone shelters along the eastern section of the fault.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-26, MICALACO FAULT

FAULT NUMBER: PE-26

FAULT NAME: Micalaco

SYNOPSIS AND GEOLOGIC SETTING The Micalaco fault is the most northerly fault in the Incapuquio fault system. This fault strikes east-southeast for about 33 km in the Southern High Desert province of Noller (1993). It extends from Cerro Yarito, west of the Toquepala Mine, over Cerro Cadete to Micalaco where it splits into three branches before dying out in an area of extensive landsliding above Rio Ilabaya. The fault has geomorphic expression that suggests latest Pleistocene (<15 ka) movement.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:
LENGTH: 32.6 km (40.6 km cumulative)
STRIKE: -66°±10° (N66°W±10°)
DIP: 90°
Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).
SENSE OF MOVEMENT: Normal
Comments: Shown as normal for late Pleistocene movement and right lateral for earlier movement in the Quaternary (Fenton and others, 1995, table 5.A-1).

GEOMORPHIC EXPRESSION: Between Cerro Cadete and Micalaco, a number of streams show 20 m to 30 m of right lateral (dextral) offset. Conversely, over much of its central portion, and especially between Toquepala and Micalaco, the fault is marked by a series of south-facing scarps on both bedrock and colluvium that are 1.5-2 m in height. The scarps on colluvium are only breached by the most recent stream channels, which suggests young movement. Other channels are offset, down-to-the-south across the fault. In places, the faut scarp is partially buried by recent colluvium.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr
Comments: Fenton and others (1995, table 5.A-1) report a low slip rate of 0.01-0.015 mm/yr throughout the Quaternary for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)
Comments: Fenton and others (1995, table 5.A-1) report the most recent movement is most likely not Holocene, but probably latest Pleistocene as evidenced by channelling (erosion) of the fault scarp and its partial burial by colluvium.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Fenton, C.H., Wong, I.G., and Bott, J.D.J., unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-27, PAMPA DEL PURGATORIO FAULT

FAULT NUMBER: PE-27

FAULT NAME: Pampa del Purgatorio

SYNOPSIS AND GEOLOGIC SETTING The Pampa del Purgatorio fault strikes west-northwest from Chulibaya for about 40 km to the Pampa del Purgatorio in the Southern High Desert province of Noller (1993) The fault offsets the late Miocene Sanan erosion surface 200-300 m (down to the south) and younger alluvial and eolian deposits on that surface. The fault shows a complex history of movement, having had episodes of right-lateral (dextral) movement during the Quaternary and scissors-type normal movement in the Holocene. Owing to the faults proximity to the Quebrada Honda tailing empoundment, two trenches and several natural exposures along the western section of the fault were studied by Fenton and others (1995) to determine the chronology and amounts of displacement of recent movement. Both sections of the fault appear to have Holocene movement, with possible ground rupturing in the past 400 years along the western section.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, field inspection, and trenching.

FAULT GEOMETRY:

LENGTH: 27.9 km (30.1 km cumulative)

STRIKE: -77°±° 18° (N77°W±18°)

NUMBER OF SECTIONS: 2

Comments: The fault is divided into two structural sections largely based on the change of dip directions across an intervening 2-km-wide left step.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Fenton, C.H., Wong, I.G., and Bott, J.D.J., unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-27A, WESTERN SECTION, PAMPA DEL PURGATORIO FAULT

FAULT SECTION NUMBER: PE-27a

SECTION NAME: Western

Comments: This section extends from a left step in the fault at the Rio Cinto, west across the eastern part of the Pampa del Purgatorio to a point about 3 km north of the Quebrada Honda tailing empoundment.

GEOMETRY OF THE SECTION:

LENGTH: 14.7 km (14.3 km cumulative)

STRIKE: -71°±7° (N71°W±7°)

DIP: 70° S

Comments: Near surface dip based on trench and natural exposures of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Shown as normal for Holocene movement and right lateral for earlier movement in the early to middle Pleistocene (Fenton and others, 1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The most recent faulting along the western section of the Pampa del Purgatorio fault has involved down-to-the-north movement as evidenced by relatively uneroded north-facing fault scarps across the Pampa del Purgatorio. The scarp is as much as 3.0 m high, strikes east-west to west-northwest (at its western end), and appears to offset all deposits with the exception of recent eolian silts. The scarp has a free face as much as 1.4 m high that shows minor recent erosion (1982-83 El Niño storms, Noller, 1993). Older stream channels show evidence for a few to several tens of meters of right-lateral offset, although the most recent event appears to have been of a normal sense. The scarp must have existed prior to 1948 (time of penultimate storm event; Fenton and others, 1995), but may be quite young. In many places, the fault cuts the modern desert soil (<15 mm thick) and an underlying volcanic ash that may be from the 1600 A.D. Huaynaputina eruption (see references and personal communications cited in Fenton and others, 1995). The most recent event produced ground ruptures along about 5 m of the western end of the fault section.

Evidence for prior faulting events is recorded by progressive deformation of successively older fluvial terrace surfaces. There appears to have been at least three faulting events, each with vertical offsets of 0.3-1 m. These terraces are not dated.

Fenton and others (1995) studied two trenches and three natural exposures. The western trench revealed a simple normal fault zone with five main planes and a cumulative vertical offset of 1.85 m. This offset is the result of 4-6 faulting events, the most recent of which had about 0.4 m of throw. Slickenlines indicate pure dip-slip movement on the active faults.

The eastern trench revealed a more complex fault zone comprising a series of upward-bifurcation normal faults with six main planes and several splays. The cumulative vertical offset is more then 2.0 m. The flower structure and lack of correlation of deposits across the fault suggest a large component of lateral motion. Vertical movement in the most recent faulting event was 0.4 m, whereas the penultimate event had about 0.45 m of displacement; the amount of lateral motion was not determined. The natural exposures show similar styles of faulting and amounts of offset as observed in the trench exposures.

RECURRENCE INTERVAL: 200-300 years

Comments: The western section of the fault appears to have characteristic vertical offsets of about 0.4 m with a return period of 200-300 years (Fenton and others (1995). The total slip may be considerably more when one considers the unmeasured lateral component.

SLIP RATE: 0.2-1.0 mm/yr

Comments: Fenton and others (1995, table 5.A-1) reported a slip rate of 0.30 mm/yr for this section of the fault during the Holocene, and 0.05-0.12 mm/yr for the entire fault since early to middle Pleistocene time.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)

Comments: Multiple faulting events are demonstrated by Fenton and others (1995), the most recent of which may have occurred in the past 400 years. The most recent event produced ground ruptures along about 5 km of the western end of the section.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-27B, EASTERN SECTION, PAMPA DEL PURGATORIO FAULT

FAULT SECTION NUMBER: PE-27b

SECTION NAME: Eastern

Comments: This section extends from a left step in the fault at the Rio Cinto, east across the Pampa de Cinto to a point about 1 km northwest of Mirave.

GEOMETRY OF THE SECTION:

LENGTH: 13.6 km (15.8 km cumulative)

STRIKE: -83°±20° (N83°W±20°)

DIP: 80° S

Comments: Near surface dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Shown as normal for Holocene movement and right lateral for earlier movement in the early to middle Pleistocene (Fenton and others, 1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The eastern end of this section, from Quebrada Ahorcado to the hillslopes above Chulibaya, has down-to-the-south, south-facing scarps as much as 2.5 m high. These scarps are formed on recent colluvium and alluvium. They show little evidence of erosion, except by active stream channels and larger perennial streams. Above Chulibaya, the scarps face uphill on Holocene talus slopes. These scarps are only partially filled by talus or colluvium. Sébrier and others (1985) inferred that movement along this fault has taken place in historic times, but not in the 20th Century. The most recent faulting event ruptured about 10 km of this section.

Prior faulting has produced from 50-95 m of right-lateral movement as evidenced by offset fan surfaces, drainage courses, and lateral moraine crests across the Quebrada Ahorcado above Mirave. Figure 5.A-3 of Fenton and others (1995) clearly shows about 90 m of right-lateral offset of the moraine crest.

RECURRENCE INTERVAL: Unknown

SLIP RATE: 0.2-1.0 mm/yr

Comments: Fenton and others (1995, table 5.A-1) report a vertical slip rate of 0.21 mm/yr for this section of the fault during the Holocene, and 0.05-0.12 mm/yr for the entire fault since early to middle Pleistocene time. The basis for these rates is not reported. However, if one assumes that the 90-m offset lateral moraine is 15-20 ka, then the resulting average slip rate is about 4.5-6 mm/yr, which seems extremely high for a non-plate boundary fault. If the moraines are related to marine oxygen isotope stage VI (>140 ka), then the long-term slip rate is <1 mm/yr.

TIME OF MOST RECENT MOVEMENT: Holocene or post glacial (<15 ka)

Comments: Multiple faulting events are demonstrated by Fenton and others (1995), the most recent of which may have occurred in the past 400 years.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-28, VILLACOLLO FAULT

FAULT NUMBER: PE-28

FAULT NAME: Villacollo

SYNOPSIS AND GEOLOGIC SETTING The Villacollo fault is expressed by an series of east-west striking south-facing scarps on bedrock, alluvium, and colluvium for about 20 km, centered near Villacollo on the Rio Sama in the Southern High Desert province of Noller (1993) and extending into the high country on either side of the valley. The fault has two sections as defined by their general strike directions and geometry. There is a general lack of surficial deposits and abundance of highly fractured bedrock at the western ends of both sections, making it difficult to determine their true lateral extent.

Both sections appear to have been active in the late Pleistocene, but not the Holocene.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

FAULT GEOMETRY:

LENGTH: 21.6 km (39.7 km cumulative)

STRIKE: -87°±21° (N87°W±21°)

NUMBER OF SECTIONS: 2

Comments: The fault is divided into two geometric sections largely based on strike directions and general geometry.

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Fenton, C.H., Wong, I.G., and Bott, J.D.J., unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-28A, NORTHERN SECTION, VILLACOLLO FAULT

FAULT SECTION NUMBER: PE-28a

SECTION NAME: Northern

Comments: This section is comprised to two sub-parallel, northwest- to southwest-trending traces that traverse high ground on the northwest side of the Rio Sama valley in the Southern High Desert province of Noller (1993). They extend northwest to the Rio Curibaya, but do not cross it.

GEOMETRY OF THE SECTION:

LENGTH: 8.7 km (17.8 km cumulative)

STRIKE: -75°±24° (N75°W±24°)

DIP: Unknown

Comments: Reported as vertical (90°) by Fenton and others, 1995 (table 5.A-1), but is probably lower given the faults curvate shape in high terrain.

SENSE OF MOVEMENT: Normal

Comments: Shown as normal by Fenton and others, 1995 (table 5.A-1),

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) reported a slip rate of 0.01-0.016 mm/yr for both sections of the fault since the late Pleistocene. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The most recent movement on the western section is Pleistocene, but the preservation of scarps on colluvium suggests that it might be as young as late Pleistocene.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-28B, EASTERN SECTION, VILLACOLLO FAULT FAULT

FAULT SECTION NUMBER: PE-28b

SECTION NAME: Eastern

Comments: This section extends east-west for about 16 km and crosses the east-southeast flowing Rio Sama at Villacollo. The fault enters higher ground on both sides of the Rio Sama valley.

GEOMETRY OF THE SECTION:

LENGTH: 21.8 km (22.0 km cumulative)

STRIKE: 83°±8° (N83°E±8°)

DIP: 90°

Comments: Vertical dip based on relatively straight fault trace (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Shown as normal by Fenton and others, 1995 (table 5.A-1).

GEOMORPHIC EXPRESSION: The eastern section is comprised of a linear 10-km long series of south-facing bedrock scarps and scarps on colluvium. The fault offsets ephemeral stream channels in the dry valley due west of Villacollo. To the east of Villacollo, the fault has been eroded by the Rio Sama, and the scarp is partly buried by recent colluvium on the hillslopes to the east of the Rio Sama. Older stream courses are offset a few to tens of meters in a right-lateral (dextral) sense. Elsewhere, the scarp has been eroded by small watercourses and buried by young alluvium, suggesting a lack of Holocene movement. The scarps are typically about 1 m high, with a maximum height of 1.5-2 m locally (Fenton and others, 1995, table 5.A-1).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) report a slip rate of 0.01-0.016 mm/yr for both sections of the fault since the late Pleistocene. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The remost recent movement on the western section is Pleistocene, but the preservation of scarps on colluvium suggests that they might be as young as late Pleistocene.

REFERENCES

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

PE-29, CERRO ROCOSO FAULT

FAULT NUMBER: PE-29

FAULT NAME: Cerro Rocoso

SYNOPSIS AND GEOLOGIC SETTING The Cerro Rocoso fault is comprised of a series of northwest-striking, southwest-dipping faults that form scarps on both bedrock and alluvium along Quebrada Gil, a tributary of the Rio Sama. The fault continues across the Pampa las Chuchilas in the Southern High Desert province of Noller (1993) as a line of discontinuous scarps on alluvium for a total distance of almost 11 km.

This fault appears to be the same as the Chulibaya fault of José Macharé (early compilation for this database). The Chulibaya fault is located between Locumba and Carabaya, at the margin of the Pacific piedmont and the Western Cordillera. Macharé reported that this is the one of the only known active faults of the coastal zone and belongs to the Incapuquio fault system to the north and east, which separates the forearc (Moquegua Basin) from the Western Cordillera.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; rewritten by Michael Machette, USGS, and Clark Fenton, URS Corporation, 2002.

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 11.8 km (11.7 km cumulative)

STRIKE: 31°±14° (N31°E±14°)

DIP: 70° SW

Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Shown as normal by Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault scarps extend discontinuously for about 11 km, face southwest and are as much as 2 m high. The scarps on alluvium are slightly degraded or partially buried by recent eolian sands. Along the Quebrada Gil, the bedrock scarps are sharp and form prominent topographic lineaments, whereas on alluvium most of the scarps have been removed by fluvial erosion.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) reported a very low slip rate of 0.001-0.016 mm/yr for the fault. The basis for these rates is not reported.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The last movement probably occurred in the early to middle Pleistocene with a rupture along the fault's entire 10.4 km length (Fenton and others, 1995). However, the poor preservation of the scarps suggests that the 10.4 km surface rupture length is a minimum.   Conversely, if the Cerro Rocoso fault is equivalent to the Chulibaya (normal) fault of Sebrier and others (1985) the fault could be quite young, having formed a 2.5-m-high uphill facing scarp that appears to have a steep free face (Sebrier and others, 1985, fig. 14). Although the scarp is partially buried by Holocene talus (scree) deposits, it is considered to have formed a hundred years or more ago (Sebrier and others, 1985).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

Sébrier, M., Mercier, J., Mégard, F., Laubacher, G. and Carey-Gailhardis, E., 1985, Quaternary normal and reverse faulting and the state of stress in Central Andes of South Perú: Tectonics, v. 4, no. 7, p. 739-780.

PE-30, CERRO CAQUILLUCO FAULT

FAULT NUMBER: PE-30

FAULT NAME: Cerro Caquilluco

SYNOPSIS AND GEOLOGIC SETTING The Cerro Caquilluco fault is a west-northwest striking bedrock feature (lineament) that can be traced about 18 km across the south-tilted late Tertiary erosion surface between Rio Sama and Tacna in the Southern High Desert province of Noller (1993). There are no scarps developed along the lineament, and no evidence for lateral offset of geomorphic features. However, the fault appears to disturb the mid-Miocene Cochapampa erosion surface and appears as a clear lineament across the cirque below Cerro Caquilluco, suggesting Quaternary movement.

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 19.1 km (19.1 km cumulative)

STRIKE: -71°±6° (N71°W±6°)

DIP: 90°

Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Unknown

Comments: Reported as unknown by Fenton and others (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: There are no scarps developed along the lineament, and no evidence for lateral offset of geomorphic features. However, the fault appears to disturb the mid-Miocene Cochapampa erosion surface and appears as a clear lineament across the Quaternary cirque (landslide head scarp) below Cerro Caquilluco. The cirque is the source of a giant rock avalance (Melosh, 1990) that came to rest on the Pampa del Pedregal, about 40 km from Cerro Caquilluco. From the degree of incision and erosion of the debris lobe, the deposit is probably older than middle Pleistocene.

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) did not report a slip rate for the fault. On the basis of slip rates reported for similar faults in the area, it is probably <0.2 mm/yr.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: Evidence for movement on the fault is indirect. On the basis of empirical earthquake-landslide relations (Keefer, 1984), Fenton and others (1995) suggested that the giant rock avalance was caused by a M>6 earthquake along the Cerro Caquilluco fault. If so, then the last movement probably occurred in the early to middle Pleistocene with a rupture along the fault's entire 17.6 km length (Fenton and others, 1995).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Keefer, D.K., 1984, Rock avalanches caused by earthquakes: source characteristics, Science, v. 223, p. 1288-1289.

Melosh, H.J., 1990, Giant rock avalanches, Nature, v. 248, p. 483-484

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-31, SAN FRANCISCO FAULT

FAULT NUMBER:PE-31

FAULT NAME: San Francisco

SYNOPSIS AND GEOLOGIC SETTING The San Francisco fault is characterized by a series of degraded, discontinuous scarps on alluvium about 16 km northeast of Tacna, immediately northeast of Pachia. The surface expression of the fault extends for about 21 km from the Rio Caplina across the Pampa San Francisco to Quebrada Cobani in the Southern High Desert province of Noller (1993).

COMPILER, AFFILIATION, & DATE OF COMPILATION: Clark Fenton, URS Corporation, and Michael Machette, U.S. Geological Survey; 2003

TYPE OF STUDIES: Aerial photo interpretation, aerial reconnaissance, scarp morphology studies, and field inspection.

GEOMETRY OF THE FAULT:

LENGTH: 18.6 km (17.8 km cumulative)

STRIKE: -44°±16° (N44°W±16°)

DIP: 70°

Comments: Dip based on topographic expression of the fault (Fenton and others, 1995, table 5.A-1).

SENSE OF MOVEMENT: Normal

Comments: Reported as normal by Clyde Consultants (1995, table 5.A-1).

GEOMORPHIC EXPRESSION: The fault is characterized by a series of degraded, discontinuous scarps on alluvium. The southeastern part of the fault is merely expressed as a bedrock fracture or as a low scarp on alluvium, partly buried by eolian deposits. However, the fault is better expressed as a low (1-1.5 m high) scarp on alluvial gravels for about 8 km at its western end. The scarp is partly degraded and was not observed across active alluvial surfaces or recent stream channels (Fenton and others, 1995).

RECURRENCE INTERVAL: Unknown

SLIP RATE: <0.2 mm/yr

Comments: Fenton and others (1995, table 5.A-1) reported a very low slip rate of 0.001-0.01 mm/yr for the fault.

TIME OF MOST RECENT MOVEMENT: Quaternary (<1.6 Ma)

Comments: The last movement probably predates the most recent (Holocene) alluvial deposits, but offsets the late Miocene Shanan erosion surface and Pleistocene(?) alluvial deposits that cover this surface (Fenton and others, 1995). Middle to late Pleistocene movement along 7.6 km of the 21-km-long San Francisco fault is suggested by Fenton and others (1995, table 5.A-1).

REFERENCES

Fenton, C.H., Wong, I.G., and Bott, J.D.J., 1995, Seismic and volcanic hazard evaluation, Quebrada Honda Tailiing Impountdment—Appendix 5A: Oakland, CA, Woodward-Clyde Consultants, unpublished report prepared for Southern Peru Copper Corporation, 51 p., 7 tables, 9 figures, 4 pls. 1:200,000 scale.

Noller, J.S., 1993, Late Cenozoic stratigraphy and soil geomorphology of the Peruvian desert, 3°-18° S: A long-term record of hyperaridity and El Nino: Boulder, University of Colorado, unpublished Ph.D. thesis, 279 p., 6 plates.

PE-32, PERU-CHILE TRENCH (NAZCA SUBDUCTION ZONE)

FAULT NUMBER: PE-32

FAULT NAME: Peru-Chile trench (Nazca subduction zone)

SYNOPSIS AND GEOLOGIC SETTING: The Nazca subduction zone (and the associated Peru-Chile trench) is located offshore, about 100-200 km west of Perú's Pacific coast. It extends well to the north and south of the map area (see map) along the entire west coast of South America as a continental-scale plate interface zone. This subduction zone is responsible for most of the great (M > 8) earthquakes and tsunamis that have struck the western coast of South America, both north and south of Perú.

COMPILER, AFFILIATION, & DATE OF COMPILATION: José Macharé, Newmont Perú, Limited, 1999; revised by Michael Machette, U.S. Geological Survey, 2002.

TYPE OF STUDIES: All studies are offshore, including seismic-refraction surveys.

GEOMETRY OF THE SECTION:

LENGTH: 2260 km

Comments: Subduction zone continues well south and north of Perú, along the coast of Ecuador and Chile. Length offshore of Perú is only a small portion of total length.

STRIKE: -23°±42 ° (N23°W±42°)

Comments: Subduction zone has variable strike, but generally parallels the west coast of South America.

DIP: Thrust, variable low angle to the east

SENSE OF MOVEMENT: Underthrusting to the east (landward)

Comments: This is the main subduction interface.

GEOMORPHIC EXPRESSION: The morphology of the trench is well expresed in the ocean-bottom bathymetry. Stress release during subduction interface earthquakes typically causes subsidence or uplift along the adjacent coastal regions, as in the 1906 Ecuador and 1960 Chile earthquakes (M.8 and 9.5 respectively), although onland surface ruptures from crustal earthquakes are not well documented.

RECURRENCE INTERVAL: Unknown

Comments: Although unknown, the extremely high-plate convergence rates suggest that large interface earthquakes (with several meters of slip) must occur over time intervals of tens to hundreds of years in Peru (see comments below).

SLIP RATE: >5 mm/yr

Comments: About 78 mm/yr (ENE-WSW) across the subduction interface as determined from Nuvel 1A plate-motion solutions (DeMets and others, 1994; see http://www.ldeo.columbia.edu/users/menke /plates2.html). In southern Perú, the Nazca plate is being subducted at a dip of about 30° (as cited in Fenton and others, 1995, p. 5.A-6)

TIME OF MOST RECENT MOVEMENT: Historic (2001)

Comments: The most recent major earthquake along the Nazca subduction zone offshore of Perú occured on June 23, 2001, but was not related to crustal faulting or surface rupturing onshore.

NAME OF EARTHQUAKE: Arequipa

DATE/FECHA: June 23, 2001

TIME: 9:33 GMT

Comments: 4:33 PM EDT (3:33 PM local time in Perú).

MAGNITUDE OR INTENSITY: M 8.4

Comments: Modified from the United States Geological Survey, National Earthquake Information Center (from http://www.eeri.org/earthquakes/Reconn/Arequipa_Peru/Arequipa.html). This major earthquake occurred near the coast of southern Perú, about 110 miles (175 km) west of Arequipa or about 370 miles (595 km) southeast of Lima. A revised magnitude of 8.4 was computed for this earthquake by NEIC. Several moderate aftershocks were recorded, the largest having a magnitude of 6.8. The focal depth was shallow, although an exact depth is problematic. This is because such a large area of the plate interface ruptured, making it difficult to assign a meaningful depth. At least 102 people werekilled, 1,368 wereinjured and extensive damage occurred in the Arequipa-Camana-Moquega-Tacna areas. In addition, at least 20 people killed and some missing from a tsunami in the Camana-Chala area.

REFERENCES

DeMets, C., Gordon, R.G., Argus, D.G., and Stein, S., 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, Geophyical Research Letters, v. 21, no. 20, p. 2191-2194.

Beck, S.l, and Ruff, L.J., 1989, Great earthquakes along the Peru trench: Physics of the Earth and Planetary Interiors, v. 57, no. 3-4, p. 199-224.

TABLE 1. QUATERNARY FAULTS OF PERÚ

[Unknown, probable slip rates shown by query (?)]

Fault number	Name of structure	Sense of movement	Time of most recent faulting	Slip rate category in mm/yr
PE-01	Amotape fault zone	Reverse	<1.6 Ma	<1 (?)
PE-02	Shitari fault	Sinistral	<15 ka	<1 (?)
PE-03	Chaquilbamba fault	Normal	Historic (1937)	<1 (?)
PE-04	Eastern Boundary fault	Normal	<15 ka(?)	1-5(?)
PE-05	Quiches fault	Normal	Historic (1946)	<1
PE-06	Cordillera Blanca fault zone			
PE-06a	Section A	Normal	<15 ka	<1
PE-06b	Section B	Normal	<15 ka	1-5
PE-06c	Section C	Normal	<15 ka	1-5
PE-06d	Section D	Normal	<15 ka	1-5
PE-07	Cayesh fault	Normal	<1.6 Ma	<1
PE-08	Huaytalpallana fault	Reverse, sinistral	Historic (1969)	<1 (?)
PE-09	Cuzco fault zone	Normal	Historic (1965 and 1986)	0.2-1
PE-10	Ocongate fault zone	Normal	<15 ka	0.2-1
PE-11	Vilcanota River (fault system)	Normal	<1.6 Ma	<0.2
PE-12	Trigal fault	Normal	<15 ka	0.2-1
PE-13	Solarpampa fault	Normal	<15 ka	0.2-1
PE-14	Machado Chico fault	Normal	<1.6 Ma	<0.2
PE-15	Pampa Huanocollo fault	Normal	<1.6 Ma	<0.2
PE-16	Cerro Cordilleras fault			
PE-16a	Northern section	Normal	<1.6 Ma	<0.2
PE-16b	Central section	Normal	<15 ka	<0.2
PE-16c	Southern section	Normal	<1.6 Ma	<0.2
PE-17	Unnamed fault west of Rio Moquequa	Normal	<1.6 Ma	<0.2
PE-18	Chololo fault	Normal	<15 ka	<0.2
PE-19	Cerro Loreto fault	Normal	<1.6 Ma	<0.2
PE-20	Chaspaya fault	Normal	<15 ka	<0.2
PE-21	Cerro Chascoso fault	Normal	<1.6 Ma	<0.2
PE-22	Altos los Chilenos fault	Normal	<1.6 Ma	<0.2
PE-23	Cerro Morrito fault	Normal	<1.6 Ma	<0.2
PE-24	Pampa Trapiche fault	Normal	<1.6 Ma	<0.2
PE-25	Toquepala fault			
PE-25a	Western section	Normal	<15 ka	0.2-1.0
PE-25b	Eastern section	Normal	<15 ka	0.2-1.0

TABLE 1—CONTINUED. QUATERNARY FAULTS OF PERÚ

[Unknown, probable slip rates shown by query (?)]

Fault number	Name of structure	Sense of movement	Time of most recent faulting	Slip rate category in mm/yr
PE-26	Micalaco fault	Normal	<1.6 Ma	<0.2
PE-27	Pampa del Purgatorio fault			
PE-27a	Western section	Normal	<15 ka	0.2-1.0
PE-27b	Eastern section	Normal	<15 ka	0.2-1.0
PE-28	Villacollo fault			
PE-28a	Northern section	Normal	<1.6 Ma	<0.2
PE-28b	Southern section	Normal	<1.6 Ma	<0.2
PE-29	Cerro Rocoso fault	Normal	<1.6 Ma	<0.2
PE-30	Cerro Caquilluco fault	Unknown	<1.6 Ma	<0.2
PE-31	San Francisco fault	Normal	<1.6 Ma	<0.2
PE-32	Peru-Chile trench (Nazca subduction zone)	Thrust	Historic (2001, many prior)	>5 (75-80)

Text Taken From Open-File Report 03-451 Map

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT OFR 03-451 Text accompanies map

Map of Quaternary Faults and Folds of Peru and Its Offshore Regions

International Lithosphere Program Task Group II-2,
Major Active Faults of the World

A cooperative project of the U.S. Geological Survey, Denver, Colorado and the URS Corporation. 2003

Relative Plate Motion
Source: Relative Plate Motion Calculator, Nuvel-1A Model; Kensaku Tamaki, Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano-ku, Tokyo, 164, Japan (tamaki@ori.u-tokyo.ac.jp)

Data compiled by Jose Machare, Clark Fenton, and Michael N. Machette.
Project coordination by Michael N. Machette (Co-chairman, •ILP Task Group II-2).Digital data prepared by Richard L. Dart with ARC/INFO version 7.2.1 running under Solaris version 2.6 on a Unix workstation. Last revision August 2003.
Map prepared by M.N. Machette and Margo Johnson using Adobe Illustrator version 10.0. Last revision November 2003.

This map is available as a PDF file at http:/cpg.cr.usgs.gov/pubs/ofrs/
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ILP Fault Maps and Open-File numbers
1. ARGENTINA 00-103
2. BOLIVIA 00-293, Plate1
3. BRAZIL 00-230
4. CHILE 00-283, Plate2
5. COLOMBIA 02-284
6. COSTA RICA 98-481
7. ECUADOR 02-284
8. PANAMA 98-779
9. PERU This Report
10. MANGUA, NI. 00-437
11. VENEZUELA 00-018