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Active Subsidence Controlled by Basement Structures in the Marañon Basin of Northeastern Peru

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ABSTRACT The Marañon Basin is located between the Brazilian shield and the Andean foothills. The southern part of the basin, called Ucamara depression, comprises large swamp and lakes, with more or less straight edges and nearly geometrical shapes. The Punga swamp is an historical example of tectonic related subsidence. Large swamps overlay structural blocks limited by faults, and uplifted or pulled down basement structures. The main trend of the swamps is related to the reactivation of basement faults. The implications for the regional geodynamic context are briefly discussed.

INTRODUCTION

The Marañon Basin in northeastern Peru is located between the Brazilian shield to the east, represented by the Iquitos uplands, and the Andean foothills to the west (Fig.1). The drainage area of the Marañon Basin is the largest of the Andean piedmont, extending from just below the Equator to near Lake Titicaca, over about 14º of latitude. This provides large water supplies from the Andes, concentrated in two large rivers, the Ucayali and the Marañon. The wet tropical climate generates heavy precipitation over the lowland areas of the basin, drained by a dense network of local rivers and extended wetlands. In the context of active subsidence, this region appears to be a good case-study of fluvial and wetland patterns in relation to neotectonics.

While neotectonic studies in uplifted areas are well documented and based on various basic methods (landform analysis, fault scarps and fault plane measurement), subsiding areas are poorly documented because current neotectonic methods do not apply. Neotectonic studies in the Amazonian Basin began probably with Sternberg's (1950, 1955) considerations on tectonic grain and river systems. In the western Amazonian regions, Rüegg (1952) mentions fold deformations in the late Tertiary lacustrine deposits, attributed to a Plio-Quaternary tectonic phase, which effect was supposed to be presently active. Later, Iriondo & Suguio (1981) pointed out the relative effect of tilting and subsidence over the Amazon River valley. In the Beni Basin of Bolivia, whose position is similar to that of the Marañon Basin, Allenby (1988) suggested the aligned, rectangular shaped lakes as controlled by an orthogonal fracture pattern propagated upward from the underlying granitic basement. Because of the lack of precise structural data for the basement, the Allenby's hypothesis remains speculative. The case provided here is based on closer relations between surface patterns observed on Landsat and SLAR images and basement structures interpreted from seismic data (Laurent & Pardo 1975; Laurent, 1985). We present here new data on the subsidence of the region, gathered through field studies.

GEOLOGICAL BACKGROUND

The Marañon Basin (Fig.1) has been mainly developed during Cenozoic. According to Laurent & Pardo (1975) and Laurent (1985), upper Triassic to Jurassic deposits exist only in the western part of the basin, and the Cretaceous deposits (Aptian-Maastrichtian) overlap eastward on the Paleozoic and crystalline basement. Thickness of post Jurassic sediments rises to 5000m in the central part of the basin (Sanz, 1974). But the more striking tectonic features of the basement are inherited from the Hercynian tectonics reinforced in part by the late Kimmeridgian phase. These features are represented by isolated horsts of crystalline basement or thin sedimentary cover overlain by Cretaceous deposits (from north to south, the Concordia, Samiria, Santa Elena and Santa Lucia uplifts). Transcurrent faulting is reported for the late Hercynian tectonics.

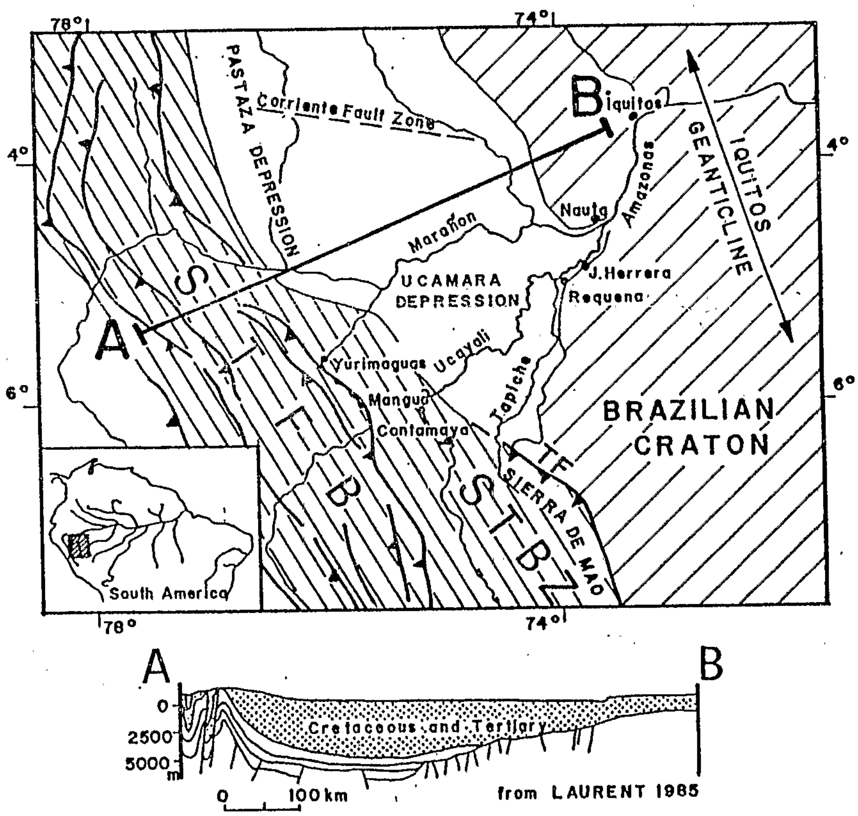

FIG. 1 Structural scheme of the Marañon Basin and surrounding areas. STFB: Subandean Thrust and Fold Belt and STBZ: Subandean Tilted Block Zone, TF: Tapiche fault. A-B, cross-section through the Marañon Basin, located on the structural scheme.

The subsidence of the basin was accompanied by positive tendencies in the Iquitos geanticline. During the late Tertiary the subsidence accelerated over the whole area and Mio-Pliocene deposits extended over the geanticline. During Mesozoic and Cenozoic the Andean foredeep basin was much more extended than now, longitudinally along the

Andean range of Peru and also laterally over the present foothills. The basin was reduced to its present extension as a result of the late Tertiary and early Quaternary tectonics in the Subandean Thrust and Fold Belt (Ham & Herrera, 1963; Pardo, 1982; Mégard, 1984), as well as in the subandean foreland of central Peru, which was completely uplifted as a result of tilted block tectonics (Dumont, 1989) related to the initiation of flat slab subduction beneath the Andes (Jordan et al., 1983). During these tectonic phases most of the Hercynian faults were reactivated, mostly in reverse motion (Laurent & Pardo, 1975; Laurent, 1985).

The present subsiding areas of the Marañon Basin are characterized by the occurrence of large swamps located from north to south along the Pastaza River, at the confluence of the Marañon and Huallaga Rivers (Laurent & Pardo, 1975), and over the southern part of the Marañon-Ucayali watershed area, known as the Ucamara depression (Villarejo, 1988). These areas of active subsidence fit approximately with the axis of the structural basin, which appears to be arcuate, trending N-S in the northern part and NW-SE in the southern (Sanz, 1974; Laurent & Pardo, 1975; Laurent, 1985).

THE UCAMARA DEPRESSION

The Ucamara depression (Fig.2) is extremely flat, drained by an intricate network of meandering rivers and permanent or semi-permanent swamps and lakes (Cabrera la Rosa,1943; Villerejo, 1988). The depression is subtily delimited on the north by the Marañon River (except in the lower Chambira and Tigre Rivers area) and on the west by the north-south branch of the Samiria River. While, the southern and eastern borders are sharp morphostructural boundaries formed by the Tapiche fault along the Sierra de Moa uplift and the bluffline at the margin of the Iquitos geanticline.

Three white water rivers cross the depression, from north to south respectively: the Marañon, the Ucayali and the Tapiche. Large swamps are located either along the course of the main rivers which cross them, or are located adjacent to the river courses.

THE MODERN RIVER REGIME

The annual rainfall average in western Amazonia is over 2000mm. Precipitation falls in all month of the year, but is heavier between January and May. As commonly occurs in Amazonian regions, the lowland drainages are separated into large white water rivers (silty water from the Andes and foothills areas) and smaller black water rivers (rain water high in organic acids, flowing out of the swampy areas).

The difference between high water level (January to May) and low water level (June to December) is up to 11m at Iquitos (García & SHNA, 1987) but decreases significantly westward: 9.5m in Jenaro Herrera on the border of the depression and of less than 2m in the Ucamara depression (personal observation). These differences are probably due to the weir effect of the Iquitos upland.

Very few and relatively imprecise topographic data are available for the area. According to the elevations of Iquitos (105m), Nauta (111m) and Requena (114m) (Ministerio de Guerra, 1984), the gradient for the Marañon and Ucayali rivers crossing the Iquitos geanticline is of about 0.06m km^{-1} (location on fig.3). Toward the Marañon Basin a similar mean gradient is found between Requena and Contamana (134m) along the Ucayali River. Data from Stiglish (1904) show a gradient of 0.04m km^{-1} between Mangua (present name Carolina) and Requena along the Ucayali River, through the Ucamara depression. Downstream from Iquitos to the sea, the Amazon River has a mean slope of 0.03m km^{-1}, the same value being mentioned by Baker (1978) between Manaus and the sea.

THE EXTENDED SWAMPS

The permanent swamps (Fig.2) are large flooded areas which are not directly related to fluvial landforms. Nevertheless, some flooded fluvial landforms like oxbow, swale, or part of channel may have been incorporated into the more extensive swamps. Three permanent swampy areas have been identified. The Chambira-Tigre (Concordia) swamp on the northern side of the Marañon River, the Puinahua swamp over the central part of the Puinahua channel, and the Punga swamp along the Tapiche River. All these swamps drain black water. When they are crossed by white water rivers, as the Punga swamp by the Tapiche River, white and black waters are separated by more or less wide fluvial levees.

The Chambira-Tigre (Concordia) swamp is located between the Chambira River westward and the Tigre River eastward, and extends about 25km to the north of the Marañon River. This area is characterized more by wetland forest than the deep swamps, represented by flooded fluvial landforms, such as ria type lakes.

The Puinahua swamp covers an area of about 25km by 60km, following the axis of the Puinahua Channel. Northeastward, the permanent swamps are discontinuous, with the flooded areas located around large oxbows. Southwestward, the swampy

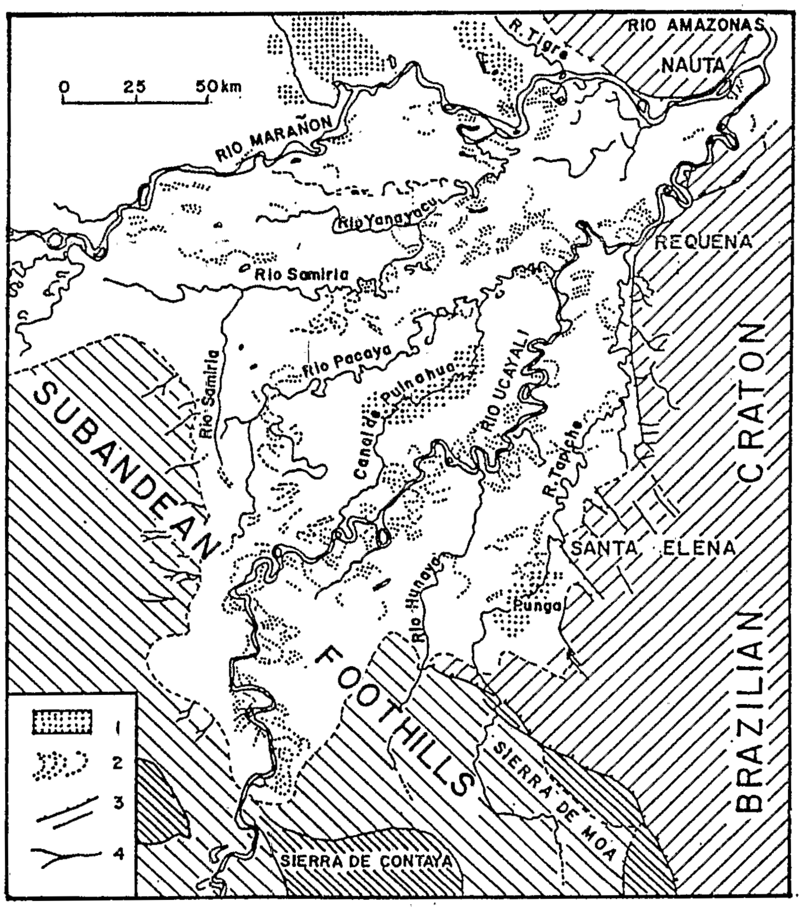

FIG. 2 Morphostructural scheme of the Ucamara depression: 1: Major swamp areas; 2: fluvial landforms (ridge and swale arrays); 3: morphological scarps; 4: Drainage in uplands.

areas are more continuous, and the relationships with fluvial landforms are obvious. While the northeastern limit of the Puinahua swamp is not clearly delimited, the southwestern limit is very distinct, and fits with a NNW-SSE trending line. The superimposition of the swamp over fluvial landforms suggest the first postdate the second.

The Punga swamp is rectangular shaped, 675km2, located between Santa Elena and Wicungo, on both sides of the Tapiche River (5 by 15km on the western side and 15 by 40km on the eastern). Stiglish (1904) described the area as an upland (bosque de altura), and convincing testimony supported by morphological observations suggest that the flooding of the area occurred about only 60 years ago. According to the testimony of two inhabitants (Arturo Pereira in Iquitos and Santiago Panduro in Santa Elena) the Punga area began to sink between 1927 and 1929, after some earthquakes occurred (Santiago Panduro, personal communication). The area was progressively flooded; settlers and Capanahuas Indians had to leave as each year the remaining dry land was reduced by flooding. According to travel accounts (Faura, 1964; Villarejo, 1988), the lower part of the tributaries of the Tapiche River (especialy the Loboyacu) were not completely flooded in the years 1930-1940. After an initial (relatively short ?), high rate of flooding, the present extension of the area was reached very progressively. All that remains of the forest are the tree trunks, preserved by the black water, and just rising above the low water level. The bases of the dead trees are presently under 2m of water during low flows. Estimates based on the present river bank (1.5m high) and the water level during high flows which overpass the levees of about 50cm, suggest a total subsidence of more than 4m.

We suggest that the flooding of the Punga is related to tectonic subsidence. We dismiss the hypothesis of flooding due to the rising of the base-level downstream, because this should have had flooded not only the Punga area, but also the watershed between the Tapiche and the Ucayali River which is barely higher than the high water level. Some change in the hydrographic network of the region resulted from the subsidence of the Punga. The valleys of the Loboyacu and Camungo Rivers, eastern tributaries of the Tapiche River, were completely flooded, and the Tapiche river migrated southward toward the center of the subsiding area. The Tapiche River is presently reconstructing its sedimentary channel through the Punga Swamp. The white, silty water of the Tapiche river is separated from the black water of the swamp by a levee 1m to 1.5m high and less than 5m wide, colonized in some places by a single row of Cecropia (trees of the pioneer stage of forest succession, Salo et al., 1986).

EVIDENCE FOR BASEMENT STRUCTURE CONTROL

According to Laurent & Pardo (1975), few deformations are reported from the Mesozoic and Cenozoic deposits in the Marañon Basin, but on the contrary, the pre-Mezosoic basement is divided in several faulted and uplifted blocks. A comparison between the scheme of the basement structures on one hand and the scheme of fluvial landforms and large swamps on the other suggest an active structural control over the surface landforms by the basement. The most striking cases will be reported here (Fig.3).

The Chambira-Tigre swamp is located over a generally depressed zone in the basement. The lower and upper Paleozoic zones are bounded by normal faults, of which a part was reversely reactivated during the late Tertiary (Quechua) tectonic phases. The western part of the swamp (Chambira River) overlays an area of horsts (e.g., the Concordia uplift) and deep grabens, with a general westward tilt which ends against the Patayacu horst zone. The western branch of the Concordia uplift has been reversely reactivated during late tertiary tectonic phase. The eastern part of the swamp (Tigre River) overlays a NNW-SSE deep, lower Paleozoic zone bounded by normal faults. To the north, the eastern faults were reversely reactivated recently. According to Laurent & Pardo (1975) the effect of the Quechua tectonic phase on the Marañon Basin

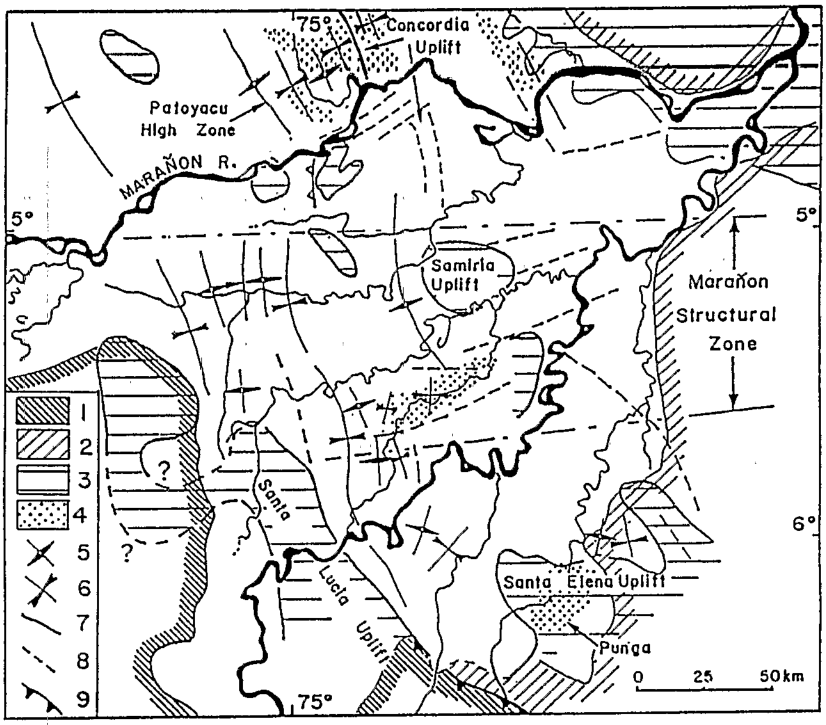

FIG. 3Sketch of the basement structures of the Ucamara depression, from Laurent (1985) and Laurent & Pardo (1975), completed with surface morphostructures: 1: Limit of the Subandean foothills. 2: Limit of the uplands of the Iquitos Geanticline. 3: Late Hercynian uplifts of crystalline rocks overlay by cretaceous deposits. 4: Major swamps. 5: Pre-cretaceous anticlines. 6: Pre-cretaceous synclines. 7: Basement fault reactivated during late Tertiary tectonic. 8: Pre-cretaceous basement faults. 9: Tapiche fault zone with post-Pleistocene uplift.

was characterized by differential vertical block motion.

The limit of the Punga subsidence fits relatively well with the northwestern part of the Santa Elena uplift defined in Laurent (1985). The structure of the Santa Elena uplift (Alto de Santa Elena) is interpreted as a crystalline horst surrounded by Paleozoic layers. The NNE-SSW direction of the Punga swamp is parallel to a few of the structural features reported by Laurent (1985), just northward and northwestward from the Santa Elena high zone. The position of the Punga swamp suggests that underlying block faults are still active in the basement. The NNE-SSW orientation of the Punga is sub-parallel to the "en echelon" system of the Marañon Fault Zone reported for the late Paleozoic (Laurent, 1985). The location of the present active subsidence just over an historically uplifted zone suggests an inverse recurrent motion of the probably normal or normal-transcurrent Paleozoic faults.

The Puinahua swamp is located within Paleozoic depressions limited toward the north, east and south by transcurrent faults in the basement. The western limit of the swamp, which is also the most evident, is defined by a fold belt parallel to the eastern border of the Santa Lucia Paleozoic uplift (Laurent, 1985). The case of the Puinahua swamp shows that the occurrence of Paleozoic faults in the basement determines the boundaries of the subsiding blocks.

The migration of the Ucayali River extends over an area characterized by NNE-SSW to W-E transcurrent late Paleozoic faults, related to the Marañon Fault Zone. On the contrary, the Marañon River which enters the basin through the northern part, flows through an structural depression located between the Marañon Fault Zone southward and the Corrientes Fault Zone northward. The common course of the Ucayali and Marañon Rivers during the Samiria stage, which corresponds to the limit of the area of extreme migration for each river, follows precisely on the belt of higher fault density, identified as the Marañon Fault Zone by Laurent (1985).

RELATIONS WITH REGIONAL TECTONICS

The geometrical relations between swamp and basement structures are not the same throughout the depression. On the north of the Marañon fault zone, swamp and basement structures are parallel to the main Andean structures (NNW-SSE). In the southern part of the depression, the direction of elongation of the swamps appears to be controlled by transverse structures, NE-SW to NNE-SSW, related to the Marañon fault zone.

The most active subsidence of the Marañon Basin occurs presently in front of the Subandean Thrust and Fold Belt (STFB) in the northern part of the basin, and extends southward in front of the northern part of the Tapiche reverse fault. This can be interpreted as a tendency of the present basin to extend toward southeast, along the preexisting Cretaceous axis of the basin that extended over the Pastaza-Ucamara-Acre areas.

The state of stress in the Ucamara depression is not known, but the case of the Punga swamp suggests that the basement is submitted to compressional stress. In our opinion this compression is weaker than that in Central Peru, where the whole Subandean foreland and Craton margin are submitted to uplift. The combination of a good compressional linkage in Central Peru and a weak one in Northern Peru may produce some adjustments in the Craton margin, like the normal faulting observed in the Iquitos Upland (Dumont et al., 1988). These faults of relatively small throw have a major control over the flood plain limits; they may be interpreted as superficial and small scale neotectonic joint generation (Hancock & Engelder, 1989). The faulting tectonic is contemporaneous with the rising of the Iquitos Upland during Quaternary. Increasing tectonics lead to a more active subsidence of the foredeep, as well as positives tendencies of the craton margin (rebound effect). A dam effect resulted, and caused the merging of all the drainages comprising the Marañon Basin toward only one exit, giving rise to the Amazon River.

CONCLUSION

In the actively subsiding Ucamara depression, relations between large swamps and basement structure is obvious. Some cases are clearly related to Hercynian structures and faults inversely reactivated during late Tertiary and Quaternary tectonic phases. Other cases are less evident, but most probably related to inverse or transcurrent reactivation of basement structures, although the transmission of the deformations through the sedimentary column is not observable on the present structural documents.

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