Fluvial shifting in the Ucamara Depression as related to the neotectonics of the Andean foreland Brazilian Craton Border (Peru)

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Abstract: *Active and abandoned fluvial landforms observed on the present day surface of the Ucamara Depression (southern part of the Marañón Basin) have been studied, using SLAR and Landsat Imagery, and field control. The rivers showing active meander belts (Marañón, Ucayali and Tapiche) are drained by white (silty) water from the Andes. Watersheds are drained by black water (from organic acids) streams with underfit patterns like the Samiria and Pacaya rivers. The underfit pattern is interpreted as the abandonment of formerly active large streams of white water. The position in the depression of the black water streams suggests successive shiftings of the Marañón River and Ucayali River respectively northward (50 km) and southeastward (75 km) during recent times, probably the Holocene. The geodynamical environment of the Ucamara Depression suggests a close relation between the recent tectonic activity and the successive shifting of the Marañón and Ucayali Rivers.*

Key words: Peru - Marañón Basin - Ucamara Depression - River shifting - Underfit river - Neotectonics.

Résumé : **Changement du cours des rivières dans la dépression Ucamara, en relation avec la néotectonique de la limite entre Subandin et Craton brésilien (Pérou).** *Les morphologies fluviales actives et fossiles visibles à la surface de la dépression Ucamara (partie sud du bassin du Marañón) ont été étudiées à partir d'images SLAR, Landsat et d'observations de terrain. Les rivières correspondant à des ceintures de méandres actives (Marañón, Ucayali et Tapiche) drainent des eaux blanches (silteuses) provenant des Andes. Les interfluves sont drainés par des cours d'eaux noires (acides organiques) comme les rivières Samiria et Pacaya et montrent des caractéristiques de sous-adaptation* (underfitness) *interprétées comme résultant de l'abandon de larges rivières d'eaux blanches. La position dans la dépression des cours d'eaux noires suggère des avulsions successives du Marañón et de l'Ucayali, respectivement vers le nord de 50 km et vers le sud de 75 km, durant la période récente, probablement au cours de l'Holocène. Le contexte géodynamique dans lequel se trouve la dépression Ucamara suggère d'étroites relations entre l'activité tectonique récente et les avulsions successives du Marañón et de l'Ucayali.*

Mots clés : Pérou - Bassin du Marañón - Dépression Ucamara - Avulsions - Cours d'eau sous-adaptés - Néotectonique.

Resumen : **Cambio del curso de los ríos en la depresión Ucamara en relación a la neotectónica del límite de la Zona Subandina con el Craton Brazileño (Peru).** *El estudio de la morfologia fluvial de la depresión Ucamara, parte Sur le la Cuenca del Marañón, ha sido hecha con imágenes SLAR, Landsat y controlado por estudios de campo. Los ríos con migración de meandros activos (Marañón, Ucayali y Tapiche) son de aguas blancas (con silts) proveniendo de los Andes. Las zonas interfluviales son drenadas por ríos de aguas negras (por ácidos orgánicos), los cuales como los ríos Samiria y Pacaya muestran morfologías fluviales subadaptadas* (underfitness),

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interpretadas como cursos antiguos de ríos grandes de agua blanca, actualmente abandonados. La posición de los ríos de aguas negras supone una sucesion de avulsiones laterales de los ríos Marañón y Ucayali, respectivamente al Norte de 50 km y al Sur de 75 km durante el periodo reciente, probablemente desde el Holoceno. Según la geodinámica de la zona se puede establecer una relación estrecha dentro de la actividad tectonica reciente y los cambios de cursos sucesivos de los ríos Marañón y Ucayali.

Palabras claves : Perú - Marañón Basin - Depresión Ucamara - Avulsíon - Rio subadaptado - Neotectónica.

INTRODUCTION

The present day Marañón Basin constitutes the foredeep transition zone between the cratonic Brazilian shield eastward, and the Andean range (Fig. 1) pushed relatively eastward by the subducting Nazca plate. The drainage area of the Marañón Basin is probably the largest of the Andes, extending from just below the Equator to near Lake Titicaca, over about 14° of latitude. The shape of the drainage basin is asymmetrical and elongated toward south due to the longitudinal drainage of the Ucayali River along the piedmont foothills. This feature results from the late Tertiary tectonic activity in the Subandes (STEINMANN, 1930 ; RÜEGG and FYFE, 1950 ; KOCH, 1959 ; PARDO, 1982 ; MÉGARD, 1984), and especially from the Plio-quaternary deformation in the lower Subandean regions of Central Peru (DUMONT, 1989) which canalize the Ucayali River along the Andean range toward the Marañón Basin leading to a high concentration of large rivers in the Marañón Basin.

Neotectonic studies in the Amazonian Basin using river patterns are not new, although the topic has been emphasized during recent years. STERNBERG (1950, 1955) determined relations between tectonic grain (direction of mountains and faults), and river system. More recently, IRIONDO and SUGUIO (1981) pointed out the relative effect of tilting and subsidence over the Amazon River valley. RÄSÄNEN *et al.* (1987) investigated the extensive Marañón — Ucayali — Madre de Dios Amazonian areas, and suggested large overturning of flooded and non-flooded areas during Quaternary over the whole Amazonian lowlands of Peru, as a result of long term Subandean tectonics. But neither the tectonic style is investigated, nor its relation to river behaviour, that lead to overestimate the river migration

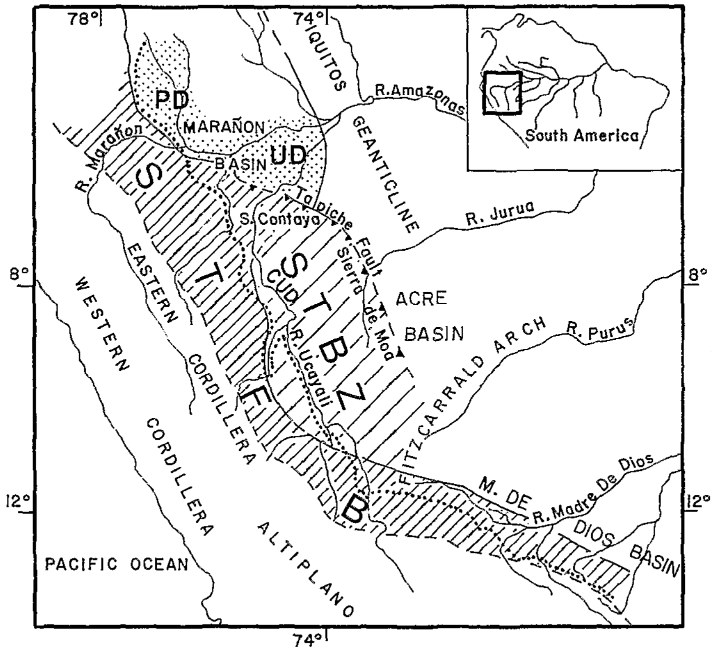


Fig. 1. — Structural scheme of the Subandean regions of Peru. STFB: Subandean Thrust and Fold Belt; STBZ: Subandean Tilted Block Zone; UD: Ucamara Depression; PD: Pastaza depression; CUD: Central Ucayali depression; Dotted line: 500 m elevation line.

Schéma structural de la zone subandine du Pérou : STFB : Zone subandine de plis et chevauchements ; STBZ : Zone subandine de blocs basculés ; UD : dépression Ucamara ; PD : dépression Pastaza ; CUD : dépression de l'Ucayali central ; le pointillé indique la courbe de niveau de 500 m.

by point bar processes. An example of detailed neotectonic studies of subsiding basin using fluvial landform has been done by MIKE (1975) in the Hungarian Basin. The methodological approach in this paper follows MIKE'S study.

This study is based on detailed observations on fluvial landforms of the southern part of the Marañón Basin, as related to the geodynamic environment. An overlook of the area has been made using SLAR imagery taken between July and December 1972, the low water stages (Petroleos del Peru, 1973), and a false color mosaic of Landsat images at the same scale (ONERN, 1975). The regions visited for field studies are the Marañón River between Iquitos and Concordia, the Chambira River, the Ucayali between Iquitos and Requena, and the Tapiche River up to the Sierra de Moa foothills. The data have been synthetized on a morphostructural scheme showing present and fossil fluvial landforms. An interpretation of river dynamics has been made using river stability parameters (DURY, 1970).

GEOLOGICAL BACKGROUNG

The **Marañón Basin** (Fig. 1) began subsiding during early Cretaceous, accumulating up to 5,000 m of post Jurassic sediments in the central part of the basin (SANZ, 1974). 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 (PARDO, 1982 ; MÉGARD, 1984 ; DUMONT, 1989). The present subsiding areas of the Marañón Basin are characterized by the occurrence of large swamps located from north to south along the Pastaza River, at the confluence of the Marañón and Huallaga Rivers (LAURENT and PARDO, 1975) and over the Marañón - Ucayali watershed area in the southern part, known as the Ucamara depression (VILLAREJO, 1988). Historical subsidence of the Santa Elena-Wicungo area along the Tapiche River (DUMONT and GARCIA, 1991) allows to extend southward the Ucamara depression up to the Tapiche River. The areas of active subsidence of the Marañón basin fit approximatively 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 and PARDO, 1975 ; LAURENT, 1985).

Tectonic differences along the **Subandean foothills** (the western border of the foredeep basins) originated the present distinctive Quaternary basins, which are successively from north to south, the Marañón (Pastaza and Ucamara depressions), Acre and Madre de Dios basins in foredeep position and the central Ucayali depression on the back side of the Subandean Tilted Block Zone in the foreland (STBZ, Fig. 1), (DUMONT *et al.*, 1991). The Marañón and the Madre de Dios basins are presently subsiding, but the Acre basin presently shows an upland topographic expression thought to be more recent than 2,800 yr B.P. .(FRAILEY *et al.*, 1988). In consequence the foredeep Marañón Basin is presently isolated, and surrounded by more or less high topographic areas.

The **Iquitos geanticline** (Fig. 1) forms the eastern border of the Marañón basin. It expresses positive tendencies at least since the early Mesozoic (SANZ, 1974 ; LAURENT, 1985), but the area sank during the late Tertiary and 500 to 600 m of cohesive silt, clay and peat of the Pebas Formation (Mio-Pliocene) were deposited (SOTO, 1979). The brackisch or freshwater lake deposits of the Pebas Formation (RÜEGG and ROSENZWEIG, 1949 ; Radambresil, 1977) are probably contemporaneous with the ultimate period of Andean tectonic quiescence, which occurred between 7 and 2 Ma B.P. (SÉBRIER and SOLER, 1991). The Pliocene subsidence ended as a result of the early Quaternary tectonic events, which may be correlated with the 2 Ma tectonic events (SÉBRIER and SOLER, in press). The Ipururo Formation overlays the Pebas Formation with 5 to 10 meters of fluvial gravel, sand, silt and clay. This sudden change in the lithology of the deposits may be attributed to Plio-quaternary tectonics, but also to climatic changes (DUMONT and GARCIA, 1989).

Late Pleistocene fluvial deposits crop out in the Jenaro Herrera area, along the southern bluffline between the Ucayali floodplain and the Iquitos upland (DUMONT *et al.*, 1988). This shows that the raising of the Iquitos geanticline was active during the late Pleistocene.

THE MODERN REGIME OF RIVERS

The annual rainfall average in western Amazonia is over 2,000 mm. Precipitation falls in all months of the year, but is heavier between January and May. As commonly occurs in Amazonian regions, the lowland drainages are separated here 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).

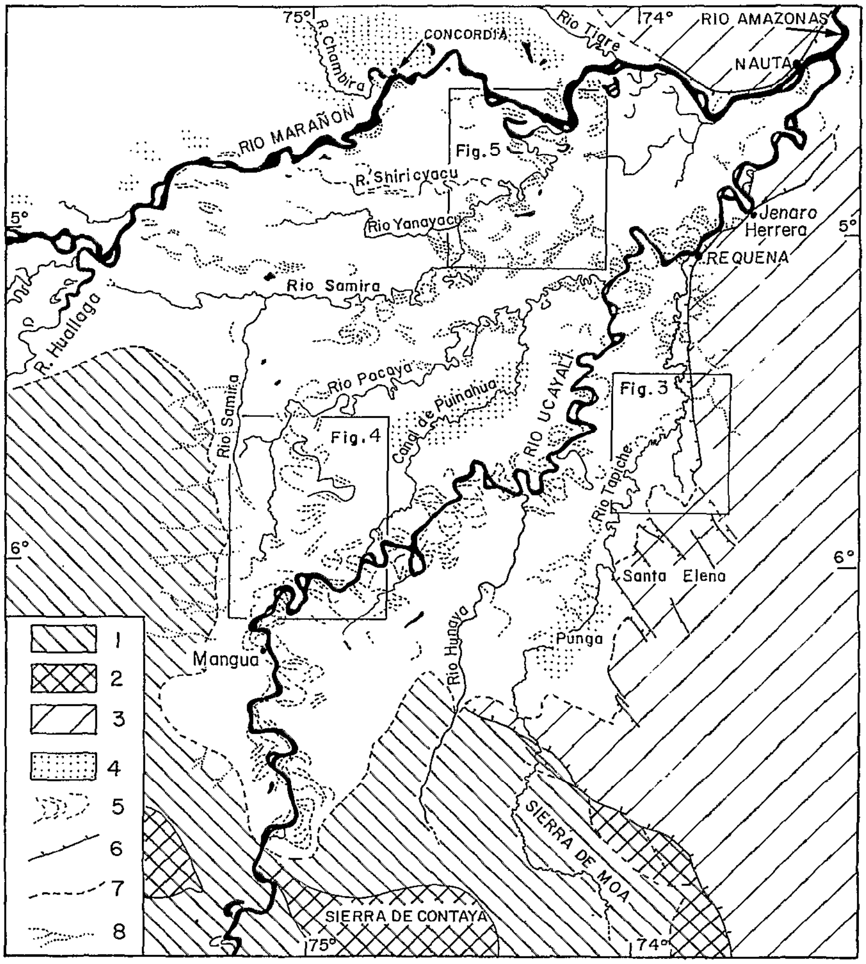


Fig. 2. — Morphological scheme of the Ucamara Depression. 1: Subandean foothills; 2: high morphology of the Subandean lowlands; 3: uplands of the Iquitos geanticline; 4: major swamp areas; 5: abandoned fluvial landforms (ridge and swale arrays); 6: morphological scarps related to faults; 7: smooth morphological limits; 8: drainage in uplands.

Schéma morphologique de la dépression Ucamara. — 1 : Collines subandines ; 2 : parties de reliefs élevés dans la zone subandine basse ; 3 : terres hautes du géanticlinal d'Iquitos ; 4 : grandes zones marécageuses ; 5 : morphologies fluviales abandonnées ; 6 : escarpements morphologiques assimilés à des failles ; 7 : limites morphologiques douces ; 8 : drainage des reliefs.

The difference between high water level (January to May) and low water level (June to December) is up to 11 m at Iquitos and in the foothills, but is lower, about 2 m, in the Ucamara Depression. According to GIBBS (1967), the annual discharge of the Ucayali and the Marañón Rivers is respectively of 0.301 . 10^{12} m^3 . yr^{-1}, (9,544 m^3 . s^{-1} mean rate) and 0.343 . 10^{12} m^3 . yr^{-1}, (10,876 m^3 . s^{-1} mean rate), lower than the respective calculated values of 12,600 m^3 . s^{-1} and 15,600 m^3 . s^{-1} from Unesco (1980). This gives a mean flow rate at the Amazon's origin at Iquitos of 20,420 m^3 . s^{-1} (GIBBS, 1967) to 28,200 m^3 . s^{-1} (Unesco, 1980), bigger than Missisipi River at its mouth. The relative drainage basin of the two rivers is quite similar according to GIBBS (1967), respectively 406 . 10^3 km^2 and 407 . 10^3 km^2, but the respective datas, 375 . 10^3 km^2 and 350 . 10^3 km^2, from Unesco (1980), suggest that the Ucayali Basin is more extended toward regions of minor precipitation. The depth of the main channel is from 10 to 20 m during low flows, with respective river width changing from 3 km to 1.5 km. Suspended load during high flows at Iquitos is of 0.46 g . l^{-1}. Most bank deposits are made of silts and very fine sands. Coarse sand deposits, recovered from the main channel at depths of 15 to 18 m or from the up-stream point of bar deposits, rises to 5 mm in size (personnal observation).

Very few and relatively imprecise topographic data are available for the area. According to the elevations of Iquitos (105 m), Nauta (111 m) and Requena (114 m) (location in Fig. 2), (Ministerio de Guerra, 1984), the gradient for the Marañón and Ucayali Rivers crossing the Iquitos geanticline is of about 0.06 m . km^{-1}. Data from STIGLISH (1904) show a gradient of 0.04 m . 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 0.035 m . km^{-1} (calculated for a 105 m elevation in Iquitos), a value of 0.03 m . km^{-1} being mentioned by BAKER (1978) between Manaus and the sea.

THE UCAMARA DEPRESSION

The Ucamara Depression (Fig. 2) is an intricate network of white water rivers running down from the foothills and black water rivers draining permanent or semi-permanent swamps (CABRERA LA ROSA, 1943 ; VILLAREJO, 1988). The depression is subtly delimited on the north by the Marañón River (except in the lower Chambira and Tigre Rivers area which belongs to the depression) and on the west by the north-south branch of the Samiria River. While, the south and east 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.

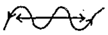
Three white water rivers and two black water rivers cross the depression. The white water rivers are from north to south respectively : the Marañón, the Ucayali and the Tapiche Rivers and the black water rivers are the Samiria and Pacaya Rivers.

The **Marañón River** flows from west to east, first across the northern part of the Marañón Basin, and then along the northern border of the Ucamara Depression. Downstream of the Huallaga-Marañón confluence, the channel pattern changes from anastomosed to mixed (anastomosed-meandering). The river width varies from 1,000 m to 2,500 m, with numerous islands located in channel curves as well as in straight parts. Curve radius ranges from 2 km for close meanders, up to 7 km for the mean of largest curves. Several straight portions of the river course are more than 20 km long. Sinuosity (ratio of the length of the channel in a given curve to the wavelength of the curve) is of 1.33 (tabl. I), that is close to the standard limit between anastomosed and meandering channels according to LANGBEIN and LEOPOLD (1966). The low sinuosity and close to anastomosed pattern of the Marañón River is probably related to the hydrodynamical characteristics, such as a flow rate 14 % higher than that of the Ucayali (GIBBS, 1967) and possibly a higher slope.

The present river belt, which is the area affected by active river migration and characterized by well preserved fluvial landforms (ridge and swale arrays, abandoned river reaches), is relatively narrow, up to 10 km in the sinuous parts of the reach. A 16-year survey of a meandering part has shown a relative stability of the straight channel parts, but an erosion of up to 20 m a year of the concave river banks in the major curves (CAMPOS, 1980).

TABLEAU I

Geometrical characteristics of the rivers, discussed in the text (n. obs = no observed).
Caractéristiques géométriques des rivières, discuté dans le texte (n. obs = non observé).

	MARAÑON	UCAYALI	PUINAHUA	TAPICHE	SAMIRIA/PACAYA
Sinuosity 	1.33	1.94	1.65 - 2	2.33	2.53
Wavelength (L =km)		7 - 11	2.5 - 4	1 - 2.5	1 - 3
L / W		9 - 14	10 - 15	8 - 11	30 - 50
Curve radius (km)	2 - 7	2.5	0.7 - 2	0.5 - 0.8	0.5 - 3
Meander amplitude (km)	5 - 7	8 - 17	2.5 - 5	1.5 - 3.4	2 - 10
Meander belt width (km)	10	30	n. obs.	n. obs.	n. obs.

The **Ucayali River** flows northward along the Subandean foothills of Central Peru, and turns sharply toward NE entering the Ucamara Depression. The channel width changes from 500 m in meander inflexions up to 1,250 m in meander curves. The mean sinuosity is of 1.94 (Tabl. I), characterized by well developed and symmetrical meanders of 2.5 km mean radius and 8 to 17 km amplitude (distance between two successive concave banks orthogonally to the river valley), which make the Ucayali River a caracteristic meandering river. Ratios of meander wavelengths to channel width (L/W) are between 9 and 14, the normal range for stable meandering channels being 8 to 11 according to BAKER (1978). This is interpreted as an underestimation of channel width due to measurements during low water stage.

The present meander belt is about 30 km wide characterized by very clear ridge and swale array patterns and abandoned meander loops (oxbows). According to LAMOTTE (personnal communication) the mean periodicity of building and abandonment of a point bar ridge in the area of Jenaro Herrera is about 4 years, measured along a 1,000 m ridge-swale array section built-up in 30 years.

Important change in the river channel can be noted comparing a 1972 SLAR image and 1975 Landsat imagery, both made during low water stage. River bank erosion of the terrain between the two meander loops led to abandonment of the Yanayacu meander by a neck cut-off. Comparative ratio of relatively stable parameters like wavelength (W_{1972}/ W_{1975}) and other quickly changing parameters like meander loop amplitude (A_{1972}/ A_{1375}) indicate an erosion of concave river banks of up to 40 m . yr^{1}.

The **Puinaha Channel** is a narrow secondary branch of the Ucayali River along its northern side. The sinuosity changes from 1.65 to 2 in the lower part, with mean curve radius of 1 km (Tabl. I). In these parts the ratio L/W changes from 10 to 15, which is close to the value for a stable channel (8-11). In up-stream part of the channel, meander wavelength are greater, with a ratio L/W ranging from 28 to 50. According to BAKER (1978) the Puinahua may be interpreted as an underfit stream, which is defined as a stream which was previously more important, and whose hydrological characteristics were reduced notably due to climatic change or shifting of the main stream. Similar patterns are present all along the Puinahua Channel, but are more or less clear because they are partly covered by extended swamp.

The **Tapiche River** is a white water river which drains the northern border of the Sierra de Moa, and enters the Ucamara Depression by crossing the Tapiche fault. It then runs northward, along the eastern margin of the depression. Inside the depression the Tapiche River is meandering, showing irregular meander loops (Fig. 3), most of compound asymmetrical type according to the classification of BRICE (1974). Width is relatively constant, changing from 100 m (lower part) to 70 m (upper part). Sinuosity ratio is of 2.33 (tabl. I), with mean radius of curves changing from 750 m (downstream of Rio Blanco) to 500 m (upperstream), with respective mean meander amplitude of 1,875 m and 1,000 m. The L/W ratio falls into the range for stable river channels (8-11). Meander migration is relatively slow, as point bar deposits are very regularly accumulated on stepped slopes (up to 35 degrees dip). This is confirmed by villages settled on the border of concave rivers banks for more than 20 years (i.e. Santa Elena, Fig. 2). This suggests a river migration rate less than 0.5 m . yr^{1}.

Several meanders with high sinuosity and short wavelength follow a longer wavelength (Fig. 3). The long wavelength is reported to fossil landforms, and the short one to the present underfit stream.

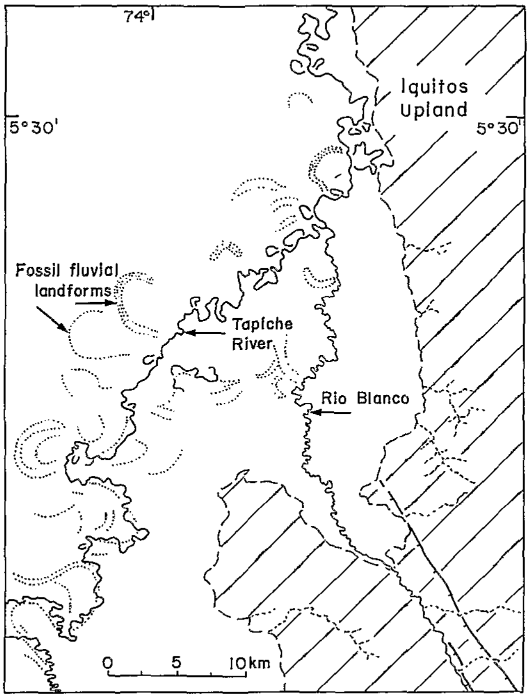


Fig. 3. — Fluvial landforms of the lower Tapiche area, commentary in text (location on fig. 2).

Morphologies fluviales de la région du bas Tapiche, commentaire dans le texte (localisation fig. 2).

Wavelengths of the fossil fluvial landforms are similar to those of the present Ucayali River, with 10 to 12 km meander amplitude, more than 2 km radius curvatures, and partly infilled oxbows up to 500 m width. Small fluvial structures like ridge and swale arrays are less clear. This is probably due to their relatively ancient age, an hypothesis which is supported by the relatively long and steady evolution of the present underfit stream.

The **Samiria** and **Pacaya** black water **Rivers** are very small streams if compared to the Marañón and Ucayali. They cross over the central part of the Ucamara Depression, following parallel directions first northward along the easternmost Andean relief of the Ucamara-Huallaga interfluve, and then turning abruptly eastward to cross the depression. Although they are partly fed by small tributaries running down from the low subandean relief of the Ucamara-Huallaga interfluve, their water supply comes principally from rainwater accumulated in lowland areas. The very channels of the rivers are not easy to follow, and controversy exists on maps as to the exact position of the main channels as well as to the positions and number of their tributaries (VILLAREJO, 1988). During high flows, several fluvial connections cross the watershed between the Marañón and Ucayali rivers (STIGLISH, 1907 ; VILLAREJO, 1988, and testimony from settlers). SLAR and Landsat imagery revealed that most of these temporary streams follow fossil fluvial landforms.

The Pacaya and the Samiria Rivers have very similar patterns. In the upper Samiria River (Fig. 4), the sinuosity is 2.53, with a 7 to 12 km meander wavelength, and amplitudes of 5 to 15 km. The L/W ratio ranges from 30 to 50, which means the channel is underscaled according to the meanders. DURY (1970) has named this variety an "Osage-type" underfit stream. According to BAKER (1978) "such streams supposedly suffer a reduction of channel forming discharge in such a way that channel width and pool-and-rifle spacing adapt to the change, but meander wavelength does not". The most intricated areas of the Ucamara Depression where the very channel is difficult to follow clearly resulted from the preservation of two or more Osage-type underfit streams, probably due to cut-off or local shifting just before the flow rate was reduced to the present one. The process probably occurred suddenly because no transitional state can be observed between the large wavelength meandering state and the present Osage-type pattern.

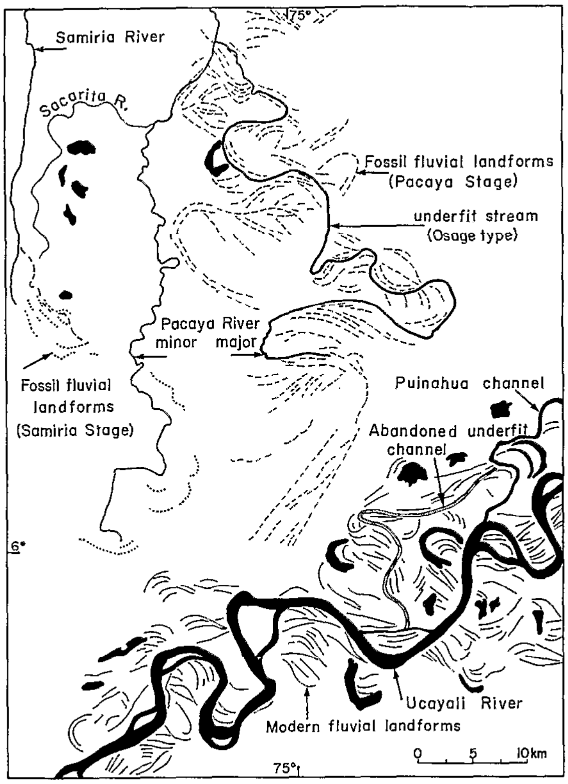


Fig. 4. — Fluvial landforms of the upper Samiria and Pacaya Rivers area, commentary in text (location on fig. 2).
Morphologies fluviales de la région du haut Samiria et haut Pacaya, commentaire dans le texte (localisation fig. 2).

The Pacaya River is about 140 km long. Its originates 20 km northward of the elbow the Ucayali makes entering the Ucamara Depression (Fig. 4), and joins the Puinahua channel about 30 km before merging with the Ucayali River. The uppermost part of the Pacaya River is drained by numerous underfit tributaries. The Sacarita River originates 2.5 km east of the Samiria River, and the Pacaya Minor originates only 10 km north of the Ucayali River. The Pacaya Major, or Pacaya, is the principal stream, surrounded by the more clear, large fluvial landforms. The occurrence of fluvial landforms in the area between the Ucayali River belt and the uppermost reaches of the Pacaya River suggests that a link formerly existed between the two fluvial systems. The old fluvial landforms along the Pacaya River belt are similar in scale and type to the present landforms of the Ucayali River belt, but less preserved. This strongly suggests that the Ucayali River previously flowed straight northward, through the Pacaya River valley. If this is true abandonment and underfitness of the Pacaya River valley is due to shifting of the Ucayali River toward southeast.

The 200 km long Samiria River originates very close to the Pacaya River (Fig. 2), and flows first northward before turning east to join the Marañón River. The up-stream part is surrounded by large fluvial structures (some oxbows, and more or less rounded oxbow lakes) which are less clear than those of the next neighbouring Pacaya River belt (Fig. 4). The down-stream part flowing toward the east shows more clear fluvial landforms, similar in scale to those of the Ucayali River belt (Fig. 5). On Landsat images this W-E portion of the Samiria River extends far westward, along a tributary which originates near the Marañón River. Abandoned fluvial landforms of large scale appear in this area, suggesting a former link between the Samiria and the Marañón River along this tributary.

Observation of fossil landforms from a large river along the Yanayacu and the Shiricyacu Rivers, northern tributaries of the Samiria River which originate close to the Marañón River (Fig. 2), suggests other links between the Samiria River and the Marañón River, probably successively spread out in time from SW to NE according to the less erased erosional patterns in that direction. The link of the Samiria River upstream with the Ucayali River (southward) and downstream with the Marañón River (northward) suggests that the Ucayali and the Marañón rivers historically joined on the western border of the depression, and that this junction migrated eastward as a result of successive shiftings.

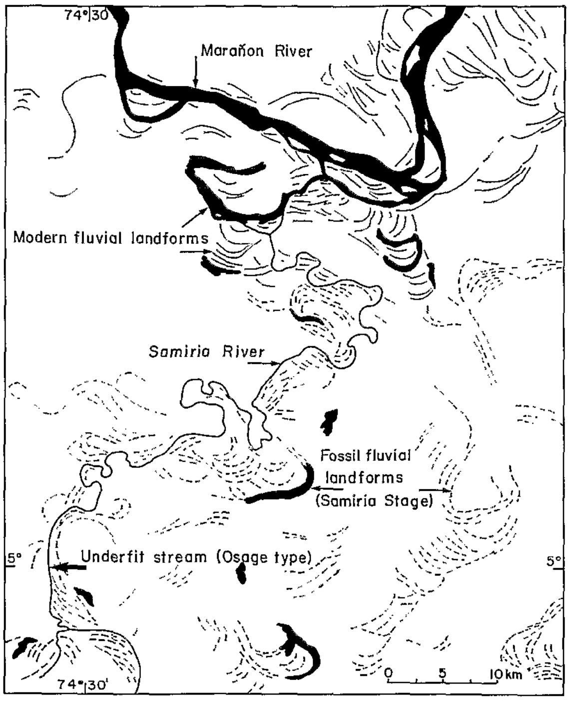


Fig. 5. — Fluvial landforms of the lower Samiria River area, commentary in text (location on fig. 2).

Morphologies fluviales de la région du bas Samiria, commentaire dans le texte (localisation fig. 2).

DISCUSSION

Successive shiftings on the Ucayali and Marañón Rivers

The observation of underfit streams and fossil river belts suggests successive migrations of the Ucayali and Marañón Rivers, from a previous **Samiria stage** (Fig. 6b) up to the present position (Fig. 6e), with successive occupation of the Pacaya (Fig. 6c) and Puinahua (Fig. 6d) courses. We will leave on the side the case of the **Tapiche stage** (Fig. 6a), which is probably the oldest stage identified here. The limits of this old meander belt are hardly visible, and its relation with the more recent stages is not clear. The Samiria stage (Fig. 6b) is characterized by a south to north flow of the Ucayali River along the western border of the Subandean foothills, joining the Marañón River close to the present Marañón-Huallaga confluence. The successively more recent **Samiria, Pacaya** and **Puinahua stages** are inferred from paleo-meander belts, and unidirectional migration evidenced from successively better preserved fossil fluvial landforms, as the ridge and swale patterns are less erased by erosion and forest colonisation. The meander belt of the Samiria stage is irregularly and scarcely preserved. The Pacaya belt is moderatly preserved, but is continuous and clearly delimited. The Puinahua belt is well preserved. Uncertainties exist, but they are limited and do not affect the general succession of identified stages. Some uncertainties are due to the migration of the rivers inside their meander belt (for example, the alternate channels during Samiria and Pacaya stages on fig. 6b, 1 and 2). Other uncertainties exist in the northeastern part of the depression, close to the exit, due to a high density of fluvial landforms in a relatively limited area, which makes it very difficult to identify the successive stages. Observations of better quality, or more detailed satellite imagery, could probably help to separate successive stages of river belt. Nevertheless, the principal results noted in the central and western part of the depression will not be affected.

The successive shiftings of the Ucayali River, each of 15 to 30 km, total a displacement of about

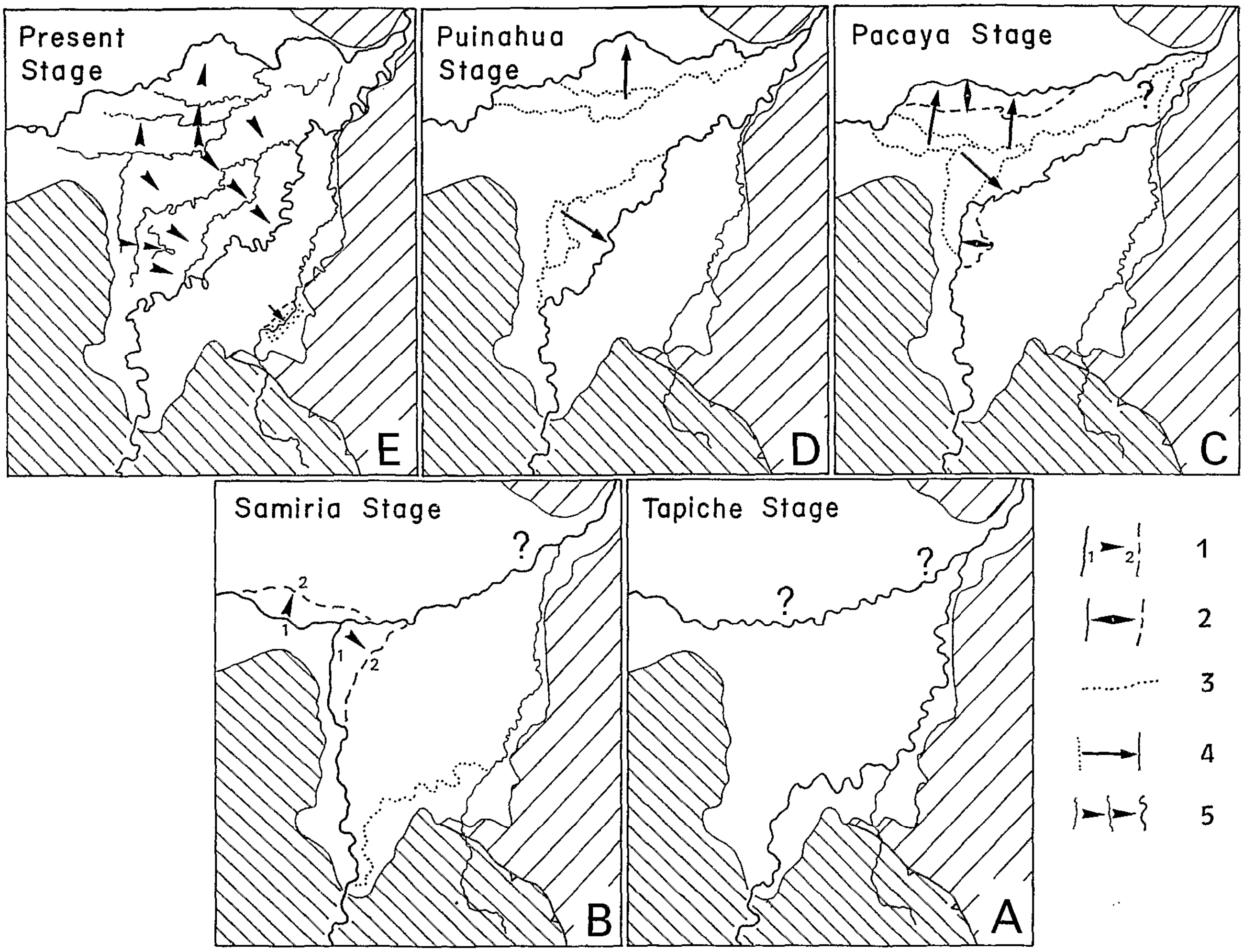


Fig. 6. — Successive positions of the Ucayali and Marañón Rivers, from the oldest identified stage (A) to the present (E). 1: Probable successive substages; 2: uncertainties of position during a stage; 3: river position during the preceding stage; 4: direction of migration from the preceding stage; 5 (E): direction of successive shiftings since the B stage.

Positions successives de l'Ucayali et du Marañón, depuis le stade le plus ancien (A), jusqu'à l'actuel (E). 1 : Succession probable de positions intermédiaires ; 2 : incertitudes de position ; 3 : position au stade précédent ; 4 : direction de l'avulsion ; 5 : stade (E), rappel des avulsions successives.

75 km toward the southeast. A correlative, but less important (about 50 km), northward migration of the Marañón River occurred, with successive occupations of the Yanayacu and Shiricyacu rivers belts.

We have established a precise timing for these migrations. The high terraces on the border of the Iquitos upland predate the modern subsidence (DUMONT *et al.*, 1988). Based on radiocarbon dating of the terraces, the identified stages of river migration, except perhaps the Tapiche stage, are more recent than 13,000 yr B.P.

Two hypothesis are proposed to interpret the successive shifting of the Ucayali River. The first hypothesis compares the migration of the Ucayali River to an alluvial fan deposit building at the exit of the Subandean zone toward the Ucamara Depression. This large fan deposit should fit with a drop in the transport energy (i.e. a lower slope). Unfortunately, morphological data on river slope as well as the few available hydrographical data are not enough to support or discard this hypothesis. One can only argue that no significant change in the Ucayali River pattern appears between the Pucallpa/ Contamana area (in northern Subandean zone) and the Ucamara Depression to support this hypothesis.

The second hypothesis relates migration to neotectonics. The historical flooding of the Punga (DUMONT and GARCIA, in press), along the Tapiche River, suggests that the subsidence is presently more active in the southeastern tip of the depression than in the northern part. According to settlers, overflow captures during high flows occur from the Ucayali toward the Tapiche rivers. The Puinahua Channel seems to be in course of abandonment according to ancient reports on fluvial navigation (VILLAREJO, 1988) ; some sections of the channel have recently been dredged in order to maintain their fluvial navigation capacities. However, all these data jointly give the Ucayali River a striking and — for the recent period — continuous trend of shifting toward the southeastern tip of the depression.

Tectonic control on river shifting

Figure 7 synthetizes the geodynamical environment of northeastern Peru. ASSUMPÇAO and SUAREZ (1988) interpreted teleseismic data from an earthquake located in the southern part of the Iquitos geanticline, 300 km eastward of the Tapiche fault, as a NE-SW shortening (Fig. 7, n° 1). Along the Tapiche fault, the late Tertiary Red Beds are folded along NW-SE axis, and the Quaternary fluvial terraces are elevated due to a continuous tectonic uplift of the Sierra de Moa (Fig. 7, n° 2). The historical subsidence of the Punga (Fig. 7, n° 3) as well as the location of large swamps above basement structures (DUMONT and GARCIA, 1991), suggest that the state of stress in the depression is presently compressional. South of the Iquitos geanticline, the Acre Basin is presently submitted to positive tendencies (FRAILEY *et al.*, 1988). These data are coherent and suggest a good compressional linkage in Central Peru between the Subandean foreland (Sierra de Moa) and the Brasilian Craton.

This compression is probably weaker in the area where a subsiding basin is present (Marañón Basin) than in the part where Subandean foreland and Craton margin are both submitted to uplift (Central Peru). The combination of a good compressional linkage in Central Peru and a weak in Northern Peru may produce some adjustments in the Craton margin. The NW-SE tensional stress regime (Fig. 7, n° 4) observed in the central part of the Iquitos geanticline, near Jenaro Herrera (DUMONT *et al.*, 1988) results probably from these adjustments.

Increasing tectonic activity during recent Quaternary has had different effects on the position of the Marañón and the Ucayali Rivers. The Marañón River, which crosses the foredeep basin radially, has supported a smaller change of his course. On the contrary, the Ucayali River, which enters the basin longitudinally, registered a large migration toward the southeastern end of the basin (Fig. 7, n° 5). The migration of the Ucayali River extends

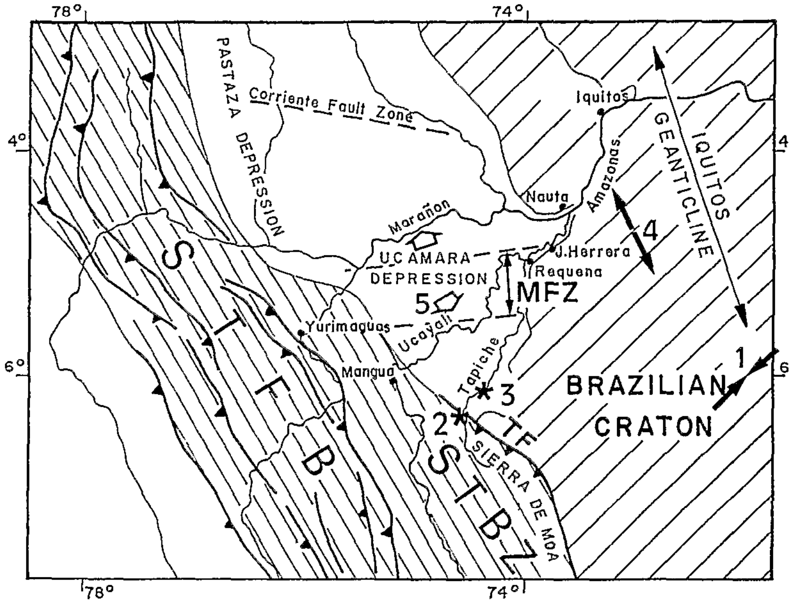


Fig. 7. — Structural scheme of the Marañón Basin and surrounding areas. STFB and STBZ, see fig. 1; TF: Tapiche fault; MFZ: Marañón fault zone. 1: compressional stress from ASSUMPÇAO and SUAREZ (1988); 2: uplifted quaternary terraces; 3: Punga subsidence; 4: tensional stress from DUMONT *et al.* (1988); 5: direction of shifting of the Marañón and Ucayali Rivers.

Schéma structural du bassin du Marañón et des régions environnantes. STFB et STBZ : voir fig. 1 ; TF : faille du Tapiche ; MFZ : zone de faille du Marañón ; 1 : direction de compression, d'après ASSUMPÇAO et SUAREZ (1988) ; 2 : terrasses quaternaires soulevées ; 3 : zone de subsidence de la Punga ; 4 : direction d'extension, d'après DUMONT et al. *(1988) ; 5 : direction des avulsions de l'Ucayali et du Marañón.*

over an area characterized by NNE-SSW to W-E transcurrent late Paleozoic faults, related to the Marañón Fault Zone (LAURENT, 1985), a belt of higher fault density.

The tectonic data suggest that shifting of the rivers may results from either tilting of the basin surface (Ucayali River), or the local and exagerated subsidence of blocks in the basin basement (Punga swamp). The first case is characterized by asymmetrical meander belts (ALEXANDER and LEEDER, 1987), a typical pattern of preferred facing-direction of the abandoned meander loops, which has not been observed in the Ucamara Depression. For this reason the second case is the most probable.

This suggests that the position of the Ucayali River in the Ucamara Depression could be related to the state of stress on the Subandean-Craton Border. Increasing constraint between foreland and craton would force the Ucayali toward the southern tip of the Ucamara Depression, and release of the constraint should lead to a more central position of the Ucayali River in the Marañón Basin, similar to its position during the Samiria stage. In this model, the Tapiche stage would represent an old period of strong constraint.

River underfitness and tectonics

The case in the Ucamara Depression, where shifting of river gives rise to an underfit stream along the abandoned channel, is an unusual case of the underfit process. DURY (1970) concluded that all well known examples of underfit stream are related to water supply reduction by climatic changes. Previously, DAVIS (1923) favoured underfitness originated by capture processes resulting from competitive development of rivers in scarpland topography, but an investigation of the proposed examples leads DURY (1970) to reject this hypothesis. Nevertheless, none of the former hypotheses fit with the occurrences described in this paper, that is underfitness due to shifting of the main stream over a large subsiding plain. Only very peculiar characteristics make this possible: 1) a very flat and extended basin surface, 2) a continuous subsidence, partly controlled by block faulting in the basin basement, and 3) important and relatively continuous rain supplies that maintain reduced local water supplies make the underfit stream to be effective after shifting of the main stream.

CONCLUSION

Study of fluvial landforms on the surface of the Ucamara Depression leads to identify successive positions of the Ucayali and Marañón River belts during the recent Quaternary. We related this to neotectonics, and the special position of the Ucamara Depression with respect to the Andean foreland. Similar features apparently do not exist in all the foreland basins: river shifting is very limited in the Pastaza, Ucayali and Madre de Dios depressions. But according to ALLENBY (1988) it occurs in the Beni Basin. The Ucamara Depression and the Beni Basin are both located near important changes in direction of the foreland border, which suggest block faulting adjustements in the basement.

The identification of paleo-fluvial landforms on the surface of large subsiding basins may be considered as a complementary method for neotectonic study of foreland-craton relationships. This result is in agreement with MIKE'S study of the Great Hungarian Basin, where tectonically controlled subsidence generates sudden shifting of rivers. Asymmetrical meander belts related to tilt tectonics have been reported by ALEXANDER and LEEDER (1987) from the Rocky Mountains. We have not observed similar features in the Ucamara Depression, probably because of the lack of blufflines to limit the lower part of the meander belts in a subsiding basin.

River behaviour is not only related to morphological changes on the basin surface, but also sedimentary and paleoclimatic conditions. We assumed in this study that no major climatic change occurred during the period under consideration, which is mostly the Holocene. But a more extended study of fluvial landforms in time should certainly also consider this point, i.e. the Tapiche stage.

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REFERENCES

ALLENBY (R.J.), 1988. — Origin of rectangular and aligned lakes in the Beni Basin of Bolivia. *Tectonophysics*, 145 : 1-20.

ALEXANDER (J.) and LEEDER (M.R.), 1987. — Active tectonic control on alluvial architecture. *In :* Barbara H. Lidz (Ed.), Recent Development in Fluvial Sedimentology, *Soc. Econ. Paleontol. Mineral., Spec.* Publ. 19 : 243-252.

ASSUMPÇAO (M.) and SUAREZ (G.), 1988. — Source mechanisms of moderate size earthquakes and stress orientation in mid-plate South America. *Journ. of Geophys.*, 92 : 253-267.

BAKER (V.E.), 1978. — Adjustment of fluvial system to climate and source terrain in tropical and subtropical environments. *In :* A D. Miall (Ed.), Fluvial Sedimentology, *Can. Soc. Pet. Geol.*, Mem. 5 : 211- 230.

BRICE (J.C.), 1974. — Evolution of Meander Loops. *Geol. Soc. Amer. Bull.*, 85 : 581-586.

CABRERA LA ROSA (A.), 1943. — Caracteristicas geomorfologícas de los ríos en la region Amazonica. *Soc. Geol. Perú Bol.*, 65 : 23-39.

CAMPOS (C.), 1980. — Evolución de las riberas del río Marañón-Isla Saramuro, Loreto, Perú. *Soc. Geol. Perú Bol.*, 65 : 23-39.

DAVIS (W.M.), 1923. — The cycle of erosion and the summit level of the Alps. *J. Geol.*, 31 : 1-41.

DUMONT (J.F.), 1989. — Neotectónica y dinámica fluvial de la baja Amazonía Peruana. *Soc. Geol. Perú Bol.*, 80 : 51-64.

DUMONT (J.F.), LAMOTTE (S.) and FOURNIER (M.), 1988. — Neotectónica del Arco de Iquitos (Jenaro Herrera, Perú). *Soc. Geol. Perú Bol.*, 77 : 7-17.

DUMONT (J.F.) and GARCIA (F.), 1989. — Pleistocene deposits in Amazonian Peru : are lithological characteristics related to glacial interstages ? IGCP project 281, First Meeting in La Paz, 13-18 May 1989, n° 1 : 4.

DUMONT (J.F.) and GARCIA (F.), 1991. — Active subsidence controlled by basement structures in the Marañón Basin of northeastern Peru. IAHS Fourth International Symposium on Land Subsidence, n° 200 : 343-350.

DUMONT (J.F.), DEZA (E.) and GARCIA (F.), 1991. — Morphostructural provinces and neotectonics in Amazonian lowlands of Peru. *South Am. Earth Sci.*, 4, 4 : 287-295.

DURY (G.H.), 1970. — General theory of meandering valleys and underfit streams. *In* : G.H. Dury (Ed.), River and River terraces, London, *MacMillan* : 264-275.

FRAILEY (C.D.), LAVINA (E.L.), RANCY (A.) and PEREIRA de SOUZA (J.), 1988. — A proposed Pleistocene/Holocene lake in the Amazon Basin and its significance to Amazonian geology and biogeography. *Acta Amazonica*, 18, 3/4 : 119-143.

GIBBS (R.J.), 1967. — The geochemistry of the Amazon River System : Part I, the factors that control the salinity and the composition and concentration of suspended solids. *Geol. Soc. Amer. Bull.*, 78 : 1203-1232.

IRIONDO (M.) and SUGUIO (K.), 1981. — Neotectonics of the Amazon plain. INQUA *Neotectonic Bulletin*, 4 : 72-78.

KOCH (E.), 1959. — Unos apuntes sobre la geomorfología del Rio Ucayali (oriente Peruano). *Soc. Geol. Perú Bol.*, 34 : 32-41.

LANGBEIN (W.B.) and LEOPOLD (L.B.), 1966. — River meanders-theory of minimum variance. *U.S. Geol. Surv. Prof. Pap.*, 422 H : 1-15.

LAURENT (H.), 1985. — El pre-Cretáceo en el oriente peruana : su distribución y sus rasgos estructurales. *Soc. Geol. Perú Bol.*, 74 : 33-59.

LAURENT (H.) and PARDO (A.), 1975. — Ensayo de interpretación del basamento del Nororiente Peruano. *Soc. Geol. Perú Bol.*, 45 : 25-48.

MÉGARD (F.), 1984. — The Andean orogenic period and its major structures in central and northern Peru. *Geol. Soc. Lond. J.*, 141 : 893-900.

Ministerio de Guerra, 1984.— Mapa físico-político del Perú, Lima.

MIKE (K.), 1975. — Utilization of the analysis of ancient river beds for the detection of Holocene crustal movements. *Tectonophysics*, 29 : 359-368.

ONERN, 1975. — Inventario, evaluación y integración de los recursos naturales de la zona de Iquitos, Nauta, Requena y Colonia Angamos. Lima, Oficina Nacional de Evaluación de recursos Naturales (ONERN), Lima.

PARDO (A.), 1982. — Características estructurales de la faja subandina del norte del Perú. *In :* Symposium "Exploracion Petrolera en las Cuencas Subandinas de Venezuela, Colombia, Ecuador y Perú", Asoc. Colomb. Geol. Geofis. Petr., Bogotá.

Petroperu, 1973. — Mosaico de radar semi-controlado. Servicio Aerofotográfico Nacional (SAN), Lima.

Radambresil, 1977. — Levantamento de recursos naturais. Vol.15, folha SB.19 Juruá. Ministério das Minas e Energia, Departamento Nacional de Produçâo Mineral, projecto Radambresil, 76 p.

RÄSÄNEN (M.E.), SALO (J.S.) and KALLIOLA (R.J.), 1987. — Fluvial perturbance in the Western Amazon River Basin: regulation by long term sub-Andean tectonics. *Science*, 238 : 1398-1401.

RÜEGG (W.) and FYFE (D.), 1950. — Algunos aspectos sobre la estructuración de la cuenca del Alto Amazonas. *Boletin Institutos Sudamericanos de Petroleo*, Montevideo, 3 : 9-29.

RÜEGG (W.) and ROSENZWEIG (A.), 1949. — Contribución a la geología de las formaciones modernas de Iquitos y de la Amazonía Superior. *Soc. Geol. Perú Bol.*, vol. Jub. XXV, 3 : 1-24.

SANZ (V.P.), 1974.— Geología preliminar del río Tigre-Corrientes en el Nororiente peruano. *Soc. Geol. Perú Bol.*, 44 : 106-127.

SÉBRIER (M.) and SOLER (P.), 1991. — Tectonics and magmatism in the Peruvian Andes from late Oligocene time to the present. *In* : Andean magmatism and its tectonic setting, *Geol. Soc. Amer. Spec. Paper*, 265 : 259-278.

SOTO (F.V.), 1979. — Facies y ambientes deposicionales cretacicos, area centro-sur de la cuenca Marañón. *Soc. geol. Perú Bol.*, 60 : 233-250.

STEINMANN (G.), 1930. — Geología del Perú. Carl Winters Universitätsbuchhandlung, 448 p.

STERNBERG (H.O'.R.), 1950. — Vales tectônicos na planicie amazonica ? *Rev. Brasil. Geograf.*, 4, 12 : 511-534.

STERNBERG (H.O'.R.), 1955. — Sismicité et morphologie en Amazonie brésilienne. *Annal. Géogr.*, 342 : 97-105.

STIGLISH (G.), 1904. — Archivo especial de Limites, plano del Rio Bajo Ucayali. *In :* Ultimas exploraciones ordenandas por la Junta de vias fluviales a los rios Ucayali, Madre de Dios, Paucartambo y Urubamba. Oficina tipografica de *La Opinion Nacional*, 461 p.

Unesco, 1980. — Balance Hídrico mundial y recursos hidrolicos de la tierra. Estudios e informes sobre hidrologia 25, Instituto de Hidrologia, Unesco, n° 134, 820 p.

VILLAREJO (A.), 1988 (first publication 1943). — Así es la Selva. Centro de Estudios Teologicos de la Amazonia, Iquitos, 330 p.