BULLETIN Of the International Association of ENGINEERING GEOLOGY
de l'Association Internationale de GÉOLOGIE DE L'INGÉNIEUR
N° 45 PARIS 1992

EROSIONAL AND DEPOSITIONAL FEATURES PRODUCED BY A CONVULSIVE EVENT, SAN CARLOS, COLOMBIA, SEPTEMBER 21, 1990

ÉROSION ET DÉPÔTS PRODUITS PAR UN ÉVÉNEMENT CONVULSIF, SAN CARLOS, COLOMBIE, LE 21 SEPTEMBRE 1990

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Abstract

The upper catchment, of the San Carlos River, located on the eastern slope of the Colombian Central Cordillera, was affected by a rainstorm which had no historic equivalent in the area, caused 20 deaths and important destruction and therefore might be called convulsive in the sense of Clifton (1988).
Steep upper slopes suffered more than one hundred shallow mudflows. In the catchment channel deepening and widening cut through older torrential and slope deposits and weathered granodiorite. A large amount of material was eroded including blocks up to 8 m in diameter. Resulting deposits show the well-known differentiation : blocks accumulated in the upper part, coarse and settled in the intermediate course and clay was carried to the Punchinà Reservoir about 20 km downstream.
A volcanic ash layer which covers the older torrential deposits shows mineral assemblages which may enable its correlation with other ashes found eastward with an age estimated in about 10.500 years BP.

Résumé

Le bassin supérieur de la rivière San Carlos, situé sur le flanc est de la Cordillère Centrale de Colombie, a été affecté par un « événement convulsif » le 21 septembre 1990. Une averse de 208 mm, sans équivalent historique dans la zone, a causé la mort de 20 personnes et d'importants dégâts.
Plus de cent coulées boueuses se sont produites sur les versants les plus élevés et les plus inclinés, quelle que soit la nature du sol. Dans les zones moyennes du bassin les lits des torrents ont été élargis et approfondis par le creusement d'anciens dépôts torrentiels et de versants et de la granodiorite météorisée. Une grande quantité de matériau a été érodée, y compris des blocs d'un diamètre atteignant 8 m. Les dépôts montrent une différenciation classique : les blocs accumulés sur la partie haute, les sables sur le cours moyen, et les argiles ont été transportées jusqu'au réservoir de Punchinà, environ 20 km en aval.
Une couche de cendres volcaniques qui recouvre les dépôts torrentiels anciens montre des associations minéralogiques qui peuvent être corrélées avec d'autres cendres trouvées plus à l'est, dont l'âge radiométrique est de 10.500 ans BP environ.

1. Introduction

The area studied is located at the eastern plant of the Colombian Central Cordillera about 160 km east of Medellin (Fig. 1). It is part of the upper San Carlos River basin and covers an area of about 10 km². During the night of September 21, 1990, a heavy rainstorm produced precipitation of 208 mm within three hours.

Such an event had never been observed in the area which has been populated for about two centuries; it produced important changes in the landscape : more than 100 shallow mudflows were observed in the slopes but the main impact has been the result of channel erosion and subsequent downstream deposition.

San Carlos rural population was strongly affected by the event. 20 people were killed, 260 had to be evacuated, 27 houses were destroyed and 30 more were damaged, several bridges and more than 100 m of highway were ruined. The Calderas Hydrolelectric Plant was flooded and severely damaged by large blocks carried by the stream. Total losses were estimated at more than US $ 6,000,000. This paper is a preliminary attempt to describe the event, which is termed convulsive following Clifton (1988), to analyse its hydrological characteristics and geomorphic processes, particularly slope movements and stream erosion and sedimentation.

Air photographs with approximate scale 1:7800 taken one week after the event were made available by Interconexión Eléctrica S.A. Field work was carried out during several visits from October to the end of December, 1990. It had to be suspended at that time due to guerrilla activities in the area. The authors gratefully

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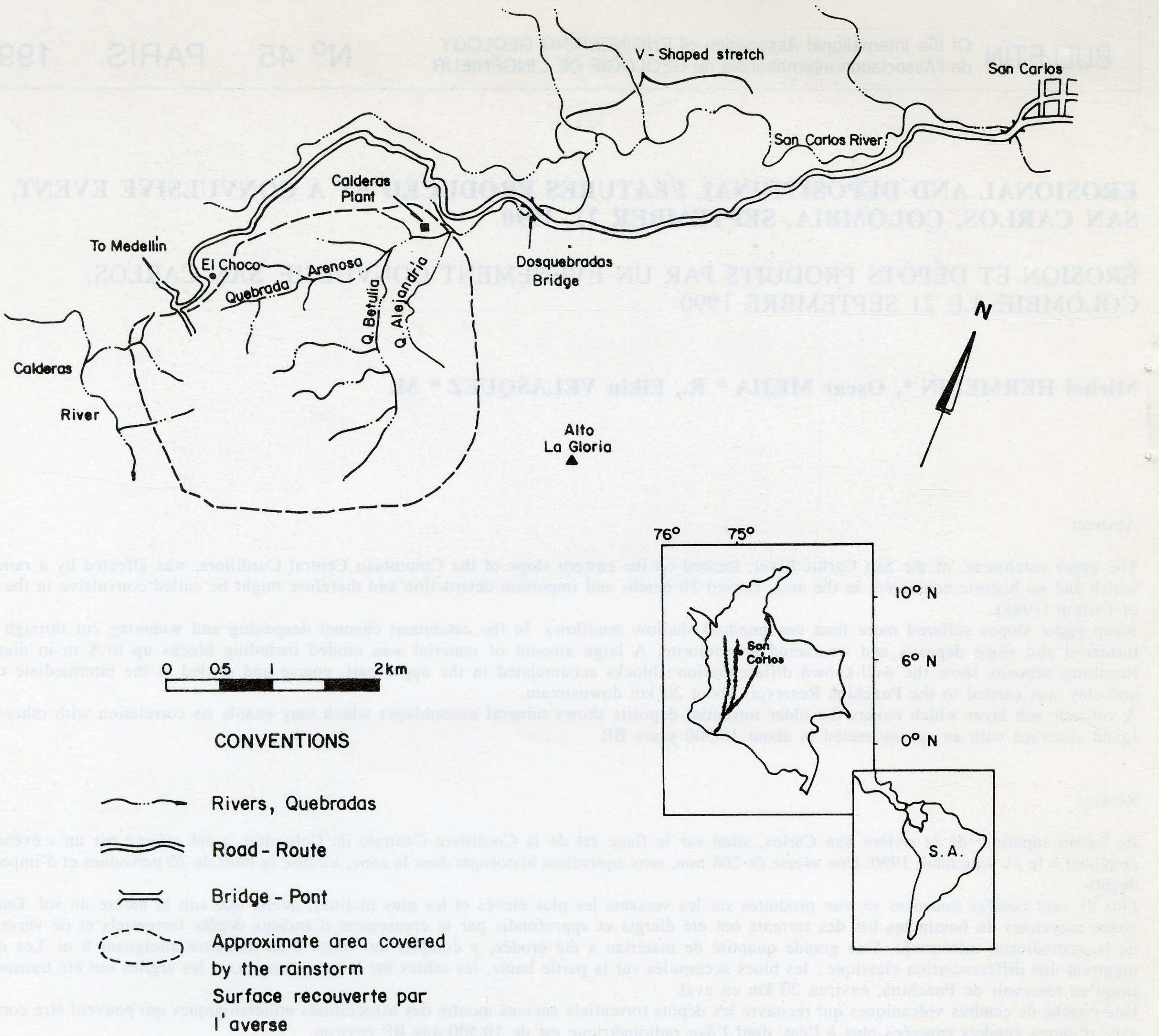

Fig. 1 : Location of the area.
Localisation de la zone.

acknowledge financial and logistical support from ISA; Departamento de Recursos Minerales, Facultad de Minas, Universidad Nacional de Colombia-Medellín; and Fondo FEN Colombia.

2. Regional setting

The area belongs to the municipality of San Carlos, a town founded two centuries ago. Due to its morphological geological and climatic characteristics the surrounding region has been selected for the development of several hydroelectric projects.

San Carlos River is formed by the confluence of the rivers Betulia, Arenosa and Alejandria. Their catchments are located at altitudes between 1.000 and 1.700 m, with steep slopes in the upper part and a hilly relief in the lower reaches. They are underlain by deeply weathered granodiorite of the Antioquian Batholith, an upper Cretaceous intrusive body, by torrential and slope deposits and by alluvial terraces (Ingeominas, 1970; Feininger *et al.,* 1972; Feininger & Botero, 1982; Universitad Nacional-ISA, 1985).

Soils are principally regoliths derived from saprolitised granodiorite and have been classified as soil from humid and very humid climates generally unstructured and deep (IGAC, 1982). Remnants of soils derived from dacitic volcanic ashes with thickness up to 1 m have been observed in the flatter areas (Universidad Nacional-ISA, 1985).

The climate is influenced by the latitude (6° N) and the relief as topography acts as a barrier for humid air masses coming along the Magdalena Valley. Average temperature is about 21 °C and does not vary around the year. Precipitation has two maxima in April and October, produced by the displacement of the Intertropical Convergence Zone. Average annual rainfall is 4.000 mm at San Carlos and 5.000 mm at Chocò, a site

Fig. 2 : General view of the San Carlos River upper basin with distribution of shallow mudflows.
Coulées boueuses sur le bassin supérieur de la rivière San Carlos.

located in the divide of the watersheds affected by the present event.

Following Holdridge's classification (Espinal, 1977), the area belongs to the vegetation zone of very humid forests (Premontane). Present land use includes secondary forests, coffee plantations under shadow trees, pastures and crops.

Climate and geology have favoured the development of thick saprolites, which may reach several tens of meters. Fresh rock outcrops are very scarce. Remnant granodiorite boulders unearthed by mass movements may be found on slopes or in Valley bottoms (Botero, 1963; Feininger, 1971; Hoyos *et al.*, 1985.

3. The September 21, 1990 Rainstorm

The rain started at 20.00 approximately and 208 mm fell in the next three hours; 23 mm more fell before dawn. Measurements were taken with a pluviometer located near Calderas Hydroelectric Plant. Although this is not exactly the centre of the storm, these data may be considered representative of the event (Fig. 1). Derived from the appearence of mudflows, the rainstorm area comprised approximately 10 km^2, including the upper basins of the rivers Betulia, Arenosa, Alejandría, Tupiada and El Sapo, all tributaries of San Carlos River, and two affluents of the Calderas River located southwest of the area.

Peasants living in the affected area reported that the rainstorm was accompanied by hail, strong winds and lightning. Some felt the earth shaking strongly enough to produce the fall of small objects. As no earthquake was registered by the national seismic stations, it is concluded that these vibrations were probably produced by the movement of boulders in the streams.

The area has been populated for about two centuries and no similar event has ever been reported. Pluviometers have been kept in the area for about two decades and they never signaled any event of this magnitude.

4. Erosional processes

4.1. Mudflows

The rainstorm caused a great series of mudflows. They occurred on slopes with an inclination greater than 75 % as determined by field measurements and photogrammetry. The occurrence was totally independent of present soil use. Almost all had a thickness of about 1 m, their length and width varied, from 2 to several metres (Figs 2 and 3).

Typical soil profiles observed at the heads of several mudflows show a humic horizon 15 to 20 cm thick underlain by a silty-clayey bioturbated horizon of red-orange colour up to one metre thick. The contact with the underlying saprolith is transitional and corresponds apparently to a decrease in permeability; this is the location of the limit of most of the flows. The mechanism of the flows seems to be related to saturation of the upper horizons which exceeded the liquid limit of the materials and produced a marked decrease of the shearing strength.

From airphotos, the total amount of material removed through this process was evaluated initially at 1.5 Mm^3. Most of it did not reach the streams directly. However it was later carried away by runoff.

Fig. 3 : River cutting on older torrential deposits by river Betulia.
Coupe dans les anciens dépôts torrentiels, rivière Betulia.

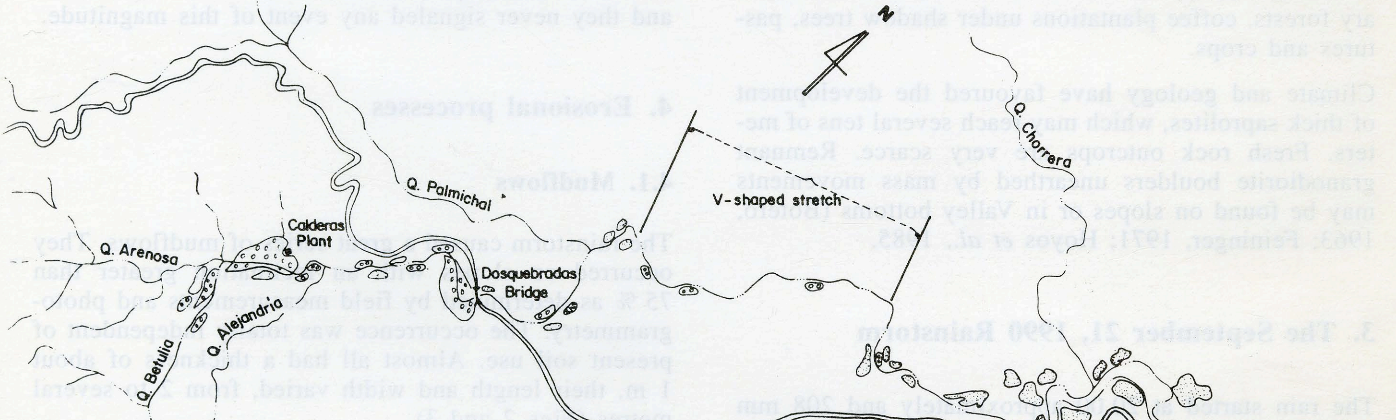

Fig. 4 : Distribution of deposits in R. Betulia, R. Arenosa and San Carlos River.
Distribution des dépôts des R. Betulia, R. Arenosa et Rio San Carlos.

4.2. Stream channels

The flood produced widening and deepening of the channels of the rivers Betulia, Alejandría and Arenosa principally above the Calderas Hydroelectric Plant. In older torrential deposits cut by the river Betulia before its confluence with the rivera Arenosa, cross sections which measured an average of 5 × 3 m before the event now reach 30 × 20 m (Fig. 3).

Several materials were affected by river erosion :

— older torrential deposits, show evidence of at least 4 older depositional events; they include several layers of blocks with diameters up to 8 m with interstices filled by sandy or silty materials. Sandy layers are also present. The development of weathering rinds which sometimes affect medium-sized blocks completely and the presence of a soil derived from volcanic ashes on the surface of this deposit point toward an age of several hundred or thousand years;

— slope deposits, mainly located in the upper part of the catchment and produced by debris and mudflows. They are generally underlain by torrential deposits;

— *in situ* granodiorite, partially weathered to saprolite or grus; in several cases the process produced the complete unearthing of blocks which were initially surrounded by spheroidal weathering or well defined by joints.

The upper reach of the river Betulia was affected by base level lowering of 2 to 20 m which resulted in hanging tributaries. Its lower reach (downstream from Calderas Hydroelectric Plant) was filled with sandy sediments, deposited in most cases 2 to 3 m above base level.

5. Deposits

Several sedimentary deposits produced by the event described were emplaced between the rivers Betulia's and Arenosa's confluence and the Punchinà Reservoir (Fig. 4). Three different sedimentary zones may be recognized :

— from the Calderas Plant to the V-shaped San Carlos River reach : this is the stretch where most of the boulders accumulated;

— from the narrow San Carlos River reach to the Punchinà Reservoir where most of the sand deposits are found;

— the Punchinà Reservoir itself where the clay fraction was deposited.

The boulder deposits were emplaced in a stretch with a lower slope and are often related to topographic barriers and changes in direction of the stream. They often appear when seen from a dowstream position as true walls formed by the largest blocks which acted as retaining dams for smaller ones (Fig. 5). Two places show specially important block accumulations : the first at the outlet of the plant discharge channel and the second at the Dosquebradas bridge. Boulders have diameters between 0.5 and 8 m and their weight can reach 500 tons. The finer fraction consisting of sand and gravel represents up to 30 % by volume of these deposits. They are lens-shaped and have their major axis sub-parallel to the stream direction. In some areas there is a decrease in the size of blocks towards the river banks.

The blocks originate from the rivers Betulia, El Sapo and Alejandría and they are the product of bank and channel excavation which affected older torrential and

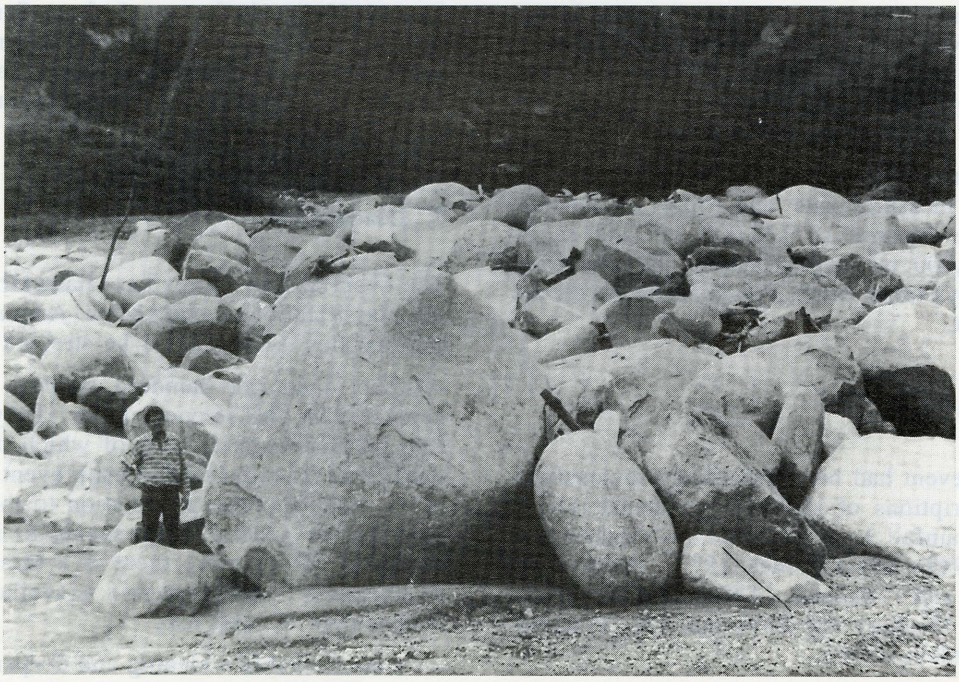

Fig. 5 : Boulder deposits formed by the event near Calderas Hydroelectric Plant.
Dépôts de blocs placés par la crue près de la Centrale Hydroélectrique de Calderas.

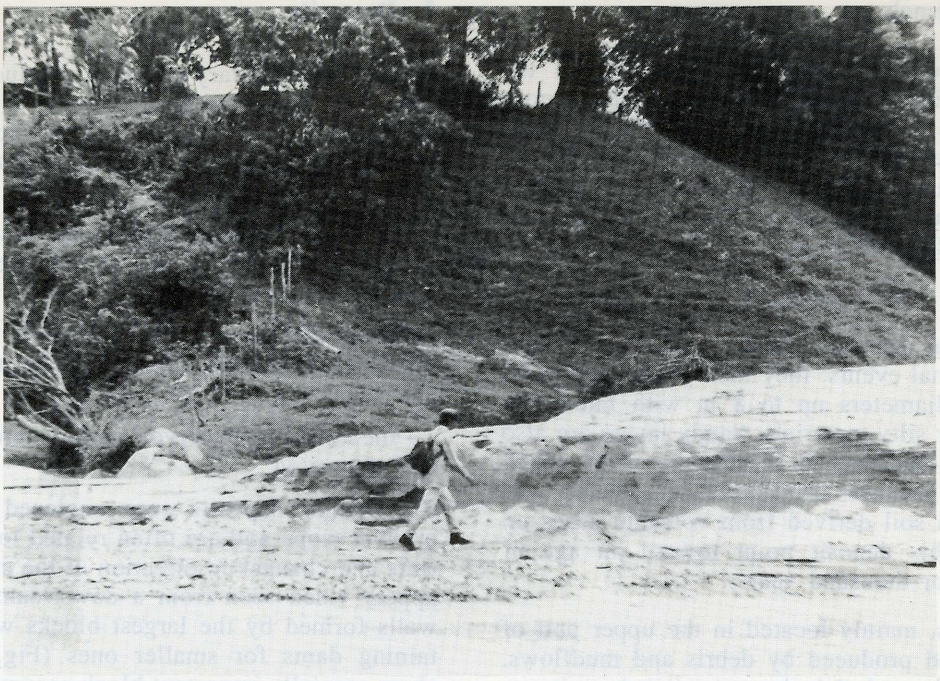

Fig. 6 : Stratified sand deposits, San Carlos River.
Dépôts sableux stratifiés. Rivière San Carlos.

slope deposits and partially weathered *in situ* rocks. The small fraction of angular blocks which was observed may have been detached from jointed fresh granodiorite which crops out at the river banks.

Sand and gravel deposits form layers with thicknesses from 0.5 to 3.0 m (Fig. 6); they show cross stratification and a lens-shaped appearance. Their source are older torrential deposits and the semi-weathered *in situ* granodiorite here called grus which means polymineralic angular aggregates up to 2 cm in diameter in opposition to the wholly weathered saprolite. The finer materials should have been deposited in the Punchinà Reservoir as no evidence of them was found in the deposits located upstream from that place.

The volume of the deposits was estimated from field inspection and measurements and from air photos. Boulder deposits amount to 170,000 m^3 and sandy deposits to 130,000 m^3 approximately. Results from echosound surveys taken in the Punchinà Reservoir are not available yet.

6. Recurrence

No comparable event had been described previously in Colombia. Descriptions of similar phenomena related to exceptional rainfall have occurred in Virginia (Jacobson *et al.,* 1989), Brasil (Jones, 1973), Puerto Rico (Jibson, 1989) and Thailand (Thiramongkol, IUGS Commission on Geology for Environmental Planning Meeting, Amsterdam, 1990).

Textures and stratigraphy of the older torrential deposits in the Calderas Plant area permit the inference that at least two similar events occurred before. As mentioned previously, the degree of chemical weathering of the boulders seems to indicate an age of several hundred or even thousand years.

The upper horizon of the soil developed on the older torrential deposits contains a large proportion of fine sand size volcanic minerals similar to that which characterizes a layer of tephras found at San Felix (Caldas), approximately 100 km south west from San Carlos. The volcanic source (Ruiz-Tolima Massif) is itself located 50 km farther south from San Felix. Organic material found under the tephra layer mentioned was dated by radiocarbon at 10,500 years BP. A more detailed correlation of this tephra layer is being carried out.

7. Discussion

The event at San Carlos has characteristics which permit classification as convulsive. Among its outstanding peculiarities, several must be stressed :

— more than one hundred shallow mudflows were generated in the steeper slopes. They only produced fine grained material, part of which did not reach the streams at least during the main event. The occurrence of the mudflows has no relation to the vegetation and land use in general. This seems to indicate that for slopes of 38º or more there is a threshold which can be exceeded if sufficient rain is available and which is independent of land use;

— a considerable widening and deepening of the channel in the intermediate and upper catchment was produced at the expense of old torrential and slope deposits and incompletely weathered granodiorite;

— an important fraction of the total sediments consists of boulders; this probably depends on several factors : the availability of large-sized clasts in the old torrential and slope deposits located along the rivers. On the otherhand, these older deposits formed because the degree of weathering of the granodiorite, also related to the distribution of joints, was favourable. Although they represent only a small fraction of the total boulder content some of them were directly excavated from an *in situ* grus-saprolite matrix;

— the coarse sand fraction is also important; it is the consequence of incomplete weathering of granodiorite, which produced grus instead of the usual saprolite;

— the segregation of the sediment as a function of size seems particularly noteworthy :

— most of the blocks remained in the intermediate stretch of the streams forming accumulations favoured by stream shape or artificial obstacles; these accumulations became barriers for finer material, particularly cobbles and sand;

— very little coarse sand was deposited in the upper part of the streams : most was carried to the flatter part of the basin and deposited along the San Carlos River;

— The clay and silt fraction was transported down to the Punchinà Reservoir, as it was not observed along the river;

— A preliminary evaluation of the age of the older torrential deposits cut by the present event, based on the presence of a soil derived from volcanic ashes on its upper part, is about 10,500 years BP. The deep chemical weathering shown by the granodiorite blocks contained in these older deposits indicates a residence time of several hundred or perhaps thousand years.

— Calculations made on the basis of the precipitation data available at San Carlos meteorological station give a recurrence interval of 200 years for the rainstorm.

— Maximum discharge measured at Arkansas bridge, a limnological station located about 5 km downstream from San Carlos, was 650 m^3/s, which corresponds to a recurrence interval of only 5 years.

The severeness of the rainstorm, which only became apparent by the victims and damages, was caused by its concentration in the upper part of the San Carlos Basin. Otherwise this flood would have remained almost unnoticed by the public.

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