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Lacustrine Megaturbidites in an Intermontane Strike-Slip Basin : the Miocene Cuenca Basin of South Ecuador

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ABSTRACT Late Mesozoic and Cenozoic intermontane basins of the Andes of Bolivia, Peru and Ecuador show generally a very thick continental infilling that occurred during a compressional tectonics. The Cuenca intermontane basin of South Ecuador is located along faults of a regional scale trending NNE-SSW and N-S. It shows the typical morphological, sedimentological and tectonic characteristics of a strike-slip basin. One of these characteristics is the lacustrine infilling of the middle Miocene age which presents exceptionally thick coarse-grained sediment gravity flow deposits. In view of the sedimentological particularities of the sequences and the great volume of sediments involved in each event, in excess of 1 or 2 km 3, these sediments can be regarded as "megaturbidites". Such deposits correspond to the products of catastrophic events during sedimentation. They are comparable, but smaller than those which have been described as belonging to a marine environment. The formation of kilometric scale synsedimentary folds and the deposition of volcanic products during this lacustrine sedimentation, suggest important tectonic and volcanic controls for the development of these catastrophic events.

INTRODUCTION

Sedimentologic and tectonic analysis of the Late Cretaceous and Tertiary intermontane basins of the central Andes (Bolivia, Peru) and partly of the septentrional Andes (Ecuador) reveal for these basins, in general, very thick continental infilling during compressional tectonics (Mégard et al., 1984; Noblet, 1985; Cordova, 1986; Marocco et al., 1987; Noblet et al., 1987; Noblet et al., 1988; Marocco and Noblet, in press).

The Cuenca basin of South Ecuador (fig.1), which is one of these intermontane basins, presents an important lacustrine infilling, middle Miocene in age (Bristow, 1973). The particularity of this lacustrine sedimentation is the existence of very thick coarse-grained deposits exceptional to such a continental environment. These deposits are comparable with marine gravity flow deposits which have been discribed as "megaturbidites" (Johns et al., 1981; Labaume et al., 1983; Séguret et al., 1984).

The purpose of this paper is to describe the sedimentological particularities of these deposits and to discuss their genesis in this continental environment, in relation to the dynamics of the basin.

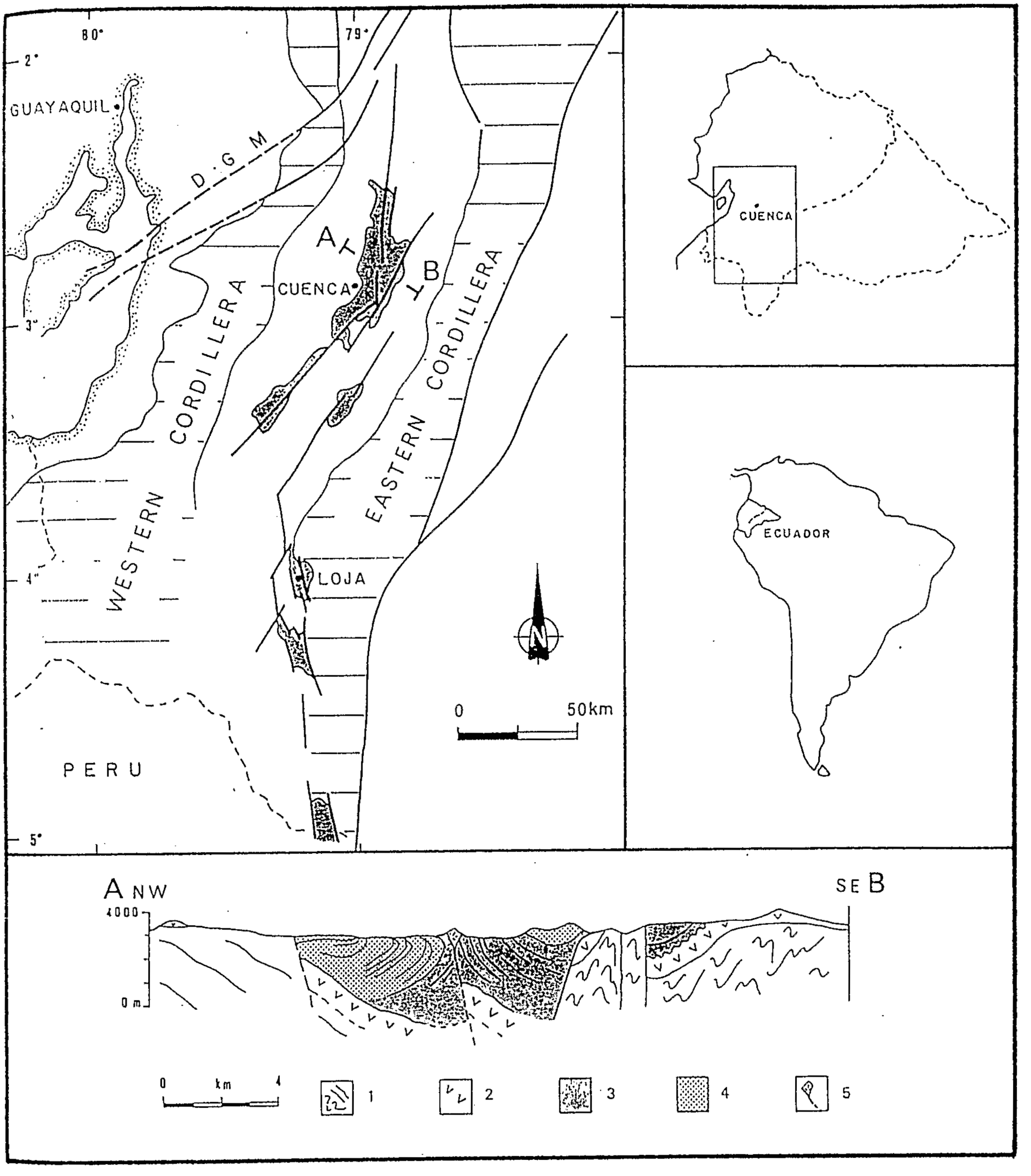

Fig. 1 Location sketch map of the Tertiary intermontane basins of Southern Ecuador. Cross section of the Cuenca basin: 1, substratum; 2, Saraguro Formation; 3, first megasequence deposits (Biblian and Loyola Formations); 4, second megasequence deposits (Azogues and Mangan Formations); 5, dacite of Cojitambo dome.

GEOLOGICAL SETTING OF THE CUENCA BASSIN

The Cuenca basin belongs to the southern part of the Northern Andes. It is Tertiary in age and therefore corresponds to the Andean orogeny. The outcrops lay at an average elevation of 2500m, between the Eastern and Western Cordilleras and are distributed along main regional NNE-SSW and N-S faults (fig.1).

The Cuenca basin infilling consists of a thick continental detrital sedimentation with intercalated volcanic beds (Barberi et al., 1988; Noblet et al., 1988; Eguez and Noblet, in press; Robalino and Noblet, in press).

Two megasequences characterize the sedimentary evolution of the basin (fig. 2). The first one consists, at the base, of thick alluvial sediments (braided rivers and alluvial fans) and lacustrine deposits at the top. This evolution, from proximal to distal deposits, marks the opening of the basin. The second one shows an inverse evolution corresponding to the basin closing. This last megasequence begins with the lacustrine sediment gravity flows (the study of which is the concern of this paper), and is followed by delta, fluvial and alluvial fan environments. In view of the dynamic evolution of the Cuenca basin, both opening and closing periods are controlled by respectively dextral strike-slip movements and reverse movements along N-S major faults (Noblet et al., 1988; Lavenu and Noblet, this volume)

Infilling and structural characteristics of this basin are typical of strike-slip basins, as they are defined by Nilsen and McLaughlin (1985). Moreover, on account of its geodynamical position, the Cuenca basin can be considered as an intra-arc basin.

DESCRIPTION OF THE LACUSTRINE GRAVITY FLOW DEPOSITS

A great part of the middle Miocene sediments of the Cuenca basin are gravity flow deposits. Their extension is about 250 km^2 (25 X 10 Km) and their thickness can rise 500m in the center of the basin. They overlay thick fine-grained deposits which contain abundant lacustrine fauna (Bristow, 1973; Bristow and Parodiz, 1982). The grain-size populations of these deposits vary from clay, silt and fine-grained sand to pebble-sized clast with a major population of coarse to very coarse-grained sand.

The most common and most complete elementary sequence (fig. 3) presents all the main characteristics of gravity flow deposits. This sequence is divided into three units, each one corresponding to a distinct dynamic state of the flow.

1 - The lower unit of this sequence consists of debris flow deposits (Middleton and Hampton, 1976) or cohesive debris flow deposits (Lowe, 1982; Postma, 1986). The basal discontinuity is an erosive surface which are channelized or more frequently sharp shapes with abundant sole marks as flute, prod and groove. Amalgamations, injection structures and load deformations are also present. Into the debris flow materials, the clasts are of centimetric to decimetric scale diameters and the intraclasts are of centimetric to metric scale diameters. During the flow, these larger boulders and blocks, which generally possess a random dispersion, are supported by the buoyancy and the cohesiveness of the fine-grained matrix. This matrix-supported texture is conserved by a sudden cohesive freezing of the flow. Furthermore, the largest intraclastic blocks are concentrated at the top of these deposits and, in this case, appear to be transported within a rigid plug which is rafted on the top of the flow before freezing (Middleton and Hampton, 1976; Lowe, 1982; Postma, 1986).

2 - The middle unit consists of sandy beds which present the main characteristics of high-density turbidity current deposits as they are defined by Lowe (1982). The lowest sand bed of these deposits, composed of very coarse-grained sandstone to small-pebble conglomerate, shows internal scour and traction structures, such as mainly flat laminations and poorly-developed oblique laminations. It is formed by the first losses of the high-density current load and corresponds to the S1 division of Lowe (traction-sedimentation). The next division consists of inversely graded coarse-grained beds, each one of

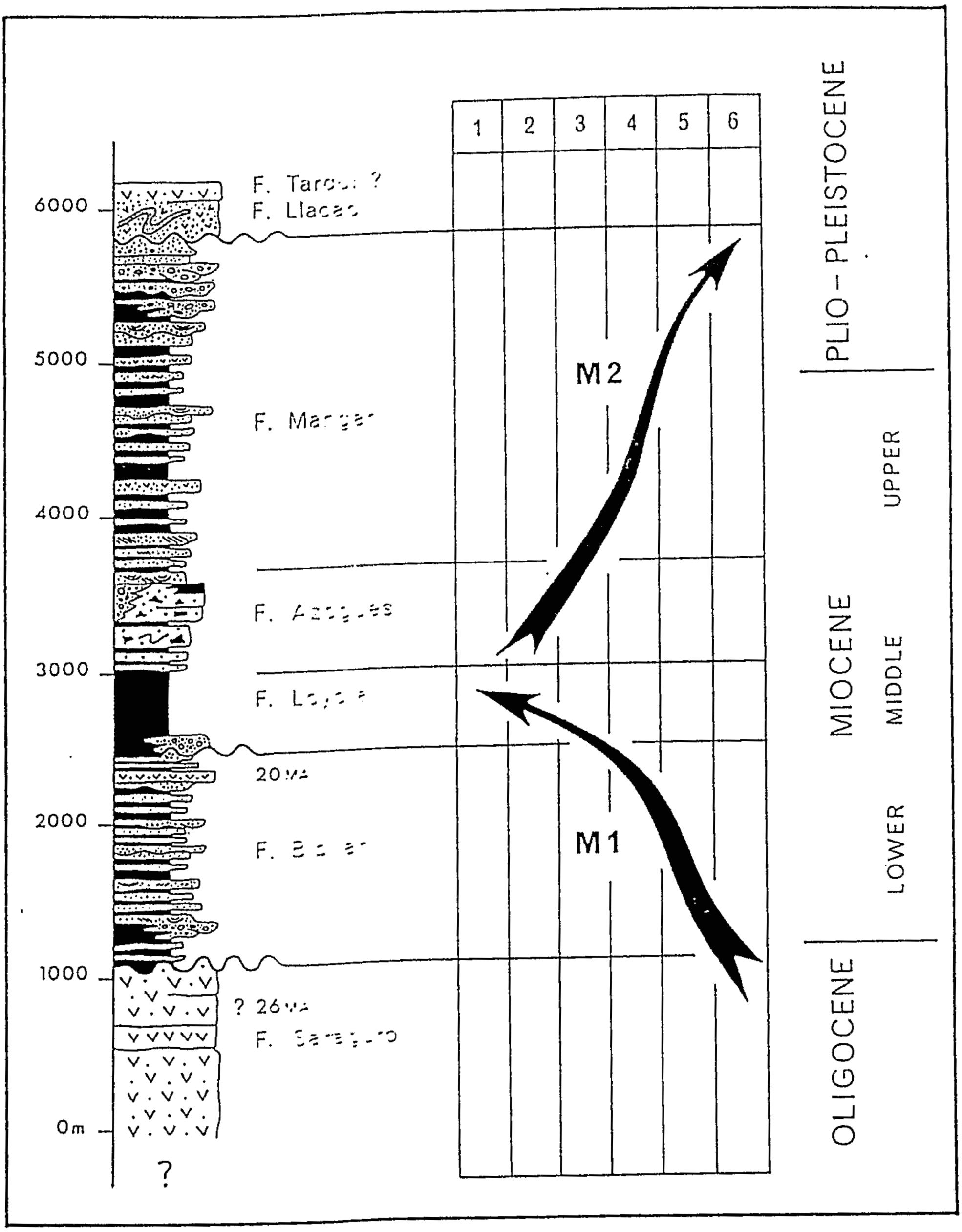

Fig. 2 Stratigraphic column of the Tertiary deposits of the Cuenca basin. The sedimentary evolution consists of two megasequences: M1 and M2. Sedimentary environments: 1, lake; 2, turbidite; 3, delta; 4, flood plain; 5, braided river; 6, alluvial fan.

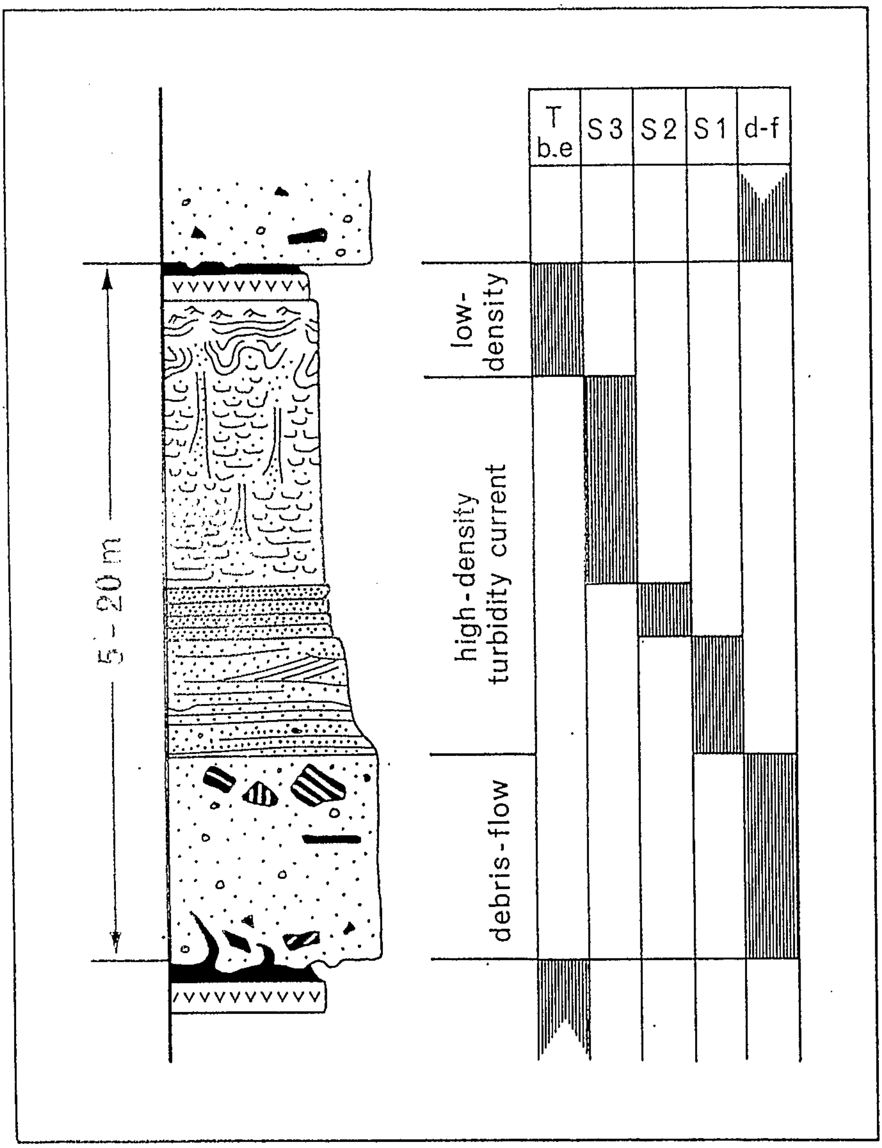

Fig. 3 Ideal sequence of the lacustrine sediment gravity flow deposits of the Cuenca basin.

a few centimeters thick, and corresponds to the traction carpet layers (S2). Their formation which includes suspension and traction mechanisms, is linked with the increasing unsteadiness of the flow. As the suspended sediment load increases toward the bed, the coarse particles concentrate until a traction carpet layer is formed. Thus, the transport in the traction carpet is mainly dominated by grain collisions (dispersive pressure). When carpet load becomes too big, the traction carpet collapses and freezes. Then, a new inversely graded layer is formed above a shear surface (Lowe, 1982; Postma, 1986). The traction carpet layers are not very common in the Cuenca basin deposits. This fact can be explained by the poor proportion of spheric grains in the sediment. Indeed, the materials have a

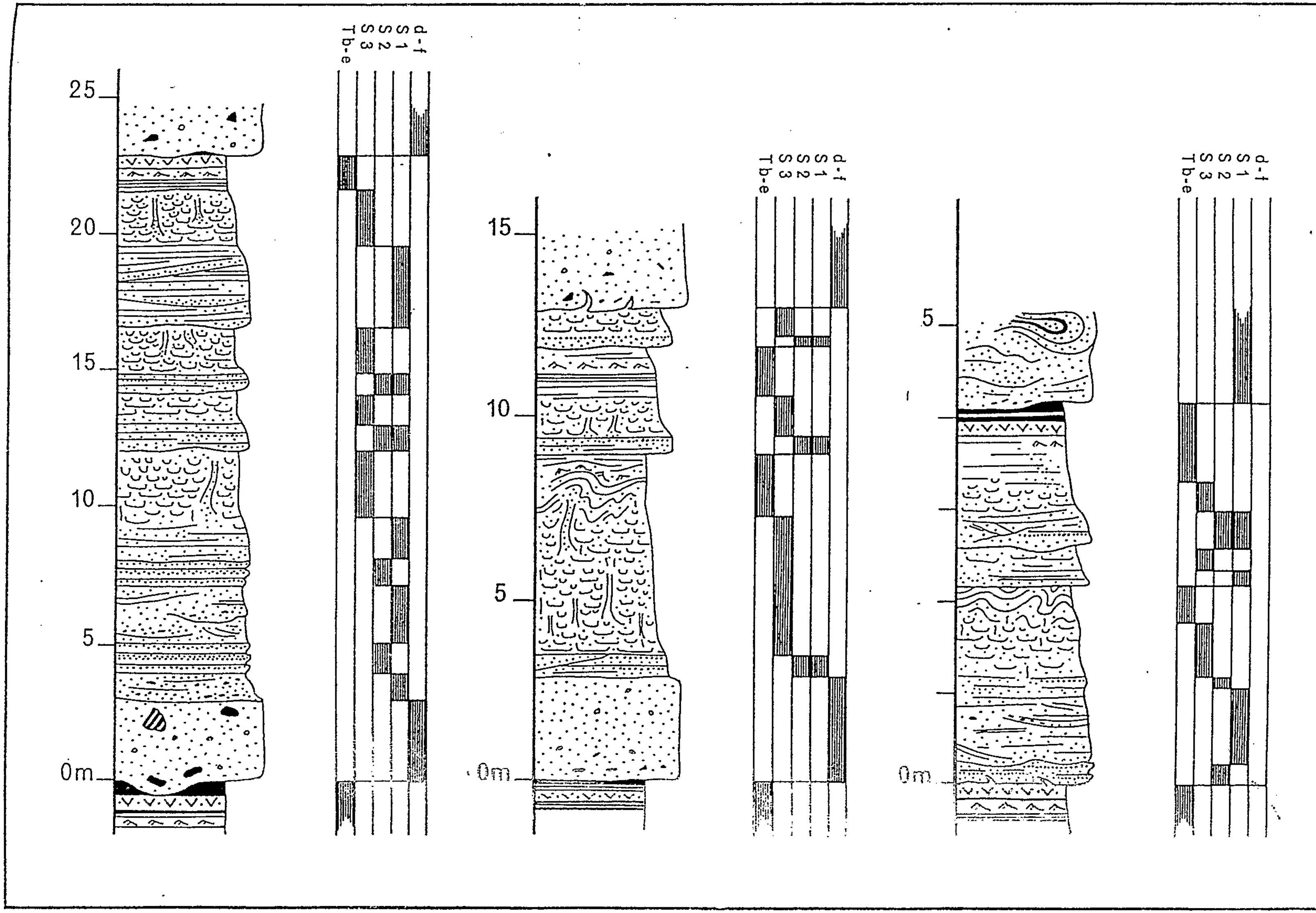

Fig. 4 Examples of the sediment gravity flow sequences of the Cuenca basin.

major volcanic composition and therefore contain mainly automorphic minerals. They must have a different behavior than more spheric grains during the period of the concentration of particles at the base of the flow. The late division of these high-density turbidity currents is represented by massive sand beds which show water-escape structures as dish and pillar. These deposits correspond to the S3 division of Lowe (1982). With the higher suspended-load fallout rate, traction carpets cannot be developed and deposition is by direct suspension sedimentation.

3 - The upper unit of this sequence is composed of coarse to very fine-grained deposits which are the result of low-density turbidity currents. These deposits correspond to the Tb-e divisions of the classic turbiditic sequence of Bouma (1962). The last divisions (Td-Te) generally consist of a cineritic layers.

The sequence previously discribed shows an ideal vertical evolution. Although the flow presents a general deceleration from the base to the top of the sequence, this deceleration appears to be irregular in detail. Thus, the flow is in fact characterized by surges, each one corresponding to abrupt velocity increases followed by gradual deceleration (Lowe, 1982). Therefore, the elementary sequences observed in the field have a more complex vertical evolution with some recurrences of the different sedimentary divisions as shown in figure 4 ..

The sequences observed in the field present distinctive conformations according to their position in the basin. In proximal zones, they present especially thick basal levels as debris flows and S1-S2 divisions. On the contrary, in distal zones the sequences begin directly with S3 and Tb-e divisions or, at the extreme, only with later divisions of the Bouma sequence.

Thus, in the Cuenca basin, this lacustrine sedimentation presents a succession of four main gravity flow mechanisms: 1) the triggering mass movement; 2) the formation of debris flows on the slope; 3) the creation of high and low-density turbidity currents by dilution of the debris flow materials; 4) the decelaration of these currents from the more distal zones. All these mechanisms have been studied by different authors, for example by Hampton (1972), Middleton and Hampton (1973 and 1976), Ravenne and Beghin (1983), Prior et al. (1984), Postma and Roep (1985).

The thickness of most of the sequences ranging from 5-10m, and the extension of these deposits (25 x 10 km), determine volumes of sediments included between 1 and 3 km^3 for each sedimentological event. These volumes are very important in comparison to the size of the basin.

The sedimentological characteristics joined with the volume of most of the individual sequences indicate that these deposits can be regarded as catastrophic events and can be named "megaturbidites". Indeed, such events are comparable, but smaller than those which have been described as belonging to a marine environment for example by Johns et al. (1981), Labaume et al. (1983), Mutti et al. (1984), Séguret et al. (1984).

SYNSEDIMENTARY VOLCANIC AND TECTONIC ACTIVITIES

The synsedimentary volcanic activity has been previously suggested by the material composition of the megaturbidite deposits. Furthermore, on the south-eastern margin of the basin, thick acid pyroclastic deposits and massive rhyolites are closely stratigraphically associated with alluvial and deltaic deposits which correspond to environments laterally equivalent to the megaturbidites (fig. 5).

The tectonic activity during sedimentation has been recognized by the existence of various synsedimentary conical folds of kilometric scale, affecting volcaniclastic deposits on the south-eastern margin (fig. 5) and megaturbiditic deposits in the center of the basin. The structural analysis of each fold and microfracturing analysis give a N60 °E trending shortening responsible to dextral movements on the N-S and NNE-SSW basin-margin faults.

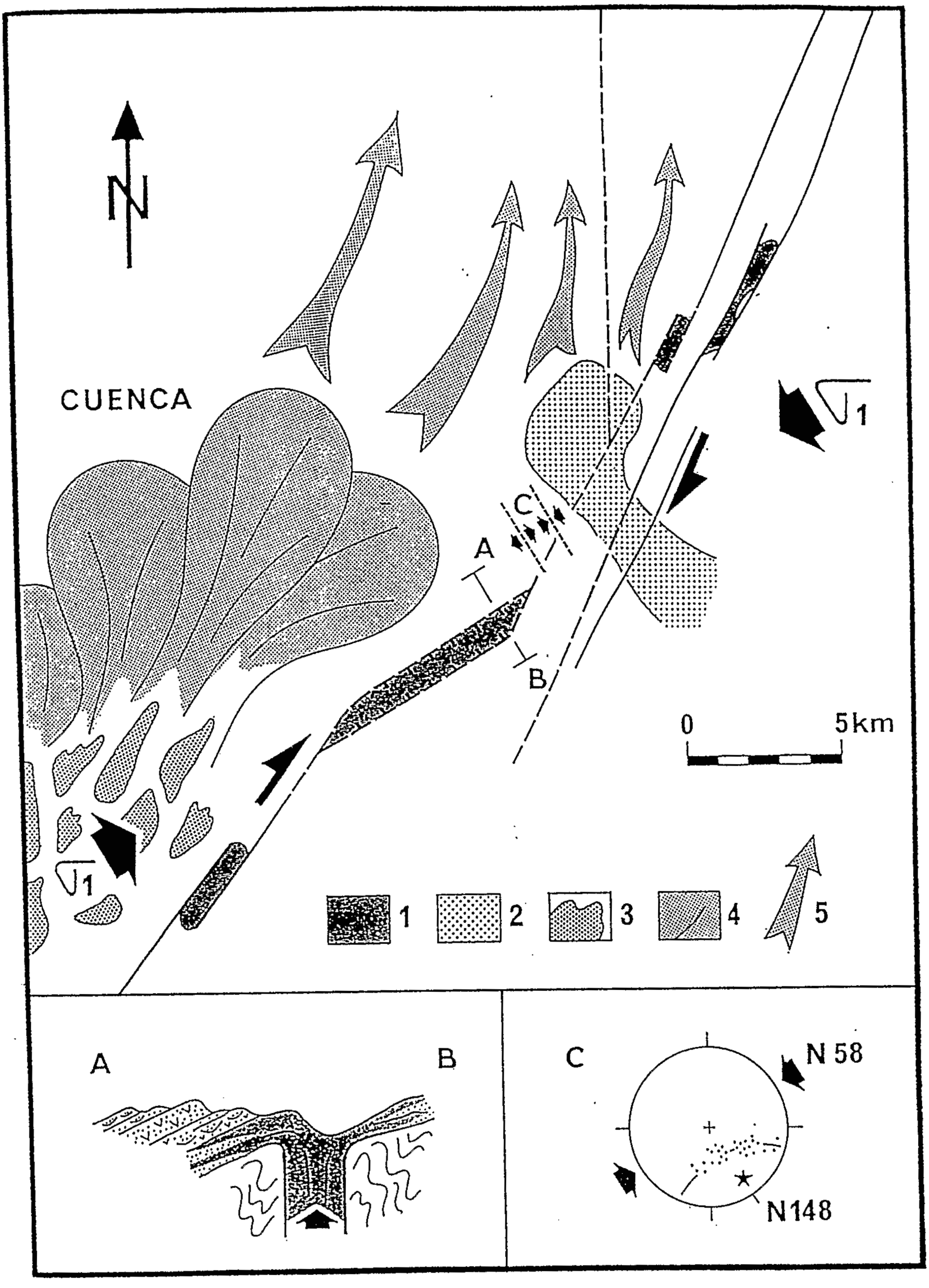

Fig. 5 Dynamic sketch map of the southeastern margin of the Cuenca basin showing the relationships between sedimentation, volcanism and tectonics.

Referring to field observations, the creation of small pull-apart structures allowing the rhyolitic intrusions appears to be the most plausible interpretation to explain the synchronism between volcanic and strike-slip tectonic activities.

CONCLUSIONS

The continental sediment gravity flow deposits of the Miocene Cuenca basin correspond to catastrophic sedimentary processes and are similar to those only previously recognized in marine environments. Because of the sedimentological characteristics and the larger volume of each individual sedimentary event these deposit can be called "megaturbidites". Their formation is closely linked with volcanic and tectonic activities during sedimentation. Among the different trigger mechanisms generally invoked to account for these abnormal events (Mutti et al., 1984) two of them can be chosen for the purpose of this paper. The first one is the sedimentary overloading on the fronts of the lacustrine fan-delta and delta lobes. This overloading and the consecutive failure of prograding fronts can be provoked by the sudden and repetitive production of volcanic materials from the basin margins as it has been also described, for example, by Busby-Spera (1984), Fisher (1984) and Kokelaar et al. (1985). The second one corresponds to the seismic activity along the major margin faults of the basin closely related to the synsedimentary tectonic activity. Indeed, superficial earthquakes have been frequently interpreted as a major mechanism for the triggering of the failure of sedimentary slopes (Hendry, 1973; Middleton and Hampton, 1976; Johns et al., 1981; Labaume et al., 1983; Mutti et al., 1984; Séguret et al., 1984; Labaume and Séguret, 1985). In fact, the action of these two mechanisms (overloading and earthquakes) must be simultaneous for most of the events. Consecutively to the failure of the delta and fan-delta fronts, the sediments start to slide and slump on the slope giving rise to debris flow. Then, the high-density and residual low-density turbidity currents which are generated by mixing water on the debris flow body, possess sufficient efficaciousness to transport sediments downslope for many kilometers (Reading, 1986).

This catastrophic sedimentation combines well with the dynamic evolution of the Cuenca basin. Indeed, this sedimentation participates in the lake colmatation and therefore corresponds to the first response to the shortening direction which is responsible for the basin closing.

As the development of these catastrophic events is closely linked with the dynamical characters of this strike-slip basin, some similar sedimentary processes must exist in such other basins tectonically controlled. Should the occasion arise, these megaturbiditic deposits could become another specific sedimentological characteristic of syntectonic sedimentary basins.

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