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Global Quaternary changes in South America

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ABSTRACT

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An overview of the Quaternary palaeoenvironmental history of South America based upon recent published data and contributions to Symposium "Global and Quaternary changes in the Southern Hemisphere" of the XIII INQUA Congress (Beijing, August 2–9, 1991) is presented Data relate basically to the Andean belt and the tropical landscapes of the eastern and central parts of the subcontinent revealing the uneven geographic distribution of palaeoenvironmental evidences In view of the limited evidence for close-fitting chronologies only a schematic sequence of Late Cainozoic events is proposed as a contribution to more consistent correlations and teleconnections in the future

Introduction

The palaeoenvironmental evolution of the southern continents during the Quaternary represent the last episodes of a palaeogeographical history beginning with Gondwanaland division ca. 220 Ma B.P. Consequently it is not surprising to find great similarities in landscapes of the southern hemisphere where cratonic stable areas and relatively low surfaces predominate (Squires, 1988). These old highly weathered areas support South American diversified ecosystems from the tropical and subtropical lowlands to the Patagonian steppe The Andean orogenic belt, the highest mountain range in the southern and western hemispheres, completes the geological framework of South America. Between the western borders of the cratonic lowlands and the eastern foothills of the Andes a series of plains follows the ancient gap between the oldest and the newest geological structures in South America from Venezuela to Argentina.

On the other hand large areas of the northern continents have been tectonically active with orogenic processes during the Cainozoic and young uplifted surfaces were produced which are subjected to active erosion. As the Pleistocene glaciations covered at least half of North America and Europe, large parts of present-day northern hemisphere landscapes show the amalgam of polygenetic landforms with soils and vegetation essentially Holocene and generally have not undergone extensive weathering (Squires, 1988).

Because of the geographical distribution of continents and oceans in the southern hemisphere only two percent of the land areas south of the Equator lie in cool temperate latitudes equivalent to those that lodged Quaternary ice sheets in the northern continents. In South America the Late Cainozoic continental record of glacier fluctuations in Patagonia is more complete and extends further in time than that of any other continent but in many other parts the Quaternary glacial record of the southern hemisphere is less complete than that of the northern hemisphere. Probably a great amount of Early and Middle Quaternary deposits were removed by erosion enhanced by tectonic instability Conversely the tectonic stability of pre-Cambrian cratons where the northern hemisphere ice sheets developed has allowed the preservation of more complete sequences in some sites (Clapperton, 1990).

Differences in the palaeogeography and palaeohistory of both hemispheres seem sufficient to question the applicability of classical models to explain landscape evolution in the southern continents (Squires, 1988). Based upon recent data Heine (1991) suggests that the classical West-European chronostratigraphy of the Late Weichselian/Wurmian cannot be transferred to the Late Quaternary glacial sequence of the tropical Andes It is also possible that singularities of the Cainozoic palaeogeographical evolution of the Andean belt and the cratonic areas in the eastern and central part of South America explain the uneven geographic distribution of Late Quaternary palaeoenvironmental records (Markgraf, 1989)

Finally it must be remembered that the Vostok isotope-based temperature records (Fig 1c) (Lorius et al , 1988) in East Antarctica indicate that environmental changes in the southern hemisphere are of global significance, at least qualitatively, as shown by the comparison with the marine ^{18}O record (Fig. 1b) of Martinson et al (1987) Those data also enhance the role of orbital forcing in the glacial–interglacial Pleistocene cycles already demonstrated on the basis of deep-sea records According to Heine (1991) climatic

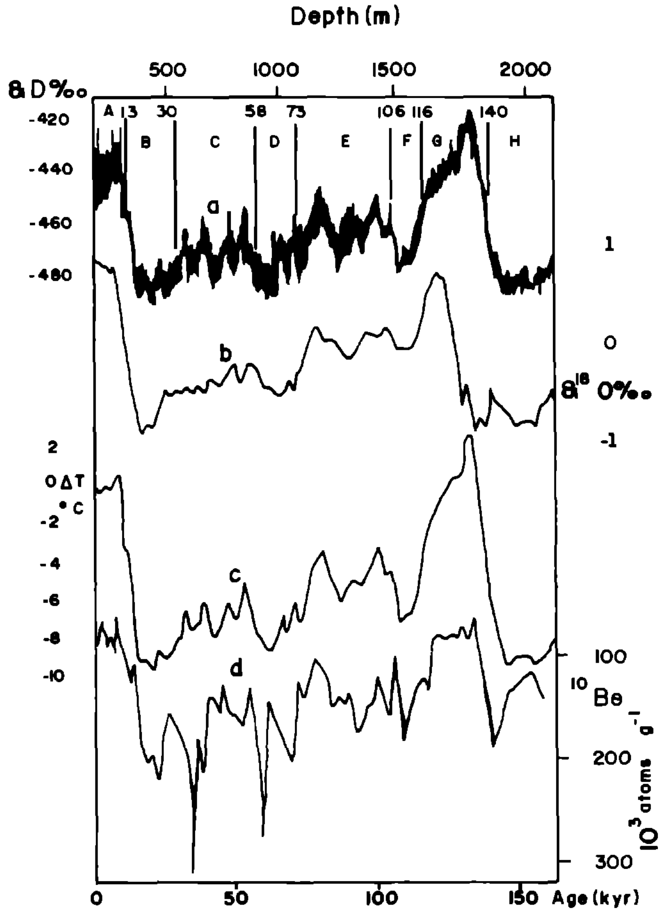

Fig 1 (a) Vostok isotope profile (deuterium content in ‰ versus S M O W) with successive climatic stages A–H as defined by Lorius et al (1985). (b) Marine $\delta^{18}O$ record of Martinson et al (1986) (c) Smoothed Vostok isotope temperature record expressed in °C as a difference with respect to current surface temperature value (from Jouzel et al , 1987) (d) Vostok ^{10}Be concentration (from Raisbeck et al , 1987) Note inverted scale to facilitate comparison with climatic records The upper scale gives the depth of the Vostok ice core; the lower scale indicates the age (ky B P) of the various records (Lorius et al., 1988)

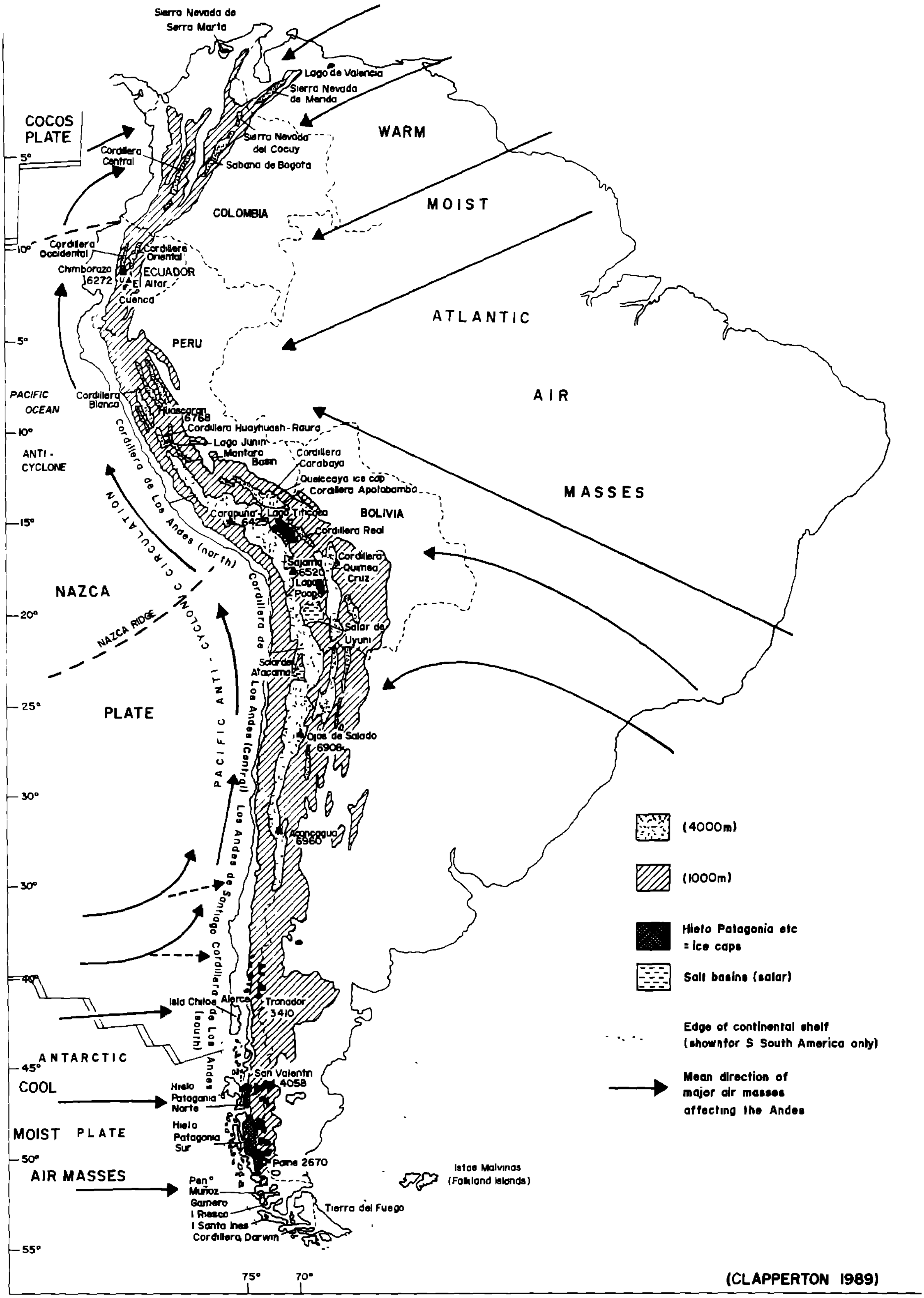

Fig 2 Map of South America showing major tectonic elements affecting the Andes and glacial evidence (Clapperton, 1989)

changes in the southern hemisphere followed the global thermic and hydric trends but it is apparent that they were superposed by regional trends; as a result global thermic and hygric changes may be inappropriate as chronostratigraphic reference boundaries in the southern hemisphere.

Chronology of Late Cainozoic environmental changes

Tertiary–Upper Pleistocene

The palaeoenvironmental record of the southern Andes (Fig. 2) is one of the most complete in the world. The Tertiary uplift of the Patagonian Andes achieved significant elevation in Mid-Miocene times (15–10 Ma B.P.); the rising mountain ranges blocked the humid westerlies from the Pacific and the climate changed from wet-warm to dry-cool (Rabassa, 1978). As the global climate was also changing, conditions were favourable for an early glacierisation of the Andes. Volcanic activity and effusion of basaltic lavas associated with tectonic development since the Miocene helped to preserve the Patagonian glacial record; the oldest glacial deposits have been found near Lago Viedma (49°S) where Mercer and Sutter (1981) found till between lavas dated at ca. 7.0–4.6 Ma B.P. In the Bolivian Andes (Fig. 2) the oldest evidences of ice expansion are exposed near La Paz, where Clapperton (1979) dated an ignimbrite covering till at 3.27 + / − 0.14 Ma B.P. and 3.28 + / − 0.13 Ma B.P. In contrast, based on additional K–Ar dates from tuffs, magnetostratigraphic analyses, and a different stratigraphic interpretation Thouveny and Servant (1989) argue that the oldest glaciation in the La Paz valley occurred after 2.48 Ma (Gauss/Matuyama limit) and most likely around 2.2 Ma probably matching with the onset of northern hemisphere glaciation according to the records of the oxygen-isotope stratigraphy of ocean-cores (Seltzer, 1990).

Mercer (1976) suggested that the "Greatest Glaciation" in Patagonia occurred ca. 1.2–1.0 Ma B.P., during the terminal phase of Matuyama reverse polarity epoch (Morner, 1991). The ice seems to have formed a continuous mountain ice cap all along the Andean summits south of the Chilean lakes (Fig. 2) and glaciers reached both the Atlantic and Pacific continental shelves (Rabassa and Clapperton, 1990). The age of this glacial event conflicts with the northern hemisphere pattern where the greatest ice volumes formed during the Brunhes magnetic epoch. Clapperton (1990) considers that tectonic subsidence, relief lowering and extent of ice shelves and ice packs around Antarctica created conditions for more extensive ice build-up in the southern hemisphere.

Middle Pleistocene

During the Middle Pleistocene data from the Patagonian Andes (Rabassa and Clapperton, 1990) indicate interstadial conditions possibly interrupted by a small scale glaciation. However, the most important event seem to have been the tectonic uplift which led to the incision of a new stream network east of the Andean ranges probably during the interglaciation of Isotope Stage 7. The "canyon-cutting event" modified the Patagonian landscape through the incision of the piedmont zone and the opening of new outlets for the discharge of the icefields; within the valleys the end moraines permitted the genesis of proglacial lakes during glaciar recession.

Penultimate Glaciation

Records of the Penultimate Glaciation (Isotope Stage 6) are generally less complete and well-defined than those of the Late Glaciation. According to Schubert and Clapperton (1990) the Penultimate Glaciation may be represented by deeply weathered drift in Ecuador and effaced morainic forms in Venezuela and Colombia, however, uncertainty will remain till radiometric dates can be obtained. It is possible that in the northern Andes the greatest glacier expansion may have occurred before 50 ka B.P. (ca. 70 ka B.P.?) (Fig. 3) in coincidence perhaps with Isotope Stage 4 (Clapperton, 1989). In southeastern Amazonia the lacustrine deposits of Carajás plateau (Fig. 4) contain detritic minerals (quartz, kaolinite) dated ca. 60 ka B.P. Those materials were transported by high energy fluxes linked to a lake level rise, and probably originated during preceding dry-climate episodes (Absy et al., 1989; Siffedine et al., 1991). In the Acre river basin (western Amazonia) calcium carbonate concretions (AMS ^{14}C ages ca. 53 and 50 ka B.P.) correspond perhaps to arid climate conditions predominating during the Penultimate Glaciation maximum (Kromberg and Benchimol, 1991). For southeastern Brazil Melo and Turcq (1989) suggest that heavy rains and sparse vegetation cover between 50 and 28 ka B.P. favoured slope erosion and colluviation episodes like those dated around 52 Ka B.P. (Melo et al., 1987) in São Paulo.

Last Glaciation

Between > 40–20 ka B P

According to Clapperton (1989) along the Andes there are consistent although sparse evidences of interstadial conditions during the time interval > 40–30 ka B.P. In eastern Amazonia a

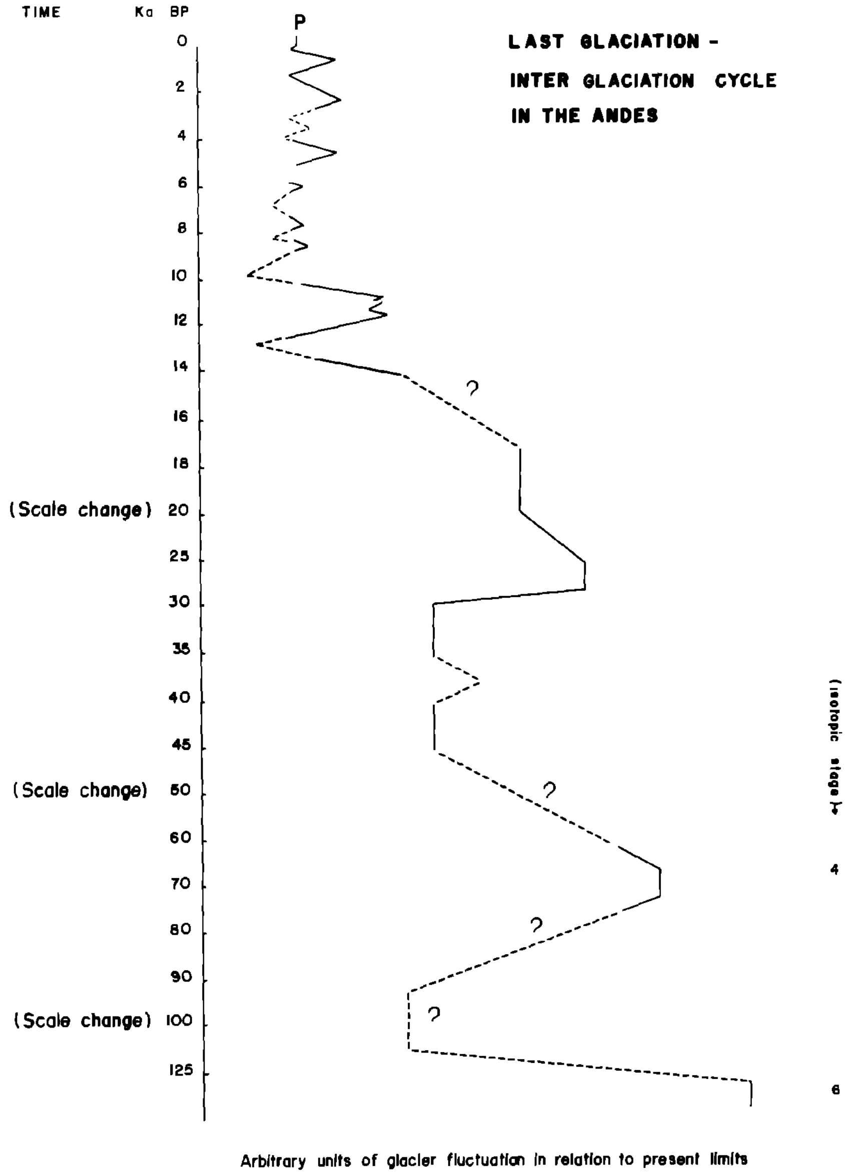

Fig 3 Last glaciation–interglaciation cycle in the Andes (Clapperton, 1989)

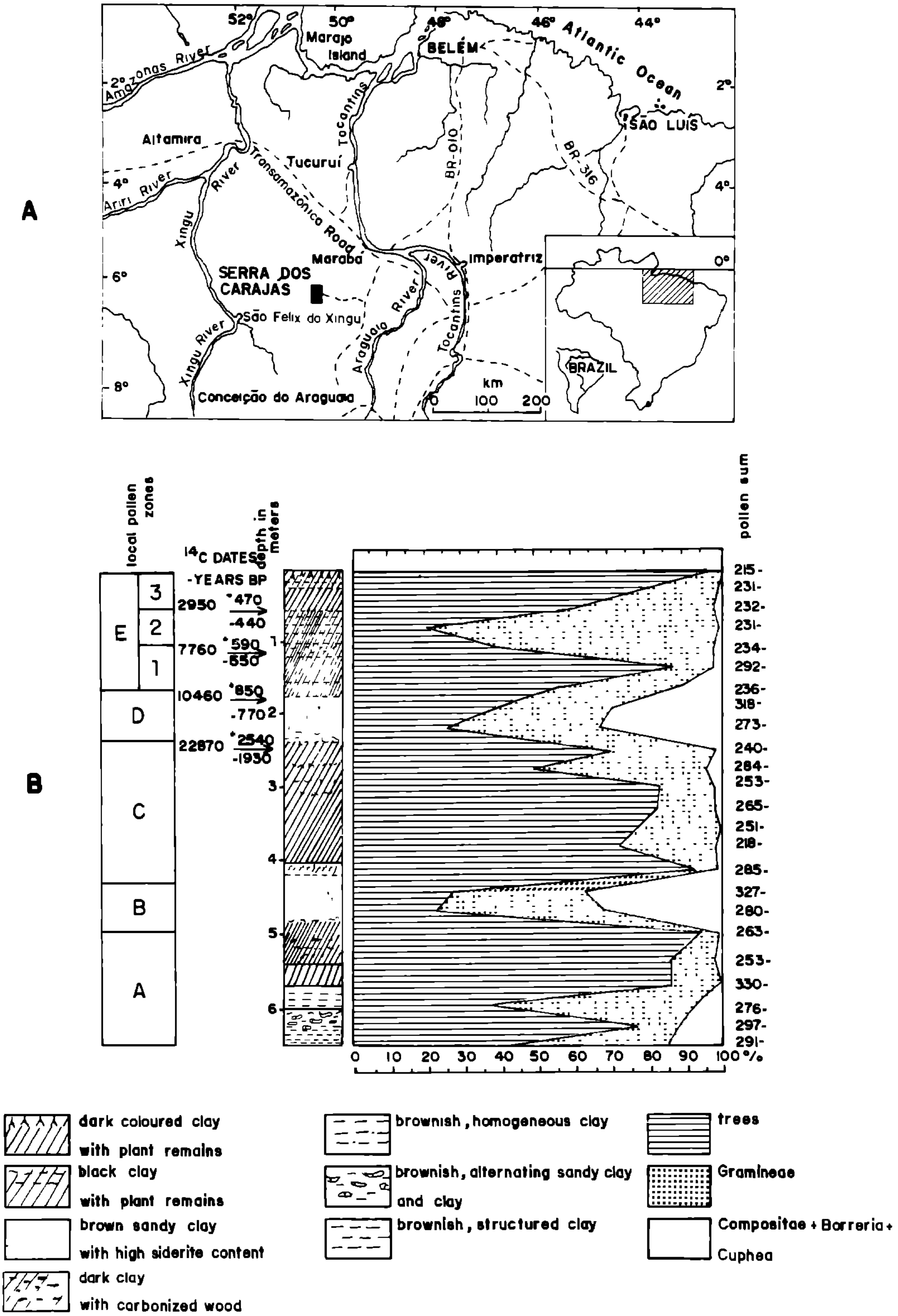

Fig 4. Serra dos Carajás, eastern Amazonia (Brazil) A Geographical situation B Pollen diagram of Lake 8 (Absy et al, 1989, Soubiès et al, 1989)

level-lake rise occurred ca. 40 ka B.P., preceded by an extremely dry climate episode during which lakes dried out (ca. 43 ka B.P.?) (Absy et al., 1989; Siffedine et al, 1991) Colluvial deposits dated ca 43 ka B.P in São Paulo (Melo et al., 1987) probably originated from enhanced morphogenesis due to more arid environmental conditions equivalent to those of the Carajás plateau.

Between 30–20 ka B.P

The northern Andes glaciers reached their greatest extent of the later part of the Late Glaciation between 30–20 ka B.P.; the biggest and more conspicuous moraines belong to this stage. In Ecuador eroded peat (ca 38–33 ka B.P.) overlain by moraines probably points out an older glacier expansion (Clapperton, 1989). In Peru the Quelccaya ice cap (Fig 2) began to expand after 28 ka B P culminating soon after 25.8 ka B.P.; in lake Junín organic deposits were replaced by clay sedimentation ca 24 ka B.P. In Chile Llanquihue I moraine may be related to this time interval and in Chiloé Taiquemó peat keeps evidence of cooling ca. 27 ka B.P. The ELA lowering was estimated in 800–1000 m (Clapperton, 1989).

In eastern Amazonia cores from Carajás lakes show a dry-climate event ca. 23–20 ka B.P. (Absy et al., 1989; Siffedine et al., 1991), in western Amazonia pollen records evidence a cooling of around 7.5°C between 33–26 ka B.P. (Colinvaux et al., 1991), and carbonate concretions ca 24 ka B.P. indicate also a cold phase (Kromberg and Benchimol, 1991). In São Paulo alluvial beds were dated ca. 28 ka B P , and an organic sequence (dated up to 18 ka B P.) within Colônia depression is interrupted at ca. 28 ka B P. by a sandy deposit (Riccomini et al., 1989)

Between 20–18 ka B.P

During the 20–18 ka B.P. interval there are no evidences that Andean glaciers were at their maximal extent at 18 ka B.P. (Clapperton, 1989) Pollen data indicate severe cold and low precipitation, probably related to the intensification of the global atmospheric circulation.

In the Peruvian–Bolivian Andes deposits of Lake Junín present the lowest pollen content, and in the southern Andes peat deposits associated to Llanquihue II moraine yielded ^{14}C ages 19 ka and 18 ka B.P., indicating that by this time the ice had already receded and the proglacial drainage system was abandoned (Rabassa and Clapperton, 1990).

In Venezuela records point out more arid palaeoenvironmental conditions, recession of humid forests and expansion of savannas ca. 18 ka B.P. However, there are also evidences of contrasted climates, humid and dry, in northern South America and the Caribbean coast (Schubert, 1991). In São Paulo (Brazil) the organic sequence of Colônia ends ca. 18 ka B.P (Riccomini et al., 1989) probably due to less humid environmental conditions On the other hand, organic clay deposits in the Paraíba river floodplain dated 20,160 (+810/−740) yr B.P. (Turcq et al., 1989), together with similar deposits dated 30–20 ka B.P. in São Paulo and other areas in southeastern Brazil (Turcq et al., 1987), point out to hydrological circulation very similar to the present one. Interbedded sandy floodplain deposits originated perhaps during more arid events (Turcq and Melo, 1989). But such evidences for contrasted climates are speculative until more detailed research is done.

Between 17–14 ka B P

For the 17–14 ka B.P. interval data from the Andes are scarce and sparse making palaeoenvironmental reconstructions difficult. In Venezuela Mucubaji records indicate possible fluctuations of expanded glaciers until at least ca. 16.5 ka and in the Ecuadorian western Cordillera outwash sediments are overlain by a peat dated 14 7 ka B.P. In Peru glaciers associated to Quelccaya ice cap remained expanded and advanced ca. 14 ka B.P.; Llanquihue III moraine in southern Chile lake district was large and fluctuating around 15–13 ka B.P (Porter, 1981). There are no radiometric ages for the maximal expansion of ice in Tierra del Fuego but at 14,960 yr B.P. Beagle glacier had receded 60 km; at ca 13.1 ka B.P. the eastern mouth of the channel was free of ice, and at 10 ka B.P. the whole valley was invaded by the sea (Rabassa, 1989, 1991).

Late Glacial

14–12 ka B.P

During the Late Glacial (14–12 ka B P.) pollen records and lacustrine sediments evidence amelioration of climate (ca. 13 ka B.P) In the northern Andes as well as in Peru and Bolivia this warm episode was replaced by a cool reversal; in southern South America the Patagonian ice lost volume and the Last Glaciation ice cap disintegrated (Clapperton, 1989)

12–10 ka B.P

Controversy exists about a glacial expansion around 12–10 ka B.P., according to Mercer (1976) after 13 ka B.P. Patagonian glaciers only expanded again around ca. 5 ka B.P., dismissing the occurrence of a cooling event equivalent to the Younger Dryas in southern South America. Markgraf (1980), Hoganson and Ashworth (1982) and Ashworth and Hoganson (1991) discuss the absence of biostratigraphical evidence for a Late Glacial cooling episode. On the other hand palynological records (Heusser et al., 1981; Heusser and Rabassa, 1987, among others, in Rabassa and Clapperton, 1990) indicate strong cooling at 11–10 ka B.P *Nothofagus* began to expand around ca. 10 ka B P and augmented during the Middle Holocene substituting steppe.

Palaeohydrological research (ORSTOM, 1987) indicates that a lake level rise was registered in Bolivia between 13 and 10 ka B.P. in coincidence with the glaciers expansion; ca. 9.5 ka both glaciers and lakes lost volume. Titicaca lake level was lower than today, with maximal lowering dating from 7.5 to 7 ka and after 4.4 ka B.P The present-day level dates from after ca. 2 ka B.P. (Servant et al., 1989a). Geomorphological evidences from non-glaciated valleys show that variations in intensity of surficial water fluxes occured from ca. 13 ka B P. High concentration of fluxes and gully formation on the whole Altiplano probably coincided with the high level of lakes (around 13 ka, 7–6 ka and < 1.5 ka B.P.) It seems however that during this interval moderate activity of slope processes, fine alluvial sedimentation and extensive development of short-lived peat deposits predominated, apparently associated to moderate water circulation and absence of violent floods (Servant et al., 1989a)

Early Holocene

10–5 ka B.P.

During the Early Holocene palaeosols and pollen studies in the tropical Andes and data from Patagonia suggest minor fluctuations at ca. 8 4 ka, 7.5 ka and 6–5 ka B.P. (Clapperton, 1989) According to biostratigraphic evidence Heusser (1974) considers that after the Late Glacial cooling the warmer interval occurred between ca. 8.5 and 6 5 when mean temperatures were 2°C higher than today. These data corroborate the global episode of Holocene warming culminating before ca. 6 ka B.P In Tierra del Fuego the mean highest level of the last transgression was dated 5.92 ka B P and peat formation augmented ca. 5 ka B.P. (Rabassa, 1989, 1991).

Late Holocene

Between 5–0 ka B P

During the Neoglacial interval expansions of glaciers in the southern Andes occurred in 4 7–4.2 ka, 2 7–2 ka B.P. and during the last three centuries (Mercer, 1976) These data are supported by pollen studies (Heusser, 1974; Heusser et al., 1981) and coincide with the ages of fluctuations in Tierra del Fuego (Rabassa, 1991), the northern tropical Andes and the northern hemisphere (Schubert and Clapperton, 1990).

In northern South America data from the interval 10–8 5 ka B.P.—Lake Valencia, Galápagos (Colinvaux, 1972)—data point out the substitution of *Graminiae* or savanna by forests. In eastern Amazonia Carajás lacustrine deposits indicate humid episodes and forest vegetation ca 11–10 ka and 8–7 ka B P. (Absy et al , 1989; Siffedine et al., 1991). Along the Caribbean coast the highest transgressive level occurred at ca. 6 ka B.P.; at ca 5 ka B.P. the sea level began to lower and reached stability. The coast-line progradation caused the substitution of mangrove by herbaceous steppe in Suriname and French Guyana (Prost, 1990).

Reduced atmospheric humidity ca. 6 ka and 5 ka B P may have been responsible for recession of the humid Amazonia forests (Martin, in Prost, 1990). Natural or man-induced fires occurred between 6.5 and 2.1 ka B.P., with the highest concentration ca. 4.5–4 ka B P. corresponding probably to dry events (Soubiès, 1980). Apparently the re-expansion of the tropical South American forests began only in 3 ka B.P.

In southeastern Brazil coarse alluvial sedimentation is dated to around 9.5–8 ka B.P. In the interfluve between Jequitinhonha and Doce rivers (Servant et al., 1989b), palaeosols and wood fragments interbedded with coarse alluvial-fan deposits and fine sands (Fig 5) date dry Early Holocene events (9440 +330/−320, 9230+420/−400, and 8710+300/−290 yr B P) It is possible that an hydrological regime characterised by well-defined seasons and concentrated rains originated surficial wash that eroded and transported slope deposits under a sparse vegetation cover. Probably the humid tropical forest appeared and expanded only after ca 8 ka B.P.

In other regions, especially in São Paulo and Minas Gerais, terraces show the alternation of sedimentation/erosion episodes between 7 and 0 ka B P. (Fig. 6); peat deposits over alluvial beds (2 02 ka and 1.07 ka B.P) are also found. These events probably represent palaeoenvironmental oscillations synchronous with global changes (Suguio et al., 1989). Around São Paulo Holocene deposits begin ca. 8 ka B.P. beneath the sedi-

A

B

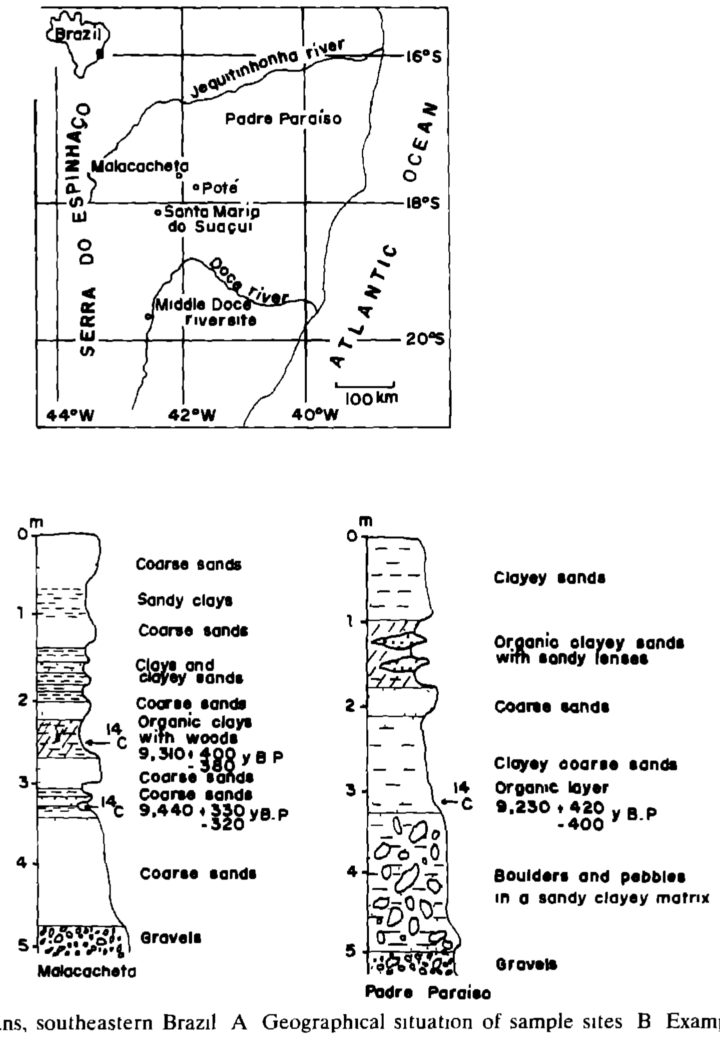

Fig 5. Early Holocene alluvial fans, southeastern Brazil A Geographical situation of sample sites B Examples of alluvial-fan depositional sequences (Servant et al , 1989b)

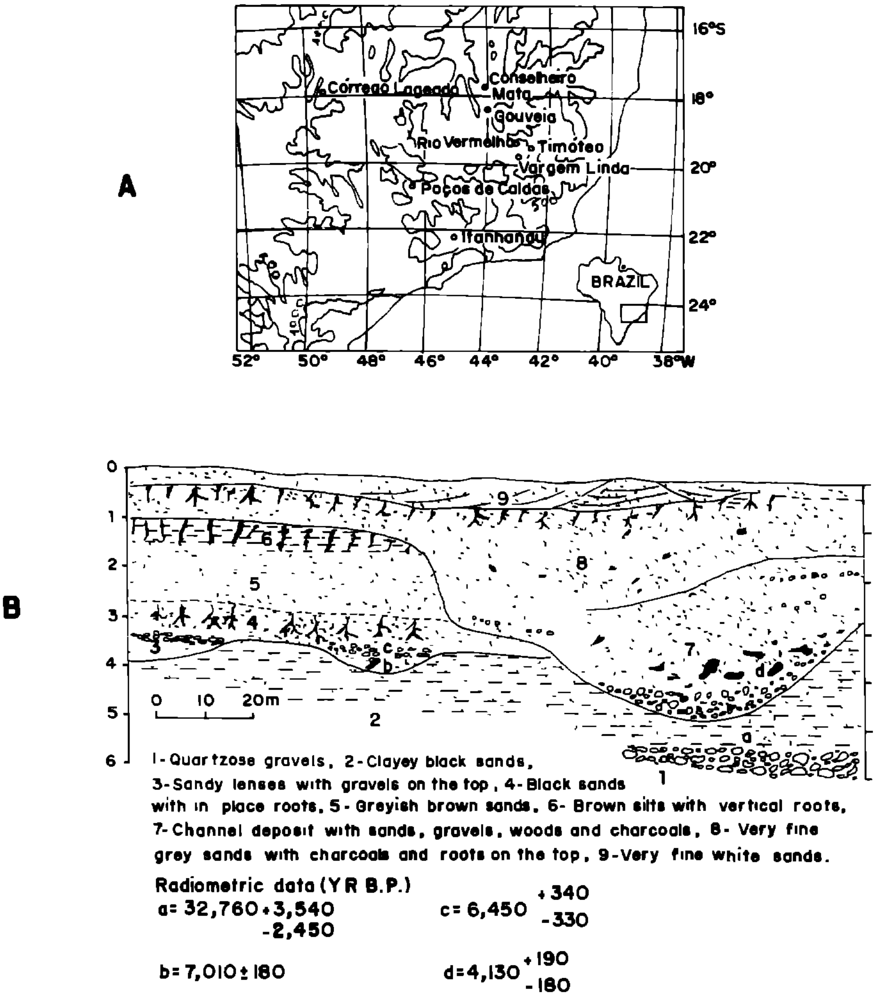

Fig 6. Holocene fluvial deposits, southeastern Brazil A Geographical situation of sample sites B Alluvial terrace, Contagem river (Minas Gerais) (Suguio et al , 1989)

ments of Paratei river floodplain (Coltrinari et al , 1984). A similar sequence is found over Itaquaquecetuba Formation in São Paulo sedimentary basin (Melo et al., 1987). In Taubaté basin cores from the Paraíba river floodplain contain clays dated 6510 yr B P. indicating high floods; organic sedimentation reappears ca 5 5 ka B.P. (Melo et al., 1987; Turcq et al., 1989). The above mentioned records of Holocene fluctuations are found also in other fluvial basins in southeastern Brazil where at least two sets of alluvial deposits corresponding to changes in precipitation regime appear.

Palaeoenvironmental records from the last 4 ka B P show few similarities among the different South American areas, both in chronology and type. According to Markgraf and Bradbury (1982) those differences may be due to a change in the variability of climate patterns, or to a greater frequency of changes, for which the resolution of records in general is not sufficiently accurate

Conclusions

At the beginning of this paper differences in the palaeogeography and the palaeohistory of both hemispheres were mentioned as hindrances for the application of classical chronologies to explain Quaternary landscape evolution in South America. Ten years ago differences in geomorphological and environmental histories and the scantiness of available data were evoked by Markgraf and Bradbury (1982) as a drawback to establish correlations among the tropical lowlands, the northern and the southern Andes.

The inclusion in this review of data from Amazonia and the Caribbean (Absy et al., 1989; Colinvaux et al, 1991; Kromberg and Benchimol, 1991; Prost, 1990, Schubert, 1991; Siffedine et al., 1991, Soubiès et al., 1989) and southeastern Brazil (Melo et al., 1987; Riccomini et al., 1989; Servant et al, 1989a, b; Suguio et al., 1989; Turcq and Melo, 1989, Turcq et al., 1987, 1989) intend to call the attention upon a series of recent data concerning those extensive and highly diversified areas known as "the tropical lowlands" where records and accurate chronologies are till today far from satisfactory For example, records and radiometric ages included in this paper refer usually to short timespans and local sites generally far away from others in the same climatic zone lacking complementary regional and/or local evidences.

We consider that in spite of limitations in number and quality those data from the northern, central and eastern part of South America cannot be dismissed as unimportant and should be considered as a contribution to more detailed and consistent correlations and teleconnections in the future. Otherwise it will be quite difficult to improve the quality and preciseness of present palaeoenvironmental reconstructions as well as the current knowledge about Southamerican tropical landscapes.

On the other hand it is necessary to multiply and diversify the application of current radiometric techniques to obtain absolute ages and expand investigation based upon pollen analysis It is also urgent to search for informations about the Quaternary evolution of deposits others than the organic layers within alluvial beds that can yield absolute ages We think especially of surficial formations on slopes and interfluves in Brazil, where oxisols predominate. It seems necessary to investigate the palaeoenvironmental conditions that permitted the development of similar soil profiles along an apparently long timespan (Upper Tertiary–Present) in order to establish a more consistent chronology of changes in the tropical South American zone.

The Andean chronology of climatic fluctuations is based upon data sets, with or without radiometric ages, that help generically to hypothesize about thermic and hydrological regimes in the different Cordillera sections during rather precise time intervals Recent contributions by Clapperton (1989, 1990), Rabassa (1989, 1991), Rabassa and Clappperton (1990), Schubert and Clapperton (1990), among others, point to the interdependence between tectonic evolution and climatic fluctuations which influenced the histories of the northern, central and southern Andean lansdcapes. On the other hand it is also possible that tectonics may partially explain some differences between the glaciation–interglaciation cycles of the Andes and those of the northern hemisphere

Last but not least we consider that a remarkable contribution to Quaternary palaeoenvironmental reconstructions in the Bolivian Andes has been made by palaeohydrological and geomorphological research along with the investigation of glacial deposits. Those data contribute positively to more detailed chronologies and better knowledge of a complex section of the Andean belt and consequently to the palaeogeographical history of our continent.

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