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THE T'ORA GEOSOL(?) (MAIN ETHIOPIAN RIFT, ETHIOPIA): PROBLEMS IN DEFINING PALAEOSOLS

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SUMMARY
The Lake Region (Main Ethiopian Rift, MER), is object of major palaeoenvironmental research since the seventies. An integrated soil and Late Quaternary stratigraphy study in this area revealed the presence, across a wide range of present soil-forming factors, of a group of soils sharing major common features, including:
- intense smectite neoformation from clay-free parent materials
- a strongly developed petrocalcic horizon
- a fairly uniform tephra addition, making them pedocomplexes with two well defined compartments

In the MER lower elevation areas, these soils, found on Lake Ziway terrace V, are incompatible with the present semiarid climate. A major pedogenetical hiatus separates them from those developed on the next oldest terrace, IV, last flooded about 5 14C ky BP.
These soils were chronologically placed with respect to the known palaeoclimatic history of the MER, with the help of a newly described and dated stratigraphic section. There is multiple evidence that they developed during the Holocene climatic optimum, between 10 and 5 C14 ky BP, when proxy records show for the area a climate moister than present.
The wide spread of these soils, their easy field recognition and the importance of early Holocene in the palaeoenvironmental history of the MER prompted their use as a key level. As such, they showed to be extremely useful in the interpretation of the geomorphic and sedimentary evolution of the Lake Region. Specifically, they were used in reconstructing phases of landscape stability and instability throughout terminal Pleistocene and Holocene.
Such importance and usefulness suggested their possible establishment as a pedostratigraphic unit, a Geosol, giving birth to the T'ora geosol definition.
However, according to current standards, existing or in discussion, basic problems exist. The T'ora geosol cannot yet be formalized as, in its present reference stratigraphy, it is not buried. A suitable stratotype has been located but not yet described. Furthermore, the T'ora geosol is mostly relic, and rarely exhumed, in its surface occurrences.
According to the present version of the INQUA Palaeopedology Glossary, the T'ora geosol cannot be defined a palaeosol, as it formed in Holocene. Consensus palaeoclimatic and chronological frameworks for many tropical areas, however, consider Holocene climatic variations to be of a similar order of magnitude of those registered throughout Late Pleistocene. It appears then rather arbitrary, at least for intertropical areas, to limit the Palaeosol concept to the Pleistocene when, as shown by our findings, Holocene soils may be as useful, or more useful, than older soils in palaeoenvironmental reconstructions.

RIASSUNTO
La Regione dei Laghi (Main Ethiopian Rift, MER), è oggetto di ricerche paleoambientali dagli anni settanta. Un rilevamento integrato dei suoli e dei depositi del Tardo Quaternario dell'area ha mostrato la presenza di un gruppo caratteristico di suoli definiti da alcuni caratteri principali, comprendenti:
- *estesa neoformazione di smectite da un parent material privo di fillosilicati*
- *un orizzonte petrocalcico fortemente sviluppato*
- *una deposizione generalizzata di tephra, che li rende dei pedocomplessi con due membri ben definiti*

Alle quote più basse della MER questi suoli, trovati ad esempio sul V terrazzo del Lago Ziway, non sono compatibili con il clima attuale, semiarido. Un forte divergenza di processi genetici li separa dai suoli del terrazzo immediatamente più recente, il IV, la cui età potrebbe raggiungere i 5000 anni 14C BP.
Questi suoli sono stati collocati cronologicamente, rispetto alla storia quaternaria nota della MER, con l'aiuto di una sezione statigrafica di nuova descrizione, corredata da datazioni. Evidenze multiple consentono di datarne la formazione tra 10000 e 5000 anni 14C BP, durante l'optimum climatico olocenico, per il quale i proxy record esistenti suggeriscono un clima più umido dell'attuale.
L'ampia diffusione di questi suoli, il loro facile riconoscimento in campagna e l'importanza dell'Olocene inferiore nell'area hanno sugge-

rito il loro uso come livello guida. Come tale, essi si sono mostrati di grande utilità nell'interpretazione dell'evoluzione stratigrafica e geomorfica della Regione dei Laghi, e in particolare nella ricostruzione delle fasi di stabilità e instabilità geomorfica attraverso il Pleistocene terminale e l'Olocene. Una tale utilità suggerisce il loro uso come unità pedostratigrafica, un Geosol, dando luogo alla definizione del T'ora geosol.
Tuttavia, gli standard correnti, o in discussione, pongono dei problemi di fondo. Il T'ora geosol non può, al momento, essere formalizzato poichè, nella attuale stratigrafia di riferimento, non è sepolto. In ogni caso, questo suolo è assai più frequente ed utile in forma relitta che non sepolta.
In base alla versione attualmente in circolazione del Glossario INQUA di Paleopedologia, il T'ora geosol non può essere definito un paleosuolo, essendo datato all'Olocene. Tuttavia, le ricostruzioni paleoclimatiche generalmente accettate per le aree tropicali evidenziano variazioni climatiche, durante l'Olocene, dello stesso ordine di grandezza registrato in generale attraverso il Tardo Pleistocene. Sembra quindi piuttosto arbitrario, almeno per le aree tropicali, limitare il concetto di paleosuolo all'Olocene quando, come dimostrato dai nostri risultati, suoli olocenici possono avere altrettanto o più valore dei suoli pleistocenici per le ricostruzioni paleoambientali.

Key-words: Palaeosols, Holocene, palaeoenvironment reconstruction, Main Ethiopian Rift, Ethiopia
Parole chiave: Paleosuoli, Olocene, ricostruzione paleoambientale, Main Ethiopian Rift, Etiopia

INTRODUCTION

The Lake Region (Main Ethiopian Rift, MER, fig. 1), is characterized by recent intense tectonic and volcanic activity, and marked climate changes. The presence of an endoreic lacustrine system made the area highly suitable for palaeoclimatic reconstructions based on lake levels. The first comprehensive reconstruction of Holocene lakes level fluctuations is due to Street (1979), also basing on previous work by Haynes and Haas (1974), Geze (1975) and Laury and Albritton (1974, 1975). Chronology was refined by Gillespie et al (1983), while more details and a general revision were presented by Alessio et al. (1996). The present state of knowledge is summarized in the diagram of Fig. 2. The most conspicuous features are the rapid oscillations of the first half of Holocene, when lake levels were often much higher then present. The last, and major, high stand occurred about 5 14C ky BP, after which a general declining trend set in.

An outstanding finding of an integrated soil survey and Late Quaternary evolution study in this area was the presence, over a wide range of parent materials, morphological positions and present climates, of a group of soils sharing major common features. Provisionally and informally, these soils are defined as the T'ora soil type.

The placement of this soil type within current concepts of Palaeosol definition presents unusual problems and a sort of a challenge to presently used or proposed definitions, and is the main subject of this paper.

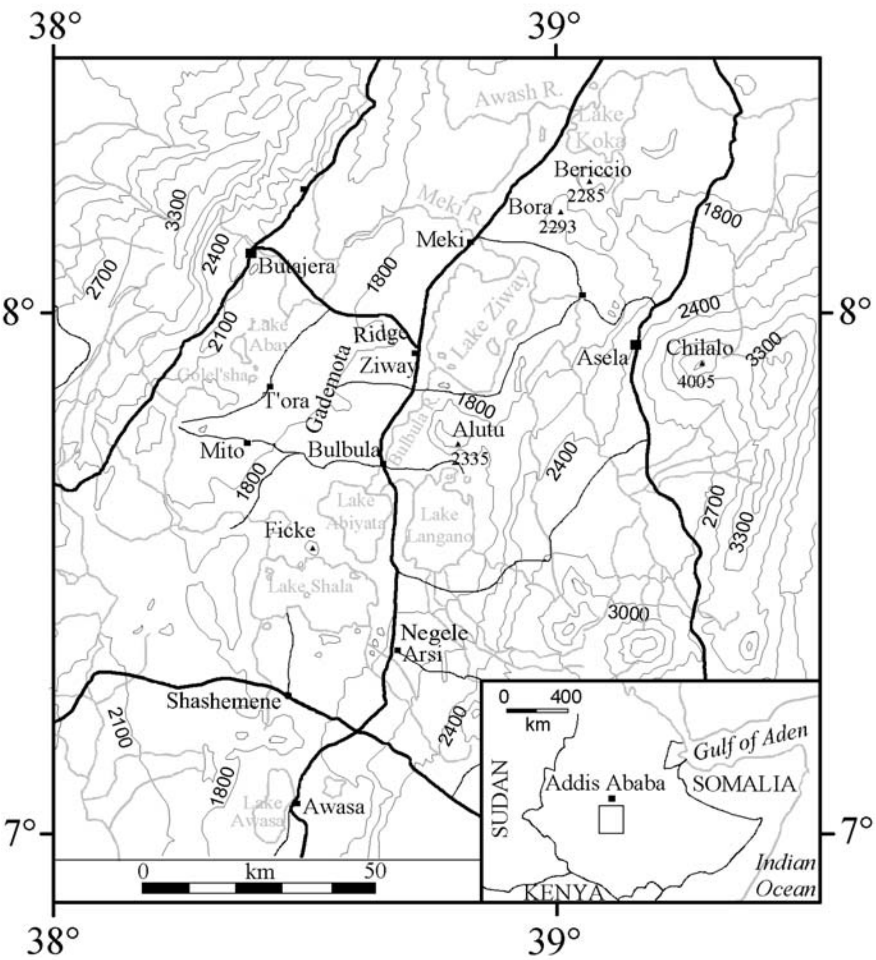

Fig. 1 - Location map and general geographical features of the area

AREA GEOGRAPHY AND METHODS

The MER floor, in the lake region, has a typical elevation of around 1.600-1.700 m a.s.l., but is not uniformly flat; the Alutu volcano rises for about 700 m, while the Gademota Ridge, remnant of a large caldera

(Laury & Albritton, 1975), forms an arc structure 20 km in diameter, rising up to 400 m above the plain. West of the Gademota relief an extended flat ridge, about 5 km wide, stretches NNE-SSW for 80 km, rising up to 2.000 m a.s.l. It is formed by a series of uplifted and/or tilted blocks, making up an horst system that separates the main MER floor from the rift-in-rift depression of the Abay-Golel'sha lakes.

The area can then be divided in two main physiographic sections: the horst system and the MER bottom. This last is rather dry: at Ziway, average annual rainfall is around 700 mm, temperature 18°C and temperature regime isothermic; areas around lakes Abiyata and Langano are probably drier. In the horst system, yearly rainfall varies instead between 900 and 1000 mm, and temperatures are somewhat lower.

Huge volumes of pyroclastic materials, mainly peralkaline rhyolitic ignimbrites, extend on most of the MER (Woldegabriel *et al.*, 1990). In the valley bottom they are covered by fluvio-lacustrine sediments, whose terrigenous component is dominated by pyroclastic materials. These sediments were laid down in a very wide lake which, in some Late Pleistocene intervals and again in early Holocene, occupied most of the MER floor (Street, 1979); the four present-day lakes are the remnants of that ancient lacustrine basin.

The lake region is crossed by two belts of recent tectonic deformation, trending SSW-NNE: the Silti-Debre Zeit Fault Zone (SDZFZ) to the west and the Wonji Fault Belt (WFB) to the east (Di Paola, 1972; Woldegabriel et al., 1990). These belts consist of hundreds of steep normal faults, forming grabens, half-grabens and fault-bounded blocks. The SDZFZ is 5-10 km wide and 80 km long, with very recent basalt effusions, dated 0.13 Myr to present (Woldegabriel et al., 1990).

In a previous pedological investigation, Verheye (1978) studied a transect of soils across five lacustrine terraces. These had been identified by Laury and Albritton (1975) and Street (1979) to the west of Lake Ziway, and numbered I to V from the lowest to the highest. Verheye (1978) noted the very strong contrast between the soils on terraces I-IV, relatively little differentiated among themselves, and the starkly more evolved soil on terrace V. According to absolute datings by Laury and Albritton (1975), terrace I-IV are of Holocene age, IV having been last flooded during the 5 14C ky BP high stand, while terrace V is considered (Street, 1979) of generic Pleistocene age. The main contrast was given by the limited weathering of glassy materials, still dominating soil fabric in terraces I-IV, and the huge amount of pedogenic clays formed within the soil of terrace V.

Very large forms of catastrophic erosion, like gullies and badlands, are prominent throughout the area, representing a major threat to natural resources and local economy. These landforms are nor completely neither easily understood, and are a primary subject of ongoing work.

The whole area was mapped according to Land System principles, basing on both aerial photographs and Landsat TM images. Extensive, integrated, field surveys were led during 4 years for geology, soils and land cover/use. Soil survey, in particular, entailed description of 106 complete soil profiles, more than half of which were analysed.

Geological sections through Late Quaternary deposits were described, suitable materials being dated by both radiometric and AMS ^{14}C techniques. In this paper, anyway, only those stratigraphic aspects relevant to the T'ora soil type are considered.

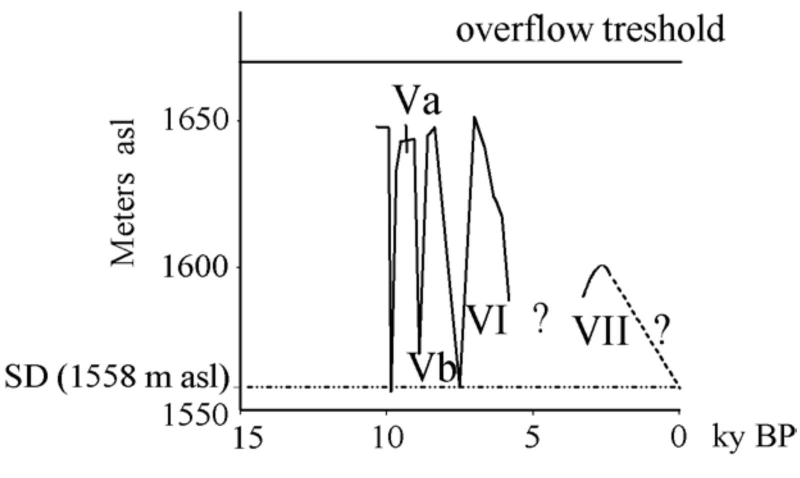

Fig. 2 - Holocene oscillations of MER lakes levels according to Gillespie et al. (1983). SD indicates Shala datum, i.e. level of lake Shala as surveyed by Street (1979); roman numerals indicate Ziway-Shala lacustrine phases.

RESULTS

The T'ora soil (fig. 3, table 1) is essentially a relic soil. Buried exposures are few and not yet completely studied. Its most relevant common properties are:

- neoformation of large amounts of smectites from parent materials dominated by volcanic glass and essentially clay-free.
- presence of a strongly developed petrocalcic horizon, normally found below 150 cm and always below 100 cm.
- presence of a fairly uniform recent tephra addition, making them pedocomplexes (Morrison, 1977) with two clearly identifiable soils.

The upper soil of the pedocomplex, T'ora A, developed from the recent tephra; it is quite homogeneous in texture and weathering degree, as evaluated from clay mineralogy, strongly suggesting that the recent tephra represents a single volcanic phase in a narrow time interval. The recent tephra then gives to the T'ora soil a unique chronological significance, in the sense that the lower soil must have been the surface soil in a specific moment of time. Unfortunately, the recent tephra is too weathered for direct dating by IRSL or similar techniques.

Basically, T'ora A soil is characterized by a Mollic horizon, whose thickness varies significantly in agreement with morphological position, as a result of some redistribution by slope processes. Profiles observed in the western part of the area often show a moderately thick Argic horizon. Consequently, the upper soil is either an Haplic, a Pachi-Haplic or a Luvic Phaeozem. A striking field reconnaissance feature is the C horizon. Pale grey in colour and slightly cemented by silica, this horizon protrudes in natural sections, where it clearly stands out.

The clay fraction of the T'ora A soil is characterized by poorly ordered smectites, representing the weathering product of the ashy materials; kaolinite is also present, as a weathering product of the sanidine component of the parent material. Clay content is below 30%, so that smectites do not express themselves in vertic characters, hampered by the very different physical behaviour of the less weathered ashes.

The lower soil of the pedocomplex, T'ora B, developed from a great variety of parent materials:
- saprolite from the Rift floor ignimbrites;
- slope and alluvial fan deposits flanking the major relief
- reworked pyroclastics of the Gademota formation (Laury and Albritton, 1975, the T'ora soil is at the top)
- the lacustrine deposits of Ziway lake terrace V (Verheye, 1978)
- air-fall tephras over terrace V, related to the Abernosa pumice member of Street (1979).

Notwithstanding this variety, the T'ora B soil has fairly homogeneous characters. It has a very thick Argic horizon, homogeneous in clayey texture and mineralogy but vertically differentiated in other characters. The upper subhorizon (2Btb1) is black, with medium to coarse prismatic structure, cracks and thick clay coatings; it is subacid. Underlying subhorizons (2Btb, 2BC) are reddish brown (7.5 YR), with fine angular blocky structure, plentiful pressure faces and thin, though continuous, clay coatings; they are often subalkaline, with ESP between 6 and 14. Main lateral variations concern total thickness, vertic features and Petrocalcic horizon expression. Thickness is mostly linked to parent material, the deepest sola being found on slope deposits. Vertic features appear in the lower part of the Btb1, and are associated with morphological position in a complex way. They are typical and strongly expressed, with sphenoid structure, in the largest depressions to the east of the horst hills; they are not normally found, instead, in the local grabens inside the horst system. The local grabens actually have more relief energy than the larger depressions, and presently experience more dramatic shifts in hydrological conditions. Morphology of the Petrocalcic horizon is linked to parent material, but in the south-western area, the moister one, this horizon grades into a Calcic with large, hard concretions. Calcic and Petrocalcic horizons are not found in any other soil of the surveyed area.

T'ora B soil classifies as a Hyposodic Vertic or Profondic Hyposodic Luvisol. Use of the Soil Taxonomy allows sometimes to express the Petrocalcic horizon, and some pedons classify as Petrocalcic Paleustalf, but most sort out as Typic Paleustalf; Vertic subgroups cannot be defined in buried soils according to the Soil Taxonomy.

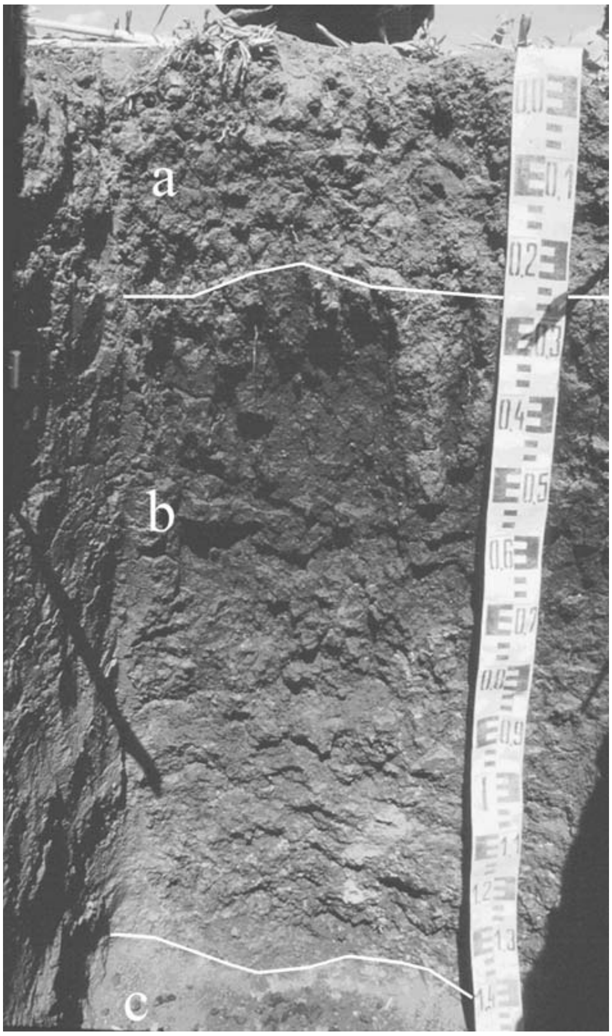

Fig. 3 - a T'ora soil profile; in this particular observation, the upper soil of the pedocomplex is a stable phase (Luvic Phaeozem); the lower soil shows some vertic features (slickensides), just to right of letter b).
a) upper soil; b) lower soil; c) Petrocalcic horizon

CHRONOLOGY

In the MER bottom, the T'ora soil is incompatible with the present semiarid climate. In this area, it is found on terrace V of Lake Ziway; a major pedogenetical hiatus, first described by Verheye (1978), and confirmed by our survey, separates it from soils on the lower terraces, represented by Phaeozems or Cambisols.

Chronological placing of the T'ora soil is presently based on multiple stratigraphical, geomorphological and palaeoclimatic evidence. A stratigraphic section in the colluvial apron of the Gademota ridge (fig. 4) clarified several ambiguities. Lacustrine sediments dated 30 14C ky BP mark, given their elevation, the most recent known date for flooding of Lake Ziway terrace V, but a successive and higher, as yet undated, lacustrine phase appears. The T'ora soils on terrace V cannot then have started developing before 30 ^{14}C ky BP, and possibly much later. Age of lake Ziway terrace IV is well known (Laury and Albritton, 1975; Street, 1979; Gillespie *et al.,* 1983); it was last flooded about 5 ^{14}C ky BP. In the Gademota section, the T'ora soils are found on top of the oldest vertical sequence of sediments, and presently at the surface. Two strong erosional unconformities follow; deposits above the second unconformity were dated about 4600 ^{14}C y BP.

On the surface represented by the top of the deposits between the two unconformities, a well developed Luvisol is visible. It is clearly differentiated with respect to the T'ora soil, as it lacks both the Petrocalcic horizon and the tephra addition. The same Luvisol is found directly burying the whole T'ora soil pedocomplex in another section in the Abay basin, to the west; this section is presently only dated and studied for the very recent part. Soils above the second unconformity in the Gademota section are never more developed than Cambisols or Phaeozems. In all other cases, when the T'ora soil is found over dated deposits, these are always known to be of Pleistocene, and never of Holocene, age.

There is then multiple evidence that the T'ora soil developed on the geomorphic surfaces existing after the very aggressive erosional phase corresponding with the Last Glacial Maximum and the terminal Pleistocene, when climate in this area is known to have been semidesertic (Gasse and Street, 1978). This is supported by the evidence that T'ora soil formed over very extensive, complex colluvial and alluvial fan buildings around the major relief. The T'ora soil is then presently understood to have formed during the Holocene climatic optimum, between 10 and 5 ky BP, when climate in the area is known to have been quite moister than present.

STRATIGRAPHIC AND PALAEOENVIRONMENTAL SIGNIFICANCE

The wide spread of the T'ora soil, its easy field recognition and the importance of early Holocene in the palaeoenvironmental history of the area prompted its use as a key level. As such, the T'ora soil was extremely useful in the interpretation of the geomorphic evolution and of undated sedimentary successions in the Lake Region. Specifically, it was of great help in reconstructing phases of landscape stability and instability throughout Late Pleistocene and Holocene.

There are several reasons to interpret variations in T'ora B as expressions of a limited amount of lateral, sin-pedogenetic ("pedofacies"), differentiation. Vertic features expression resemble a catenary sequence, weak and inconsistent with respect to present relief. Inconsistency is reconciled by reconstructions of recent tectonic activity, according to which relief, in the horst system, has been enhanced in late Holocene by dislocations along riftwise fault swarms. Slope processes taking place in consequence of this relief rejuvenation are instead well marked in the lateral differentiation of T'ora A, the present surface soil in this phase. T'ora A can clearly be divided in stable (Argic Phaeozems), eroded (Haplic Phaeozems) and cumulic (Pachi-Haplic Phaeozems) phases, perfectly consistent with present slopes in the horst system.

Expression of the Petrocalcic horizon varies consistently with the modern rainfall gradient. In the MER such gradients, however, are controlled by the orographic influence of the main escarpments, and their geographic structure should not have varied greatly during the Late Quaternary, except for changes in abso-

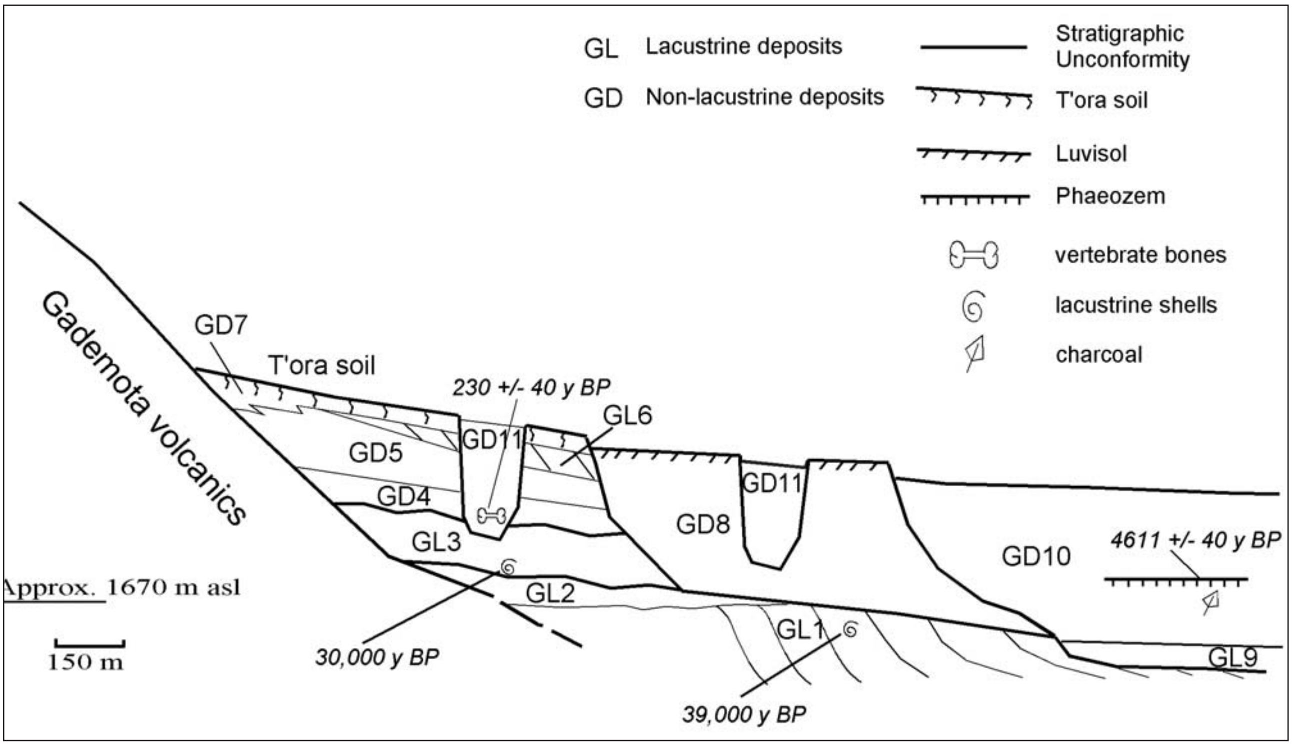

Fig. 4 - Summary of the Gademota north stratigraphic section, with datings

lute rainfall values and intensity of the gradient itself. The present distribution of the T'ora soils leads, in fact, to suspect that, in moister Holocene intervals, the gradient ought have been less intense than at present. This is suggested by the very limited differences between T'ora soil occurrences in the presently dry MER bottom and in the presently moister horst hills. The early Holocene increase in rainfall appears then to have been greater in the central than in the side portions of the MER bottom. Such kind of differentiation of early Holocene from modern climate is also expressed by the huge pedogenetic hiatus separating the T'ora soil from soils on Ziway terrace IV, while a much lesser hiatus is evident in the presently moister areas.

Matching the occurrence of the T'ora soil with observed landforms, clear phases can be distinguished in the geomorphic evolution of the area. The Late Pleistocene was marked by the build-up of massive colluvial aprons and alluvial fans, smoothing the links between high-lying and depressed areas. These surfaces, covered by the T'ora soil, have undergone a complex Holocene evolution. Most colluvial aprons underwent multiple cycles of incision and filling up of large, gully-like channels. Alluvial fans apparently remained quite stable until recent times, when, in most cases, the build-up of an upper storey, burying the T'ora soil surface, is observed. Recent tectonic activity in the horst system has instead consistently brought about the partial destruction of the T'ora soil surface and the build-up of complex response colluvial aprons at the base of the escarpments.

DISCUSSION

The use that could be made of the T'ora soil in studying the Late Quaternary history of the area would suggest its definition as a pedostratigraphic unit, a Geosol (Morrison, 1977), giving birth to the T'ora geosol definition. However, checking definitions with current, existing or in discussion, standards revealed basic problems.

According to NACSN (1983), the T'ora geosol cannot presently be formalized as, in its present reference stratigraphy (the Gademota section), it is not buried. A suitable stratotype (the Abay section) has been located but not yet fully described and dated. However, the T'ora geosol is mostly relic, and rarely exhumed, in its surface occurrences, so it is questionable whether it would satisfy the NACSN requirements even after description of an adequate stratotype.

According to the present draft of the INQUA Palaeopedology Glossary, the T'ora soil cannot be defined a Palaeosol, because it formed in Holocene.

The consensus palaeoclimatic and chronological framework for this area, as for many other tropical areas, considers the Holocene as far from a homogeneous period. It is agreed that climatic variations during the last 10k years are of a similar order of magnitude to those registered throughout Late Pleistocene, with the only exception of the Glacial Maximums. It appears then rather unsatisfactory, at least for intertropical areas, to limit the Palaeosol concept to the Pleistocene when, as shown by our findings, Holocene soils may be as useful, or more useful, than older soils in palaeoenvironmental reconstructions.

Generally speaking, excess formalism in definitions appears disadvantageous in a field like Quaternary Sciences, where totally new findings and paradigm upset are the order of the day.

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