Report on a visit to Brazil in October-November 2009 by Professor Michael F Thomas, FGS, FRSE, Emeritus Professor in Environmental Science at the University of Stirling, Scotland, U.K.

A. Itinerary and Schedule

28/29 October: outward journey flying Edinburgh/London/São Paulo

30 October: Lecture at Institute of Geography, University of São Paulo, on ‘Geodiversity and Landscape Sensitivity’ *abstract below

31 October: Fly Sao Paulo - Manaus, overnight in Manaus

01 November: Fly Manaus – Barcelos, to join river boat for scientific expedition to Rio Negro

01/02 November: - On board boat at Barcelos
- 01 Nov – visits to river-bank sections in Barcelos area
- 02 Nov – use of outboard to visit distant sections in River Demini, left bank tributary of Rio Negro
- 03/04/05/06 – Travel by river boat upstream to Camanaus, then by road to São Gabriel da Cachoeira

06/07 November: Stay Hotel in São Gabriel

06 November – By outboard and forest track to inspect pre-dug soil pit

07 November – Travel Sta Gabriel to Manaus (overnight)

08 November – Travel Manus-Brasilia-Belo Horizonte

08/09/10 – Based in Belo Horizonte
- 09/10Nov – field excursions in Quadrilátero Ferrifero

11November - Lecture at Institute of Geography in UFMG on ‘Geodiversity and Landscape Sensitivity’
- 11Nov Fly to São Paulo (GRU)


B. Lecture Abstract: Landscape Sensitivity and Geodiversity

The links between biodiversity and geodiversity have often been seen through the fossil record, and wider issues of conservation are usually based on geological data bases, as in Brazil (but also in England, Poland and elsewhere). Yet much geomorphological research is directly relevant to geodiversity studies: through an understanding of earth surface systems and their operation over
different spatial and time scales. The links between biodiversity and geomorphological diversity are also often direct and important, but can be complex and scale dependent. Applications of the concept of geodiversity to geoconservation and geotourism are developing as important aspects of applied earth science, but the contributions of geomorphology, and of a wider geographical analysis, to the field have been limited in scope and depth.

Related ideas concerning geomorphological complexity have been a focus of some recent papers, and complexity is seen as a function of the operation of non-linear dynamical systems. Theoretical discussions have included fractals and chaos theory. In this presentation the sensitivity of landscapes in the humid tropics to change will demonstrate the importance of weathering to landscape sensitivity on different timescales, and its significance in developing and maintaining geodiversity. The impacts late Quaternary climate changes on sensitive, weathered landscapes will also be emphasised and simple models for predicting changes due to climate forcing presented.

C. Report on field observations and published research

Observations were made regarding the relations between geology, geomorphology and soils, initially over the Içá (Madre de Dios) Formation, then upstream over the basement granites and close to the junction between the two. The field sites were selected by Dr. Bueno and Professor Nadia Nascimento, to illustrate soil profile development and in particular the processes involved in the formation of Podzols. The following observations and comments also make reference to the scientific papers listed. Many of these papers can be characterized as studies examining the relationship between Acrisols (Latossolos, ferrallitic soils) and Podzols (Spodosols); others concern the geomorphology and Quaternary climate changes. Soil terms used are from the World Reference Base for Soil Resources 2006 by ISRIC.

Soil patterns and relations to geomorphology

Much interest has been generated by the lithologic, spatial and topographic relationships between Oxisols/Acrisols and Podzols in the Rio Negro area, and also in French Guyana (Lucas et al., 1987). These authors postulated that, over crystalline rocks, lateritic soils became transformed to Podzols by loss of clay at depth, in the hydromorphic zone, forming a white, sandy horizon that spread laterally from the interiors of low plateaus and, because of a loss of volume, encroached progressively on the upper soil horizons, ultimately intersecting the ground surface. Over coastal plain sediments, however, strong leaching and loss of clays (lessivage) progressed from the surface down profile, developing hydromorphic conditions at depth without ground surface lowering. Relationships in the Rio Negro area, over the Barreiras Formation sediments, were considered in terms of a slope toposequence in which a podzolic mantle extended progressively upslope. Bravard and Righi (1990) also considered the slope relations between Oxisols/Acrisols and Podzols and observed the sandy character of the lower members of the sequence, which they though might reflect: 1) coarser sediments towards the base of the slope; 2) colluviation of sand from upslope; 3) direct transformation of the parent materials; or 4) progressive transformation of Acrisols to Podzols, noting that the quartz in both soils had a common inheritance. Subsequently Dubreucq and Volkoff (1998) conducted more detailed investigations in the Rio Negro area and proposed a process of lateral transition of Oxisols to Podzols. They state:

‘The soil transformations highlighted by the catena studies are: i. the gradual clay eluviation and oxide removal from the hilly landscape; ii. the destruction of the Oxisol mantle and the
formation of albic and spodic horizons, and iii. the destruction of the sandy mantle in the plains. These processes are thought to exert a direct influence on the landform evolution. The multi-convex landform with Oxisols and Ultisols can be gradually transformed into a smooth undulating landform with Ultisols and Spodosols. The ferrallitic plain with oxisols can be gradually transformed into a flat surface with hydromorphic spodosols’ (p268).

More recent studies in the Rio Negro include those by Nascimento et al (2004, 2008) and by Fritsch et al (2009), which trace Fe-III movement and its separation from Al species within the profile. The Fe-III comes from the Acrisols and is transferred down profile and then exported along hydraulic gradients at depth, under reducing, hydromorphic conditions. Nascimento et al (2008) state: ‘Iron is released by the reductive dissolution of Fe oxides, mostly in the Bg horizons of the upslope Acrisols. It moves laterally under the control of hydraulic gradients and migrates through the iron-depleted Podzols where it is exported to the river network’ (Abstract).

The more recent studies have not sought to verify or refute specific hypotheses of progressive transformation of Acrisols to Podzols by the expansion of podzolic soils across the landscape over time, but their findings are certainly supportive of the general hypothesis that the podzolisation process of Fe and Al depletion acts to destroy the Acrisol profile. Dubroeucq and Volkoff (1998) indicate this as a progressive process of landform/soil evolution and the question of external climate and vegetation change is not explored. At the key site visited near São Gabriel, where a soil pit had been opened, the podzolisation front can be seen overprinting an older ferrallitic profile. The boundaries are sharply cross cutting and the morphology of the soil profile does not appear to me to indicate a gradual process of transformation within the Acrisol profile (see below). The possibility that a step change in the environment of soil formation, possibly as a consequence of climate forcing seems likely.

Hypotheses and processes to explain soil distributions and transitions thus fall into the following categories:

1. Control by lithology, mainly through its influence on soil hydrology
2. Development of toposequences, associating soil character with slope position
3. Chemical denudation, including lessivage and loss of volume at depth, leading to the formation of depressions within which hydromorphic conditions lead to transport and further dissolution of Fe-III and Al. This hypothesis implies some control over topography by soil-forming processes.
4. A step change in soil forming processes leading to increasing podzolisation acting on a regional Oxisol/Acrisol soil cover.

Evidence for environmental changes over long timescales (10³-10⁶ y) was observed in terms of: 1/ soil processes and profile changes; 2/ occurrence of river-bordering palaeodunes to heights above 24m; 3/ river terraces, mapped by Latrubesse and Franzinelli (2005), and by Rosetti et al (2005) in the Solimoes, record changes in river palaeohydrology and by extension soil palaeohydrology; 4/ remnant surface iron nodules (pisoliths) and duricrust fragments under rainforest. The regional geomorphology contains a widely recognized, Ucayali planation surface with an age span of 9.5-3.2 Ma (Campbell, 2008), while a recent study of RIDs in kaolinites taken from lateritic soils in this area indicates ages of 10-6 Ma (Balan et al, 2005). This suggests that the widespread lateritic cover derives from a weathering mantle developed across a late Miocene plain, although stillolder elements of the relief (inselbergs, tepuis, pediments) coexist with the extensive planation surface.
Geomorphology of the middle and upper reaches of the Rio Negro

Current understanding of the evolution of the Amazon Basin (following Campbell et al. 2006) indicates the formation of an extensive planation surface (Ucayali) dating to the late Miocene (9.5-9.1 Ma), which was overlain by sediments of the Madre de Dios or Içá Formation post 9.1-ca 3.1 Ma. Initially rapid erosion led to conglomeratic sediments, but these gave way progressively to sands and then muds. The lower member (A) is described (p197) as: ‘the basal conglomerates (are) different types of aggradational basin fill deposits that moved as a rapidly passing front away from the Andes over the Ucayali Peneplain, probably carried by large scale, high energy, braided rivers with marked seasonality. Deposits of this depositional phase would have leveled the landscape, filling first the topographic lows formed during formation of the Ucayali Peneplain, but not necessarily covering topographic highs. The Upper part of this sequence is thought to represent sediments from a mega lake (Lagos Amazonia) containing palaeodeltas. Campbell at al., (2006, p206) conclude: ’compared to the Amazonia forests that cover the modern landscape, lowland Amazonia in the late Neogene was probably a vast complex of shallow mega-lakes surrounded by swampy, grassland savanna that endured months-long periods of seasonal inundation. It is also reasonable to expect that climatic cycles leading to extended periods of exceptional precipitation could have produced years-long periods of inundation.’

From geomorphological viewpoint there appear to be ambiguities concerning the source of the coarse sediments of the basal Içá Formation in Brazil. At this time the Amazon drainage was still westwards towards the Pacific, and sediment sources may have been within the basement areas, and the commonly encountered clay-ball conglomerates must have been of local provenance. If weathered basement (crystalline) outcrops were a major source for this material, substantial relief above the Ucayali ‘peneplain’ must have survived or been created perhaps by uplift of the northern rim of the basin. The present-day basement outcrop may be partly exhumed with much its saprolite cover. This has then been removed largely by fluvial erosion to reveal the details of the basal surface, which in turn now control the channel depth and morphology in the upper Rio Negro.

Climate changes on different timescales have impacted on the Rio Negro basin. From Campbell et al (2006) and other authors it appears that the Miocene climates were variably seasonal and in the late Neogene were humid enough to maintain mega lakes, prior to the establishment of the Atlantic drainage. Our recognition of duricrusts and pisoliths (on pediments from residual relief forms according to Bueno, personal communication, photos below).

A  Fe pisoliths exposed on forest floor
B  Fragments of Fe duricrust on forest floor
(card is 10 cms wide)
suggests soil formation under seasonal conditions in the past, but whether these survive from the Ucayali surface is not known, and the residual relief is likely to be older. The relief of the Upper Rio Negro increases upstream with inselbergs and inselberg ranges.

Figure from Rosetti et al., 2005.

Evidence from the Pliocene and early Pleistocene appears absent from much of the literature (?), and there is still uncertainty surrounding the late Pleistocene climates of western Amazonia. But evidence of climate change comes from palaeodunes, river terraces and the soil profiles (above) Latrubesse and Franzinelli (2005) recognized two main terrace levels and found evidence of abundant sedimentation in the Middle Pleniglacial (Marine Isotope Zone, MIS3, ca (60) >40-28 ka). Van der Hammen et al (1992) recorded similar events in the Caquetá River (Colombia) and this signature is widely found elsewhere in the humid tropics. According to Latrubesse and Franzinelli (2005), the lower terrace dates from around the LGM to ca 12.6 C¹⁴ BP (but there is no date brackets the onset at the LGM). In addition, Rosetti et al (2005) have proposed four terrace levels in the Solimões-Amazonas River, extending into the Rio Negro basin (see Figure above). We observed palaeodunes bordering the right bank of the river (S 00 29 14.7 / W 064 49 36.9) and these rise to 24 m, with a possible higher occurrence farther from the bank (35 m). Dunes in the Rio Negro were dated by Carneiro Filho et al (2002) using TL dating techniques, with interesting results (but because TL dates are large samples, burial dates for individual grains are not possible. The use of the single grain OSL protocol could refine the picture). If the dates for the dunes and the terraces are tabulated together an interesting picture emerges:
Solimões terraces1  Rio Negro-Tiquié2  Rio Negro dunes3
Terraces

Q1 43.7-37.4 >40-28/27 32.6-28
Q2 27.2 LGM
17.2-12.7
13.4 - ?*
10.4-7.8
Q3 5-2.5
Q4 recent 280-130 y


*Latrubesse and Fanzinelli suggest 13.4- 4 ka, but a single date of 4 ka comes from the Curicuriari river and the inference that this belongs to the same unit seems tenuous.

The available data indicate that dune formation alternated with fluvial sedimentation, which is not unexpected. But the overlap towards the end of the Middle Pleniglacial is puzzling, if the dunes were formed on the Q1 terrace. But the distances between samples and the very few dates obtained are reasons for considerable uncertainty regarding correlations and interpretation of the distribution. The dates, however, show agreement with the view that abundant sedimentation characterized rivers in Amazonia during the Middle Pleniglacial and that this phase ended around 30/27 ka. Lack of data from the period of the LGM is common within many proxy records from Amazonia (Ledru et al, 1998) and remains unexplained, though a regional change in the wind regime with a slackening of wind strength might be argued, along with reduced rainfall.

The nature of geologic controls affecting the Rio Negro channel were addressed by Latrubesse and Franzinelli (2005). Figures 2 and 5 from this paper are reproduced below. Our investigations began in Barcelos (BA on map), and included visits to local sections, and by outboard to the middle Demini River. According to their interpretation Reach III (Fig. 5) is strongly influenced by structure and by neotectonic movement, faulting being particularly influential at the junction of the Demini River with the Rio Negro near Barcelos. Neotectonics rather than a rising base level from Solimões sedimentation downstream probably influences the anabranching pattern found in reach III. A right-bank section a few km downstream from the Barcelos landing area clearly illustrates disturbance of the exposed sediments (Içá Formation), which are warped/draped over a probable fault. Sediments in this section are mainly pale muds, but with sandy beds (channel deposits) and pockets (?) of gravel. Some iron staining has resulted from seasonal drying of the profiles during periods of low water. Higher, terrace deposits show more profile development, with the appearance of Acrisols, plus some iron staining close to the water level.
A visit upstream and into the Demani River showed a marked transition from the anabranching pattern of the Rio Negro (with mid-channel bars and suppression of lateral migration) to the Demani channel, which progressively changes towards a meandering pattern with eroding banks and deposition of point bars. Farther upstream the Demani displays some stabilization of bars and banks by vegetation. A section (river terrace) displayed deep podzolisation in the 3m + profile.
As shown in the photographs above. Below the illuvial horizon some gritty material may be inherited from granite (transported grus?). It also overlies a white kaolin (section is disturbed and thicknesses difficult to define). The origins of this material may be processes in the hydromorphic zone deep in the profile, but the possibility of a nearby basement source has to be kept in mind.

In the two photographs (below), the long section (A) shows characteristic white colouration in what appear to be low terrace deposits. The upper part of the section contains (recent) dark grey overbank clay/swamp (active floodplain?) deposits, which may overlie and partly cut out the underlying bleached sediments forming the low terrace. Possible sedimentary structures towards the base are likely to be part of the Içá Formation. In the lower photograph (B) the reddened soil profile (probable Acrisol) appears to occur beneath a low hill that stands above the surface at the left. This may be a bedrock outcrop, deeply weathered and with a ferrallitic soil. It is not known whether crystalline basement outcrops in this area.
Other observations come from the Rio Negro channel and sections.
In particular, the configuration of the basement (granite) rock surface, which has been largely stripped of a saprolite cover to expose the basal weathering surface (photo above) dominates the channel morphology. The river appears to flow over this surface without causing obvious modification. Weathered cores, now forming surface boulders of varying size remain perched on convex (domed) rock exposures. These display many small weathering pits but no fluvially eroded potholes. These may be formed at depth along an inner, concealed channel. This phenomenon was observed by Tricart (1959), and Zonneveld (1972) used the term *sula* and *sula complex* to describe the channels and rapids that resulted from the rivers flowing in a largely non-erosive manner between highs in the basal weathering surface. The scale of the phenomenon in the middle-upper Rio Negro is such that the river channels effectively form a drowned etchsurface. The basement rocks bordering the river outcrop mainly as low ‘whaleback’ forms that emerge from a saprolite cover, and appear to extend away from the channels as a low relief surface or *etchplain* (for references see Thomas, 1994). This is entirely consistent with the observed importance of chemical denudation and extreme weathering represented by the acrisol-podzol soil complexes.

Higher up the Rio Negro close to São Gabriel and on basement rocks (or deposits derived therefrom) a large soil pit had been dug for Dr Bueno and this illustrates an interesting phenomenon (see photo below). Here the podzolisation process/front can be seen penetrating (overprinting) an older reddened soil (acrisol?). Possible explanations that can be given for this phenomenon include: 1/ Auto response to prevailing conditions without important environmental change. This implies that the soil forming processes transform the ferrallitic soil in a process of continuous evolution; and 2/ Soil forming processes have been altered as result of environmental change, which might include rainfall regime and amount, groundwater hydrology, and vegetation cover. The latter is favoured here because the podzolisation front appears to be overprinting the lateritic soil with sharp, cross-cutting boundaries. It does not seem likely that this sequence could result directly from changes to the landform since both soils depend on free drainage to produce the observed horizonation. But more complex relationships possibly exist within a wider area and the site occupies a depression in the landsurface.
If the date of onset of overprinting (podzolisation) of the lateritic soils could be established within defined limits then this would be important (this assumes that the profiles do indeed indicate an important environmental change).

Summary Comment

No view of the development of the Rio Negro river basin can proceed without addressing the geological and structural history and the evidence of neotectonics. Progress has been made in this respect during the last five years. Although planation has taken place during the Cenozoic and there is no case (for me) to challenge the existence of a Miocene Ucayali surface, it is necessary to use available models of long-term geomorphic development to understand the relief and the morphology of the Rio Negro channel itself. In the upper reaches exposure of the basal weathering surface is evident in some detail and the surrounding terrain has the character of an etchplain, punctuated by inselbergs and other hills. Climate/vegetation changes in the Rio Negro basin have almost certainly been frequent and at time profound, but we so far have rather little knowledge of the chronology of these events. Periodic changes in the palaeohydrology of the river, together with episodes of dune formation during the late Quaternary must have implications for the interpretation of soil profiles according to the age of the parent materials (terraces, Miocene sediments, basement outcrops with saprolite cover). The dating of kaolinites to the late Miocene suggests that the older ferrallitic cover may have formed (in part) on the Ucayali Surface. Where an advancing podzolisation front is found it does not appear to be relict from the Pliocene or even early Quaternary. If this is the case, then the importance of Quaternary climate and vegetation changes in this equatorial rainforest area of the Amazon basin have probably been of great significance. Our knowledge of the chronology and understanding of the severity of these changes, however, remain uncertain.

References consulted


Michael F Thomas
Stirling
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