SOME REMARKS ON THE BASES OF LANDSCAPE EVOLUTION THEORIES

ALGUMAS NOTAS SOBRE O EMBASAMENTO DAS TEORIAS DE EVOLUÇÃO DAS PAISAGENS

José Antonio Urroz Lopes

Como é fato conhecido, não são as situações normais mas sim as excepcionais que fazem evoluir a paisagem.
Cruz, 1974, p. 103
The dialectics of the interrelations between stability and instability means that instability defines and explains development processes better than stability.
Trofimov and Phillips, 1992, p. 210
It is scarcely surprising that one recent outgrowth has been that of the so-called "neo-catastrophist" school (which, it can be argued, has merely rediscovered the erratic sequence of high- and low-magnitude events that is earth history).
Kennedy, 1992, p. 248

ABSTRACT

The author briefly discusses the evolution of geomorphological thinking between uniformitarism and catastrophism and the classical theories of landscape evolution: the conclusion is that they are all based on the concept of struggle, between climate as active element and lithologic framework as passive one, without considerations on the effects of the mechanical properties of the lithological-pedological masses involved. In sequence, are presented and discussed many papers, written around the world, dealing with "catastrophic" events of landscape evolution, in variated climatological-lithological contexts, and the author develops the concepts of "stability limiting curves" and "stability fields" and concludes that all the features of the landscape are resultants of the laws that command forces and resistances inside the rock and soil masses.

Key-words: landscape, versants, evolution and stability, stresse and strains, mass mouvements.

RESUMO

É apresentada uma breve discussão sobre a evolução do pensamento geomorfológico a partir dos conceitos uniformitaristas e catastrofistas e sobre as bases das teorias clássicas de evolução das paisagens, em que se busca mostrar que as mesmas sempre configuraram o efeito de um determinado contexto climático como elemento ativo sobre um outro contexto, o litológico-pedológico como elemento passivo, sem levar em consideração o comportamento mecânico das massas de rochas e solos envolvidos. Na seqüência, o autor apresenta e discute sua própria experiência e trabalhos publicados em contextos climático-litológicos os mais diversos, que tratam sobre eventos catastróficos de reesculturação da paisagem via movimentos de talude.

Das conclusões retiradas das descrições desses eventos e de suas causas, tais como deduzidas pelos diversos autores, conclui-se que os movimentos de massa são uma constante em todas as condições climáticas, sendo o agente predominante da esculturação do relevo em muitas delas; que os escorregamentos resultam de um desbalanço entre forças ativas e resistentes que atuam nas massas de solos e rochas; que eles têm como gatilho, eventos tais como grandes chuvas, terremotos, desflorestamentos, modificações da geometria das encostas por agentes naturais ou humanos, surgências de água subterrânea, ação do gelo/degelo etc.; que a energia inicial para vencer a resistência no interior das massas é fornecida sempre por soerguimento de origem tectônica, mas que uma vez estando esta disponível, o caminho para os escorregamentos pode ser dado por aumento dos desníveis ou por degradação dos parâmetros de resistência mecânica das massas.

A partir daí, utilizando conceitos consagrados na Mecânica dos Solos e suas próprias observações de campo, o autor conclui que todo talude natural ou segmento de talude, definido por dois pontos extremos, ou seja, toda a feição natural não plana, constituída por massas de rochas e/ou solos, possui um "campo de estabilidade" definido por duas "curvas limite de estabilidade", uma côncava e outra convexa: sempre que a geometria de um talude ou segmento de talude se situar no interior desse campo, permanecerá estável e sempre que tender a sair fora do mesmo, se instabilizará (figura 1a). Mais ainda, o autor mostra que a instabilização pode dar-se tanto por modificação na geometria do talude, como por degradação dos parâmetros de resistência do(s) material(is) envolvido(s) e conseqüente mudança no(s) campo(s) de estabilidade (figuras 1b e 1c).

Com base na forma das curvas limite de estabilidade, particularmente na da curva côncava que é sempre a que resulta das instabilizações, o autor explica a forma dos sólidos instabilizados (figura 2) e das cicatrizes por eles deixadas nas encostas e que constituem anfiteatros (figuras 3 e fotos 3, 4, 5, 7 e 8) que podem ou não estar embutidos em vertentes convexas. Em condições de clima quente e úmido, as vertentes originalmente tendem a uma forma convexa por ação da erosão que retira rapidamente o material alterado, particularmente nos vértices e arestas, fazendo com que as vertentes comportem-se como "controladas pelo intemperismo". Gradativamente, entretanto, a vegetação se instala, protegendo o regolito formado e tornando mais efetiva a ação do intemperismo, o que significa que as vertentes se tornam "controladas pelo transporte". Essa acumulação, entretanto, não pode manter-se indefinidamente em razão de que a resistência mecânica do material tende a ser ultrapassada em algum ponto (ou seja, o seu o campo de estabilidade é ultrapassado) e as vertentes, ou segmentos das mesmas, evoluem para côncavas via escorregamento, usualmente pela degradação dos parâmetros de resistência na passagem de rocha para solo, mas podendo também, dar-se, por exemplo por aprofundamento da drenagem.

Esse modelo, originalmente desenvolvido (LOPES, 1995, 1997) para as condições de clima quente e úmido (fotos 1 a 4), é extendido às condições de climas glacias (fotos 5 e 6) e áridos (fotos 7 e 8). No caso de climas glaciais, similarmente ao que ocorre no caso de climas quentes e úmidos, a acumulação de neve produz escorregamentos nas massas de gelo que afetam as rochas sotopostas e que geram os anfiteatros glacias (fotos 5 e 6), em tudo semelhantes aos provocados por escorregamentos nestes últimos (fotos 1 a 4). No caso de o clima ser árido, as vertentes tendem a permanecer côncavas em função da ação enérgica da erosão que as leva ao estado de "controladas pelo intemperismo" e, portanto, no limite inferior do campo de estabilidade. Nessas condições, fica claro que a forma das vertentes – côncavas ou convexas – não é resultante de uma determinada condição climática, mas sim representa um estágio evolutivo, das mesmas, dentro dessa condição e que toda a evolução do relevo é comandada pelas leis que regem a ação das forças trativas e resistentes no interior das massas de solos e rochas. Nesse modelo, o papel reservado ao clima é o de responsável pelo tipo e velocidade da mudança de rocha para regolito e pela acumulação ou rápida remoção desse material. Desse modo, a ação do clima "prepara" as encostas no sentido de levá-las a aproximar-se dos limites dos seus campos de estabilidade, além de ser a responsável pelo tipo de "mecanismo-gatilho" que as levará à instabilização.

Palavras-chave: paisagem

RESUMEN

El autor hace una breve discusión sobre la evolución del pensamiento geomorfológico entre el uniformitarismo y el catastrofismo y acerca de las teorías clásicas que tratan de la evolución del paisaje: concluye que todas esas teorías se basean en el concepto de lucha entre el clima como elemento activo y las rocas y suelos como elementos pasivos, sin ninguna consideración acerca de las efectos de las propriedades mecánicas del conjunto litologico-edafologico envolvido. A seguir, el autor presenta y discute trabajos escritos en muchos lugares del mundo que tratan de eventos catastróficos de evolución del paisaje, en diferentes contextos de climatología y litología donde, utilizándose de conceptos como "curvas límite de estabilidad" y "campo de estabilidad", concluye que todas las formas que componen el paisaje, resultan de la acción de las leyes que comandan fuerzas y resistencias en el interior de las masas de suelos y rocas.

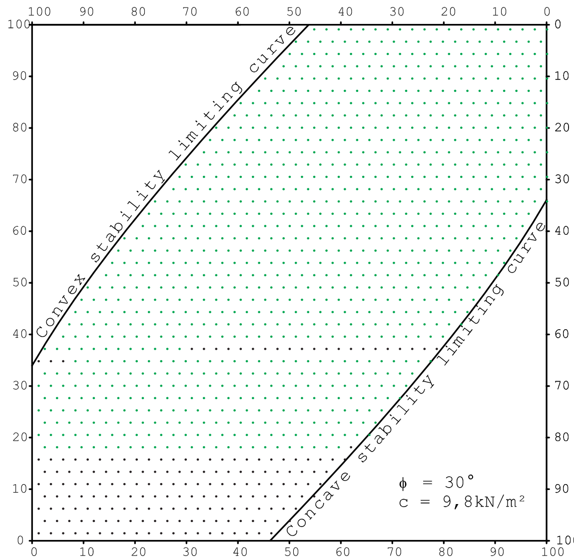

Figure 1a: Stability limiting curves and stability field.
Curvas de limite de estabilidade e campo de estabilidade.

Stability field
Campo de estabilidade

Unstable slopes region
Regiões de declive instáveis

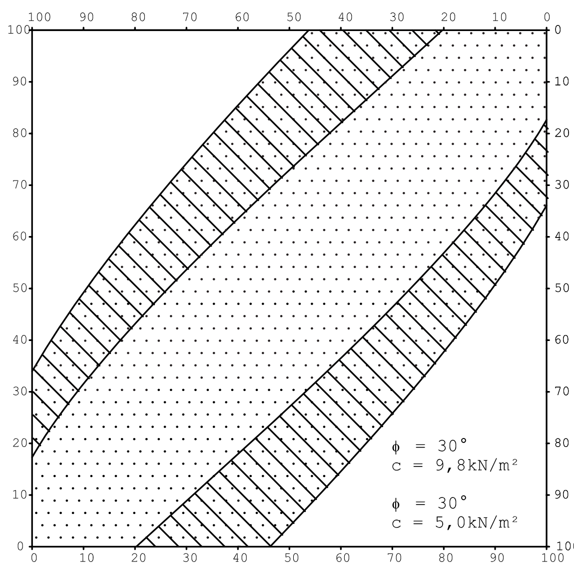

Figure 1b: Variation of stability limiting curves and stability field with c degradation.
Variação de estabilidade estabelecendo limites entre curvas e o campo de estabilidade com degradação.

Original stability field
Campo de estabilidade original

Unstabilized region by c degradation
Região instável com degradação

Original unstable slopes region
Região de declives instáveis originariamente

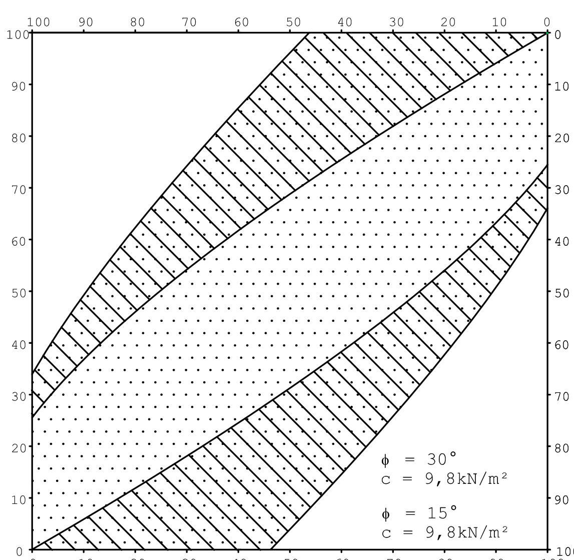

Figure 1c: Variation of stability limiting curves and stability field with ϕ degradation.
Variação de estabilidade estabelecendo limites entre curvas e o campo estável com degradação.

Original stability field
Campo estável originariamente

Unstabilized region by ϕ degradation
Região instável pela degradação

Original unstable slopes region
Região de declives instáveis originariamente

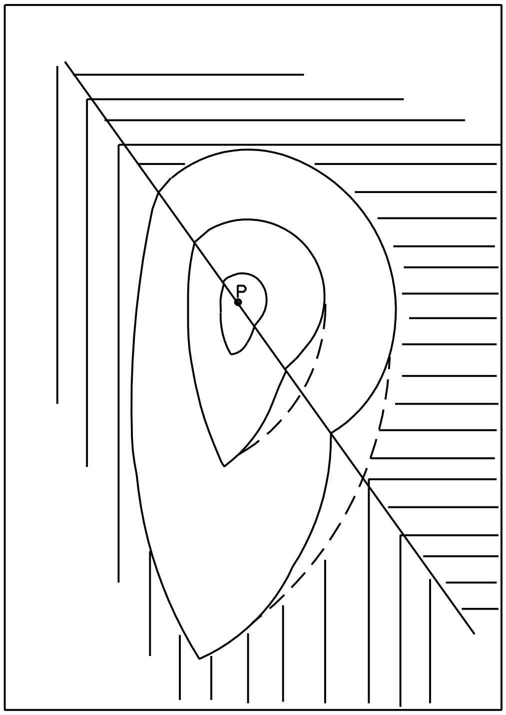

Figure 2: Potencial rupture solids resulting from spined stability curves. (LOPES, 1995). *Sólidos de ruptura potencial resultante de curvas de estabilidade em ponta saliente (LOPES, 1995).*

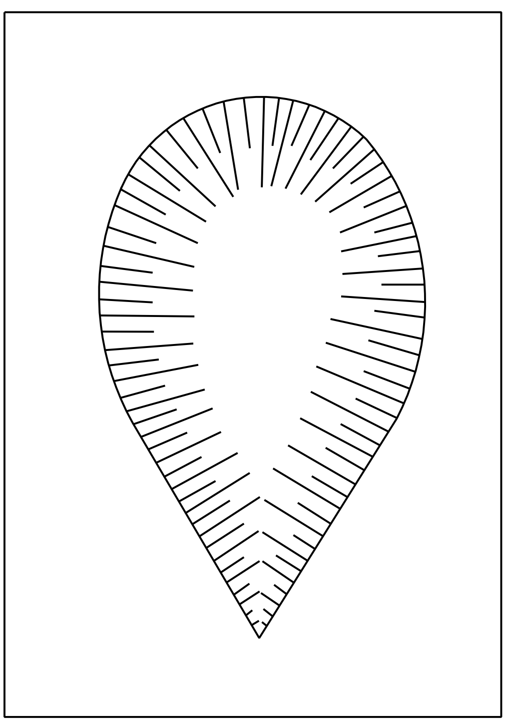

Figure 3: Idealized aspect of rupture scars in plants or aereal photographs. (LOPES, 1995). *Aspecto idealizado de cicatrizes em rupturas em plantas ou em fotos aéreas (LOPES, 1995).*

Photo 1: A delineated landslide in a convex portion of a slope isolated by two amphitheatres - São Paulo - Brazil. *Uma paisagem desmoronada em uma porção convexa de um declieve isolado por dois anfiteatros - São Paulo - Brasil.*

Photo 2: A landslide scar with instabilized material (“correlative deposit”) still remaining over - São Paulo - Brazil. *Uma paisagem em forma de cicatriz com material instável (depósito correlato) que ainda existe em São Paulo - Brasil.*

Photo 3: A landslide scar (amphitheatre) with a correlative deposit, washed by rain, at the toe - São Paulo - Brazil. *Uma paisagem em forma de cicatriz (anfiteatro) com depósito correlato, que foi levado pela chuva “no pé da serra” - São Paulo - Brasil*

Photo 4: Four different age landslides scars (amphitheatres)without correlative deposits: from very old (1) to recent (4) - Minas Gerais - Brazil. *Paisagens em forma de cicatriz com quatro diferentes faixas etárias (anfiteatros) sem os depósitos correlatos: desde a mais antiga até a mais recente em Minas Gerais - Brasil.*

Photo 5: Incipient slides in snow in Andes mountains - Chile. *Declives incipientes pela neve nas montanhas dos Andes - Chile.*

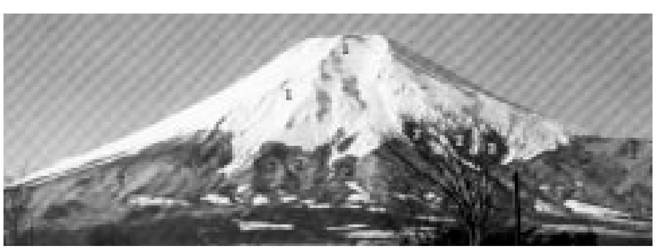

Photo 6: Glacial circus (amphitheatres) in snow (1) and in rock (2) in European mountain. *Circo glacial (anfiteatro) coberto pela neve (1) e por rochas (2) em montanhas na Europa.*

Photo 7 - Rupture amphitheatres in arid climate - Salt Lak City - USA. *Anfiteatros em ruptura em clima árido de Salt Lake City - USA.*

Photo 8 - Rupture amphitheatres in arid climate- Bossavash - Afeghanistan. *Anfiteatros em ruptura em clima árido em Bossavash - Afeganistão.*

INTRODUCTION

As is long-time known, the landscape forms are the result of the struggle between endogenetic (volcanism, epeirogenesis and orogenesis) and exogenetic (intemperism, withdrawal, transportation and deposition) geological processes: between the "attractors" constituted by creation and maintenance of irregularities and planation in the Earth. The first group creates a chemical-mineralogical-topographical gradient and the second works to anulate it; the first accumulates potential energy and the second searches equilibrium with the surrounding environment: both constitute a natural system. The physico-chemical action of intemperism degrades the mechanical strength of rocks transforming them into particulate and loose material, the "regolith" that, worked by pedogenetic processes, give rise to soils. Soils and regolith are mobilised firstly to the toe of elevations and after to regions of lowest potential energy where they are deposited.

The classical battle that opposed, in the primordial of geological science, in one side, the "catastrophists" that attributed the changes in the Earth, to catastrophic periodic events and, in the other, the "uniformitarians" that, based in an exaggerate interpretation of Hutton's principle: "the present is the key of the past", meaning that the observed effects of a cause in the present, can be extrapolate to the past, have attributed these changes always to slow continuous events (GOULD, 1991, p. 124). This erroneous vision of the "uniformitarism" won, and according to it and to observations made initially in temperate and cold climates and after, in semiarid climate, the theories of landscape evolution elect erosion (i.e. isolated particles transportation by wind, water, ice or gravity) as the main mechanism of withdrawal and mobilisation of loose materials and consequently of landscape carving. In geomorphological's dominant thinking, landslides and other mass movements (i.e. grouped particles transportation by gravity with or without water or ice) seems to continue today to be looked as an accessory phenomenon in the evolution of landforms. A recent work concluded: "landslide are just one element in the overall denudation of the landscape, although in high active mountain areas such as the Himalayas, it is often a dominant process" (GERRARD, 1994, p. 222). The "transport limited" process of versant evolution of the Gilbert's original classification (meaning that the tax of regolith stripping is lower than the tax of regolith formation) opposed to "weathering limited" (when the tax of transport is lesser than that of regolith formation) is almost took as synonymous of "erosion limited".

It's usual, also, in the geomorphological literature, and particularly in the Brazilian literature, to attribute landslides to environmental degradation due to human action (BIGARELLA; MOUSINHO, 1967; BIGARELLA et al., 1965; MEIS; SILVA, 1968; BIGARELLA; BECKER, 1975). About this issue, (GERRARD, 1994, p. 230) concluded: "the close relationship between rock type and landsliding has led several workers to suggest that landsliding is not necessarily related to human activity". This conclusion, means, at least, a Gerrard's ambiguous position on the subject.

Observations made in tropical and subtropical climates however, indicate that solution of chemical elements or radicals (TRICART; CAILLEUX, 1965, p. 152; GARNER, 1974, p. 179) and mass movements (THORNBECKE, 1927; JAEGGER, 1927; SAPPER, 1935; FREISE, 1935, 1938; BRIAN, 1940; WENTWORTH, 1943; WHITE, 1949 all in: DEERE; PATTON, 1970, p. 97-100) can be the main processes of withdrawal and transportation of materials and slope evolution in this climatic condition. "Landslides are a common and perhaps the predominant method of slope development in areas of deep residual soils" (DEERE; PATTON, 1970, p. 99). In the same way, the observations made by the author, and the examination of many "disasters" related in the Brazilian technical literature and discussed in previous papers (LOPES, 1995, p. 75-102; 1997, p. 92-94) confirm the simple conclusion that landslides are not exceptional events in tropical and subtropical climates, but common events; that their occurrence is independent of human action although can be accelerated by it; that they are more common in mountainous regions, but can occur also in hilly regions and that they occur in all kinds of lithological-pedological framework. Those conclusions agree with others authors that have worked in others parts of the tropical and subtropical world like Wentworth (1943); White (1949); Mabut (1961); Bik (1967) and Deere (1970) all in: Deere and Patton (1970, p. 98-99).

In this paper, after a brief discussion on the bases of old landscape evolution theories, it will be made a random examination of technical papers on the subject, published in the last times, that demonstrates slope movements constitute a very important process of transportation of materials from the top to the toe of elevations and a fundamental element in the sculpturation of the landscape in all climatic conditions, being, in most situations, the predominant one. Moreover, this literature review and the observation of forms and processes, without prejudices, permits the extension of a postulated model of landscape sculpturation in tropical and subtropical climates, based in the balance stress/strength inside rock and soil masses (LOPES, 1995, 1997), to other climatic conditions.

THE BASES OF THE CLASSICAL THEORIES OF LANDSCAPE EVOLUTION

The oldest theory of landscape evolution, the Davis' theory, published between the end of the 19th Century and beginning of 20th was based in two principles: the uplift of land masses followed by erosional dissecation and search of equilibrium between the capacity of transportation of the agent and the work of transport to be done. Penck's theory, developed at almost the same time, on the contrary, assumed the contemporaneousness between uplift and dissecation and the alteration and breakdown of successive narrow bands of rocks as the mechanism. These theories were hardly criticised, especially in the 1950-1960's by "climatic geomorphologists" (Peltier, Budel, Triccart, Cailleux and others) because the observations made by the previous authors, in regions of temperate climate, were extrapolated to other climatic regions and the climatic variable was decisive from the point of view of these last authors. Peltier have established nine morphogenetic regions, all of them characterised by temperature and rainfall and having particular groups of processes; similarly, five morphogenetic zones were established by Budel.

King, the author of the third classical theory (1950-1960), postulate the fact that his observations were made in a "most adequate" climatic region (semiarid) because the later theories were developed in temperate regions, where there were relict forms of old periglacial climates between the existing landforms. The King's theory admits rapid uplift periods sequenced by large stability periods of denudation when "pediplanes" are developed by "parallel retreat" of the free face of the versants. This "parallel retreat", according to King is made by action of water and/or mass movements and the resulting versant is the "natural" product of the process. King concluded that "the basic physical controls of landscape remain the same in all climatic environments short of frigid and extremely arid" (KING, 1957, in: YOUNG, 1975, p. 37).

At 1950 von Bertalanffy exposed his "general system theory" whose influence generated in the 50's - 60's, new vigorous attacks to the older landscape evolution theories, and specially to the Davis' one. Those critics came, particularly from Strahler that clamed for the necessity of to adopt a "quantitative-dynamic approach that focuses on processes (applied force and internal resistance) resulting in specific landforms" and that "geomorphic phenomena must be studied as various kinds of responses to gravitation and molecular shear stresses acting upon materials behaving characteristically as elastic or plastic solids, or viscous fluids" (STRAHLER, 1950, in: SACK, 1992, p. 255).

Another very important branch of science, related with the subject, the Soil Mechanics - that was born at 1925 with the publication by Terzaghi of his "*Erdbaumechanics*" followed by many other publications persecuting quantification and forecasting in natural and artificial slopes - had not caught the geomorphologists' attention, with some grateful exceptions, like the excellent works of Carson (1971) and Carson and Kirkby (1972).

Although those postulations of advancements, inexplicably in geomorphological dominant thinking the discussions continued to be almost centred in the old theories of landscape evolution and the landforms continued to be explained in a qualitative or "stochastic" way, and dependent upon the mutual influence of the materials: rocks, regolith and soils, their structure, texture and "defects" as passive element and climate as active. Moreover, the basic mechanism postulated to the mobilisation of particulate materials, continue to be of erosion type, albeit "the alteration and breakdown of narrow bands of rocks" was at the basis of the Penck's theory and "mass movements" were quoted by King as a mechanism of mainslope retreat. This so high "relaxation time" (in the sense of RENWICK, 1992, p. 267) of geomorphology could be attributed or to natural difficulties in following a new paradigm or because "it requires considerable expertise in physical science, including such subjects as geology, mechanics, thermodynamics, hydrology, mathematics and statistics" (STRAHLER, 1950 in: SACK, 1992, p. 255)

Since climate, and consequently weathering, transportation agents and processes and rock behaviour, including their own nature and particularities, are variables, the theories themselves (including King's) were necessarily influenced by the place where the studies were made. But rocks, regolith and soils, in any climatic condition, are subjected to the physical laws that deal with forces and resistance as postulated by Strahler and, as a consequence, the same occurs with landforms. These laws constitute the basic control of landform stability and evolution and, consequently, the real base for a comprehensive landscape evolution theory. In this sense, albeit "reductionist", King was right, but in this sense, even "the frigid and extremely arid" dominia are included if we understand his "natural tendency" by effect of stress/strength laws.

SOME EXAMPLES OF "CATASTROPHIC" SLOPE MOVEMENTS IN BRAZIL

Since the nineteenth century there are registrations of landslides in Brazil. Deere and Patton, 1970, report Freise's (1935-1938) observations in coastal mountains of Brazil, about the "recurrent cycles of avalanching that produce periodic deforestation". Between 1940 and 1996, at least in 31 of these years, one or more "disaster" happened in one or more points of the Brazilian territory (LOPES, 1995, p. 76-77; AUGUSTO FILHO; WOLLE, 1996, p. 46). Someone of these will be described in sequence, to illustrate the above written.

In Mach 1, 1956, a series of landslides and rock slides in the granitic and gnaissic mountains recovered by thick regolith mantle, around Santos, in the State of São Paulo (Southeast of Brazil), caused the death of 21 persons, injuries in 43 persons and destruction of 50 houses and in 24 of the same month and year, a new series of landslides caused the death of 43 persons and destruction of 100 houses. Pichler (1956, p. 75 -76) described the event and attributed it to the rain ("effective cause"), to the geological environment ("basic cause") and to human occupation ("favorizing cause").

In 1966/1967 around the city of Rio de Janeiro and in the mountainous region of Serra das Araras (similarly of granitic and gnaissic nature, regolith recovered) between this city and São Paulo, 1.000 persons died in 1966 and 1.500 in 1967 in hundred of landslides, mudflows, debrisflows, slumps, debris slides, avalanches, rock slides and rock falls caused by heavy rains "of unbelievable magnitude (...) ever recorded in geological literature" (USGS, 1967, p. 12). The Rio de Janeiro-São Paulo Highway was almost destroyed and the Nilo Peçanha Power Plant, overcovered. Near Rio de Janeiro, the antropized areas were the most affected but in the Serra das Araras, the most affected were the forested areas, "untouched by at least sixty years". "Landslides numbering in the tenth of thousands turn green vegetation-covered hills into waste lands similar to the 'badlands' and the valleys, into seas of mud" (USGS, 1967, p. 2). "Rocks of 30-100 tons rolled from altitudes more than 300 m (...) were moved around 250.000 tons" (CRUZ, 1974, p. 13). Meis and Silva (1968 p. 55) that have described the events of Rio de Janeiro, concluded that "deforestation and engineering works" were the "threshold" of the instabilization; the USGS Report, on the contrary, attribute it "to the rains, to the weight of the soil and to gravitational stresses".

In march, 1967, Caraguatatuba, a town localised in the seacoast of the State of São Paulo had a hard experience described by Cruz (1974). "It was raining since 16, growing in 17 (115 mm) and arriving to 420 mm in 18 (...) Giant landslides made a dam that is braked after (...) the mud blocked the streets (...) the sea avenue disappeared invaded by the sea, pushed by the flood (...) abysms of hundreds of meters were formed (...) the mountains were striped and the sea was tinted of red". Cruz (1974) writes that all the slopes of the Vale de Santo Antonio in the Serra de Caraguatatuba (mainly granitic and gnaissic, regolith covered) that were covered by rainforests (State Reserve), were the most affected and that the event was independent of human action. According to Cruz (1974) the mass movements exist continuously and made angularities in the rounded mountains. Fúlfaro et al., (1976, p. 343-345) studying core drillings with C^{14} datation in the coastal plane, in front of Caraguatatuba concluded that in this place, in the last 8.000 years, there were, at least, 5 big events of landsliding what means 1event/1.350 years. Since the Europeans discovered Brazil 500 years ago and since Indians are not considered "predators" the conclusion is that the instabilities can't be attributed to the man's occupation.

In April 29, 1974, the Serra de Maranguape, a granitic massif of 920 m high, in Ceará State, North-eastern of Brazil, suffered a instabilization in this Southeast watershed, described by Guidicini and Nieble (1976 p. 14-15) as "debris avalanche". The movement began near the altitude of 720 m as a "translational slide that striped the soil in an area looking like an amphitheatre". The mass destroyed many houses and is stabilised near the height 260 m as a talus deposit. The authors above attributed the instability to the high pluviosity and deforestation. Ponçano et al. (1976) affirms that the deforestation was the responsible for the catastrophic character of the movement that are in other way "natural attributes of slope evolution of steep terrain in humid tropical climates".

In March, 1974, in the region around the border between the States of Santa Catarina and Rio Grande do Sul (South of Brazil) a big rain event (742 mm in 16 days in Urussanga town and 532.2 in 17 days in Laguna, being 240.2 mm in 24 hours) caused the partial submersion of Tubarão town and the death of hundreds of persons and the destruction of almost all bridges. The avalanches killed many peoples and animals and destroyed many houses. In the Tubarão river flood plain .6 to 1.5 m of materials were deposited (BIGARELLA; BECKER, 1975). According to these authors, many of the mass movements were reactivation of old pleistocenic movements. The author of this paper, at this time, was working in a highway project in the region, and saw the destruction of a little town – Vila Brocca – situated at the foot of the Serra Geral's scarp. The landslides caused by the rains created a temporary dam that when broke down transformed the town in a flood plain recovered by clays and boulders. The people, saved themselves in the roof of the church, the only building not destroyed. The slope of the Serra Geral – a basaltic "cuesta" – in the place, were recovered by native forest, one of the last remaining reserves in Rio Grande do Sul.

In October, 31, 1991, the BR-277 Highway, that links the State of Paraná (south of Brazil) to the Republic of Paraguay was interrupted in the km 161 (near Palmeira town) by a landslide transformed in a flow movement. The rain although high, was not exceptional: 191 mm in the month (being 4.6 mm at 30 and 17.6 mm at 31), the topography in the place is smooth and hilly and of sedimentary geological nature (mainly argillaceous and organic shales). The region is and was not forested, but of grassland type and others scars of old movements were seen in the slope of the hills. The highway is situated about 250 meters far and 10 meter down of the landslide place. In the accident, four vehicles, two cars and two trucks, were caught by the mud that filled a valley situated between the hill of the landslide and the street, and covered a bridge of 6 m long and about 500 m of the highway (LOPES, 1995, p. 92-95).

In July, 1983 and May, 1992 the northern region of the State of Santa Catarina and the Iguaçu River valley, in the south of Paraná State (South of Brazil) suffered many instability problems caused by exceptional rains. In 1983, cities like Blumenau and União da Vitória were partially covered by floods and around others, like Joaçaba, Campos Novos and Curitibanos, hills and mountains were greatly modified by processes of landsliding, flowing, slumping and "bulging" in areas covered or not by forests. A television channel registered in videotape the "liquefaction" of a fill that vanished under a truck, near the city of União da Vitória. In the Iguaçu valley, constituted, in the region, by sandstones covered by basalts, many landslides developed in the upper (basaltic) portion transformed in flows in the middle (arenitic) portion that flowed down, one during a week, forcing the Highway Department (DER/PR) to clean continuously the street PR-446. Observations made in the region showed the presence of an argillaceous sheet covering the valley slopes (arenitic), indicating the anterior occurrence of such movements, testified also by many scars. Many of the older landslides showed overcovered tree trunks testifying the presence of forests in the slopes, fact confirmed by some of the oldest residents (LOPES, 1995, p. 96-98).

The conclusions we can arrive from the facts exposed in this session confirm the affirmatives of the third and fourth paragraphs of session 1.

SLOPE MOVEMENTS IN THE HYMALAIAS

According to Gerrard (1994, p. 221) "Landslides [...] are greatest in areas of weak rock and steep slopes. For these simple reasons, landsliding tend to be extensive in mountainous areas. [...] Casual observations are sufficient to indicate many examples of active landslides, mudflows, rockfall and debris avalanches".Gerrard reports Laban's (1979) conclusion: "geological structure and lithology accounted for more than 75% of all observed landslides [in the Himalayas]" and concludes: "The evidence suggests that many small mass movements are partially influenced by human activity but conditioned by the nature of the weathered material. The larger failures may be more determined by rock type and structure" (GERRARD, 1994, p. 230). About the "threshold" mechanism (GERRARD, 1994, p. 221) writes: "an external trigger, such as heavy rainfall, slope undercutting or seismic activity initiates the process".

Cooks (1983, in: GERRARD, 1994, p. 223), comparing South Africa and United States rocks and their influence in the erosional incision in drainage basins assumed that "landsliding is a major component of landscape evolution" and Gerrard adds "a similar interpretation can be made for the results of a study by Tandon (1974) in the Kumaun Himalayas. In page 224, Gerrard affirm "the various forms of mass movements are the dominant process controlling hillslope form of all rock types except the gneiss of the Lower Himalaya unit. On slopes in gneiss, failures are associated with the development of gullies in the deeply weathered regolith".

From Gerrard observations, it's clear that in high mountains, landslides, beyond to be very common events, consitute the dominant process of landscape evolution and are independent of human activity although can be accelerated by it and triggered by rains, slope modifications or earthquakes.

SLOPE MOVEMENTS IN MOUNTAINS OF CENTRAL-SOUTHERN NORTH AMERICA

Six debris flows were studied by DeGraff (1994) in the Sierra Nevada, California, "selected [...] because [...] were initiated on natural slopes [...] and were generally free from the influence of road or similar ground-disturbing activities" (DEGRAFF, 1994, p. 232).

The Camp Creek slide was caused by "a major storm system [...] on April 10 - 11, 1982 [that] produced a rain-snow event responsible for triggering numerous landslides including a debris flow in Camp Creek". This slide "originated at the upper edge of the reforested area [...] was almost immediately mobilised into a debris flow" that "about 53 m below entered an ephemeral channel" and after "to the main channel of Camp Creek [...] at 146 m below. [...] The debris flow impact the Stump Springs road at 166 m below [...] removed 50% of the road fill" (DEGRAFF, 1994, p. 235).

The Calvin Crest debris flow, occurred "on a national forest [...] an open stand of mixed oak and Jeffrey pine with an understory of herbaceous vegetation" after "the winter of 1982-83 [that] produce an unusually deep snowpack [of] 132 - 155 cm [a] precipitation 190% of normal statewide [...] persisting to an unprecedent July" (DEGRAFF, 1994, p. 237). The occurrence is assumed to be on July 5, 1993, one day after an observation of "water discharging from a depression" and according to reports of many campers about "feeling ground vibrations and windows rattling" so they had "the impression that an earthquake had occurred" (DEGRAFF, 1994, p. 237). According to DeGraff (1994 p 239) "the force of the flow [...] was sufficient to uproot several trees and tilt others [...] muddy splash marks were found at heights 0.5 to 1.5 [...] slickensides were visible on the surface of the overturned soil" and ""n succeeding years, grass grew over the debris flow scar and flow path [...] The scarp created by the movement removed support of the slope above and permitted several additional retrogressive movements". DeGraff (1994, p. 239) concluded "the movement seemed to be a product of ground water conditions resulting from above-average recharge".

The Shingle Hill debris flows occurred between "the night of February 17, 1986 or early the morning of February 18 when a major frontal storm system crossed the Central Sierra Nevada [...] in form of rain [...] triggered three debris flow on the north facing slopes. From these, one [...] was originated in a really undisturbed slope; [the others] in a deforested slope, but without anyone other disturbation". "…were initiated in swales at the heads of first-order ephemeral drainages [...] revealed bedrock hollows [...] similar to those described by Dietrich *et al* (1986) (DEGRAFF, 1994, p. 240)". DeGraff (1994, p. 247) also reports that "in 1983 [after a intense period of rainfalls] three large landslides began moving in San Joaquin drainage [...] two [...] were existing, inactive landslides which were reactivated [and] the third was [...] initiated at the head of first order stream". The triggering of debris flows in Sierra Nevada were "intense rainfall, rain-on-snow events, and snow melt" (DEGRAFF, 1994, p. 245).

According to DeGraff (1994, p. 244) "...it is typically the debris flow scar [...] which is recognised [...] the deposits are relatively rare features" because of the difficulty in recognise them and because of their short permanence in the terrain mainly by the re-working by water streams. DeGraff also discusses the failure mechanism and concluded, "Camp Creek provide [...] a clear indication that initial movement involved sliding of a rigid mass, which almost immediately became a viscous slurry".

The "bedrock hollows" quoted by DeGraff were attributed by Dietrich and Dorn (1984, p. 147) to landslides in the rocky mass filled by deposits and "periodically empty by recurrent landslides". According to these authors "about 20-40% of the basin was recovered by those hollows partially empty". In the same way, the progress of the head of drainage lines by a combination of erosion and landslides was also observed and documented by the author in Brazil (LOPES, 1986, p. 2033; 1995, p. 66). Dietrich *et al* (1993, p. 259 and 275) using a digital model concluded that there is a "threshold" controlled by slope stability and surficial erosion that made progress the fluvial erosion.

The conclusions from DeGraff's and Dietrich's observations in Sierra Nevada, California, are: the observed landslides were independent of human action; they were triggered by rains and/or snow precipitation or melting or ground water recharge; there is a recurrence of events of landsliding and a "threshold" between fluvial erosion and landsliding and there is a sequence between landslides and flows and usually only landslide scars are available for observation and study.

SLOPE MOVEMENTS IN GLACIAL MOUNTAINS OF NORTH AND SOUTH AMERICA AND NEW ZELAND

Working in the mountains of western Canada, Evans and Clague (1994, p. 107-108) concluded that "climatic warming during the last 100-150 years has resulted in widespread destabilisation of many mountain geomorphic systems and accelerated certain catastrophic processes, largely as a result of dramatic glacier ice loss. These processes include glacier avalanches, landslides and slope instability caused by glacier debuttressing [...] the total loss of life [...] has been in excess of 30,000; damage to the economic infrastructure [...] more than one billion dollars". "Slopes adjacent to glaciers that have significantly thinned and retreated since the Little Ice Age [1450-1890] are particularly prone to landslides. Glacial erosion and oversteepening of the slopes, in combination with subsequent debutressing due to glacial retreat, have caused instability, evidenced by progressive mountain slope deformation, rock avalanches and other landslides" (EVANS; CLAGUE 1994, p. 109).

Within the rock avalanches, Evans and Clague (1994, p. 110-112) reported a 1992 event of 5-10 x 10^6 m^3 occurred in Mount Fletcher above Maud Glacier in the Southern Alps of New Zealand and two highly destructive landslides from the north peak of Nevados Huascaran in the Cordillera Blanca of Peru. This last moved approximately "13 x 10^6 m^3 of rock and glacier and travelled 16 km at an average velocity of 47 m/s" and "overwhelmed several towns and villages and killed about 4,000 people..." In 1970, in the same place, undermined by this event, "fell 50-100 x 10^6 m^3 of rock and ice" triggered by an "earthquake centred 130 km to the west". The debris travelled a vertical distance of 4,200 m over a horizontal distance of 16 km at a mean velocity of 75 m/s causing about 18,000 deaths continuing downstream as a debris flow.

According to Evans and Clague (1994, p. 111) "landslides caused by glacier downwasting and retreat are common on steep slopes adjacent to glaciers in western North America. [...] at least three twentieth-century rock avalanches at Mount Rainier, Washington, occurred on valley and cirque walls that were supported by glacier ice during the Little Ice Age" (O'CONNOR; COSTA, 1992, in: EVANS; CLAGUE, 1994, p. 111). " Of the 30 known, large (> 1 x 10^6 m^3), historic rock avalanches in the Canadian Cordillera, 16 have occurred on glacially debuttressed slopes. Field observations have shown that detachment surfaces of many of these landslides intersect the slopes below Little Ice Age trimlines and were thus exposed during recent glacier retreat (EVANS; CLAGUE, 1994, p. 111).

"Glacier thinning and retreat may also cause non-catastrophic slope deformation, manifested by cracking, subsidence at the top of the slope, and bulging at the toe. Spetacular examples have been reported from St. Elias Mountains of British Columbia [...] and Alaska [...]. At Melbern Glacier for example, a 400-600 m lowering of the glacier surface has debutressed adjacent mountains causing extensive, non-catastrophic slope deformation [...]" (EVANS; CLAGUE, 1994, p. 112). "Tension cracks, uphill-and-down-hillfacing scarps, grabens, and collapse pits extended for a distance of 1.3 km along Affliction Creek" in southern Coast Mountains of British Columbia were described by Bovis (1990, in: EVANS; CLAGUE, 1994, p. 113) due to ice debutressing. Debris flows triggered by intense rainfall, in the Swiss Alps, during the summer of 1987 were reported by Haeberli and Naef (1988) and Zimmerman and Haeberli (1992) *in*: Evans and Clague (1994, p. 114). Also melting of ice has caused debris flow in Coast Mountains of British Columbia according to Jordan (1987, in: EVANS; CLAGUE, 1994, p. 114).

We can conclude, from theese authors, that mass movements are a natural process in glacial climatic conditions; that mass movement are very common and caused by advance and retreat of glaciers; that mass movement can be also triggered, in this environmental conditions, by intense rainfall and snow melt and earthquakes and that the oscillation of glacier cause also slope deformations represented by tension cracks in the upper part of the slopes and bulging of the toe, what means slopes are carried to a "active pressure condition" in terms of Soil Mechanics or, what is the same, to a Security Factor near 1. On the other hand, if the glacier retreat after the Little Ice Age was able to make such "catastrophic" and "non-catastrophic" effects related by Evans and Clague, we can imagine what must occurred in the Pleistocenic interglacial times in terms of slope instabilization in glacial areas.

EARTHQUAKE-INDUCED LANDSLIDES AROUND THEWORLD

Studying earthquake-induced landslides, Keefer (1994, p. 265) reports that "damaging earthquake-induced landslides have been documented from at least as early as 1789 BC in China and 373 or 372 BC in Greece" and that "analyses [...] have shown that large earthquakes can generate tens of thousands of landslides over thousands of square kilometres, dislodging [...] several billion cubic meters of material from slopes".

Erosion rates from earthquake-induced landslides were compared with rates directly determined for other slope processes (including landslides not directly related with earthquakes), by Keefer (1994). From this comparison Keefer (1994, p. 278-279) concludes: "Because Yosemite Valley is walled by spectacularly high and steep slopes [...] the mean regional erosion rate from earthquake-induced landslides [...] is about 5 percent of erosion rate from all landslides..." "Throughout California, the mean erosion rate from earthquake-induced landslide is about 11 percent of the mean calculated for other slope processes". "The earthquake-related rate for Hawaii is 3.5 times higher than the maximum rate of long-term slope erosion in Oahu, and earthquake-induced landsliding is thus almost certainly a predominant process..." "In western New Guinea, the high mean erosion rate from earthquake-induced landslides [...] is slightly higher than the rate for landslides not related to earthquakes". "In New Zeeland [...] the range in erosion rates [...] is nearly the same as the range in rates determined for other slope processes". "In central Japan, the range of erosion rates calculated for earthquake-induced landslides is lower than the range calculated for other slope processes".

From the "comparison of erosion rates from earthquake-induced landslides to erosion rates calculated by the fluvial discharge method" Keefer (1994, p. 279-282) obtained: "In three regions - San Francisco Bay, the island of Hawaii, and the Sierra Nevada-Great Basin- the mean erosion rate calculated for earthquake-induced landslides is higher than the rate calculated for fluvial discharge. In five additional regions - onshore California, Turkey, western New Guinea, Peru and New Zeeland - [...] is a substantial fraction (between about 20 and 65 percent. In four other regions studied - southern California, Iran, central Japan, and Tibet [...] are much lower, less than 10 percent..."

It's evident in the upper Keefer's conclusions, the importance of the balance between the influences of climate, topography and seismic activity: in dry and or cold climates, erosion predominates in spite of seismic activity; in temperate and or subtropical climates, earthquake-induced landslides dominate or are an important fraction of denudation processes in dependence of the importance of seismic activity; in the presence of high topographical gradients landslides predominate independently of seismical activity.

SLOPE MOVEMENT MECHANISMS

The observations made in different places around the World by the authors reported in the former sessions, can be summarized as follows:

1. Slope movements are common events in all climatic conditions, including semiarid as quoted by King and even desertic, since although desert would be seen as the "erosion dominion", according to Small and Clark (1982, p. 93) "even more surprising is the widespread occurrence of mudflows in deserts, owing to the prolonged collection of detritus in valley bottoms and the reduction of strength of this materials by sporadic rains";
2. Slope movements are the predominant mechanism of slope evolution and landscape carving in tropical and subtropical humid climates and in mountainous regions of any climatic condition;
3. Slope movements are a very important (and perhaps the most important) element in the slope evolution of glacial alpine mountain type areas;
4. Slope movements are produced by an unbalance between the strength of the natural materials and the active forces derived from gravity; the way this unbalance is achieved vary according to local, particularly tectonic, lithologic and or climatic, conditions;
5. Slope movements are "triggered" by natural events such a big rain; a snow accumulation and/or melt; an earthquake vibration; a slope modification (by river erosion for example) or underground water flow;
6. The human action represents only one more "triggering mechanism" upon the naturally "prepared" slope; this action can be for example, slope modification by cuts; deforestation; human occupation by cities; channel and or dam construction and so on;
7. The energy necessary to overcome inertial strength to motion, is always furnished by gravity and consequently the land elevation is always at the beginning of the process, but once potential gravitational energy is available, different ways can be followed to the final instabilization: the growing of energy difference between two points (i.e. the growing of the slope highness); the growing of the energy gradient between two points (i. e. the growing of the slope inclination); the strength reduction in one or more points (i.e. the alteration by intemperism of the materials that constitute the slope) and the coming on of additional forces (for example water and/or ice pressures and/or earthquake motion pressures).

Soil Mechanics demonstrates that in natural materials (soils, regolith, rocks) the strength parameters are: "f" (internal friction angle) and "c" (cohesion), being this last, actually, a combination of forces of chemical, capillar and eletrostatic nature. Moreover, Soil Mechanics demonstrates that in natural materials, slope's stable highness is inversely proportional to slope's steepness i. e., to maintain stability, slopes must be so gentler, as higher they are. A known expression called the "Cullmann expression" permits to calculate slope's highness/slope's angle pairs, representing stability limit conditions for natural materials, as a function of f, c and g (specific gravity). The loci of points, calculated in this way, delineate a curve that begins vertical and asymptotically approaches the inclination of the friction angle f. This can be taken as a limiting model of a stable convex versant. Lopes (1995, p. 41-43; 1997, p. 94-95) however, conclude that another limiting stability curve exists and is a inverse of the former: it begins in top with a vertical portion and approaches f inclination angle in the toe. This last is the curve that can be observed in the principal section of slopes' ruptures (photos 3 and 4). As ilustrate in fig. 1a, all slopes, located between the convex and the concave limiting curves, are stable ones and all outside this space are unstable (LOPES, 1997, p. 98).

Although the numerical expression of those curves can be calculated as was also shown by the above author in the same papers and pages, for the purpose of this paper, it's enough to realize that as the cohesion is bigger, than higher can be the vertical initial portion of the curve and as the friction angle grows, so it heavens the possible inclination of the slope in it's final portion. This means that, if both, cohesion and friction have high values, the limiting convex curve will be "high" and relatively the concave will be "low" and if those values are low, the convex resulting curve will be "low" and the concave relatively “high” i.e the space between both curves (that represents the stable situations) is reduced when c and f are reduced or, in other words, the “sensibility” of the slope to environmental changes is inversely proportional to the resistance parameters of the constituting materials (figs. 1b and 1c). As a consequence, rock cliffs remain relatively stable for long time while clayey or sandy gentler slopes are rapidly instabilized.

If a tectonic uplift causes a sufficient elevation of the slope’s highness and/or angle, and/or if a river causes a sufficient incision, and if f, c and g of the materials remain constant, the slope will be setted in an unstable condition (out of the stable space) and, in this case, a mass movement will result. On the other hand, if f and c are reduced and the other variables remain constant or grow, the instability condition will be attained since the convex limiting curve is lowered and the concave elevated making the slope to reach one of them at a point P. This may be done by intemperism as will be discussed in the next session.

In three dimensions, all the sections around the overpassing point P will be limited by the same curve what means a solid limited by the versant in one side and by this “spined” curve (what means a amphitheatre) in the other, is isolated (fig. 2). As a consequence, being observed in aerial photographs or delined in a topographic chart the scar of the rupture has the characteristic aspect of a “leaf”, of “a ear” or a “inversed drop” more or less elongated (fig. 3). The details of the figure are dependent upon the kind of movement (landslide or flow); upon the values of c, f and g of the materials; upon the distribution of inhomogeneities in the interior of the mass; upon the presence, position and pressures of water and upon the way the curve split up the versant i. e. upon the inclination and shape of this one (concave, convex etc.) and the position of the rupture in the versant.

The action of aditional forces in mass moviment processes is depending on local particularities and many times represents a “threshold” or “triggering” mechanism. The presence of water beyond to be the most important agent of intemperism, as rain precipitation, can lead slopes to fail as a result of effective stress and suction pressure reduction. The action of water also includes dragging of particles and withdrawal of cement. Snow precipitation causes a surcharge and snow melt, a stress distribution modification and soil saturation. The freezing of water in soils causes expansion and soil structure destruction and the ice melting, volume reduction and saturation. Glacier advancement causes erosion and oversteepening of slopes and the subsequent debutressing due to retreat causes progressive mountain slope deformation, rock avalanches and other landslides (EVANS; CLAGUE, 1994, p. 109). The earthquake ground vibration causes destruction of material’s structures and growing of water pressures. The deforestation, according to Prandini et al. (1976, p. 60) causes the acceleration of creep, the growing of surficial run off and erosion and of soil moisture, the elevation of water table and the decay of soil resistance by the effect of root death.

THE ROLE OF SLOPE MOVEMENTS IN THE SLOPE EVOLUTION AND LANDSCAPE SCULPTURATION

To stablish a landscape evolution model and since the interest is on a comprehensive vision of the problem and once the details of rock slopes evolution (influence of kinds of rocks, inhomogeneities, deep of horizons) in the final landforms, are exhaustively discussed in geomorphological textbooks, it will be used here, as a starting point, an homogeneous infinite rock body disposed in three extreme climatic environments: extremely arid, very hot humid and glacial.

In a extremely arid condition the action of chemical intemperism is practically inactive, the physical intemperism tend to rock fragmentation and the surficial and channel erosion are very active, since there is no vegetational cover: the versants are “intemperism controlled”. To this situation, the “mechanistic” base model was developed by Terzaghi (1962, in: CARSON; KIRKBY, 1972, p. 122), that is complementary with King’s model since it explains the “natural tendency” of the slope retreat by erosion (pediment formation) and mass movements and the tendency to concave versants generation. About this model, Carson and Kirkby (1972, p. 123) said: “it is refreshing to come across a description based on the underlying principles of mechanics in contrast to the speculative, non-quantitative and confused thinking of early geomorphologists attempting to deal with this issue”. Terzaghi’s model is resumed as follows: as a river cuts his valley, the shear stresses on any potential failure plane passing through the base of the valley walls increases. The shear strength, along potential failure planes, is represented by portions of intact rock mass with big values of cohesion and portions constituted by joints whose resistance is only of frictional nature. The stress concentrations along the rock masses between joints, make them split successively transforming the rock cliff in a wall constituted by a dense aggregate of angular blocks and making the comprehensive strength resistance decay. The combination of the resistance decay and growing of the slope’s highness lead the original stable condition to a progressively unstable condition: a stability limiting curve is attained and the equilibrium is searched by individual or collective drop out of blocks. As a consequence, the original slope angle will be progressively reduced to a final value in dependence on the nature, shape and distribution of joint patterns and since, as explained by Lopes (1997, p. 98) the ruptures always go along the minimum limiting possibility (concave curve) i. e. the tendency is always to the generation of concave versants.

In a tropical rainy climate, the same rock will be immediately attacked by alteration, in the initial times almost counterbalanced by erosional processes, resulting in an enlargement of joints and rounding of apexes of rock blocks and of landforms, figuring a tendency to convex versants. At the same time, however, the struggle for life fixation begins and, since the climatic conditions are favourable, the vegetation develops in progressively powerful stages giving rise at least, to the tropical forest. The forest installation at one side will increase the power of intemperism and on the other side protects the generated regolith making it thicken. In other words, the “weathering limited” versants become “transport limited” ones. This means the shape of the versants is poorly modified while their skin constituting materials are largely degraded. In this situation, a “threshold” process like a heavy rain, a earthquake or a rapid modification of versant’s shape, give the start up to the instabilizations that will be “landslides”, “avalanches” or “flows” or other kinds of movements, in dependence of the nature and thickness of regolith, of its water content and of the versants’ shapes and inclinations; usually flow movements begin with landslides as before discussed: the first is transformed in the former, with time and movement. In the initial times, the instabilities will occur mainly in the edges (convexities), if the regolith is thick and homogeneous and in this case the scars will have a shape approaching the expected from the theoretical curve. If the regolith is not homogeneous, the weakness surfaces will command, in details, the shape of the instabilized solid. The ruptures will be planar if the regolith is thin and the versants highly deeping; will constitute wedges if there were conveniently orientated planar structures; it will be block drop if the density of jointing is big with random orientation and versants of cliff type and will be composite if the rupture occur in mixed layers.

After the events of instabilization, the biostasis will be restored, the vegetation gradually will return to the deforested areas - helped, in some degree, by the shape modification from convex to concave that concentrates water and consequently elevates the moisture content of the soil albeit this shapes also favorizes erosion and new “flow” movements of regolith - and the scars of the slope movements will be gradually softened taking aspect of “amphitheatres” sticked in the convex slopes typical of humid climates. The presence of these “amphitheatres” isolates convex portions that became still unstabler (photo 1). On the other side, the scar of ruptures are in limiting stability condition what means that in a relatively short period intemperism will re-instabilize them, making the concavities move up in the slopes. The continuity of this process will make a generalised smoothing of the slopes and reduction in the altitudes of the elevations (a kind of Davisian peneplanation made by a Penck’s type mechanism) if the compensatory processes “of internal origin” wouldn’t come to action. “Although it is obvious that there is a tendency to reduce large land masses to altitudes near base level, quantitative data have shown that base-level changes occur with sufficient frequency to obviate peneplane model” (BULL, 1975, p. 1489-1490).

In glacial regions, the advancement of glaciers causing slope steepness by erosion and or rotation is the preparating or even effective cause of slope instabilization; the retreat makes the upper portion of glaciers hang and stay under tensile stresses condition what produces ice avalanches and rock slides. On the other hand if not carried to instabilization, “non catastrophic” deformations carry the slope to a limiting stability condition, what means a heavy rain or a snow melt or even a ice surcharge can trigger “mass movements”. The ice accumulation provides sliding mechanisms and, consequently, similar forms to that due to regolith and soil accumulation in humid climates as was discussed for example by Haefeli (1953) and more recently by Carson (1971): “studies of cirque glaciers over the last twenty-five years suggest that much of the movement of cirque glaciers is rotational, analogous to the rotational earth slips” (CARSON, 1971, p. 148) and “Clark and Davis (1951) used this rotational motion of cirque glaciers in explaining the origin of cirque landform. They argued that abrasion at the rock-ice interface under the rotating ice mass must mould the bedrock surface into an arcuate form producing the typical long profile of cirques” (CARSON, 1971, p. 149).

The similarity of forms in tropical and glacial mountains is so notable (photos 1 to 6) that European geomorphologists working in Brazil, like Martone (1943, in: LEHMANN 1960, p. 1) for example attribute to a “diluvial glaciation”, the origin of the landslide amphitheatres found in the region of Campos do Jordão (Sate of São Paulo) and Itatiaia (State of Rio de Janeiro). Lehmann, himself although affirmed that “it’s necessary to look with the biggest reserve at the moment, to the glacial origin [proposed] to the [Itatiaia’s] suspended and closed valleys” (LEHMANN, 1960, p. 1) developed a complicate theory including parameters like the “extraordinary pluviosity (2.500 mm)” and the “isolation” of the massif to explain the “so extraordinarily low limit of the snow in the place”

(LEHMANN, 1960, p. 2). In the same mistake can fell many geomorphologists that atribute concave versants now existing in tropical climates, originated from old mass movements, to semiarid climate and or to climatic alternation (photos 1 to 8).

In any climate condition between those extreme situations discussed, the same rock will behave in an intermediate manner: as the climate is hotter and wetter and bigger the vegetation cover, then most the regolith will accumulate developping convex versants until the convex liming stability curve is attained; at this moment it will locally evolue to concave ones, by mass movements. As the climate approaches the dry conditions and the vegetation cover vanishes, then more the erosion ("pediment" formation in the sense of King) makes the versants to approach the concave limiting stability curve, and whence that is attained, mass movement occurrence will maintain it (photos 7 and 8). In mountainous regions since there is a strong topographical gradient there is a kind of convergence of forms: in all climates the tendency is to concave versants in the upper portion in accordance to the minimum possible conformation (concave curve) of slope stability. On the other side, as the topography becomes hilly or platy, then the tendency to convex versants is dominant in humid climates since the topographic gradient is low and there is consequently conditions to the maximum stability conformation (convex curve). In dry and frigid climates, the tendency is always to concave versants since those are of "intemperism controlled" kind. In all climatic conditions, however, the fundamental aspect of landscape evolution is its dependence on the mechanical laws that command the action of forces and resistance (as proposed by STRAHLER, 1950), inside the rock, regolith and soil masses. The climatic action over the geological-pedological framework is the responsible by the kind and speed of changes from one to another of these materials; by the accumulation or rapid remotion of the intemperized materials and by the way the slopes are leaded to instabilization.

From the ecological point of view, cycles of slope skin streapping and deforestation as those inherent to the model, in turn of been viewed as "disasters" resultants of human degradation, can be viewed as an important natural process of rejuvenation of vegetation in the same way as reported by Odum (1983, p. 177-179; p. 211-214) related to fire or insects. As a matter of fact the areas of "disasters" related in Session 4 (at least the oldest) are today almost naturally recuperated.

CONCLUSIONS

Three main conclusions can be extracted from this paper: the first one is the affirmative of slope movements as natural processes, independents, in essence, of human action, and extremely important in versants evolution.

The second deals with versants' forms and the conclusion is they not necessarily reflects a climatic condition but can be only an stage in their evolution: in semiarid climates, concave versants are maintained because the environmental conditions force the minimum stability curve, but in humid climates, this form represents a threshold between maximum (convex) and minimum stability curves. In glacial conditions, the ice action provides processes of slides that affect the underlying rocks, resulting in forms similar to those resultants of landslides in humid climates.

The last is: the landscape evolution result of the action of the stress/strength behaviour, inside the rock and soil masses and this, must be, as a consequence, the real base for a comprehensive landscape evolution theory since laws that command forces and resistance are independent of local variables. The landscape forms evolutes searching equilibrium not only with external forces, but mainly with internal stress/strength characteristics. The role of external forces, in some theories quoted as fundamental in the forms and processes of landscape sculpturation, is basically to establish the kind and speed of rock degradation, and consequent regolith and soil generation, and the destine of the loose material generated: accumulation or removal.

FINAL CONSIDERATIONS

In geomorphology, like in other branches of science, ideas that, when born, cause heated debates between authors and are apparently incompatible, after seating of time's dust, become complementary and permit a best approach to the searched truth. The evolution of the "peneplanation" concept due to Davis; the mechanism of rock bands alteration and breakdown due to Penck; the introduced concept of "climatic zones" by "climatic geomorphologist"; the King's affirmation of uniformity of "basic physical controls" in landscape evolution and the Strahler's force/resistance mechanism are all present in the developed model.

As says the Bible: "there is nothing new under the sun..."

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