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Technogenic landforms: conceptual framework and application to geomorphologic mapping of artificial ground and landscape as transformed by human geological action

Formas de relevo tecnogênicas: quadro conceitual e aplicação ao mapeamento geomorfológico de terrenos artificiais e da paisagem transformada pela ação geológica humana

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ABSTRACT

The shaping of the Earth's surface by human geological action has produced original landform types, namely technogenic landforms. In this paper we will revise the conceptual framework concerning the geomorphic agency of humankind and introduce a new proposal for classifying these new landforms, which join the existing criteria for the identification of technogenic processes, the analysis of technogenic layers and the characterisation of the resulting newly formed technogenic ground. The proposal itself is enhanced by a taxonomic classification which considers the technogenic landforms as constituent parts of the land shape compartments that, by their way, form extensive technogenic landscapes. The classification was applied to the geomorphologic mapping of two urban areas in Presidente Prudente City (São Paulo State, Brazil) in which technogenic ground occurs.

Keywords: Technogenic landforms; Technogenic ground; Man's geomorphologic action.

RESUMO

A modelagem da superfície da Terra pela ação geológica do Homem tem produzido tipos originais de formas de relevo tecnogênicas. Neste trabalho é revisado o quadro conceitual concernente à ação geomorfológica da humanidade e introduzida uma proposta de classificação dessas novas formas de relevo, segundo os critérios de identificação dos processos tecnogênicos, as análises das camadas tecnogênicas e a caracterização do resultante terreno tecnogênico recém-formado. A proposta referida é desenvolvida por uma abordagem taxonômica que considera as formas de relevo tecnogênicas como partes integrantes de compartimentos de modelado tecnogênico que, por seu lado, formam paisagens tecnogênicas mais amplas. A classificação foi aplicada ao mapeamento geomorfológico de duas áreas urbanas na cidade de Presidente Prudente (Estado de São Paulo, Brasil) onde ocorrem terrenos tecnogênicos.

Palavras-chave: Formas de relevo tecnogênicas; Terrenos tecnogênicos; Ação geomorfológica do homem.

1. Introduction

The main scope of this paper is to promote the discussion about the technogenic landforms – that is, the landforms formed directly or indirectly by human agency –, on one hand as related to genetic processes and, on the other hand, as related to the geomorphic surfaces generated by these processes.

For this to happen it was necessary to revise the knowledge available regarding the subject, which leads us to believe that it is necessary to clear up the issues concerning the results of human geomorphic action.

One of these necessities is just the creation of specific geomorphologic maps able to display adequately the particular effects of the land transformation as promoted by humans and that are affecting extensive regions all over the world, especially in urban areas.

2. The study of the geomorphologic action of humankind

The transformation of the physical configuration of the Earth's surface by human activities implies the creation of particular settings of landforms, known as *technogenic relief*. This action may be considered part of the environmental changes taking place since humankind became an agent of geological proportions, which has since gone global.

The scientific study into human geomorphologic action is in its infancy, despite of the early contributions, for example, of Charles Lyell, in his main book *Principles of Geology* (Peloggia 2005a). For Lyell, humankind works geomorphologically as a "levelling agent" who tends to plane the relief as a result of joined aggradation and degradation processes.

However, more recently the impacts of human's shaping the Earth's surface have been recognised and described by many authors (e.g. Brown 1970, Drew 1983, Nir 1983, Vita-Finzi 1993, Goudie 1993, 1994, Hooke 1994, 1999, 2000, Rohde 1996, Peloggia 1998, 2005b, Rosembaum *et al.* 2003, Price *et al*. 2004, Trenhaile 2004, Peloggia & Oliveira 2005, Goudie & Villes 2010, Araújo & Barbosa 2010, Price *et al.* 2011, Peixoto *et al.* 2011). These papers are convergent on the point of the significance of the geomorphic effects of humankind, qualitatively as a direct or indirect creator of new landforms and quantitatively as an agent comparable in capacity (and even superior in his effects) with the natural ones.

As a comparison of human geomorphic action against other landscape transforming agents, Ab'Saber (1969) talked about the modification of the land shape and of the processes that shape the landscape. These processes are in many cases irreversible to the "primary metabolism by nature" (p.2). Already cited by the same author, the human actions affecting the soils, and we can extend this proposition to include the relief, are responsible for various alterations on the land surface that may impersonate, up to a certain point, the climate changes that have occurred during Quaternary times.

Nir (1983) works with the idea of human geomorphologic agency in terms of actions "[...] involving the destruction of the soil cover and the subsequent denudation and erosion" (p.8). Among the factors influencing this "anthropic geomorphology", the author considers that there is a great dependency on social issues, i.e., demographic, economic, and iconographic aspects of humanity.

The author also cited that there are a few cities in which the original land topography has not been altered yet, which may have occurred by three main ways: cuts in the slopes, constructions of embankments and dumping of formerly swamp areas. Among the examples cited, there was the Flamengo embankment in Rio de Janeiro City (Brazil), were the material removed from the hills has been used to extend the shore line out to sea. The modification of Rio's geomorphology by human actions is also referred by Brown (1970).

The studies carried out have produced a general conceptual basis for advanced and systematic research. In this context, one particular open and significant way for increasing knowledge is the development of specific techniques for the geomorphologic mapping of technogenic landforms and landscapes.

Based on the contributions cited above, we agree it is possible to outline a general *theory of the technogenic landforms*, as indicated by Peloggia (1998, 2005b), which deals with specific geomorphic processes (*anthropogenic*, *anthropogeomorphic* or, as adopted in this paper, *technogenic*) and its resultant landforms and relief shaping.

3. Technogenic landform classification

The first step for the establishment of this theoretical conceptual framework is, of course, a general classification, of descriptive character, of the landforms formed through the consequence of human action. Currently there are two main options for classifying these technogenic geomorphic categories: the first (and more simple) one is based on the consideration of the direct or indirect nature of the human action producing or influencing geomorphic processes, as in Brown's (1970) and Haig's (*apud* Goudie 1994) classifications (tables 1 and 2); the second way is related to the nature of the land surfaces that have been produced, as proposed in the British Geological Survey *artificial ground* classification (table 3). The landforms produced by direct and indirect manner have been referred as *first type* and *second type* technogenic forms by Peloggia (1998, 2005b).

Table 1: Brown's (1970) classification of the human influence upon geomorphologic processes

HUMAN ACTIONS			EXAMPLES
Direct instrument of change	Purposeful actions	Negative forms	Highway cuttings
		Positive forms	Building of embankments
	Incidental consequences		Opencast coal working
			Quarrying of sand and gravel
Indirect influence	Modification and diversion of geomorphologic processes		Induced mass movements
			Soil erosion
			Intensification of weathering

Table 2:- Haig's classification of major "anthropogeomorphic" processes, according to Goudie (1994) and Goudie & Viles (2010), lightly modified

ANTHROPOGENIC PROCESSES	NATURE OF PROCESS
Direct (First type)	Constructional, excavational, hydrological interference
Indirect (Second type)	Acceleration of erosion and sedimentation, subsidence (collapse, settling), slope failure, earthquake generation, weathering

Table 3: British Geological Survey (BGS) "artificial ground" classification (after Rosembaum *et al*. 2003, Price *et al*. 2004, 2011)

GROUND CLASS	DESCRIPTION
MADE GROUND	Areas where material is known to have been placed by humans on the pre-existing natural land surface.
WORKED GROUND	Areas where the pre-existing land surface is known to have been excavated by humans.
INFILLED GROUND	Areas where the pre-existing land surface has been excavated and subsequently partially or wholly backfilled by humans.
DISTURBED GROUND	Areas of surface or near surface mineral workings where ill defined excavations, areas of subsidence caused by the workings and spoil are complexly associated with each other.
LANDSCAPED GROUND	Areas where the pre-existing land surface has been extensively remodelled but where it is impracticable to delineate separate areas of made ground, worked ground or disturbed ground.

In this paper, it is proposed a third way for classifying technogenic landforms, considering *technogenic processes*, *technogenic layers* (all type of superficial formation created directly by or indirectly under influence of Man's geological agency, including deposits or horizons), and the related *technogenic ground.*

Just in relation to what concerns to artificial ground, Price *et al*. (2004) proposes an enhancement of the original five categories classification, consisting of a scheme using a hierarchy of classes, types and units, as shown in table 4, in which each level of hierarchy can be subdivided providing progressively more detailed information.

Table 4: Example of the BGS enhanced hierarchic classification (Price *et al*. 2004)

CLASS	TYPE	UNIT
Made ground	Engineered embankment	Flood defense embankments
		Rail embankments
		Road embankments
	Many further types	Many further types

It´s remarkable that the "made ground" category has already been described by Sherlock (1922), in his study of the human geological agency in the City of London, as an "incoherent and superficial deposit, analogous in texture and position to a river deposit or glacial drift" (p.334), consisting of *débris* accumulations, that is, varied masses of "human exuviae of every conceivable kind, mixed with more or less with soil or rock" (p.193), that conforms an artificial surface level.

Taking it into account, in terms of constituent material, the made ground and the infilled ground are formed essentially by technogenic built up deposits, according to the classification of technogenic ground and geological material proposed by Peloggia *et al.* (submitted).

Furthermore, the BGS classification lacks on the consideration of important types of geological material formed due to human geological agency. For example, there isn't an artificial ground class that represents, without ambiguities, the sedimentary deposits formed under indirect influence of humankind (the induced technogenic deposits), or the surfaces that have been eroded by human induced processes (eroded ground). Or also these ones formed by the superposition of layers of genetically differentiated artificial ground (layered ground). In this ground class, of course, it is necessary to characterise the local technogenic profile (the vertical setting of superposed technogenic layers, that is, technogenic deposits or technogenic soil horizons) and its specific technogenic layering mode (geometric relationship between layers).

This kind of mapping has been used, for example, by Barros & Peloggia (1993), who proposed detailed geological-geotechnical mapping (1:500 scale) units defined by the superposition of technogenic layers and natural soil horizons.

In this context, the classification of technogenic ground proposed by Peloggia *et al.* (2014) (table 5a and 5b) enhances the former classifications of artificial ground, including the technogenic deposits and horizons, and provides 13 additional categories of mappable ground, grouped into four main classes.

Be as it may, it is now possible to introduce another way to classify the technogenic landforms using, as criterion, the type of movement of the geological material: removal, deposition or *in situ* displacement. This procedure allows three main genetic categories of technogenic landforms, as displayed in tables 6a and 6b.

So in this context, it's also useful to introduce an integrated classification to what joins the three former criteria, associating the nature of human action, the nature of the technogenic processes and the associated movement of geological material. The proposal for the new classification is displayed in figure 1, and the final result is the definition of four main genetically homogeneous geomorphic technogenic land surface types. Each surface type, by its time, may represent different specific landforms related to particular technogenic environments.

Table 5A: The classification of technogenic ground proposed by Peloggia *et al*. (2014), resumed and adapted

TECHNOGENIC GROUND CLASSIFICATION		
CLASS	**TYPES**	**TECHNOGENIC LAYER OR FEATURE**
Aggraded Technogenic Ground	Made ground (1,2)	Technogenic built up deposits
	Infilled ground (2)	Technogenic built up deposits covering worked ground
	Technogenic sedimentary or wash ground	Induced alluvium-like sedimentary technogenic deposits
	Colluvial technogenic slope ground	Induced colluvium-like technogenic deposits
	Displaced ground	Remobilized technogenic deposit
Degraded Technogenic Ground	Eroded ground	Erosion scars due to induced processes
	Slipped or Scared ground through landslides	Slope mass movement scars due to induced processes
	Sunken or Disturbed ground (2)	Subsidence sinkholes due to induced processes
	Excavated or Worked ground (2)	Excavation surfaces
Modified Technogenic Ground	Chemically modified ground	Contaminated soil horizons
	Mechanically modified ground	Compacted or revolved soil horizons
Mixed Technogenic Ground	Complex ground	Complex technogenic profiles
	Layered ground	Composed technogenic profiles

(1) In the original sense as cited by Sherlock (1922).
(2) According to the British Geological Survey (BGS) artificial ground classification.

Table 5B: Version in Portuguese of the technogenic ground classification

CLASSIFICAÇÃO DE TERRENOS TECNOGÊNICOS		
CLASSE	**TIPO**	**CAMADA OU FEIÇÃO TECNOGÊNICA**
Terreno tecnogênico de Agradação	Terreno produzido (1,2)	Depósitos tecnogênicos construídos
	Terreno preenchido (2)	Depósitos tecnogênicos construídos recobrindo terreno escavado
	Terreno tecnogênico sedimentar aluvial	Depósitos tecnogênicos sedimentares induzidos de tipo aluvial
	Terreno tecnogênico sedimentar coluvial	Depósitos tecnogênicos induzidos de tipo coluvial
	Terreno remobilizado	Depósitos tecnogênicos remobilizados
Terreno tecnogênico de degradação	Terreno erodido	Cicatrizes de erosão criadas por processos induzidos
	Terreno escorregado ou marcado por cicatrizes de escorregamentos	Cicatrizes de escorregamentos criadas por processos induzidos
	Terreno movimentado ou afundado (2)	Depressões de subsidência criadas por processos induzidos
	Terreno escavado (2)	Superfícies de escavação
Terreno tecnogênico modificado	Terreno quimicamente alterado	Horizontes de solo contaminados
	Terreno mecanicamente alterado	Horizontes de solo compactados ou revolvidos
Terreno tecnogênico misto	Terreno sobreposto	Perfis tecnogênicos compostos
	Terreno complexo	Perfis tecnogênicos complexos

(1) No sentido original atribuído por Sherlock (1922).
(2) De acordo com a classificação de terrenos artificiais do Serviço Geológico Britânico.

Table 6A: A proposal on the genetic classification of technogenic landforms based on the displacement of geological-technogenic material criterion

MAIN CATEGORIES	**GENESIS**	**ORDINARY TYPES**
Aggraded Landforms	Land surfaces produced through *building up processes* due to *accumulation of material*, namely landfilling, or by intensification of sedimentary deposition.	(1) Sedimentary-like depositional landforms (2) Landfills and dumps in general
Degraded Landforms	Land surfaces produced or modified by the *removal of geologic material*: directly by human mechanical action or indirectly by human intensification of erosion, or even by natural erosion of ancient technogenic deposits.	(1) Natural surfaces that suffered induced accelerated erosional processes (2) Former technogenic deposits further eroded (3) Directly excavated surfaces
Disturbed Landforms	Land surfaces and geomorphic systems topographically altered by *in situ dislocation or displacement of geologic material* due to induced superficial or underground mass movements.	(1) Natural surfaces that suffered subsidence or collapse processes (2) Former aggradation technogenic surfaces further dislocated (3) Modified river system patterns

Table 6B: Version in portuguese of the proposal of genetic classification of technogenic landforms

PRINCIPAIS CATEGORIAS	**GÊNESE**	**TIPOS COMUNS**
Formas agradativas	Superfícies geomórficas produzidas por processos de elevação topográfica devida à acumulação de material, notadamente aterramento, ou pela intensificação da deposição de sedimentos.	(1) Formas deposicionais sedimentares. (2) Aterros em geral.
Formas degradativas	Superfícies geomórficas produzidas ou modificadas pela remoção de material geológico: diretamente por ação mecânica humana ou indiretamente pela intensificação da erosão, ou mesmo pela erosão natural agindo sobre depósitos tecnogênicos antigos.	(1) Superfícies naturais que sofreram processos de erosão acelerada induzidos. (2) Depósitos tecnogênicos anteriores erodidos posteriormente. (3) Superfícies diretamente escavadas.
Formas movimentadas	Superfícies e sistemas geomórficos alterados topograficamente por movimentação *in situ* de material geológico devida a movimentos de massa superficiais ou subterrâneos induzidos.	(1) Superfícies naturais que sofreram processos de subsidência ou colapso. (2) Formas tecnogênicas agradativas anteriores posteriormente movimentadas. (3) Padrões fluviais modificados.

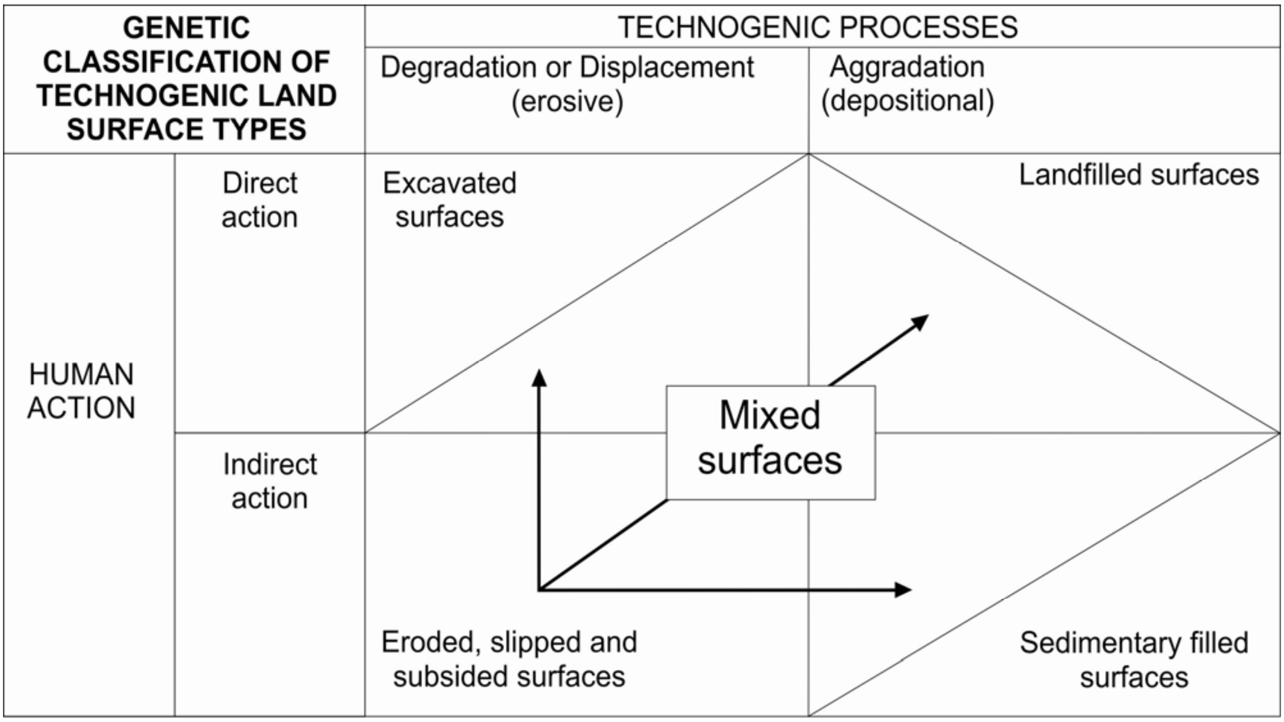


Figure 1: Proposal for integrated genetic classification of technogenic land surface types

After this procedure it's possible to summarize the basic geomorphic technogenic processes that are responsible for the configuration of the technogenic landforms, as viewed in figure 2.

4. The taxonomic approach and the geomorphologic mapping of technogenic landforms

In general, the geomorphologic mapping of technogenic landscapes or technogenic ground presents the same main problems concerning geomorphologic mapping. In addition to the shared problems there are other specifically associated questions. One of them is the particularity of the taxonomic issue or, in other words, the relation between the mapping scale and the dimensions of the possible objects presented by cartographic generalisation.

Nevertheless, considering the ground classification proposed by the BGS works, and using the simplified taxonomic proposal from Demek (1965 *apud* Ross 1992), it is possible to propose a specific approach applied to the technogenic relief cartographic representation. Demek's classification itself joins three levels of mapping: 1) genetically homogeneous surfaces (representing the smaller spatial dimension); 2) landforms (the intermediate dimension), and; 3) relief types. According to Ross (1992), this approach is applied to detailed scales of mapping of 1:5.000 to 1:10.000, and because of this limitation it's necessary to add an additional level to be able to feature major spatial dimensions joining up settings of diversified landforms.

Ross (1992) proposes a relief taxonomic classification in which six classes (taxa) are recognized as being: morphostructural units, morphosculptural units; morphologic units or landform patterns; landform types; slope types and contemporary processes related landforms. According to the author, the last class in general includes landforms originated by human induced processes, such as accelerated erosional events. By comparing the landforms produced due to human action with the landform categories proposed by Ross (1992), Peloggia (2005b) writes that it is possible to consider the occurrence of technogenic landforms from the sixth up to the fourth class (landform types). However, a primordial difference is that Ross' classification reveals a strong genetic link among the smaller landforms and the larger ones. But in the specific case of technogenic landforms, according to Peloggia (2005b), the smaller ones may not have any kind of genetic relationship with the larger ones, in terms of generating processes. Following on from this idea, there is certainly a spatial conditioning linking the technogenic land shape with the natural relief compartments, because human geomorphologic action taking place overlaps on former natural landforms.

In this point of view (tables 7a and 7b), the technogenic landform may be considered as the basic taxonomic category. The technogenic landforms themselves (figure 2) are defined by technogenic land surfaces (related to excavation, landfilling, erosion or sedimentary filling). The technogenic land shapes (figure 3) are settings of various origin technogenic landforms that conform with a specific relief shape found in a certain area. And the technogenic landscapes (figure 4) consist of large areas extensively transformed by geomorphic human action, which include landforms generated by all the four land surface genetic processes.

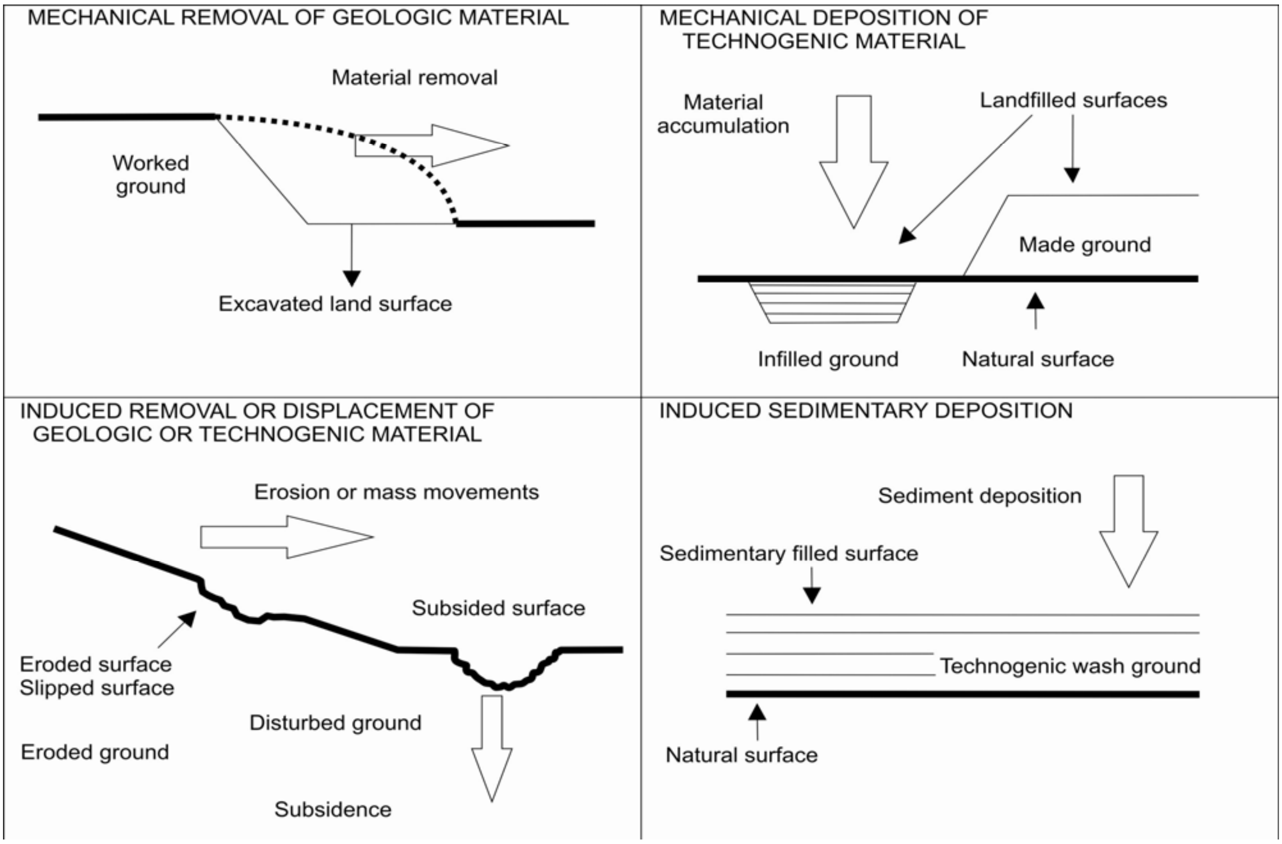


Figure 2: Schematic view of basic geomorphic technogenic processes and related land surface types and technogenic ground

5. Technogenic Landform mapping in Presidente Prudente City and surroundings (São Paulo State, SE Brazil)

The City of Presidente Prudente is found within the Paraná Sedimentary Basin Morphostructure and in the São Paulo Western Plateau morphosculpture within it, namely in its Mid-Western Plateau unit (Ross & Moroz 1997). The rocky substratum is the Adamantina sandstone, a Mesozoic sedimentary formation, which was included into the Bauru Group (IPT[1] 1981). According to Soares *et al.* (1980, *apud* IPT 1981), this formation is composed by finely granulated sand bars alternated with mudstones. The weathering and pedogenesis processes acting over this basement have produced in general sandy soils highly susceptible to erosion.

What concerns the natural relief configuration of the urban area is the predominance of low hills (300 to 600 m high) with slope declivities of about 10% to 20%. There is a remarkable difference between the West side and the East side of the area. The West side has larger hills with gently undulated tops and also gentle slopes (declivities varying from 0 to 10%), compared to the East side, in which the hills are predominantly shorter with undulated tops and more inclined slopes (declivities from 5% to 20%) (Nunes *et al*. 2006).

Due to the modifications caused by the human activities, specifically in the urban area, the geomorphology and the superficial ground have also been altered. Two areas have been studied in detail, namely the Alexandrina Park and the Industrial District I (Antônio Crepaldi area), in each one of them the occurrence of technogenic deposits have been investigated.

5.1. Technogenic deposits and techniques of sampling

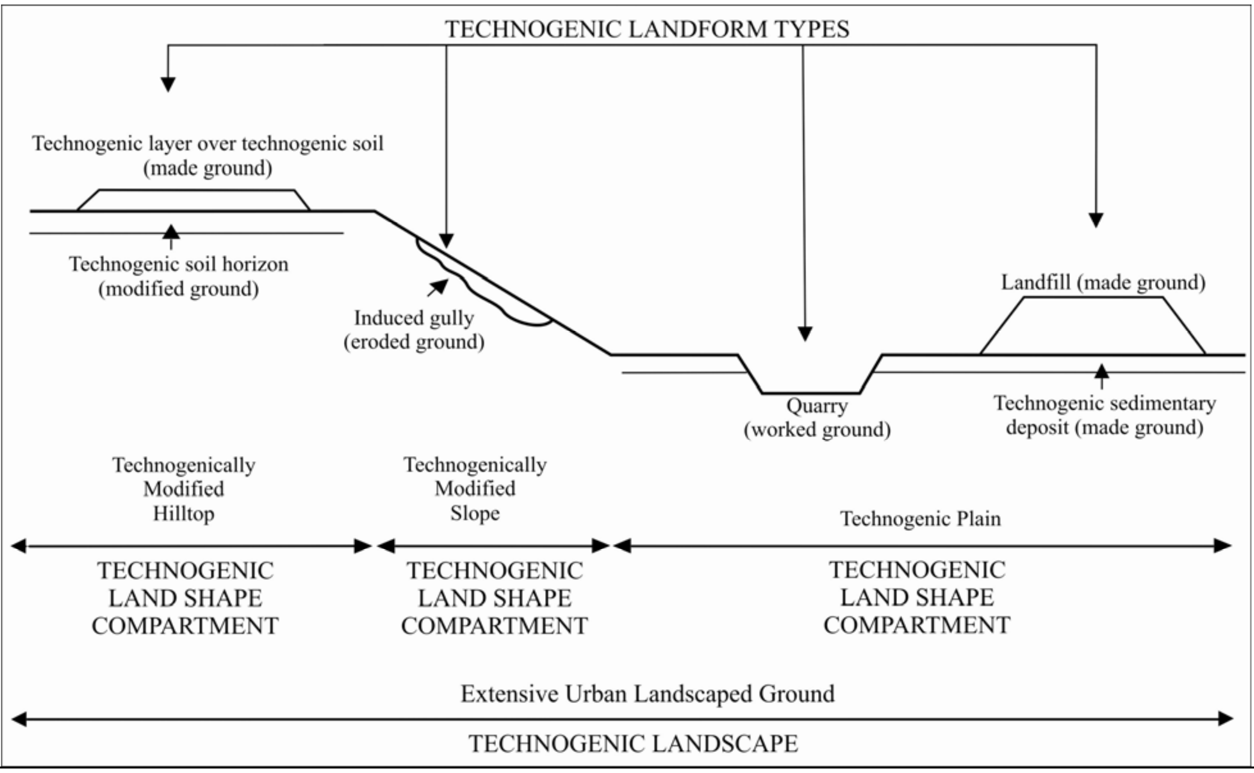
The induced technogenic deposits of Alexandrina Park and Industrial District I (Antônio Crepaldi area) have been deposited over hill slopes and their formation can be associated to land use and settlement processes, in particular due to accelerated erosion rates.

Alexandrina Park is a popular residential area, found on the East side of the city (where the slopes are more inclined than in the West side), specifically in the places near the “V” valley flats, which can have only restricted narrow floodplains. In this way it has been made possible the deposition of technogenic layers (*induced colluvium-like technogenic deposits*) in the slope compartment, producing a particular type of aggraded artificial ground, classified as *colluvium technogenic slope ground*, according to the Peloggia *et al.* (submitted) classification.

[1] IPT: Instituto de Pesquisas Tecnológicas do Estado de São Paulo.

Table 7A: Proposal for taxonomic classification of technogenic relief

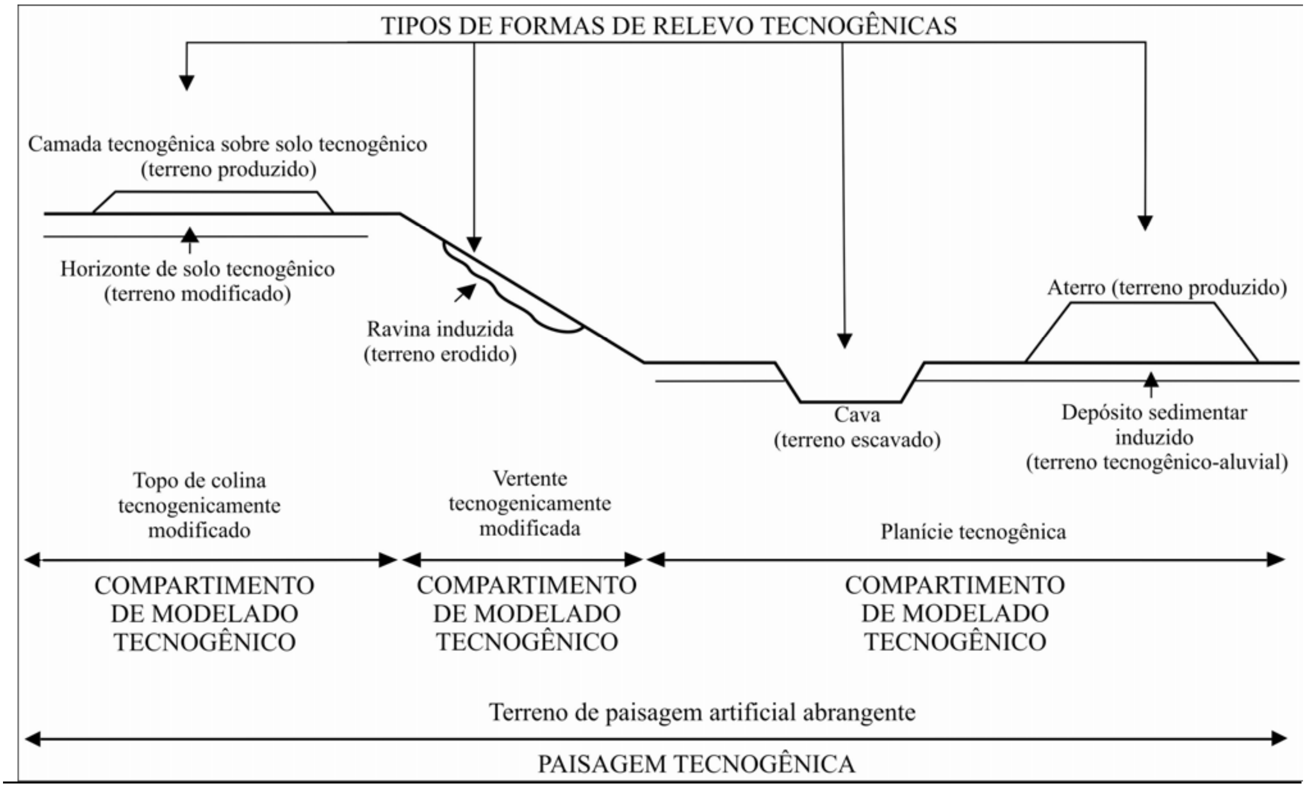
TECHNOGENIC-GEOMORPHOLOGIC TAXON	1. TECHNOGENIC LANDSCAPES	2. TECHNOGENIC TERRAINS (LAND SHAPE COMPARTMENTS)	3. TECHNOGENIC LANDFORM TYPES AND RELATED LAND SURFACES
CONCEPT	Widespread areas with extensive typical relief transformed or produced by human action	Technogenic features of a tract of land (Settings of technogenic landforms associated with natural relief compartments)	Individually defined aggradational, degradational or disturbed forms shaped by different technogenic land surfaces genetic types (excavation, landfilling, sedimentary or erosion surfaces)
EXAMPLES	Urban, mining and agricultural landscaped ground, "bad lands" etc.	Technogenic plains, hilltops or slopes modified by technogenic processes	Landfills, technogenic terraces, induced gullies, open pits
RELATION WITH GEOMORPHOLOGIC TAXONOMIC CLASSIFICATION (1)	Ross' 3rd taxon (morphologic units or landform patterns)	Demek's 3rd taxon (relief types) *** Ross' 5th taxon (slope types) and 4th taxon (landform types)	Demek's 1st and 2nd taxa (genetically homogeneous surfaces and landforms) *** Ross' 6th taxon (contemporary processes landforms)
RELATED TECHNOGENIC (ARTIFICIAL) GROUND (2)	The overall extensive landscaped ground which forms parts of the Anthopostrome (3)	Settings of artificial ground related to one or more classes	Specific categories of aggrades, degraded, modified or mixed technogenic ground
REFFERENCE MAPPING SCALES (4)	Reconnaissance and Regional maps (up to 1:25.000)		Detailed (up to 1:10.000) and Specialized maps (up to1:2.500)



(1) According to Ross (1992).
(2) Based on the BGS artificial ground classification, modified.
(3) According to Passerini (1984).
(4) Nomenclature as used by Barnes & Lisle (2004).

Table 7B: Version in Portuguese for taxonomic classification of technogenic relief

TAXON GEOMORFOLÓGICO TECNOGÊNICO	1. PAISAGENS TECNOGÊNICAS	2. COMPARTIMENTOS DE MODELADO TECNOGÊNICO	3. TIPOS DE FORMAS DE RELEVO TECNOGÊNICAS E SUPERFÍCIES GEOMÓRFICAS RELACIONADAS
CONCEITO	Áreas amplas com extenso e típico relevo transformado ou produzido pela ação humana	Conjuntos de formas de relevo tecnogênicas associadas a compartimentos de relevo naturais	Formas de relevo agradacionais, degradacionais ou movimentadas definidas por diferentes tipos genéticos de superfícies tecnogênicas (de escavação, aterramento, sedimentação ou erosão)
EXEMPLOS	Paisagens urbanas, minerárias ou rurais de terrenos artificiais, extensos terrenos ravinados, etc.	Planícies tecnogênicas, topos de colinas ou vertentes modificadas por processos tecnogênicos	Aterros, terraços tecnogênicos, ravinas de induzidas, cavas de mineração
RELAÇÃO COM A CLASSIFICAÇÃO TAXONÔMICA DAS FORMAS DE RELEVO (1)	3º taxon de Ross (unidades morfológicas ou padrões de formas)	3º taxon de Demek (tipos de relevos) *** 5º taxon (tipos de vertentes) e 4º taxon (tipos de formas de relevo) de Ross	1º e 2º taxa de Demek (superfícies geneticamente homogêneas e formas de relevo) *** 6º taxon de Ross (formas de processos atuais)
TERRENOS TECNOGÊNICOS (ARTIFICIAIS) ASSOCIADOS (2)	Terrenos de paisagens artificiais que constituem partes do Antropostroma (3)	Conjuntos de terrenos artificiais relacionados a um ou mais tipos de forma de relevo tecnogênica	Categorias específicas de terrenos tecnogênicos agradativos, degradativos, modificados e mistos
ESCALAS DE REFERÊNCIA DE MAPEAMENTO (4)	Mapas de reconhecimento e Mapas regionais (escalas 1:25.000 e maiores)		Mapas de detalhe (1:10.000 ou maiores) e especializados (1:2.500 e maiores)



(1) Conforme Ross (1992).
(2) Baseada na classificação de terrenos artificiais do Serviço Geológico Britânico, modificada.
(3) No sentido proposto por Passerini (1984).
(4) Nomenclatura utilizada por Barnes & Lisle (2004).

Figure 3: Technogenic land shape compartments: an extract of Guanabara State Geological Map, original scale 1:50.000 (Brazilian Ministry of Mines and Energy, Geology and Mineralogy Division, 1965). The “at” grayish areas near the shore are settings of flat lands (embankments) built up by technogenic deposits (made ground)

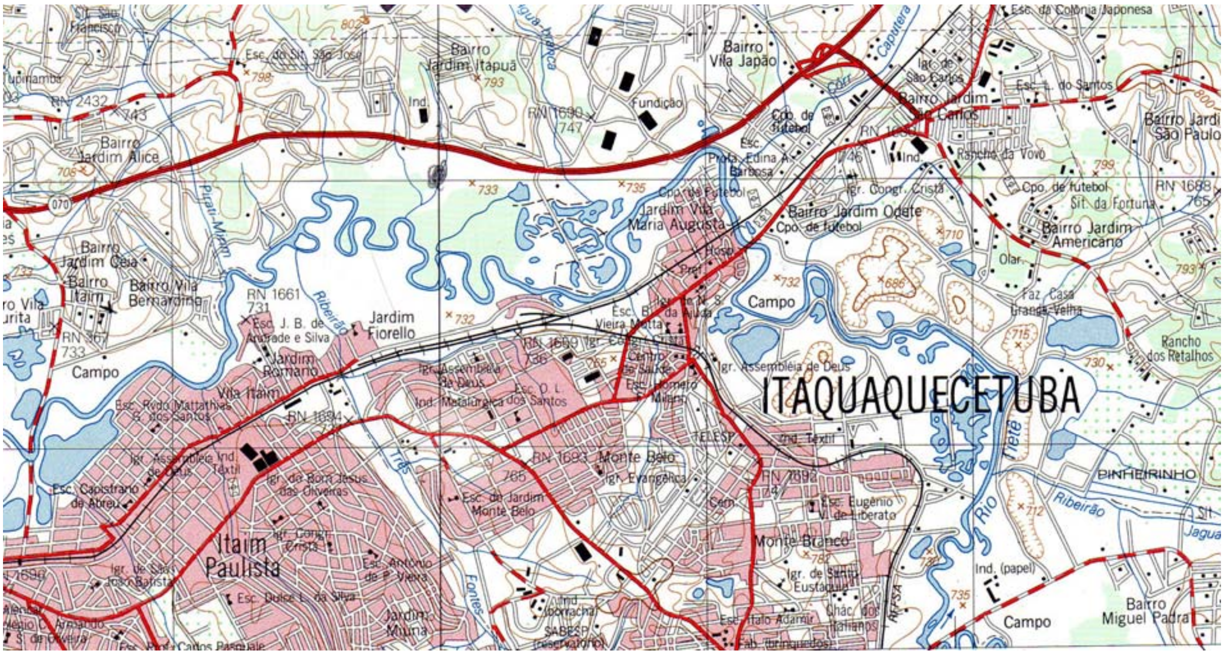


Figure 4: Technogenic landscape : The Tietê River technogenic plain, near São Paulo City, in which can be clearly viewed the worked ground (sand quarries) and technogenic lakes formed upon them. The former alluvial floodplain is even recognizable by the meandering river remaining. Extract of 1:50.000 (original scale) geographic map, Itaquaquecetuba Sheet SF.23-Y-D_I_3 (IBGE – Brazilian Institute of Geography and Statistics, 1984)

Contemporarily, this part of the city has reached a consolidated stage of urbanization, the settlement taking place over several years, in particular the late 1970’s and through to the end of the 1980’s (Fernandes 1988, Sposito 1990). This urban evolution has allowed the formation of artifact-rich technogenic deposits, such as tile fragments, plastic materials, tissue rests and some garbage (figure 5), that can be classified as *urbic* materials according to the proposal by Fanning & Fanning (1989). The sampling of the technogenic deposit was extracted by using a one meter long 6” PVC tube (figure 6), and the material has been excavated from a gully wall. Finally, it is remarkable that in this area the valley flats had also been habitually used for domestic garbage and kitchen midden deposal, and this type of technogenic material can be classified as *garbic* (Fanning & Fanning 1989), that is, waste material.

Figure 5: Technogenic deposit found at Alexandrina Park. The presence of artifacts (technogenic fragmented manufactutered materials) can be identified as building refuse (Silva 2012).

Figure 6: Technogenic material sampling from Alexandrina Park (Silva 2012).

The technogenic deposit cited is nowadays being intensivelly eroded, what is explained by the hypothesis formulated by Oliveira (1990), from whom as the urbanisation processes move forward, the superficial runoff increases (due to street pavements, for example) and the former technogenic deposits can be themselves eroded. In this way the technogenic material can be well deposited on lower portions of the slopes and just in the valley *thalweg.*

Industrial District I (Antônio Crepaldi area) was formed in the late 1970's and presents different land uses although the main use is industrial, as the district's name indicates. The land occupation has been concentrated along the gentle undulating hilltops, but the hillsides present steeped sloped areas like the ones at the headwaters and the slope basis.

The occurrence of a major domestic waste deposit is another specific feature of the area (figure 7). The deposit has been considered inadequate by the São Paulo State Environment Agency (CETESB 2012), and can be classified as a *built up technogenic deposit* composed by garbic material, that is, garbage with organic waste able to generate Methane under anaerobic conditions (Fanning & Fanning 1984). The induced techogenic deposit studied is found just downslope from the waste deposit cited above, and its constituent materials are derived from the erosion processes taking place in the mid slope, induced by human activities. The same PVC tube sampling technique was used in this area, the sampler being inserted into the ground up to a depth of 59 cm in a gully wall formed by the superficial flow of rain water and of the contaminated water resulting from the waste deposit.

Figure 7: Contemporary view of Presidente Prudente solid waste dump referring to the sampling point of technogenic deposit (Silva 2012).

This deposit can be classified as the induced colluvium-like sedimentary type (see table 4), because the human influence in its formation has occurred previously and at an upslope place, turning the downslope technogenic deposition possible due to the action of a superficial runoff. In the studied area there is a large quantity of materials coming from the dump; however, specifically in the deposit just a few traces of these components were fround among the sampled technogenic sedimentary layers.

5.2. Geomorphologic natural configurations and the geomorphologic technogenic mapping of Presidente Prudente City

The geomorphologic mapping of Presidente Prudente City was carried out by Nunes *et al.* (2006) in 1995, based on aerial photographs (BASE S.A.). In this map there are outlined land shape compartments as well as the valley flat and slope related landforms.

These compartments and landforms have been outlined without considering the technogenic modifications that have been superimposed over the original landforms. The main issue associated with this is how to include the new technogenic landforms within the former geomorphologic map.

The method employed to resolve the issue was just to insert, into the previous maps, appropriated textures and non shaded polygons to indicate the occurrence of technogenic ground that was found in the landscape. The shaded coloured polygons have remained in the map showing the original land shape compartments.

To identify the technogenic landforms it was necessary to use aerial photographs of two distinct times (1962 and 1995)[2] in 1:25.000 map scale, afterwards complemented by satellite images (Google Earth) from 2013.

After all, the identification and mapping of the technogenic ground and its related landforms was possible using former images and by the investigation of the technogenic layers themselves. These procedures have permitted the inference of the processes that have led to the formation of the technogenic deposits and, as a directly related consequence, the technogenic landforms. In the Industrial District area, the main modifications to the land have been caused through erosion and stream dynamics modification (figure 8).

By observing the aerial photographs it has been possible to view several consequences of the technogenic actions over the landscape. In the 1962 photo it is possible to view a little vegetation and several erosion scars related to the removal of former woodland. As the urbanisation had not started yet in this area, the changes occurred can be associated with rural activities.

In the 1995 aerial photo, which has been used for the geomorphologic mapping, it is just possible to observe the urban-industrial development in the area. Between 1962 and 1995 there were extensive changes to the landscape, as the filling of eroded ground by technogenic materials and the start of new erosion processes. Another remarkable change has occurred to the river dynamics, by the disappearance of stream segments between 1962 until 1995, and the urban development on the former sites of stream sources, that conforms nowadays with hilltops. In this situation it is likely that what has occurred is the direct deposition of technogenic material.

The floodplain has also suffered from sedimentary deposition processes, which can be observed by comparing the aerial photos between 1962 and 1995, which also shows the disappearance of stream segments.

The deposition of technogenic materials (wastes and garbage) has been identified by comparing the aerial photographs with the recent Google Earth images, because this kind of deposition has been taking place since 1997, as it has already occurred at Alexandrina Park area (figure 9), as cited above.

According to Mazzini (1997), two specific areas at Alexandrina Park were used for domestic waste deposition, one which had been a former erosion gully, was completely filled by 1978, and the other was the valley flat, which was used as a deposition place until 1987. Beyond the filled gullies other ones have been created already through erosion, and it was observed that many stream channels have been buried.

According to the results of the geomorphologic mapping, the identified relief features can be classified as technogenic landforms of aggraded and degraded types (table 7). In some cases the aggraded forms occur over formerly degraded ground, as in the above described buried erosion gullies.

6. Final remarks

In this context, nowadays it is clear that the landscapes produced or modified by humans are not only just visual images, but they have a material basis that has been created directly or indirectly through human activity. These features are specifically geological in that they refer to the new layers of aggraded ground that have been created, and are specifically geomorphologic when the newly created landforms and land shapes are considered.

In other words, humankind is in a broad sense a geological agent just in the way he, changing or creating processes (which implies degradation, aggradation or disturbance of natural land), produces new types of artificial ground recognized as specific landforms. This action has been termed by Chemekov (1983) as *geotechnogenesis.* This specific aspect of the technogenesis refers to the creation, through human action, of landforms and land shapes in the way which is referred to as *morphotechnogenesis* (Peloggia 1998).

Understanding the dynamics and mode of work of this new agent is a new challenge for geoscientists. Of course, one of the first tasks for them is to observe, identify, map and classify the products of this original geological action. In this paper, we have proposed support for both the classification and mapping of the technogenic landforms. But it was essentially an exercise that has attempted a first approximation of an original subject. The case study must be understood as being an exploratory study that needs to be further developed as the authors wish this study to be useful as a basic conceptual framework and as a tangible example of application.

[2] Laboratory of Aerofotogeography e and Remote Sensing – Department of Geography – São Paulo University (IS/ many companies). 1962 flight over Presidente Prudente - SP. Aerial photographs (semi-controlled mosaic). Scale: 1:25000. N. 6780 e 6479.

BASE S/A 1995. BASE Aerofotogrametria e Projetos S/A (São Paulo). September 1995 flight over Presidente Prudente - SP. Aerial photographs. Scale1:25000. Fx 04. N 12 e 9.

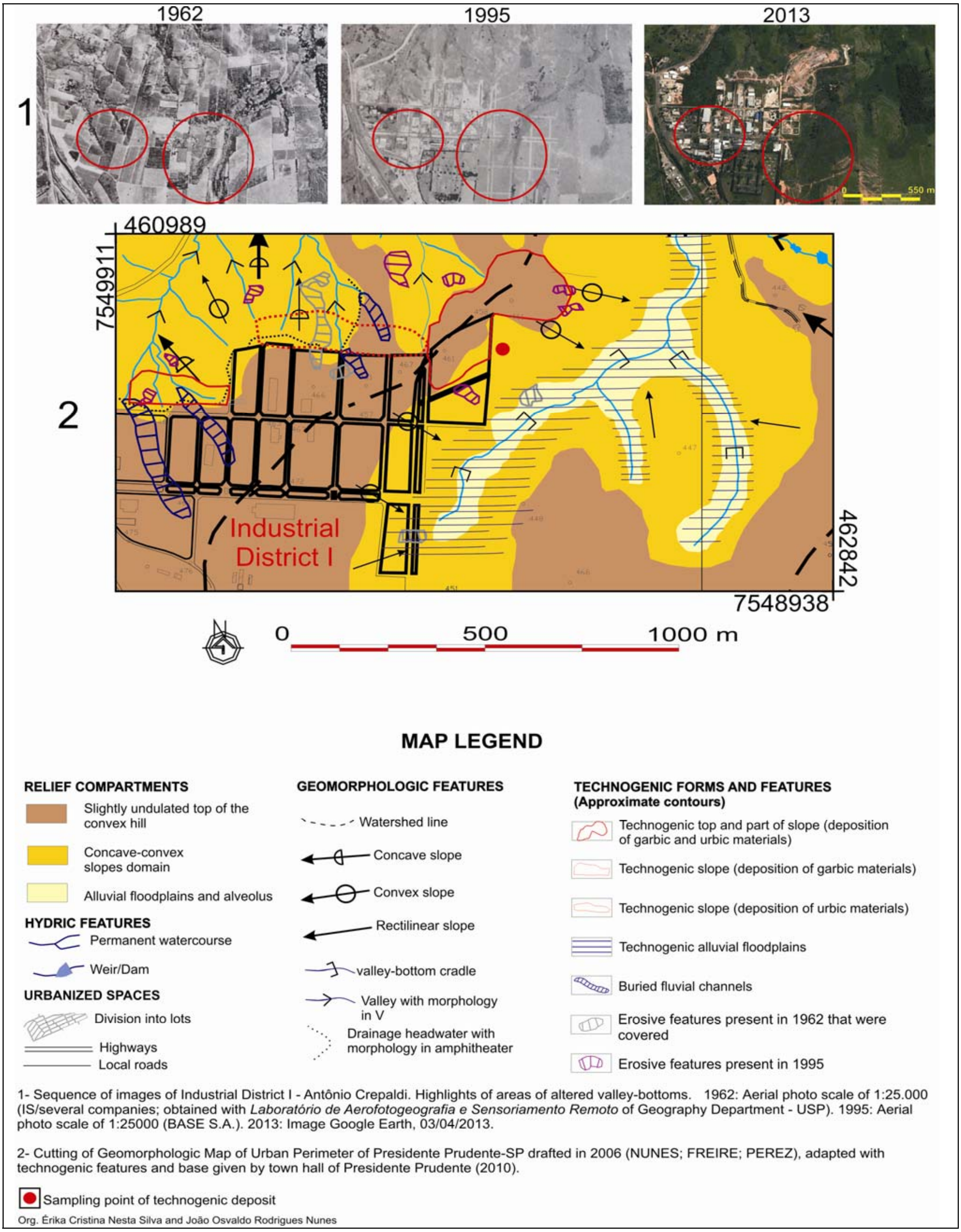


Figure 8: Technogenic landforms related to land shape compartments in Industrial District I

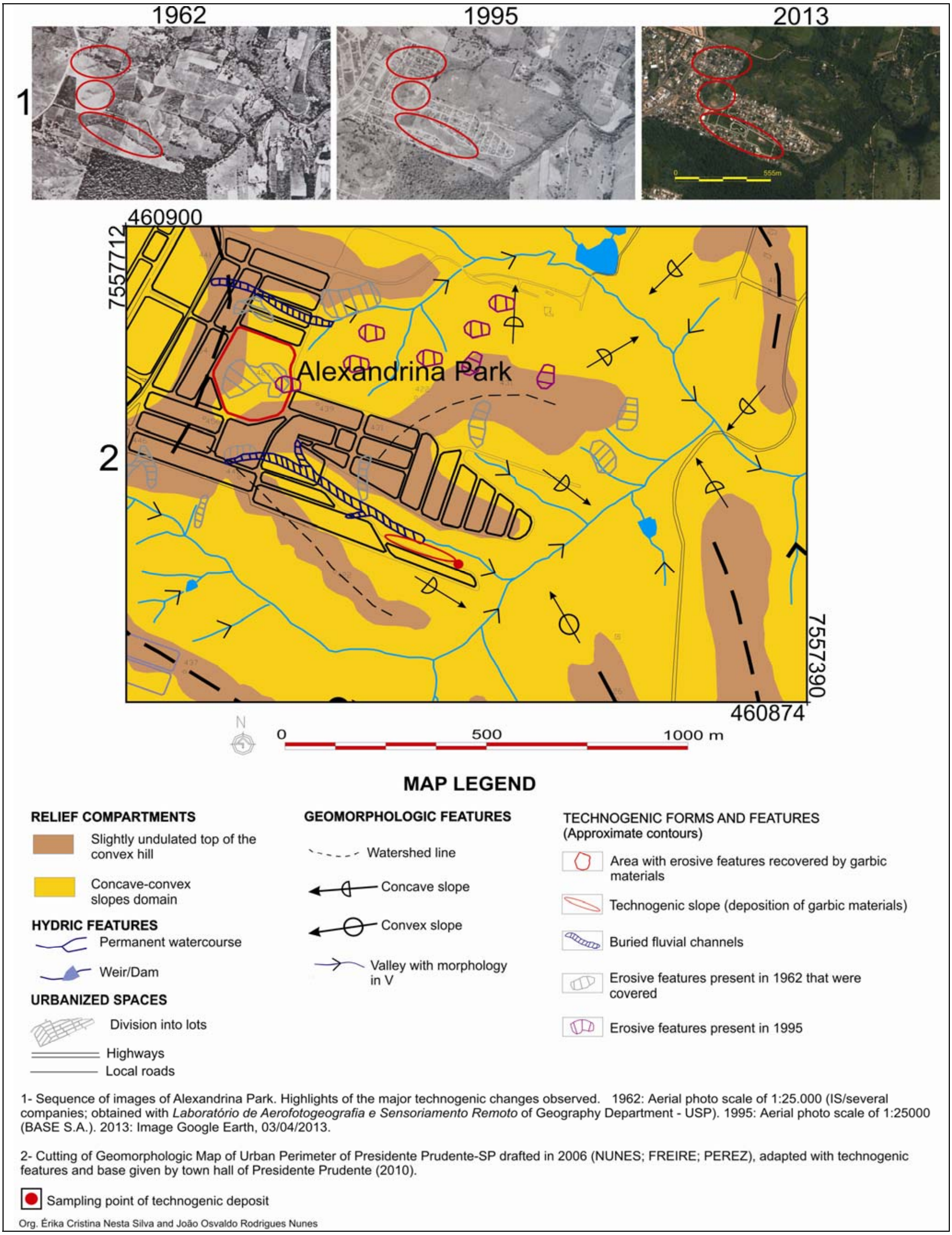


Figure 9: Technogenic landforms associated to land shape compartments at Alexandrina Park

Table 7: Land shape compartments and related technogenic landforms observed at the mapped areas

LAND SHAPE COMPARTMENTS AND RELATED TECHNOGENIC LANDFORMS		LAND SHAPE COMPARTMENTS		
		Hills		Alluvial floodplains
		Tops	Slopes	
Technogenic landforms	Aggraded	Flat made ground consisting of technogenic built up deposits (landfilled surfaces)	Colluvial technogenic slope ground ramps Erosion gullies filled with technogenic deposits (Infilled ground with infilled surfaces) "V" valleys filled with technogenic deposits (terrace made ground) and buried stream channels (landfilled surfaces)	Alluvial deposits covered by technogenic deposits (terraced made ground with landfilled surfaces)
	Degraded	Gullies associated to land use processes (eroded surfaces)	Erosion gullies induced by land use (eroded surfaces)	

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