

# Technogenic geodiversity: a proposal on the classification of artificial ground

## *Geodiversidade tecnogênica: uma proposta de classificação dos terrenos artificiais*

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### ABSTRACT

This paper's main purpose is to propose and discuss a specific geological classification (termed geotechnogenic) of artificial ground, that is, the new ground types formed as a direct or indirect result of human action, be it related to erosion or deposition processes or whilst *in situ* modification of the natural land. These technogenic grounds are classified into four main categories, namely the *aggraded ground*, the *degraded ground*, the *modified* and the *mixed* ground, each of them is subdivided into specific genetic types. The foundations of the proposal are derived from two main "schools" of thinking about the geological products of mankind's activity, on one hand the British works on the artificial ground and, on the other hand, the former Soviet, after Russian and east European studies on technogenic deposits and soils. These contributions have been compared with and joined to the American and Brazilian contributions on the study of technogenic deposits, leading to a comprehensive and synthetic table that can be used for basic purposes of geological and geotechnical analysis and mapping of land areas transformed by human action, as well as to aid their geomorphologic interpretation and mapping.

**Keywords:** technogenic ground (degraded, aggraded, modified, mixed); technogenic deposits; technogenic soils; geotechnogenic.

### RESUMO

O principal propósito do presente trabalho é propor e discutir uma classificação especificamente geológica (denominada geotecnogênica) dos terrenos artificiais, ou seja, os novos terrenos formados como resultado direto ou indireto da ação do ser humano, seja esta relacionada a processos erosivos ou deposicionais ou ainda a transformações ocorridas *in situ* dos terrenos naturais. Esses terrenos tecnogênicos são classificados em quatro categorias principais, a saber os terrenos de agradação, os terrenos de degradação, os terrenos modificados e os terrenos mistos, cada qual por sua vez é subdividida em tipos genéticos específicos. Os fundamentos da proposta são derivados de duas "escolas" de pensamento principais sobre os produtos geológicos das atividades humanas, por um lado os trabalhos britânicos sobre terrenos artificiais e, por outro lado, os estudos soviéticos e leste-europeus sobre solos e depósitos tecnogênicos. Essas contribuições foram comparadas e agregadas às contribuições norte-americanas e brasileiras sobre o estudo dos depósitos tecnogênicos, levando a uma tabela sintética e prontamente utilizável para os propósitos básicos da análise e do mapeamento geológico e geotécnico de áreas transformadas pela ação humana, assim como para subsidiar sua interpretação e mapeamento geomorfológico.

**Palavras-chave:** terrenos tecnogênicos (de degradação, de agradação, modificados, mistos); depósitos tecnogênicos; solos tecnogênicos; geotecnogênico.

## 1. Introduction

The *technogenic deposits* can be categorised as a class of superficial formation created due the geological action of humankind, according to the original concept by Chemekov (1983). On the other

hand, the *artificial ground* concept, as proposed by the British Geological Survey (Rosebaum *et al.* 2003) implies the modification of the Earth's surface due to both degradation and aggradation, each of these processes being essentially related to direct "human made" effects. Additionally, both classifications don't

consider the characteristics of the ground built up but only transformed through human action, as described for example by [Fanning & Fanning \(1989\)](#) in their article concerning man-influenced soil horizons, or by Russian and Polish researchers (e.g. [Mozharova & Gol'tsova 2008](#), [Charzynski et al. 2013](#)).

In this context, the scope of this paper starts with the statement that all these kinds of material (deposits, grounds, soils) have the statute of human action geological records in order to discuss the former contributions and wishing to propose a new classification of *technogenic ground*. This concept joins all categories of geological products “made or genetically influenced” by Man and expresses what we also propose to call *technogenic geodiversity*.

## 2. Historical approach on the study of the geological records of human action.

### 2.1. Some ancient references

The reference to the specific geological action of humankind is not so frequent in the literature, but it has been covered by very important authors. For example, Charles Lyell, in his *Principles of Geology*, cites the reference in Dante's *Inferno* to artificial embankments, and describes Man as an “levelling agent”. References to 1700's gold mining placer deposits from Minas Gerais (Brazil), induced by the mining works, have been made by Von Eschwege in his book *Pluto Brasiliensis*. Edward Suess is also cited by his study of Viena's geological substratum in the 1800's ([Peloggia 2005](#)).

Afterwards, Brazilian writer Euclides da Cunha, in his 1902 book *Os Sertões* (“Rebellion in the Backlands”), and other works, have cited Man as a new powerful geological agent. [Branner \(1906\)](#), in his book *Geologia Elementar*, refers to “typical deposits” formed by city waste dumping. These references have almost remained absent from the main textbooks and, for this reason, have resulted in a lack of awareness in the geological education.

All in all, synthesis and references about former studies concerning human geological action are presented, for example, by [Sherlock \(1922\)](#), [Peloggia \(1994, 2005\)](#) and [Oliveira et al. \(2005\)](#).

### 2.2. The British research: the artificial ground

In the context of the pioneer studies cited below, Charles Lyell has been certainly one of the first geologists interested in the issue of Man's action on nature. It is interesting to cite that, in fact, Lyell himself has used the term “made ground”, in his book *The Geological Evidence of the Antiquity of Man*, to indicate the 2 to 3 feet thick superficial layer of a section of a gravel pit containing flint implements at St Acheul (France), as viewed in figure 1 ([Lyell 1863](#)), and also filled graves material.

Lyell himself is responsible for one of the first descriptions of what can be nowadays classified as the *eroded ground*: the Pamona ravine (Georgia, USA), created as a result of accelerated erosion beyond deforesting, as viewed in the *Principles of Geology* ([Lyell 1867](#)). Lyell also describes, in the cited book, an artificial deposit from Brazil: the sepulchral mounds in Santos which is the same type of deposit (*Sambaqui* archaeological layers) as cited by [Moraes Rego \(1933\)](#) in his São Paulo State Cenozoic Formation's Classification.

Meanwhile, the British research on the subject have had a substantive enhance with the book *Man as a Geological Agent*, by [Sherlock \(1922\)](#), who provides a detailed description of Man's geological activities such as denudation (excavation and attrition), the creation of made ground, subsidence, accumulation of man-made rocks, alteration of sea-coast, circulation of water and influence over climate and atmosphere (including “a considerable increase in the amount of carbon dioxide”, p.343). This publication can be considered one of the first really systematic studies concerning the new methodological proposal that nowadays we call *technogenic approach* ([Oliveira 1990](#)) and the foundation stone of this new discipline.

According to [Sherlock \(1922\)](#), *made ground* was an useful term used to refer to the *débris* accumulation covering the natural ground and sustaining an artificial surface level, as observed in London and other places referred to by the author, and “consisting of varied masses of human ‘exuviae’ [detritus] of every conceivable kind, mixed with more or less of soil and rock”. Geologically, the “made ground”, for Sherlock, consists itself in an *incoherent and superficial deposit* analogue to a river deposit or glacial drift. This description and mapping of the *made ground* and other categories of artificial ground is the central point to the approach developed by the British Geological Survey (BGS) in its artificial ground classification ([McMillan & Powell 1999](#), [Rosebaum et al. 2003](#), [Price et al. 2004, 2011](#)).

Be as it may, basically the BGS classification of artificial ground defines five main classes of ground produced directly or indirectly by human action, as viewed in table 1. These classes themselves can be subdivided into types and units, but do not include the sedimentary deposits formed under genetic influence of Man's actions.

As it will be discussed later in this paper, this last type of deposit is classified as *induced technogenic deposit* by [Oliveira \(1990\)](#), who expands the former soviet concept of technogenic deposit proposed by [Chemekov \(1983\)](#). The *made ground* category corresponds to the technogenic built up deposits proposed by [Oliveira \(1990\)](#).

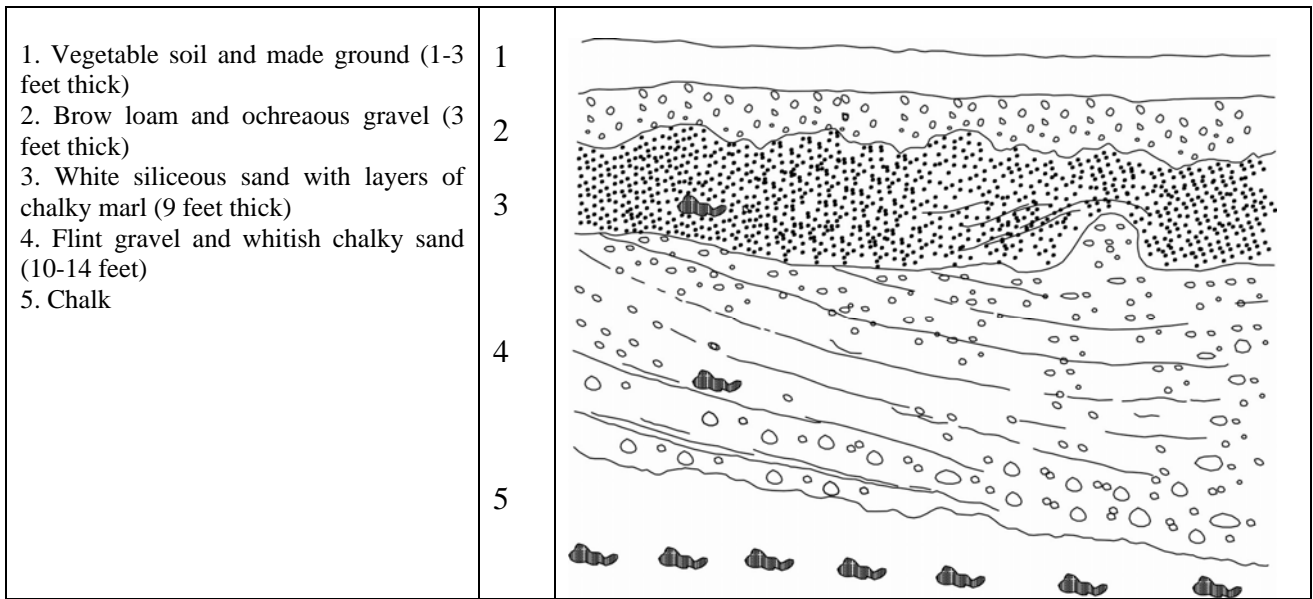


Figure 1: Lyell's (1863) section of a gravel pit at St. Acheul observed in 1860; perhaps the first "technogenic section" ever published (redrawn and adapted from the original)

Table 1: BGS Artificial Ground Classification (McMillan & Powell 1999, 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.

### 2.3. The East European research: technogenic soils and deposits.

Chemekov (1983) defines technogenic deposits as those formed as a result of human activity, having the following geological features: several ways of formation; "technogenic" transport and sedimentation processes independent from the climate and tectonics;

varied composition; wide range of thickness. For the author, these deposits can be classified into three "series" according to the parameters genesis, composition and morphology: sub-aerial, subaqueous and subterranean. The main types in which the classes are subdivided are presented below (table 2):

Table 2: Chemekov's technogenic deposit types

Technogenic deposit type	Description
Dumped	Ores extracted from mines, dumps from different enterprises, construction refuses etc.
Filled	Deposits which are to fill gullies, abandoned mines, quarries etc.
Mixed or agrotechnical	Arable and garden lands.
Washed up	Artificial islands, beaches, banks etc.
Rewashed	Dredged dumps etc.
Construction	-
Cultural layers	-
Precipitation	Precipitated materials in technogenic water reservoirs.
Linear aggradation	Deposition in technogenic streams.
Technogenically changes	Natural deposits with technogenic components.
Technogenically caused	Natural sedimentation in dammed reservoirs.

Ter Stepanian (1988), in the same sense presented as Chemekov (1983), remarks that technogenic (or technogenous) deposits are distinguished by their great variety and characterized by clearly defined distinguishing features. They also comprise an independent genetic class (like the volcanic or alluvial ones) and can be differentiated by origin and composition. However, the author only proposes a specific classification method for “technogenic deposits of cities forming artificial soils”: changed soils

of natural origin, hard domestic garbage and industrial waste.

Since these former proposals, interest in the study of technogenic soils has increased in Russia and eastern Europe, resulting for example in the conceptions of technogenic soil layers and horizons presented by Mozharova & Gol'tsova (2008) (table 3) and the classification of technogenic urban soils from Poland presented by Charzynski *et al.* (2013) (table 4), both related to the soil science study discipline.

Table 3: Technogenic units present at *in situ* underground profile (Mozharova & Gol'tsova 2008)

Technogenic layers (techno-sediments)	Non-soil formations purposefully inserted in the soil during technological operations.
Technogenic horizons	Formed under the combined effect of natural and technogenic factors of pedogenesis with addition of technogenic material.
Technogenically modified horizons	Resulted from the mechanical disturbance or chemical contamination of natural soils without addition of technogenic material.

Table 4: Polish technogenic urban soil classification (Charzynski *et al.* 2013)

Technogenic soil units	Main characteristics and place of occurrence.
Urbisols	Large quantities of artefacts in the profile and high horizontal and vertical variability. Urbanised areas.
Industrisols	Contamination with various substances. Industrial areas.
Gardens soils	Thick and dark humus horizons. Horticultural areas.
Soils of parks and laws	Technogenically transformed natural soils.
Necrosols	Absence of natural horizons, presence of urban layers with abrupt transitions and artefacts.
Ekransols	Soils covered by pavements.
Constructosols	Artificial soil products built of several different layers of mineral material brought by man.

#### 2.4. American contributions to the study of Man's influenced deposits

In the United States of America the occurrence of geological deposits related to Man's action was for the first time cited in early 1800's by Moore (1801) and Taylor (1813) (according to Roehl & Holeman 1975), who have called them *culturally accelerated deposits* because of their relationship with accelerated erosion processes, in counterpoint to the geologic erosion considered as *normal*, in the American literature. These are genetically induced deposits so long as they are related to erosion-transport-deposition processes started by land use forms that were the consequence of the American agricultural expansion through the West.

Taking into account the origin of these deposits as resulting from the agricultural land use of drainage basins, Roehl & Holeman (1975) have included, in the book *Sedimentation Engineering*, edited by the American Society of Civil Engineers (Vanoni 1975), a chapter concerning the study of these *accelerated valley deposits* as adequate for the formulation of parameters for sediment production measuring. This approach has been mainly based on the work from Happ *et al.* (1940), who have studied the deposit formation in small drainage basins in which the accelerated deposition has caused the valley aggradation. The deposits were recognised by features, like colour, texture and compactness, contrasting in comparison with the buried natural soil of the ancient

valley. This procedure was used by Oliveira (1994) to measure the sediment production in small basins in the western countryside of São Paulo State (Brazil), aiming to study a hydroelectric reservoir sedimentation process. The deposit type considered above is also referred to the American literature as *post-settlement alluvium* (PSA) (Knox 1977), a concept also applied into research carried out in Brazil by Brannstrom & Oliveira (1999).

At the same time the last research cited above was carried out, it was proposed by Fanning & Fanning (1989) a classification for the highly man-influenced soils, as shown in table 5.

This proposal deals with the material composition of the ground (soils, deposits or excavated surfaces) and also represents a first approximation to and a basis for the definition of a new concept that we propose in this paper and will be referred to below: the *technogenic facies*.

#### 2.5. The Brazilian research

Despite some former references, the first reliable Brazilian research on the subject of Man's geological action did not appear until the 1990's, concerning induced sedimentary technogenic deposits associated to deforestation processes and built up deposits related to urban land use, as well as theoretical synthesis and the proposal for classification (*e.g.* Oliveira 1990, 1994, 1995, Peggia 1994, 1997ab, 1998, Rohde 1996, Ribeiro *et al.* 1996). During this decade, the Brazilian



Geological Survey (CPRM 1996) proposed the use of the anthropogenic deposit category to map deposits resembling archaeological shell mounds (*sambaquis*),

landfills, dumps and mining waste piles, all considered as being superficial formations.

Table 5: The highly man-influenced soil constituent materials (Fanning & Fanning 1989)

Soil materials	Definition
Urbic	Mineral soil materials that contain fragments of manufactured objects of modern man (artefacts commonly broken like bricks, glass, slag, ashes, concrete, asphalt, nails, lumber, plastic, metal alloys and crushed stone).
Garbic	Organic wastes of human activity (refuses that contain organic matter enough to generate significant quantities of methane in anaerobic conditions) and artefacts.
Spolic	Earthy (predominantly mineral) soil materials that have been moved by earth-moving equipment in surface mining, highway construction etc. Contain too few manufactured object artefacts.
Dredged	Soil materials (usually mineral) that have been dredged through human action from waterways.
Scalped Surface	Land surfaces where previously existing soils or geologic materials have been cut by Man.

In what concerns the classification of these new geological deposits, Oliveira *et al.* (2005) highlights that the concept of correlative deposits (as records of human geological action) is an essential part for the classification of the technogenic deposits. They wouldn't exist the way they are unless due to a specific action made by humans and that can be identified and described. As it is stated, the characterization of the deposit is made possible without the necessity for distinct lithologic markers.

The first classification proposed in Brazil, Oliveira (1990), based on the proposal from Chemekov (1983), separates the technogenic deposits into three main kinds: built up deposits (resulting from direct human action); modified (natural deposits, transformed by human action), and; induced deposits (resulting from modified natural processes, like accelerated erosion).

Peloggia (1999) has reformed this classification, adding to it a broader character, and proposing the following concepts: first order (or generation) deposits, encompassing the classes that have been formerly proposed by Oliveira (1990), and; second order deposits, including the remobilised type (for example, a valley deposit created by a landslide from a former landfill in the adjacent hill slope) and the reworked type as proposed by Nolasco (2002) (for example, landfills that have suffered superimposed erosion processes).

The same author (Peloggia 1999) has presented an enhanced proposal dealing with the field description and mapping, called *integrated classification*, which consists of the sequential application of five parameters: genesis (implying the identification of formation processes); composition (constituent material or "lithology"); structure (mode of disposal of the materials inside the deposit); mode of placing (related landforms and geomorphologic position), and; technogenic environment (the context of production and deposition of the technogenic material). For example, according to this approach a deposit like the post settlement alluvium cited above can be described as an *induced alluvium-like sedimentary technogenic deposit related to rural landscapes*.

Nolasco (2002), on the other hand, has proposed another classification for technogenic deposits, based on the nature of the related human action: *direct*

*deposits*, subdivided into built up deposits (deposited by man, like landfills), induced ones (resulting from the human action through other geological agents, for example as in the case of promoted landslides in mining areas), and; *indirect deposits*, resulting from the joined actions of mankind and other geological agents, without intervention of intentionality.

In another way, in the soil science study area, Curcio *et al.* (2004) proposes a classification for *anthroposols*, that is, soils (in a broad sense) produced by Man, conceived as soil volumes constituted by one or more *anthropic layers* (at least 40 cm thick), formed by organic or inorganic material and created only due to human interference. These soils are classified as follows (in free English version): 1) "lixic" (corresponding to the *garbic* concept from Fanning & Fanning 1989) - mixed or layered soil volumes constituted by organic or inorganic human derived materials; 2) "decapithic" (corresponding to the scalped land surface concept by Fanning & Fanning, op. cit) - soil volumes exposed by human action; 3) "Somic" (reasonably corresponding to the Fanning & Fanning (1989), concepts of *spolic* and *urbic* soil materials); 4) "Mobilitic", (corresponding in part to the BGS concept of *infilled ground*) - soil volumes constituted by mixed layers of other soils directly deposited through human action.

It can be remarked that, in the Brazilian geoscientific studies concerning the subject, Fanning & Fanning (1989) classification has been applied to the description of technogenic material in general, as in the work by Silva (2013). Finally, the use of BGS artificial ground classification must also be highlighted (Price *et al.* 2011) as well as the recently research by Oliveira *et al.* (2013), Marques *et al.* (2013).

### 3. A new proposal for classification

The former works cited in this paper make it possible to identify and describe a great variety of ground around the world that is produced directly or indirectly through human action. We call IT *technogenic geodiversity* and we support the necessity for a systematic approach for the classification of this new class of geological materials.

The basis for this classification has been put together by previous research, and consists of some essential

concepts: technogenic ground, technogenic layers, technogenic deposits, and technogenic soil horizons, as follows:

- 1) *Technogenic (or artificial) ground*: represents all new geologic substratum or land surface created directly or indirectly through human action, by the accumulation or removal of material.
- 2) *Technogenic layer*: a general term used to indicate any category of technogenic deposit or soil horizon, and specifically used to describe the ground classes in which there is a superposition of technogenic materials.
- 3) *Technogenic deposit*: a category of superficial formation (*sensu* Campy & Macaire 1989) created by direct or induced deposition processes.
- 4) *Technogenic soil horizon*: an in situ soil layer modified through human action.

Starting with these basic concepts, the classification criteria used to classify all the artificial ground is as follows:

- 1) It is possible to be distinguished through four main classes or artificial ground (table 6): that is formed by the accumulation of geologic material; that is produced by removal or displacement of geologic material; that is created through the transformation of ancient geological material and lastly, created by the superposition of different genetic processes at the same place. The genetic processes responsible for the creation of the artificial ground are, by definition, *technological* processes (Fornasari *et al.* 1992).
- 2) Each of these classes of artificial or technogenic ground can be associated to one or more mapping categories by specific layers or geomorphic features used for identification, description and mapping of the technogenic geological units (tables 6 and 8).
- 3) Each of the main classes of technogenic ground can be subdivided into many types of technogenic ground that are created by distinct direct or induced technogenic processes. This procedure provides the essential part of the classification that is the identification of the main types of technogenic ground that has been recognized and described until today. The proposed classification has preserved the original nomenclature of the former classification, in both historical precedence and the adjustment in describing specific situations.
- 4) Typical examples of each type of ground and geographical Brazilian references are provided (tables 7 and 9). Finally, a general correlation between the aggraded ground, degraded ground classes and the technogenic landforms

associated to their existence are demonstrated (tables 10 and 11).

#### 4. Final remarks

The diagnostic criterion for technogenic ground would not exist without human intervention. All technogenic ground consists of one or more technogenic layers, of one or more categories of deposit or soil horizon, by newly exposed substratum surfaces or just by disturbed land surfaces.

All the technogenic deposits or soils are formed by the accumulation of material (aggraded ground) or the transformation of original non-technogenic material (modified ground). In both situations the constitution and aspect of the accumulated or transformed material is often an essential feature of the deposits or soil horizons. This characteristic aspect is closely related to the processes of layers formation, as well as to the human environment surrounding the new formed ground. In many cases this "aspect" is just as essential to define the genesis of the technogenic layer, in the same way as the sedimentary *facies* concept.

Also in the case of aggraded or modified ground classes (and, of course, in specific mixed ground types), it must be highlighted that the technogenic layers are, as we have cited previously in the introduction, essential to geological superficial formations.

A superficial formation can be defined as a geological layer with a specific spatial position (the lithosphere-atmosphere contact, flooring or sub-flooring situation), a relation to the ancient substratum (autochthonous in the case of soil horizons, allochthonous in the case of deposits), a site related to geomorphologic context (the technogenic land shape, in this case) and the lithological material (in the case of technogenic facies) (Campy & Macaire 1989).

As in all superficial formations, the technogenic layers (and not only the induced technogenic sedimentary deposits) can be viewed as correlative records of the geological action of mankind, or technological process, and must be considered in stratigraphic terms. These overall ground-forming layers conforms to what was once called the *anthropostrome* (Passerini 1984), and the technogenic landforms related to each artificial ground conforms to settings that create technogenic land shapes and technogenic landscapes.

The human action is nowadays a main responsible for shaping the face of the Earth. This paper is an attempt to classify, in terms of hierarchy and ordination, the geological ground newly formed by these actions, and represents a special effort to increase and enhance the Brazilian contributions to the subject.

Table 6: Technogenic Ground Classification Proposal

TECHNOGENIC GROUND CLASSES	DEFINITION	MAPPING CATEGORIES	TECHNOGENIC GROUND, SOIL AND DEPOSIT TYPES (GENETIC CLASSIFICATION)	UNITS TYPICAL EXAMPLES
AGGRADED TECHNOGENIC GROUND	Natural terrains or former excavated surfaces overlapped by technogenic deposits.	Technogenic Deposits	<p>Built up deposits of 1st generation</p> <p><b>Built Up Deposits</b> (deposits over natural ground: made ground<sup>(1)</sup>)</p> <p><b>Built Up Infilled Deposits</b> (deposits covering worked ground: infilled ground<sup>(1)</sup>)</p> <p>Induced deposits of 1st generation</p> <p><b>Induced Sedimentary Alluvial Deposits</b> (valley deposits or technogenic wash)</p> <p><b>Induced Sedimentary Colluvial Deposits</b> (slope deposits or tech. hillwash)</p> <p>2nd generation deposits</p> <p><b>Remobilised Deposits</b> (Displaced Ground)</p>	<p>Landfills, embankments, dumps, waste sites.</p> <p>Sedimentary deposits at contemporary drainage systems.</p> <p>Deposits formed through displacement or erosion of former technogenic deposits.</p>
DEGRADED TECHNOGENIC GROUND	Natural or technogenic ground perturbed and topographically altered by removal or displacement of material	<p>Induced erosion Scars</p> <p>Excavation scars</p>	<p><b>Eroded Ground or Land</b> <sup>(2)</sup></p> <p><b>Slipped Ground or Land</b> <sup>(2)</sup> (Scared ground through landslides)</p> <p><b>Sunken Ground or Land</b> <sup>(2)</sup> Disturbed Ground <sup>(1)</sup> (induced subsided or collapsed ground)</p> <p><b>Excavated Land</b> Worked Ground <sup>(1)</sup> (excavation surfaces)</p>	<p>Gullies, rill and sheet erosion, “bad lands”.</p> <p>Landslide scars.</p> <p>Sinkholes.</p> <p>Cut and fill surfaces, quarries, pits.</p>
MODIFIED TECHNOGENIC GROUND	Natural ground with in situ modified layers	Technogenic Soil Horizons	<p><b>Chemically Altered Soil</b></p> <p><b>Mechanically Modified Soil</b></p>	<p>Contaminated soil horizons</p> <p>Compacted or revolved soils.</p>
MIXED TECHNOGENIC GROUND	Ground formed by superposition of two or more technogenic layers.	<p>Composed units</p> <p>Complex units</p>	<p><b>Layered Deposits</b> (composed sections)</p> <p><b>Complex Deposits or Soils</b> (complex or undifferentiated sections)</p>	<p>Landfills over induced deposits. Landfills over technogenic soil horizons.</p> <p>Landfills altered by effluents, archaeological layers.</p>

<sup>(1)</sup> Former categories from BGS classification (McMillan & Powell 1999, Rosebaum *et al.* 2003, Price *et al.* 2004, 2011).

<sup>(2)</sup> We suggest the use of “land” and “ground” according to the adopted geological mapping scale.

Table 7: Main characteristics of Technogenic Ground

TECHNOGENIC GROUND CLASS	MAPPING CATEGORIES	TECHNOGENIC FACIES	INTERNAL STRUCTURE	SOME GEOGRAPHIC EXAMPLES AND BRAZILIAN REFERENCES	
AGGRADED TECHNOGENIC GROUND	Technogenic Deposits	Built up of 1st generation	Earthy or rocky materials with or without garbage and waste	Massive or layered	Landfills in the ancient alluvial plains of São Paulo City (1). Reclaimed land in Guanabara Bay (2) Ancient landfills in Recife City (3)
		Induced of 1st generation	Clastic sediments with or without artefacts	Usually stratified when originated by sedimentary deposition. Massive when originated by landslides	Tick and Rescue alloformations in Paraíba do Sul Valley (SP/RJ) (4) Technogenic deposits in Santa Bárbara Reservoir (RS) (5) São Paulo Western Plateau technogenic deposits (6)
		2nd generation	Depending on the composition of the former deposit	Dependent on the mobilisation process	São Paulo City "reworked covers" (7) Technogenic deposits in Capivara Reservoir (SP/PR).(8)
DEGRADED TECHNOGENIC GROUND	Induced technogenic scars	-	-	Serra do Mar landslides (9) Cajamar (SP) and Sete Lagoas (MG) sinkholes (10) São Pedro(SP) ravines (11)	
	Excavated technogenic scars	-	-	-	
MODIFIED TECHNOGENIC GROUND	Altered horizons	Chemical alteration	Natural soil with loose or addition of chemicals	Soil structure not necessarily modified	-
		Physical modification	Natural soil with density and porosity changes	Soil reconfigured	structure
MIXED TECHNOGENIC GROUND	Units	Composed	Depending on the specific section	Well defined contacts between layers. Eventually stratified	Geologic-geotechnical units formed by superposed layers at São Paulo City (12) Cananeia Sepulchral Mound (SP) (13) Indian "black soil" (13) "Bugre landfills" at Mato Grosso State wetlands. Meia Ponte River deposits (GO) (14)
		Complex	-	Irregular or undefined contacts	Presidente Prudente City technogenic sections (15)

(1) Peloggia (1998), Kutner & Bjornberg (1997), (2) DGM (1965), (3) Gusmão (1993), (4) Mello *et al.* (1995), (5) Korb (2006), (6) Brannstrom & Oliveira (1999), (7) Peloggia (1994), (8) Oliveira (1990), (9) Ab'Saber (1985), (10) Prandini (1990), (11) Capellari & Castro (1996), (12) Barros & Peloggia (1993), (13) Kipnis & Scheel-Ybert (2005), (14) Rubin *et al.* (2008), (15) Silva (2012).



Table 8: Version in Portuguese of the Technogenic Ground Classification Proposal

CLASSE DE TERRENO TECNOGÉNICO	CONCEITO	CATEGORIAS DE MAPEAMENTO	CLASSIFICAÇÃO GENÉTICA DE TIPOS DE TERRENOS, SOLOS E DEPÓSITOS TECNOGÉNICOS	EXEMPLOS TÍPICOS	
TERRENO TECNOGÉNICO DE AGRADAÇÃO	Depósito tecnogénico sobre terreno natural ou escavado	Depósitos tecnogénicos	Depósito construído de 1ª geração	<b>Depósito Construído</b> (depósito sobre terreno natural) <b>Depósito Construído de Preenchimento</b> (depósito sobre terreno escavado ou erodido)	Aterros em geral, diques e barragens de terra, bota-foras, depósitos de lixo e aterros sanitários, enrocamentos.
			Depósito induzido de 1ª geração	<b>Depósito Sedimentar Induzido Aluvial</b> (depósito de fundo de vale) <b>Depósito Sedimentar Induzido Coluvial</b> (depósito de encosta)	Depósitos sedimentares relacionados às redes de drenagem atuais
			Depósito de 2ª geração	<b>Depósito Remobilizado</b>	Depósitos formados por retrabalhamento de depósitos previamente existentes.
TERRENO TECNOGÉNICO DE DEGRADAÇÃO	Terreno natural ou tecnogénico alterado em sua morfologia por perda de volume de material	Cicatrices tecnogénicas induzidas	<b>Terreno Erodido</b> (cicatrices erosivas)	Sulcos, ravinas e voçorocas.	
			<b>Terreno Escorregado</b> (cicatrices de deslizamentos)	Escorregamentos em geral.	
			<b>Terreno Afundado</b> (afundamentos por subsidência ou colapso)	Dolinas, poços, sumidouros, depressões.	
		Cicatrices Tecnogénicas Construídas	<b>Terreno Escavado</b> (superfície de escavação)	Cortes de terraplanagem, cavas de mineração.	
TERRENO TECNOGÉNICO MODIFICADO	Terrenos <i>in situ</i> Modificados	Horizontes alterados	<b>Solo Quimicamente Alterado</b> (horizontes com alteração química)	Solo contaminado com efluentes ou pesticidas.	
			<b>Solo Mecanicamente Alterado</b> (horizontes compactados ou revolvidos)	Solo compactado, subsolagem de solo agrícola.	
TERRENO TECNOGÉNICO MISTO	Terreno resultante da superposição de ações antrópicas	Unidades Compostas	<b>Camadas Sobrepostas</b>	Aterro (depósito construído) sobre depósito de assoreamento (induzido) ou sobre horizontes de solo tecnogénico.	
		Unidades Complexas	<b>Camadas Complexas</b> (unidade indiferenciada)	Aterro alterado por efluentes (depósitos construído e modificado), camadas arqueológicas.	

Table 9: Version in Portuguese of the main characteristics of Technogenic Ground

DE CLASSE TERRENO TECNOGÊNICO	DE UNIDADE MAPEAMENTO	FÁCIES TECNOGÊNICA	ESTRUTURA INTERNA	ALGUNS EXEMPLOS GEOGRÁFICOS BRASILEIROS REFERÊNCIAS
TERRENO TECNÓGENICO DE AGRAÇÃO	Construído de 1ª geração	Materiais terrosos, rochosos, com ou sem entulho, lixo, resíduos industriais ou misturas.	Maciça ou estratificada	Aterros nas antigas planícies aluviais na cidade de São Paulo (1). Aterros na Baía da Guanabara (2) Antigos aterros na cidade do Recife (3)
	Depósito tecnógeno Induzido de 1ª geração	Sedimentos clásticos com ou sem artefatos	Frequentemente estratificada quando originado por deposição. Maciça quando originado por movimento de massa.	Aloformações Carrapato e Resgate no Vale do Rio Paraíba (SP/RJ) (4) Depósitos de assoreamento do Reservatório Santa Bárbara (RS) (5) Depósitos tecnógenicos no Planalto Ocidental Paulista (6)
	2ª geração	Dependente da constituição do depósito de origem	Dependente do processo de formação	Coberturas remobilizadas na cidade de São Paulo (7) Depósitos de assoreamento do Reservatório de Capivara (SP/PR).(8)
TERRENO TECNÓGENICO DE DEGRADAÇÃO	Cicatriz tecnógena induzida	-	-	Escorregamento da Serra do Mar (9) Depressões de Cajamar (SP) e Sete Lagoas (MG) (10) Voçorocas de São Pedro (SP) (11)
	Cicatriz tecnógena construída	-	-	
TERRENO TECNÓGENICO MODIFICADO	Horizontes alterados	Alteração química	Solo original com perda ou acréscimo de substâncias	Estrutura do solo não necessariamente modificada
	Alteração Física	Horizontes alterados	Solo com mudanças de densidade e porosidade	Estrutura do solo reconfigurada
TERRENOS TECNÓGENICOS MISTOS	Unidades Composta	Específica de cada terreno	Contato bem definido entre camadas. Pode ser estratificado.	Unidades geológico-geotécnicas de superposição na cidade de São Paulo (12 ) Sambaqui de Cananeia (SP) (13) Terra Preta de Índio (13) Aterro de Bugre do Pantanal (MT) (13) Depósitos do Rio Meia Ponte (GO) (14 )
	Complexa		Contatos irregulares ou indefinidos	Perfis tecnógenicos da cidade de Presidente Prudente (15)

(1) Peloggia (1998), Kutner & Bjornberg (1997), (2) DGM (1965), (3) Gusmão (1993), (4) Mello *et al.* (1995), (5) Korb (2006), (6) Brannstrom & Oliveira (1999), (7) Peloggia (1994), (8) Oliveira (1990), (9) Ab'Saber (1985), (10) Prandini (1990), (11) Capellari & Castro (1996), (12) Barros & Peloggia (1993), (13) Kipnis & Scheel-Ybert (2005), (14) Rubin *et al.* (2008), (15) Silva (2012).

Table 10: Technogenic ground classes (aggraded and degraded) related landforms (adapted from Peloggia *et al. submitted*)

Technogenic Ground Classes	Mapping Categories	Related Technogenic Landforms
<b>Aggraded Technogenic Ground</b>	Aggraded Landforms	Land surfaces produced through <i>building up processes</i> due to <i>accumulation of material</i> , namely landfilling, or by intensification of sedimentary deposition.
<b>Degraded Technogenic Ground</b>	Degraded Landforms	Land surfaces produced or modified by the <i>removal of geologic material</i> : directly by human mechanical action or indirectly by human intensification of erosion, or even by natural erosion of ancient technogenic deposits.
	Disturbed Landforms	Land surfaces and geomorphic systems topographically altered by <i>in situ dislocation or displacement of geologic material</i> due to induced superficial or underground mass movements.

Table 11: Technogenic Ground Classification Synthesis and Correlation Table

Main class of technogenic ground	Type of technogenic ground	Concept	Correlation with other classifications cited in this paper
<b>Aggraded Technogenic Ground</b>	<b>Made ground (1,2)</b>	Technogenic built up deposits.	Urbic soil materials, dredged soil materials, spolic soil materials, garbic soil materials, urbisols, constructosols, techno-sediments, urban soils.
	<b>Infilled ground (2)</b>	Technogenic built up deposits covering worked ground.	
	<b>Technogenic sedimentary or wash ground</b>	Technogenic wash, that is induced alluvium-like technogenic sedimentary deposits or colluvium-like technogenic deposits.	Cultural layers, culturally accelerated deposits, accelerated valley deposits, post settlement alluvium, technogenic-alluvial sediments.
	<b>Displaced ground</b>	Remobilised technogenic deposit.	Reworked covers.
<b>Degraded Technogenic Ground</b>	<b>Eroded ground (3)</b>	Erosion scars due to induced processes.	Scalped land surfaces, decapithic soils.
	<b>Slipped ground or scared ground through landslides</b>	Slope mass movement scars due to induced processes.	
	<b>Sunken or disturbed ground (2)</b>	Subsidence sinkholes due to induced processes.	
	<b>Excavated or worked ground (2)</b>	Excavation surfaces.	
<b>Modified Technogenic Ground</b>	<b>Chemically altered ground</b>	Contaminated soil horizons	Anthropogenic soils, antroposoils, technogenically modified horizons, industrisols, ekranosols.
	<b>Mechanically modified ground</b>	Compacted or revolved soil horizons.	
<b>Mixed Technogenic Ground</b>	<b>Complex ground</b>	Complex technogenic profiles.	
	<b>Layered ground</b>	Composed technogenic profiles.	

(1) In the original sense as cited by Sherlock (1922)

(2) According to the British Geological Survey (BGS) artificial ground classification.

(3) The classical reference to the eroded ground can be FOUND in Lyell's description, in the 10<sup>th</sup> edition of his Principles of Geology, of the Pamona's newly-formed ravine in Georgia (USA), originated twenty years afterward the land's native forest had been removed (Lyell 1867).

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