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CLASSIFICATION OF ARTIFICIAL UNDERGROUND STRUCTURES

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Abstract
A classification scheme for artificial underground cavities is proposed in the paper. The structure-based classification distinguishes five methods: usage of the existing cavity, mining (closed method), geotechnological (elimination) method, backfilling (open method), embedding. Artificial underground cavities can be divided also based upon the interaction with environment into caves, quasi-caves and partially reinforced structures. It is possible to divide artificial underground cavities based upon their purpose into phyla (artificial and natural), superclasses (elementary, simple and complex which include hybrid and composite types structures), classes (mine workings, architectural structures, occasional cavities, construction cavities), genera and species. The variety of underground structures in terms of their volume, shapes, tipology, orientation, lateral extent, etc., can be described by morphological models.
Keywords: artificial underground cavities, structure methods classification, interaction with environment, purpose classification, morphological models.

Riassunto
L'autore propone uno schema per la classificazione delle cavità artificiali. La struttura-base della classificazione prende in esame cinque fattori: uso della cavità esistente, metodo di scavo (metodo chiuso), metodo Geo-tecnologico (eliminazione), riempimento (metodo aperto), incorporamento. Le cavità sotterranee artificiali possono essere suddivise anche secondo l'interazione con l'ambiente in grotte, quasi-grotte e strutture parzialmente rinforzate.
È possibile suddividere le cavità sotterranee artificiali in gruppi secondo il loro scopo (artificiale e naturale), superclassi (elementari, semplici, e complessi che comprendono strutture ibride e composite), classi (opere minerarie, strutture architettoniche, cavità occasionali, cavità costruite), generi e specie. La varietà di strutture sotterranee in termini di forme, volume, tipologia, orientamento, estensione laterale ecc., può essere descritta da modelli morfologici.
Parole chiave: *cavità sotterranee artificiali, classificazione dei metodi strutturali, classificazione secondo l'interazione con l'ambiente, classificazione secondo lo scopo, modelli morfologici.*

Introduction

Spelestology[1] is a the scientific study of artificial underground cavities. Nowadays it is in its early stage of phenomenology and statistics collection period. However the value of the information which is already gathered requires analysis, i.e. data structuring which can help in clarifying directions of further research, detailing the subject matter and finding out common factors of spelestological objects distribution (Dolotov & Sokhin, 2001). Spelestological object is an underground cavity with artificial genesis[2], accessible by a human being[3] for some period of of its existance[4] and is not being used according to its intended purpose at the present time.
The proposed classification scheme for artificial underground objects based on construction method, interaction with the environment, purpose and morphological features relies heavily on previous schemes (Slukin, 1991; Dublyansky, 2000; Dublyansky et al., 2001; Gusakov & Dolotov, 2002) and uses their terminology. The functional division principle was used instead of object-oriented functional approach while developing the artificial underground objects classification scheme based on their purpose.

The structure-based classification

There are five artificial underground cavity construction methods.

- ***Usage of the existing cavity***. A spelestological object is situated or develops in a natural or artificial cavity, already existing.
- ***Mining (closed method).*** The cavity is created by mining, (i.e. desintegration of enclosing rocks and waste material removal from the excavated volume), produced either directly by a man in working space reachable for him or with mechanical effectors in unreachable working space.
- ***Geotechnological method.*** The cavity is created with the help of geotechologies, i.e. using an artificial agent as a result of physic-chemical processes in the working area.[5]
- ***Backfilling (open method).*** In this case the created volume is covered with an artificial roof and backfilled with ground.

1) Such term for "speleology in artificial caves" as a discipline is used in Russia and several other countries.

2) The "artificial genesis" term might have two definitions: firstly it means that something is created as a result of reasonal being activity (soft version); or secondly it means that something is created with the help of tools (strict version). We use the "soft" definition.

3) At least during construction process.

4) I.e. subject matter of spelestology is macrocavities.

5) So for example, usage of a hydromonitor in hydraulic excavation face is a sort of mining (hydraulic mining), and hydraulic surface-borehole mining is method providing the creation of geotechnological cavities.

• ***Embedding*** is filling of the cavity with artificial or waste material. In this case the cavity has a residual nature.

The *usage of an existing cavity* is the most ancient way known to mankind and used throughout all its history. *Arranging an object in the cavity* without any considerable change of its topography (for example, backfill removal does not change the cavity shape) should be distinguished from the *usage of a former cavity* with changing its morphology using some method.

Mining and *backfilling* are also ancient underground cavity creation methods. The eldest excavated and backfilled structures such as mines, shelters and mud huts are about ten thousand years old (SLUKIN, 1991). Cavities created with mining can be divided into the following categories:

• ***Dugouts*** - cavities worked out in soft ground with manual tools.

• ***Quarries*** - driven mainly with manual impactor tools in rock or half-rock.

• ***Saw workings*** - driven mainly with sawing the blocks out of the rock mass.

• ***Blast workings*** - driven mainly with rock blasting.

• ***Pyrogenous workings*** - driven using the destructive effect of fire.

• ***Water jet workings*** - created with jet monitor washout.

• ***Machine workings*** - created with mining machines in an open stope.

• ***Shield workings*** - driven with tunneling shield machines using various rock desintegration methods.

• ***Drilled workings*** - driven with drilling, i.e. using a rotating effector.

• ***Penetration workings*** - created by ground punching.

The *geotechnological method* is well-known for a long time but is being used only since the 20th century. In this case cavities are created with:

• ***Solvation method****:* rock dissolution with physical solvent pumping in the ground (for example water injection to dissolve salt rocks).

• ***Alkylation***: chemical or biochemical metal extraction from ore using acids, alkalis, etc. and/or bioactive solutions.

• ***Physico-chemical shattering***, i.e. mechano-chemical rock effect with physical phenomena or chemical processes for rock physic-chemical properties modification. The method is often used in coal mining.

• ***Sweating*** - melting out of the extracted deposit, for example super-heated steam injection at sulphur extraction.

• ***Holeburning*** - burning out (gasification) of coal or shale rock to produce power gas.

• ***Hydraulic borehole mining*** - water jet monitoring and the produced pulp extraction through a borehole.

• ***Explosion method*** - cavity (camouflet) creation as a result of a single strong explosion.

Backfilling differs from *embedding*. In the first case the volume is filled with moved natural or artificial ground, i.e. disorganized (with amorphous or low-ordered structure) material. In the other case the space is routinely filled with organized material (with ordered structure and/or composition) for example bricks, worked stones or concrete.

Classification by interaction with environment

Artificial underground cavities (AUCs) can be divided into *caves* being in natural balance with the background medium and *quasi-caves,* that is their stability in the ground massif is provided with supporting casing. As it is often rather difficult to distinguish these two cases without a complicated survey (tunnel casing may carry no real load), we can propose to distinguish other sorts of AUCs: *unreinforced* (without casing) and *reinforced* (with closed casing). There are also *partially reinforced* structures which do not have casing.

Classification by purpose

It is possible to divide artificial underground cavities by their purpose into *phyla*, *superclasses*, *classes*, *genera* and *species*. The structure of the classification of the AUCs by their purpose is presented in Table 1.

The first underground cavity division has to be provided on the genetic **phylum** level which determines the existence of the subject aimed at a cavity creation (direct or indirect purpose): **artificial (anthropogenic) cavities (AUCs)** and **natural caves (NCs).** Later we are going to analyze mainly the fist ones. NCs will be considered as soon as they take part in the spelestolo-

Phylum	Super-class	Class		Genum	Symbol txt	Symbol grf
Artificial cavities (AUCs)	Elementary underground structures (EUS's)	Mine workings (MWs)		mines	:mn	⌘
				shafts	:sh	S
				quarries	:qr	#
				exploration	:ep	◊
		Construction cavities (CCs) / Architectural structures (AS's)		residential	:rs	⌂
				production	:pr	◻
				storage	:st	Θ
				defensive / protective	:df	☆
				transport	:tr	∞
				scientific	:sc	☼
				religious	:rl	Δ
				optimising	:op	☺
		Occasional cavities (OCs)		technogenic karst	:tk	©
				technogenic suffosion	:ts	↳
				technogenic abrasion	:ta	≈
				technogenic glacial	:ti	❄
				technogenic gravitational	:tg	ğ
				buried (sunken)	:br	₪
				technogenic pyrolysis	:tp	§
				outburst cavities	:ob	Q
				explosion	:ex	♂
	Mixed underground structures (MUSs)					۞
	Hybrid underground structures (HUSs)					&
Natural caves (NCs)						Ω

Tab. 1: AUC classification by their purpose.
Tab. 1: classificazione delle cavità artificiali (AUC) per scopo.

gical object design.
It seems to be possible to associate all the anthropogenic cavities with four elementary **classes**:
- **underground mine workings (MWs);**
- **underground architectural structures (AS's);**
- **occasional cavities (OCs);**[6]
- **construction cavities (CCs).**

Class characterizes the purpose (motivation) of the cavity volume creation. *Mine workings* occur as a mining side-effect and *underground architectural structures* are created specially for underground volume production (Dolotov & Sokhin, 2001). *Occasional cavity* is an underground volume created as a side result of a human activity (Dolotov & Sokhin, 2001). *Construction cavities* are formed as a residual volume inside massive architectural structures[7]. They are related to spelestological objects by V. Dublyansky (Dublyansky, 2000; Dublyansky et al., 2001). It's rather hard to agree with him. Speleology (and spelestology as its subdiscipline) studies underground relief forms (speleosphere objects) which are by definition laid in ground (at least in artificial ground) instead of surface architectural structures body. Only underground structures (created in caves and cavities) of this class fully belong to spelestological objects. However we do not exclude CCs in surface structures from this classification scheme which is also able to describe NCs used by human beings. So our classification scheme is beyond the scope of spelestology as such engaging the areas of speleoarcheology and architecture history.
Class is divided into cavity **genera**. *Genum* characterizes the underground structure creation purpose. For example, the following genera are distinguished among MWs: mines, pits, quarries, exploration workings; among AS's: residential structures, religious structures, transport structures, etc. (see *Table 1*).
The lowest taxonomic category is **species.** The *species* characterizes the task in the scope of AUCs creation purpose. For example mines and pits are classified by the kind of their production and AS's by the serve function.

AUCs superclasses
There are multiple examples of various phyla and classes qualities combined in one paticular spelestological object. The following stages of AUCs polyfunctionality can be distinguished:
Elementary underground structures (EUS's) are monofunctional cavities having the unity of purpose and task while being created which can be referred to a particular *class, genum* and even *species*. EUS's can exist as stand-alone objects or be integrated into complex underground structures.
Simple underground structures (SUS's) have a single or dominant purpose in the scope of their *class* but can be divided into a variety of elements including the ones with auxiliary and/or accessorial tasks. For example the main purpose of mine working driving is mineral deposit excavation. In this case a variety of particular and auxiliary tasks is solved: people, ore and cargo transportation (using hauling roadways), ventilation (using air workings), ore refining (at underground refineries), etc. It follows form the cavity creation purpose unity, that auxiliary and/or accessorial elements only help to accomplish the main purpose implementation and all the complex should be referred to the *MW class* (although some of its elements studied in isolation from the entire complex should be referred to AS's).
In other words, auxiliary elements are the cavity fragments being certainly necessary for the main purpose accomplishment which can be referred to other genera and species sometimes even in another class (for example hauling roadways, air workings, storage and workshop premises, etc. and other parts of a mine working). Accessorial elements are the cavity fragments indirectly promoting the main cavity task accomplishment but not directly serving the main cavity function; they can be referred to other genera and species, sometimes even in another class (for example, staff residential premises, crypts, etc. inside mine or quarry complexes).
If the accessorial elements of the complex have their own independent tasks, the entire cavity should be classified as a **complex underground structure (CUS)**.
To give characteristics to such objects the concept of a cavity **superclass** should be introduced. There can be two kinds of CUSs:
***Mixed underground structures* (*MS's*)** are the *connected* cavities without their corporate creation purpose. They are created by connecting individual fragments of different classes including *natural cavities (NCs*. The entire structure has no corporate purposes, its elements are separated in space. *Speleoinfirmary* in the *salt pit* BKZ-4 in Berezniki, MW and NC intersection (*Tuimsky polymetallic mine* in Khakassia, *Kugitangsky lead mine* in Turkmenistan, *Tenishevsky Rudnik* gypsum quarry in Tatarstan, opening karst caves) or AS and NC connection (*Shatrishegorskaya* religious cave in the Voronezh Region opening tectonical cavities).
***Hybrid underground structures* (*HS's*)** combine the qualities of two or more classes, i.e. they have several equal purposes of creation (polyfunctional) and appear as a result of three-dimensional intersection of different classes cavities volumes, giving existence to the general configuration usually having a historical aspect. Such structures are either amalgamated (elements with different functions cannot be distinguished) or their distinguished elements are also polyfunctional (for example, architectural volumes created from the mine workings, or quarries driven to be used for residential or utility needs such as in Kansas-City and other regions of Missouri in the USA; Legget, 1973). Artificial cavities with a configuration significantly changed by natural processes (karst, gravity influence, etc., and NCs suffering from significant changes of their volumes as a result of speleological surveys, mi-

6) The usage of a "strict" artificiality (creation with the help of tools) definition excludes this class from the number of spelestological objects.

7) Such construction method as backfilling is a typical one for CC, embedding is typical for AS and OC.

ning or treasure searching, etc.) can be also referred to this superclass.
As an extra characteristic beyond our classification scheme we can propose to distinguish the cavity *clubs* - grouping the cavities by some particular quality for example, hydrotechnical structures (their main purpose is associated with water) or utility ones (associated with housekeeping), etc.

Elementary underground structures
Let us look upon the *EUS class* structure.

Underground mine workings **(MWs)** serve for mineral deposit excavation. *Mining*[8] *(closed method)* is a specific method of mine workings creation. The overwhelming majority of AUCs of this class are created in this way, many MWs are developed in NCs or artificial cavities (for example ore mining in NCs or stone mining in abandoned AS's). In NCs cave deposits are excavated (guano, clay, onyx marble, etc.). Geotechnological (salvation) method is used, for example, for salt production within the Bakhmut Basin (Ukraine), cavities, created by this process, are sometimes accessible for people. Cavities created with *sweating* may also be accessible for spelestologists while intersecting with MWs and NCs (DUBLYANSKY et al., 2001). As underground coal combustion is usually performed in old mines (SELIVANOV, 1991), cavities created with *holeburning* are also accessible for researchers. MW *genera* include:
Mines. This MWs genus serves for ore (rock material, used for extraction of some of its components) excavation. It includes *mines* used for gem and ornamental stone production. This is its fundamental difference from other MWs genera where the produced rock mass is *refined* (grinding, burning) or *processed* (stone shaping) instead of undergoing a *component extraction* process (chemically bonded metal from ore, inclusions – slugs, gems or calcedonies – from rock). As stated above, *mines* can be distinguished into *species* by a kind of produced component – *copper, iron, polymetallic, diamond, flint, etc.*
Pits are MWs serving for excavation of non-rock mineral deposits, for immediate usage or refining (salt, ice, coal, clay, etc.). *Pits* are distinguished into *species* by the kind of their production.
Quarries. Rock material is produced in *quarries* for immediate usage or refining for industrial needs (mainly in construction industry). *Quarries* are distinguished into two *species:* ***single-peace quarries*** (producing individual stones of definite size and shape) and ***gross quarries*** (producing crushed ballast, quarrystone and other gross output).
Exploration mine workings. These are workings, driven for experimental mineral deposit excavation and mining and for geological excavation conditions research (geological environment survey).
Some drill-holes can also be referred to exploration MWs. Often they cannot be referred to spelestological objects as such as their sizes do not allow direct research by human but contemporary technologies allow to bore deep drill-holes with a diameter up to one meter and even more. This allows a researcher to get into a hole.

Underground architectural structures (AS's).
As stated above, AS's are created to get useful volume which can be created by any method. V. SLUKIN proposed a term of "terratekture structures" or "*terratektura"* for this *class* (SLUKIN, 1991). AS's can be distinguished into the following genera:
Residential AS's have a function of holding a subject in normal conditions (i.e. designed for everyday residence of human beings inside and their direct life-support). The *class* includes the following *species* (Table 2):
Production cavities house production activities (production provision, products manufacturing). This *class* includes the following *species* (Table 3):
Storage AS's serve for objects housing (temporary or permanent storage, mothballing, preservation, items or substances isolation, etc.)
This *class* includes the following *species* (Table 4):
Protective structures. Defensive and protective structures providing protection (serving as barriers: limiting socially dangerous factors, first of all military ones).
Fortification underpasses were required features of surface fortresses throughout the history. They had very different purposes (mainly communications, accessibility and maneuvering purpose). Other fortification AS's provide protection in shelters, offensive and defensive actions, barrage functions, etc.
This *class* includes the following *species* (Table 5):
Transport AS's. Intended to solve relocation and communication tasks (transportation, moving, elimination, communications, broadcasting, transmission). They include the following species (Table 6):
Optimizing AS's. They are intended to influence the geological and geomorphological environment to improve its properties, and can include the following species:
• ***Pressure relief tunnels***: they are driven to remove rock load, improve general mine technical conditions of the adjacent ground mass, e.g. to prevent rockbursts. They are usually included to mining complexes.
• ***Blasting tunnels*** – workings driven to be filled with explosives during blasting operations.
• ***Water drainages***: they are driven to collect and remove underground waters..
• ***Gas exhausts*** – they are created to remove gases (from the rock massif).
Scientific AS's complete tasks associated with knowledge production, collecting and transfer. Scientific AS's were built mainly in XXth century. Includes the following species (Table 7):
Religious structures**:** intended to host ceremonies

8) MWs cannot be created with embedding or backfilling. Cavities of the Moscow region quarries seem to be an exception from this rule. They consist of the passages in artificial backfill or mine workings filled with solid backfill and form artificial monolith with volumes saved below. But such cavities were created as a result of mining and their reconfiguring with backfilling is a secondary process.

Performed functions	Ownership	
	Individual	***Social***
Residence	***Dwellings***. Directly used for residence of human beings (NCs, dugouts, inhabited caves, basement floors)	***Settlements***. *Underground settlements*, which are polyfunctional residentual complexes consisting of interconnected cavities must be distinguished from *cave settlements* consisting of several stand-alone caves. *Town cave complexes (*regular settlements with non-residential caves*)* and *town underground complexes* (underground engineering structures providing the city life-support) should also be distinguished.
	Ephemeral residences. Temporary structures used for protection from natural hazards (snow caves, etc.)	
		Hotels - temporary visitant residences.
	Shelters. Permanent structures used for temporary protection from natural hazards: bad weather, natural disasters, etc.	
Life-support	***Household AS's.*** Structures used to support the human residence (kitchens, canteens, toilets, etc.).	***Merchant AS's.*** Business premises.
Entertainment	***Estate AS's.*** Structures used only to entertain visiting hosts and guests.	***Park AS's.*** Structures used for architectural decoration of parks, other public and recreational places.
		Sports AS's. Structures giving place to sports-grounds and arenas.
	Playrooms. Cave volumes which are dug out by children for their games.	***Excursion AS's.*** Caves adapted for excursion needs; sometimes the cavity is significantly rebuilt for it.
		Attractions. Structures where attractions for vacationers are organized.
Social life		***Halls.*** Structures used to hold meetings and other public events.
		Demonstration AS's. Structures used to host performances, expositions, etc.
		Waiting halls. Structures used for temporary residence of people waiting for a special time moment (event)/
Medical treatment	***Medical AS's.*** Structures used to cure people; they are divided into *underground hospitals* placed below ground for some reason, and *speleoinfirmaries*, using healthful features of speleological environment.	

Tab. 2: residential AS's species.
Tab. 2: classificazione delle strutture architettoniche sotterranee (AS) ad uso abitativo.

(religious and funeral[9]). In other words, religious structures purpose is representation of a transcendence, distinctive for a particular society, in the material world.
According to a number of modern theories religion is somewhat a side product of the human thinking evolution (Markov, 2011), its specifics made humans extremely susceptible to religious ideas regardless their rationality and practicality (Boyer, 2008). On the other hand it is a useful adaptation developing in the course of evolution (e.g. promoting a large group solidarity, complex rituals and limitation systems can be hard to fake signals of loyalty and readiness for cooperation; Norenzayan & Shariff, 2008). This leads to a conclusion that religiosity is one of the most ancient *Homo sapiens sapiens* properties which developed almost simultaneously with a modern human genesis.
Religious AS's genum includes the following *species* (Table 8):
Occasional cavities. The *occasional cavity class* includes rather various underground objects, their volume was created unintentioally as a result of natural and technogeneous processes combination.
So OC are created with a spontaneous factor the presentation of wich is caused by human activity as random, secondary or unintended results of such activity.
The OC class cavities are created with geotechnological methods or embedding. They are divided into the following genera, nearly each of them having an analogue

9) Funeral AS's serve for burrying dead people. They also serve for funeral ritual performance directly connected with religious cults along with getting rid of corpses themselves.

Output	Production process		
	Production	**Processing**	**Creation**
Animals	***Hunting AS's.*** Structures intended for animal trapping (pitfalls, etc.).	***Slaughterhouses.*** Premises for animal slaughtering.	***Stalls and pounds.*** Structures made for temporary (periodical) animal keeping.
			Farms. Structures intended for terricolous animals and birds keeping and breeding.
			Fish wells. Structures intended for fish and other aquatic animals keeping and breeding.
			Ecological AS's. Structures serving for rare or beneficial animal species existence support.
Plants			***Greenhouses.*** Structures created for plant cultivation.
Mushrooms			***Mushroom farms.*** Structures created for mushroom cultivation.
Food		***Technological pits***. Subsurface reservoirs used for food production with fermentation and other methods.	***Vine-vaults.*** Premises used for vine production.
			Beer-vaults. Premises used for beer production.
			Cheese-vaults. Premises used for cheese production.
Waters	***Water intake facilities.*** Structures providing direct access to underground water.	***Sewage treatment plants.*** Structures where water purifying is provided.	***Condensators***. Used for atmospheric condensate collecting.
	Water collecting facilities. Structures intended for underground water collection, accumulation and transportation.		
Gases	***Gas production structures.*** AS's serving for natural gas collection; usually using production wells or in MWs, for example, idle coal mines.		
Ore	***Production structures***. Structures used to reach and collect liquid underground resources besides water.	***Refineries.*** Premises used for equipment placement and ore processing technological processes realization, including *refineries*.	
Goods	***Treasure hunting AS's.*** Structures driven to gain access to hidden treasures (to organize an access to ownerless derelict property).	***Plants.*** AS's serving for equipment placement and industrial production technological processes realization.	
	Criminal AS's. Structures driven for alien property stealing (organizing access to guarded property).	***Process equipment.*** A buried volume housing a technological process.	
		Workshops. AS's serving for equipment placement and handicraft industry technological processes realization.	
Energy	***Geothermal stations***. Geothermal collectors and other equipment used to produce heat from underground resources.	***Electric substations***. Rooms for energy transforming equipment (transformer plants, etc.).	***Power stations.*** Rooms for energy generating facilities.
Information	***Industrial intelligence AS's***. *AS's* constructed by private enterprises and individuals to get intelligence about their economical competitors, etc.	***Data-centers***. Rooms used for electronic computing machines placement.	***Administrations***. Structures used for civil and economical (business) management structures (creating of control information).

Tab. 3: production AS's species.
Tab. 3: strutture architettoniche sotterranee (AS) ad uso produttivo.

<table>
<tr><th rowspan="2">Housed objects</th><th colspan="3">Storage type</th></tr>
<tr><th>permanent (burying)</th><th>temporary (transit)</th><th>preservation (conservation)</th></tr>
<tr><td>Transport</td><td rowspan="7">Repositories. Structures serving to bury harmful / useless substances and items, waste materials, etc.</td><td colspan="2">Parkings. Civil garages and parkings used to park vehicles.</td></tr>
<tr><td rowspan="3">General filler (items)</td><td rowspan="3">Storages. Premises for property storing One should divide cellars and basements (a cellar is a mine or backfill buried AS and a basement is situated directly under a building being its underground part).</td><td>Ice-cellars (Refrigerators). Storages with cold (below water freezing point) microclimate which helps to preserve the content.</td></tr>
<tr><td>Cache storages. AS's serving to store property; providing consealed storage</td></tr>
<tr><td>Treasuries. AS's serving to store property; their situation is not a secret, and their safety is provided with guarding.</td></tr>
<tr><td>Loose materials</td><td colspan="2">Reservoirs. Volumes used for loose materials storage. The most ancient form is a grain storage pit. Pits were also used to store salt fish. Bunkers are used to store produced mineral deposits.</td></tr>
<tr><td rowspan="4">Liquids</td><td colspan="2">Water tanks. Volumes used for water storage.</td></tr>
<tr><td colspan="2">Oil tanks. Volumes used for oil and oil products storage.</td></tr>
<tr><td colspan="2">Storage tanks. Volumes used for liquid products storage apart from water, oil and oil products.</td></tr>
<tr><td>Cesspits. Structures serving for temporary excrements storage, which are extracted later for usage or wasting.</td><td></td></tr>
<tr><td>Gases</td><td colspan="2">Gas holders. Volumes for gas storage.</td></tr>
<tr><td>Energy</td><td>Heat exchangers. Facilities used for heat astraction to the ground.</td><td colspan="2">Energy accumulating structures. Underground volumes including specially driven ones used to arrange energy accumulating devices (air accumulating, water accumulating or heat storages).</td></tr>
</table>

Tab. 4: storage AS's species.
Tab. 4: strutture architettoniche sotterranee (AS) per immagazzinamento.

among natural cavities.

Technogenic karst. *Technogenic karst cavities* are carst cavities created as a result of human activity (Pudovkin, 1997). The main reason for technogenic karst OCs evolution can be water or chemical solutions discharge (***influential cavities***), ground water level depression as a result of pumping-out or drainage, which gives start to ground water movement in aerated zone (***infiltrating cavities***), change of ground water stream regimen as a result of water basin filling, surface streamflow mutation, saturation, artificial ground properties mutation, etc. (***fluvial cavities***), and also water basin creation in conditions when the coastline consists of karsting rocks (***pseudo-abrasive cavities***).

Technogenic suffosion. Develop as a result of suffosion process:

- at water leaks from hydrotechological systems;
- at ground waters drainage to artificial water bodies;
- while at some specific water piping methods (non-seepage airlift);
- karst cavities filler suffusion removal at their regime changes.

Technogenic abrasion cavities. Develop as a result of waves infulence on the coasts of artificial basins.

Technogenic glacial. Technogenic thermokarst and ***technogenic glacial-thermal*** processes rarely cause creation of underground cavities, however they are rather widespread (Kachurin, 1961).

Technogenic gravitational. They are created by gravity. This *genum* can be divided into several *species*.

- ***Secondary cavities (gravitational drift).*** Are created as a result of source cavity collapse caused by gravity. In this case the cavity «floats up» (gravitational drift). In the limit case a fully *secondary cavity*, situated upper then a source arching, is formed.
- ***Stratificational cavities*** appear in the rock massif above mine workings (Samarin & Barsukov, 1990).
- ***Technogenic disjunction***. Cavities created by cracks opening (it can be often observed in quarries walls) similar to natural dilatancy cavities (Dublyansky et al., 2001).
- ***Dump cavities*** are formed between individual blocks in man-made ground fills (mining enterprises dumps, blasted rocks, etc), they are similar to natural types of gravitational cavities (Dublyansky et al., 2001).
- ***Ruin.*** If a conglomeration of a ruined building debris is interpreted as a technogenic ground, then cavities in it should be of OC type.

Buried. Structures or construction cavities closed as a result of natural process or unintended human activity with embedding causing underground volume creation.

<table>
<tr><th rowspan="2">Purpose</th><th colspan="3">Activity type</th></tr>
<tr><th>Passive protection</th><th>Active protection</th><th>Supply/auxilary</th></tr>
<tr><td>Counterfighting inner antisocial elements</td><td>Traps. Serve for immobilization of people trying to infiltrate a guarded place.</td><td>Prisons. Underground premises used to isolate people, who are dangerous for the state and/or the society.</td><td rowspan="6">Torture chambers. Serve for tortures and interrogation.

Intelligence structures. AS's constructed for intelligence geathering purposes.

Observation structures. For enemy observation.

Hearing tunnels – fortificational underground structures used for accoustic examination of an enemy underground activity.
Concealed passages – underground passages leading to water and other resources sources.
Command bunkers (centres). Premises for military control authority, etc.
Armouries. Serve for weaponry, ammunition and military equipment storage.</td></tr>
<tr><td rowspan="5">Defensive actions (defense against an external threat)</td><td rowspan="3">Shelters. Serve for sheltering people and property either from military hazards or harassment by government (in case of persecuted social, religious or ethnic groups).</td><td>Counter mine galleries. Defensive underground passages, serving to countereffort the offensive ones.</td></tr>
<tr><td>Postern. Underground passages providing the manouver inside the defense perimeter.</td></tr>
<tr><td>Concealed exits. Underground passages used for undetected exiting the defense perimeter.</td></tr>
<tr><td rowspan="3">Caponiers. Used to protect the military machines.</td><td>Firing points. Serve for weaponry installation intended for area bombardment.</td></tr>
<tr><td>Fortifications (Fortresses) Systems of underground defensive structures.</td></tr>
<tr><td>Missile bases. Underground protected objects used to base and launch missiles.</td></tr>
<tr><td rowspan="3">Offensive actions(defense during offensive actions)</td><td rowspan="3"></td><td>Blasting mine. Offensive underground passages, created to get under a sieged enemy fortification, to plant an explosive device and destroy a perimeter or important defence resources.</td></tr>
<tr><td>Saps. Offensive military mines used to intrude into enemy's territory.</td><td rowspan="2">Experimental structures. Used to test weapons.

Shooting range galleries – used for shooting practice and other shooting.</td></tr>
<tr><td>Tactical tunnels – for undetected moving, protection and sheltering in the open terrain.</td></tr>
</table>

Tab. 5: protective structures species.
Tab. 5: strutture militari.

Technogenic-pyrolysis. Technogenic-pyrolysis OC are nearly the same as cremation cavities excluding the fact that the former are not associated with intentional underground coal burning but rather with endogenous fires developing at coals self-inflammation in mine workings areas.

Outburst cavities. Rock outbursts to a mine working are a catastrophic event caused by rock and gas pressure relief with cavities forming in the rock mass.

Explosion (camouflets). Cavities created underground by powerful explosions, the most significant ones are caused by underground nuclear tests.

Construction cavities (CCs). We can propose the following definition to divide construction cavities from architectural volumes. A *construction cavity* is a cavity included into an architectural structure, with the embedding layer thickness exceeding its largest cross section length. Its creation method is backfilling in most cases, also mining method usage is known (cavities were made in a finished structure). CC genera are the same as the AS genera.

***Hybrid underground structures* (*HUS's*)**

As stated above, hybrid underground structures compose forms and functions of different class objects in one particular volume. Often they are a product of historical evolution. Their purpose doesn't serve one task. As in the case of EUS's, we ignore natural elements for this superclass, classifying them using artificial factors only (using the fact that a natural cavity can be used in the complex creation process).

Classification within this superclass is as follows: cavities of the same class with a different class properties are distinguished (AS's with MWs properties, MWs with AS's properties, etc; see *Table 1*. Cavities including properties of many classes are called complex hybrid (CH). Some classes of HUS's are regular and widespread, others are quite rare. Example include but not limited to:

- **AS-MW.** Mineral deposits production in AS's.
- **AS-OC.** Cavities in the destructed AS's.
- **AS-CC.** AS cavities with massive structures built

<table>
<tr><th rowspan="2">Transported objects</th><th colspan="3">Sort of transporting</th></tr>
<tr><th>Moving (A→B)</th><th>Delievery (→B)</th><th>Elimination (A→)</th></tr>
<tr><td rowspan="3">Human beings</td><td rowspan="3">Passages. Civil pedestrian tunnels used for people walking.</td><td rowspan="2">Temporary structures. Cavities created to organize an access to parts of a constructed underground structure.</td><td>Evacuation AS's. Escapee passages were driven to escape from prisons, prison camps and other detention facilities. A sort of evacuation tunnels is preventive passages, driven in advance to escape in case of pursuit.</td></tr>
<tr><td>Rescue ways. Driven to rescue people who are isolated in a mine working or a cave.</td></tr>
<tr><td colspan="2">Stations. AS's intended for passenger transport boarding/ unboarding and exit to the surface.</td></tr>
<tr><td rowspan="2">Animals</td><td>Wildlife crossings. Are built under highways.</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Culvert fishways. Are created in hydro electric power plant complexes for fish pass-through.</td></tr>
<tr><td rowspan="3">Transport</td><td>Transport tunnels. Are intended to pass the transport (automobiles, trains, ships) through particular parts of surface transport ways.</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Transport shafts. Vertical or inclined workings with permanently placed lifting equipment (lifts, cages, etc.).</td></tr>
<tr><td>Subways. Type of transport based on train traffic mainly in a tunnel system.</td></tr>
<tr><td>Bulky</td><td colspan="2">Gravity tracks. Are intended to move bulky goods using the gravity. Ore passageways are usually used in mining for ore delivery.</td><td>Dump tracks. To remove bulky materials and masses.</td></tr>
<tr><td rowspan="3">Liquid</td><td colspan="2">Waterways. Are intended for water transportation.</td><td rowspan="2">Drainages. Drainage is intended to remove unnecessary water (water pass, storm drains, river collectors, etc.).</td></tr>
<tr><td colspan="2">Oil pipelines. Pipelines used for oil and petrochemicals transportation.</td></tr>
<tr><td colspan="2">Pipelines. Pipelines used to transport other liquids except oil, petrochemicals and water.</td><td>Sewage systems. Intended to collect and remove the drainage.</td></tr>
<tr><td rowspan="2">Gases</td><td rowspan="2">Gas pipelines. Pipelines used for gas transportation.</td><td colspan="2">Ventilation shafts. Intended for air supply and polluted air removal.</td></tr>
<tr><td>Smoke ducts. Intended to remove combustion products.</td></tr>
<tr><td rowspan="3">Energo-informational stream</td><td>Utility tunnels. Intended to lay power cables, communication lines, pipelines, etc. inside of them.</td><td>Skylights. Are created to provide daylight to an underground structure so they are elements of complex structures.</td><td rowspan="3"></td></tr>
<tr><td>Heat supply tunnels Are intended for heat transfer and are often realized as warm air delivery tunnels.</td><td rowspan="2">Mail tunnels. For mail delivery including pneumatic mail.</td></tr>
<tr><td>Voice tubes. Intended for acoustic messages transfer.</td></tr>
</table>

Tab. 6: transport AS's species.
Tab. 6: strutture architettoniche sotterranee (AS), opere di trasporto.

Knowledge:	Sort of activity		
	studying (observations, analyzing)	***methodological (practice, synthesis)***	***Transfer (accumulation, transfer, reproduction)***
Fundamental	***Observational***. Are intended to provide scientific observations of natural phenomena and processes.		***Schools*** - premises serving to host educational process.
	Laboratory. Premises for scientific research with human beings present or taking part. Sometimes they have complex polyfunctional configuration with transport, residence and housekeeping facilities (research complexes).		
	Archeological. Workings driven to gain access to archaeological layers.		
Applied	***Experimental chambers.*** Cavities used to place the equipment for research where human presence is unavailable or undesirable.	***Testing cavities***. Intended to house tests and experiments.	***Training AS's.*** Premises serving to host educational demonstrations.
	Survey cavities. Are often called exploration ones but serving other purposes, i.e. a rock conditions and properties studying, e.g. at unique structures construction.	***Research cavities.*** Intended to test and research new technological methods including mineral deposits mining methods.	
Knowledge storinge			***Museums.*** Intended to save the examples of research objects and traces of historical events.
			Book storages – intended to save knowledge storages (books, etc.).

Tab. 7: scientific AS's species.
Tab. 7: strutture architettoniche sotterranee (AS), opere di interesse scientifico.

within.
Particularly these are military bunkers built deep under the ground which have complex massive structures inside the excavated cavities (the Cheyenne Mountain nuclear bunker, the Alsu bunker in Crimea). The Abu Simbel temples transferred to their new place can be also referred to this *class*. The enclosing rock massif was cut into blocks and transferred to a new place to avoid underground temples flooding by the Aswan reservoir (Legget, 1973).
• **MW-AS.** Quarries in Kansas-City are driven specially to give room for different departments in the workings (storages, offices, etc.; Legget, 1973).
• **MW-OC.** Mine workings heavily changed by natural processes, for example, with gravity.
• **MW-CC**. This class can include some parts of mine workings where the worked out space is partially backfilled with concrete or other backfillings.
• **OC-AS**. Occasional cavity turned into AS.
• **OC-MW**. Mineral deposit production in OC.
• **OC-CC**. A construction structure built in OC.
• **CC-MW**. Workings inside massive structures (Pyramids of Egypt) in which stone was produced such as in a mine.
• **CC-AS**. Treasure-hunters' tunnels in the Egyptian Pyramids.
• **CC-OC.** Karst cavities in structure massif, built of limestone.
• **CH**. An AS created from a mine working being destructed with gravitational drift.

Mixed underground structures *(**MUS's**)*

Mixed underground structures consist of interconnected volumes, including natural ones, with different purpose, sometimes of independent origin . The classification within the *MUS superclass* is provided with distinguishing the cavities consisting of pairs of different *classes* and *phyla*: AS combined with MW (**AS+MW**); MW combined with a natural cave (**MW+NC**) etc. (see *Table 1*); cavities including volumes of different classes are called complex mixed structures (**CM**).
Some (not full) examples are listed as follows:
• **AS+MW**. Chambers driven from coal mine workings in rock massif to place repair workshops.
• **AS+OC.** Include such objects as experimental nuclear tunnels leading to nuclear explosion camouflets.
• **AS+CC.** Cavities of such class are known in pyra-

Performed rituals	Affiliation	
	individual	**Communal**
Shaman	***Altars and sanctuaries*** – sacred places, intended for personal communication with the higher powers. Altars host sacrifices to the higher powers.	
		Initiation structures. Intended for initiation rituals.
Druidical		***Temples*** intended for priestly religious practices.
		Crypts. Labyrinths of passages – either constructed under surface temples and occasionally being of indirect cult significance, or not associated with surface facilities.
		Sacrariums – cult objects and treasures storage premises. Two types are available: practical sacrariums (for cult inventory, clothes, etc used in rituals) and sacred ones (for cult objects).
Cloistral ahd	***Hermit cave***. Residential, private, usually standalone cavities for anchorets residence, they often precede a foundation of a monastery.	***Underground monasteries*** are multifunctional facilities (including cave monasteries consisting of individual underground cavities of various purpose) as monasticism is harder than Templar service, they also have a more complex configuration (the presence of structurally separated different purpose premises: temples, necropoleis, residential and domestic structures).[1]
	Ahd cavities. Were digged under a religious ahd for the digging process itself.	
Sepulture (dead people funeraries)	***Sepulchral vaults*** – standalone underground premises in a form of a chamber, often with a short entrance corridor – a dromos.[2]	***Catacombs –*** a system of underground premises or galleries created specifically for burial.[3]

Tab. 8: religious AS's species. Note: 1) Yu. Shevchenko proposes to divide monastery underground structures into three types. Firstly it's an urban sanctuary which is a labyrinth of various purpose structures: people lived here (in cells), prayed (in churches) and were buried (in funeraries). This type of monasteries was born in extensive labyrinths and dungeons of pharaohs crypts and Egyptian funerary temples used by the Christian monkery. Secondly it's catacomb sanctuaries functionally similar to the Ancient Rome catacomb complexes housing ancient Christian temples and cemeteries but without cells – a complex includes a temple and a cemetery but is not used for residence. The third type is anchorets cave dwellings (Shevchenko, 2000) considered to be a separate type – hermit caves. 2) ground crypts were initially constructed underground (excavation AS's) whereas barrow crypts are tombs with a subsequently raised covering barrow (embedded AS's); 3) necropolis term should be interpreted as a combination of individual buryings (Irmscher & Johne, 1987).
Tab. 8: suddivisione delle strutture architettoniche sotterranee (AS) di uso funerario e religioso.

mids. Funeral complexes under the pyramids were usually driven in native soil using closed methods and then (or simultaneously) a surface structure with CCs was built above.

• **MW+OC**. A mine working which has opened an OC.

• **MW+CC**. A mine working driven from a building basement.

• **CC+OC.** A massive structure with passages leading into an OC.

• **AS+NC.** There are many examples of natural cavities opened with hydrotechnical tunnels and transport tunnels.

• **MW+NC.** A natural cave opened by a mine working.

• **CC+NC**. A massive structure with passages leading into a natural cave.

• **OC+NC.** The Fata-Morgana Cave (Turkmenistan) is supposed to be a rare example of ***OC+NC*** combination. Sulphur production with sweating is provided in the block enclosing it and some of the shafts lead into natural caves (Maltsev, 1997). It is possible that sweating cavities, the existence of which in the Gaurdak deposit is proved by surveys (Tiunov & Nikitkin, 1986) can also be connected to this cave.

• **CM.** Speaking about the *CM class*, we must mention the Odessa Catacombs. They are a complex of mine workings (sawing quarries and exploring mines), *AS's* (military bunkers, utility rooms, drainages, conduits, etc.), *OCs* (gravity drift cavities) and *NCs* (carst caves), interconnected invarious combinations (Pronin, 1998).

Morphological models of spelestological objects

The variety of underground structures in terms of their volume, shapes, topology, orientation, lateral extent, etc., can be described by morphological models. AS's, especially the reinforced ones, usually have slightly regular shape in contrast to natural cavities (Slukin, 1991). Even the morphology of such cavities as MWs and OCs which are more dependent from geological conditions, is organized with a rank-order technological geometric structure.

The proposed classification scheme is based on morphologo-typological models of artificial underground struc-

tures offered by SLUKIN (1991): one can distinguish three main morphogenetic AUS's volumes: linear-extended, planar and chamber. Linear-extended volume is created by a solid form one dimension of which (length) far exceeds two other ones (height and width; SLUKIN, 1991). Four AUS's source linear elements can be distinguished by axis dimension character: *rectilinear, curvelinear in plan* (horizontal plane), *curvilinear in profile* (vertical plane), *multidiretional* (incurved both in vertical and horizontal planes).[10]

According to their common direction in vertical plane linear *source elements* form *structure elements* of a cavity:

• *Horizontal passage* can be formed with a *rectilinear* source element. This way a straight *horizontal passage* appears. *Curvilinear in plan* element forms an *incurved horizontal passage.*

• *Inclined passage* is formed when the element axis common inclination to the horizon is from 15° to 75°: *rectilinear volume* forms *rectilinear inclined passage (inclination)*, curvilinear one in plan forms *incurved inclined passage (slope)*; curvilinear one in profile forms two elements – *a straight passage with rises and descents* in case of horizontal direction, an *inclined passage with benches* in case of inclined direction; *multidirectional volume* forms an *incurved passage with rises and descents* in case of horizontal direction and *incurved inclined passage with benches* in case of inclined direction.

• *Vertical volumes* are formed with: *rectilinear volumes* (*vertical shafts; shaft*); *curvilinear in profile* (*cascade shafts; cascade*); *multidirectional* (*helix shafts; helix*).

Planar volume is a solid form one dimension of which (usually height) is significantly less than two other ones (width and length). They can form three *structure elements*: *horizontal planar*, *inclined planar* and *vertical planar ones.* Planar cavities can have columns and pillars within.

One source/structure element should be added to mentioned elements –*chamber volume.* Chamber volume is a cavity, linear dimensions of which are either equal (*isometric volume*) or have nearest correlations (*quasi-isometric volume*), or one of the dimension is a little (not more than three times) more than other ones (*prismatic volume*). *Chamber volumes* can represent a square, a rectangle, a circle, a regular or irregular polygon, etc. in plan (SLUKIN, 1991).

Cavities consisting of one structure element

• *Straight horizontal passage*. Goes straight ahead without deviations.

• *Incurved horizontal passage.* Such passages can make a close curcuit.

• *Rectilinear inclined passage. Incurved inclined passage*. Inclined slopes, often ladder (benching).

• *Straight passage with rises and descents.* Inclined rises and benches of underground galleries.

• *Inclined passage with benches. Incurved passage with benches*. Parts of structures with floor inclination connect to horizontal platforms from where the passage or tunnel continues in the same direction or turns angle wise.

• *Vertical shaft* – vertical linear working.

• *Cascade shaft*. Vertical shaft with benches.

• *Helix shaft*. Twisted helical shafts.

• *Horizontal planar.* Such volumes often form column halls.

• *Inclined planar*. *Vertical planar*. Such volumes are usually created at ore bodies block mining in place of these bodies, they can have significant sizes and be rather stable.

• *Single chamber*. Consists of one single isolated chamber volume.

Combined cavities

Consist of several structure elements, combining in different combinations. One can imagine loads of such combinations; we'll mention only most typical ones.

Linear elements combinations. They can be described under topological trees (branching cavities; BOARDMAN & VOGT, 1973) and graphs (labyrinth cavities; BERGE, 1962). Individual linear elements (cave passages sections) are considered as edges (branches) and their crossings (branchings) – as topological nodes of a graph or a tree (planar or 3-dimensional). A node is described with a power $\boldsymbol{i}$ (the number of branches incidental to the node), in this case – the number of passages going from a crossing. Branches connecting nodes with $\boldsymbol{i} > 1$ (passage sections between crossings) are called internal ones while branches with a leaf node (i.e. with $\boldsymbol{i} \leq 1$, passages leading to a dead end or an exit) are called external ones. A particular case of a cavity consisting of a single basic linear element is a trivial tree or graph consisting of one branch with leaf nodes. Labyrinth cavities ideally exclusively consist of internal branches (i.e. the cave passages are interlocked). The real cavities of 'course have at least one leaf node (surface exit) and usually some number of dead ends as well. Non-branching cavities consisting of omnidirectional linear structural elements are described as a topological tree with $\boldsymbol{i} = 1$ type nodes.

• *Horizontal-inclined*. A horizontal linear cavity turning into an inclined one.

• *Horizontal-vertical*. A horizontal linear cavity with a vertical shaft, up- or undergoing.

• *Branching (dendritic)*. They are a combination of branching linear volumes and can be described under a planar topological tree model with its nodes having $\boldsymbol{i} = 3$ (all divarications are tripple).

• *Cross-shaped (arcosolium)*. Branching horizontal systems of linear volumes (a planar tree) with tetradic ($\boldsymbol{i} = 4$) crossings.

• *Branching multitier*. They are branching structures of inclined passages including horizontal parts (a three-dimensional tree).

• *Branching shaft-type ones*. Branching vertical shafts.

• *Shaft-type*. Vertical linear cavities opening a horisontal or inclined cavity part in the bottom. They served as entrances to the underground structures or their ven-

10) Circular linear volume distinguished by V. SLUKIN should be considered a sort of curvilinear in plan element since they are topologically identical.

tilation or water-feeding facilities.
• *Cellular*. Labyrinth cavities, described under a planar graph model having only nodes with $i = 3$.
• *Intersecting (grid)*. Labyrinth cavities described under a planar graph model having only nodes with $i = 4$ (a grid structure).
• *Complex labyrinths*. Labyrinth-type cavities having either tripple or tetradic or higher exponent crossings.
• *Vertical-cellar cavities. Vertical-grid cavities*. They are often realized as a linear structures system where the structures are set one above another but all of them have one direction and they are interconnected with wells and slopes. Also they can exist as a vertical wells system interconnected with horisontal or inclined passages at different levels.
• *Three-dimensional labyrinths*. A labyrinth structure including horisontal,inclined and vertical elements, described under a 3-dimensional graph model.

Chamber elements combination. Chamber elements can either interconnect with short passages and embrasures in bulkhead walls or be separated with colonnades or monolith.
• *Enfilades*. Underground volumes consisting of inline arranged cavities with a common direction along one axis.
• *Aisles*. Premises volumes are situated one near another to the sides of the first one. The number of connected aisle chambers can be various but usually two or three. Chambers are alike by size.
• *Dominant volumes*. Multichamber volumes with a strongly pronounced central volume – a dominant one. A central volume existance connected to the smaller premises to the sides of the central one is supposed.
• *Systematic volumes*. Rather systematically situated chambers are interconnected with multidirectional links.
• *Systematic multitier.* Steric underground chamber-type volumes can be multitier and interconnected with vertical links.

Linear and chamber elements combinations. Linear and chamber underground volumes form different combinations realizing in underground systems.
• *Corridor-chamber.* Linear cavity leading to a chamber.
• *Chamber-corridor*. A chamber with a linear passage leading out from it.
• *Inclined-chamber*. *Chamber-inclined*. Combination of inclined linear passages with chamber volumes.
• *Shaft-chamber. Chamber-shaft.* Vertical shaft is opened into a chamber or starts from a chamber.
• *Linear-chamber.* Rather complex branching and/or intersected structures includeng either linear or chamber elements.

Underground structures nomenclature
As we can see there are rather complicated combinations of cavities with different genesis and purpose.
The proposed classification schema gives the ability to provide a formal spelestological object description with a word or symbol formula. The last one is convenient in use as rather complicated and large taxonomic cavity descriptions can appear, so a short object specifications record can be needed. Such description order is proposed (Table 9). (It's available to suppress unknown or not important to a particular case characteristics.)
Examples of naming and nomenclature (with short/full names and nomenclature versions):
1. **The Ajanta Cave-1** (India):
M.**AS** - excavated architectural structure
M.**AS**:rl**(-)-** excavated architectural structure, not reinforced
2. **The Louvecienne quarry** (France):
M.**MW** - excavated mine working
M.**MW**:qr(-) - excavated mine working, not reinforced
3. **The Newgrange** (Ireland):
E.**AS**- embedding architectural structure
E.**AS**:rl**(+) -** embedding architectural structure, reinforced
4. **The Fersman mine** (Kyrgyzstan):
N→M.**MW** - from a natural cave a mine working
N→M.**MW**:mn (-) - from a natural cavity an excavated mine, not reinforced
5. **The Wieliczka Salt Mine** (Poland):
M.**MW**-**AS** - excavated mine working in a set with an architectural structure
M.**MW**:sh-**AS**:rl(±) - excavated mine shaft in a set with a religious structure, partially reinforced
6. **The New Athos Cave system** (Abkhazia):
M.**AS**+**NC** - excavated architectural structure combined with a natural cavity
M.**AS**:tr(+)+k.**NC** - excavated transport architectural structure, reinforced, combined with a natural karst cavity.
7. **The Zhemchuzhnaya quarry** (Russia):
M.**MW**-g.**OC** - excavated MW in a complex with an occasional cavity
M.**MW**:qr-g.**OC**(-) - excavated quarry in a complex with a gravitational secondary cavity , not reinforced at all.
A standard of graphical symbols for different class cavities notation (for example, on maps and plans) is also proposed (see Table 1, column 6).

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Description order	Object specification	Symbol
A. Cavity creation method is determined	**Genesis:**	
	Mining Open method (embedding) Geotechnological method Construction method	**M.** **E.** **T.** **C.**
	Processes creating OPs: technogenic karst technogenic suffosion technogenic abbrasion technogenic glacial technogenic gravitational buried technogenic pirolysis outburst explosion (camouflet)	 **k.** **s.** **a.** **i.** **g.** **b.** **p.** **o.** **x.**
	Usage of en existing cavity: • without changing its shape: in a natural cave (NC) in an artificial cavity (AUC) • with changing its shape from a natural cave, changed (where **Z** is a method of configuring symbol: M., E., T., C.) from an artificial cavity, changed (where **Z** is a method/process of configuring symbol: M., E., T., C.; **Y** – a former cavity class: AS, MW, OC, CC) (If all the parts of a complex structure have an equal creation method it's possible to notice it once in the beginning.)	 **N.** **A.** **N→Z.** **Y→Z.**
B. Described cavity class is determined	**Cavity class:** (Cavity genus is also allowed for description):	
	Architectural structure Mine working Occasional cavity Construction cavity	**AS** **MW** **OC** **CC**
	When the description uses the cavity genus the genus symbol is added to the class symbol (see *Table 1*, column 5).	
	Describing HUS's the following note is used: … *in a set with …* Describing MUS's the following note is used: … *combined with ...*	**–** **+**
C. Reinforced or not	**Cavity reinforcement:** (A complex object reinforcement common characteristic is allowed to be noticed in the end of the formula.)	
	… not reinforced … reinforced … partially reinforced	**(–)** **(+)** **(±)**

Tab. 9: spelestological objects nomenclature description order.
Tab. 9: classificazione "spelestologica".

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