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The Karst Landforms and Cycle of Erosion

Taruna Bansal

Karst is a landscape which is underlain by limestone and has been eroded by dissolution, producing towers, fissures, sinkholes, etc. It is so named after a province of earlier **Yugoslavia on the Adriatic sea** coast where such formations are most noticeable. The development of all karst landforms requires the presence of rocks such as limestone, dolomite, and gypsum which is capable of being dissolved by surface water or **ground water**.

In simple words, the term karst describes a distinctive topography that indicates **dissolution** (also called chemical solution) of underlying soluble rocks by surface water or ground water. Although commonly associated with **carbonate rocks** (limestone and dolomite) other highly soluble rocks such as evaporates (gypsum and rock salt) can be sculpted into karst terrain. Understanding karst is important because approximately ten percent of the Earth's surface is occupied by karst landscape and as much as a quarter of the world's population depends upon water supplied from karst areas. Though most abundant in humid regions where carbonate rock is present, karst terrain occurs in temperate, tropical, alpine and polar environments also. It is a dry, upland landscape with underground drainage instead of surface streams

The Karst Topography

The degree of development of karst landforms varies greatly from region to region. Large drainage systems in karst areas are likely to have both **fluvial** (surface) and karst (underground) drainage components. As stated in the introduction, the term **karst** describes a distinctive topography that indicates **dissolution** of underlying rocks by surface water or ground water.

Water falls as rain or snow and seeps into the limestone through small channels and moves underground through a network of subterranean channels and caves. The water becomes weakly acidic because it reacts chemically with carbon dioxide that occurs naturally in the atmosphere and the soil. This acid is named carbonic acid and is the same compound that makes carbonated beverages taste tangy. Rainwater seeps downward through the soil and through fractures in the rock responding to the force of gravity. The carbonic acid in the moving ground water dissolves the bedrock along the surfaces of joints, fractures and bedding planes, eventually forming cave passages and caverns.

Limestone is a sedimentary rock consisting primarily of calcium carbonate in the form of the mineral calcite. Rainwater dissolves the limestone by the following reaction:

Calcite + Carbonic acid = Calcium ions dissolved in ground water + Bicarbonate ions dissolved in ground water.

Cracks and joints that interconnect in the soil and bedrock allow the water to reach a zone below the surface of the land where all the fractures and void spaces are completely filled (also known as saturated) with water. This water-rich zone is called the saturated zone and its upper surface is called the **water table.** The volume of void space (space filled with air or water) in soil or bedrock is termed **porosity.** Larger the proportion of voids in a given volume of soil or rock; greater is the porosity. When these voids are interconnected, water or air (or other fluids) can migrate from void to void. Thus the soil or bedrock is said to be **permeable** because fluids (air and water) can easily move through them. Permeable bedrock makes a good aquifer, a rock layer that holds and conducts water. If the ground water that flows through the underlying permeable bedrock is acidic and the bedrock is soluble, a distinctive type of topography, karst topography, can be created.

Conditions essential for development of Karst Topography:

1. Presence of soluble rocks, preferably limestone at the surface or sub-surface level.
2. These rocks should be dense, highly jointed and thinly bedded.
3. Presence of entrenched valleys below the uplands underlain by soluble and well- jointed rocks. This favours the ready downward movement of groundwater through the rocks.
4. The rainfall should be neither too high nor too low.
5. There should be a perennial source of water.

Erosional Landforms:

The landforms in the Karst landscape develop on three scales ranging from a scale of less than 10 m – these include varieties of solution pits, pans or grooves collectively known as "karren"; to intermediate scale features ranging approximately from 1 to 1000 m namely dolines or sinkholes to large scale forms where landforms are normally greater than 1 km in length e.g poljes, dry valleys or gorges. Most of the karst landscapes are formed by the combination of all these landforms and sometimes may extend for thousands of square kilometres.

A great diversity of forms and combinations occur in the karst terrains found in different parts of the world. This diversity in the landforms is the product of physical and chemical variations in the rocks themselves; geologic structure; tectonic and geomorphic history; regional topography; and past and present climatic conditions. Various scholars have studied this diversity at regional level for many countries. Some prominent studies include work of Gams (1974) for Yugoslavia, Jakucs (1977) for Hungary, Gvozdetskij (1981) for the USSR and Zhang (1980) for the People's Republic of China.

In the following section the landforms formed due to erosional processes have been discussed. Since each one of the landform is distinct in nature, it is apparent that one understands every one of them.

1. Karren/Lapies:

Karrens are highly corrugated and rough surface of limestone lithology with low ridges and pinnacles. These are formed when rain falls onto bare limestone or waves break into it. Therefore, falling droplets, sheet and channelled runoff, film flow and ponded water all create small scale solution forms also termed as lapies. The most commonly form found are circular pits with rounded bottoms and pans with flat bottoms, sinuous channels and descending slopes where joints or dipping bedding planes have opened up.

2. Terra Rosa- These are red claystones up to several meters thick and kilometres across that occur at the earth's surface. These are thought to be formed by residual dissolution of limestones and/or by accumulation of detrial mud, ash or dust on pre-existing karst terrain.

3. Limestone Pavement – These are only found in places that were covered by ice during the last ice age. They are formed in some beds of limestones where following characteristics are found –

i) beds that do not contain many fractures

ii) beds that are more resistant to dissolution by rainwater

iii) beds that are mechanically stronger

4. Grikes – Grikes are vertical or near-vertical fissures in limestone pavement. In the initial stage, the cracks pr fissures are only microscopic in size but as rainwater seeps in and dissolves the limestone, the cracks become wider.

5. Solution Holes - Holes produced by dissolution of lime stones by chemically active standing water. These are small, shallow, round and flat bottomed depressions or pools on the limestone pavement. They are usually 5 – 30 cm wide.

6. Cavern:

This is an underground cave formed by water action by various methods in a limestone or chalk area. There are differing views on the mode of formation of these caverns. The Mechanical Action School represented by Penck, Weller and Dane considers mechanical action by rock debris and pebbles to be responsible for cavern excavation. This school argues that the water table is too low to have a solution effect. The Chemical Action School, on the other hand, considers the solution action of water to be mainly responsible for cavern excavation. This school is represented by Davis and Piper. The largest cavern in Kentucky (USA) is 48 km long and 25 metres high. In India, such caves can be seen in Bastar, Dehradun, Shillong plateau.

7. Arch/Natural Bridge:

These are formed due to collapse of the roofs of caves or due to disappearance of surface streams and their reappearance; which keeps standing forming an arch.

8. Sink Hole/Swallow Hole:

Sink holes are funnel-shaped depressions having an average depth of three to nine metres and, in area, may vary from one square metre to more. These holes are developed by enlargement of the cracks found in such rocks, as a result of continuous solvent action of the rainwater. The swallow holes are cylindrical tunnel-like holes lying underneath the sink hole at some depth. The surface streams which sink disappear underground through swallow holes because these are linked with underground caves through vertical shafts.

9. Karst Window:

When a number of adjoining sink holes collapse, they form an open, broad area called a karst window.

10. Karst Plain:

Upper surface having several sink holes is called karst plain.

11. Sinking Creek:

Numerous sink holes located in a line.

12. Dolines:

Dolines are bowl shaped enclosed depressions in the Karst terrain that can be several metres to several hundred metres in range. The formation of dolines is associated with four distinct processes that usually operate alone. These are –

i) Solution, acting downward
ii) Mechanical collapse
iii) Subsidence without rupture into an inter-stratal solution cavity and
iv) Sapping or seepage erosion into caves or adjoining dolines.

Mostly, two or three of the above mentioned processes operate together to develop or enlarge a depression. These range from cylindrical shafts to shallow saucers although intermediate funnel and bowl shapes are more common.

13. Karst Lakes:

When Dolines plugged by clay are filled with water karst lakes are formed.

14. Uvala:

A number of adjoining dolines may come together to form a large depression called uvala.

15. Polje:

A number of uvalas may coalesce to create a valley called polje which is actually a flat-floored depression. An ideal polje is an elongated, flat-floored, closed depression surrounded by limestone hills that are well karstified.

16. Sinking Creeks/Bogas:

In a valley, the water often gets lost through cracks and fissures in the bed. These are called sinking creeks, and if their tops are open, they are called bogas.

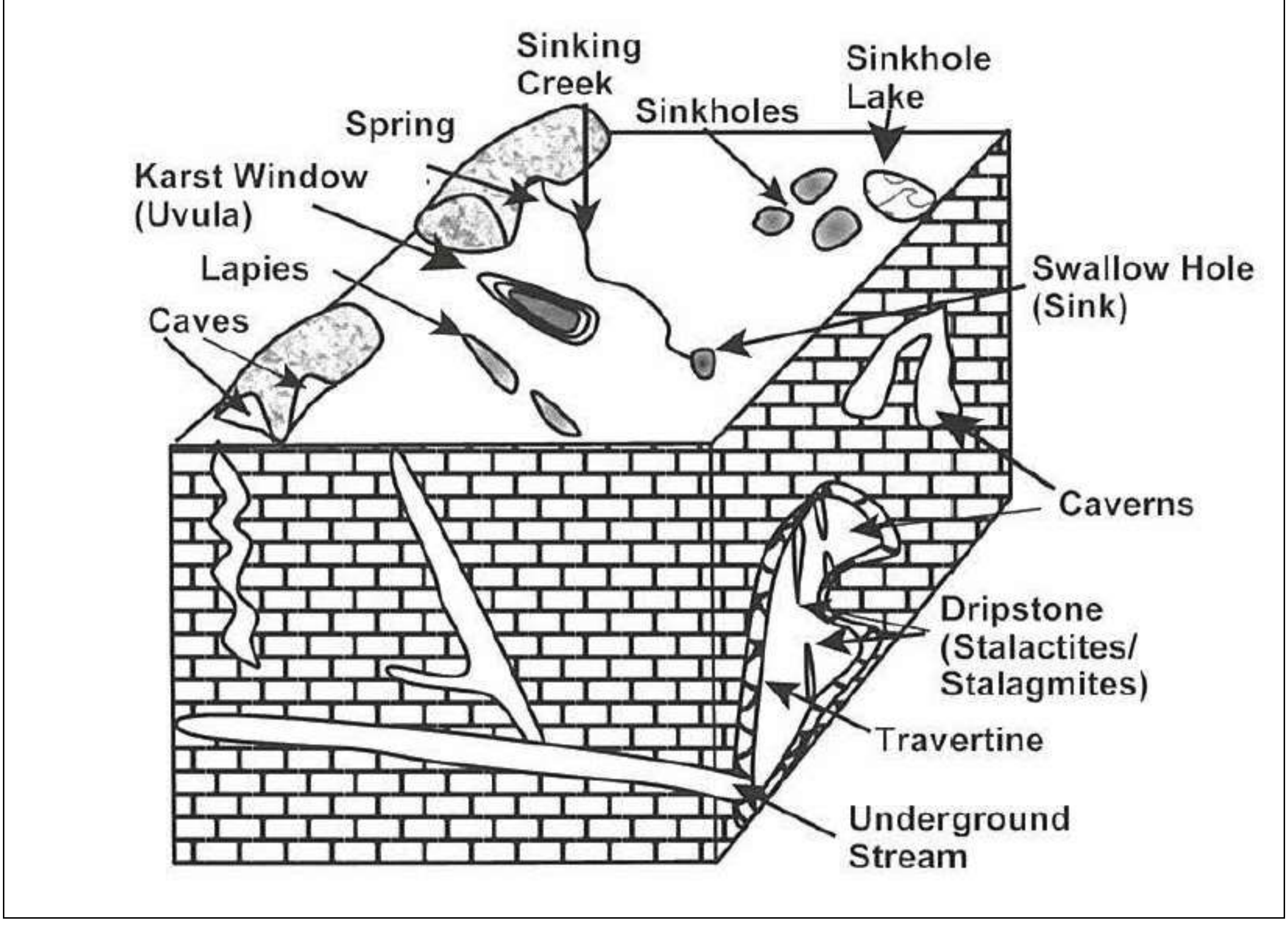
17. Dry Valley/Hanging Valley/Bourne:

Sometimes, a stream cuts through an impermeable layer to reach a limestone bed. It erodes so much that it goes very deep. The water table is also lowered. Now the tributaries start serving the subterranean drainage and get dried up. These are dry valleys or bournes. Lack of adequate quantities of water and reduced erosion leaves them hanging at a height from the main valley. Thus, they are also referred to as hanging valleys.

18. Blind Valleys:

If the streams lose themselves in these valleys, then these are called **blind valley**. These valleys may have surface streams and may be used for agriculture. In other worrds when streams become deeply entrenched creating valleys within the paleovalley a blind valley is formed.

Erosional and Depositional Karst Landforms



Depositional Landforms:

Water is also responsible for the formation of a large number of depositional landforms in a karst landscape. Chemically saturated water degasses as it drips, pools, flows and percolates in the below ground karst environment. In the following section, some of the landforms formed due to deposition process have been discussed.

1. Speleothems:

Deposits in the karstic caves are collectively called 'Speleothems'; these are crystalline deposits of calcium carbonate as a result precipitation from dilute aqueous solutions entering the cave, typically as drips from the roof.

2. Travertines:

Banded calcareous deposits are called Travertines

3. Drip Stones:

These are calcareous deposits formed by dripping-of water in dry caves or caverns. These can only form when a cave is at or above the water table where water can evaporate. When groundwater drips from the roof of a limestone cave, it slowly deposits calcite. Several types of drip stones are found in karstic caves. Stalactitis, stalagmites, cave pillars, drapes, helictites and heligmites are such drip stones found in a karst cavern.

i) Stalactites and Stalagmites:

The water containing limestone in solution seeps through the roof of caverns in the form of a continuous chain of drops. A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the roof.

The remaining portion of the drop falls to the floor of the cavern. This also evaporates, leaving behind a small deposit of limestone aiding the formation of a stalagmite, thicker and flatter, rising upwards from the floor.

ii) **Cave Pillars:**

Sometimes, stalactite and stalagmite join together to form a complete pillar known as the column.

iii) Drapes or curtains:

Numerous needle shaped dripstones hanging from the cave ceiling.

iv) Helictites:

Sideward growth from stalactites.

v) Helgmites:

Sideward growth from stalagmites.

The Karst Cycle of Erosion:

W.M. Davis has been credited for standardizing the various stages in the evolution of landforms under normal climatic conditions where rivers flow upon the surface of the ground. He along with Passarge provided cycle of erosion in arid conditions. But these cycles cannot be used to describe the forms that evolve in a karst terrain. It was only in 1918 when Cvijic provided an ordered description of successive changes that take place in the progress of the karst cycle. Karst topography develops mainly in limestone and dolomite regions because the response of these rocks to weathering is different from other rocks. This is mainly because of solubility of calcium carbonate in natural waters. In karst terrain water circulates almost entirely underground. The basic assumption for the occurrence of all stages of evolution is a mass of pure limestone which is soluble and is formed of strata inclined at a great angle but without disruptions from crushing or faulting. Another important criterion is the thickness of the limestone mass; it should not have a thick protective covering of vegetation and must have a developed system of streams.

Cvijic also opined that there are three hydrographic zones in a well developed karst landscape. These are –

i) The zone immediately underneath the surface is compiled of channels and reservoirs which transmit water in time of storm but are generally dry.

ii) The inter-mediated zone lies between dry and wet where caverns and channels are generally flooded for considerable time but not permanently.

iii) The lowest zone lies immediately above the underlying impermeable strata; this zone has permanent streams and reservoirs which are always full of water.

He further states that there are four stages in the evolution of landforms in a karst terrain: youth, maturity, late maturity and old age.

(i) Youthful Stage:

The youth begins with surface drainage on an initial limestone surface or one that has been laid bare and is marked by a progressive expansion of underground drainage. This stage is marked with imperfect underground drainage that leaves most of the rain on the ground surface; although the cracks and crevices of the rock are filled with water. Wherever the limestone is exposed to the rain the ground is now covered by a network of furrows eaten out of the rock by the dissolving water. These have been named differently such as Karren or rascles. Cvijiv uses the term *lapies* for such landforms. When water penetrates through lines of weakness such as faults, bedding plane of joints, these deep and narrow chasms are eroded and form what Cvijic calls *bogaz.* Slowly these furrows and chasms are deepened and underground channels are created and the surface streams disappear in the ground leaving their valleys dry- either wholly or in part. Such valleys are called blind valleys.

There is beginning of normal valley cutting in elongated depressions of tectonic origins i.e poljes begin to appear along with scattered dolines – a funnel shaped depression. Permanent lakes also exist. No great caverns are yet formed as only one hydrographic zone has established. By late youth two zones may be distinguished – an upper zone which is flooded intermittently and a lower zone which is entirely saturated. Therefore, this stage is marked by a progressive loss of surface drainage. Rivers flowing above the ground start disappearing. Examples of such topography may be found in Tennessee, Kentucky and Virginia in the United States.

(ii) Mature Stage:

In the mature stage there is maximum development of underground drainage as teh subterranean system is adequately developed to carry off all the surface water. As now all the surface water is carried immediately underground no lakes exist unless the depressions are so deep that they dip below the upper level of the saturated zone. So the presence of intermittent lakes is common. Large number of caves and caverns characterize this stage developing a full network of caverns and channels permeating the entire mass of limestone. Surface drainage is limited to short sinking creeks which end in swallow holes and blind valleys. This stage is characterized by the development of thousands of swallow holes and dolines. This stage represents the maximum development of karst topography with all its characteristic landforms. Such topography is found to have developed in the Dinaric coastal strip of the Adriatic Sea.

(iii) Late Maturity Stage:

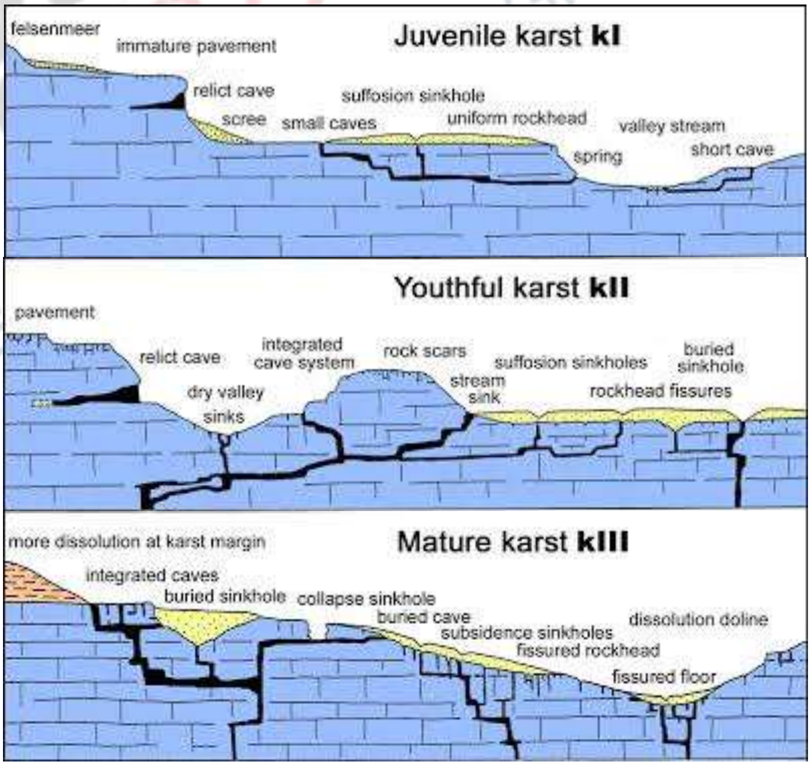
Late maturity in the Karst cycle begins with the decay and decline of karst topography as now the limestone is gradually stripped off the underlying impermeable strata. As this happens the drainage can no longer flow underground and surface streams reappear. Initially they are not above ground for long distance, occurring most frequently where the limestone mass has been eroded as well as undermined by the extension of subterranean caverns. Various feature of the karst topography expand and coalesce to form uvalas. Poljes with their hums are to be seen on the surface. All over the karst region, cavern after cavern falls in and gorges are created everywhere. The polje flow is again covered in part by an intermittent lake and streams flowing in gorges exist side by side with dolines and uvalas.

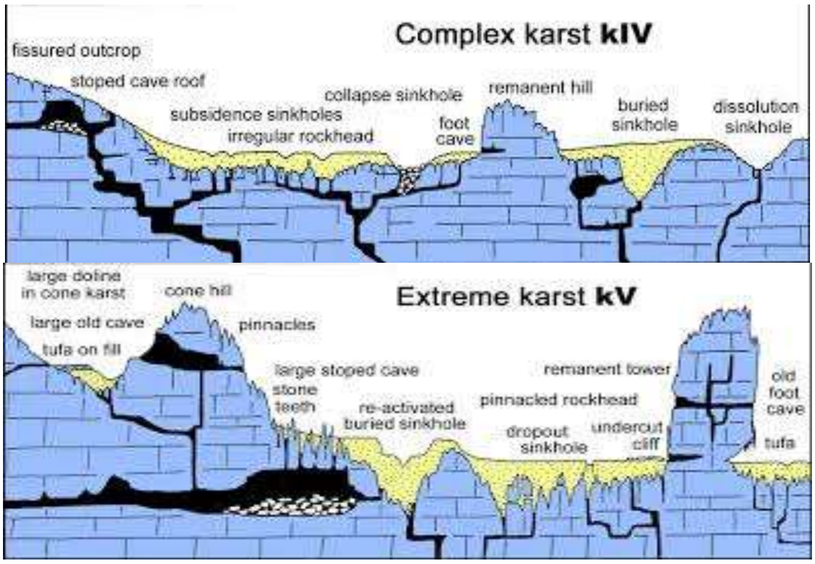
(iv) Old Stage:

With the beginning of the old stage there is return to surface drainage. Now, the caverns collapse, leaving open, flat-floored valleys. Solution activity has removed most of the limestone formations. The process of un-roofing of caverns and regressive erosion takes place at both the edges of the plateau and along the sides of the gorges where the streams cut back and capture the dolines and uvalas. As a result, the karst windows, natural tunnels and bridges and other solution features disappear. Only isolated knolls remain as remnants of the former limestone surface which are mere shells honeycombed with caverns. A normal system of surface streams is now in possession of the land which was formerly dominated by limestone mass. These landforms may be found in Natural Bridge County, Virginia and in the Causse of central France.

These stages can be best understood through the following diagrams:

Stages of Karst Cycle of Erosion




Complex karst kIV
fissured outcrop
stoped cave roof
subsidence sinkholes
irregular rockhead
collapse sinkhole
foot cave
remanent hill
buried sinkhole
dissolution sinkhole
Extreme karst kV
large doline in cone karst
cone hill
large old cave
tufa on fill
pinnacles
large stoped cave
stone teeth
re-activated buried sinkhole
remanent tower
pinnacled rockhead
dropout sinkhole
undercut cliff
old foot cave
tufa

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