1. Details of Module and its structure

Module Detail	
Subject Name	Geography
Course Name	Geography 01 (Class XI, Semester - 1)
Module Name/Title	Landforms — Groundwater – Part 2
Module Id	kegy_10702
Pre-requisites	Basic knowledgeabout the landforms developed by the action of groundwater.
Objectives	After reading this lesson, learners will be able to: 1. Acquire the knowledge and understanding of action of groundwater. 2. They will understand the concept of development of landforms by the action of groundwater. 3. They will understand the erosional and depositional landforms of the *Karst* region.
Keywords	Karst topography, Sinkhole, Uvala, Lapies, Speleothems, Stalactites, Stalagmites.

2. Development Team

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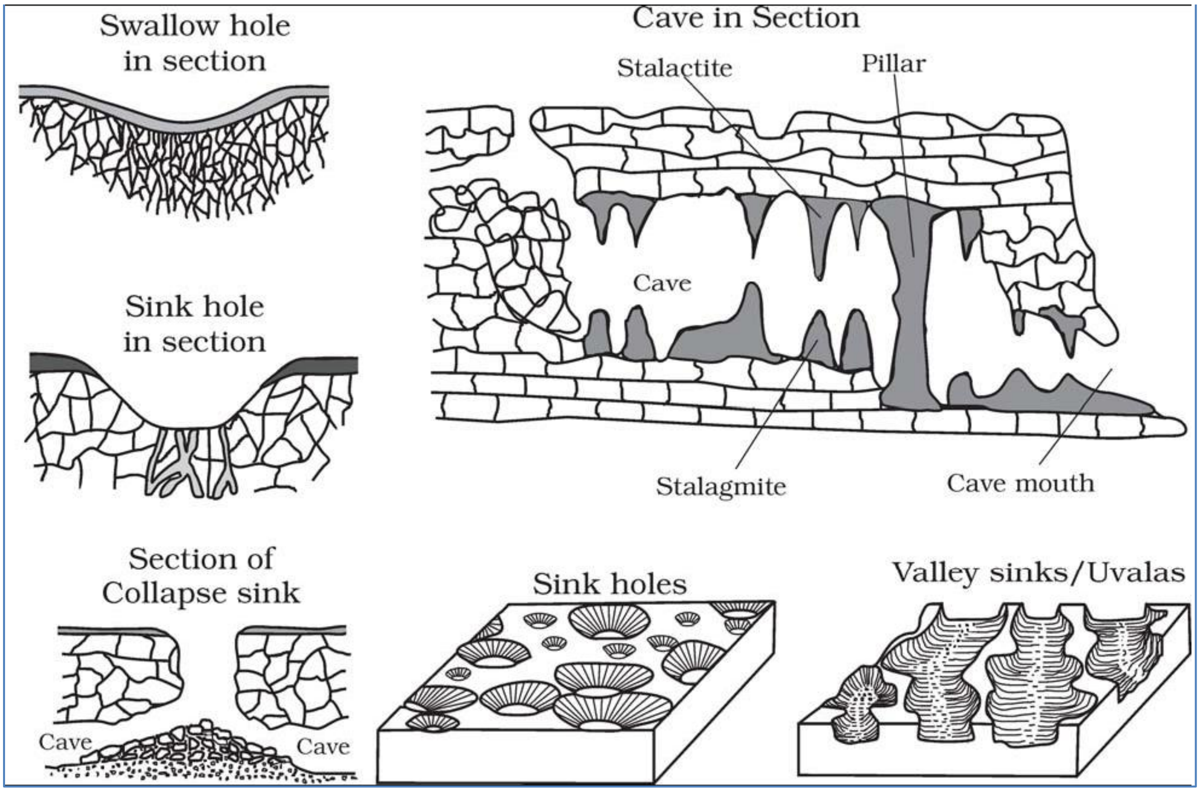
Groundwater

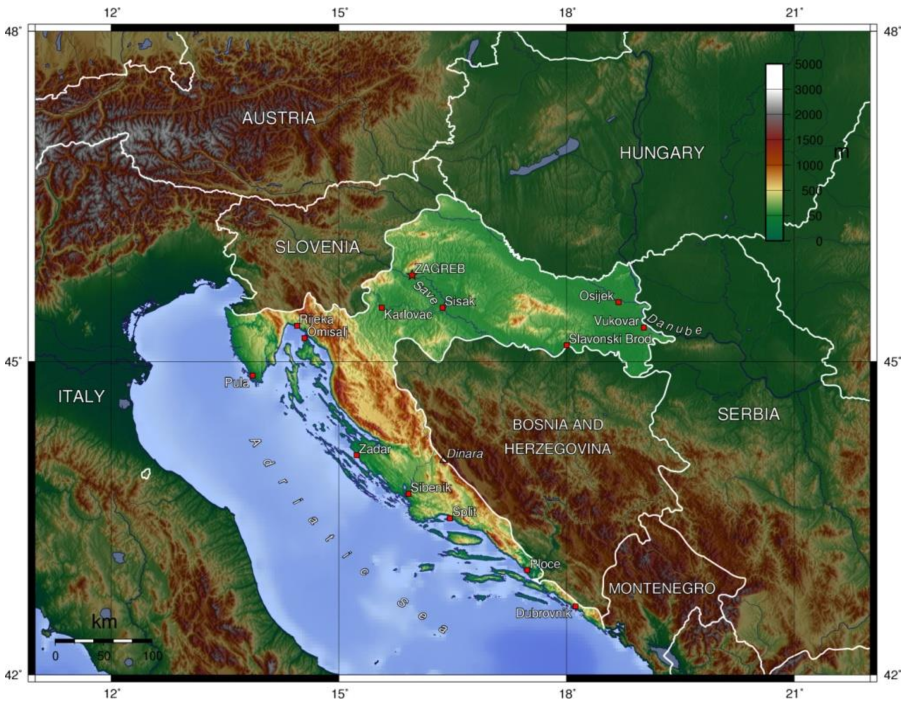
Here the interest is not on groundwater as a resource. Our focus is on the work of groundwater in the erosion of landmasses and evolution of landforms. The surface water percolates well when the rocks are permeable, thinly bedded and highly jointed and cracked. After vertically going down to some depth, the water under the ground flows horizontally through the bedding planes, joints or through the materials themselves. It is this downward and horizontal movement of water which causes the rocks to erode. Physical or mechanical removal of materials by moving groundwater is insignificant in developing landforms. That is why; the results of the work of groundwater cannot be seen in all types of rocks. But in rocks like limestone or dolomites rich in calcium carbonate, the surface water as well as groundwater through the chemical process of solution and precipitation deposition develops varieties of landforms. These two processes of solution and precipitation are active in limestone or dolomites occurring either exclusively or inter bedded with other rocks. Any limestone or dolomitic region showing typical landforms produced by the action of groundwater through the processes of solution and deposition is called *Karst topography* after the typical topography developed in limestone rocks of Karst region in the Balkans adjacent to Adriatic Sea.

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.

Karst topography is a three-dimensional landscape shaped by the dissolution of a soluble layer or layers of bedrock usually carbonate rock such as limestone or dolomite. These landscapes display distinctive surface features and underground drainages, and in some cases there may be little or no surface drainage. Some areas of karst topography, such as southern Missouri and northern Arkansas in the United States, are underlain by thousands of caves. Understanding caves and karst is important because 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.



Karst Topography



The English word *karst* was borrowed from German *Karst* in the late 19th Century. The German word came into use before the 19th century. According to the prevalent interpretation, the term is derived from the German name for the Kras region (Italian: *Carso*), a limestone plateau surrounding the city of Trieste in the northern Adriatic (nowadays, located on the border between Slovenia and Italy, in the 19th century part of the Austrian Littoral). Scholars disagree, however, on whether the German word (which shows no metathesis) was borrowed from Slovene. The Slovene common noun *kras* was first attested in the 18th century and the adjective form *kraški* in the 16th century. As a proper noun, the Slovene form *Grast* was first attested in 1177, referring to the Karst Plateau—a region in Slovenia partially extending into Italy, where the first research on karst topography was carried out.

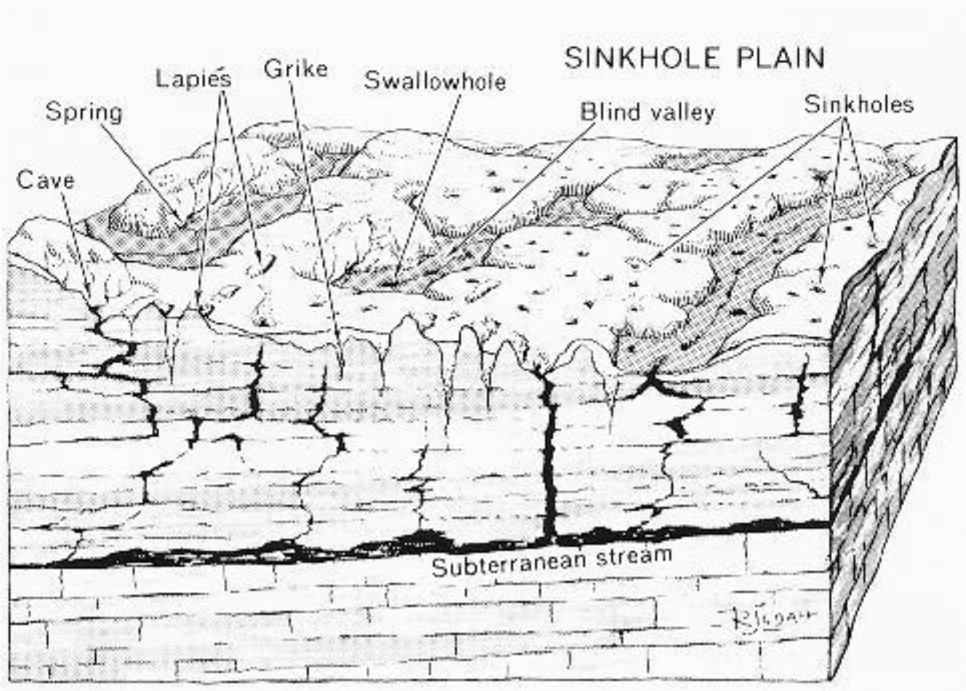
The development of karst occurs whenever acidic water starts to break down the surface of bedrock near its cracks, or bedding planes. As the bedrock (like limestone or dolostone) continues to break down, its cracks tend to get bigger. As time goes on, these fractures will become wider, and eventually, a drainage system of some sort may start to form underneath. If this underground drainage system does form, it will speed up the development of karst arrangements there because more water will be able to flow through the region.

The karstification of a landscape may result in a variety of large- or small-scale features both on the surface and beneath. Beneath the surface, complex underground drainage systems (such as karst aquifers) and extensive caves and cavern systems may form. Erosion along limestone shores, notably in the tropics, produces karst topography that includes a sharp makatea surface above the normal reach of the sea and undercuts that are mostly the result of biological activity or bio erosion at or a little above mean sea level. Some of the most dramatic of these formations can be seen in Thailand's Phangnga Bay and Halong Bay in Vietnam.Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time. In caves, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals.

Do You Know

The world's largest limestone karst is Australia's Nullarbor Plain. Slovenia has the world's highest risk of sinkholes, while the western Highland Rim in the eastern United States is at the second-highest risk of karst sinkholes,

The Arbuckle Mountains of south central Oklahoma contain intensely folded and faulted carbonate beds that have produced some of the highest densities of karst features found in the United States. Due to the nature of the uplifted beds, the Arbuckle Mountains contains a sequence of limestone ridges and shale valleys. This causes waterfalls to develop where creeks descend over a limestone ridge into a shale valley. Because the waters are rich in calcium carbonate dissolved from the karst system, large deposits of travertine have accumulated on the waterfalls where turbulence causes mineral precipitation. The most notable of these waterfalls is Turner Falls near the city of Davis.



The karst topography is also characterized by erosional and depositional landforms.

Erosional Landforms

Pools, Sinkholes, Lapies and Limestone Pavements

Small to medium sized round to sub-rounded shallow depressions called swallow holes form on the surface of limestones through solution. Sinkholes are very common in limestone/karst areas.

Sinkhole

A sinkhole is an opening more or less circular at the top and funnel-shapped towards the bottom with sizes varying in area from a few sq. m to a hectare and with depth from a less than half a metre to thirty metres or more. Some of these form solely through solution action (solution sinks) and others might start as solution forms first and if the bottom of a sinkhole forms the roof of a void or cave underground, it might collapse leaving a large hole opening into a cave or a void below (collapse sinks). Quite often, sinkholes are covered up with soil mantle and appear as shallow water pools. Anybody stepping over such pools would go down like it happens in quicksands in deserts. The term dolineis sometimes used to refer the collapse sinks. Solution sinks are more common than collapse sinks. Quite often the surface run-off simply goes down swallow and sinkholes and flow as underground streams and re-emerge at a distance downstream through a cave opening.

Sinkholes may capture surface drainage from running or standing water, but may also form in high and dry places in specific locations. Sinkholes that capture drainage can hold it in large limestone caves. These caves, in turn, drain into tributaries of larger rivers.

The formation of sinkholes involves natural processes of erosion or gradual removal of slightly soluble bedrock (such as limestone) by percolating water, the collapse of a cave roof, or a lowering of the water table. Sinkholes often form through the process of suffusion. For example, groundwater may dissolve the carbonate cement holding the sandstone particles together and then carry away the lax particles, gradually forming a void.

Occasionally a sinkhole may exhibit a visible opening into a cave below. In the case of exceptionally large sinkholes, such as the Minyé sinkhole in Papua New Guinea or Cedar Sink at Mammoth Cave National Park in Kentucky, an underground stream or river may be visible across its bottom flowing from one side to the other.

Sinkholes are common where the rock below the land surface is limestone or other carbonate rock, salt beds, or in other rocks, such as gypsum, that can be dissolved naturally by circulating ground water. Sinkholes also occur in sandstone and quartzite terrains.

As the rock dissolves, spaces and caverns develop underground. These sinkholes can be dramatic, because the surface land usually stays intact until there is not enough support. Then, a sudden collapse of the land surface can occur.

Uvala

When sink holes and dolines join together because of slumping of materials along their margins or due to roof collapse of caves, long, narrow to wide trenches called valley sinks or Uvalas form. Uvala is originally a local toponym used by people in some regions in Croatia, Bosnia and Herzegovina, Montenegro and Serbia. In geosciences it denotes a closed karst depression, a terrain form usually of elongated or compound structure and of larger size than that of sinkholes (dolines). It is a morphological form frequently found in the "Outer Dinarides" anywhere between Slovenia and Greece. But large closed karst depressions are found on all continents in different landscapes and therefore uvala has become a globally established term, used also to distinguish such depressions from Poljes (size of many km). Definitions of uvalas are often poorly empirically supported. "The coalescence of dolines" is a most frequently found and still dominant explanation. Yet because of the ongoing dissatisfaction with this definition the term 'uvala' has often been belittled – occasionally it was even proposed that the term be given up altogether.

Polje

A polje, in geological terminology, is a large, flat-floored depression within karst limestone, whose long axis develops in parallel with major structural trends and can become several miles (tens of kilometers) long. Superficial deposits tend to accumulate along the floor. Drainage may be either by surface watercourses (as an open polje) or by swallow holes (as a closed polje) or ponors. Usually, the ponors cannot transmit entire flood flows, so many poljes become wet-season lakes. The structure of some poljes is related to the geological structure, but others are purely the result of lateral dissolution and planation. The development of poljes is fostered by any blockage in the karst drainage.

A polje or karst polje covers the flat bottomed lands of closed basins which may extend over large areas, up to 1,000 km². The flat floor of a polje may consist of bare limestone, of a nonsoluble formation (as with rolling topography), or of soil. A polje typically shows complex hydrogeological characteristics such as exsurgences, estavelles, swallow holes, and lost rivers. In colloquial use, the term "polje" designates flat-bottomed lands which are overgrown or are under cultivation. The Dinaric Karst has many poljes. They are mostly distributed in subtropical and tropical latitudes but some also appear in temperate or, rarely, boreal regions. Usually covered with thick sediments, called "terra rossa", they are used extensively for agricultural purposes. Some poljes of the Dinaric Alps are inundated during the rainy winters and spring seasons as masses of water called izvor or vrelo appears at the margins. The water disappears through shafts called ponor.

Lapies

Gradually, most of the surface of the limestone is eaten away by these pits and trenches, leaving it extremely irregular with a maze of points, grooves and ridges or lapies. Especially, these ridges or lapies form due to differential solution activity along parallel to sub-parallel joints.

Limestone Pavement

The lapies field may eventually turn into somewhat smooth limestone pavements. A limestone pavement is a natural karst landform consisting of a flat, incised surface of exposed limestone that resembles an artificial pavement. The term is mainly used in the UK where many of these landforms have developed distinctive surface patterning resembling paving blocks. Similar landforms in other parts of the world are known as alvars.

Conditions for limestone pavements are created when an advancing glacier scrapes away overburden and exposes horizontally beddedlimestone, with subsequent glacial retreat leaving behind a flat, bare surface. Limestone is slightly soluble in water and especially in acid rain, so corrosive drainage along joints and cracks in the limestone can produce slabs called clints isolated by deep fissures called grikesor grykes (terms derived from a northern English dialect). If the grykes are fairly straight and the clints are uniform in size, the resemblance to man-made paving stones is striking, but often they are less regular. Limestone pavements that develop beneath a mantle of topsoil usually exhibit more rounded forms.

Caves

In areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between or in areas where limestones are dense, massive and occurring as thick beds, cave formation is prominent. Water percolates down either through the materials or through cracks and joints and moves horizontally along bedding planes. It is along these bedding planes that the limestone dissolves and long and narrow to wide gaps called caves result. There can be a maze of caves at different elevations depending upon the limestone beds and intervening rocks. Caves normally have an opening through which cave streams are discharged. Caves having openings at both the ends are called tunnels.

Caves are the most frequently occurring in rock that is soluble, such as limestone, but can also form in other rocks, including chalk, dolomite, marble, salt, and gypsum. Rock is dissolved by natural acid in groundwater that seeps through bedding planes, faults, joints, and comparable features. Over geological epochs cracks expand to become caves and cave systems.

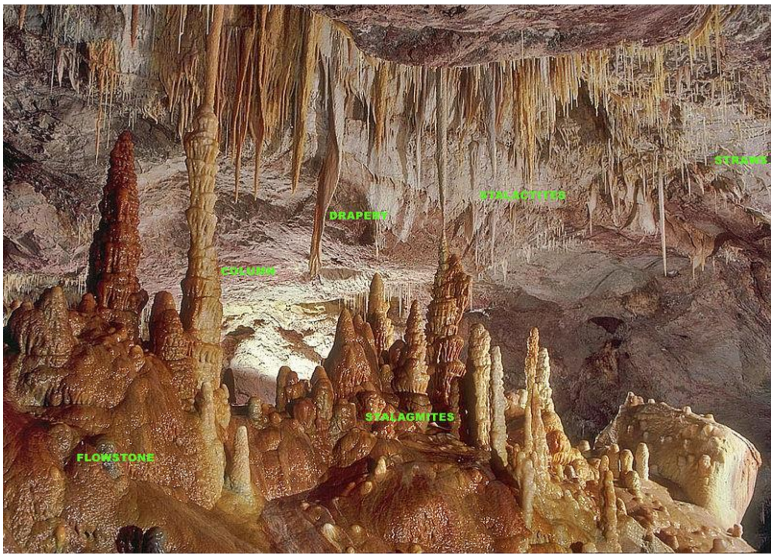
The largest and most abundant solutional caves are located in limestone. Limestone dissolves under the action of rainwater and groundwater charged with H2CO3 (carbonic acid) and naturally occurring organic acids. The dissolution process produces a distinctive landform known as karst, characterized by sinkholes and underground drainage. Limestone caves are often adorned with calcium carbonate formations produced through slow precipitation. These include flowstones, stalactites, stalagmites, helictites, soda straws and columns. These secondary mineral deposits in caves are called speleothems.

The portions of a solutional cave that are below the water table or the local level of the groundwater will be flooded.

Lechuguilla Cave in New Mexico and nearby Carlsbad Cavern are now believed to be examples of another type of solutional cave. They were formed by H2S (hydrogen sulfide) gas rising from below, where reservoirs of oil give off sulfurous fumes. This gas mixes with ground water and forms H2SO4 (sulfuric acid). The acid then dissolves the limestone from below, rather than from above, by acidic water percolating from the surface.

Depositional Landforms

Many depositional forms develop within the limestone caves. The chief chemical in limestoneis calcium carbonate which is easily soluble in carbonated water (carbon dioxide absorbed rainwater). This calcium carbonate is deposited when the water carrying it in solution evaporates or loses its carbon dioxide as it trickles over rough rock surfaces.



Stalactites

Stalactites hang as icicles of different diameters. Normally they are broad at their bases and taper towards the free ends showing up in a variety of forms.

The most common stalactites are speleothems, which occur in limestone caves. They form through deposition of calcium carbonate and other minerals, which is precipitated from mineralized water solutions. Limestone is the chief form of calcium carbonate rock which is dissolved by water that contains carbon dioxide, forming a calcium bicarbonate solution in underground caverns.

This solution travels through the rock until it reaches an edge and if this is on the roof of a cave it will drip down. When the solution comes into contact with air the chemical reaction that created it is reversed and particles of calcium carbonate are deposited. The reversed reaction is:

All limestone stalactites begin with a single mineral-laden drop of water. When the drop falls, it deposits the thinnest ring of calcite. Each subsequent drop that forms and falls deposits another calcite ring. Eventually, these rings form a very narrow (0.5 mm), hollow tube commonly known as a "soda straw" stalactite. Soda straws can grow quite long, but are very fragile. If they become plugged by debris, water begins flowing over the outside, depositing more calcite and creating the more familiar cone-shaped stalactite. The same water drops that fall from the tip of a stalactite deposit more calcite on the floor below, eventually resulting in a rounded or cone-shaped stalagmite. Unlike stalactites, stalagmites never start out as hollow "soda straws." Given enough time, these formations can meet and fuse to create pillars of calcium carbonate.

Stalagmites

Stalagmites rise up from the floor of the caves. In fact, stalagmites form due to dripping water from the surface or through the thin pipe, of the stalactite, immediately below it.

The most common stalagmites are speleothems, which usually form in limestone caves. This stalagmite formation occurs only under certain pH conditions within the underground cavern. They form through deposition of calcium carbonate and other minerals, which is precipitated from mineralized water solutions. Limestone is the chief form of calcium carbonate rock, which is dissolved by water that contains carbon dioxide, forming a calcium bicarbonate solution in underground caverns.

If stalactites – the ceiling formations – grow long enough to connect with stalagmites on the floor, they form a column.

Stalagmites should normally not be touched, since the rock buildup is formed by minerals precipitating out of the water solution onto the existing surface; skin oils can alter the surface tension where the mineral water clings or flows, thus affecting the growth of the formation. Oils and dirt from human contact can also stain the formation and change its color permanently.

Pillars

Stalagmites may take the shape of a column, a disc, with either a smooth, rounded bulging end or a miniature crater like depression. The stalagmite and stalactites eventually fuse to give rise to columns and pillars of different diameters.

Pilars are not really a different speleothem, but they are the late stage of stalactites and stalagmites. And the two dripstones grow now from water which runs down on the outside, without dripping. After some time the pillar looses the typical shape with a thick lower part and a thin upper part, and becomes a more or less cylindrical column. The former stalagmite and stalactite are not identifiable any more.

There are numerous shapes of such pillars, as there are numerous shapes of stalactites and stalagmites. Most common are the ones looking like on the image to the right: Upper end thin, lower end thick and a little bit like a pyramid, getting thinner step by step.

It is rare but possible, that stalactite and stalagmite are not formed at the same time. This is e.g. when the floor is covered by a cave river in river caves. The water hinders the growth of the stalagmite. But if the stalagmite becomes long enough to reach the floor it will still form a pillar.