GEOCHEMISTRY AND PETROGRAPHY CHARACTERIZATION OF ORDOVICIAN DEVONIAN LIMESTONE FORMATION IN KINTA DISTRICT, PERAK

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DECLARATION

I hereby declare that I conducted, completed the research work, and wrote on the dissertation entitled ‘Geochemistry and Petrography Characterization of Ordovician Devonian Limestone Formation in Kinta District, Perak’. I also declare that has not been previously submitted for the award of any degree or diploma or another similar title of this for any other examining body or University.

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μm	Micron
mm	millimeter
cm	centimeter

LIST OF ABBREVIATIONS

XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
SEM	Scanning Electron Microscope
IPS	Institut Pengajian Siswazah
USM	Universiti Sains Malaysia

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PENCIRIAN GEOKIMIA DAN PETROGRAFIK PEMBENTUKAN BATU KAPUR ORDOVICIAN DEVONIAN DI LEMBAH KINTA, PERAK

ABSTRAK

Batu kapur adalah salah satu yang paling penting dari semua batu sedimen. Ia sebahagian besarnya terdiri daripada kalsium karbonat (CaCO3) dalam bentuk mineral calcite atau aragonit, dan terdapat beberapa mineral karbonat penting lain yang berkaitan dengan batu kapur. Ia mungkin mengandungi sejumlah besar magnesium karbonat (dolomit) serta konstituen kecil yang lebih biasa dipaparkan termasuk tanah liat, feldspar, kuarza, pyrite, dan karbonat besi. Objektif utama projek ini adalah untuk menilai komposisi kimia dan sifat petrografi sampel karbonat, untuk menentukan kadar pembubaran sampel karbonat dan untuk mengaitkan mineralogi, komposisi kimia dan prestasi pembubaran kepada ciri-ciri karstifikasi sampel karbonat dan juga indeks ketahanan sampel batu kapur tersebut. Sampel karbonat dari kuari dan batu kapur di Lembah Kinta akan diambil untuk menjalani analisis petrografik dan geokimia. Pembelauan sinar-X (XRD) akan digunakan untuk pencirian mineral sampel. Analisis bahagian nipis petrografi dilakukan dengan memeriksa bahagian nipis di bawah mikroskop polarisasi untuk memerhatikan ciri-ciri mineralogi dan variasi teks untuk menentukan ciri-ciri petrografi mereka. Selain itu, ujian pembubaran dan ketahanan juga dijalankan kerana ia berkaitan dengan karstifikasi dan cuaca. Calcite banyak terdapat dalam batu karbonat dari kuari terpilih manakala mineral lain sedikit. Kepekatan dan komposisi mineral yang berbeza dapat membantu menjelaskan ciri unik setiap batu karbonat, seperti warna, kekuatan, dan kandungan lembapan. Memahami proses sekunder seperti karstifikasi, dolomitisasi, dan pembubaran dapat dibantu oleh kajian petrografi dan geokimia lengkap batu karbonat daripada Lembah Kinta. Daripada keputusan

eksperimen yang dijalankan, korelasi antara mineralogi, sifat kimia dan mekanikal batu dapat ditentukan. Kebanyakan sampel mempunyai indeks ketahanan yang tinggi. Dan ini dapat dibuktikan daripada prestasi larutan sampel tersebut sewaktu ujian larutan. Batu kapur dari kawasan terpilih di Lembah Kinta mempunyai kandungan calcite yang tinggi dengan kandungan mineral lain yang rendah.. Mineral dan sifatnya yang tidak dapat dilihat oleh mata manusia dapat dilihat melalui fotomikrograf dan kewujudan mineral itu disahkan oleh analisis XRD manakala kekuatan mekanikal batu yg berkait dengan peluluhawaan dapat dikaji melalui ujian mekanikal yg telah dijalankan. .

GEOCHEMISTRY AND PETROGRAPHY CHARACTERIZATION OF ORDOVICIAN DEVONIAN LIMESTONE FORMATION IN KINTA DISTRICT, PERAK

ABSTRACT

Limestone are one of the foremost vita of all sedimentary rock. It is composed largely of calcium carbonate ($CaCO_3$) within the mineral form calcite or aragonite, and there are a few other imperative carbonate minerals with which limestones are related. It may contain considerable amount of magnesium carbonate (dolomite) as well as minor constituents moreover commonly display incorporate clay, feldspar, quartz, pyrite, and iron carbonate. The main obejective of this project is to evaluate the chemical composition and petrography properties of the carbonate sample, to determine the dissolution performance of the carbonate sample, and to correlate mineralogy, chemical composition and dissolution performance to karstification features, and also durability of of the carbonate sample. The carbonate sample from quarry and limestone outcrop in Kinta Valley will be taken to undergo petrographic and geochemical analysis. X-Ray Diffraction (XRD) were used for the mineral characterization of the samples. The analysis of petrographic thin section is performed by examining thin section under a polarizing microscope to observe the mineralogical features and textural variations in order to determine their petrographic characteristics. Besides that, dissolution test and slake durability were also conducted as it related to karstification and weathering respectively. Calcite is abundant in carbonate rocks from selected quarries whereas other minerals are few. Different mineral concentrations and compositions can help explain the unique features of each carbonate rock such as color, strength, and moisture content. Understanding secondary process like karstification, dolomization, and dissolution can be aided by complete petrographic and geochemical study of carbonate rocks in Kinta Valley . From all the results, the correlation between mineralogy, chemical and mechanical properties of the rock were made. Most of the sample has high durability index. This can be approve from dissolution performance of the sample. Limestone rock from selected area in Kinta Valley have high content of calcite with low content of other minerals. Minerals and their properties that are invisible to the human eye can be observed on photomicrograph, and the existence of the mineral was confirmed by XRD analyses while the durability of the rock related to weathering can be known from the mechanical test conducted.

CHAPTER 1

INTRODUCTION

1.1 Background of the research

Limestones are one of the foremost vital of all sedimentary rocks. It is composed largely of calcium carbonate ($CaCO_3$) within the mineral form calcite or aragonite, and there are a few other imperative carbonate minerals with which limestones are related (Selley, 2005). It may contain considerable amounts of magnesium carbonate (dolomite) as well as minor constituents moreover commonly display incorporate clay, feldspar, quartz, pyrite, and iron carbonate.

Most limestone has a granular texture. The range size of their constituent grains is from 0.001mm(0.00004 inches) to visible particles. In numerous cases, the grain is minuscule part of fossil creature shells. (1) biogenic precipitation from seawater, the primary agents being lime-secreting organisms and foraminifera, and (2) mechanical transport and testimony of pre-existing limestones forming clastics deposits are the origins of limestone. Tufa, caliche, chalk, micrite, sparite, and travertine are all varieties of limestone. Because of its high fossil concentration, limestone has long piqued the interest of earth scientists. The study of fossils buried in limestone and other carbonate rock has yielded a wealth of information about the Earth's history and evolution. Limestone is also quite important in the economic world. Limestones that have been enhanced in phosphate by the chemical action of ocean waves are a major source of fertilizer raw materials. Limestones dissociate calcium carbonate and generate carbon dioxide and lime when heated to temperatures of 900 to 1,000 °C (1,650 to 1,800 °F), the latter having considerable applications in the making of glass and agriculture. Limestone is also utilized as a construction stone, it is commonly used for flooring, exterior and interior facings, and monuments.

1.2 Study area

Peninsular Malaysia consists of the confluence of different types of terranes. It has unique properties of stratigraphy, magmatism, geological evolution, and other geophysics attributes. Consisting of disparate structural blocks formed on the vast Paleozoic continent of Gondwana, Sibumasu Terrane is one of the building blocks of today's Southeast Asia. The terrane geographically occupies parts of China, Myanmar, western Thailand, Western Peninsular Malaysia, and northwestern Sumatra (Metcalfe, 2013). Fork from Gondwana in the Late Paleozoic, Sibumasu moved to the north and collided with another block derived from Gondwana, an Indochina terrain in the early Mesozoic. Sibumasu Terrane was formed as a result of segregation and accretion and is characterized by widely distributed sediments around the Paleozoic continent. The western belt is part of the Sibumasu block. The Central and Eastern terrane is part of the Indochina block. The central and eastern strata are different from the western belt since they are linked to structural origins. The carbonates of the peninsula are mainly distributed in the Western Stratigraphic Belt. These include Kinta Limestone. Global sea levels have increased since the Devonian to Mississippian period, which may indicate the available space for the deposition of thick sedimentary components such as the Kinta Limestone.

Perak is located in the northwest corner of Malaysia's peninsula. Limestone is the most abundant mineral deposit in the Perak state. The Kinta Valley is covered in limestone in several places. Perak's limestone deposit is estimated to be 3.5 billion tonnes. The majority of Perak's limestone is high in calcium and magnesium. Kinta Valley is Devonian to Permian in age, with the majority of the sedimentary strata being Devonian. Kinta Limestone was dated as Carboniferous by Ingham and Bradford (1960), however, Foo (1983) claimed that it was Silurian to Permian in age(Zahir et al., 2020). Metcalfe

(2009) then developed a Kinta Valley stratigraphic scheme based on the estimated ages of Kinta Limestone and Saiong Beds. The Kinta Valley is well recognized for its scenic karstic limestone hills, which have some similarities to China's famed Kwei Lin Hills. The Kinta Valley's karstic hills are punctuated with dolines, caves, and caverns, as well as needle-shaped stalactites hanging from the roofs and stalagmites emerging from the cave floors. Many of these caves and caverns are occupied by Buddhist or Hindu temples, which are frequented by both worshipers and visitors. The Kinta Valley, located in western Peninsular Malaysia, is limited by 4^0 15'N – 4^0 50' and 100^0 55'E – 101^0 20'E. It is bounded on the east by the Main Range and on the west by the Kledang Range, both of which created a reverse-V shape in topography. On the eastern edge of the Kinta Valley, there are several karstic limestone outcrops, some of which are on the verge of vanishing due to their usage as raw materials for cement manufacturers, building stones, and aggregates, and fillers.

Thermal and regional metamorphism triggered by granitic intrusion and earth movements that preceded, persisted during, and after granitic emplacement have influenced sedimentary rocks. The leftover hydrothermal fluids, which are rich in ores like cassiterite (tin), are discharged from the cooling granitic magma into cracks and faults that are abundant around the granite-limestone contact (Meng et al., 2014). Kinta Valley is underlain by clastic sedimentary rocks such as interbedded sandstone, mudstone, and shale, as well as granite and limestone (Meng et al., 2014). The Malay Peninsula frames are part of the Sundaland SE Asian continental centre (Metcalfe, 2009), which includes two blocks formed by the Late Triassic Sibumasu Terrane (west portion) and the Sukhothai Arc (East Malaya Block). The Bentong-Raub suture zone and subduction beneath the Indochina Block or Sukhothai Arc defined the boundary between the Sibumasu Terrane (Western Belt) and the Sukhothai Arc (Central and Eastern Belts).

They have eliminated the Devonian-Permian principal Palaeo-Tethys sea basin, which formed the Permian–Triassic andesitic volcanism and I-Type granitoid observed in the Malay Peninsula's Central and Eastern Belts ((Metcalfe, 2013) The Main Range granite, combined with the large-scale folding of the sedimentary units, produces a highly fractured and followed by the exhumation of the granite bodies during the late Early Cretaceous and Early Cenozoic (Krahenbuhl, 1991) (Cottam et al., 2013) (François et al., 2017) (Sautter et al., 2017)). They also proposed that flowing liquids in the late cretaceous remagnetized Palaeozoic and Triassic rocks (Metcalfe, 2013) (Richter et al., n.d.) (Ramkumar et al., 2019). Thermal events in the Main Range granitoid during the Late Cretaceous may be characterized by massive acidic or felsic fluids obstructing existing structural sets (Sautter et al., 2017) As previously reported, a thermal event occurred in the Late Cretaceous, causing recrystallization and dolomitization of parts of the Kinta Limestone (Suntharalingam, 1968, Zahir et al., 2020)

Numerous tiny karstic hills with steep slopes rise out from the flat alluvial plain along the eastern edge of the Kinta Valley and next to the foot of the Main Range granite. The DEM clearly shows such characteristics. These hills range in height from a few tens of meters to a few hundred meters, with an area of up to 20 square kilometers. Fractures are extensively developed in these hills, but less apparent than in the granitic mountains. The DEM clearly shows such characteristics. These hills range in height from a few tens of meters to a few hundred meters, with an area of up to 20 square kilometers. Fractures are extensively developed in these hills, but less apparent than in the granitic mountains. The drainage on the limestone hills is straightforward, and it is normally developed along the steep slopes of the hills, with some cutting deep into the hillsides, but some may disappear after a short distance. The disappearance of drainage channels indicates the capture of surface drainage by a subsurface groundwater system. An underground river frequently runs through the base of the limestone slope. The end output of limestone dissolving will be karsts such as caves, caverns, dolines, sinkholes, and so on. After the limestone was deposited, a tectonic event occurred in the Kinta Valley during the Triassic period that resulted in the distortion (folding) of all existing lithologies. Limestone also makes up the bedrock that covers 80% of the valley floor. Pinnacles and troughs are characteristic karstic features of the limestone bedrock. Rich tin ore resources are frequently trapped beneath the pinnacle bedrock's trough. Figure 1 below shows the lithology map of the sampling area in Kinta Valley.

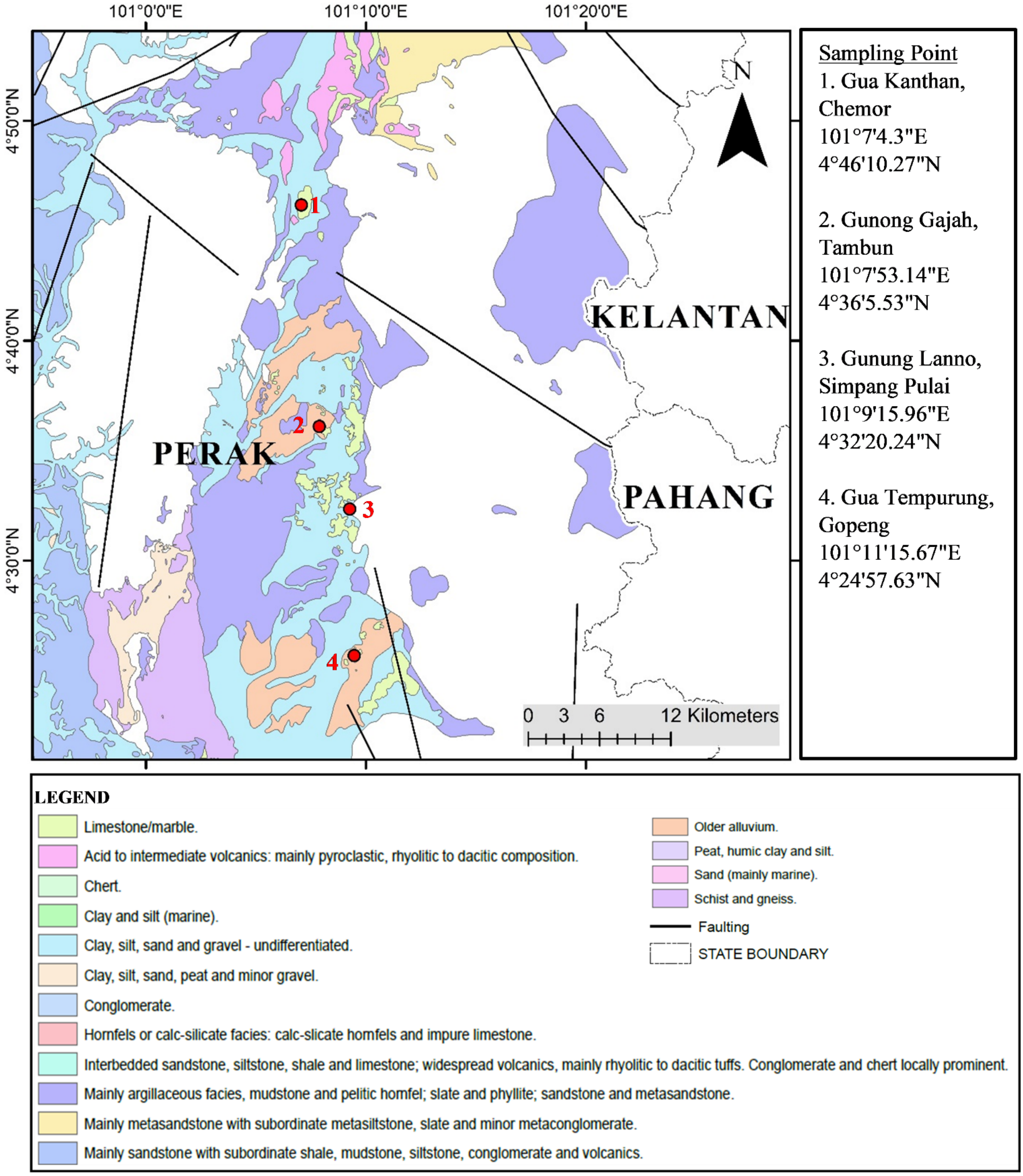

Figure 1 Lithology map of sampling area

1.3 Problem Statement

The petrographic and geochemistry study of limestone is complex yet stimulating, but studies based on petrographic considerations alone have been of limited value in discussing problems such as geological correlation, pre- and post-depositional conditions, and related topics. Petrography study is a convenient effective way to study optical properties of rock where information such as grain size, mineral intrusion, and pores of rock is obtained from the polished thin sections.

Characterization by geochemistry and petrography methods will explain on differences in mineralogy, chemical composition, and geological formation of carbonate samples in Kinta Valley where this information is necessary in the evaluation of industry application, karst landscape conservation, and geotechnical properties of the formation.

1.4 Objectives of the research

This research project is on preliminary study of the limestone deposit from 6 places in Kinta Valley area which include Kanthan, Simpang Pulai, Gunung Gajah (Gopeng), Tambun, Gua Tempurung and RCI Quarry (Gopeng). Limestone is a sedimentary rock made primarily of calcium carbonate (calcite) or calcium-magnesium double carbonate (dolomite). Tiny fossils, shell pieces, and other fossilised detritus are often found in it. On careful observation of the stone surface, these fossils are frequently apparent to the unassisted eye, but this is not always the case. The grain of some limestone kinds is exceedingly fine.

The purpose of this study is to evaluate chemical composition and petrography properties of the carbonate sample. Petrography is particularly useful because it allows for the identification of constituent grains, comprehensive categorization of sediments and rocks, interpretation of deposition settings, and determination of the frequently complicated history of post-depositional modification (diagenesis). The ability to determine the timing of diagenetic events like cementation or secondary porosity development in relation to the emplacement of hydrocarbons or metallic ores makes petrography an important component of geochemical and sedimentologic studies in energy and mineral resource exploration applications as well as academic research. Carbonate grains, unlike clastic terrigenous grains, are generally formed in close proximity (from less than a meter to hundreds of meters) to the location of their eventual deposition, making petrographic analysis of carbonate rocks particularly helpful. Furthermore, because carbonate grains are generated primarily by organisms, the grains communicate biological information about the formation environment as well as stratigraphical information about the deposit's age. As for geochemistry of the limestone, limestone geochemistry research is critical for determining the tectonic settings of the basins where the limestones were formed.

Apart from that, this project also studies the durability of the limestone rocks. Weathering or the natural processes of wind, rain, and temperature change weaken limestone exposed to the elements. Limestone is incredibly long-lasting. It can, however, absorb water, and since it is a carbonate rock, it is very reactive when exposed to acids, even weakly acidic rain water, and it may deteriorate significantly. The loss of exact detail is the most typical result of weathering and erosion. In this project, slake durability test was performed for the determination of slake durability index of limestone.

Understanding cave, karst, and landscape processes requires determining the dissolving rates of carbonate rocks. Carbonate dissolution also has a significant impact on the global carbon budget and climate change. In karst terrain, building and maintaining roadways and ancillary infrastructure frequently causes sinkhole collapse, subsidence, and floods. According to (Moore, 2006.), grading and ditching activities that modify the flow patterns of surface and subsurface water are a major contributing factor to sinkhole collapses. Over 75% of the sinkhole collapses that the Tennessee Department of Transportation (TDOT) has recorded along the highways in East Tennessee were discovered to have taken place in the drainage ditch of the roadway, according to studies done by (Moore, n.d.) that were previously mentioned. Thus, the dissolution test was also conducted in this research.

By the end of this particular project will find out about:

1. Evaluation of chemical composition and petrography properties of the carbonate sample.

2. Determination of dissolution performance of the carbonate sample.

3. Determination of slake durability index of the carbonate sample.

4. Correlation mineralogy, chemical composition and dissolution performance to karstification features of the carbonate sample.

1.5 Strategy for Approaching the Problem

In this particular project, all sample were collected from Kinta District area. Specimens were then tested for the characterization of mineralogy properties. The optical mineralogy thin section study of minerals, as well as the microtexture and structure, are used to determine the rock's origin. X-ray diffraction also be used to examine individual mineral grains in a rock sample. As well as slake durability test and dissolution on the sample.

1.6 Outline of Thesis

There are five chapters to this thesis. The first chapter provides an overview of the project's general concepts and goals. The second part is a literature review, which includes data gleaned from journals and books. The methodology chapter, which will cover the technique and equipment utilized in this research, will be discussed in the third chapter. The results analyses and discussion will be discussed in Chapter 4, while the conclusion and future recommendations will be provided in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Limestone Mineralogy, Grains, and Rock names

Limestones are a type of sedimentary rock that is extremely significant. Limestones are primarily made of calcium carbonate ($CaCO_3$) in the mineral form calcite, although they also contain a number of other significant carbonate minerals.

2.1.1 Limestone Mineralogy

Calcium carbonate in the form of calcite is the primary component of limestones ($CaCO_3$). They may also contain non-carbonate impurities and a variety of different carbonate minerals, as indicated in Table 2.1. Calcium carbonate ($CaCO_3$) is divided into two types: aragonite, which has an orthorhombic crystal system, and calcite, which has a hexagonal crystal system. Aragonite is found in carbonate mud and numerous shells. However, it is extremely unstable in the subsurface and quickly dissolves, resulting in mouldic porosity, either at the surface or after shallow burial. In ancient and/or deeply buried limestones, it is extremely rare. Calcite can be found in a variety of shells and carbonate grains. Aragonite is less stable than this. The third and most significant mineral found in limestones is dolomite ($CaMg(CO_3)_2$). It seldom occurs on the surface of the Earth, although it is ubiquitous underground. Limestones go from dolomitic limestones to limey dolomites, and eventually to dolomite rock, as dolomite content increases (Selley, 2005). Dolomite is a mineral, whereas dolostone is a rock, according to geopedants. Magnesite, ankerite, and siderite are all uncommon limestone components. Table 2.1 shows summary of minerals commonly associated with limestones.

Table 2.1 Summary of minerals commonly associated with limestones

Mineral	Formula	Crystal system	Occurrence
Aragonite	$CaCO_3$	Orthorhombic	Some shells and mud , unstable during burial
calcite	$CaCO_3$	Hexagonal	Some shells and mud, relatively stable during burial
Magnesite	$MgCO_3$	Hexagonal	Rare surface mineral
Dolomite	$CaMg(CO_3)_2$	Hexagonal	Rarely at the surface , more common as a subsurface replacement
Ankerite	$Ca(MgFe)(CO_3)_2$	Hexagonal	A rare cement
Siderite	$FeCO_3$	Hexagonal	As ooliths and cement

2.1.2 Limestone Grains and Matrix

Limestones are made up of framework grains, syndepositional matrix, postdepositional cement, and, occasionally, pores. Carbonate grains come in a variety of shapes and sizes. Shell debris is perhaps the most prevalent grain type in limestones.

Many limestones are comprised entirely of fossils, whether complete or fragmentary. These limestones are known as bioclastic or biogenic limestones. Palaeoecology is an essential tool in the diagnostic of the depositional environment due to its origin. Whole fossils, as well as fragmentary bioclasts, may be discernible and hence diagnostic. Some limestones include spherical grains known as ooids or ooliths, as well as the rock oolite (called after oos the Greek word for egg, because the rock resembles a fish's roe). Ooids have a concentric growth ring structure around the nucleus of a quartz grain or shell fragment on the inside (Selley, 2005). Carbonate precipitates episodically around an agitated centre in shallow, high-energy marine settings with higher temperatures and salinity, forming ooids. Pisoliths are larger concentric carbonate grains, while oncolites are algally covered clasts. Some limestones are made up of comminuted shell fragments and structureless, bullet-shaped grains of lime mud. Faecal pellets, the excrement of a variety of burrowing aquatic organisms, make up these grains. As bizarre as it may appear, such material makes up whole rock formations. Inner shelves, protected bays, and lagoons all have a grain form known as faecal pellets. Intraclasts are carbonate grains of varied lengths and sizes that are irregular and often platy-shaped. They're made up of lithified carbonate sediment that's been eroded penecontemporaneously. Continental shelf and slope settings are common places to find intraclasts. A finer grained syndepositional matrix may exist between the framework grains mentioned before. Clay minerals make up the majority of this in sandstone. Micrite, a kind of lime mud, is more commonly found in limestones. Micrite can be aragonitic or calcitic depending on its composition. Micrite is a mineral that comes from a variety of sources. When calcareous algae disintegrate, skeletal aragonite needles are released into the water, and this is how it originates. Disaggregation of structural shells into comminuted lime mud is aided by waves and tidal currents, as well as shell-munching predators. The direct precipitation of aragonite mud in saltwater has been seen in current warm shallow waters. Calcite, often known as spar or sparite, is widely used to cement limestone. Several additional carbonate and evaporite minerals precipitate out as postdepositional cement in limestone pore spaces.

2.1.3 Limestone Classification and Nomenclature

Carbonate rocks are classified in a number of ways. Dunham (1962) proposed the most extensively used. The name boundstone refers to limestone that was produced from biological skeleton material that grew bound together at the Earth's surface, or reef rock. Micrite with less than 10% grains is referred to as mudstone, whereas micrite with more than 10% grains is referred to as wackestone (Wright, 1992) . Mudstone and wackestone are both mud-supported rocks. The grains appear to float within the micrite, in other words. Packstone, on the other hand, is grain supported, with micrite matrix partially or entirely filling the space between the grains. The term grainstone refers to grain that is supported by a micrite matrix. The mudstone, wackestone, packstone, grainstone series represents increasing depositional turbulence and energy, making it valuable for palaeoenvironmental reconstruction (Wright, 1992). Grain type qualifies Dunham's rock names. Faecal wackestone, bioclastic packstone, ooidal grainstone, and so on are some examples. Crystalline carbonate, which includes dolomite and marble, is the last rock term in Dunham's classification.

2.2 Limestone Depositional Environment

Organic activities precipitate all carbonate sediment, either directly through the secretion of lime skeletons by animals and plants, or indirectly through metabolic changes in water that cause carbonate to precipitate as individual crystals. Plants are the foundation of all ecosystems, with the exception of a few deep sea settings, and all plants require sunshine to photosynthesize and flourish. Plants are necessary for the development of higher living forms. Carbonate precipitation occurs in shallow water, with the majority of it occurring on the bottom, and is generated or facilitated by plants. Because photosynthesis is inhibited by darkness, carbonate skeletal growth slows as water depth rises (Selley, 2005). As a result, a carbonate shelf will form on a gently sloping seabed over time. This shelf will progressively expand or prograde into deeper water if the sea level remains constant. This softly sloping ramp may have a sharp break in the slope in some scenarios. The bottom might be thrown into deeper water if a rupture occurs. If the water level dips, erodes a sea cliff, and then rises again, the rim will be oversteepedened by fast carbonate development on the summit of the drowned sea cliff, resulting in rapid deepening(Selley, 2005). The gently sloping accretionary ramp and the rimmed carbonate platform are two forms of carbonate setting causes by these processes. Organic debris of plant and animal plankton that floated near the surface may settle and create basinal lime mud. Many lime mudstones, including chalk, were created in this way. These basinal muds might contain shallow-water carbonate material carried downslope by turbidity flows, submarine debris flows, and slides. On the steep sides of rimmed platforms and reefs, such transported carbonates, also referred to as re-deposited or allodapic limestones, are very abundant. Organic reefs are formed when corals, bryozoa, algae, and a variety of other sedentary biota develop in situ in warm, clear, shallow water. As observed in the contemporary carbonate banks of the Bahamas, shoals of oolitic and skeletal grainstone can occur in tumultuous situations. Burrowing marine creatures may discharge faeces pellets in protected lagoons behind the high-energy environments of reefs and shoals, forming thick formations of peloidal packstones and wackestones. These sediments may then flow through sabkha (arabic for salt marsh) in dry regions, where dolomite and evaporite minerals may develop. The carbonate lagoons may interfinger with siliciclastic sand and mud in humid regions where terrigenous silt flows off from the land.

2.3 Limestone Diagenesis

Limestone minerals are significantly less stable in the subsoil than sandstone minerals. The two isomorphs of calcium carbonate, aragonite and calcite, make up recent carbonate deposit at the Earth's surface. The majority of recent lime mud is aragonitic, but skeletal material contains both kinds, which vary in significance across animal and plant groups. The transformation of unconsolidated lime silt to limestone occurs swiftly and with little burial. Calcite and aragonite combine in these early cements. The disintegration of aragonite shells in skeletal sands is one of the first diagenetic events. Biomoldic porosity arises as a result of this. Aragonitic muds undergo a rearrangement of the crystal lattice after burial, resulting in the formation of calcite (Selley, 2005). This shift is accompanied by an 8% increase in volume and a commensurate decrease in porosity. This is why most old lime mudstones, especially those from before the Mesozoic, are often hard, tight, and splintery rocks. Many Cretaceous and newer lime mudstones, on the other hand, are light, porous, and chalky in appearance. Coccolithophoridae fossils, disaggregated skeletal plates, coccolith-rich faecal pellets, calcispheres, and unicellular planktonic foraminifers make up the majority of chalk. Coccoliths are made up of calcite rather than aragonite, which is more unstable. As a result, unlike aragonitic muds, these lime muds don't expand upon burial. They keep their chalky texture and are very porous, but are typically impervious unless shattered. During the diagenesis of carbonate sands, early cementation may decrease some porosity during shallow burial, while aragonite dissolution may augment it. Calcite cement may infill both biomolds and any residual intergranular porosity if the burial is sustained. A cemented limestone may, however, be exposed to a variety of additional diagenetic processes.

Recrystallization of limestones can result in the loss of some or all of the main fabric. Individual carbonate grains, known as bioclasts or ooids, may be pressure-solved. Due to overburden pressure, this is a process in which dissolution occurs at grain interactions. Simultaneously, dissolved mineral particles may precipitate as cement in nearby pores (Selley, 2005). Stylolites are another type of evidence for dissolution. These are sutured surfaces that are typically subparallel to bedding and have an insoluble remnant of clay, kerogen, and other materials along the suture as a result of extensive dissolution.

Pure limestones and quartzose sandstones both include stylolites. Limestone diagenesis should not be seen as a one-way street in which all porosity and permeability are lost. Acidic pore fluids may be washed through limestones, generating secondary porosity and permeability due to their leaching qualities. Acidic fluids might be ejected from nearby compacting clay layers, providing secondary porosity in advance of petroleum invasion. Uplift and erosion, as well as the flushing of limestone by acidic meteoric water, are the most common causes of secondary solution porosity. Mold and vuggy pores may occur as a result of the solution. It can expand fractures and, in the worst-case scenario, create karstic caves with collapse breccias. Where solution porosity has been generated and retained beneath unconformities, many of the finest carbonate petroleum reserves exist. Petroleum invasion, which expels cementing connate fluids, is the most effective technique of retaining porosity in a limestone. Without the advantage of petroleum invasion, renewed burial may result in total recementation of the limestone as it works its way to a totally cemented and recrystallized rock known as marble. Dolomitization, a difficult and crucial diagenetic process to which limestones are treated, is the final important diagenetic process to which limestones are subjected.

2.4 Karst Terrane

A terrane characterised by sinkholes, sinking streams, subterranean cave streams, and springs develops from bedrock dissolution in locations underlain by carbonate rocks often limestone or dolomite. A karst terrane is the general term for the landscape created in areas with soluble rock. Terrane, as opposed to topography, is used to describe both surface and underlying elements (Moore, 2018.). Typically, this terrain is referred to as karst. Because surface water may enter the subsurface immediately under these conditions, with little to no filtering by soil, groundwater is more vulnerable to pollution. Karst groundwater may quickly transfer pollutants from recharge places such sinkholes to far-off cave streams, water wells, springs, and surface streams because it frequently flows via relatively extensive cracks and conduits within the bedrock. A karst environment might include gradually sloping hills and valleys that are dotted with sinkholes, cave openings, sinking streams, and limestone outcrops that have weathered through time. The patterns of the solution holes and ensuing caves typically reveal the orientation of the bedrock, the density of the fractures, and the circulation of the groundwater.

Important characteristics such as springs, sinkholes, and cave passage patterns may aid in understanding the regional groundwater flow. For those involved in the planning and building of roadways, especially infrastructural development, the identification of sites with active karst subsidence and collapse is of utmost importance.

2.4.1 Character of Karst

The most typical karst characteristics, which are frequently encountered when developing and building roadways, are caves and sinkhole collapse. Karst also features sinkhole plains, vanishing streams, resurgent streams, subsurface drainage, and fragile ecosystems, which creates tricky problems when finding or building transportation infrastructure. Karst feature formation is significantly influenced by the geologic makeup of the bedrock. In addition to lithology, karst development is also influenced by structural traits including faulting, folding, and fracture density. While flat-lying strata often generate larger, dendritic-type stretches of karst, folded and faulted strata typically create long linear belts of karst. Furthermore, karst landscapes form more quickly in highly fractured strata than in less fractured strata because they offer more pathways for groundwater's solution activity (Moore, 2018.). Numerous studies, such as Cave development in karst environments, demonstrate the connection between geologic structure and karst development. The weak spots are often parallel to rock bedding planes or zones of rock fractures (joints and faults). These weak sections of cracked rock that experience solution expansion typically merge into elaborate caverns with interconnected channels, some of which are lavishly ornamented with cave formations speleothems or dripstone.

Usually, depressions and sinkholes are the surface manifestation of the underlying conditions in karst environments. The size of the sinkholes varies, measuring anything from a few feet to several hundred feet broad and up to tens of feet deep. While some of the sinkholes could contain active swallets or entrances into the cave systems, others might just be silted up and covered with vegetation. There are also many of rock outcrops, as well as sinking streams, cave openings, and springs. The most common cause of sinkhole development beside roads is the collapse of the residual clay soil into voids created in the subsurface soil as a result of the residual clay's erosion. These soil cavities get bigger and get closer to the surface, at which point the remaining soil bridge over the hollow weakens and crumbles, creating a classic sinkhole collapse. The bedrock's solution cavities are flushed with the eroding soil. Elias et al., (1981), and (Moore, 2018.) have all previously discussed this particular sort of induced sinkhole failure.

2.4.2 The Karst Cycle Solution of Weathering and Erosion

Cvijic (1918) was the first to propose the concept of karst erosion cycles, which included five key assumptions: a thick and extensive mass of limestone, an underlying impermeable stratum, a surface layer of impermeable rock on which the stream pattern was initiated, a geological succession above sea level, and enough time for the cycle to develop fully (Sanders, 1921.). Because karst groundwater often travels through relatively extensive fissures and conduits within the bedrock, it has the potential to quickly carry pollutants from recharge sources such sinkholes to far-off cave streams, water wells, springs, and surface streams. A karst environment might include gradually sloping hills and valleys that are dotted with sinkholes, cave openings, sinking streams, and limestone outcrops that have weathered through time. Figure 2.4 below shows idealized stages of karst development.

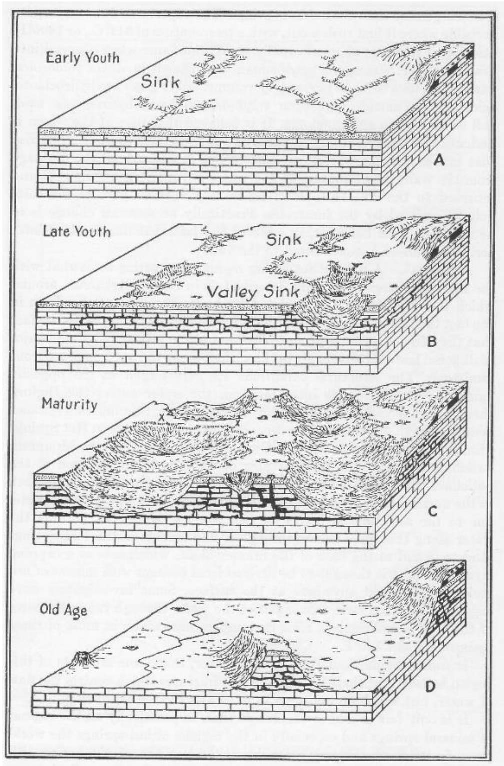

Figure 2.4 Idealized stages of Karst development

Surface streams running through typical valleys before vanishing into stream sinks, some with blind ends, remove the upper impermeable layer in the period of youth (Fig. 2.4A). Underground drainage takes a long time to develop. When all rivers have gone underground (Fig. 2.4B), the landscape has three traditional zones: an upper zone of downward movement, a lower zone of lateral movement, and a middle zone that is either lateral or downward depending on the level of the water table. When underground streams reach the impermeable underlying strata and cave roof collapse, it is said to have reached late stage maturity (Fig. 2.4C). All huge cave roofs have fallen due to age, and drainage has resurfaced on the exposed impermeable substrate under the surface (Fig. 2.4D). Finally, the limestone cover is weathered away, leaving just a few outliers honeycombed with caves and solution structures. Only in Yugoslavia's type region, where limestones of enormous thickness cover a large area, has the karst erosion cycle been successfully used to date. Where limestones are thinner and occupy smaller areas, as in the United Kingdom, they are subjected to the typical Davisian cycle of erosion, resulting in specialised relief within non-carbonate landscapes (Fookes & Hawkins, 1988). Locally, drainage will be subterranean in such locations, nevertheless, due to the overall ground water level, bigger streams will exist. The rarity of all of the stated requirements, particularly the areal extent, limestone thickness, and depth to ground water level, implies that the geomorphologically perfect karst cycle will probably never be employed to explain limestone relief. The notion of a karst cycle, on the other hand, aids in focusing attention on the solution features progressive nature and evolution, and serves as a suitable model for constructing a categorization sequence of limestone solution features.

2.5 Weathering

The effects of rock weathering have long been seen and researched, and a large body of literature indicating the interest in this area of geological study. The fundamental contributions of research in weathering gain increasingly greater relevance as attention on sedimentation and the creation and evolution of soils grows.

Grading of weathering is crucial from an engineering perspective since weathering generally refers to the process that causes a variety of changes to a rock mass's characteristics as a result of its exposure to shifting environmental (physical, chemical, and biological) conditions (Gratchev & Kim, 2016). Weathering can change the engineering qualities of rocks at the mass scale (rock strength, swelling potential, slaking index, compressibility, consolidation characteristics) or at the material scale (rock strength, swelling potential, slaking index, discontinuities, fracture, joint, settlement, permeability). Additionally, how weathered rocks behave depends on the environmental factors to which they are exposed. For instance, worn rocks in dry condition may bulge or begin to crumble when exposed to water. Similar to this, various applications emphasize various characteristics of the weathered rocks. When building on worn rocks, an engineer will be more interested in the rocks' bearing capability; but, when creating slopes and embankments, he will be more worried about changes in permeability brought on by weathering. However, grading weathered rocks is a highly challenging process, and as a result, changes in a weathered rock's technical qualities are extremely unexpected and cannot be predicted using any calculating method. Engineering can also expose the rock mass to a new environment, which could result in weathering that lasts long after the building is finished. Researchers, engineers, and geologists have made efforts to categorize weathered rocks and their influence on various engineering qualities of rock mass.

Rock weathering is an extremely complicated occurrence. The pace of weathering depends not only on the environment, but also on the characteristics of the rock, as well as their interaction, length of exposure, and types of environmental cycles such as wetting-drying, freeze-thaw and others. Additionally, the distribution and concentration of the weather-resistant (such as quartz and feldspar) and weather-prone (such as biotite, muscovite, and hornblende) minerals will determine the degree of weathering. Despite these drawbacks, several researchers have attempted to correlate the rate of weathering using a variety of laboratory procedures, including as X-ray diffraction (XRD) analysis, mineral investigation using a scanning electron microscope (SEM), and the slake durability test. When subjected to oxidation and reduction, hydration and dehydration, ion exchange, and leaching processes, silicate minerals found in basic and ultrabasic igneous rocks, metamorphic rocks, limestone, sandstone, and mudshale readily transform into clay minerals like montmorillonite, illite, and kaolinite. Carbonates below the surface of the earth dissolve and then precipitate, increasing the grain contacts that result from cementation and subsequently the strength of loose sedimentary deposits. Additionally, the weather resistance of some rocks, such as shale and mudstones, varies greatly, therefore testing for durability under typical drying and wetting cycles should be used to further define rocks that are likely to deteriorate under exposure. When rock is exposed, fast slaking and erosion in the field is likely if, for instance, wetting and drying cycles decrease shale to grain size.

2.5.1 Affect of Weathering on Limestone

In addition to surface depressions and other unique dips and grooves, weathering also produces subsurface caverns and tunnels in limestone. Karst is a type of terrain created by limestone weathering. The major component of limestone, a sedimentary rock formed from the remnants of extinct marine organisms, is calcium carbonate. Limestone has a lot of vertical and horizontal fissures. These fissures make it simple for water to penetrate through the rock. When water comes in touch with calcium carbonate, it behaves like an acid, dissolving the limestone. It's possible for the dissolved calcium carbonate to seep into weathered-out subsurface caverns. Stalactites are formed when calcium carbonate, which is dripping from the cave ceiling, occasionally evaporates. Stalagmite-like stumps are produced when calcium carbonate drops and evaporates on the ground (Gratchev & Kim, 2016). On rare occasions, additional peculiar forms, such curtains or columns, result from the dripping and evaporation of calcium carbonate. As limestone weathers, intricate subsurface tunnels form. These tunnels allow water to circulate, creating vast subterranean networks of rivers and streams. Humans may access these water flows and use them as aquifers to store and draw water. Water supplies in many locations are derived from limestone aquifers. Utilizing limestone aquifers requires caution since contaminants and rainwater can readily travel through the limestone.