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LIMESTONE, in petrography, a rock consisting essentially of carbonate of lime. The group includes many varieties, some of which are very distinct; but the whole group has certain properties in common, arising from the chemical composition and mineral character of its members. All limestones dissolve readily in cold dilute acids, giving off bubbles of carbonic acid. Citric or acetic acid will effect this change, though the mineral acids are more commonly employed. Limestones, when pure, are soft rocks readily scratched with a knife-blade or the edge of a coin, their hardness being 3; but unless they are earthy or incoherent, like chalk or sinter, they do not disintegrate by pressure with the fingers and cannot be scratched with the finger nail. When free from impurities limestones are white, but they generally contain small quantities of other minerals than calcite which affect their colour. Many limestones are yellowish or creamy, especially those which contain a little iron oxide, iron carbonate or clay. Others are bluish from the presence of iron sulphide, or pyrites or marcasite; or grey and black from admixture with carbonaceous or bituminous substances. Red limestones usually contain haematite; in green limestones there may be glauconite or chlorite. In crystalline limestones or marbles many silicates may occur producing varied colours, *e.g.* epidote, chlorite, augite (green); vesuvianite and garnet (brown and red); graphite, spinels (black and grey); epidote, chondrodite (yellow). The specific gravity of limestones ranges from 2.6 to 2.8 in typical examples.

When seen in the field, limestones are often recognizable by their method of weathering. If very pure, they may have smooth rounded surfaces, or may be covered with narrow runnels cut out by the rain. In such cases there is very little soil, and plants are found growing only in fissures or crevices where the insoluble impurities of the limestone have been deposited by the rain. The less pure rocks have often eroded or pitted surfaces, showing bands or patches rendered more resistant to the action of the weather by the presence of insoluble materials such as sand, clay or chert. These surfaces are often known from the crust of hydrous oxides of iron produced by the action of the atmosphere on any ferriferous ingredients of the rock; they are sometimes black when the limestone is carbonaceous; a thin layer of gritty sand grains may be left on the surface of limestones which are slightly arenaceous. Most limestones which contain fossils show these most clearly on weathered surfaces, and the appearance of fragments of corals, crinoids and shells on the exposed parts of a rock indicate a strong probability that that rock is a limestone. The interior usually shows the organic structures very imperfectly or not at all.

Another characteristic of pure limestones, where they occur in large masses occupying considerable areas, is the frequency with which they produce bare rocky ground, especially at high elevations, or yield only a thin scanty soil covered with short grass. In mountainous districts limestones are often recognizable by these peculiarities. The chalk downs are celebrated for the close green sward which they furnish. More impure limestones, like those of the Lias and Oolites, contain enough insoluble mineral matter to yield soils of great thickness and value, *e.g.* the Cornbrash. In limestone regions all waters tend to be hard, on account of the abundant carbonate of lime dissolved by percolating waters, and caves, swallow holes, sinks, pot-holes and underground rivers may occur in abundance. Some elevated tracts of limestone are very barren (*e.g.* the Causses), because the rain which falls in them sinks at once into the earth and passes underground. To a large extent this is true of the chalk downs, where surface waters are notably scarce, though at considerable depths the rocks hold large supplies of water.

The great majority of limestones are of organic formation, consisting of the debris of the skeletons of animals. Some are foraminiferal, others are crinoidal, shelly or coral limestones according to the nature of the creatures whose remains they contain. Of foraminiferal limestones chalk is probably the best known; it is fine, white and rather soft, and is very largely made up of the shells of globigerina and other foraminifera (see CHALK). Almost equally important are the nummulitic limestones so well developed in Mediterranean countries (Spain, France, the Alps, Greece, Algeria, Egypt, Asia Minor, &c.). The pyramids of Egypt are built mainly of nummulitic limestone. Nummulites are large cone-shaped foraminifera with many chambers arranged in spiral order. In Britain the small globular shells of *Saccamina* are important constituents of some Carboniferous limestones; but the upper portion of that formation in Russia, eastern Asia and North America is characterized by the occurrence of limestones filled with the spindle-shaped shells of *Fusulina*, a genus of foraminifera now extinct.

Coral limestones are being formed at the present day over a large extent of the tropical seas; many existing coral reefs must be of great thickness. The same process has been going on actively since a very early period of the earth’s history, for similar rocks are found in great abundance in many geological formations. Some Silurian limestones are rich in corals; in the Devonian there are deposits which have been described as coral reefs (Devonshire, Germany). The Carboniferous limestone, or mountain limestones of England and North America, is sometimes nearly entirely coralline, and the great dolomite masses of the Trias in the eastern Alps are believed by many to be merely altered coral reefs. A special feature of coral limestones is that, although they may be to a considerable extent dolomitized, they are generally very free from silt and mechanical impurities.

Crinoidal limestones, though abundant among the older rocks, are not in course of formation on any great scale at the present time, as crinoids, formerly abundant, are now rare. Many Carboniferous and Silurian limestones consist mainly of the little cylindrical joints of these animals. They are easily recognized by their shape, and by the fact that many of them show a tube along their axes, which is often filled up by carbonate of lime; under the microscope they have a punctate or fenestrate structure and each joint behaves as a simple crystalline plate with uniform optical properties in polarized light. Remains of other echinoderms (starfishes and sea urchins) are often found in plenty in

Secondary and Tertiary limestones, but very seldom make up the greater part of the rock. Shelly limestones may consist of mollusca or of brachiopoda, the former being common in limestones of all ages while the latter attained their principal development in the Palaeozoic epoch. The shells are often broken and may have been reduced to shell sand before the rock consolidated. Many rocks of this class are impure and pass into marls and shelly sandstones which were deposited in shallow waters, where land-derived sediment mingled with remains of the creatures which inhabited the water. Fresh-water limestones are mostly of this class and contain shells of those varieties of mollusca which inhabit lakes. Brackish water limestones also are usually shelly. Corallines (bryozoa, polyzoa, &c.), cephalopods (*e.g.* ammonites, belemnites), crustaceans and sponges occur frequently in limestones. It should be understood that it is not usual for a rock to be built up entirely of one kind of organism though it is classified according to its most abundant or most conspicuous ingredients.

In the organic limestones there usually occurs much finely granular calcareous matter which has been described as limestone mud or limestone paste. It is the finely ground substance which results from the breaking down of shells, &c., by the waves and currents, and by the decay which takes place in the sea bottom before the fragments are compacted into hard rock. The skeletal parts of marine animals are not always converted into limestone in the place where they were formed. In shallow waters, such as are the favourite haunts of mollusca, corals, &c., the tides and storms are frequently sufficiently powerful to shift the loose material on the sea bottom. A large part of a coral reef consists of broken coral rock dislodged from the growing mass and carried upwards to the beach or into the lagoon. Large fragments also fall over the steep outward slopes of the reef and build up a talus at their base. Coral muds and coral sands produced by the waves acting in these detached blocks, are believed to cover two and a half millions of square miles of the ocean floor. Owing to the fragile nature of the shells of foraminifera they readily become disintegrated, especially at considerable depths, largely by the solvent action of carbonic acid in sea water as they sink to the bottom. The chalk in very great part consists not of entire shells but of debris of foraminifera, and mollusca (such as *Inoceramus*, &c.). The Globigerina ooze is the most widespread of modern calcareous formations. It occupies nearly fifty millions of square miles of the sea bottom, at an average depth of two thousand fathoms. Pteropod ooze, consisting mainly of the shells of pteropods (mollusca) also has a wide distribution, especially in northern latitudes.

Consolidation may to a considerable extent be produced by pressure, but more commonly cementation and crystallization play a large part in the process. Recent shell sands on beaches and in dunes are not unfrequently converted into a soft, semi-coherent rock by rain water filtering downwards, dissolving and redepositing carbonate of lime between the sand grains. In coral reefs also the mass soon has its cavities more or less obliterated by a deposit of calcite from solution. The fine interstitial mud or paste presents a large surface to the solvents, and is more readily attacked than the larger and more compact shell fragments. In fresh-water marls considerable masses of crystalline calcite may be produced in this way, enclosing well-preserved molluscan shells. Many calcareous fragments consist of aragonite, wholly or principally, and this mineral tends to be replaced by calcite. The aragonite, as seen in sections under the microscope, is usually fibrous or prismatic, the calcite is more commonly granular with a well-marked network of rhombohedral cleavage cracks. The replacement of aragonite by calcite goes on even in shells lying on modern sea shores, and is often very complete in rocks belonging to the older geological periods. By the recrystallization of the finer paste and the introduction of calcite in solution the interior of shells, corals, foraminifera, &c., becomes occupied by crystalline calcite, sometimes in comparatively large grains, while the original organic structures may be very well-preserved.

Some limestones are exceedingly pure, *e.g.* the chalk and some varieties of mountain limestone, and these are especially suited for making lime. The majority, however, contain admixture of other substances, of which the commonest are clay and sand. Clayey or argillaceous limestones frequently occur in thin or thick beds alternating with shales, as in the Lias of England (the marlstone series). Friable argillaceous fresh-water limestones are called "marls," and are used in many districts for top dressing soils, but the name "marl" is loosely applied and is often given to beds which are not of this nature (*e.g.* the red marls of the Trias). The "cement stones" of the Lothians in Scotland are argillaceous limestones of Lower Carboniferous age, which when burnt yield cement. The gault (Upper Cretaceous) is a calcareous clay, often containing well-preserved fossils, which lies below the chalk and attains considerable importance in the south-east of England. Arenaceous limestones pass by gradual transitions into shelly sandstones; in the latter the shells are often dissolved leaving cavities, which may be occupied by casts. Some of the Old Red Sandstone is calcareous. In other cases the calcareous matter has recrystallized in large plates which have shining cleavage surfaces dotted over with grains of sand (Lincolnshire limestone). The Fontainebleau sandstone has large calcite rhombohedra filled with sand grains. Limestones sometimes contain much plant matter which has been converted into a dark coaly substance, in which the original woody structures may be preserved or may not. The calcareous petrified plants of Fifeshire occur in such a limestone, and much has been learned from a microscopic study of them regarding the anatomy of the plants of the Carboniferous period. Volcanic ashes occur in some limestones, a good example being the calcareous schalsteins or tuffs of Devonshire, which are usually much crushed by earth movements. In the

Globigerina ooze of the present day there is always a slight admixture of volcanic materials derived either from wind-blown dust, from submarine eruptions or from floating pieces of pumice. Other limestones contain organic matter in the shape of asphalt, bitumen or petroleum, presumably derived from plant remains. The well-known *Val de Travers* is a bituminous limestone of lower Neocomian age found in the valley of that name near Neuchâtel. Some of the oil beds of North America are porous limestones, in the cavities of which the oil is stored up. Siliceous limestones, where their silica is original and of organic origin, have contained skeletons of sponges or radiolaria. In the chalk the silica has usually been dissolved and redeposited as flint nodules, and in the Carboniferous limestone as chert bands. It may also be deposited in the corals and other organic remains, silicifying them, with preservation of the original structures (*e.g.* some Jurassic and Carboniferous limestones).

The oolitic limestones form a special group distinguished by their consisting of small rounded or elliptical grains resembling fish roe; when coarse they are called pisolites. Many of them are very pure and highly fossiliferous. The oolitic grains in section may have a nucleus, *e.g.* a fragment of a shell, quartz grain, &c., around which concentric layers have been deposited. In many cases there is also a radiating structure. They consist of calcite or aragonite, and between the grains there is usually a cementing material of limestone mud or granular calcite crystals. Deposits of silica, carbonate of iron or small rhombohedra of dolomite are often found in the interior of the spheroids, and oolites may be entirely silicified (Pennsylvania, Cambrian rocks of Scotland). Oolitic ironstones are very abundant in the Cleveland district of Yorkshire and form an important iron ore. They are often impure, and their iron may be present as haematite or as chalybite. Oolitic limestones are known from many geological formations, *e.g.* the Cambrian and Silurian of Scotland and Wales, Carboniferous limestone (Bristol), Jurassic, Tertiary and Recent limestones. They are forming at the present day in some coral reefs and in certain petrifying springs like those of Carlsbad. Their chief development in England is in the Jurassic rocks where they occur in large masses excellently adapted for building purposes, and yield the well-known freestones of Portland and Bath. Some hold that they are chemical precipitates and that the concentric oolitic structure is produced by successive layers of calcareous deposit laid down on fragments of shells, &c., in highly calcareous waters. An alternative hypothesis is that minute cellular plants (*Girvanella*, &c.), have extracted the carbonate of lime from the water, and have been the principal agents in producing the successive calcareous crusts. Such plants can live even in hot waters, and there seems much reason for regarding them as of importance in this connexion.

Another group of limestones is of inorganic or chemical origin, having been deposited from solution in water without the intervention of living organisms. A good example of these is the “stalactite” which forms pendent masses on the roofs of caves in limestone districts, the calcareous waters exposed to evaporation in the air of the cave laying down successive layers of stalactite in the places from which they drip. At the same time and in the same way “stalagmite” gathers on the floor below, and often accumulates in thick masses which contain bones of animals and the weapons of primitive cave-dwelling man. Calc sinters are porous limestones deposited by the evaporation of calcareous springs; travertine is a well-known Italian rock of this kind. At Carlsbad oolitic limestones are forming, but it seems probable that minute algae assist in this process. Chemical deposits of carbonate of lime may be produced by the evaporation of sea water in some upraised coral lagoons and similar situations, but it is unlikely that this takes place to any extent in the open sea, as sea water contains very little carbonate of lime, apparently because marine organisms so readily abstract it; still some writers believe that a considerable part of the chalk is really a chemical precipitate. Onyx marbles are banded limestones of chemical origin with variegated colours such as white, yellow, green and red. They are used for ornamental work and are obtained in Persia, France, the United States, Mexico, &c.

Limestones are exceedingly susceptible to chemical changes of a metasomatic kind. They are readily dissolved by carbonated waters and acid solutions, and their place may then be occupied by deposits of a different kind. The silification of oolites and coral rocks and their replacement by iron ores above mentioned are examples of this process. Many extensive hematite deposits are in this way formed in limestone districts. Phosphatization sometimes takes place, amorphous phosphate of lime being substituted for carbonate of lime, and these replacement products often have great value as sources of natural fertilizers. On ocean rocks in dry climates the droppings of birds (guano) which contain much phosphate, percolating into the underlying limestones change them into a hard white or yellow phosphate rock (*e.g.* Sombrero, Christmas Island, &c.), sometimes known as rock-guano or mineral guano. In the north of France beds of phosphate are found in the chalk; they occur also in England on a smaller scale. All limestones, especially those laid down in deep waters contain some lime phosphate, derived from shells of certain brachiopods, fish bones, teeth, whale bones, &c. and this may pass into solution and be redeposited in certain horizons, a process resembling the formation of flints. On the sea bottom at the present day phosphatic nodules are found which have gathered round the dead bodies of fishes and other animals. As in flint the organic structures of the original limestone may be well preserved though the whole mass is phosphatized.

Where uprising heated waters carrying mineral solutions are proceeding from deep seated masses of igneous rocks they often deposit a portion of their contents in limestone beds. At Leadville, in Colorado, for example, great quantities of rich silver lead ore, which have yielded not a little gold, have been obtained from the limestones, while other rocks, though apparently equally favourably situated, are barren. The lead and fluorspar deposits of the north of England (Alston Moor, Derbyshire) occur in limestone. In the Malay States the limestones have been impregnated with tin oxide. Zinc ores are very frequently associated with beds of limestone, as at Vieille Montagne in Belgium, and copper ores are found in great quantity in Arizona in rocks of this kind. Apart from ore deposits of economic value a great number of different minerals, often well crystallized, have been observed in limestones.

When limestones occur among metamorphic schists or in the vicinity of intrusive plutonic masses (such as granite), they are usually recrystallized and have lost their organic structures. They are then known as crystalline limestones or marbles (*q.v.*). (J. S. F.)

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