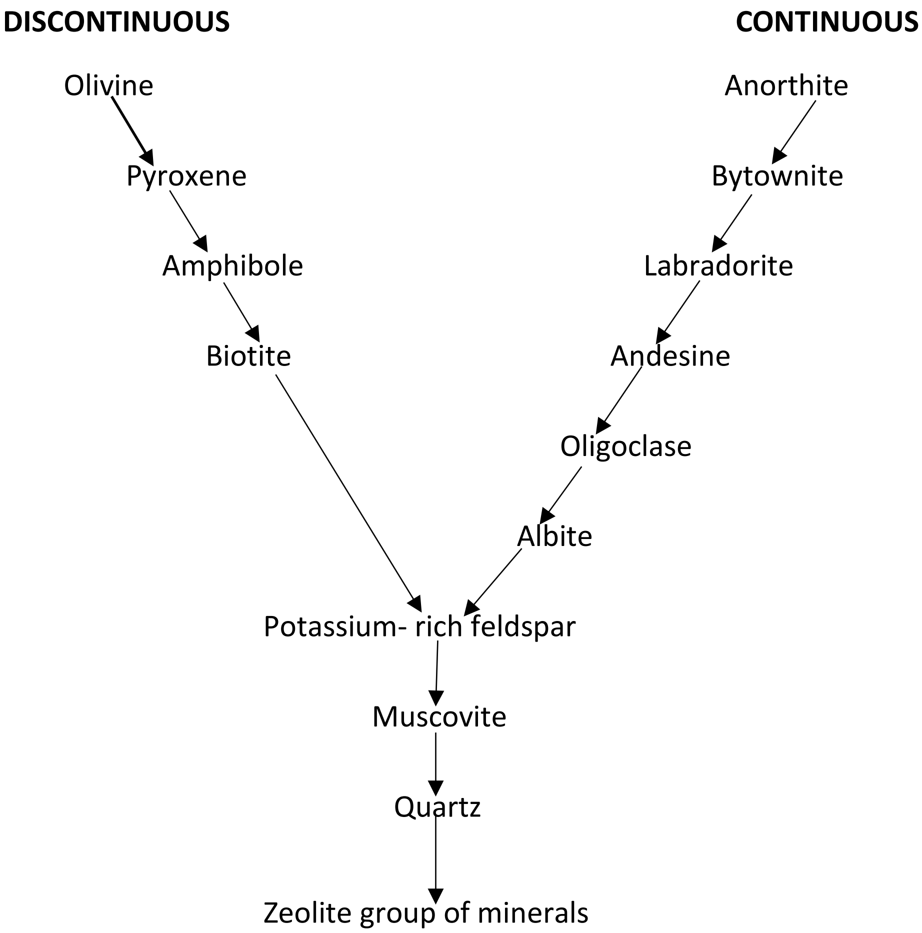
HYDROTHERMAL DEPOSITS

As we know, a magma due to the alteration of physicochemical conditions gradually cools down,producing rock forming silicate minerals under different conditions of temperature and pressure. It also gives rise to a segregation of residual solution enclosed within that parent rock, which is obvious from the bowen's reaction series.



HYDROTHERMAL SOLUTION

Thus towards the end of the process of crystallization, the once widely dispersed gases and metals have collected near the top of the intrusive body. In moving up, the gases ooze and steam through the magma and collect some of the metals in their journey. At this stage the pressure may force the gases and their dissolved rare elements to leave the magma chamber and to move along zones of weakness towards the surface. Such fluids may begin their journey upwards as liquids or gases which later becomes liquid and this hot water solution is known as HYDROTHERMAL SOLUTION.

Such hydrothermal solutions are important in the formation of certain kinds of mineral deposits, as they carry out metals from the consolidating intrusive to the site of deposition.

They are mostly epigenetic deposits. Since hydrothermal solution is originated from the magma, its temperature is about 350^0C **and** it is under very high pressure. It is acidic in nature containing non- metallic and volatile constituents mostly. Metallic constituents of iron, zinc, nickel, gold, silver, lead, etc, also find their places in the hydrothermal solution.

CAUSES OF DEPOSITION:

1) Changes in the temperature.
2) Changes in the pressure of the system.
3) Exchange reactions between the substances in the solution.
4) Exchange reactions following mixing of solutions.
5) Exchange reaction between solution and wall rocks.
6) Changes in the pH of the medium.
7) Coagulation of the colloids, which is brought about by exchange reaction, by breaking down of complexion, by the action of electrolytes arising from exchange reactions, and sometimes by super saturation or super-cooling of the solution.
8) Filtration effect, which helps in the precipitation of components when hydrothermal solutions filter through poorly permeable rocks and mineralize the rocks in front of such barriers.

CLASSIFICATION OF HYDROTHERMAL DEPOSITS :

On the basis of temperature, pressure, depth of formation and the distance from the magmatic source, the hydrothermal deposits are of the following types :

1) **Hypothermal Deposits :** These deposits are formed at great depths, near the intrusive and within the temperature range of 300^0C to 600^0C.
2) **Mesothermal Deposits :** They are found at a depth of 1500 to 4000metres below the surface and within the temperature range of 200^0C to 300^0C. The pressure ranges from 140 to 400 atmosphere.
3) **Epithermal Deposits :** These are formed at shallow depths (further away from the surface). The temperature range is from 50^0C to 200^0C.
4) **Telethermal Deposits :** These are formed under low temperature and pressure, far away from the parent igneous body with which their genetic relationship is not well established.
5) **Xenothermal Deposits :** These are formed by high temperature ore forming fluids expelled from huge igneous rock masses, which have intruded into shallow depth of formation and rapid cooling.

On the basis of mode of formation, the hydrothermal deposits are of two types :

1) **Cavity filling deposits.**
2) **Metasomatic replacement deposits.**

CAVITY FILLING : The filling of open spaces or cavities in the rocks is an important mode of formation of hydrothermal deposits. More mineral deposits are formed by filling of cavities rather than by any other process. The fissure filling, i.e., fissure veins is by far the most common and generally accompanied by replacement.

Essential requirement for the formation of hydrothermal deposits are :

1) Available mineralizing solutions capable of dissolving and transporting mineral matter.
2) Available openings in rocks through which the solutions may be channelized.
3) Available sites for the deposition of the mineral content.
4) Chemical reactions that results in deposition and
5) Sufficient concentration of deposited mineral matter to constitute workable deposits.

OPENINGS IN ROCKS :

1) Original cavities, which includes pore spaces, crystal lattices, vesicles, lava drain channels, cooling cracks, bedding planes and igneous breccias cavity.
2) Induced cavities, which include volcanic pipes, shear zones, solution caves, collapse breccias, and cavities due to folding and warping (saddle reef, pitches, flats, longitudinal cracks)

CHARACTERISTIC FEATURES OF CAVITY FILLING DEPOSITS :

Cavity filling consists of precipitation of minerals from the solution in rock openings. The solutions may be dilute, or concentrated, hot or cold and of magmatic or meteoric origin. Mostly they are hot and dilute. Precipitation of the minerals is brought about by changes in chemical character and temperature and pressure of the mineralizing solutions.

The first mineral to be deposited lines the walls of the cavity and grows inward generally with the development of crystal faces pointing towards the supplying solution. In some cases the same mineral may be deposited continuously on both the walls until the cavity becomes filled or nearly so. Such type of filling gives rise to homogenous or massive ore. Generally, however, successive crusts of different minerals are deposited upon the first one until the filling is complete and gives rise to crustification. If the cavity is fissure, a crustified vein results. If the crusts surround breccias fragments, cockade ore results. If prominent crystals project from the walls, it forms comb structure. Commonly , the filling may not be complete and open vug remains in the centre.

Vein crustification may be symmetrical with similar crusts on both sides or asymmetrical with unlike layers on each side. The latter is generally caused due to reopening of the fissure, permitting further deposition.

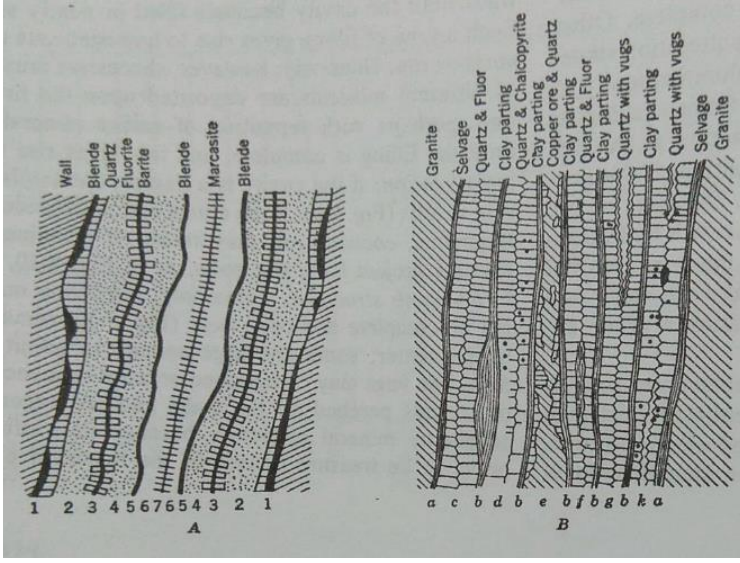


Figure 8-9 Crustified veins. A, Symmetrical crustification, Freiberg, Germany (after Von Wissenbach); B, asymmetrical crustification in tin vein, Redruth, Cornwall (after Phillips).

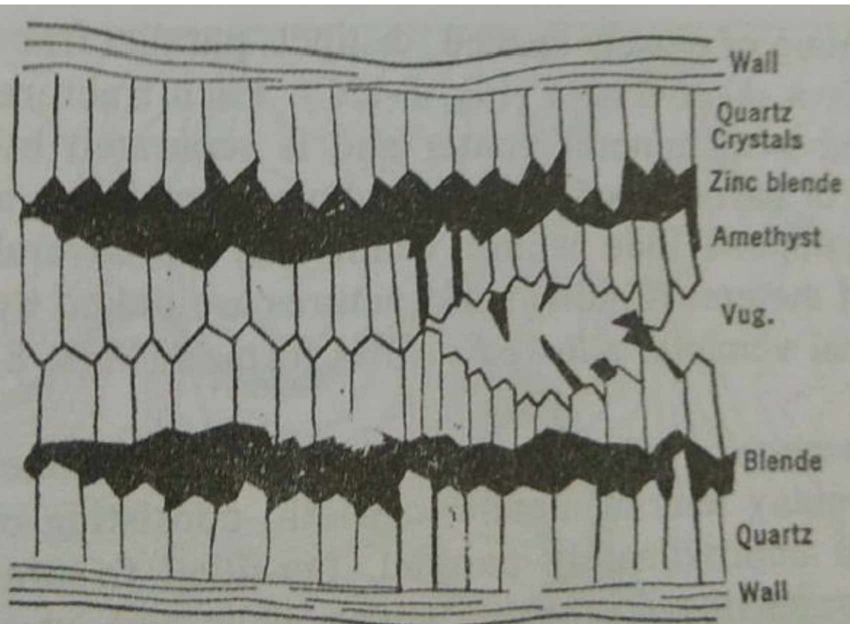


Figure 8-10 Growth of quartz crystals from fissure walls toward the center, forming a comb structure, and a vug in the center containing latest crystals.

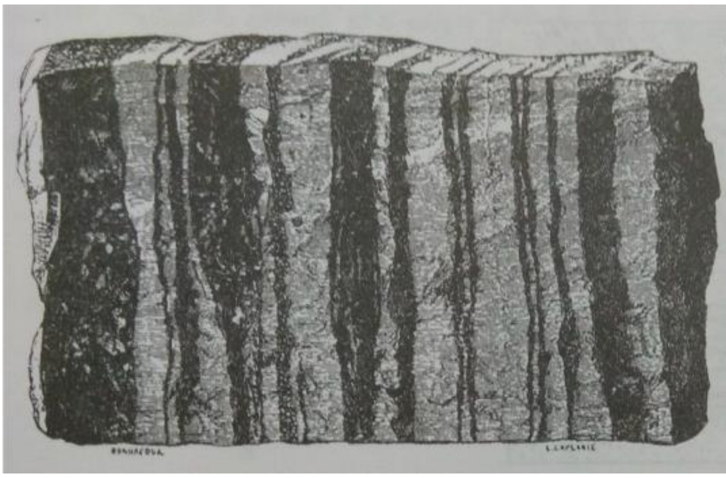


Figure 8-11 Drawing of Zellerfeld vein, Harz, Germany, with crusts of galena, blende, and calcite. (Burat, 1870.)

TYPES OF CAVITY FILLING DEPOSITS:

FISSURE VEINS: A fissure vein is a tabular ore body that occupies one or more fissures. The two dimensions of fissure veins are much greater than the third. Fissure veins are the most widespread and most important of the cavity fillings and yield a great variety of minerals and metals.

Fissures may be formed by stresses operating within the earth's crust and may or may not be accompanied by faulting. Also they may be formed at the time of mineralization due to the intrusive force of the mineralizing solution.

VARIETIES OF FISSURE VEINS : The fissure veins could be **simple, composite, linked, sheeted, dilated and chambered.** The simple fissure vein occupies a single fissure whose walls are relatively straight and parallel. If the walls are irregular and brecciated, it is called chambered vein. Dilation or lenticular veins are flat lenses in schistose rocks. Generally, several occur together, like a string of sausages, or they may be disconnected en- echelon lenses. A group of closely spaced, distinct, parallel fractures gives rise to a sheeted vein. Each fracture is separated by a barren rock called horses and the whole rock is mined as a single lode. If individual fracture is linked by a diagonal veinlet, a linked vein is formed. A composite or lode is a large fracture zone, up to many tens of metres in width, consisting of parallel, ore filled fissures and connecting diagonals, whose walls and intervening country rock have undergone some replacement.

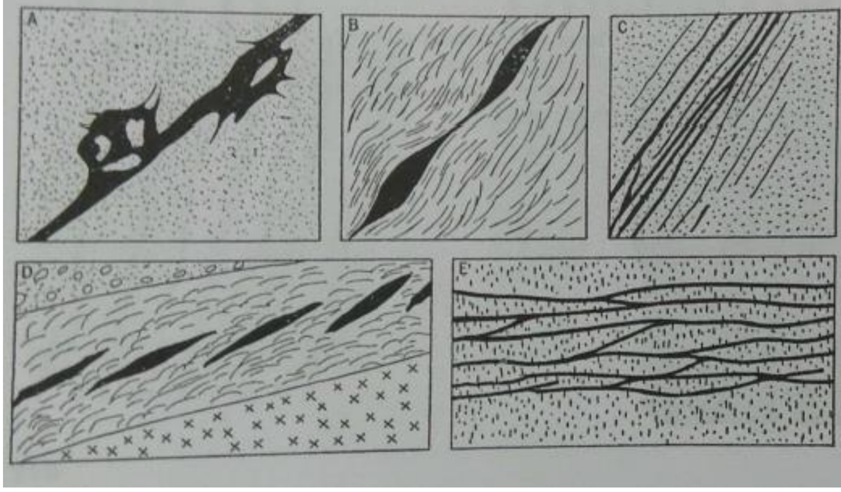


Figure 8-12 Varieties of fissure veins. A, Chambered vein (after Becker); B, dilation veins in schist; C, sheeted vein, Cripple Creek, Colorado; D, en echelon veins in schist; and E, linked vein.

CHARACTERISTICS OF FISSURE VEINS : Most fissure veins are narrow and range in length from a few hundreds of metres to few kilometres. Few are vertical; most are highly inclined and apex at the surface. Most veins exhibit irregularity in width, or pinches and swells, owing to the movement of one wall past the other. Fissure veins branch, divide, and join again enclosing horses of the country rock.

The walls of the fissure veins are commonly marked by a band of selvage or gouge, which is a clay like or gummy substance formed by the movement of one wall upon the other. The vein matter may consist of several minerals. Generally, both gangue and ore minerals are present.

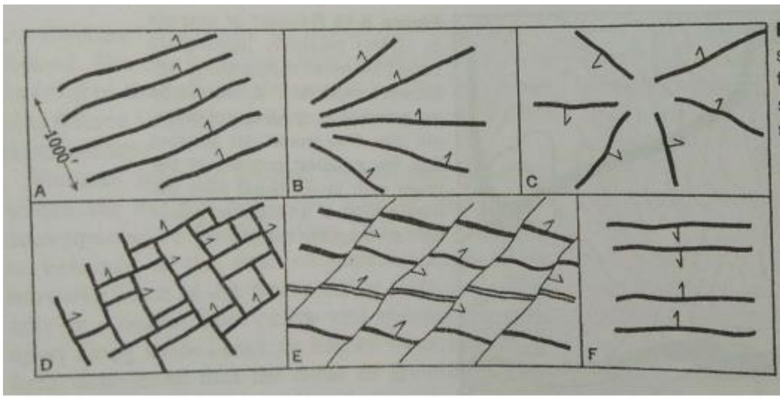


Figure 8-15 Classes of fissure systems. A, Parallel system; B, fan-shaped; C, radial; D, intersecting cognate; E, intersecting systems; and F, conjugated.

RELATION OF FISSURE VEINS TO EACH OTHER : Fissures seldom occur alone but tend to occur in groups and if a group of fissure veins are of the same age and have approximately parallel strike and dip, they constitute a fissure system. Fissures formed at the same time are called cognate fissures. Those with parallel strike but intersecting dip are said to be conjugated veins. Two intersecting systems may differ in age or they may be cognate and of the same age. Those differing in age, generally displace each other, carry different ores and have independent legal rights. Those of the same age carry similar ores and do not fault each other.

EXAMPLES OF IMPORTANT FISSURE VEIN DEPOSITS : Some of the world's most famous deposits are Butte, Montana and Potosi, Bolivia. Vast treasures of gold and silver have been won from them. They also contribute largely to the world's production of Cu, Pb, Zn, Tn, antimony, cobalt, germanium and much of uranium.

SHEAR ZONE DEPOSITS : The thin, sheet like connected openings of a shear zone serves as a excellent channel ways for mineralizing solutions, and some deposition takes place within the seams and crevices.

STOCKWORKS : A stockwork is an interlacing network of small ore bearing vein lets traversing a mass of rock. The individual vein-let rarely exceeds a centimetre or so in width or a few metres in length, and they are spaced a few centimetres to a few metres apart. In general, the vein-let consist of open space fillings that exhibit comb structure and crustification.

SADDLE REEFS : If a stack of writing papers is sharply arched, openings form in between the sheets at the crest of the arch. Similar ore bodies are formed when alternating beds of competent and incompetent rocks, such as quartzite and slate are closely folded. When filled with ore, they resemble the cross section of a saddle. The saddles are repeated in ore bed after ore bed down the axial plane.

LADDER VEINS : It is the name applied to more or less regularly spaced, short, transverse fractures in dyke. These generally extend roughly parallel to each other, from wall to wall of the dyke. Their width is restricted but they may extend for considerable distance along the dyke. Such openings may become filled with mineral matter to form commercial deposits. The individual fissure may form separate vein, or if they are closely spaced the dyke as a whole may be mined. Such transverse veins in a vertical dyke resemble the rungs of a ladder, hence their name.

PITCHES AND FLATS : Gentle synclinal folding of brittle sedimentary rocks gives rise to a series of connected tension cracks at the crests of the anticlines. These cracks generally have small vertical extent but may extend along the axis of the fold, as a series of disconnected fractures, for considerable distances. They are generally wedge shaped and commonly terminate abruptly.

BRECCIA FILLING DEPOSIT : The haphazard arrangement of the angular rock fragments in breccias gives rise to numerous openings that permit the entry of solutions and mineral deposition , forming breccias filling deposits. The breccias may result from volcanism, collapse or tectonics and accordingly the deposits formed in them is called volcanic breccias deposits, collapse breccias deposits and tectonic breccias deposits respectively.

SOLUTION CAVITY FILLING DEPOSITS : Various types of solution openings in soluble rocks have afforded receptacles for primary and secondary mineral deposits. They occur most commonly in limestones.

CAVE DEPOSITS : Caves of various shapes and sizes are characteristics of limestone plateau areas. They may be almost completely filled by ore minerals or contain only peripheral crusts of ore minerals.

GALLERIES : These are horizontal or gently inclined caves, which result from solution along fissures.

GASH VEINS : These are small wedge shaped fissures in stressed brittle rocks. They are common in limestone regions.

PORE SPACE FILLINGS : Small pores in the rocks may contain ores.

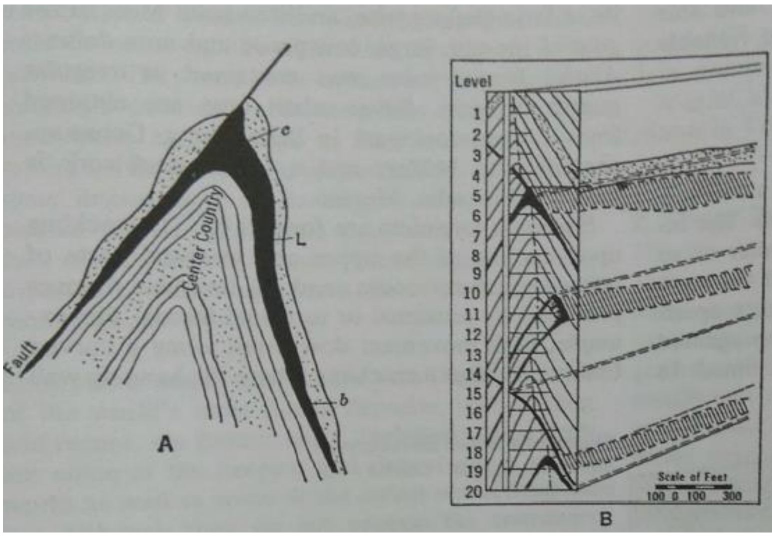


Figure 8-25 A, Typical saddle reefs of Bendigo, Australia, c, cap; L, leg, b, back; black is gold quartz ore. B, Three types of Bendigo reefs and methods of mining them. (After Report by Bendigo Mines, Ltd.)

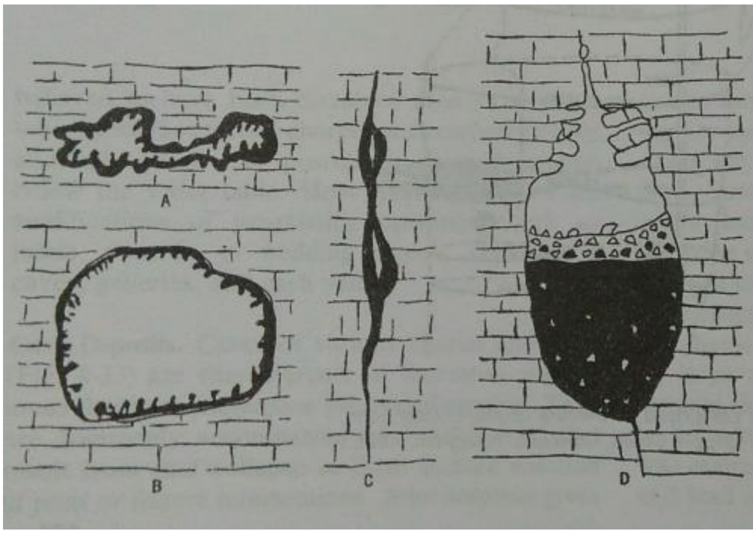


Figure 8-33 Solution caves and cavities in limestone. A, B, Open solution cavities lined with crusts of crystals, Wisconsin lead-zinc region (after Chamberlin); C, gash vein or solution enlargement along joint (after Whitney); D, solution cave occupied by ore (black) and cave breccia on bottom, overlain by later breccia and ore, and by breccia fragments (after Walker).

METASOMATIC REPLACEMENT : It is the dominating process of mineral deposition in the hypothermal and mesothermal zone. It is also important in the epithermal zone. The ore minerals of contact metasomatic deposits are entirely formed by this process. Also it is the controlling process of deposition in supergene sulphide enrichment.

Replacement may be defined as a process of essentially simultaneous capillary solution and deposition by which a new mineral is substituted for one or more earlier formed minerals. By means of replacement, wood may be transformed to silica, (petrification), a single mineral may take the place of another, retaining its form and size (pseudomorph) or a large body of solid ore may take the place of equal volume of rock.

THE PROCESS OF REPLACEMENT: If the mineralizing solution encounter minerals that are unstable, substitution may take place and replacement ensues. The exchange is practically simultaneous, and the resulting body may occupy the same volume and may retain the identical structure of the original body.

MODE OF INTERCHANGE: THE THEORY OF EQUAL VOLUME:

If in a brick wall, each brick were removed one by one, and a silver block of similar size substituted, the end result would be a wall of the same size and form, except that it would be composed of silver instead of clay. This is how the replacement proceeds, except that the parts interchanged are infinitesimally small, of molecular or atomic size. Consequently the shape, size, structure and texture may be faithfully preserved even below the visible magnification of the microscope.

If the replacement were molecule by molecule, a simple chemical equation would express the interchange, such as ZnS (sphalerite) + $CuSO_4$ CuS (covellite) + $ZnSO_4$.

Such interchange, however takes place only with free growing crystals where pressure is negligible. The theory of equal volume can be best explained with the help of above reaction i.e. a cm^3 of sphalerite is replaced by a cm^3 of covellite. In volume for volume replacement, the interchange is not molecule by molecule. A single crystal of pyrite, for example may cut across and replace some half- dozen different rock minerals, which proves that volume for volume replacement cannot be expressed by any single chemical equation.

The simultaneous interchange must be by infinitesimal particles of molecular or atomic size. The growing mineral is in sharp contact with the vanishing substance, between them there must be a thin film of solution that supplies by diffusion of the replacing materials and removes the replaced substance.

If solution supplied to a centre, such as a pore space, the growth may proceed outward in all directions from the centre, giving rise either to discrete, shapeless grains or to crystals with well-developed faces in sharp contact with the enclosing host. In this manner isolated, doubly terminated crystals may grow at the expense of limestone or other rock which is diagnostic of replacement. If the supply of material to feed a given crystal ceases, then other minerals may continue to deposit at its margin, and eventually earlier formed euhedral minerals will be enclosed within replaced minerals. Thus pyrite crystals are common within Cu, Zn, Pb, and other ores.

STAGES OF REPLACEMENT : In the initial stages of the replacement of rocks, ferromagnesian minerals (e.g. olivine) are attacked first, followed by feldspar and quartz. The first formed metallic minerals such as pyrite and arsenopyrite are common ores may also replaced by later sulphide.

GROWTH OF REPLACEMENT : In non homogenous rocks the growth of replacement may be controlled by favourable beds, structural features or chemical or physical properties of the host rock. In homogenous rocks, replacement may advance in one or more ways.

A) **Bold Face Advance :** Starting from a fissure, the walls are first replaced and the replacement then advances outward with a bold face of massive ore against un replaced country rock. The end product is a massive ore body consisting mostly of introduced materials.

B) **Outer Fringe Of Disseminated Replacement :** The growth may take place with a bold front , but preceding it with a fringe of disseminated replacement where partial replacement is going on at many small centres. The massive part of the ore body has resulted from the continued growth and coalescence of innumerable centres of replacement.

C) **Multiple Centre Growth :**If the country rock becomes permeable and permit mineralizing solution, replacement may start simultaneously at innumerable closely spaced centres.

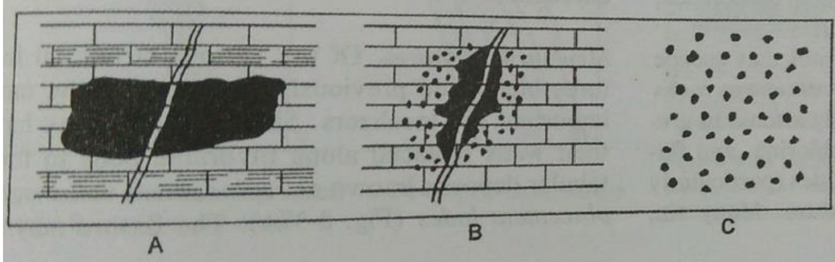


Figure 8-36 Replacement advance. A, Bold face advance; B, outer fringe of disseminated replacement (black is ore); C, multiple center.

TEMPERATURE AND PRESSURE OF FORMATION: Replacement may take place under almost any condition of temperature and pressure. It is dominant at high temperature and is most effective at elevated temperatures, since heat tends to accelerate the chemical activity. The nature of replacement varies according to the conditions of temperature, pressure and pH.

At atmospheric temperature the replacement is confined mostly to soluble rocks such as limestone. At elevated temperature the intensity of replacement also increases. The metallic minerals such as pyrite, arsenopyrite, galena, etc, are formed.

LOCALIZATION OF REPLACEMENT: Various physical, chemical and structural features serve to localize hydrothermal deposits. Of the various structural features, fissures are the most important ore localizers. Single fissure may have their wall replaced along favourable beds to form tabular deposits known as replacement veins or replacement lodes. Closely spaced fissures and shear zones give rise to larger replacement lodes. Intersection of fissure may give rise to ore bodies of limited horizontal extent, but their vertical extent may be great.

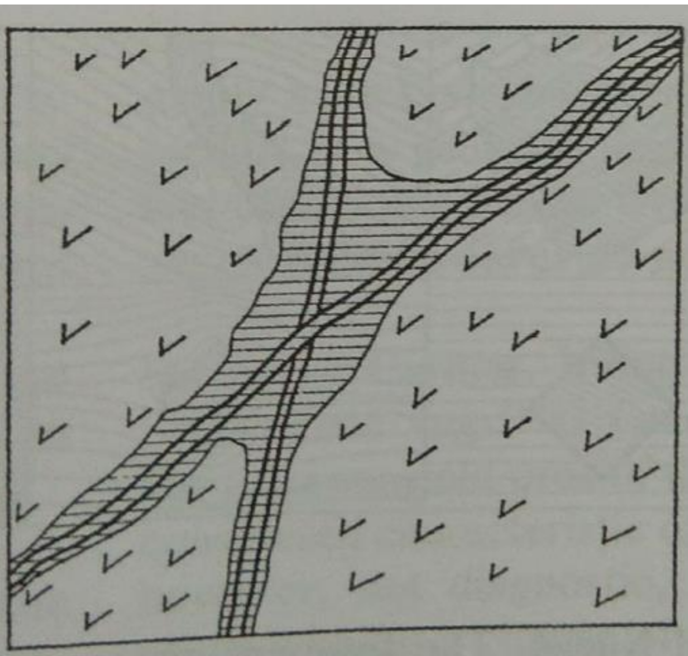


Figure 8-38 Replacement ore localized by fissure intersections.

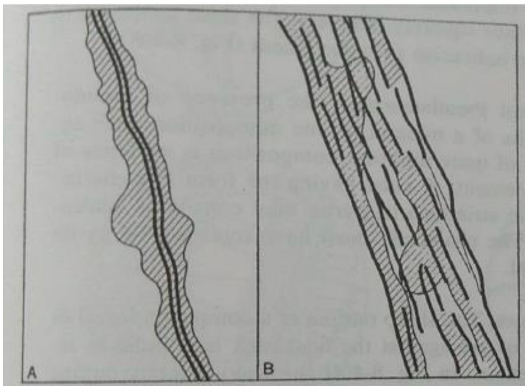


Figure 8-37 Replacement lodes. A, Developed along single fissure; B, along shear zone.

"Cavity Filling," which are lacking in replacement deposition. Therefore, their absence constitutes dependable negative criteria for replacement.

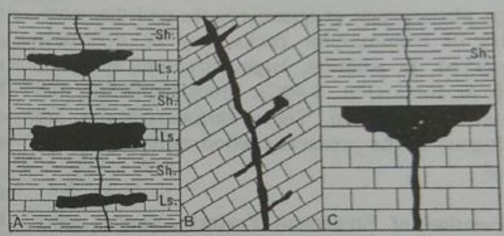


Figure 8-39 Relation of replacement to sedimentary features. Black, ore. A, relation to intercalated limestone beds; B, to bedding planes; C, to overlying impervious bed.

CHARACTERISTIC OF REPLACEMENT DEPOSITS : replacement deposits generally exhibit one or more characteristic features of replacement.

1) **UNSUPPORTED RESIDUAL NUCLEI:** The small islands of country rock entirely enclosed within mineral bodies. They are unsupported residuals of country rock that escaped replacement while the surrounding rock was converted to ore.
2) **PRESERVATION OF ROCK STRUCTURE:** When particle by particle of rock is replaced by ore, the original structure of the rock is commonly preserved in the ore. e.g. stratification, cross bedding, fossils and dolomitization rhombs. If these features are preserved in ore, they clearly indicate that the ore has replaced the rock.
3) **INTERSECTION OF STRUCTURAL FEATURES:** A massive sulphide body may abute the ends of thin limestone beds. This shows that the ore is later in age then the bedding of the rock.

4) **COMPLETE CRYSTALS:** Crystals that grow by replacement in homogenous rocks, commonly display developed faces, and grow outward from the walls of the open spaces.
5) **MINERAL PSEUDOMORPH:** The presence of pseudomorph of a mineral of composition after another of quite different composition is evidence of replacement. e.g. a cube of pyrite having striations must have been replaced by chalcocite.
6) **OUTLINES:** A sharp outline of a compact mineral or body of ore against the host rock may indicate replacement.

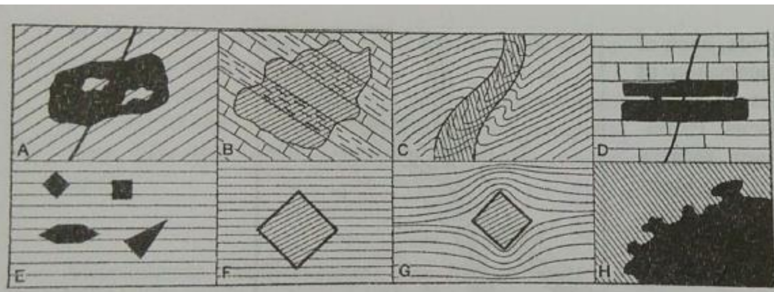


Figure 8-40 Features illustrating criteria of replacement. A, Unsupported residual nuclei; B, preserved rock strata; C, preserved folded structure; D, ore abutting bedding; E, doubly terminated crystals; F, pyrite cube truncating bedding, in contrast to G, which has grown in yield shale; H, irregular outlines of replacement contacts.