Exploration Geology

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Mining is practised in rocks varying in their composition, textural and structural features, degree of jointing and in the intensity of secondary alterations. Such a variety of mineralo-petrographic, lithological and tectonic characteristics of rocks preconditions a still greater difference in their physico-mechanical and technical properties, such as hardness, drillability, blastability, etc.

One and the same rock can be of different hardness, depending upon their bedding, foliation, porosity, crystallinity, etc.

The excavation of mine workings includes successive or parallel operations, such as: drilling off the heading face or making a cut, drilling shot holes, their charging and firing, aeration of the face, construction of temporary (initial support), loading the mineral and country rock, mine-car change or conveyor line extension, transportation of the mineral and waste, construction of permanent mine support, tracking and digging the drain depth.

Drilling and Blasting

At the root of drilling and blasting lies detachment and breaking up of rocks from the rock mass in situ and breaking up at the expense of energy produced by explosives. These are essential operations during the excavation of mine workings.

Blasting

The object of blasting is to fragment the rock and then displace it into a pile that will facilitate its loading and transport. This method of mining operations is used most widely in making mine openings in a strong ground. For this purpose, explosives are placed into shot holes drilled in the ground by means of hammers, electric rotary drills or by hand. Their efficiency is largely dependent upon the proper choice of explosive, the weight of the charge, the number, depth and location of shot holes, and on other parameters of drilling and blasting operations in conformity with the properties of the ground traversed and the cross-section of the opening.

Each explosion or blast is characterised by a practically instantaneous transformation of a solid explosive into a gas attended by evolution of a large amount of heat. A blast of 1 kg of explosives produces about 1 m^3 of gaseous products whose volume under the effect of heat increases roughly 16-fold, this raising the pressure in the surrounding atmosphere up to 16 thousand atmospheres. A blasthole 400 mm in diameter and 7.5 m deep can develop one billion horsepower.

A pressure or shock wave originates in the environment surrounding the charge and spreads spherically from the centre of explosion. The destruction of rocks occurs as a composite result of the action exerted by the shock wave and the pressure of gases. As concerns their effect, explosives are classed into low (propelling) and high (disruptive) ones. The performance of the former consists in separating rocks from the rock mass in situ and their displacement in space, and that of the latter, in breaking the detached rocks into individual pieces.

Explosives comprise solid chemical compounds and mechanical mixtures. Explosive chemicals, containing some nitrogen are highly sensitive when exposed to light shocks and slight heating. For this reason, they are used in their pure form only in small amounts as initiating or primary explosives for loading blasting caps, electric detonators and detonating fuses. There exist primary initiating explosives, which include fulminate of mercury - $HgC_2N_2O_2$; lead azide - PbN_6; teneres -

$C_6N(NO_2)_3PbH_2O$; and secondary initiating explosives such as tetryl - $C6H(NO_2)_3NCH_3NO_2$, hexogen - $C_3H_6N_3(NO_2)$, pentaerythritol tetranitrate - $C(CH_2ONO_2)_4$. Mechanical explosive mixtures consist of chemically uncombined constituents, both explosive and nonexplosive. Generally they are ammonium nitrate - NH_4NO_3, nitoglycerine - $C_3H_5(ONO_2)_3$, along with trotyl (trinitrotoluene) - $C_6H_2(NO_2)_3CH_3$ and hexogen $C_3H_6N_3(NO_2)$.

The rock demolition zone is subdivided into three sub-zones or spheres.

1. Breakage Sphere
2. Rupture Sphere
3. Rock Fracture Sphere

The breakage sphere is formed in the immediate vicinity of the explosive charge. The rocks here are greatly reduced to fragments and compacted. Rocks within the rupture sphere are crushed. Given favourable conditions, the broken rocks within the range of the first two spheres can be thrown away some distance with simultaneous formation of a blasting cone or crater. Within the outer sphere rocks undergo disintegration in place with or without their spatial displacement.

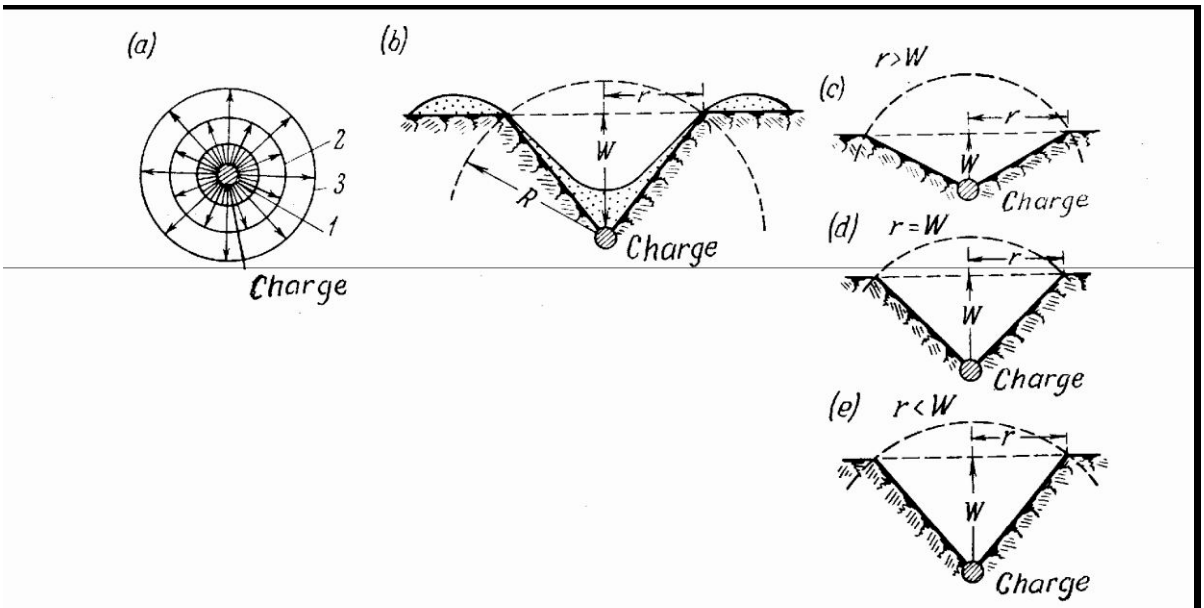

Fig. 1.1. Rock demolition zone in blasting

(*a*): *1*—breakage sphere; *2*—rupture sphere; *3*—rock-fracture sphere; blasting cone (*b*): *R*—radius of blasting (heaving) effect; *W*—line of least resistance (burden); *r*—radius of blasting cone; (*c*) increased blowout cone; (*d*) normal blowout cone; (*e*) reduced blowout cone

A condition favouring the formation of the blasting cone is created when the distance between the explosive charge and free face of the ground (line of least resistance or burden) is small than or equal to the radius of the cone. When the line of least resistance is greater than the radius of the cone. When the line of least resistance is greater than the radius, a reduced blow out cone is formed.

Drilling

Drilling (boring) is widely used in reconnaissance and prospecting work. It also finds application in hydrogeological and geophysical investigations and in engineering geological surveys.

The name of *bore hole* is given to an opening of a cylindrical shape, which has a small cross-section as compared to its depth.

Major Elements of Bore Hole

1. Collar (mouth)
2. Bottom
3. Shaft
4. Walls

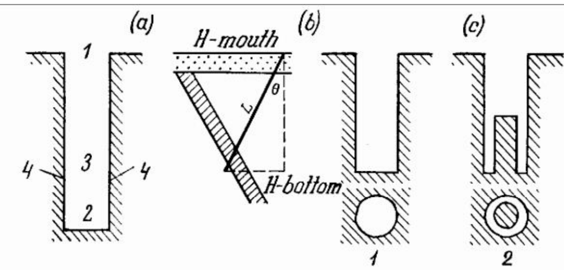

Fig. 4.1. Major elements of borehole

(a): 1—collar (mouth); 2—bottom; 3—shaft; 4—walls; (b) determination of inclined borehole depth; (c) full-hole and cored bottom: 1—full-hole bottom; 2—cored bottom

In a vertical bore hole depth L is equal to the differences of elevation marks between the mouth and the hole bottom, and when the bore hole is inclined with respect to the horizon its depth L is then greater than the difference of the elevation marks and is expressed as:

$$L = (Hm\text{-}Hb) \cos \theta \text{, where } \theta \text{ is the zenith angle.}$$

The diameter of the bore hole is taken to be equal to the outer diameter of the rock breaking tool, notwithstanding the fact that the true diameter of the bore hole is somewhat greater than that of the tool.

Bore holes can be drilled either throughout the whole of the bottom plane - ***full hole drilling*** or ***core drilling***. Core drilling is predominant in the practice of exploration works.

1. Full hole bottom
2. Cored bottom

Drilling methods are chosen according to physical and mechanical properties of rocks. Depending upon the forces developed and types of the rock-breaking tools used the drilling methods are classified as:

1. Rotary
2. Percussive and
3. Percussive-rotary.

The drill bit, made up of three cones containing either steel or tungsten-carbide cutting edges, is rotated against the hole bottom under a heavy load, breaking the rock by compression and shear. An air compressor on the drilling machine forces air down the centre of drill string so that the cuttings are removed. In smaller pits, holes are often drilled by pneumatic or hydraulic percussion machines.

Holes are drilled in special patterns so that blasting produces the types of fragmentation desired for the subsequent loading, hauling, and crushing operations.

Major operations in drilling include:

1. Boring proper (breaking of rock at the bottom),
2. Transportation of drilled rock to ground surface,
3. Erection of bore hole support and pulling out of drill and case pipes, and
4. Assembly and erection of drilling rigs.

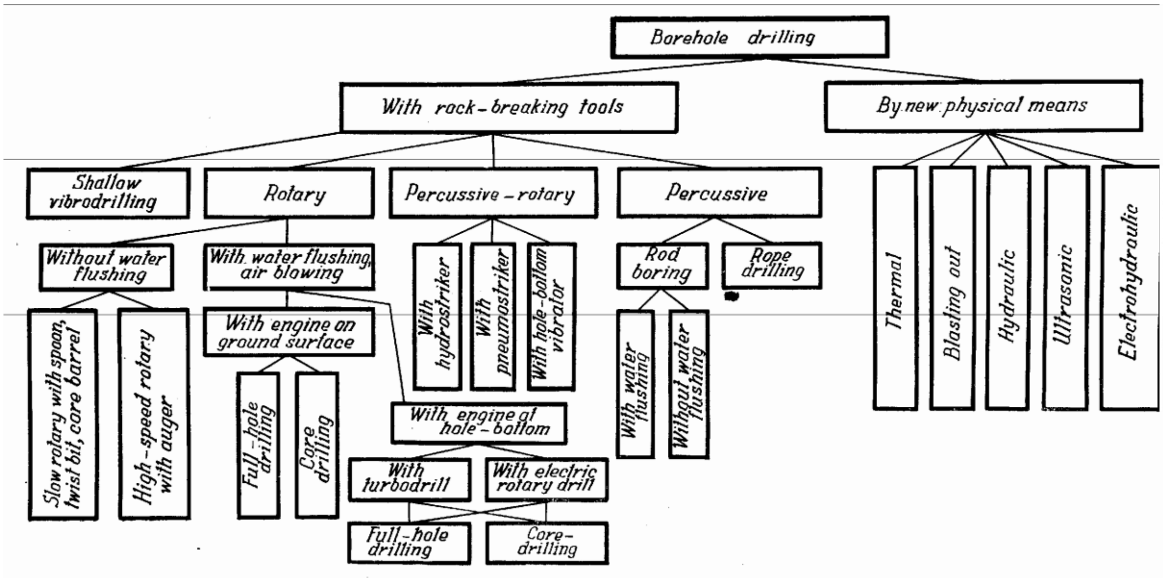

Fig. 4.2. Classification of drilling methods (according to S. Volkov)

Mining

Mining, in its broadest sense, the process of obtaining useful minerals from the earth's crust. The process includes underground mining and surface mining. In addition, recent technological developments may soon make economically feasible the mining of metallic ores from the seafloor. Mining normally means an operation that involves the physical removal of rock and earth. A number of substances, notably natural gas, petroleum, and some sulphur, are produced by methods (primarily drilling) that are not classified as mining.

Surface mining

It has been estimated that more than two-thirds of the world's yearly mineral production is extracted by surface mining. There are several types of surface miming, but three most common are open-pit mining, strip mining and quarrying. These differ from one another in the mine geometries created, the techniques used and the minerals produced.

Open pit mining often (but not always) results in large hole, or pit, being formed in the process of extracting a mineral. It can also result in a portion of a hilltop being removed. In strip mining, a long, narrow strip of mineral is uncovered by a dragline, large shovel, or similar type of excavator. After the mineral has been removed, an adjacent strip is uncovered and its overlying waste material deposited in the first excavation of the first strip.

There are two types of quarrying. There is the extraction of ornamental stone blocks of specific colour, size, shape, and quality – an operation requiring special and expensive production procedures. In addition, the term quarrying has been applied to the recovery of sand, gravel, and crushed stone for the production of road base, cement, concrete, and macadam.

Deposits mined by open-pit techniques are generally divided into horizontal layers called benches. The height of the benches depends on the type of deposit, the mineral being mined, and the equipment being used; for large mines, it is in on the order of 12 to 15 m. Mining is conducted on a number of benches at any one time. The top of each bench is equivalent to a working level, and access to different levels is gained through a system of ramps. The width of ramp depends on the equipment being used, but typical widths are from 20 to 40 m. Mining on a new level is begun by extending a ramp downward. This initial or drop cut is then progressively widened to form the new pit bottom. The largest open pit operations can move up to one-half million tons of material (both ore and waste) per day. In smaller operations, the rate may be only a couple of thousand tons per day.

The walls of a pit have certain slope determined by the strength of the rock mass and other factors. The stability of these walls, and even of individual benches and groups of benches, is very important – particularly as the pits get deeper. Increasing the pit slope angle by only a few degrees can decrease stripping cost tremendously or increase revenues through increased ore recovery, but it can also result in a number of slope failures on a small or large scale. Millions of tons of material may be involved in such slides. For this reason, mines have ongoing slope stability programs involving the collection and analysis of structural data, hydrogeologic information, and operational practices (blasting in particular), so that the best slope designs may be achieved. It is not inusual for five or more different slope angles to be involved in one large pit.

As a pit is deepened, more and more waste rock must be stripped away in order to uncover the ore. Eventually there comes a point where the revenue from the exposed ore is less than the costs involved in the recovery. Mining then ceases.

Underground mining

When any ore body lies a considerable distance below the surface, the amount of waste that has to be removed in order to uncover the ore through surface mining becomes prohibitive, underground techniques must be considered.

Underground, or deep, mining is done to extract minerals without removal of the overlying strata. Miners build a shaft mine that enters the earth through a vertical opening and descends from the surface to the ore body. In the mine, the minerals are extracted by various methods, including conventional mining, continuous mining, longwall mining, and room-and-pillar mining. The process includes a sequence of operations that proceed in the following order: (1) supporting the roof, (2) ventilation, (3) cutting, (4) drilling, (5) blasting, (6) extraction, and (7) loading.

Counting against underground mining are the costs, which, for each ton of material mined, are much higher underground than on the surface. There are a number of reasons for this, not the least of which is that the size of underground mining equipment, owing to ground conditions, ore body geometry, and other factors, is much smaller than in the surface mining. All of this means that productivity, as measured in tons produced per worker per shift, can be 5 to 50 times lower, depending on the mining technique, than on the surface. Balanced against this is the fact that, underground, only ore is mined, whereas in the surface mining there are often several tons of waste stripped for each ton of ore.

Methods of underground mining vary according to the size, shape, and orientation of the ore body, the grade of mineralization, the strength of rock materials, and the depths involved. For example, if the ore is very high grade or carries a high price, then a higher cost method can be used. The orientation, specifically the dip, of the ore body is particularly important in method selection. If the dip is greater than 50°, then systems using gravity to move the ore can be considered. If the dip is less than 25°, then systems using rubber-tired equipment for ore transport can be considered. For ore bodies having dips in between these, special designs are required.

Vertical and lateral pressures increase with depth, the amount of which depends on the rock type and geologic situation. In the world's deepest mines, which are more than 4 km below the surface, pressure becomes so intense that the rock literally explodes. These rock bursts are major limitations to mining at a depth.

Mining operations

Mining operations generally progress through four stages: (1) prospecting, or the search for mineral deposits; (2) exploration, or the work involved in assessing the size, shape, location, and economic value of the deposit; (3) development, or the work of preparing access to the deposit so that the minerals can be extracted from it; and (4) exploitation, the work of extracting the minerals.

Mine Workings

Mine workings or openings have a mouth (collar), face and walls. The *mouth* of a working is a site adjoining the day or ground surface or contiguous to another mine working. The *face* is the end of the working which is pushed forward during excavation. In level workings there are, apart from walls, also the roof (back) and floor (bottom). With respect to the day surface the workings are classified into open and underground. As regards their spatial position, the workings are classed into horizontal (level), vertical and inclined. With reference to objects under study, the workings may be transverse (cross-cutting), and longitudinal (running along the strike). And, finally as concerns the scope and complexity of excavation the workings are known to be easy- and difficult- to make. In the practice, the widest use has found shallow dug holes, ditches, test pits, shafts, adits, drifts, cross-cuts, cross-drifts and others.

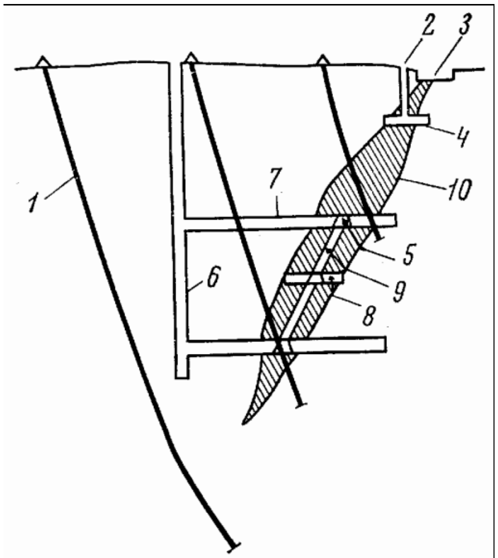

Fig. 3.1. Mine workings
1—borehole; 2—test pit; 3—ditch; 4—through-cut; 5—drift (entry); 6—shaft 7—cross-cut; 8—cross-drift; 9—raise 10—mineral body

Mine Transport

In large mines, the main implements for loading are electric, diesel-electric, or hydraulic shovels, while electric or mechanical-drive trucks are used for transport. The size of the shovels is generally specified by dipper or bucket size; those in common use have dipper capacities ranging from 15 to 25 cubic metres. This means that 30 to 50 tons can be dug in a single “bite” of the shovel. The size of the trucks is matched to that of the shovel, a common rule of thumb being that the truck should be filled in four to six swings of the shovel. Thus for a shovel of 15 cubic metres capacity, a truck having a capacities of more than 120 tons (four swigs) to 180 tons (six swigs) should be assigned. The largest trucks, used in open-pit mining, have capacities of more than 200 tons and equipped with 2000-horsepower engines; their tire diameters are often more than 3 m.

One of the alternative modes of transporting broken ore and waste rock is the belt conveyor, but in general this method requires crushing of the run-of mine material prior to transport.

After loading waste rock is transported to special dumps, while ore is generally hauled to a mineral-processing plant for further treatment. If ore is of sufficiently high quality, direct shipment is done without intermediate processing. In some operations, separate dumps are created for the various grades of sub-ore material, and these dumps may be remined later and processed in the mill. Certain dumps can be treated by various solutions to extract the contained metals (a process known as heap leaching or dump leaching).

Mine Lighting

Current is supplied through a mine power transformer, whose power rating (P_t) is calculated by

$$P_t = (\Sigma\ P_m F_l F_v)/\eta_m \eta_t \cos\phi_\omega$$

Where Σ P_m = total indicated power rating of motors fed from the transformer,

F_l = load factor, commonly put at 0.8 to 0.9,

F_v = varian factor for motors in the district, usually put at 0.7 to 0.8,

η_m = weighted mean efficiency of motors, set at 0.8 to 0.9,

η_t = power transmittance efficiency, put at 0.9 to 0.95, and

$\cos\phi_\omega$ = weighted mean power factor for the group of current consuming units, put at 0.7 to 0.9.

Transformer ⇒ Substation ⇒ Switching Station < Stationary / Mobile

For mobile switching station, spare 100-200 m low-voltage cables is used. Voltage losses should not be more than 5-7%.

Mine Ventilation

The mine air is polluted with active toxic and explosion gases, along with dead air, or a mixture of CO_2 and N_2. Dead air brings down the proportion of oxygen in the mine air and thus hampers the breathing of men and burning lamps. After blasting, the air in development workings becomes contaminated with nitrogen oxides and carbon monoxide. To safeguard normal working conditions there should be 20% oxygen. For this and to remove the explosion products, ventilation is must. Aeration time should not exceed 30 min.

Two methods of supplying fresh air are distinguished:

(a) ventilation with the main air current directed along parallel workings, with the aid of longitudinal air-partitions, special pipe lines, or combined ventilation, and

(b) setting up special fans for local ventilation with the use of forced, exhaust or combined ventilation schemes.

Among them (b) is most used.

The amount of air required for forced ventilation of blind development openings after blasting (Q_f) is estimated by the formula:

$$Q_f = 7.8\ S_{fin}/t_v\ \sqrt{q'_{ex}\ l^2_{v.o}}\quad m^3/min$$

Where S_{fin} = finished section of the ventilated mine opening, m^2

t_v = time of ventilating a development opening after which the concentration of conventional carbon monoxide falls to 0.008% along the entire length of the opening and the men are allowed to enter it, m

q'_{ex} = explosive consumption per 1 m^2 of the cross-sectional area of the opening, kg/m^2, and

$l_{v.o}$ = length of the ventilated opening, m.

To ensure effective ventilation, the distance from the heading face to the end of the ventilation pipe must be equal to $4\sqrt{s}$ and at any rate should not exceed $6\sqrt{s}$.

In aerating development workings with the aid of booster fans after blasting the needed volume of exhaust air (Q_{exh}) is determined by the formula

$$Q_{exh} = 18\ S_{fin}/t_v\ \sqrt{q'_{ex}\ l_{g.th}}\quad m^3/min$$

Where $l_{g.th}$ = length of the gas thrown zone, m.

$$l_{g.th} = 2.4\ Q_{ex} + 10,\ m$$

Where Q_{ex} = quantity of simultaneously fired explosives, kg.

So, the amount of air needed (Q_c) can be calculated as

$$Q_c = 7.8\ S_{fin}/t_v\ \sqrt{q'_{ex}\ l^2_{s.e}}\quad m^3/min$$

Where $l_{s.e}$ = maximal distance from the heading face to the air stopping or to the suction end of the second fan pipe-line, m.

Note:
1 kg of explosive produces 40 l of CO.
Velocity of airflow should not be less than 0.15 m/sec.
The quantity of air delivered should be at least 9 m^3/m^2 of the opening.

Mine Drainage

During excavation of horizontal mine workings abundant inflow of water necessitates measures for its timely removal. The diversion of mine water from the heading is complicated if the opening slopes towards the face. For that purpose, ditches are made, cross-sectional area of which depends upon the amount of water.

Type of Ditch	Water Inflow, m^3/hr		Dimensions, mm			Cross-sectional area of ditch
	From	To	Top Width	Bottom Width	Height	
Unlined	-	50	360	200	220	0.062
	50	100	450	250	280	0.098
Lined	-	100	230	180	260	0.055
	100	150	250	220	300	0.070
	150	200	280	250	320	0.085
	200	300	350	300	350	0.114
	300	400	420	370	350	0.138

The first intermediate pumping station is set up at a distance from the face not greater than

$$L = C_{r.p}\ H_p/\sin\alpha$$

Where $C_{r.p}$ = coefficient accounting for resistance in the pip-line, put at 0.9
H_p = vertical head of the face pump, m and
α = slope angle of the opening bed.

The number of intermediate pumping stations, which ensure discharge of water directly onto the level, is found by the formula

$$P_s = \frac{(L_i - L)\sin\alpha}{C_{r.p}\, H_p}$$

Where L_i = full length of the incline being driven, m
L = distance from the face of incline to the first intermediate pumping station, m
α = gradient of the incline, degree.

In vertical workings, water is removed by three methods: in kibbles by light pumps, by suspended heavy pumps, or by horizontal screw pumps (it accommodates a receiving reservoir and another pump).

Mine Support

Mine supports depend upon the geological and hydrogeological conditions in which the work is carried out. Type of supports in mine workings may be temporary or permanent. The support should meet the technical, operational and economic requirements.

The technical requirements include the strength of the support which must withstand the forces acting upon it, retaining its integrity without changing the dimensions of the opening in the clear. The operational demands amount to ensuring uninterupted mining operations. The economic requirements consist in securing minimal dimensions of the opening in the rough and low cost of erecting the support, and also minimal outlays for resupporting through out the entire period of the service of the working.

Timbering

Wooden timbering is employed in workings with a section not exceeding 9 m^2 intended for a limited period of service and at insignificant rock pressure. The principal type of wooden timbering is an ordinary frame set of trapezoidal shape.

Frame sets with a headpiece or cap made of old mine rail lengths are often used. In the case of composite timbering consisting of timber and steel use is made of special joints that prevent the cap from sliding off the timber props and protect the prop ends from damage. In the event of high top pressure and a considerable width of the working reinforced paired frame sets may be used. Frame sets are commonly made of round timber 150-230 mm and more in diameter. Sets are spaced at an average distance of 0.6 to 0.8 m. In weak ground, frames are set closely.

The service life of wooden timbering is contingent upon the rock pressure and the ventilation conditions in the opening and ranges between a few months and 3 to 4 years.

Protective impregnation of mine timber members is recommended where they support workings subjected to balanced rock pressure sites of intensive rotting of the timber. This treatment enables the service life of wooden timbering to be increased 3- to 4-folds.

When the wall rock is strong, timbering may consist of a single cap with the ends inserted into hitches made in the wall of rock; in this case there is no need for frame posts. The use of propless support saves mine timber. With this type of support, wood, metal or reinforced concrete caps may be used and also re-used many times.

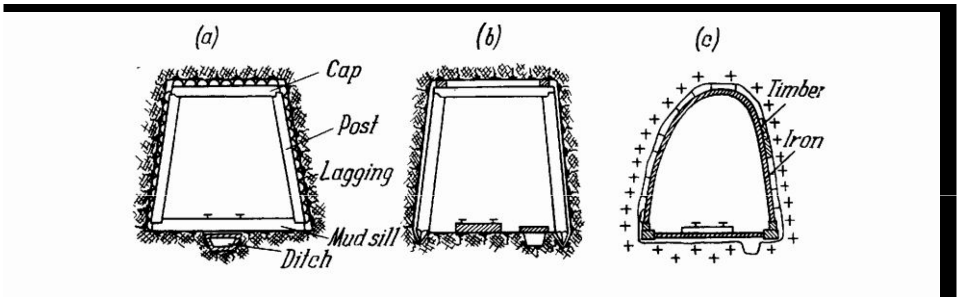

Fig. 3.7. Timbering of adits
(a) with four-piece sets and timber slab lagging; (b) with three-piece sets; (c) metal frame support

Metal support

Metal support of two basic shapes – double T and arched – is made up of mild steel.
Trapezoidal metal support is employed when a mine working is subjected to a balanced (virtual) rock pressure and its cross-section does not exceed 6 or 7 m^2, or when it is inexpedient to adopt a domed shape for the working in order to maintain it by using arched support (for example in the presence of loose rocks and running ground or very strong rocks in the back, whose ripping is labour-consuming). This kind of support usually consists of three-piece frame sets. The posts and caps are joined by means of detachable cast shoes, cover plates made of angle iron, and bolts.

The posts are either inserted directly into hitches or set up on wooden sills or sleepers, depending upon the properties of floor rocks in the opening. In the former case, steel bearing slabs in the form of square plates are welded to bottom ends of the posts, and in latter case, cast steel shoes are used.

Arched metal support may have a variety of shapes, which largely depend upon the magnitude and direction of rock pressure. In practice, arched support made of special yielding members, arched joint-shaped yielding and arched rigid support are used. Metal consumption and basic data on widely employed types of arched mine support made of beams of special grooved shape are listed in the following table.

Wt of beam	Type	H, mm	Width, mm		Cross-section, cm^2	Moment of inertia		Moment of resistance	
			top	bottom		J_x	J_y	w_x	w_y
18		77	128	85.0	22.71	168.1	399.0	42.9	62.3
		86	128	71.0	22.75	216.6	335.3	50.6	52.4
24	Single	109	131	57.0	30.68	422.8	475.1	75.8	72.5
28	A	116	155	82.0	35.82	533.3	788.8	94.8	104.5
	B	115	155	69.7	35.89	534.8	675.6	102.2	89.5

Reinforced-Concrete Support

This can be monolithic (cast in situ) or prefabricated.

Monolithioc reinforced-concrete support is mainly intended for workings, which are subjected to non-uniform and high rock pressure, and also for sustaining shaft stations and service rooms, etc. The use of monolithic reinforced concrete is limited owing to the difficulty of its erection, which involves setting up sheathing and iron reinforcement, and placing of concrete.

Concrete reinforcement is commonly made of round steel, 8 to 25 mm in diameter, and placed in vaults, where tensile forces may act along with compressive ones. Single and double reinforcement is used to absorb tensile forces. Reinforcement rods located in the plane of the cross-sectional area of a working are called main, or active. To fix the main rods in the installation of concrete reinforcement, distributive rods are used which are laid along the vault axis and connected with main rods at points of their crossing. Distributive rods are 5 to 12 mm thick.

Approximate data on the consumption of ingredients for the preparation of a concrete mix are given in the following table.

Mix ingredients	For concrete	
	Grade B	Grade B
Cement, kg	268	410
Sand, m^3	400	425
Rubble, m^3	972	953
Water, l	140	210
Calcium chloride (4% of cement weight)	10.7	16.4
Sulphite-alcohol grains (0.3% of cement weight)	0.8	1.23

Prefabricated reinforced-concrete mine support enjoys ever-increasing popularity. The possibility of utilisation of local building materials for batch manufacture of support members and their mechanised installation, the high strength of the bearing members with a substantial reduction of support weight per unit of mine opening of a length by comparison with other types of support open up bright prospects for the application of this type of support. The existing designs of prefabricated reinforced-concrete mine support provide for the following types of member joints:

Rigid member joints – for workings fenced off with protective pillars and driven outside the zone of influence of stoping operations (shaft station openings, stone drifts, cross-cuts);
Articulated member joints – for openings not affected by stoping operations, but exposed to non-uniform ground pressure which brings about critical stresses in rigid mine support and is readily withstood by a support possessing some traverse mobility;
Flexible member joints – for openings within the zone influence of stoping operations.

Rock Bolting

Rock bolting (anchoring) of mine workings consists essentially in that the rocks layers of the immediate roof of medium stability are fastened with each other and with the stronger regular roof of medium by means of anchor (or rock) bolts. This type of support has the advantage of retaining part of the initial stress in the mass of rock, which is always greater originally than after the mine openings.
The distance (l_b) between rock bolts (when arranged on a square spacing pattern) is calculated by

$$\boldsymbol{l_b = (P_k/F_s h_n \gamma\ )^{1/2}}$$

where P_k = minimal keying strength in a hole, in tons,

F_s = safety factor, put at 2 to 3,

h_n = height of dome of caving, in m,

γ = unit weight of rocks, t/m^3.

Prospecting/Exploration

The prime objectives of prospecting and exploration work are the outlining or delineation of a deposit, determination of the quality or grade of economic minerals through sampling and geological conditions of its occurrence and estimation of reserves. Prospecting comprises several stages: (a) search, (b) preliminary, (c) detailed, and (d) mine exploration.

The object of search is to establish the presence of a deposit and evaluate its promise from the geological point of view. This includes study of the local geological and economic conditions to the extent necessary to answer the main questions concerning further exploration. At this stage, answers are sought to such questions such as the characteristics of the rocks that compose the deposit; the possible depth of occurrence of the mineral; the kinds of openings and equipment needed for subsequent prospecting; and the required transport facilities, power, materials and labour and the local sources thereof.

During the preliminary stage, the deposit is studied by sparsely located openings and bore holes allowing a general idea of the deposit – general geologic conditions of occurrence, size and commercial value of the deposit. It is designed to settle the question whether or not the deposit can be profitably worked to establish the main guidelines for future mining operations.

Detailed exploration helps clear up with a high degree of accuracy the geological structure of the deposit, the shape of ore bodies, the grade and distribution of the ore, along with the prevailing hydrogeological and mining conditions. The reserves are estimated. The data derived from the detailed exploration serve as a background for the preparation of technical project of the mining enterprise.

The mine exploration is conducted in order to ascertain more precisely the shape and position of the mineral bodies, the distribution of the ore grades and the mode of occurrence of the mineral during actual exploitation of the mine. It is conducted in permanent, development and productive mine workings. Its findings help to enlarge the raw material resources of the running enterprise.

Principles of Prospecting

Since mineral deposits are characterised by their variability, governed by different regularities, the following points must be laid at the basis of prospecting.

1. **The principle of comprehensive and full exploration**: the whole area occupied by a deposit should be investigated in detail. Therefore, (a) all bodies in the deposit and the deposit as a whole must be delineated during detailed geological survey on scales of 1:1000 and 1:2000 (for small deposits) and on scales of 1:10,000 and 1:50,000 (for big ones). Covering the entire deposit, (b) the mineral bodies should be completely traversed by mine opening and bore holes, (c) the quality of the mineral and that of associated constituents in complex ores are to be fully and

thoroughly studied, (d) the hydrogeological conditions and physical properties of rocks in the deposit should be subjected to a sufficiently detailed investigation.

2. **The principle of successive approximations**. It leans upon the conduct of exploration work according to stages. Such a principle of studying deposits helps any possible need for re-exploration and extra outlays.
3. **The principle of uniformity** which provides for (a) an equally full coverage by mine openings of the entire deposit or of its individual sections at the same stage of exploration; (b) uniformly distributed sampling points within the bounds of an exploratory opening and those of the deposit, with due regard for its geological features.
4. **The principle of minimum outlays.** The number of openings, samplings and other types of investigations, as well as the time schedule should be minimal, but sufficient to solve the problems facing the prospecting.

Prospecting Criteria

Geological prospecting criteria mean such geological settings, which point to the possibility of discovering various mineral deposits.

1. Structural-tectonic Criteria

Endogenous deposits are associated chiefly with folded regions. These often contain so-called ore belts (metallogenic provinces). Folded structures in the shape of domes, anticlines and flexures favour the formation of oil, gases, rock salt, sulphur and also of some deposits of non-ferrous metals and fluorite. Zones of complex fracturing and dislocations are very important for the formation of many endogenous deposits. Minor faults can serve as passage for hydrothermal solutions, or become the site for the localisation of mineral bodies. Fractures often play an important role in the formation of mineral bodies. Many deposits appear as series of veins or lodes formed in and along fractures of a definite system. Oil and gas are examples of economic deposits associated mostly with foredeeps, marginal parts of intermontane troughs and the slopes of arched uplifts of platforms. Bituminous coals are generally confined to folded regions whereas brown coals occur on platforms.

2. Stratigraphic Criteria

A number of sedimentary deposits is associated with specific paleogeographic conditions that had existed only during certain stages of the geologic history of a particular segment of the earth’s crust. Ninety-five percent of all deposits of the sedimentary sulphur occur in the Permian, late Jurassic and Neogenic rocks. The biggest in the world occurrences of rock salt originated in the Permian and Neogenic periods. A similar stratigraphic association is noted for deposits of Mn, Fe, coal, crude oil and others.

3. Lithological Criteria

Lithiological composition of rocks quite often features with a fair degree of accuracy the facies conditions attending their formation and consequently, possible generation of certain types of deposits. Oil deposits accumulate in porous sands, sandstones and cavernous limestones. Coals are associated with sandy-clay sequences, often irregularly banded (alluvial sandy sediments), sometimes with the presence of abundant vegetable remains. Coal is not likely to be found in a rock series when limestones or conglomerates are predominant in it.

The chemical composition and texture of rocks are also of great importance in the search for endogenous deposits. Fissured and porous rocks easily invaded by gaseous and aqueous ore bearing solutions favour the formation of hydrothermal and skarn deposits. Chemically active carbonate rocks interact with ore bearing solutions and facilitate deposits of ore elements therefrom.

4. Magmatogenic Criteria

It is based on the paragenetic association of economic minerals with definite rocks. Investigation of it is of paramount significance in the search for igneous deposits. For instance, chromite, platinum, diamond, and corundum deposits are confined to the solid masses of ultrabasic rocks; deposits of titano-magnetite, copper-nickel, cobalt, silver and apatites are associated with intrusions of basic composition; miocaceous pegmatites are related to large-sized granite intrusions, while pyrite deposits are localized amidst metamorphosed effusive rocks. Deposits of talc, asbestos and magnesite are associated with ultrabasic rocks metamorphosed by the action of hydrothermal solutions (serpentinites). Acid magmas are associated with deposits of Sn, muscovite, Li, W, Mo, Au, Ag, Cu, Pb, Zn, Sb, Hg, fluorite, beryl, gem stones, etc.

5. Geomorphological Criteria

Surface relief forms are primarily controlled by the geological factors – the composition and mechanical properties of the rocks that compose the given area of the earth's crust, dislocations, etc. Placer deposits are frequently associated with river valleys and terraces. Outcrops of hard rocks occurring on large peneplained areas, as elevations and hills, often contain deposits of valuable minerals. Small depressions and sink holes bear evidence to the presence of gypsum or limestone series. With glacial landscape features are associated deposits of sand, gravel, brick-clays and other building materials.

6. Geophysical Criteria

Prospecting Guide

Prospecting guides point to the unquestionable presence of mineralisation in an area.

1. Outcrops of valuable minerals or productive rocks

It is direct indication of the presence of mineral bodies. In many cases, the outcrops are altered either chemically or mechanically. A considerable influence on such changes exerts the circulating groundwater, with sulphide deposits being particularly liable to them. A humid warm climate is propitious for the development of an oxidation zone, the presence of permeable ore bodies and host rocks also being a contributing factor. At the same time, veins and rock layers at the outcrop bend downward along the slope and changes in the attitudes are observed. Thickness of ore bodies is increased due to "spreading out' of the oxidation products, while it is decreased if ores constitute of readily soluble minerals.

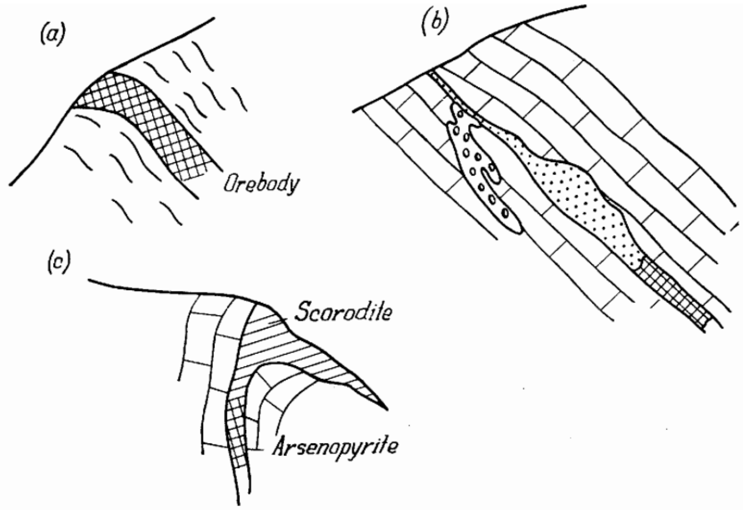

Fig. 20.4. Mechanical alterations of orebodies at outcrops
(a) changes in the mode of occurrence; (b) decreased thickness; (c) increased thickne

2. Rock Zone Alteration

Alteration of host rocks taking place during the formation of mineral bodies is a good prospecting guide. These changes become particularly clear in skarns, greisens and chloritised, sericitised, kaolinised, silicified and dolomitised rocks. Talcose transformation, tourmalisation, fluoritisation, and serpentinisation are other types of alterations occurring in the ore-bearing rocks.

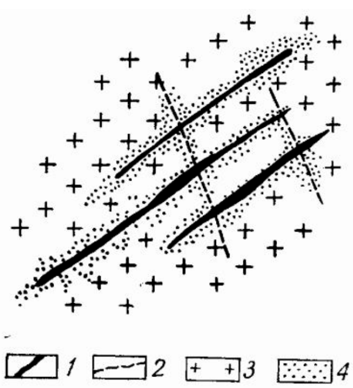

Fig. 20.1. Zone of altered rocks in a wolframite deposit
1—wolframite-containing quartz reefs; 2—barren quartz reefs; 3—unaltered granites; 4—greisenized granites

3. Dispersion haloes (aureols)

Rocks surrounding ore bodies commonly contain the ore forming components in microscopic fractions, which, however, exceed the Clark concentration. Areas presenting such an elevated metal content bear the name of dispersion haloes.

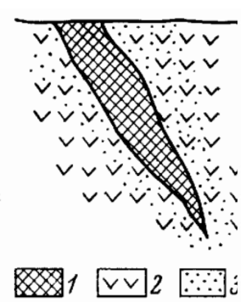

Fig. 20.2. Primary dispersion halo at a pyrite deposit
1—pyrites; 2—host rocks; 3—poor impregnations

a) **Primary dispersion haloes** – appear as a result of the some processes, which attended the formation of ore body. These haloes are usually distinguished by the presence of micro-insets or veinlets surrounding the ore body or deposits of impregnated (disseminated) ores.
b) **Secondary dispersion haloes** – arise as a result of chemical and mechanical destruction and oxidation of ore bodies and of primary dispersion haloes, especially in the near surface zones.

  i) ***Salt dispersion haloes*** owe their origin to dissolution and redeposition of soluble constituents in the host rocks. Most likely they develop in deposits, where the primary and secondary minerals are unstable in the oxidation zone and form soluble compounds.

  ii) ***Mechanical dispersion haloes*** are formed as a result of the mechanical destruction of the superficial portion of an ore body and displacement of the clastic product over and along the surface.

  iii) ***Gas dispersion haloes*** are associated with oil fields and deposits of bituminous combustible shales. Uranium and thorium deposits have often accumulation of radon and actinon gases superposed upon them.

  iv) ***Mixed dispersion haloes*** – Salt haloes in association with mechanical aureols form mixed dispersion haloes.

Mineralised water is also a carrier of dispersion haloes and is a good prospecting indication.

Metals	Surface and groundwater of non-deposit region, gm/l	Water percolated through a mineral deposit, gm/l
Ni	$n.10^{-6}$ - $n.10^{-5}$	$n.10^{-5}$ - $n.10^{-3}$
Co	$n.10^{-7}$ - $n.10^{-5}$	$n.10^{-5}$ - $n.10^{-3}$
Pb	$n.10^{-7}$ - $n.10^{-5}$	$n.10^{-5}$
Cu	$n.10^{-6}$ - $n.10^{-5}$	$n.10^{-5}$
U	$n.10^{-8}$ - $n.10^{-5}$	$n.10^{-5}$ - $n.10^{-3}$
Mo	$n.10^{-7}$ - $n.10^{-6}$	$n.10^{-3}$

4. Ore boulders or float

Ore boulders or fragmented ore bearing products found are a good prospecting guide. By their make-up, the degree of roundness and location, one may judge as to the composition of the primary deposit and distance separating it from the revealed float.

5. Heavy Concentrations

Following the disintegration of rocks on the ground surface, heavy and chemically stable minerals are carried by streams downwards. Seggregations of valuable and accessory minerals are found in the areas of heavy concentrations. Quite often a good prospecting is an association of minerals in a heavy concentrate, it being informative of which rocks participated in the formation of such a concentrate.

6. Geophysical anomalies

Due to different physical properties of rocks and ore minerals, different geophysical anomalies are observed. Presence of these anomalies indicates the heterogeneous physical fields, and consequently, it leads to the possibility of finding deposits. Magnetic and radioactive anomalies directly indicate the presence of deposits, but electrical, gravity and seismic anomalies have only indicative significance.

7. Botanical

Since certain conditions arise over and above mineral deposits, this brings about changes in the vegetable kingdom in the area occupied by the deposit: either there appears a definite species of plants, this or that type of them vanishes, or else certain plant themselves assimilate and amass metals. For example: *Viola calaminaria* and *Thlaspri calamenarium* – zinc, *Trientalis europeal* – tin, *Gypsophila patrinii* – copper, *Alyssum biovulatum* – copper and nickel.

8. Paragenetic

A good prospecting guide is the paragenetic relationship among individual valuable minerals. For instance, asbestos occurrences often come in association with deposits of talc and magnesite, those of bauxites come together with refractory coal, etc.

9. Popular

These include: (1) ancient mine workings and dumps; (2) remnants of old concentration plants; (3) archaeological and historic information; and (4) localities which frequently carry the names corresponding to the type of certain deposits.

Prospecting Methods

The prospecting methods are divided into:

1. Geological,
2. Geophysical, and
3. Geochemical.

Geological Method

The geological observations and analysis recorded on geological, tectonic and geomorphological maps are very important for prospecting. However, geological maps give too general idea of a district and outline too vast area where deposits of one mineral or another may possibly be discovered. Besides the various geological maps, different satellite imageries and aerial photos are widely used in geological exploration. At present, use of computers and digitised data is also gaining an impact in developed countries.

Though interdependent, geological mapping and prospecting are not the same operation, and therefore should be considered and planned separately. In view of this it is necessary to develop and apply various prospecting methods based on the geological map. Depending upon the complexity of the prospecting objects, the following working scales are generally taken for geological prospecting.

Prospecting Object	Scale
Sedimentary deposits of coal, phosphorites, iron, manganese and other	1:50,000-1:10,000
Endogenous deposits and exogenous deposits of complex structures:	
Ore field	1:25,000-1:10,000
Deposit	1:5000-1:2000
Ore body	1:2000-1:500

The geological prospecting method (apart from the geological mapping) considers the river and glacial float tracing and panning.

River Float Tracing: It is one of the oldest prospecting methods. This method consists in finding and tracing ore-bearing fragments and fragments of the country rocks. A rough idea of distance the float has travelled is given by the degree of wear. If float is found in the channel, or on the banks of a stream, it is followed along a certain line known as a traverse. Fragments usually become more and more numerous and less water-worn. When float is no longer found in the alluvium, this is taken as an indication that this is the spot where it begins to come from hillside waste. The search is then continued up-slope, and trenches and shallow test pits are dug near the spot where the last pieces of float were found. Traverses are sometimes planned across the strike of the rocks rather than parallel to a river or approximately along a single contour line around a hill if the object is to find ore-bearing debris at its foot.

Glacial Float Tracing: The prospector is guided by the material brought down by glaciers. The movement direction of glaciers (especially the last movement) is important. It is determined by striations on the rocks, whose orientations coincide with the direction in which boulders were transported, and this in turn, depends on the direction of depressions in the relief. Some indication of the movement direction is given by the orientation of terminal moraines, eskers and drumlins.

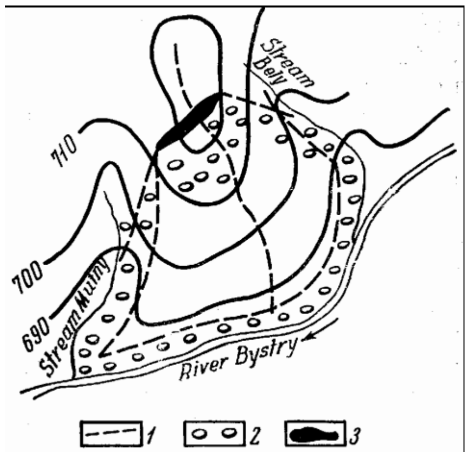

Fig. 21.1. Float tracing
1—direction of prospecting routes (reconnaissance traverses); *2*—ore boulders; *3*—outcrop of deposit

In practice, glacial float tracing begins as soon as the first indicating boulders are found. This may happen as a result of a systematic search, but they are often found by local residents, or in excavation made for canals and roads. The prospector's task is to look for the source of such float and associated rocks. Glacial float often fans out in the movement. The fan should be sketched; its apex will point to the area most favourable for finding the primary deposit buried beneath glacial drift. This, in essence, completes the float tracing, which should be followed up by geophysical prospecting and, if indications are favourable, by exploratory drilling or mining.

Panning: Like float tracing, this is based on the recognition and tracing of small pieces of metal and ore minerals which have migrated from outcrops and appear in concentrates obtained by panning alluvial and colluvial material taken at regular intervals along the sides of valleys and rivers and streams, and on tracing them to their source.

Three main tasks are accomplished by panning: (1) the location of primary deposits of various minerals; (2) the location of areas of alluvium, colluvium and eluvium carrying increased concentrations of economic minerals, i.e. placer deposits; (3) ascertaining the general geological and mineralogical characteristics of the area (usually by panning crushed material and further study of concentrates).

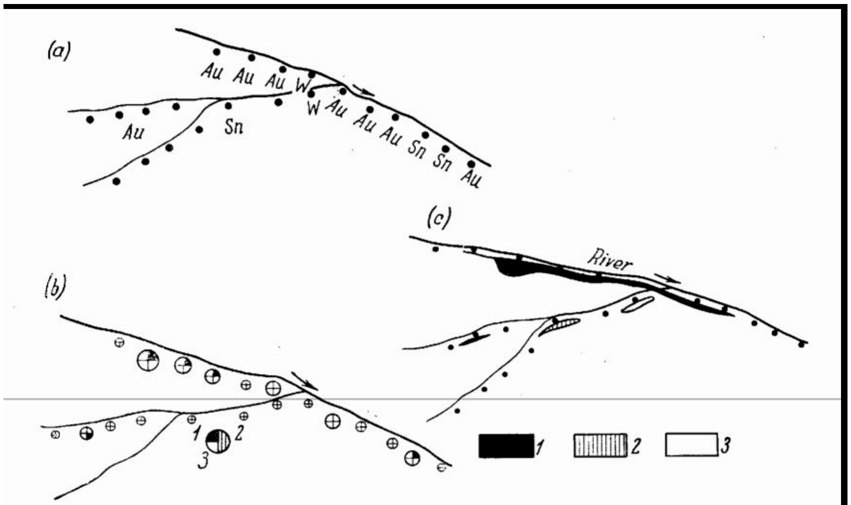

Fig. 21.2. Heavy concentration or panning maps
(a) spot; (b) circle; (c) strip: 1—gold; 2—cassiterite; 3—scheelite

Geophysical Method

The five important geophysical methods relate to five most common characteristics of the earth, which can be determined from the surface, viz. (1) electrical conductivity, (2) density, (3) magnetism, (4) elasticity and (5) radio activity. These are investigated respectively by: (1) electrical (a) self potential, (b) equipotential line, (c) resistivity, (d) potential drop ratio method, (e) electromagnetic, and (f) induced polarisation, (2) gravity, (3) magnetic, (4) seismic and (5) radioactive methods. In addition, geophysical methods are also used in the logging of bore holes and these are classified as (1) electro-logging, and (2) radioactive logging.

Electrical Method

Al the electrical methods are widely used in the exploration work connected with metalliferous deposits, in groundwater exploration and engineering geological investigations.

Self Potential or S.P. Method: This method utilises the natural flow of current and oerates on fundamental principle that an ore body, undergoing oxidation, is a source of electric current. If a tabular sulphide ore body is present in the ground, oxidation at the upper levels near P induces greater chemical activity than at Q. Hence a potential difference is induced; and a current flows from P towards Q. Two types of circuits are employed to measure the weak earth currents: (1) potentiometer and (2) micro-ammeter.

Equipotential Line Method: In this method, artificially created potentially fields are utilised. In principle, when an electric current is applied, between two points or between two parallel line conductors on the surface of the ground, an electric current will flow across from one conductor to other. The potential distribution produced by the flow of current in homogenous medium can be calculated. Where the ground is not homogenous medium, can be calculated. Where the ground is not homogenous, the potential distribution will not follow the pattern obtained by calculation. Hence, it is possible to detect any variation in homogeneity in the ground by comparing the measured potential distribution with the calculated theoretical distribution. Either direct or alternating current may be used.

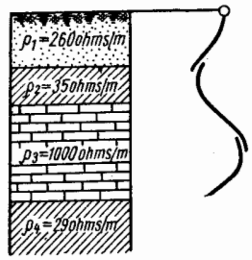

Fig. 120 VES curve identifying a high-resisting limestone horizon

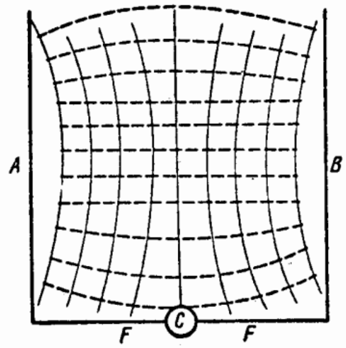

Fig. 121 Normal field of linear electrodes

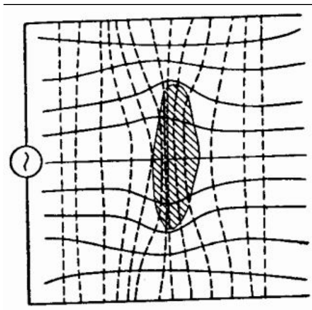

Fig 122 Anomalous field over a conducting body

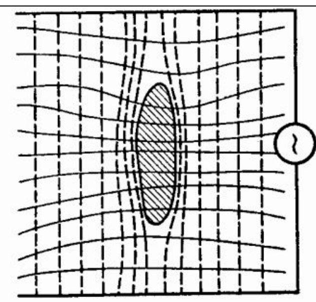

Fig. 123 Anomalous field over a poor conductor

Resistivity Method: In this method, current is passed into the ground by metallic (copper) electrodes and potential difference is measured.

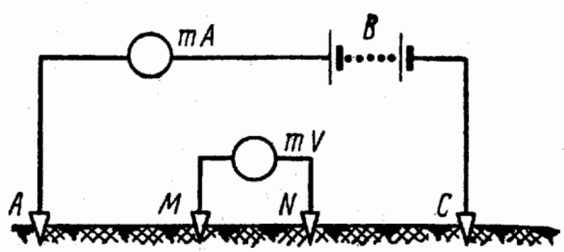

Fig. 119 Diagram of a four-electrode installation

Two types of resistivity surveys are carried out: (a) resistivity traversing and (b) resistivity sounding.

Potential Drop Ratio Method (P.D.R.): This method involves comparison of voltage differences with respect to magnitude and phase, on successive ground intervals represented between three stakes arranged in a straight line, radiating from one of the power electrodes (using alternating current). This method is used to detect horizontal discontinuities in subsurface and is comparable with seismic refraction method.

Electromagnetic Method: It measures directly the magnetic field associated with the flow of current in the subsurface. The subsurface current may be generated by creating an alternating field at the surface of the ground. If alternating current is made to flow in a loop or coil of wire suspended either on or above the earth, the current flowing in a coil or loop creates an alternating magnetic field (primary field), spreading out from the coil. The primary magnetic field spreads into the earth, induces varying voltages and also an alternating magnetic field (secondary field), at the surface, which distorts the primary magnetic field. The detection of distorted field is done in different ways in different instruments. Different instruments measure the following different parameters:

1. Amplitude of the resultant field,
2. Direction of the resultant field (dip angles),
3. Horizontal intensity of resultant field,
4. The in-phase component (or real component),
5. The out-phase component (or imaginary component), and
6. The in-phase and out-of-phase components.

The instruments measuring the direction of the resultant field (dip angles) are most commonly used for reconnaissance survey. The detailed investigations are carried out with in-phase and out-of-phase measuring equipment. The modern equipment available today can be used for both the purposes.

Induced Polarisation (I.P.) Method: It has been observed, in resistivity surveys, that on disconnecting the battery from current electrodes, the voltage in potential electrodes does not drop to zero immediately, but persists for some time with a continuously decreasing magnitude. This phenomenon is termed as induced polarisation or IP. IP measurements can be made by (a) Time domain method, and (b) Frequency domain method.

Gravity Method

This method implies the technique of measuring of the gravitational field at the earth's surface and the data thus obtained is utilised to predict the subsurface and structure. In this method, the natural field of earth's gravitation is used. In geophysical work, it is the acceleration due to gravity, which is made use of for the identification of gravity anomalies, and not the absolute value of force of gravity. The gravity anomalies are expressed in milligals.

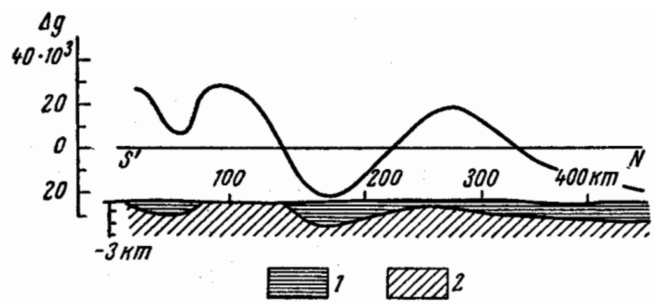

Fig. 115 Gravity profile and geological section of the Donets basin:
1—Cenozoic and Mesozoic strata; 2—Carboniferous (coal-bearing)

Magnetic Method

This method utilises the natural magnetic field of the earth. The earth's field behaves as if a bar magnet is placed inside the earth with its south and north poles very near to geographical north and south poles respectively. The "magnetic elements" composing the earth's field are d, v, H and Z, where d is the declination or the angle between the magnetic and geographic north, v is the dip or inclination or direction of the resultant field due to horizontal and vertical components of magnetic field, H is the value of the horizontal component, and Z is the value of the vertical component of the earth's field.

The presence of magnetic minerals in the rocks increases the earth's field locally. This increase is dependent on a factor called the permeability (u). As u is too small to be measured, K or susceptibility is measured.

$$u = 1 + 4\pi K$$

The magnetic survey uses magnetometer that measures (a) the dip and (b) the declination. The magnetometer comprises needle *K* turning about horizontal axis *O* (Fig. 116). Attached to needle *K* on horizontal rod *L* weight *M*. Under the action of the vertical component of the magnetic field *L* and gravity *P* acting upon weight *M*, at a given point the needle will assume a certain equilibrium position at an angle α angles is a measure of ΔL. Then ΔL values are used to construct isodynamic maps and profiles (Fig. 118), from which it is possible to locate the magnetic rocks in the earth's crust.

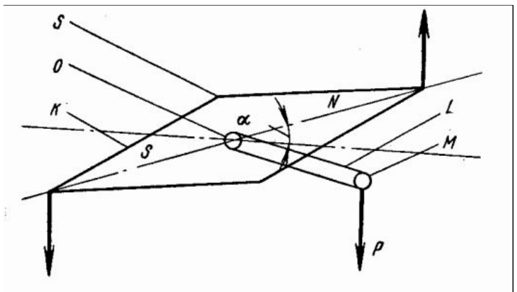

Fig. 116 Diagram of a vertical magnetic variometer

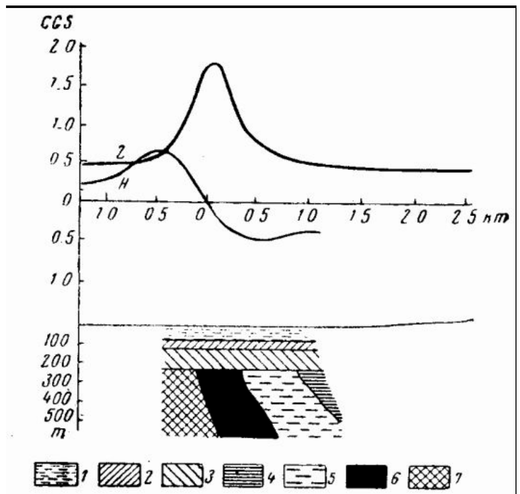

Fig. 118 Distribution of magnetic forces over blanket iron ore deposits:
1—Cretaceous strata; 2—Jurassic strata; 3—Devonian strata; 4—crystalline schists; 5—biotite schists; 6—ferruginous quartzites; 7—chlorite schists

Seismic Method

This method is based on measurement of elastic waves generated in the ground by artificial explosions set off in the earth's crust near the surface. Different rocks possess different elastic properties. Therefore, the velocity and direction of elastic waves change at the contact of two different media. By recording the time of the explosion and the time of recording of the waves by the instrument, it is possible to determine the depth and configuration of the boundaries of these rocks.

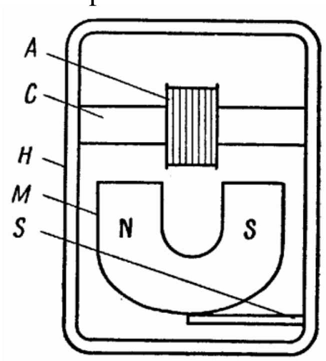

Fig. 124 Diagram of an electromagnetic seismic detector

The velocity of seismic waves is measured at the surface by means of seismic pick-ups which transform the arriving mechanical impulses of ground vibrations into corresponding electrical impulses. A massive magnet M is suspended by spring S inside the instrument housing H. An iron core C with induction coil A is rigidly secured near the poles of the magnet. Upon vertical displacement of the soil (caused by the seismic wave) the housing will be displaced together with the soil. Due to inertia the displacement of the massive magnet will be less than the displacement of the housing. As a result the distance between the poles of the magnet and core C will change and so will the magnetic flux passing through the core. An electromotive force will be induced in the coil proportional to the velocity of the displacement of the housing relatively to the magnet. The electromotive force is supplied to voltage amplifiers and passed through an oscillograph, which records the electric oscillations as a seismogram.

Radioactive Method

This method is based on measurement of radioactive radiation. Upon fissioning radioactive elements (U, Th, Ra, etc.) give off α, β, γ rays. These rays ionise gas, which becomes electrically conductive as a result. Different radioactive methods are based on measurements of the radioactive capacity of α, β, γ rays. The Greiger counter or G-M counter and scintillation counter are used for this purpose.

In aeroradiometric method, γ-activity is measured from aeroplanes flying low over the earth. The ground $\gamma+\beta$ surveys are based on a regular measurement of the radioactive emissions from rocks. This reveals sections of the γ-anomalies in which detailed γ-surveys are started along profiles running across the strike of the anomalies. The profiles are spaced at 10 to 80 m. Zones of an increased activity are traced between the profiles along the strike.

The γ-surveys furnish the background for the compilation of the γ-activity curves according to the profiles and the latter serve as a basis for plotting a map of igneous rocks with singling out of areas of high γ-activity. The γ-ray logging of bore holes and γ-ray surveying of the underground mine workings are practised in addition to the ground γ-prospecting. These areas are opened up by mine workings.

A modification of these methods, the emanation method, is widely employed at present in the search for deposits of radioactive elements. It is based on measurements of the content of radon in air samples taken from holes made in hard rocks, or by special probes. In studying emanation anomalies, scattered-ray well logging is applied. Changes in the radon content are measured every 20 to 50 cm. Sampling is done by using special dry sample barrels.

Logging comprises a complex of geophysical investigations and special operations carried out in exploratory bore holes. It consists of measuring natural and artificially induced physical fields along the bore holes. It is used: (1) to determine the lithological composition of the rocks, to detect deposits of economic minerals and determine their thickness, depth of occurrence and grade, (2) to measure the temperature, establish the presence of gas and other factors that bear on the exploitation of deposits, (3) to investigate the condition of the bore holes and locating pipe break-offs, which is very important for taking remedial measures.

Logging is the principal method of compiling geological records in core-less drilling. Electrical and radioactive bore hole logging are most commonly used at present. The practical importance of logging is enormous and it is widely used in exploration for coal and oil, since coal and oil bearing formations possess high electrical resistivity.

Electrical Logging: The equipment used for logging is the same as in vertical electrical sounding (VES). It consists of a battery and a potentiometer. M and N are receiving electrodes and A is the transmitting electrode (electrode C is grounded on the surface near the bore hole). The receiving electrodes are run into the bore holes, and moved up and down by means of a reel, enabling measurement of the potential differences at various depths.

The measurement results are plotted on a chart. The depths of the measuring intervals are plotted on the axis of ordinates and apparent resistivity on the axis of abscissae. Coal and oil are dielectrics, and therefore, the intervals in which they occur appear on the chart as AR peaks.

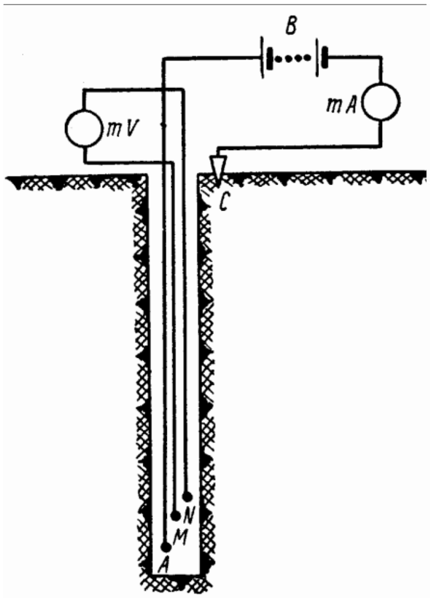

Fig. 125 Diagram of electric resistivity logging

Radioactive Logging: Specifically γ -logging (GL) and γ -γ logging (GGL) are based on measurements of air ionisation by γ -particles emitted in the fission of radioactive elements, which in varying amounts are present in all rocks. When the air is ionised an electrical current appears in the circuit increasing in direct proportion to the intensity of γ -radiation.

Current measurements are made by means of a γ -detector, which is lowered into the bore hole on a cable, and a three tube amplifier (with an electromagnetic counter) located on the surface. γ -γ -ray logging consists of irradiating the walls of the bore hole (at different levels) with γ -rays and measuring the γ -radiation which increases with decreasing rock density.

Lateral Projectile Sampler: When logging charts do not permit unambiguous interpretation of the results, the intervals which according to logging data may contain a coal seam are sampled by means of a lateral projectile sampler. This sampler consists of a chamber with a hollow projectile which upon detonation of a powder charge is ejected from the chamber into the wall of the bore hole and then is withdrawn together with the sample by means of special cable. Samples thus taken can serve for laboratory mineral grade determinations.

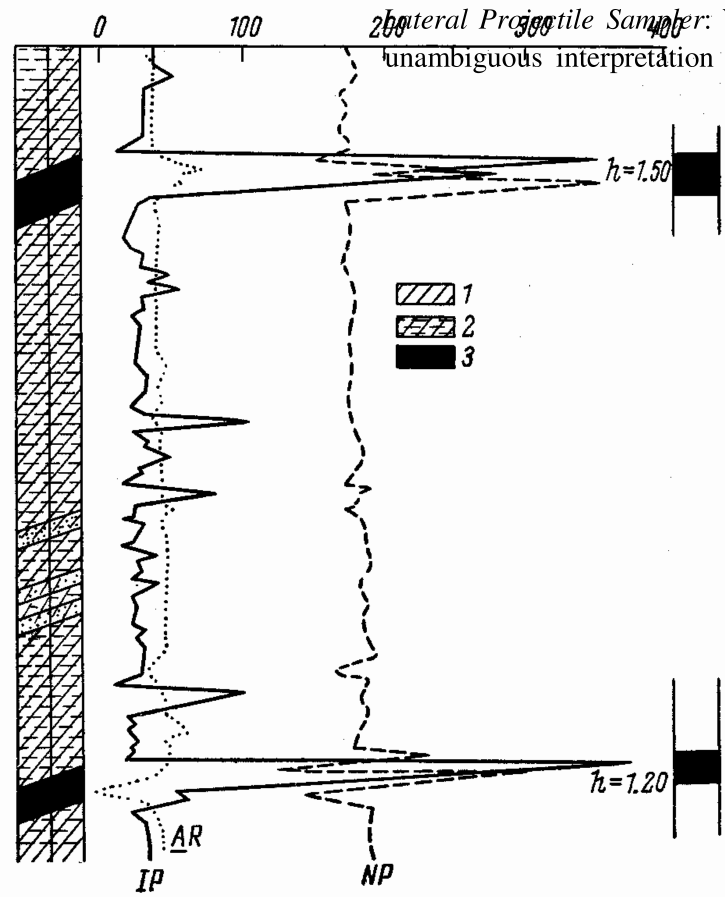

Fig. 126 Logging diagram:

1—sandstone; 2—aleurolite; 3—coal; AR—apparent resistivity curve; IP—induced potentials' curve; NP—natural potentials' curve

Geochemical Method

Geochemical prospecting is concerned primarily with the examination of the earth's crust, comprising not only the rocks, but also the waters and the gases, with a view to locate mineral deposits.

Metallometric Surveying:

It consists of identifying and tracing the haloes of dispersion by taking small from the soil or the eluvial-colluvial layer at depths ranging from a few centimetres to 1 m over a thick regular grid and making spectrographic and microchemical qualitative and quantitative analyses for the presence of various metals (Li, Be, B, F, P, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ge, As, Sr, Zn, Nb, Ta, Mo, Ag, Sn, Sb, Ba, Ce, W, Hg, Pb, Bi, U and others).

Scale	Distance between profiles	Sampling distance on a profile	No. of samples/km^2
1:1,000,000	12-18 km	100 m	1
1:500,000	6-4 km	100 m	2
1:200,000	2 km	100-50 m	5-10
1:100,000	1 km	100-50 m	10-20
1:50,000	500 m	50 m	40
1:25,000	250-200 m	50-20 m	80-250
1:10,000	100 m	20-10 m	500-1000
1:5000	50 m	20-10 m	1000-2000
1:2000	25-20 m	10 m	4000-10,000
1:1000	10 m	5 m	>20,000

Hydrogeochemical Method: It is based on the study of hydrchemical haloes of dispersion and consists of analysing the chemical composition of subterranean waters, which in the vicinity of ore bodies show increased concentrations of ore constituents (chiefly U, Mo, Zn and Cu). And then to trace their flow up to the source.

Biogeochemical Method: The root system of plants, which sometimes pierces the soil to a considerable depth, assimilates many metals (Mn, Cu, Zn and others) together with nutritive substances. Such metals cumulate in the plant tissues (bark, wood, leaves). The samples are taken from plants of a single species, better from one and the same part, being then reduced to ashes, which then go for a spectral analysis. Its finding undergo the same processing as in the case of metallometric surveying.

Gas Surveying: It is used to outline the dispersion haloes of different gases, which seep through from depth to the surface. Samples are taken from sampling points located in a dense regular pattern by means of hand augers adapted to withdrawing gas from a depth of 1.5-2 m.

Sampling

Economic mineral deposits are sampled to ascertain the grade of minerals, which is sometimes decisive for the commercial evaluation of a deposit. This is achieved by taking samples from mine openings, bore holes and natural exposures.

The results of sampling furnish the necessary information for determining the mean thickness of mineral bodies and the average content of the useful constituent therein; they help study the technical and technological properties of useful minerals, delineate the mineral bodies, determine correlation of individual constituents and elements in the ore, establish the priority in mining the minerals, their losses and dilution during exploitation.

Sampling may be chemical, mineralogical, technical and technological.

1. **Chemical**: Samples are taken for determining the content of useful and secondary components.

2. **Mineralogical**: It is done to ascertain the mineral and petrographical composition of the mineral. It helps to establish the origin of the deposit, the dependences governing grade variations and also to plan the ore dressing and beneficiation.
3. **Technical**: Samples are taken to study the technical properties of the raw material, which does not require metallurgical or chemical treatment. Thus in the case of building stone, it is their bearing capacity, in the case of asbestos – the length, strength and flexibility of fibres; mica – the size; sand and gravel – grain size distribution, etc.
4. **Technological**: Samples are collected for the study of the technological properties of the raw material in the course of its beneficiation and processing. In the case of coals, for example, apart from their beneficiation properties,it is necessary to establish their briquetting and coking qualities and the yield of liquid products.

Besides these above-mentioned types of samplings, there exist geophysical sampling,which enable one to define the physicalproperties of rocks and ores without collecting actual samples; and in the case of radioactive and some other ores, to determine the metal content therein.

The process of sampling falls into several stages:

1. Taking of samples,
2. Their processing,
3. Laboratory studies of the sample (assaying), and
4. Analysis of the laboratory findings.

Sampling in Mine Openings

The following methods are generally used: point or spot, face or lump, channel or trench, drill or shot hole, chip and bulk sampling.

Point or Spot Sampling consists of taking a number of equal portions of a mineral at points distributed in a regular grid over a work face or a mineral exposure. Sampling may be done from a pile of the mined mineral and from mine cars. These samples are, in the main, destined for chemical assaying. The number of points making up an individual sample depends upon the uniformity of mineralisation.

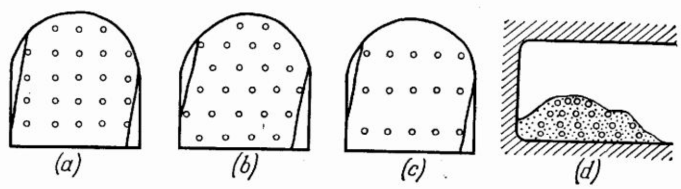

Fig. 17.1. Disposition of point sampling sites
(a) according to square spacing pattern; (b) according to rhomb spacing pattern; (c) according to rectangle spacing pattern; (d) point sampling in a pile of broken ore

Face or Lump Sampling: This method of sample taking may be referred to the group of point sampling. One to three lumps of rock are gathered in the face or taken from a pile of broken mineral with the purpose of determining the mineral, and sometimes, also the chemical composition.

Face sampling is a very simple, quick and cheap procedure, but the taking sample is often done subjectively and for this reason the accuracy of the method is rather low. This type of sampling is employed in lumpwise metallometeric surveying. Large pieces are occasionally collected for the purpose of determining the physical properties of the mineral.

Channel or Trench Sampling: It is most widely used and consists of scooping out a rectangular channel across the entire thickness of a mineral deposit or a certain part thereof.

A channel sample is taken across the entire deposit either when the deposit is of simple uniform structure and relatively thin. In deposits of complex structure, channel samples are taken from each band or layer separately.

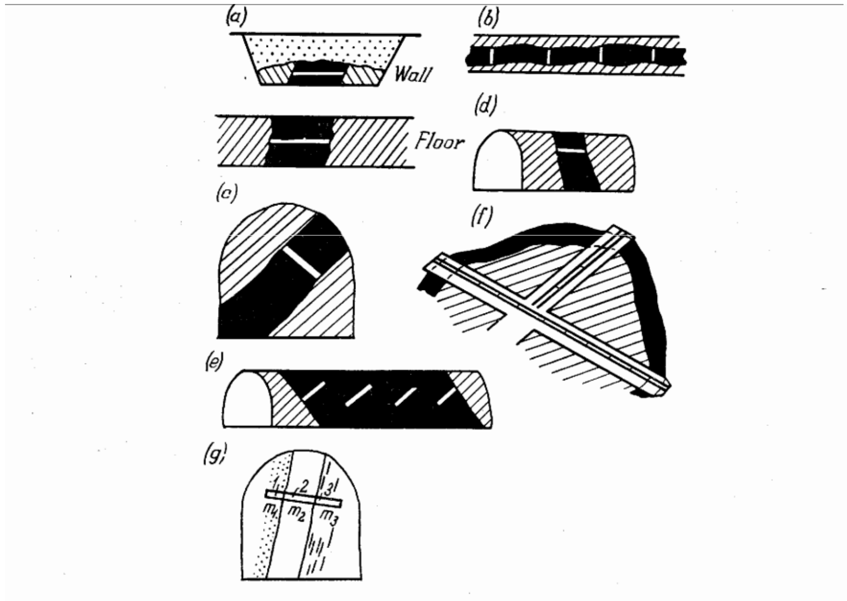

Fig. 17.3. Disposition of channel samples
(a) in ditches dug across the strike of orebodies; (b) in ditches driven along the strike of orebo dies; (c) in drifts pushed forward along the strike of an orebody; (d, e) in cross-cuts and cross drifts; (f) in workings crossing pipe-like bodies; (g) sectional channel sampling

Recommended Cross-Section of Channel Sampling, cm^2

Distribution of components	Thickness of ore bodies, m		
	> 2.5	0.5-2.5	< 0.5
Strong Mineral Deposits			
Highly homogenous and homogenous (regular)	2x5	2x6	2x10
Inhomogenous	2.15x8	2.5x9	2.5x10
Extremely inhomogenous (non-uniform)	3x8	3x10	3x12
Soft Mineral Deposits (without consideration of thickness of ore bodies)			
Highly homogenous and homogenous	(2-5)x(5-10)		
Inhomogenous and highly inhomogenous	(5-10) x (10-20)		

Sectional samples usually 1 m long are also taken from uniform but very thick deposits. Sectional sampling makes it possible to study the distribution of the valuable constituents in various parts of the mineral body; it also provides the necessary prerequisites for selective mining of different grades of the mineral, or helps determine the extent of dilution and losses during the exploitation of the deposit.

Drill and Shot Hole Sampling: It is applied on ore deposits. This is employed in collecting samples for chemical assaying. The samples are taken from blast holes drilled in driving mine workings, or from special sampling bore holes. Drill holes intended for taking samples are disposed along the line of the greatest regularity or across the thickness of mineral body.

The number of drill holes depends upon the degree of the irregularity: a uniform ore may be sampled from a single drill hole; with an extremely variable (irregular) ore samples are taken from 3 to 4 holes per each advance of the face. This type of sampling has the merit of a possible collection of specimens beyond the range of a mine opening, i.e. it enables thick ore bodies unexposed by the opening to be sample-tested. The method has, however, substantial disadvantages, such as: (1) it is not always possible to locate drill holes along the line of the maximum irregularity, (2) thin ore bodies can not be test-sampled, (3) sectional sampling is lacking.

Chip Sampling consists of chipping off a uniform 3 to 10 cm thick layer of ore from the entire work face. This method is not widespread and has limited use, chiefly in the exploration and extraction of thin veins and deposits wit a most regular distribution of values (Au, Platinum group of minerals, rare earth elements).

Bulk Sampling consists of taking large (up to 10,000 kg) sample, their volume not infrequently reaching scores of cubic metres. Bulk samples are collected for making technological laboratory and sampling mill and smelter tests, and also check tests on other types of sampling.

Sampling of Exploratory Bore Holes

In the case of core drilling, the sampling material comes from the core, core and sludge, and sludge. To make sure of complete core recovery and obtain representative samples double core barrels are used.

Core Recovery (C.R.) = l/L * 100%

Where l = length of the core, and L = bore hole length.

Sludges are less valuable material than the core samples because of their being contaminated and incomplete catching. Therefore when the core recovery is as high as 70 to 80% no sludge samples are taken.

If core recovery is incomplete or the core is lost entirely and a layer of the economic mineral is missed (which is established by logging), the bore hole is then artificially deflected for repeated drilling through a definite rock interval. In some cases, lateral projectile samplers are used in stead of artificial deflection of bore holes.

The extracted cores are laid in their proper order into the core-sample containers. After that, core recovery is measured and the normal section of the deposit is recorded for kinds of rock, mineral, and structural features, and sketched. During sample taking the core is split longitudinally. One half of it goes to laboratory to assess grade and content of mineralization; and the other is stored.

Sample Spacing

The distance between the sampling sites is determined by the variability of mineralisation and the size of the deposit as well as by the objectives and detailed nature of the investigation.

Group	Metal Distribution	Coefficient of variation in metal content, %	Type of deposit	Sample spacing
I	Very regular	Up to 20	Marine sedimentary deposit of Fe and Mn	50-15
II	Regular Irregular	20-40	Sedimentary deposits of Fe, Mn, bauxites; some metamorphic occurrences of Fe	15-4
III	Very Irregular	40-100	Most occurrences of non-ferrous metal deposits, some deposits of rare metals	4-2.5
IV	Extremely	100-150	Predominantly non-ferrous metal deposits and also occurrence of Au	2.5-1
V	Irregular	>150	Some Au and rare metal deposits	1.5-1

Treatment of Samples

Bulk samples of 50 to 10,000 kg for pilot and mill tests are usually shipped in their natural state. Sieve and fractional analyses are usually carried out right on the site. Especially in chemical sampling, the initial weight and number of samples should be kept to a minimum, but the representative nature of the sample must be preserved.

A *representative sample* is a specimen in which the content α , of the constituents in the reduced sample accords well with their content α_o in the face.

In order that a mineral sample be of minimum but satisfactory weight it is recommended to take into consideration the following factors:

a) the structure or the texture of the ores; when sampling ores of brecciated and mottled textures, the required samples must be of a greater weight than in sampling ores of massive structure and banded texture,
b) the grain size of the ore minerals; the coarser the grains, the greater should be the weight of the sample,
c) the number of ore mineral grains in the sample; with the sample containing a large number of the ore mineral grains the reduction error is minimised.
d) the unit weight of the useful component; the greater the difference in the unit weights of the ore and gangue minerals, the heavier must be the sample.
e) the higher in the average metal content in the ore and the more uniform in the distribution of the component therein.
f) the degree of the chemical assay precision; the greater the accuracy demands on the analysis, the heavier should be the sample.

The dependence between weight and the biggest diameter of particles in a sample is given by

$$Q = kd^2$$

Where Q – weight of the sample,
k – factor of the regularity with which useful component is distributed in ore,
d – diameter of the largest particle in the sample.
Desmond and Halferdahl (USA) gives the formula as:

$Q = kd^{\alpha}$, where α varies from 1.5 to

2.7. $k = \sigma / c_m * 100\%$

Where σ is root mean square deviation and c_m is mean concentration of constituents.

$$\sigma = \pm(\Sigma\ x^2/n-1)^{1/2}$$

Where x^2 – squares of deviation and $x - c_s - c_m$

$$c_m = \Sigma\ c/n$$

Treatment of samples consists of crushing, sieving, mixing and reduction. A sample is treated in several stages. Crushing is done to the following sizes: coarse 100-30 mm, intermediate 12-5 mm, fine 0.7 mm, superfine 0.15 0.07 mm. A sample is passed through standard sieves of different sizes. Before reducing a sample it is mixed several times to obtain a homogenous mixture. A most common reduction procedure is quartering. A conical pile of the sample is flattened into a thin disc and divided by means of a wooden cross or a plank into four equal segments. Two opposite segments are then discarded and the remainder is then reduced sample. To avoid error it is advisable to use an automatic splitter for reducing samples.

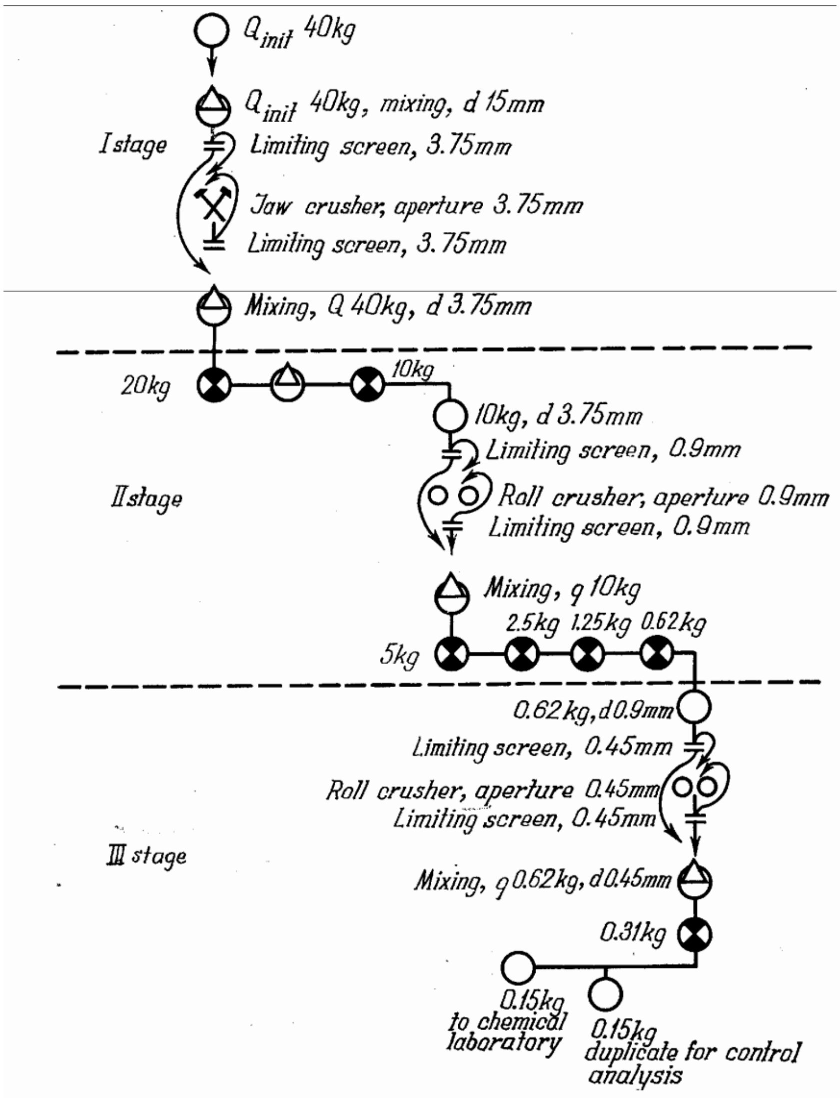

Fig. 18.2. Sample reduction (quartering) flow chart

Estimation of Reserves

The total quantity of mineral in a given deposit is referred to as mineral inventory, but only that quantity which can be mined at a profit is termed as reserve. Reserve is estimated in thousands of tons, tons or kilograms, or in units of volume. Minerals that are treated for extracting the useful constituents are estimated both in terms of ore reserves and in terms of useful constituents. Reserve is estimated in place, without subtracting the possible future loss in mining, concentration and treatment. The composition and properties of minerals are also determined in their natural state without taking into account of possible dilution during mining operations.

When mining operations are planned it is necessary to determine the loss of the mineral in place which for different reasons can not be extracted after which the commercial reserves of the mine, i.e. the difference between the actual reserves and loss are estimated.

Description of classes of reserves

Class	Degree of exploration of the deposit	Economic importance of reserve class
A	Delineated by mine openings or bore holes; position, form and structure of the mineral body, distribution of the mineral by grades in different blocks and mining conditions are known	May be used for planning current production, mine designing and investment planning
B	Delineated by mine openings or bore holes, the principal indicators: thickness of mineral bodies, mineral grade, position, mining conditions are known for the deposit as a whole. The individual blocks of different characteristics are not outlined. In the case of deposits of sustained thickness and grade, a limited zone of extrapolation may be included.	May be used as a basis for detailed exploration. If some reserves are classed as A, the B reserves may be used as a basis for mine designing and investment planning. In the case of complex and variable deposits, where A reserves can not be determined by exploration, mine are designed on the basis of B reserves.
C_1	The main features of the deposit are known only in general terms. The deposit is outlined by exploratory openings and by extrapolation of geologic and geophysical data.	May be used for long-range production planning and as a basis for exploration. When some A and B reserves are present, C_1 reserves may be used as a basis for designing and investment planning. In the case of very complex and extremely variable deposits, in the absence of reserves classed as A+B, C1 reserves are used as a basis for mine designing and investment planning.
C_2	Reserves are estimated tentatively; the main features of a deposit are determined on the basis of geologic and geophysical data confirmed by a few exploratory openings.	May be used as a basis for organisation of exploration

Calculation of Reserves

The reserves of valuable ingredients in the ore (P) are calculated according to the formula:

$$P = Qc$$

where Q = reserves of the ore and c = content of valuable in the ore.

The reserves of the ore are found from the formula:

$$Q = Vd$$

where V = volume of the ore in place and d = unit weight of ore.

In turn, volume is given by the formula:

$$V = St$$

Where S = area of the ore body and t = average thickness.

Therefore, the general formula can be given as follows:

$$P = Stdc$$

In case of non-metallic deposits, whose reserves are estimated in terms of weight (such as coal, salts),

$$P = Std.$$

The reserves of non-metallic minerals estimated in terms of volume (e.g. building material) are given by the following formula:

$$P = St$$

Determination of Exploitable Reserves

In determining which portion of a mineral can be considered an exploitable ore reserve, it is necessary to estimate extraction costs and the price that can be expected for the commodity. Extraction costs depend on the mining system selected, the level of mechanization, mine life, and many other factors. This makes selecting the best system for a given deposit a complex process. For example, deposits outcropping at the surface may initially be mined as open pits, but at certain depth the decision to switch to underground mining may have to be made. Even then, the overall cost per ton of ore delivered to the processing plant would be significantly higher than from the open pit; to pay for these extra costs, the grade of the underground ore have to be correspondingly higher.

Ore dressing or Beneficiation

Ore dressing or beneficiation is the process by which an ore is improved in grade so that the product can be used in the metallurgical industry. There are several methods adopted, for the purpose, each taking advantage of some peculiar physical, mechanical or chemical property, or a combination of properties of the ore mineral. Some properties of minerals, commonly utilised and the possible beneficiation process(es), are as follows:

1. Particle size, i.e. screening, e.g. beach sands, coal, etc.
2. Cleavage or fracture, i.e. whether the grains are flat or rounded jigs, e.g. feldspars, manganese ore, etc.

3. Specific gravity – sink and float, - tables (Wilfley) – Cyclones – Spirals, e.g. coal, gold, tin ore, etc.
4. Surface energy – floatation, e.g. complex sulphide ores of copper, zinc, lead, etc.
5. Magnetic susceptibility – magnetic separation, e.g. magnetite, ilmenite, etc.
6. Fluorescence, as in the case of certain minerals, e.g. uranium minerals, scheelite, etc.
7. Hardness – washing, e.g. clayey iron ores, kaolin.
8. Volatility, e.g. sulphur, also crude antimony, etc.
9. Solubility, e.g. certain salts from evaporites.
10. Colour, e.g. coal, manganese ores, etc.
11. Electric conductivity – in electrostatic separation, e.g. graphite.
12. Interfacial energies, e.g. diamond.
13. Amalgamation, e.g. gold and silver with mercury.

Ore dressing comprises the following processes:

1. Crushing,
2. Sizing,
3. Grinding
4. Concentration,
5. Storage.

Crushing and Grinding

Crushing is done either manually or by using different types of crushers. For grinding, different mills are utilised. While crushing yields a relatively coarse product, grinding produces finer material. For this purpose, the parts of the machine which are used for grinding come into contact with each other, while crusher jaws and rolls do not touch each other. Another feature of grinding is that the operation is generally continuous, while crushing is commonly intermittent.

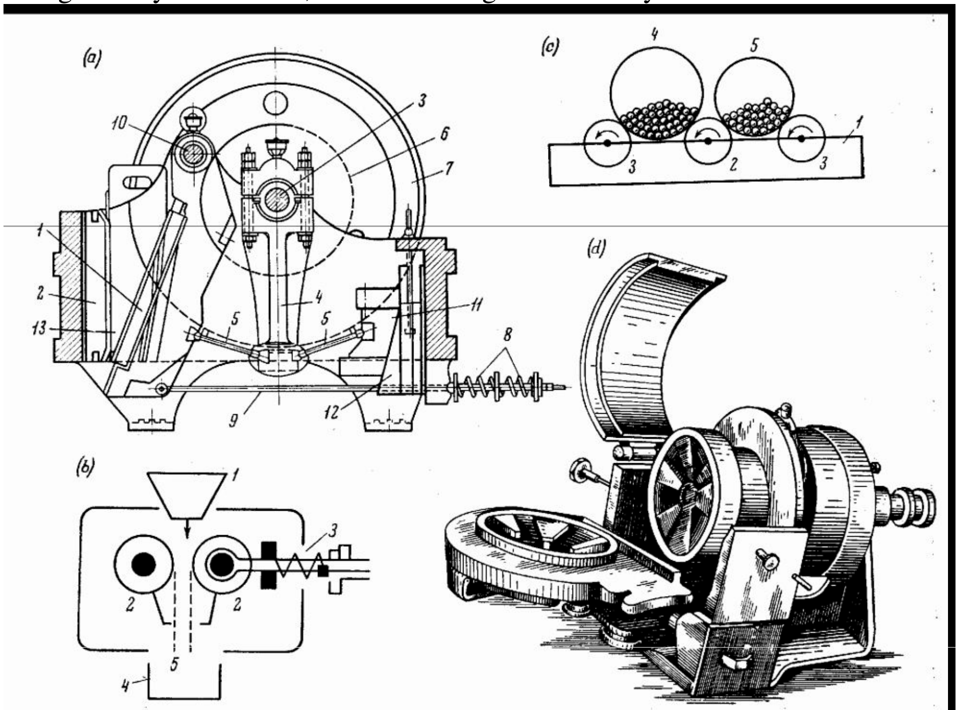

Fig. 18.1. Diagrammatic representation of crushers

(a) jaw crusher: 1—movable jaw; 2—fixed jaw; 3—eccentric shaft; 4—connecting rod; 5—toggle lever; 6—driving pulley; 7—flywheel; 8—spring; 9—rod; 10—movable jaw axle; 11, 12—wedges; 13—aperture determining maximal size of particles; (b) crushing rolls, section: 1—ore receiving bin; 2—rolls with fluted steel shells; 3—buffer spring; 4—feed box with a tray; 5—gap between rolls; (c) ball mills: 1—metal bearer bedplate; 2—driving roll; 3—idlers; 4, 5—ball and rod mills; (d) attrition disc mill

The purpose of crushing is generally, to reduce the size of the run of mine product, but grinding is essential for liberating valuable minerals from the gangue. Grinding is also necessary in order to liberate minerals, where the minerals occur as intergrowths, e.g. galena and chalcopyrite, so that these ores may be rendered amenable to ore dressing processes, e.g. floatation. In the case of non-metallics, e.g. feldspar, sillimanite, limestone, coal, etc.

grinding is done to make them marketable. The mills for non-metallic minerals are generally designed for dry grinding. Grinding is also needed where hydrometallurgical practised, e.g. leaching of low grade copper ores.

Sizing

Purposes of sizing are: (1) to remove the coarser fractions, (2) to remove the finer material from the grinding circuit, (3) to obtain commercially marketable sizes of material, e.g. sand, rock chips, etc., (4) to obtain suitable sizes for further beneficiation, and (5) to separate different minerals, which occur together, but each mineral being characterized by a particular grain size. In beach placers, ilmenite, monazite, garnet, etc., can be separated as well as quartz, and these can sometimes be separated by sizing.

Requirements and conditions for proper sizing are: (1) All particles should be brought to the screen opening, oriented in such a way, and moved at such a rate, that the undersize particles will pass through freely unhampered, without rebounding, from the edges of the screen opening, (2) Ideally, every undersize particle should be at standstill and centrally placed, in respect of the aperture, (3) Larger tonnage can be obtained if the particles of the material move over the screen, and (4) Even though screen, made of extremely fine wire or metal, they are ideal for efficiency, in practice, these can not be employed as they are mechanically too weak.

Concentration

This aspect of beneficiation takes advantages of the differences in specific gravity, which come into play under the influences of forces impressed upon various particles.

Hand-Picking

There are many primitive mining operations in various parts of the world where groups of men, women, and children break up pieces of ore with hand hammers on hard stones or blocks of steel and, by sorting and re-sorting, discard the gangue and garner pieces of valuable mineral into separate piles. Primitive as it is, hand-sorting can be the most economical method of ore-dressing when circumstances favour it. In its modern form, hand-picking is facilitated by mechanical aids; the ore, after coarse crushing, goes over a screen to separate the fines and under a spray to wash off dust and mud. Then a broad conveyor belt, or, less commonly, a revolving table, carries it in front of the pickers.

Used alone, hand-picking is likely to be wasteful. If the gangue is picked out of the ore, the remaining product will still be low in grade; if the ore is picked out of the waste, there will be excessive loss in the residue. But, as a preliminary to mechanical concentration, hand-sorting is often the cheapest method of separating ore from waste at coarse sizes. It may be employed either to get rid of part of the gangue and wall rock or to collect pieces of high-grade ore for direct shipment. In either case, it reduces the bulk of the ore that has to be milled and so, in effect, increases the capacity of existing treatment plant.

Gravity Concentration

This method is based on mechanical refinements of the simple processes of washing and panning. Its effectiveness depends on the difference in specific gravity between different minerals; naturally, the greater the difference the better the separation. Since liquid buoys up a body by the weight of the liquid displaced, a particle immersed in water has its apparent specific gravity reduced by 1. But the size as well as the specific gravity of a particle affects its behaviour in a liquid. Large particles of light minerals settle as fast as small particles of heavy minerals; thus a quartz particle 4 mm in diameter settles at about the same rate as a galena particle of 1 mm. For this reason separation is imperfect unless the particles all have the same size. Among particles of very small size, gravity separation is not efficient.

A great variety of machines have been used in gravity concentration, but much the commonest are jigs and vibrating tables. Auxiliary to these are boxes and cones of various forms designed to permit settling in an ascending current of water. Gravity concentration, pure and simple, is not widely used except for relatively coarse ores of simple mineralogy and for ores that do not respond to floatation.

Heavy-Fluid Separation

This method uses the heavy fluid, which is a pseudo-liquid consisting of a finely-ground heavy solid in suspension in water. Galena and ferrosilicon are the solids most commonly used. For lead ores galena is convenient as a medium because it is readily available and the portion that becomes too fine for further use can be recovered and sold along with the concentrate. Ferrosilicon has the advantage of being ferromagnetic so that it can be recovered and cleaned for re-use by means of a magnetic separator. This method uses sink-and-float process and operates most successfully on coarse ore from 2” down to ¼”, but it has been used on some types of ores as fine as 48 mesh (0.116”), which is about the coarser limit for floatation. This method is best adapted to ore that breaks in such away that the valuable mineral or the gangue, or both, occur in chunks of fairly large size. For most ores it is a preliminary to further concentration by floatation or other methods. On iron ores, however, since a coarse product is desired, it may be used alone. When used as a pre-concentration process it may serve either to recover a coarse marketable product leaving a tailing that can be further concentrated or to reject coarse waste and recover a low-grade concentrate for additional treatment.

Floatation

The principle of the floatation process is illustrated by the parlor-trick of floating a sewing needle on water. The water is reluctant to “wet” the needle, especially if it has gathered a little oil from the fingers, so the surface of the water is locally depressed by the weight of the needle yet does not allow the needle to sink completely through it. Similarly, a particle of sulphide, suitably treated, would float at the surface of the water while a particle of quartz would sink. This is because the quartz, unlike the sulphide, is “wetted” by the water. This same preferential adherence applies not only to mineral particles at the top of the liquid but also to particles that are submerged, thus sulphide particles adhere to bubbles of air and are buoyed upward as the bubbles rise to the surface.

Although each mineral behaves in its own way with regard to adherence to air and water, the natural tendencies may be modified almost at will by introducing suitable chemicals into the pulp (the mixture of water and finely ground ore). According to modern conceptions of surface chemistry, a mineral particle immersed in a solution surrounds itself with a layer of molecules or of ions, and the nature of the coating determines its susceptibility to floatation.

Practice is to mix the appropriate reagents into the pulp and cause air to bubble up through the mixture. The sulphide particles rise with the air-bubbles to form a froth, which overflows the tank. This froth, or rather the suspension that results when the bubbles collapse, is filtered to recover the mineral-bearing concentrate.

Magnetic Separation

Magnetic methods have long been used for concentrating magnetite ores. The othr iron oxides (hematite and goethite) as well as siderite are virtually non-magnetic, but they may be converted into artificial magnetite by controlled roasting. They are thus made amenable to magnetic separation. Magnetic methods may be used “in reverse” to purify non-ferrous ore by removing the undesired magnetic minerals. Such methods are used on a large scale for removing magnetite from the titanium ore. Many other minerals – for example, chromite, manganese oxides, and garnet – are weakly magnetic and can be concentrated by machines using a strong field. Wolframite or tantalite can be separated from cassiteite by this means, and garnet can be eliminated from scheelite concentrates.

Amalgamation

Mercury forms an amalgam with metallic gold or silver. This principle is utilised in the recovery of precious metals by passing a layer of pulp over a table consisting of a plate of silvered copper, which has been coated with mercury. The mercury holds and partially absorbs the particles of precious metals, while gangue and sulphides pass onward. In stead of using a plate, the ore and mercury may be brought into contact inside a revolving barrel. The mercury and gold are later separated by distillation of the amalgam.

Cyaniding

The cyaniding process is applicable commercially only to ores of gold and silver. Any base metals in the ore are not recovered. The solvent is a weak solution of sodium or calcium cyanide which, when aerated, readily dissolves the precious metals.

$$4Au + NaCN + O_2 + 2H_2O = 4NaAu(CN)_2 + 4Na\ OH$$

They are then recovered by agitating the “pregnant” solution in the form of shavings or dust and filtering out the precipitate which is then melted and cast into bars (bullion).

$$NaAu(CN)_2 + Zn + 2NaCN + H_2O = Na_2Zn\ (CN)_4 + Au + H^+ + NaOH$$

Leaching

Some copper ores can be treated by leaching, using a solvent either ammonia, ferric sulphate, or sulphuric acid, according to the nature of ore. Ammonia in presence of CO_2 dissolves native copper and is used in retreating tailings. Ammonia also dissolves copper carbonate. Sulphuric acid readily dissolves copper carbonates and sulphates but is uneconomical for ores with limestone gangue because of the high acid consumption. This rules out sulphuric acid for most malachite deposits but it is used along with ferric sulphate on malachite-chrysocolla ore in schist.