

floor is too uneven or where exceptional accuracy in linear measurement is required. It may also be preferred where roof supports or existing line-pegs allow intermediate bobs to be arranged without much trouble.

Trigonometrical levelling will sometimes be preferred when the suspended tape is used and may be used with either method of taping. However, dumpy levelling is customarily used in conjunction with ground taping except on steep gradients. Theodolite levelling with long sights is only possible under rather exceptional conditions. The reasons for preferring dumpy to trigonometrical levelling for long sights are :—

(a) Long sights normally occur only in extensive surveys and in this case the levelling can conveniently be done on another occasion or by another surveyor. Then the question of bringing in additional equipment does not arise.

(b) Dumpy levelling is more accurate. It has been mentioned that surveyors generally have an exaggerated idea of the accuracy of dumpy as against trigonometrical levelling, but the fact remains that it is possible for a mining theodolite, if used on sights of say 500 ft., to exceed the limits of error considered here as desirable.

(c) On long sights it is not possible to check

linear measurement by the use of more than one target on the bob-string.

(d) Where linear measurement is not made at the same inclination as the line of sight the calculation of horizontal distance involves additional work. Dumpy levelling allows the calculation of horizontal distance without reference to a vertical angle and deals with the case where measurement is made on ground that is not of uniform slope.

(e) Dumpy levelling can effectively be checked by repeating the work using different turning points between stations.

Conclusion

The question of underground levelling has been discussed in very general terms without recommending any particular method. No method is suited to all circumstances and the choice is for the surveyor himself. An attempt has been made, however, to draw attention to what appear to be the essential features of each method. It is now suggested that mine surveyors might profitably examine their own practice in underground levelling particularly as regards (a) the standard of accuracy really required, (b) the standard actually achieved, as shown by closing or repeating surveys, (c) the possible presence of systematic error not revealed by closure or repetition, and (d) the possibility of achieving the desired result with less effort.

Identification of Lithium Minerals

K. F. G. Hosking, M.Sc., Ph.D., A.M.I.M.M.¹

Methods of use in
the recognition of
lithium-bearing ores
critically reviewed

Abstract

The increasing importance of lithium is stressed and the sources and characteristics of the more important lithium-bearing minerals are noted.

The flame test for lithium is critically reviewed and means of identifying the commoner lithium minerals by a fusion technique and of confirming amblygonite are described.

Methods have been established for identifying grains of amblygonite, spodumene, and petalite in composite samples and for determining—with

varying degrees of accuracy—the amounts of those minerals which are present.

Introduction

Since the war there has been an ever-increasing interest in sources of lithium because of the numerous industrial uses that have been found for the element and also because it is widely thought that it may have an important role to play in the thermo-nuclear field.

In view of the continually increasing

¹ Camborne School of Metalliferous Mining, Cornwall.

importance of this metal the writer has gathered together and critically reviewed the aids to the identification of lithium minerals in the field and the mill which are scattered throughout the literature and has described certain new tests which he has developed.

Occurrences of Lithium Minerals

Economics.—Although the present major source of lithium in the United States is the Searles Lake evaporite deposit, from which the metal is recovered as Li_2NaPO_4 , appreciable quantities of the element are obtained from granite pegmatites and it is in such bodies that economic quantities of lithium-bearing minerals are most likely to be found throughout the world.

Although some 140 lithium mineral species are known only spodumene, amblygonite, lepidolite, zinnwaldite, and petalite are of economic importance and of these spodumene is the most popular lithium source in America, while amblygonite is favoured in Europe. In the United States only deposits containing more than about 1% Li_2O are considered worthwhile working and there it is axiomatic that lepidolite and petalite deposits are of no value unless concentrates can be made by hand-picking alone.

Mineralogical Characteristics of the Major Lithium Minerals

The mineralogical characteristics of the major lithium minerals noted here are such that they do not always permit rapid and certain identification of the various species to be made in the field or in the mill. On occasion feldspar might well be mistaken for petalite—or even spodumene—and lepidolite for a non-lithium-bearing mica if only visual and other simple physical tests are resorted to.

Spodumene, $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$. Monoclinic. Prismatic crystals—often large—with the vertical planes striated and furrowed. Cleavage perfect. Fracture uneven to subconchoidal. Brittle. Lustre vitreous; pearly on cleavage faces. Transparent to translucent. Colour white to emerald green, also yellow, pink and amethyst, streak white. Hardness = 6.5–7. Specific gravity = 3.13–3.20. Fusibility = 3.5. Insoluble in acids.

Amblygonite, $\text{LiAl}(\text{F}, \text{OH})\text{PO}_4$, may also contain sodium. Triclinic. Crystal forms rarely distinct. Polysynthetic twinning lamellae common. One perfect cleavage and others less distinct. Fracture uneven to subconchoidal. Brittle. Lustre vitreous to greasy; pearly on certain cleavage faces. Sub-transparent to translucent. Colour white to pale green, also yellowish, greyish, and brownish. Streak white. Hardness = 6. Specific gravity = 3.01–

3.09. Fusibility = 2. When finally powdered it dissolves in sulphuric acid and less readily in hydrochloric acid.

Lepidolite (lithia mica), essentially $(\text{OH}, \text{F})_2\text{-KLiAl}_2\text{Si}_3\text{O}_{10}$. Compact aggregate of mica-like plates forming a scaly-granular mass. Occasionally occurs as short prisms. Perfect basal cleavage. Sectile. Lustre pearly. Translucent. Colour white, greyish, yellowish, violet-grey or lilac and rose-red. Streak white. Hardness = 2.5–4. Specific gravity = 2.8–3.3. Fusibility = 2–2.5. Partly decomposed by sulphuric acid.

Zinnwaldite, an iron-bearing lithium mica. Similar to lepidolite. Colour pale violet, or yellow to brown and dark grey. Hardness = 2.5–3. Specific gravity = 2.82–3.2. Fusibility = c. 2. Slightly soluble in hydrochloric acid.

Petalite, $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2$. Monoclinic. Usually massive. One perfect cleavage and others less distinct. Fracture imperfectly conchoidal. Brittle. Lustre vitreous; pearly on certain cleavage faces. Transparent to translucent. Colourless, white, greenish- or reddish-white, and grey. Streak white. Hardness = 6–6.5. Specific gravity = 2.39–2.46. Fusibility = 5. Soluble in hydrofluoric acid.

Identification

As the lithium minerals vary in their economic value it is important not only to show that a given mineral is lithium-bearing but also to establish its complete identity. Therefore it is appropriate to consider first the methods of testing for lithium in minerals and then those which enable the major lithium species to be identified.

Tests for Lithium

Under appropriate conditions lithium compounds impart a carmine colour to a flame and this fact is the basis of the only quick and simple method yet available for establishing the presence of lithium in minerals. However, when considering the lithium flame-test it must be remembered that strontium imparts a crimson colour to the flame which might be misinterpreted and that the frequent occurrence of sodium in some of the lithium minerals may tint the flame golden-yellow and so mask the lithium colour. However, the latter difficulty may be overcome by viewing the flame through blue didymium glass when the lithium—but not the sodium—flame coloration will be seen. Nevertheless, potassium imparts a colour to the flame which is lilac when observed through the blue glass and which might be mistaken by the inexperienced for the lithium colour which is, in fact, considerably redder.

The alcohol flame which is often used for the examination of minerals by blow-pipe and allied techniques is not sufficiently hot to

cause the development of the characteristic colour when a fragment of lithium mineral—or even powdered material—is introduced into it. However, if the powder of lepidolite or amblygonite is admixed with about three times its volume of Turner's flux (4.5 parts, by weight, of KHSO_4 to 1 part CaF_2), then taken up on a platinum wire and introduced into the alcohol flame, the lithium colour—visible either directly or through blue glass—is occasionally seen although the test cannot be regarded as satisfactory. By applying a blow-piped flame to the flux-mineral mixture somewhat better results are obtained.

In the laboratory no difficulty is experienced in obtaining a satisfactory lithium flame-coloration if the test is conducted as follows:—

By means of a forceps introduce a fragment of the mineral under test into the non-luminous flame of a large bunsen burner so that the tip of the mineral is about 1 in. above the top of the burner and half-way between the blue cone and the outer edge of the flame. After about a minute the characteristic lithium flame may be seen, particularly around the tip of the fragment, but in the absence of masking elements the strongest colour will appear on withdrawing the fragment slowly to the outer edge of the flame. If the flame is yellow observation should be made through a blue glass.

If possible a fragment of dimensions about $\frac{1}{2}$ in. by $\frac{1}{4}$ in. by $\frac{1}{8}$ in. should be used as it is most satisfactory when observing certain fusion characteristics—noted in what follows—which enable the major lithium species to be identified with certainty.

MacKay and Brown (1955)¹ have demonstrated that the flame test for lithium is best conducted in the field by employing a "Prestolite" acetylene torch in much the same manner as a large bunsen burner is used in the laboratory. These workers also recommend wearing spectacles fitted with didymium glass when observing the flame colour.

If uncertainty arises as to whether a particular flame colour is due to lithium or potassium the difficulty may be readily resolved by observing the flame through a direct-vision spectroscope. Lithium is characterized by a red line and a faint orange-yellow line whereas potassium is indicated by the appearance of two closely-spaced red lines near one end of the visible spectrum and two

closely-spaced violet lines near the other end. It is to be remembered that even minerals which contain little more than traces of lithium may give rise to a good lithium spectrum.

In the absence of a spectroscope a Merwin screen may be used to differentiate between the lithium and potassium flame colours, but not between those of lithium and strontium. The screen is composed of strips of blue and violet celluloid which partly overlap forming three filters. The colours seen on observing the lithium, strontium, and potassium flames through the filters as are set out in Table 1.

Table 1

Element.	Colours observed through blue (B.), blue-violet (B.V.), and violet (V.) filters.	
	B.	B.V.
Lithium	B.—invisible ; B.V.—invisible ; V.—crimson.	
Strontium	B.—invisible ; B.V.—invisible ; V.—crimson.	
Potassium	B.—blue-violet ; B.V.—faint violet-red ; V.—reddish-violet.	

To differentiate between lithium and strontium flame colorations Smith (1953, pp. 62-4) recommends adding a little barium chloride to the powdered sample, then on carrying out the flame test the lithium colour appears before the olive-green colour due to barium while the strontium persists after the barium coloration has disappeared. Winchell (1942, p. 200) notes that strontium minerals give an alkaline reaction after ignition whereas lithium minerals do not.

Finally, it may be mentioned that in the absence of masking elements a most spectacular lithium flame-coloration may be obtained by applying the test-mineral to a rotating grinding wheel and allowing the dust to fall into the flame of a bunsen burner which is held horizontally.

Tests for Specific Lithium Minerals

The following tests enable differentiation to be made between the lithium minerals of economic importance and also between these species and certain other similar but non-lithium-bearing minerals with which they are commonly associated.

(i) Fusion Test

While most text-books of mineralogy note the degree of fusibility—according to Von Kobell's scale—of many of the minerals which are described they rarely note in anything but the briefest detail the characteristics of the species when they are in the

¹ References appear at the end of this article.

process of being fused and after they have cooled, yet in the case of the identification problems under review such information is of the greatest value for it not only serves (in conjunction with the flame test) to establish the identity of spodumene, amblygonite, and the lepidolite-zinnwaldite micas with certainty but it enables petalite to be recognized by a process of elimination.

In the laboratory the fusion and flame tests are conducted simultaneously in that not only are any flame colorations noted when the mineral fragment is in the flame of a large bunsen burner—as described earlier—but also the characteristics of the mineral fragment are observed as it is being heated and after it has cooled. Heating should be continued for several minutes and doubtless the "Prestolite" torch could be used for this combined test in the field. The cooled fused mineral can often be examined quite adequately without optical aids but it is generally preferable to use a magnifying glass.

The results may be summarized as follows:—

Lepidolite-zinnwaldite.—Most of the fragment in the flame fuses readily to a pale bubble-filled glass. Lithium flame colour often much in evidence. Fused residue gelatinizes on treatment with HCl. (Fusibility = 2.)

Muscovite-gilbertite-sericite-biotite micas. Much less fusible than the lithium micas. Usually only whiten along the edges but may show slight peripheral fusion to a greyish or yellowish glass. (Fusibility = 5·7.)

Amblygonite.—Fuses readily with intumescence to a white plastic mass which can be deformed when hot by touching it with an iron nail or by pressing it against the barrel of the burner. When cold the fused mineral is white and opaque and is reminiscent of hard-gloss white paint. (Fusibility = 2.)

Spodumene.—Initially, on heating, the end of the fragment tends to split up and become somewhat chalky and is then somewhat reminiscent of the end of a wooden stake which has been severely hammered. (This change is probably due to the conversion of α -spodumene to the β form.) As heating is continued small luminous globules develop and tend to fall off in a very characteristic manner. The cooled mass consists of partially-separated chalky strands to which a number of small colourless glassy beads adhere. (Fusibility = 3·5.)

Petalite.—This mineral normally only fuses to a bubble-filled colourless glass along the edges, but if the fragment is pointed a solitary globule may develop. (Fusibility = 5.)

Felspars.—These species only fuse slightly along the edges. (Fusibility = 4–5.)

Quartz.—Practically infusible.

Eucryptite (LiAlSiO_4).—A rare mineral which occurs in certain Southern Rhodesian pegmatites. It resembles quartz superficially but fuses to a

transparent glass along the periphery of the fragment and imparts a strong carmine colour to the flame. It also differs from all similar minerals in fluorescing pink under short-wave ultraviolet light. (Fusibility c. 4.)

(ii) Confirmation Tests for Amblygonite

Most amblygonites contain sufficient fluoride for the radical to be easily established by simple chemical methods. The establishment therefore serves, with reservations, as a confirmatory test for amblygonite and this may be done most convincingly by the following method:—

Warm a pea-size crystal of potassium dichromate with a few ml. of concentrated sulphuric acid in a test-tube until the solid has dissolved. Then hold the tube in a nearly horizontal position and rotate it until a film of yellow liquid attaches itself to the glass and does not collapse when the tube is held vertically. Add a little of the powdered suspected-amblygonite to the solution and warm gently. The liberation of hydrofluoric acid from amblygonite causes the yellow film to collapse leaving only a few globules of liquid adhering to the glass.

Unfortunately fluor-apatite, cryolite, and fluorite behave similarly, but unlike those three species all samples of amblygonite yet tested by the writer give negative results when subjected to the following fluoride test:—

Scatter a few grains of the test mineral on spot-reaction which has been damped with pink zirconium-alizarin reagent and rest the paper on a beaker of boiling water. After about 5 min. remove the paper and shake off the grains. The spots on which fluor-apatite, cryolite, and fluorite grains rested will be pale yellow to colourless but the paper remains pink where the amblygonite grains were. The reagent is prepared by dissolving 0·05 g. zirconium nitrate in 50 ml. water and 10 ml. concentrated HCl and mixing it with a solution of 0·05 g. sodium alizarin sulphonate in 50 ml. water.

Identification of Grains in Composite Samples

As several lithium minerals may occur in a given deposit which it may be desired to subject to a mineral-dressing treatment involving crushing it is desirable to be able to rapidly identify individual grains of these minerals in samples and so quickly obtain

quantitative data. The following tests are of some assistance in this respect :—

i. *Staining of Amblygonite Grains*

By employing the following treatment grains of amblygonite are stained yellow whereas grains of quartz, feldspar, spodumene, petalite, lithium and other micas and apatite are unaffected :—

Place a few grams. of the sample in a small beaker and cover to a depth of about $\frac{1}{2}$ in. with a solution prepared by dissolving 5 g. ammonium molybdate in 100 ml. cold water and pouring it into 35 ml. conc. HNO_3 . Bring the solution nearly to the boil and continue at this temperature for about 5 min., occasionally agitating the grains. Finally decant and wash the sample several times with water.

Other Notes.—This test depends on the production of insoluble yellow ammonium phospho-molybdate. Apatite also causes the development of this compound, but under the conditions of the test it does not adhere to the apatite grains although a heavy precipitate may appear in the beaker. It is possible, however, that the lithium-bearing phosphates triphylite, Li(Fe, Mn)PO_4 , and lithiophyllite, Li(Mn, Fe)PO_4 , may be stained yellow by the above treatment, but samples have not been available to the writer for examination.

ii. *Decrepitation and Staining Tests for Spodumene*

It is well known that α spodumene is converted to the less dense (S.G. = 2.4), sulphuric acid-soluble β variety on heating for 30 min. at about $1,050^\circ\text{C}$. The writer has established that this fact may be used to demonstrate the presence of spodumene grains in certain composite samples and also to determine the percentage of this mineral in such samples with ease and rapidity. Thus, if a weighed sample composed of pegmatite material which has been crushed to such a degree that the minerals are completely liberated is placed in bromoform (S.G. = 2.9), spodumene—together with such minerals as amblygonite, tourmaline, apatite, cassiterite, and tantalite—will sink, whereas quartz, feldspars, petalite, and beryl will float. Micas—including the lithium varieties—may either sink or float. If amblygonite and lithium-bearing micas are absent the heavy fraction is placed in a silica crucible and heated in a "tin furnace" (see later) for 30–45 min. The crucible is then removed

and the cooled contents are again shaken with bromoform, when only the spodumene will float. This fraction may be removed and weighed and the percentage in the original sample calculated. Both lithium micas and amblygonite must be removed before the heavy fraction is heated as these minerals fuse at the temperature employed. To facilitate the recognition and removal of amblygonite grains they can be stained by the molybdate method noted above.

The tin furnace which is employed in the Beringer assay of tin ore for reducing cassiterite to metal by zinc vapour consists of a sheet-iron cylinder which is lined with fireclay and open at both ends and resting on three metal legs. The fireclay is so moulded that a crucible can be supported in the upper part. The furnace is heated by a large bunsen burner and in order to increase the temperature a truncated conical "chimney" is placed over the top as soon as the furnace is reasonably hot. When the bunsen is delivering its maximum heat the temperature necessary for the conversion of spodumene is achieved automatically in the furnace.

Doubtless the "Prestolite" burner could be substituted for the bunsen burner in the field—certainly a modified painter's blow lamp would prove effective as it has been used successfully for the tin assay noted.

Even in the absence of bromoform the decrepitation test may be employed to facilitate the recognition of spodumene grains provided that readily-fusible components are not present in the fraction that is heated, as the chalky appearance of the β -spodumene grains enables them to be fairly readily identified. However, identification of the β -spodumene grains may be further facilitated by heating them near to boiling for 5 min. in a 1.2% aqueous solution of Methylene Blue then decanting and washing the grains repeatedly with water until the latter is uncoloured and examining the *wet* grains. This treatment causes the spodumene grains to become dark blue while those of other white species are either stained a very pale blue or are unchanged. It is to be noted that on drying the treated sample there is little or no colour difference between spodumene and a number of other species, but on damping the sample the difference again becomes apparent.

(iii) *Fluorescence Test for Petalite*

While no test has yet been evolved for identifying every grain of petalite in a

composite sample some idea of the amount present may be obtained by *gently* warming some of the sample on an iron plate in a dark-room. This treatment will cause every petalite grain to fluoresce a very pale blue. However, fluorite and certain other species which behave somewhat similarly to petalite must be absent.

Acknowledgment.—The writer wishes to express his thanks to Mr. R. G. Head, who kindly sent him certain lithium-bearing minerals from Southern Rhodesia which were

of the utmost value during the experimental phases of the work described herein.

References

MACKEY, A. M., and BROWN, D. F. G. "Field Method for Detecting Lithium." Abstract—of paper in the *Precambrian* (July, 1955)—in the *MINING MAGAZINE*, XCIII, 1955, pp. 186.

SMITH, Orsino, C. "Identification and Qualitative Chemical Analysis of Minerals" (2nd. Ed.). Van Nostrand Co., Inc., New York, 1953.

WINCHELL, A. N. "Elements of Mineralogy." Prentice-Hall, New York, 1942.

Rock-Drilling Cost Breakdown

Jan Holdo¹

Relation between
working costs
and the cost of
compressed air.

Introduction

In rock drilling, as in other operations, it is important that the costs should be kept as low as possible. When studying costs the total is as a rule broken down into items which are often inter-independent, an increase of one item involving a reduction of another or *vice versa*. In consequence the minimum cost cannot be determined by establishing and merely adding the lowest values of the various items. Actually it is necessary to determine how the cost should be apportioned to such items in order to ensure that the total is as low as possible.

The total cost of a rock-drilling job can be split up essentially in the following way:—

- (a) Working costs ;
- (b) drill steels and drill bits ;
- (c) compressed air, and
- (d) other costs.

Besides direct wages the working cost includes expenditure connected with holidays, social insurance fees, allowances, and extras, costs which are essentially related to time. Drill steel and drill bit costs cover, besides the purchase price, storage expenses and the

cost of transporting the drilling equipment to the site. The compressed-air item constitutes the product of the total air consumption of the rock-drills and the compressed-air price, per m.³, say, at the point of use. This price includes the amortization, interest, maintenance, and working costs of the compressor plant and also the cost of air pipes and the expenses resulting from leakages and pressure drops. The last item—other costs—covers depreciation, spare parts, repair, and other maintenance costs connected with the rock-drills.

Fig. 1 shows the approximate proportions between the four items when using pneumatic-pusher drills on sites where the compressed air is supplied by a large stationary compressor. As will be seen the working cost amounts to about 50%, the drill steel and drill bit costs to about 30%, and the "other costs" to about 15% of the total, whereas compressed-air expenditure only amounts to about 5%. As the working cost constitutes the largest factor, a reduction of that item is particularly important. One way to achieve this is to equip the operators with rock-drills which give a high gross drilling speed, which improves efficiency and gives a more satisfactory utilization of the most expensive single factor. As a rule, however, an increase

¹ Chief Engineer, Test Laboratory, Atlas Copco.