Macroscopic inclusions of fluid in British fluorites from the mineral collection of the British Museum (Natural History)
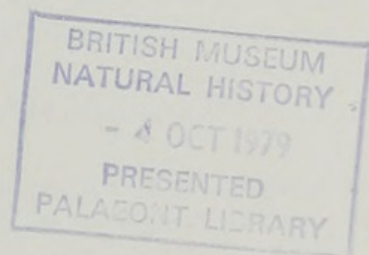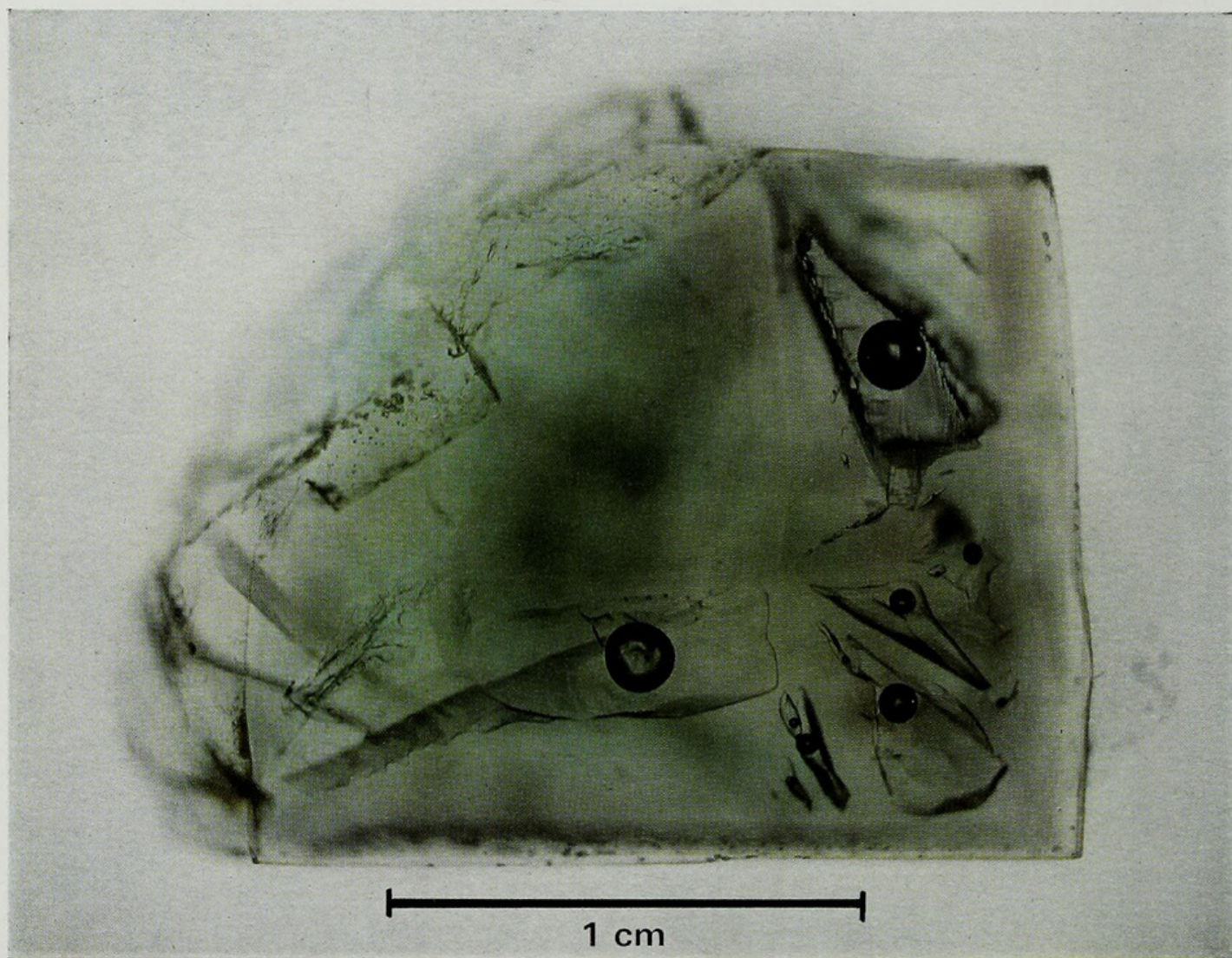
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With photographic contributions by

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Frontispiece

Weardale fluorite containing a group of two phase (gas/liquid) macroscopic inclusions of fluid. BM 56271.

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Contents

Synopsis

Exceptionally large (macroscopic) fluid inclusions are present in 21 fluorite specimens from the mineral collection of the B.M.(N.H.). The maximum size of the inclusions, in three dimensions at right angles to one another, range from $1 \times 1 \times 2$ to $24 \times 17 \times 4$ mm. It is estimated that the largest cavity contains between 1 and $1 \cdot 5$ cm^3 of fluid. They are primary in origin, show no visible signs of leakage and, as such, are suitable for further work on the chemical composition of their contained fluids. Macroscopic inclusions (those whose maximum dimensions at right angles to one another exceed 1 mm) are restricted to fluorite from the Weardale area of the North Pennine orefield; they are absent in fluorite from other British localities.

Introduction

Crystal imperfections range from point defects on the atomic scale to gross defects, including twinning, on the macro scale (Bollman, 1970). To the crystal grower these imperfections cause endless obstacles in his efforts to grow near-perfect crystals (Egli & Johnson, 1961), but to the geologist, gross imperfections, in the form of occluded gases, liquids and solids in minerals, can provide a valuable key to his understanding of the physical and chemical conditions prevailing during the growth of rocks and minerals (Roedder, 1967).

For more than 150 years scientists have been intrigued by the existence of fluid-filled cavities (fluid inclusions) in natural crystals, but before the development of suitable high resolution optical microscopes studies were usually restricted to exceptionally large ($>0 \cdot 5$ cm) fluid inclusions in minerals (for example, Boyle, 1672; Davy, 1822; Hidden, 1882). In recent years, however, the

majority of fluid inclusion studies* have been concerned with the more common microscopic (< 100 μm) cavities, and although these have contributed greatly to the formation of current ideas on the nature and gross composition of ancient mineral-forming fluids (Roedder, 1967 and 1972), they have failed to provide much in the way of useful quantitative information on the chemical composition of individual fluid inclusions. This is perhaps understandable when one considers that a spherical inclusion 100 μm in diameter contains no more than 5×10^{-5} cm^3 of fluid. The problems involved in the extraction and quantitative analysis of such minute quantities of fluid are, at present, almost insurmountable (it is possible, however, with ultra-sensitive, non-destructive, analytical techniques, such as neutron activation analysis, to obtain quantitative data on certain elements present in unopened inclusions, though serious problems of contamination from the host mineral are inherent in these methods).

The most obvious solution to these analytical problems is to sample exceptionally large (macroscopic) fluid inclusions which would provide a larger, more usable volume of fluid. With this object in mind the fluorite crystals in the mineral collection of the B.M.(N.H.) were examined. This paper will provide the results of the first part of this investigation, that is, a description of the size, distribution, abundance and physical characteristics of the most notable macroscopic inclusions. In addition, the origin and significance of such inclusions will be discussed. A second paper, to be published elsewhere, will provide chemical analysis of the fluid contained in certain of the fluorites described.

Before considering these inclusions, it is necessary to consider some of the more important general characteristics of fluid inclusions in minerals.

Fluid inclusions in minerals

Size and abundance

Fluid inclusions rarely exceed 1 mm in size (Roedder, 1967), and those whose contents are clearly visible to the unaided eye are exceptionally rare. Most are smaller than 100 μm and, according to Roedder (1967), could conceivably range in size down to the dimensions of single dislocations (2 Å).

Deicha (1976) refers to fluid inclusions as *macroscopic* if they exceed 1 mm in size, *microscopic* if they fall within the size range 1 mm to 1 μm and *nanoscopic* if they are less than 1 μm. This convention has been adopted in this paper.

The abundance of fluid inclusions depends to a large extent on the physical and chemical conditions prevailing during, and after, the growth of the host crystal, and on the size of the inclusions. To illustrate this latter point, let us assume fluid inclusions occupy 0·1% of the volume of a given crystal, and that these inclusions are cubic in shape. Table 1 shows the maximum number of inclusions of a particular size that can be accommodated per unit volume of a crystal. It is apparent that this number increases dramatically with decrease in inclusion size.

Table 1

Average inclusion size	Maximum number of inclusions per cubic centimetre occupying 0·1% of volume
1 mm	1
100 μm	10^3
10 μm	10^6
1 μm	10^9

Morphology and gross composition

Fluid inclusions exhibit a variety of different shapes. They may be *well-formed* with a regular 'negative crystal', tubular, ovoid or spheroidal morphology, or highly irregular with complex

* For up-to-date information on the extensive literature on fluid inclusion the reader is referred to the yearly publication of abstracts, Proceedings of COFFI, Fluid inclusion research.
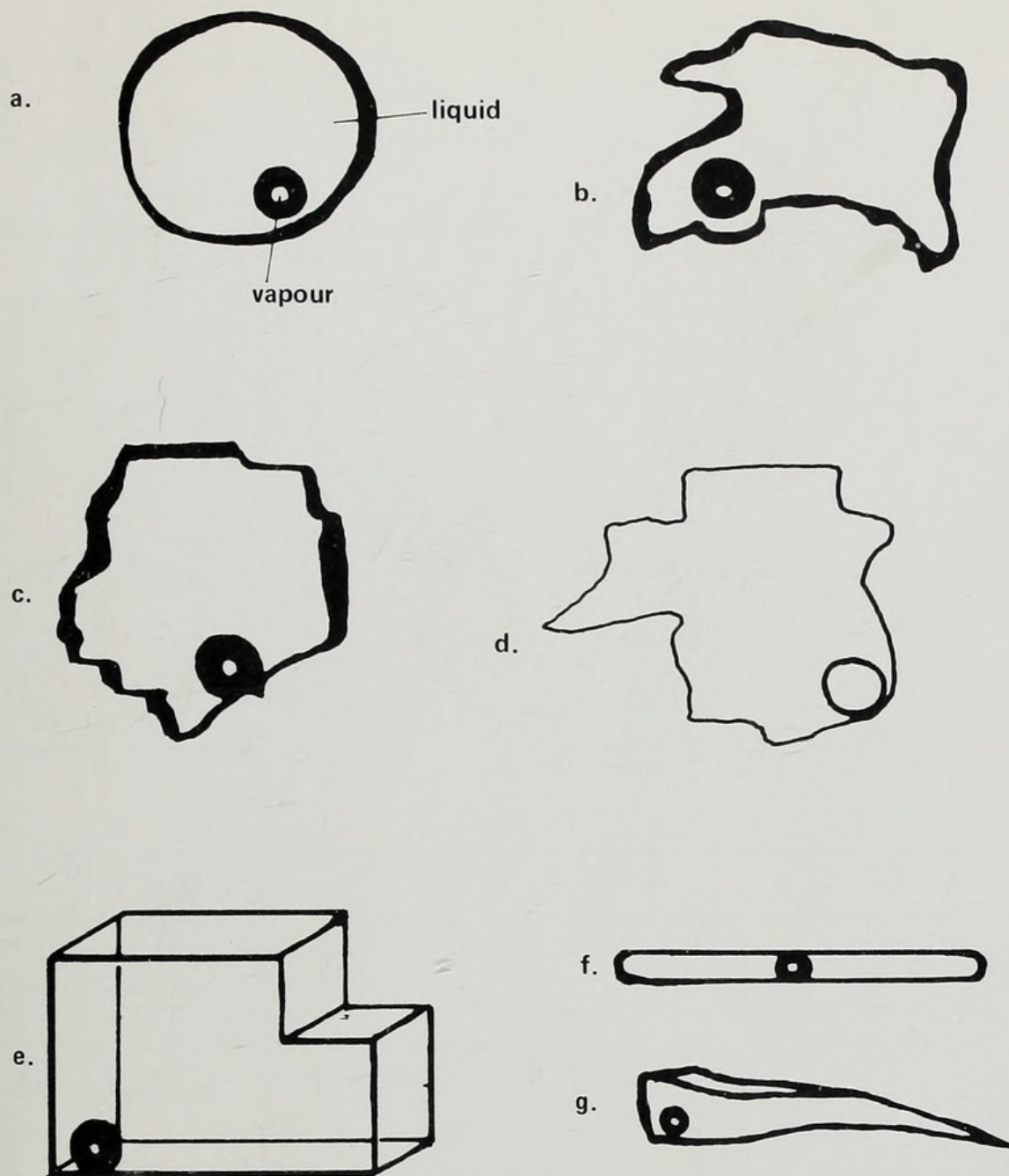
Fig. 1 Some common morphologies of fluid inclusions in fluorite. (a) Spheroidal; (b) irregular; (c) semi-regular, faceted; (d) flattened, irregular; (e) negative crystal (cubic); (f) tubular; (g) tapered. Note all inclusions are two-phase (vapour-liquid). The vapour bubble in (d) is flattened.

shapes. The different fluid inclusion morphologies most commonly encountered in fluorite are illustrated in Fig. 1.

At room temperatures most fluid inclusions in minerals formed by hydrothermal processes in the presence of homogeneous aqueous fluids contain a vapour bubble in addition to an aqueous brine (liquid phase). These bubbles generally owe their origin to the differential shrinkage of the contained fluid and host mineral during cooling from the higher temperature at which they were trapped (Fig. 2a); the coefficient of volumetric thermal expansion of minerals such as quartz and fluorite is exceedingly small in relation to that of the aqueous fluids. H. C. Sorby was one of the earliest mineralogists to recognize the significance of the vapour bubbles. He realized that by re-heating the specimen and recording the temperature at which the liquid and vapour phases re-homogenized an estimate of the minimum formation temperature of the host mineral could be obtained. His comprehensive paper on the subject, published in 1858, laid the foundation for the now widely used method of fluid inclusion geothermometry.

A   B

T$_1$

T$_2$

T$_3$

T$_4$

Decreasing Temperature
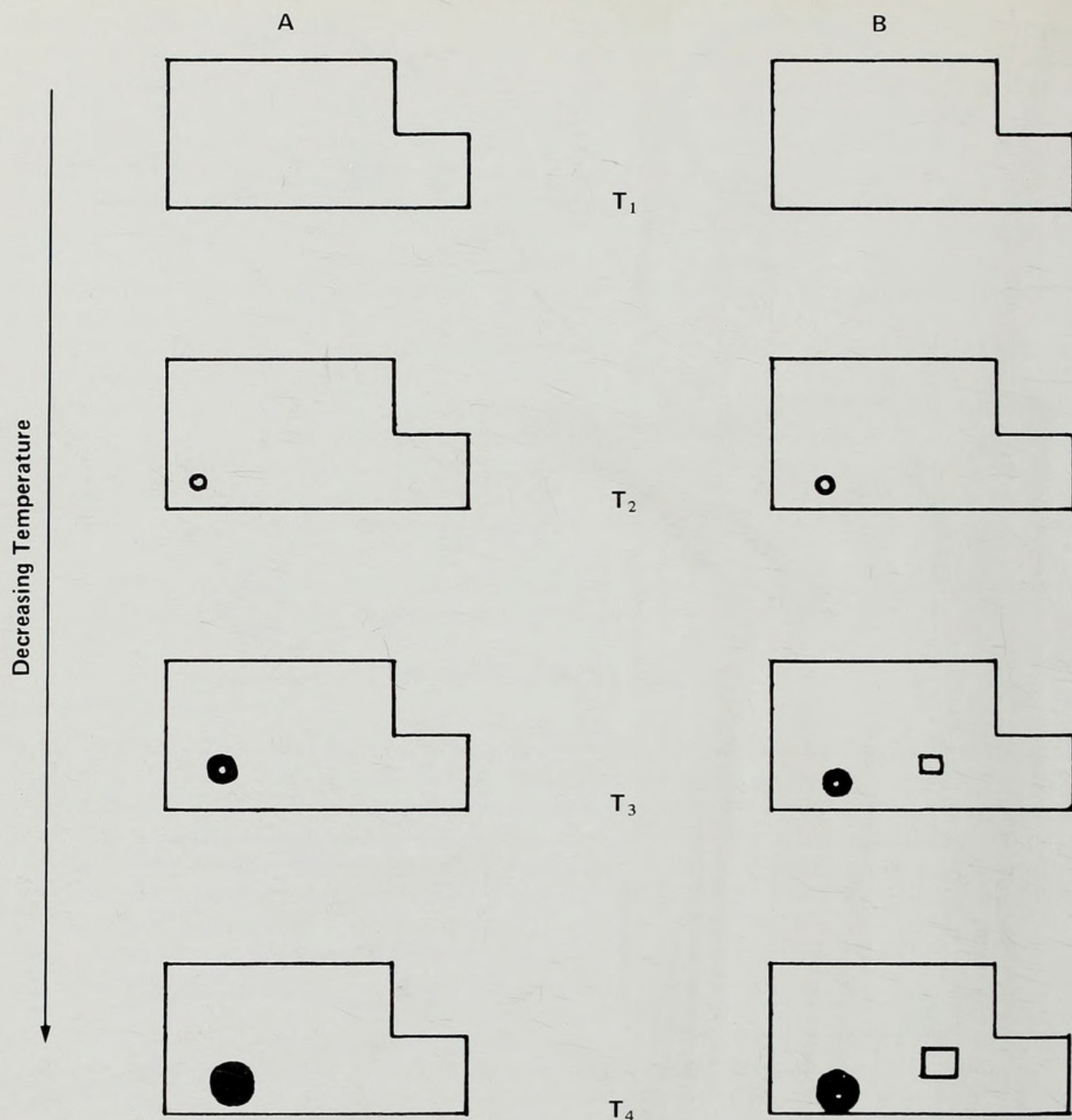
Fig. 2 Development of a contraction vapour bubble and a daughter mineral in fluid inclusions. As the inclusion cools from its temperature of trapping (T$_1$), a vapour bubble nucleates at temperature T$_2$ and continues to grow in size on cooling from T$_2$ to T$_4$ (room temperature). A small daughter phase also develops on cooling in the more saline brine contained in inclusion B. If inclusions A and B are reheated, their contents re-homogenize at temperatures slightly above T$_2$. This gives an estimate of the minimum formation temperature of the inclusion, and, if it is primary, of the host mineral, and forms the basis for fluid inclusion geothermometry.

Fluid inclusions trapped from high density, homogeneous, concentrated brines often contain *daughter minerals*. These are observed at room temperatures because the solubility of components in fluid inclusions, such as NaCl and KCl, decreases with temperature. As the trapped fluid cools from the temperature at which the inclusion formed, a point is reached at which the fluid becomes saturated with respect to these components, and crystalline phases begin to precipitate (Fig. 2B).

Some fluid inclusions contain liquid and vapour phases other than, or in addition to, aqueous
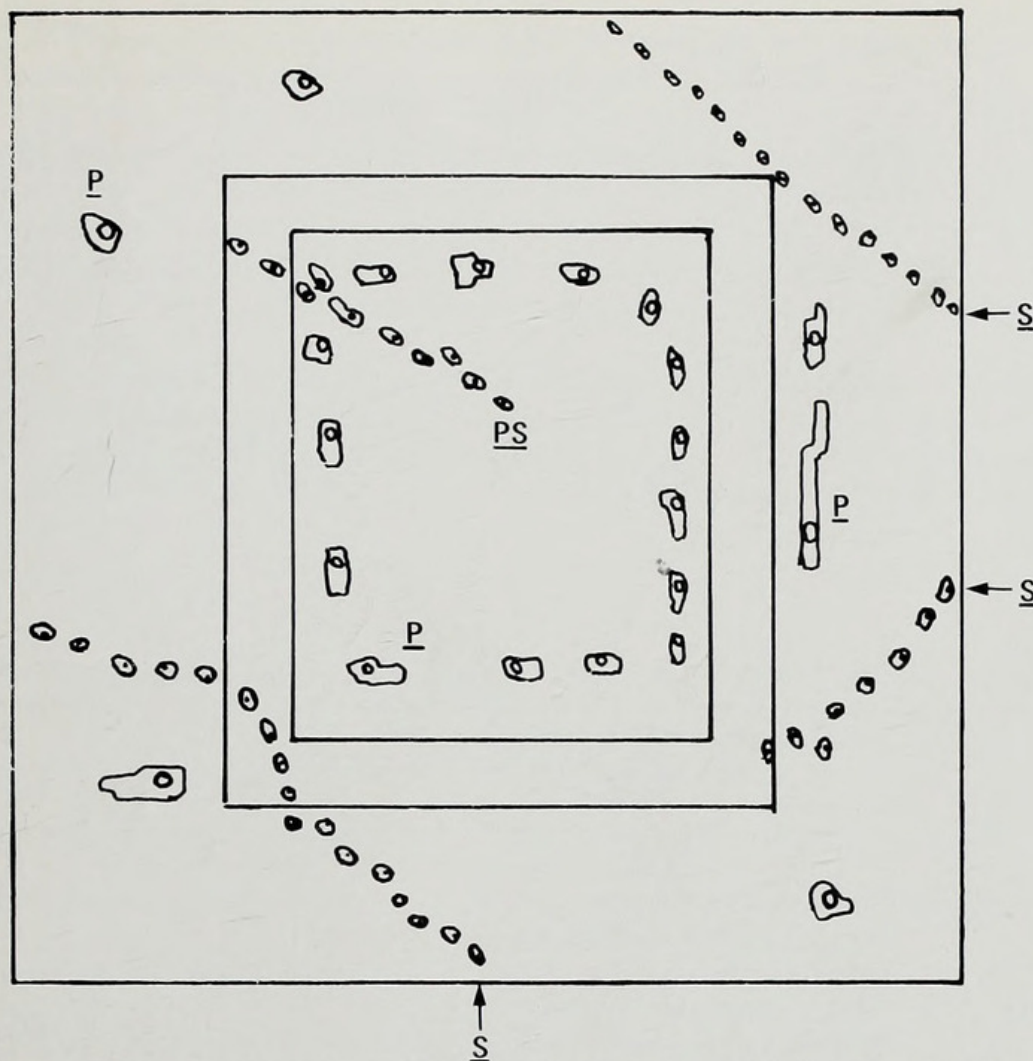
Fig. 3 Diagrammatic representation of the distribution of P, PS and S inclusions in a section through a cubic crystal of fluorite.
Secondary and pseudosecondary (S and PS) inclusions occur in planes which traverse growth zones. Primary (P) inclusions occur either as isolated cavities, unrelated to fractures, or in planes parallel to, and within, growth zones.

brines and water vapour. The most common is carbon dioxide, but hydrocarbons and hydrogen sulphide have also been reported (Roedder, 1972).

Origin
Three different genetic classes of fluid inclusions are generally recognized (Fig. 3). These are termed primary (P), secondary (S) and pseudosecondary (PS). Primary inclusions are those formed during the primary growth of a crystal. Secondary inclusions are formed after growth has terminated, usually as a result of healing of post-depositional fractures within a crystal. Pseudosecondary inclusions are those formed by healing of a fracture before primary growth has terminated. The common distribution of these three classes of inclusions is shown diagrammatically in Fig. 3. Plate 1 shows the cross-cutting relationship of different generations of microscopic inclusions in fluorite from Illinois. When studying samples containing an abundance of micro-inclusions it is often difficult to distinguish between these three different types of inclusions. Fortunately, it has been possible in this present study to classify with confidence all the macro-scopic inclusions.

Leakage and 'necking down'
It is generally assumed that the composition of primary fluid inclusions approximates in com-position to that of the fluid from which the host mineral crystallized, provided that fluid has not
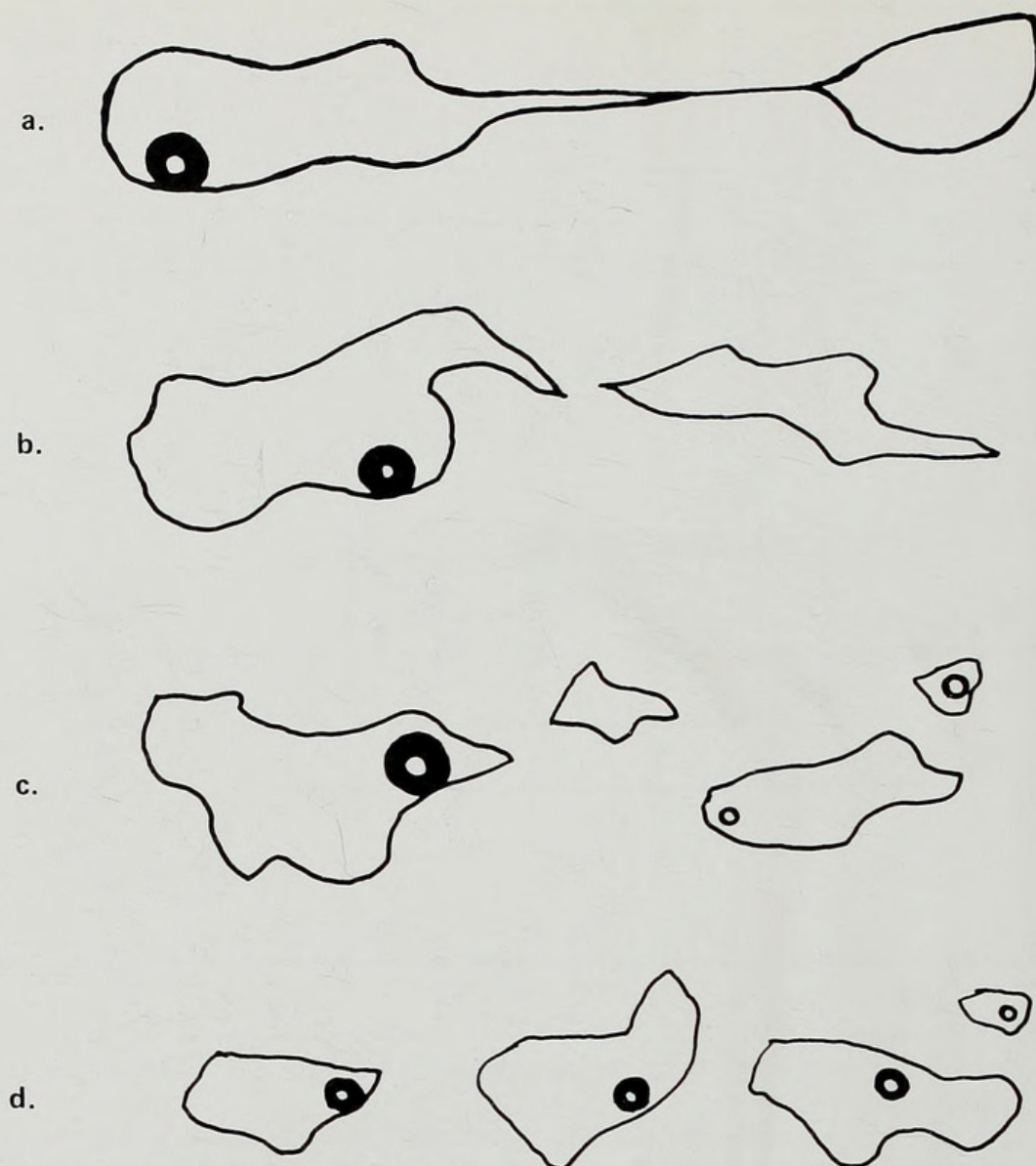
Fig. 4 'Necking down' of fluid inclusions.
    (a) Partial 'necking down'. Two portions of the inclusion (one with a vapour bubble) are connected by a thin tube of fluid. (b) Completely necked inclusions. One portion contains a vapour bubble, the other does not (complete necking down has taken place below the temperature of formation of the inclusion). (c) Several 'necked down' inclusions. The vapour bubbles occupy different volumetric proportions of each of the cavities. (Necking down has taken place at different temperatures.) (d) Several 'necked down' inclusions. The vapour bubbles occupy the same volumetric proportion of each of the cavities. (Necking down has taken place at approximately the same temperature.)

subsequently leaked into or out from the inclusion. Roedder (1967) has dealt fully with this subject, and points out that there is indisputable evidence that some inclusions have leaked and that others have remained sealed. It is usually possible to recognize inclusions which have leaked, but difficult to judge whether partial leakage has occurred.

    Roedder (1967) has also described the common phenomenon, referred to as 'necking down', whereby larger, irregular inclusions tend to split up into a series of smaller, more regular portions. This, however, makes little difference to the composition of the fluid, but can markedly affect the results of homogenization temperature determinations (Fig. 4).

Macroscopic fluid inclusions in fluorite

All available British fluorite samples in the collection were examined with the naked eye for the presence of macroscopic fluid cavities. Inclusions smaller than 1 mm in less than three directions,

at right angles to one another, were not considered. A hand lens and binocular microscope were used to determine the size, shape and contents of the inclusions.

The major deficiency of this procedure is that only clear, light-coloured fluorites could be studied; translucent or deeply coloured specimens could not be examined (at least, without immersing them in a liquid of suitable refractive index, such as kerosene). It is also possible that macroscopic inclusions deep within large crystals were not detected. However, these are likely to be relatively small (1–4 mm). There are also other specimens with fluorite as an accessory mineral. These could not be considered in the time available. Only those specimens catalogued as fluorite were studied.

Macroscopic inclusions were located in 21 fluorite samples. Nine of these specimens are in the Russell collection (Table 2) and 12 in the main collection (Table 3). All of these fluorites are from the North Pennine orefield, more specifically, with the possible exception of specimen BM 88944, Weardale. The significance of this observation will be discussed in the following section.

Table 2 British fluorite specimens from the Russell Collection containing macroscopic fluid inclusions

Sample Number*	Locality given on specimen label	Description (and approximate size of crystal containing the macroinclusions)
1414	Bolt's Burn mine, Weardale	Purple green cube (4–5 cm³) intergrown with several smaller crystals
1443	Bolt's Burn mine, Weardale	Green, twinned cube (2·5 cm³) intergrown with several other similarly sized crystals
1534a	Height's mine, Weardale	Green, twinned cube (3·5 cm³)
1538	Weardale	Green, twinned cube (1·5 cm³)
1539	White's level, Westgate, Weardale	Green twinned, cube (2·5 cm³)
1540	White's level, Westgate, Weardale	Green, twinned cube (2 cm³)
1541	Weardale	Green, twinned cube (1·5 cm³)
1542	Weardale	Green, twinned cube (1·5 cm³)
1559	Burtree pasture mine, Weardale	Purple, twinned cube (3·5 cm³)

* All numbers are prefixed by BM 1964R.

Table 3 British fluorites from the main collection containing macroscopic fluid inclusions

Sample Number	Locality given on specimen label	Description (and approximate size of crystal containing the macroinclusions)
BM 1907, 433	Bolt's Burn mine, Weardale	Purple, twinned cube (3·5 cm³)
BM 33216	Weardale	Green, twinned cube (3 cm³)
BM 40238	Weardale	Green, twinned cube (2·5 cm³)
BM 46482	Weardale	Green, twinned cube (2 cm³)
BM 56268	Height's mine, Weardale	Green, twinned crystal (2 cm³) intergrown with several smaller crystals
BM 56269	Weardale	Green, twinned cube (2 cm³)
BM 56270	Weardale	Green, twinned cube (2 cm³)
BM 56271	Weardale	Green, twinned cube (2 cm³)
BM 56313	Weardale	Green, twinned cube (2 cm³)
BM 69124	Weardale	Pale purple, twinned cube (2 cm³)
BM 88944[1]	Alston or Weardale	Pale yellow, twinned cube (2 cm³)
	Height's mine, Weardale[2]	Green, twinned cube (1·5 cm³)

[1] Locality of the specimen was originally given as Alston, but later changed to Weardale (?).
[2] This specimen is a duplicate and has not been assigned a B.M. number.

The number and size of the inclusions in each of the samples is given in Tables 4 and 5. Size refers to the three maximum dimensions of the cavity, at right angles to one another. The maximum number of macroscopic inclusions seen in any one crystal is seven (BM 56271). Most commonly, however, individual crystals contain only one such inclusion. The largest inclusion (in

Table 4   Number and size of macroscopic fluid inclusions in fluorites from the Russell Collection

Sample Number BM 1964R	Number of inclusions	Approximate dimensions (mm)	Comments
1414	1	$7 \times 2 \times 2$	Note 1
1443	1	$24 \times 17 \times 4$	Note 2
1534a	2	$3 \times 2 \times 2$ $3 \times 2 \times 2$	Note 3
1538	1	$5 \times 2 \times 2$	Note 4
1539	1	$4 \times 2 \times 1$	Note 3
1540	1	$7 \times 4 \times 2$	Note 5
1541	1	$8 \times 3 \times 2$	Plate 4A
1542	1	$10 \times 4 \times 2$	Plate 4B
1559	1	$7 \times 3 \times 2$	Plate 5B

Notes
1. Microscopic inclusions have necked-down from this inclusion.
2. Inclusion is flattened parallel to the uppermost cube face of the crystal.
3. Internal fractures are common but do not traverse the inclusion.
4. Inclusion roughly elongate parallel to one of the cube crystal faces.
5. Inclusion walls show stepped growth.

Table 5   Number and size of macroscopic fluid inclusions in fluorite from the main collection

Sample Number BM	Number of inclusions	Approximate dimensions (mm)	Comments
1907,433	1	$4 \times 3 \times 3$	Plate 3, note 1
33216	4	(a) $6 \times 4 \times 2$, (b) $4 \times 3 \times 2$ (c) $3 \times 1 \times 1$, (d) $4 \times 3 \times 3$	Note 2
40238	3	(a) $5 \times 2 \times 1$, (b) $2 \times 1 \times 1$ (c) $3 \times 3 \times 1$	Plate 6B
46482	1	(a) $4 \times 1 \times 1$	Plate 6A
56268	5	(a) $5 \times 2 \times 1$, (b) $5 \times 1 \times 1$ (c) $3 \times 2 \times 1$, (d) $3 \times 2 \times 1$ (e) $3 \times 1 \times 1$	Note 3
56269	3	(a) $11 \times 6 \times 4$, (b) $6 \times 3 \times 2$ (c) $4 \times 2 \times 1$	Plate 7
56270	1	$14 \times 6 \times 5$	Plate 8
56271	7	(a) $12 \times 3 \times 2$, (b) $6 \times 5 \times 3$ (c) $2 \times 2 \times 2$, (d) $3 \times 3 \times 1$ (e) $4 \times 3 \times 1$, (f) $4 \times 2 \times 1$ (g) $2 \times 1 \times 1$	Plate 9, note 4
56313	2	(a) $8 \times 3 \times 2$, (b) $2 \times 1 \times 1$	Plate 2, note 5
69124	1	$13 \times 5 \times 4$	Plate 5B
88944	1	$4 \times 1 \times 0.5$	Note 6
Duplicate	1	$3 \times 2 \times 2$	Note 7

Notes
1. Dimensions refer to the equant portion only.
2. Inclusions a, b, c occur in the larger of the two cubes comprising the twin. Inclusion d is in the smaller cube.
3. The inclusions occur in a planar grouping parallel to one cube face.
4. Several smaller (0·5 to 1 mm) inclusions are also present.
5. Several other smaller, tubular inclusions are present. Their length is 1 to 2 mm and width less than 0·5 mm.
6. One smaller inclusion has necked down from this larger cavity.
7. Small monophase liquid inclusions have necked from the macroscopic inclusion.

sample 1443, Russell collection) has a maximum dimension of 2·4 cm, and occupies between 5 and 10% of the total volume of the host crystal. It contains between 1 and 1·5 cm³ of fluid.

Most of the inclusions possess complex, irregular morphologies which can be only be described as amoeboid; many are roughly elongate or flattened parallel to the external cube faces of the crystal. In no instance can the inclusions be described as roughly equant or true negative crystals. In detail, parts of the cavity walls are aligned with distinct crystallographic directions within the crystal; most commonly the cube directions {100}, {010}, {001}, less commonly the octahedral directions, {111}, {11$\bar{1}$}, {$\bar{1}$11}, {1$\bar{1}$1}. The larger inclusion in sample BM 56271 (Plate 9) exemplifies this tendency towards shapes governed by crystallographic directions.

All the inclusions contain a mobile vapour bubble in addition to the aqueous fluid. This occupies less than about 10% of the total volume of the cavity, but, because of the irregular shape of the inclusions, it is not possible to give a more precise estimate. The diameter of the vapour bubble is 3·5 mm in the largest inclusion (1443, Russell). Whether the bubbles are composed entirely of water vapour is not yet known. Two inclusions from different samples (BM56269 and BM 56270) contain a mass of small, unidentified crystals (Plates 7 & 8). These crystals are probably a captured phase and not true daughter minerals.

Without exception the inclusions are believed to be primary in origin, because:
  (i) they are large in relation to the size of the host crystal;
  (ii) they are commonly aligned roughly parallel to external faces of the host crystal;
  (iii) when coloured growth zones are present the inclusions occur within a particular growth zone and do not extend into other growth zones.

In some samples, microscopic inclusions are closely associated with the macroscopic inclusions. Usually it is possible to demonstrate (Plates 3, 7 & 8) that these represent necked-down portions of the larger cavity.

Obvious signs of leakage of the contents of the macroscopic inclusions, such as an anomalously large vapour bubble, or the presence of small fractures leading from the inclusion to the crystal surface are, with one exception (BM 56270), absent. In this specimen (Plate 8) a fracture, now healed, traverses the inclusion, but, instead of leading to the crystal's surface, terminates abruptly at the outer colour growth zone. Evidently, fracturing took place after growth of the central portion of the crystal containing the inclusion, but before the growth of the outermost portion. Because leakage took place before primary growth had ceased, the inclusion contents are still primary at least with respect to the outer crystal zone.

Discussion

This study has shown that all the macroscopic fluid inclusions are suitable for chemical analysis, because they are primary in origin and do not appear to have leaked. Their characteristics are no different from the more common microscopic inclusions apart from their unusually large size.

With the possible exception of one sample (BM 88944), all the fluorites containing macroscopic inclusions (as defined) are confined to the Weardale area of the Northern Pennine orefield. It might be thought that the vast majority of fluorites in the collection are from this area. It can be seen, however (Table 6), that although just under one half of the Russell collection, and approximately one quarter of the main collection fluorites are from Weardale, a large number of fluorites from other localities, all apparently devoid of macroscopic fluid inclusions, constitute the main part of these collections. Two alternative explanations can be proposed:
  1. Because they commonly occur as large (>2 cm) transparent crystals with well-developed crystal faces, Weardale fluorites are more amenable to the methods of study used than less perfect fluorites from other localities. (Considered least likely.)
  2. Growth conditions were more favourable to the formation of large inclusions at Weardale than at other localities in the British Isles. (Considered most likely.)

Roedder (1967), and more recently Deicha (1975), have summarized the factors governing the formation of primary fluid inclusions in minerals. These are complex and varied, but perhaps the simplest explanation is that inclusions form when growth rates are relatively fast (in other words, the degree of supersaturation in the mother liquor is high) (Pamplin, 1975). In essence,

Table 6 Geographical distribution of fluorite samples from the British Isles in the Mineral Collection of the B.M.(N.H.)

	Number of samples (figures rounded to the nearest 5)	
Location	Russell collection	Main collection
Northern England*	490	280
(Weardale localities)	(475)	(160)
Rest of England	470	440
Wales	30	5
Scotland	65	5
Ireland	130	5
Total	**1185**	**635**

* The old counties of Westmorland, Northumberland and Cumberland (now Cumbria) and Durham.

the degree of supersaturation of the solution close to the face of a crystal is lower than at the edges. Edges grow faster than the centre which leads to a depression at the face centre. Covering of the surface during a period of slower growth (lower supersaturations), when growth rates decrease below a critical value, will form an inclusion of mother liquor (see, for example, Denbigh & White, 1966; Belyustin & Fridman, 1968; Brooks et al., 1968; Wilcox, 1968; Petrov et al., 1969). If the degree of supersaturation is very high, the growth rate is also very high and the crystals grow as dendrites.

To produce macroscopic inclusions of fluid it is necessary, therefore, to sustain a uniformly higher degree of supersaturation at the edges of a growing crystal than at the centres of its faces for a prolonged period of time. This can be achieved if material is continually being supplied to the growing crystal by mass flow of fluid as opposed to diffusion (see Roedder, 1967, for discussion). Unfortunately, it is not possible to assess whether the degree of supersaturation of fluid was locally maintained at a higher level for a longer period of time in the Weardale area during the formation of fluorite than at any other British fluorite locality, and this contention must remain speculative. It can be said, however, that mass movement of fluid was indeed important in the formation of the North Pennine fluorite deposits (Smith & Phillips, 1975) and that locally the vertical flow velocity was between 0·5 and 1·0 cm s^{-1} (op. cit.).

Acknowledgements

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Appendix

Photographic procedure

The essential requirements of this study were to obtain clarity of image of the fluid inclusions, which were located at various depths within the fluorite crystals, while retaining, in most instances, some indication of the external morphology. In addition, it was important that colour banding (or zonation) and growth zonation should be rendered as accurately as possible.

Following a suggestion by P. G. Embrey, it was decided to immerse the crystals in a liquid of nearly identical refractive index to the fluorite. Odourless kerosene was used for this purpose. This was contained in a specially constructed 'box' made from transparent optical glass flats.

A vertically mounted monorail, 5 × 7 inch format camera, equipped with Leitz 120, 80, 40 and 20 mm lenses, was used to obtain maximum definition (a smaller format could have been used with little loss of detail). The specimen container was held in, or near, the focus of a pair of glass condenser lenses, selected to match the camera lens in use. An aluminized plane mirror was placed below the condensers at 45° to the camera lens axis, and with the light source at 45° to this (normal to the lens axis). Illumination for focusing was provided by a 600 W quartz halogen source, which was part of the 1400 W electronic flash spotlight used to expose the Agfa half-plate transparency film. This source has a fairly high ultraviolet component, but the glass fresnel lens in the spotlight and various glass surfaces interposed between it and the fluorite crystals successfully prevented unwanted fluorescence.

The kerosene immersion liquid rendered even crystals with surface imperfections (crazed and/or overgrown) transparent; indeed, crystals which, in air, were deeply coloured and translucent, became thoroughly transparent. Its use also resulted in a greatly increased depth of field (the depth of focus was controlled by the selection of the required aperture followed by adjustment of the light reaching the film with neutral filters). The enhanced transparency had one disadvantage, in that crystal boundaries tended to merge with the background. In extreme cases this was overcome by using conventional dark field illumination.

Finally, colour fidelity and consistency were achieved by colour matching the background areas of the transparencies and by visual comparison with the immersed specimens. These colours are visually true. However, it will be understood that they are somewhat different from the colours of the crystals, out of the immersion liquid, in air.

Plate 1

A. Cross-cutting planes of secondary inclusions (the two planes are arrowed) in an octahedral cleavage fragment. Individual inclusions are less than 100 μm. (Photograph taken with oblique illumination.) BM 1931,472. Spar Mountain mine, Hardin Co., Illinois, U.S.A.

B. Planes of microscopic primary inclusions, parallel to the purple colour growth band {100}, cut by later generations of secondary and pseudosecondary inclusions (one of these later planes is shown by the arrow). (Photograph taken in oblique illumination.) BM 1931,469. Spar Mountain mine, Hardin Co., Illinois, U.S.A.
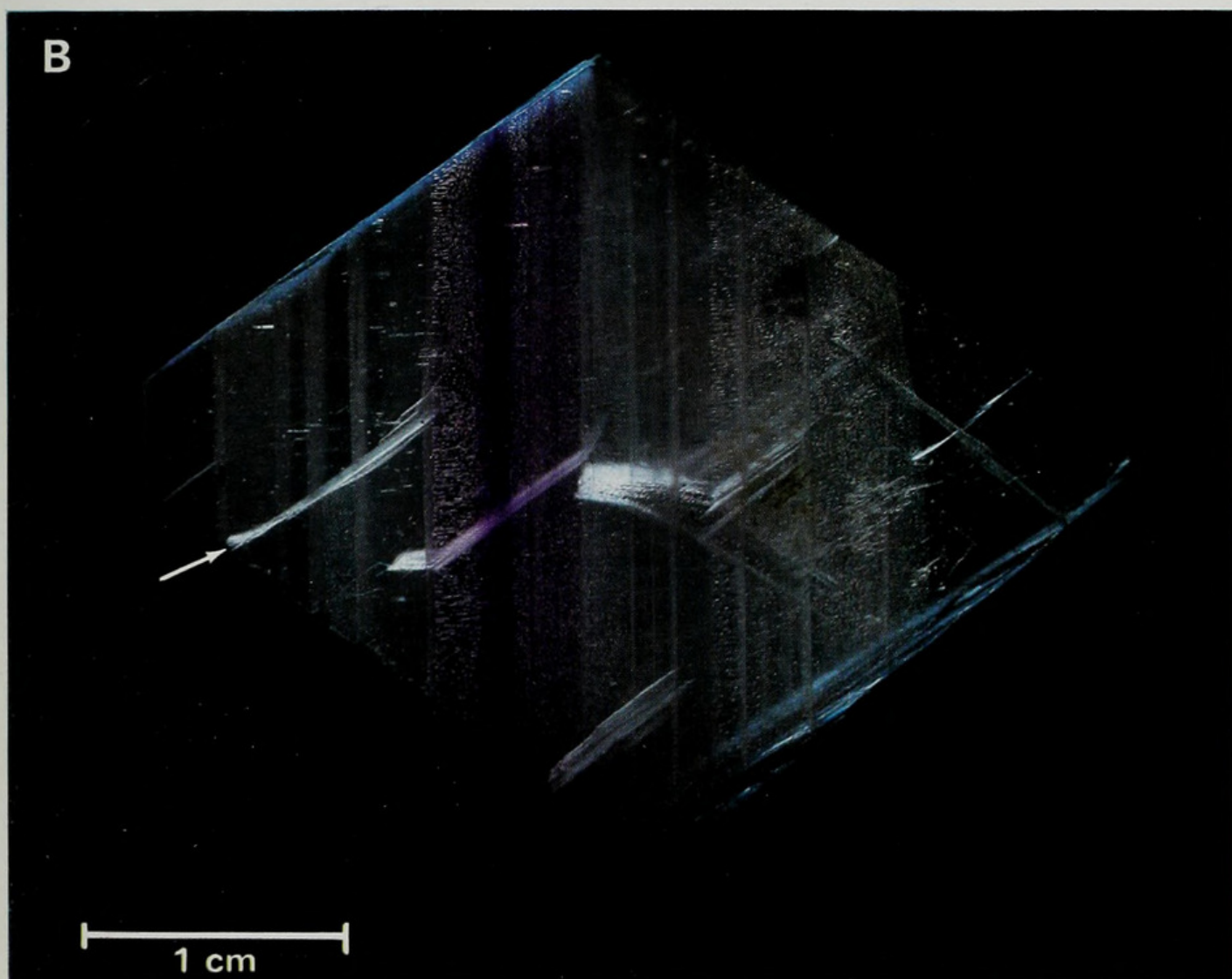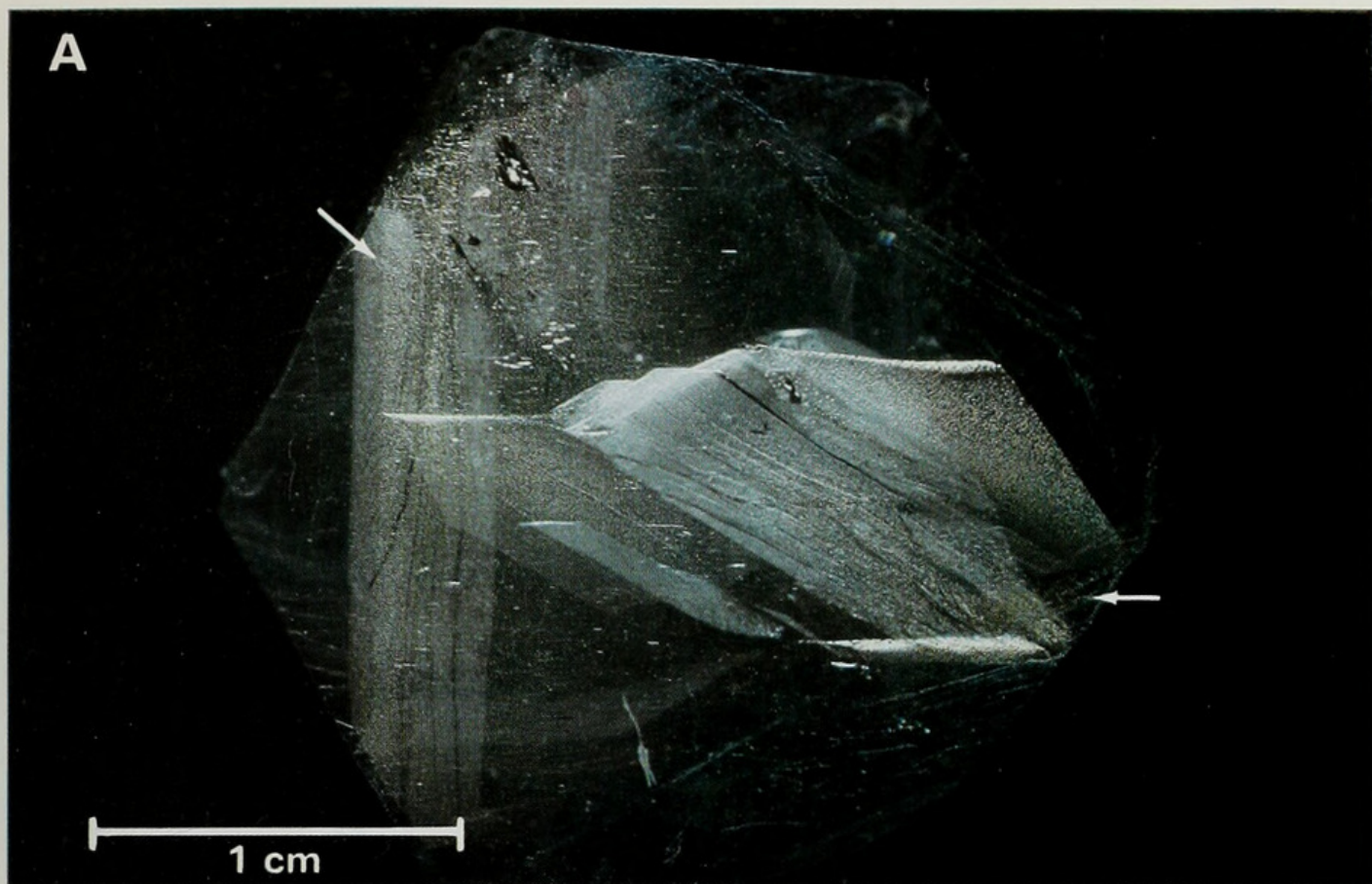
Plate 1

Plate 2

A. BM 56313. Planar group of one large and several smaller inclusions parallel to, and only about 1 mm from, one of the cube faces of the host crystal. (Photograph taken with oblique illumination.)

B. BM 56313. Close-up of a portion of A above showing the main group of inclusions. (Photograph taken with oblique illumination.)

C. BM 56313. As B above, showing details of the inclusions when viewed in a different orientation, and in transmitted light.
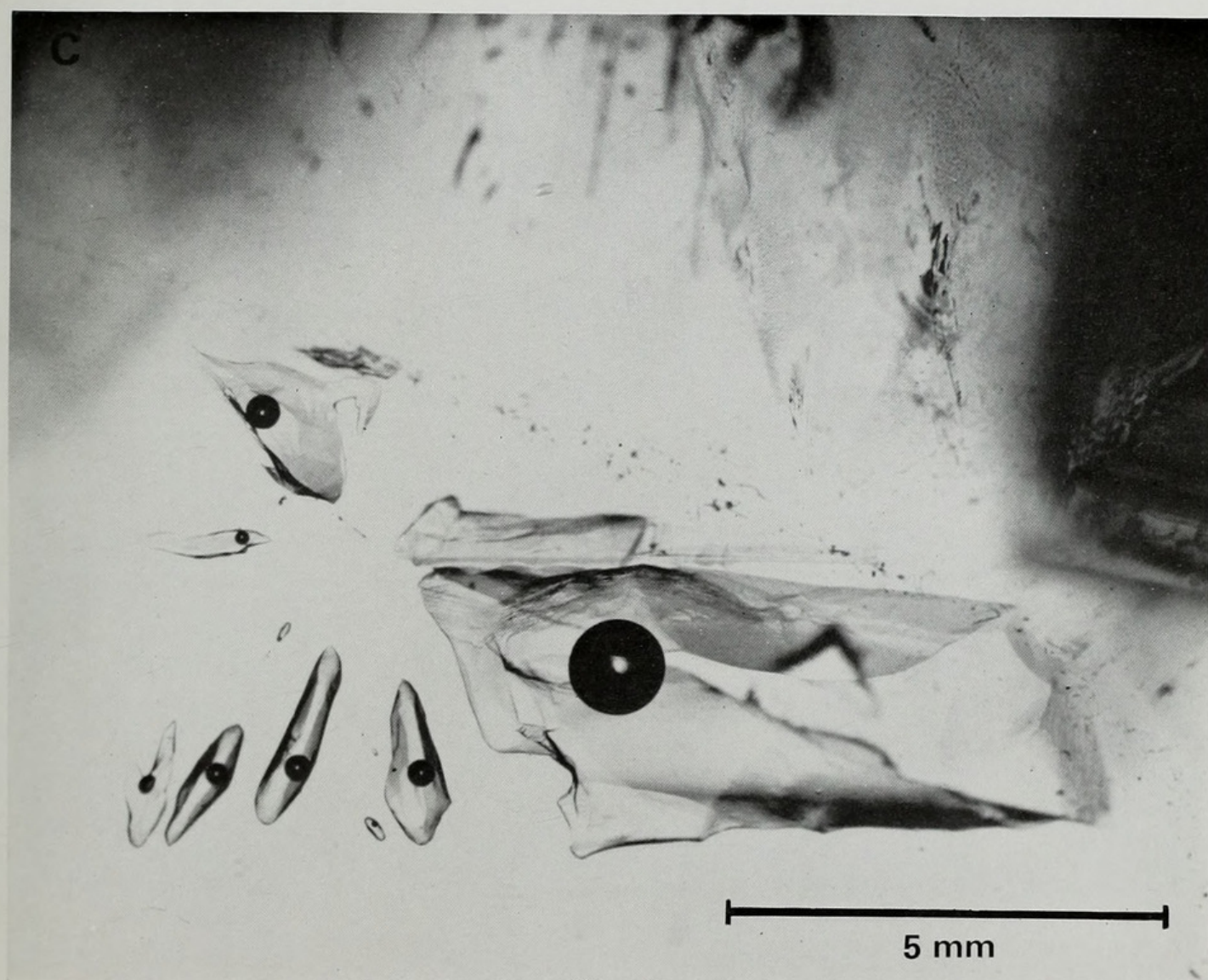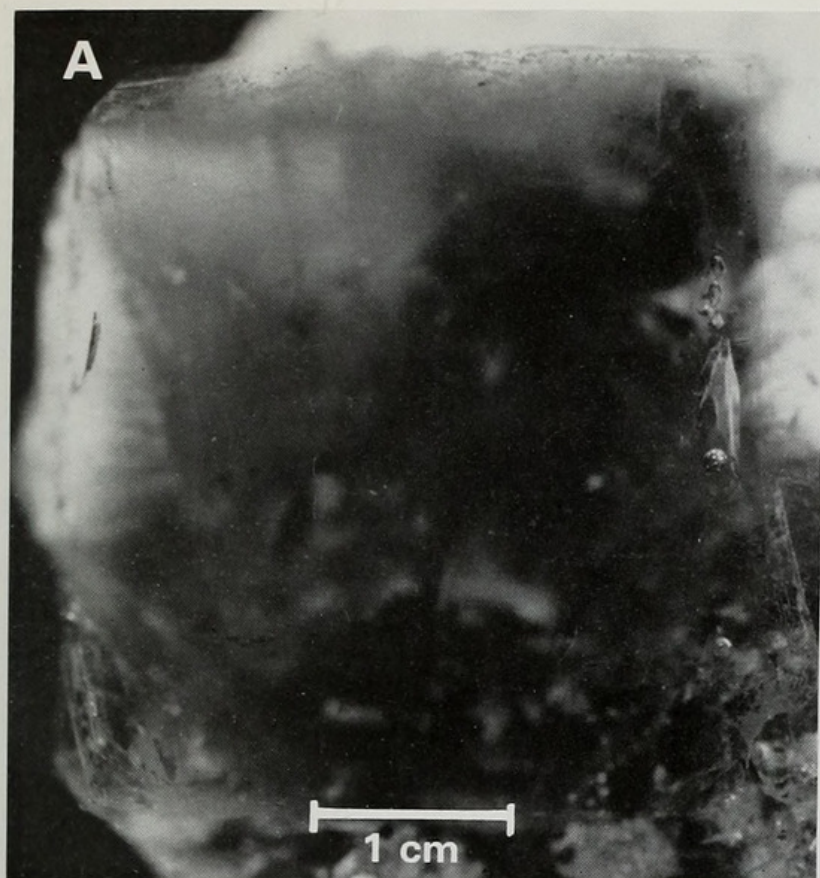
Plate 2

Plate 3

A. BM 1907,433. Complex shaped, two-phase (liquid plus vapour) macroscopic inclusion in well-formed cubic crystal. Although located less than 2 mm from the surface of the crystal, leakage does not appear to have taken place.

B. BM 1907,433. Close-up of A above. The central, well-faceted equant portion of the cavity, which contains the vapour bubble, is connected to a much flatter (0·1 mm in width), more irregular portion. A train of smaller, monophase liquid inclusions (arrowed) have necked down from this larger cavity. Some of the walls of the equant portion of the cavity are parallel to cubic {100} crystallographic directions, others to octahedral {111} directions.

A

B

1 mm
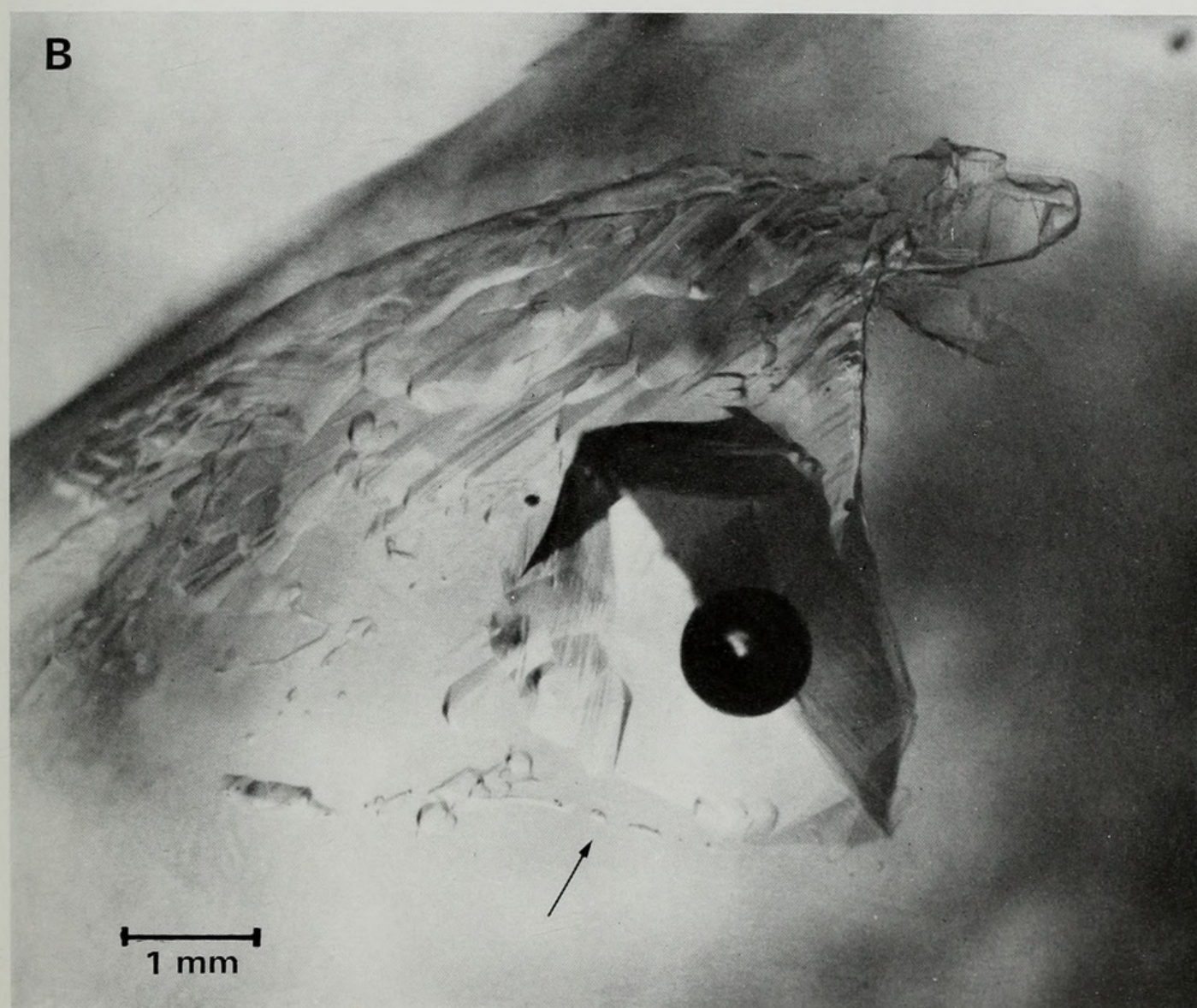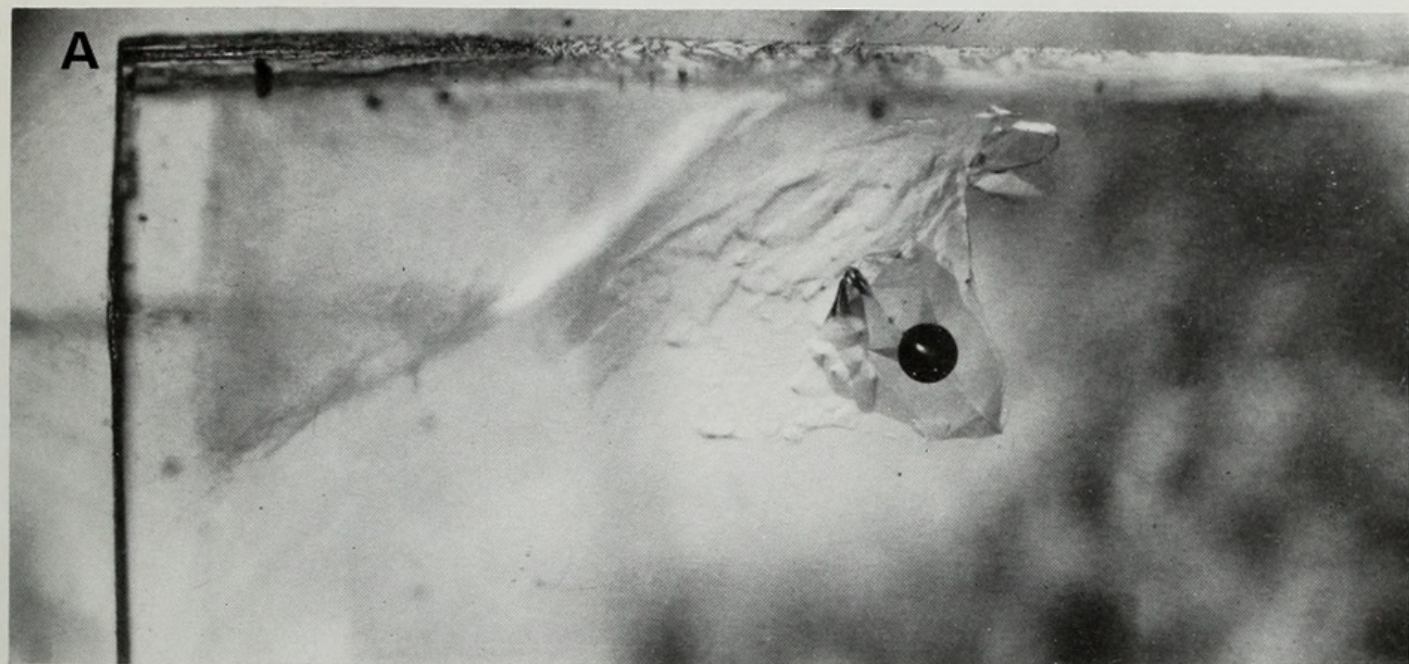
Plate 3

Plate 4

A. BM 1964R,1541. This unusually shaped inclusion is located in the central portion of the zoned crystal. Note how the red-coloured zone 'bends' to accommodate the inclusion. The shape of the cavity is unusual because it is reminiscent of a butterfly with closed wings; the elongate, regularly shaped portion containing the bubble corresponds to the body, and the upper, flat, irregular portion corresponds to the wings.

B. BM 1942,1542. One macroscopic and three smaller inclusions are present. Note the weak colour zonation parallel to the faces of the smaller penetration twin crystal, and the way in which one of the edges of the inclusion is parallel to these growth zones.

A

5 mm

B

5 mm
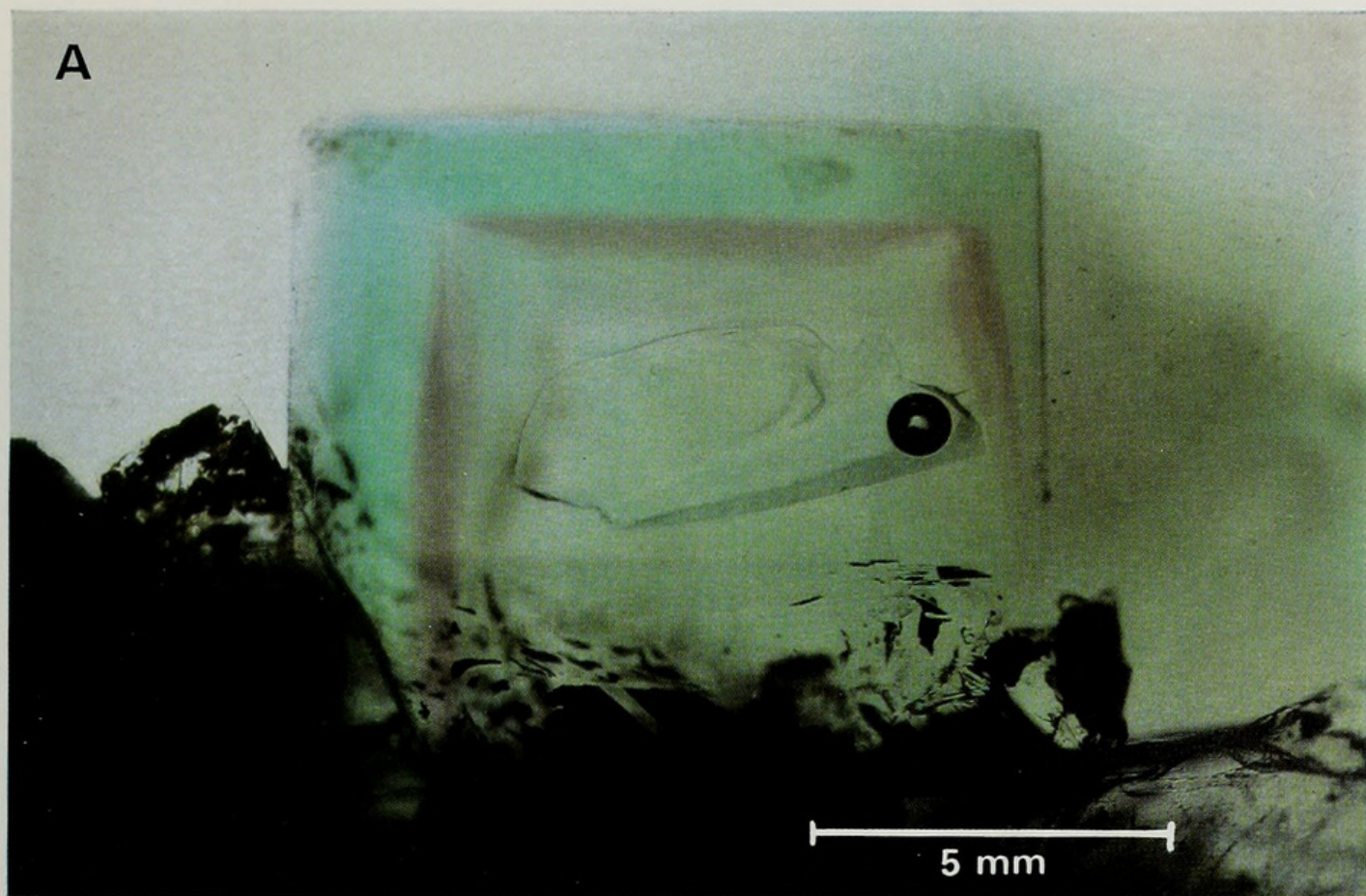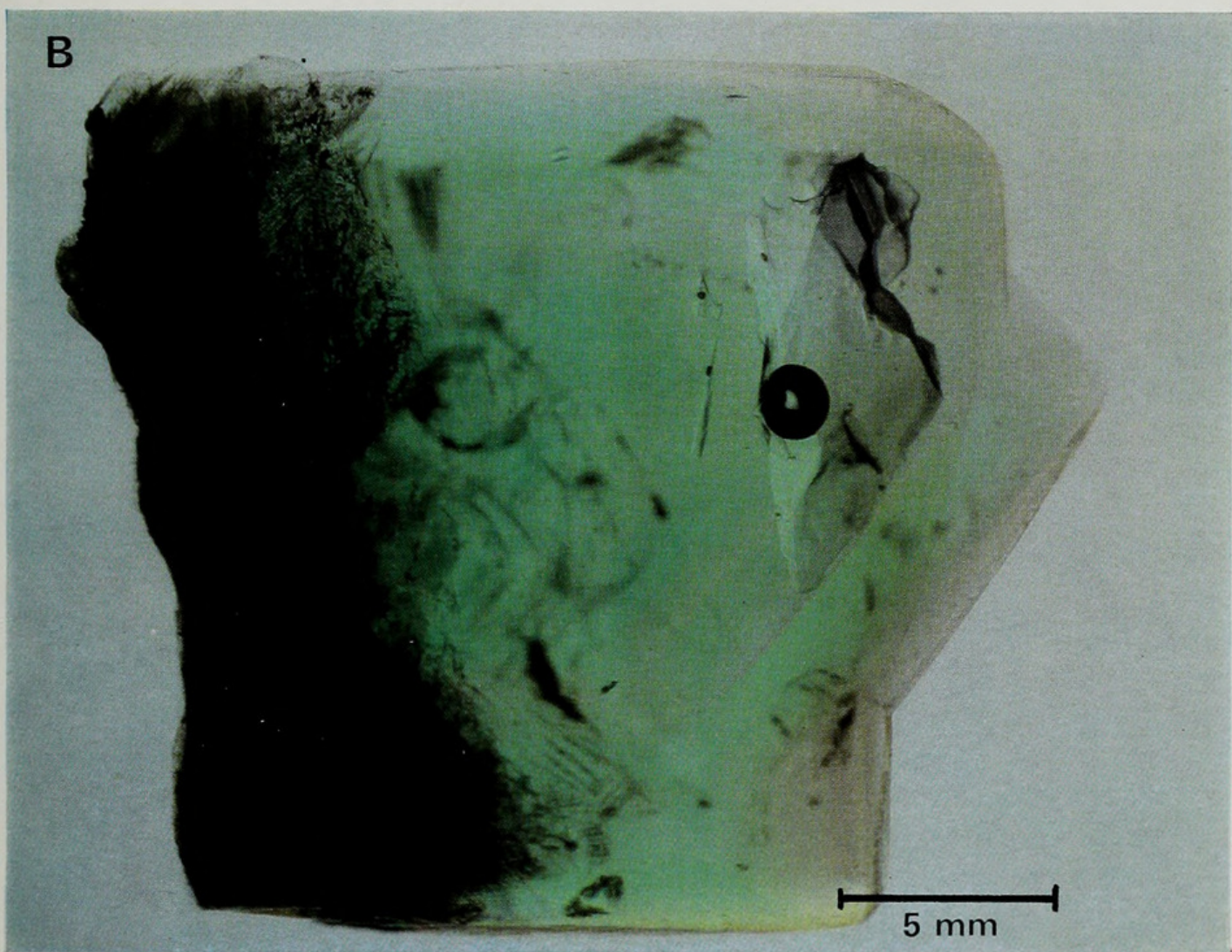
Plate 4

Plate 5

A. BM 1964R,1559. The large inclusion is located in a clear portion of this colour-zoned crystal. The inclusion is elongate in the plane of the paper. The small elongate feature apparently within the inclusion is actually a portion of the inclusion itself extending below the lower wall of the cavity.

B. BM 69124. Purple-zoned crystal (with quartz overgrowth) containing a macroscopic, elongate inclusion parallel to the right-hand cube face of the crystal.

A

1 cm

B

1 cm
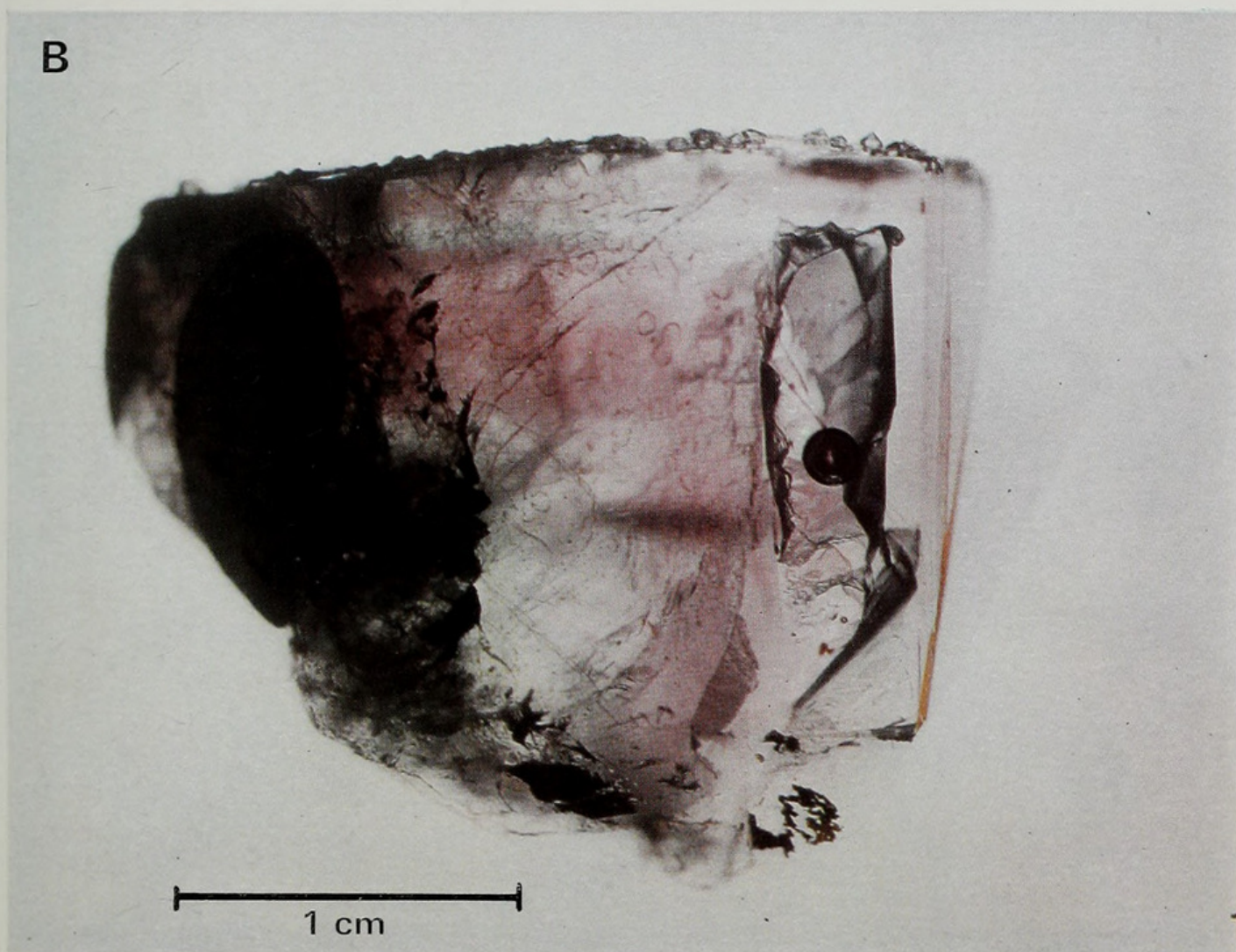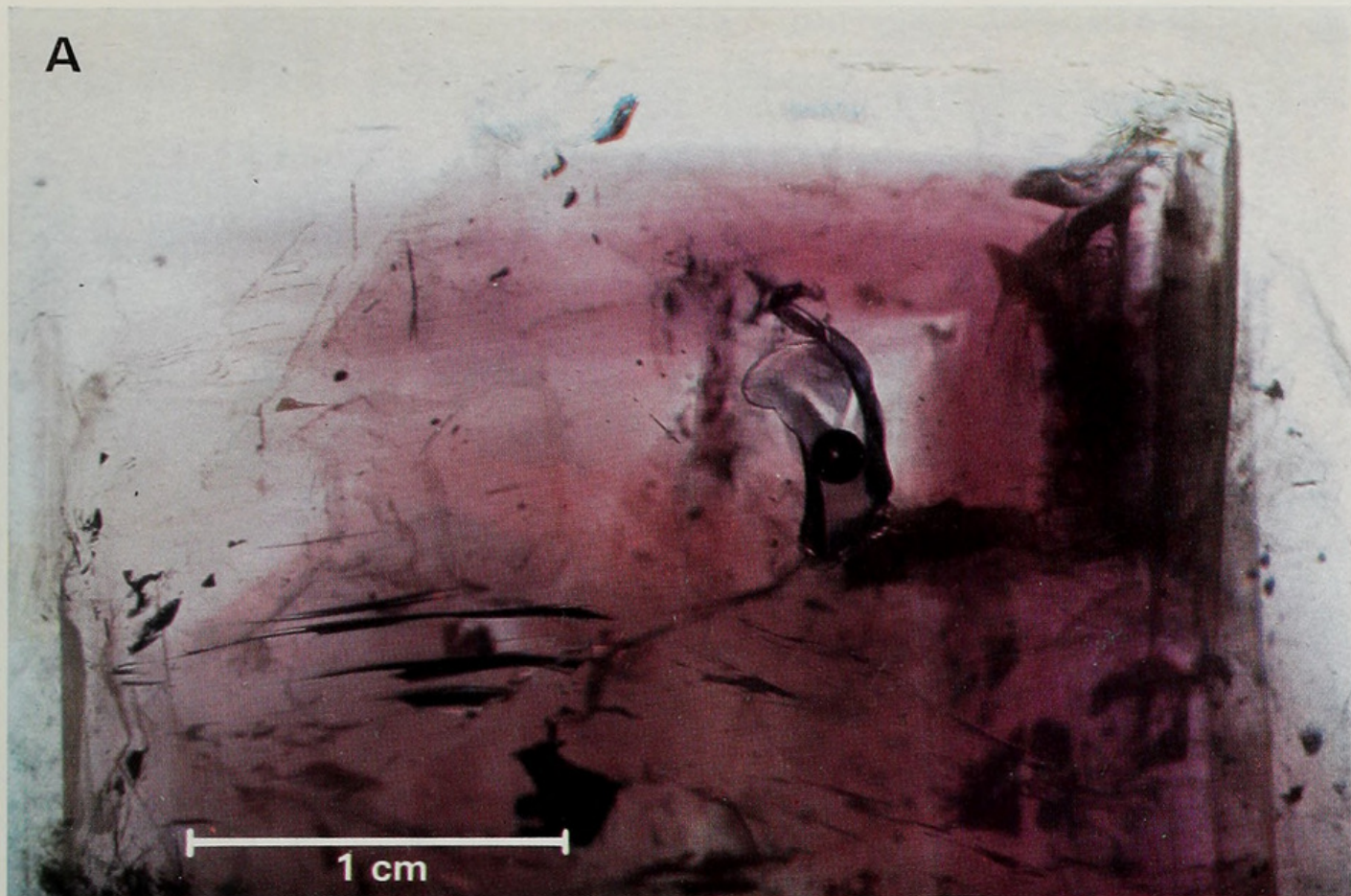
Plate 5

Plate 6

A. BM 46482. The complexly shaped macroscopic inclusion is contained within the clear, inner-most zone of the fluorite. A healed fracture, which under the microscope is seen to consist of numerous secondary microscopic aqueous inclusions, is also apparent (arrowed).

B. BM 40238. A group of three irregularly shaped macroscopic inclusions occurs in the centre of the fluorite crystal. The largest inclusion appears to contain two vapour bubbles, but the smaller bubble belongs to the third inclusion.
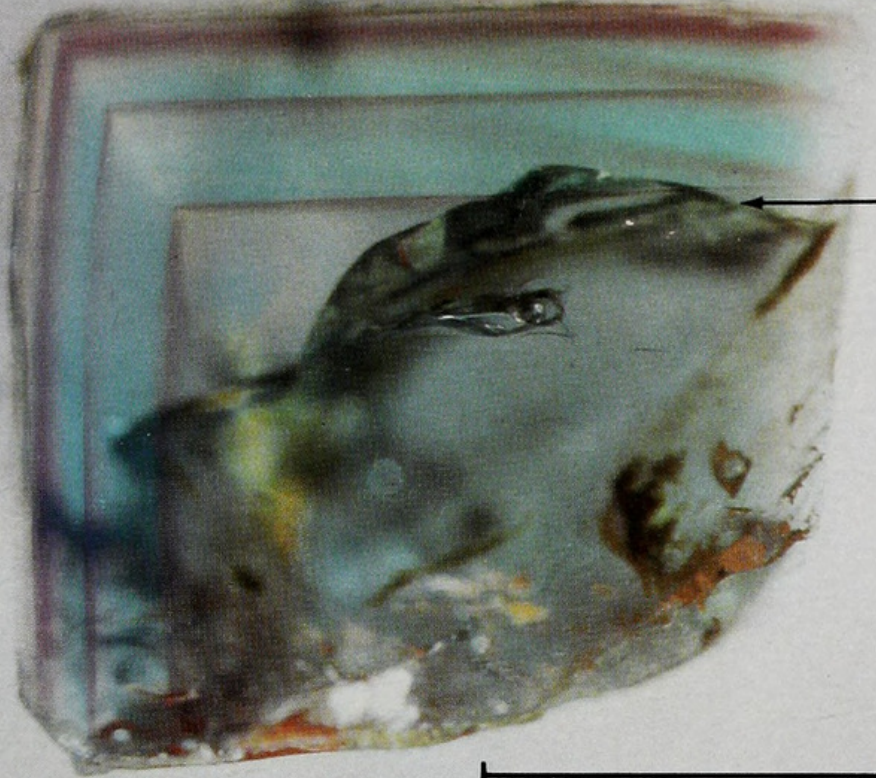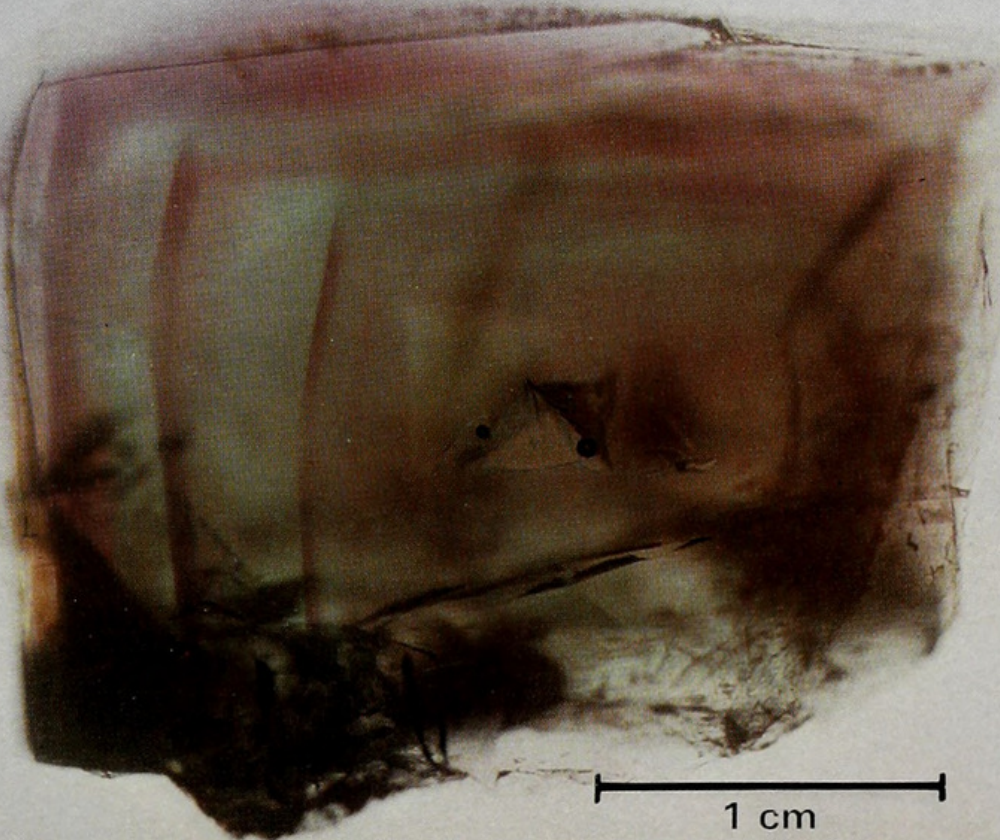
Plate 6

Plate 7

A. BM 56269. Three macroscopic and several smaller inclusions are present. The largest, whose outline is partly obscured by shadows, contains a number of crystalline phases in addition to liquid and vapour. A thin, tubular, 'necked down' portion of this inclusion is shown by the arrow. The other two macroscopic inclusions are aligned roughly parallel to the right hand cube face of the fluorite.

B. BM 56269. Close-up of the crystals contained in the larger inclusion in A (above) viewed in approximately the same orientation. These tiny crystals adhere to the walls of the inclusion and are probably a captured mineral phase or phases. At first they were identified as quartz but in view of the form and habit of many of the crystals, this is probably not the case. Some of them resemble quartz, others an unusual habit of fluorite. However, it has not proved possible to identify them from their morphology alone. The walls of the cavity and its necked down portions (arrowed) are composed of a series of intricate 'steps'. The sides of these steps are parallel to the external cube faces of the host fluorite.
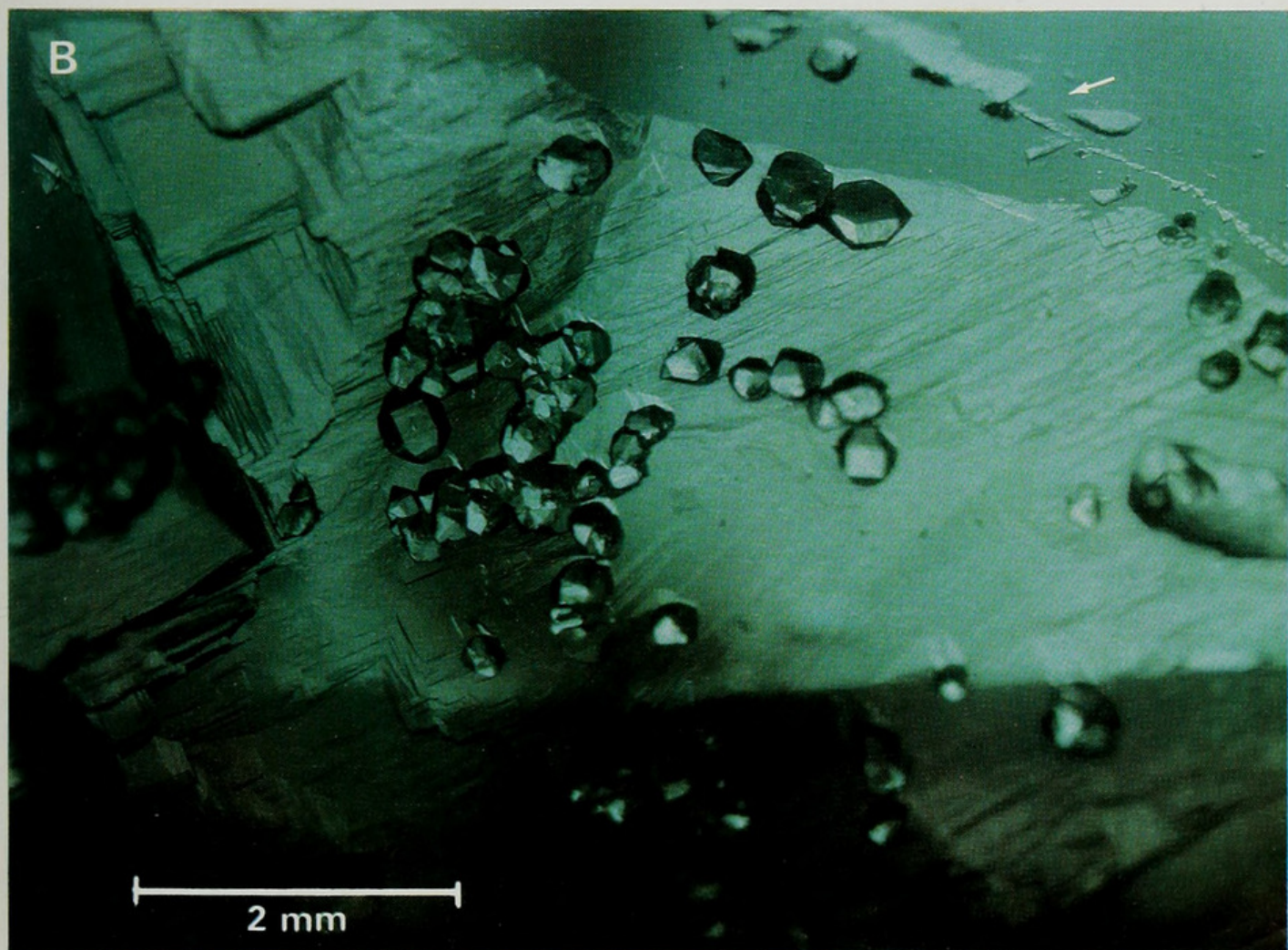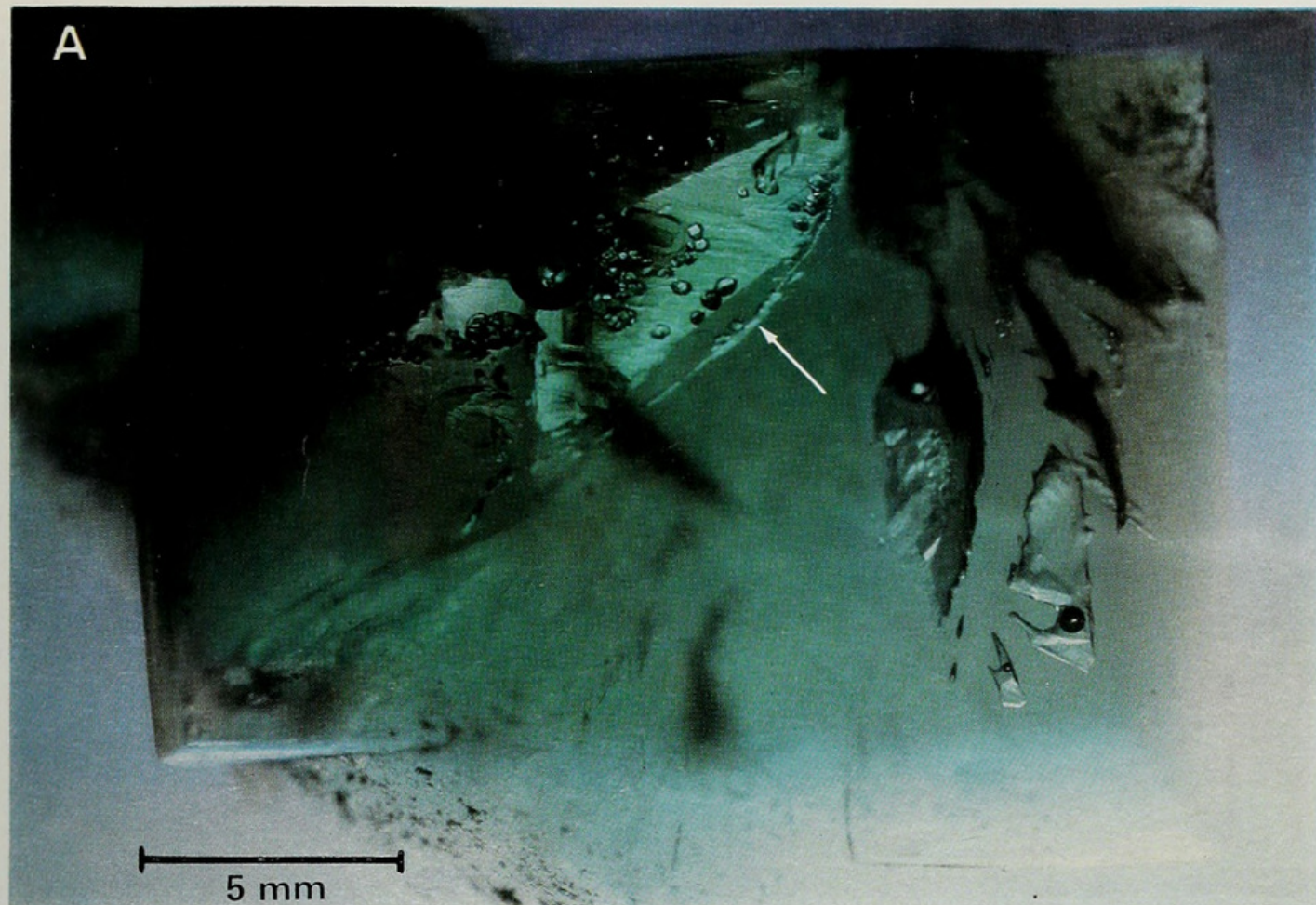
Plate 7

Plate 8

A. BM 56270. Zoned fluorite crystal containing a single macroscopic inclusion. Two smaller inclusions containing smaller vapour bubbles are also visible (arrowed). These probably necked down from the larger cavity. Small triangular depressions (just visible) are present on the inside walls of the cavity. Unidentified, captured crystalline phases (not visible in photograph) similar to those shown in Plate 7 are also present. The large arrow shows the orientation of the photograph in B (below).

B. BM 56270. As A (above), but viewed in a different orientation. A small healed fracture (arrowed) traverses the inclusion and the inner green, colourless and pink inner growth zones, but ends at the base of the outer green colour zone.

A

1 cm

B

1 cm
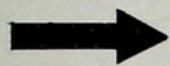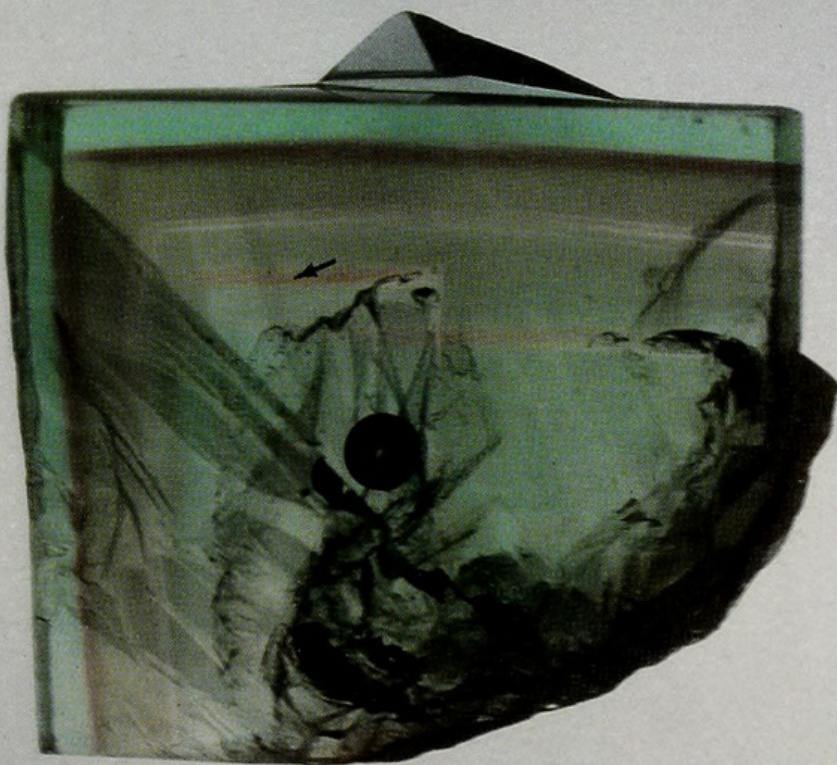
Plate 8

Plate 9

A. BM 56271. A group of several macroscopic and microscopic inclusions apparently located in the outer growth zone of the fluorite crystal. The walls of the largest inclusion (top right) are composed of series of steps with sides parallel to the external cube faces of the host crystal. The inclusions, viewed in a different orientation, (indicated by the arrow) are shown in B (below).

B. BM 56271. Viewed in this orientation the complex stepped nature of the walls of the largest cavity are clearly visible. The overall shape of this inclusion approximates to a negative cubic crystal. All but one of the inclusions (arrowed) are located in the outer portion of the fluorite crystal.

A

1 cm

B

1 cm

Plate 9