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Zonal dissolution in analcime and pseudomorphs of adularia after analcime from the Lizard, Cornwall

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SUMMARY. Analcime of hydrothermal origin occurs in the gabbros and in the amphibolites and granulites. Crystals from the different rock suites display the same unusual characteristics upon dissolution: the interior is much more susceptible to attack than the outer growth zone; the former may be converted to a skeletal boxwork, and the latter may suffer extreme differential dissolution along successive narrow growth horizons. Pseudomorphs of adularia after analcime have been found in various stages of development, from partial to complete replacement. Some of the latter preserve the very delicate dissolution structures in detail. Up to fourteen growth horizons have been detected in the outer millimetre of the crystal. This demonstrates that both the growth and dissolution of analcime occurred prior to the formation of adularia, an event that has been dated.

THE specimens used came from the east coast of the Lizard peninsula: Dean quarry, approximately 3 km north-east of Coverack (783183), and the cliffs and disused quarries between Porthallow (797232) and Porthoustock (806218), particularly in the neighbourhood of Porthkerris Cove and Porthkerris Point, some 2½ km north of Dean quarry. Gabbro occurs in the latter and Landewednack hornblende-schists and Traboe hornblende-schists crop out in the coastal section north of Porthoustock (Flett, 1946). Green (1964) has recognized four metamorphic assemblages in these hornblende-schists, belonging to the almandine-amphibolite and granulite facies. The minerals to be described occur in hydrothermal veins that post-date the metamorphism. The analcime at Dean quarry shows varied modes of decomposition and dissolution (Seager, 1971). Analcime from the amphibolites and granulites near Porthkerris Point also exhibits dissolution features that appear to be identical in character to those in analcime from the gabbro.

Holyer (1972) has recorded that 'crystals are found which look like analcime but are perhaps orthoclase after analcime' for several localities in the Lizard.[1] Halliday and Mitchell (1976), writing about the dating of adularia in the Lizard, stated that 'pseudomorphs of adularia after analcime are known, e.g. at Porthkerris Cove'. The author found examples of various stages in the formation of these pseudomorphs during a study of the hydrothermal mineralization in the neighbourhood of Porthkerris. The pseudomorphs exhibit some unusual features, which can be explained by the local paragenesis.

Dissolution and decomposition of analcime

Dean quarry. Some small crystals of analcime are colourless and transparent, but the majority are white and sub-translucent. Three types of alteration have been recorded in this analcime from Dean quarry (Seager, 1971): solution cavities on the surface of colourless, transparent crystals; alteration to white montmorillonite, much of which is removed from the analcime; and conversion to compact bluish-grey montmorillonite, which forms pseudomorphs after analcime—this took place after the alteration to the white montmorillonite, which occurs as inclusions.

When alteration to white montmorillonite occurred, some unusual properties became apparent in the analcime. The outer growth zone of the crystal, up to *c.* 1 mm in thickness, was much more resistant to attack than the interior. Whereas much of the outer zone is often preserved, most of the interior of the crystal has been removed, leaving a

[1] The Revd. V. A. D. Holyer has priority in finding and identifying pseudomorphs of orthoclase (adularia) after analcime in the Lizard. His statement was cautiously phrased after he showed specimens to the present author, who believed the evidence then available was insufficient to establish the nature of these pseudomorphs with certainty.

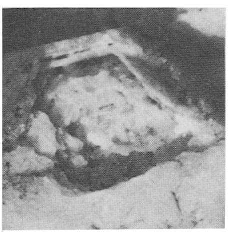
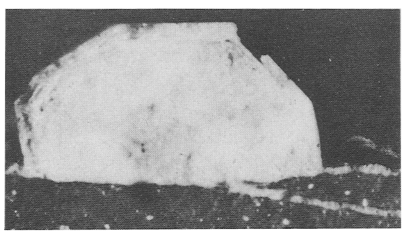
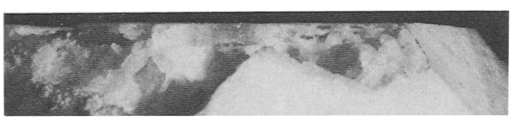
skeletal boxwork of thin plates. In the outer zone chemical reaction or solution has taken place at very different rates along adjacent closely spaced growth horizons, leaving a series of thin plates with intervening planar cavities parallel to the {211} faces.

Porthkerris. Analcime, which had been recorded from Porthkerris quarry by Holyer (1972), was found in the amphibolites and granulites around Porthkerris Point. A few crystals are completely colourless and transparent, but most of them are white and sub-translucent. Some translucent crystals have a vitreous, transparent outer layer, which appears very fresh. The crystals strongly resemble those from Dean quarry, having an outer zone differing in character from the interior. The largest crystals from Porthkerris, *c.* 20 mm in diameter, have an outer zone *c.* 1 mm thick. This is so coherent, compared with the interior of the crystal, that it remains as a white rim adhering to the rock when some analcime crystals are broken from the matrix.

Cavities of several kinds occur on and within the analcime. No montmorillonite has been found within the analcime, although it was an abundant alteration product at Dean quarry. It is not known whether the removal of analcime was essentially a physical or chemical process at Porthkerris. In specimens from both localities the first evidence of inhomogeneity may be a slight variation of transparency along successive growth horizons in the transparent outer layers of some crystals. Three types of cavity occur:

Cavities on the surface of crystals. One particularly fresh crystal had suffered superficial dissolution, developing a cavity with a stepped topography of strongly reflecting planes parallel to the trapezohedron face. Steps were present at ten different levels and appeared to represent subcomponents of the outer layer. Crystals that only have small holes on the surface may have suffered extensive dissolution within.

Cavities within crystals. Part of the surface of a crystal from Porthkerris (fig. 1) has been removed by a fracture, exposing two types of internal cavity. The style of dissolution in the more coherent outer zone with planar cavities is in strong contrast to the much less regular cavities within. Similar structures occur in crystals from Dean quarry (fig. 2). The proportion of the interior that is removed varies greatly. A boxwork is developed in some crystals. One hand specimen from Porthkerris was cut into slices to study the relationship of the vein minerals to each other and to the country rock (fig. 3). There is a crystal of analcime in contact with the wall rock and a thin encrustation of adularia on the surface of the vein, but not below the analcime. A vein of adularia also cuts the rock, meeting the base of the analcime obliquely. The more transparent and coherent outer

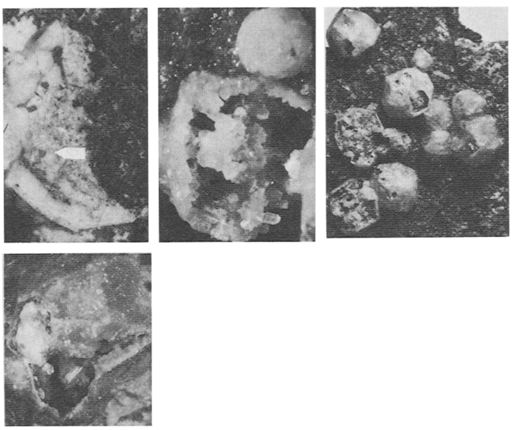
FIGS. 1–3: FIG. 1 (*top left*). Analcime, Porthkerris. Fractured surface of crystal reveals two styles of dissolution: planar in the outermost growth zone and less regular within. × 3·8. FIG. 2 (*bottom*). Analcime, Dean quarry. Viewed almost along the plane of a {211} face. Shows similar phenomena to fig. 1. × 3·4. FIG. 3 (*top right*). Porthkerris. Surface of slice cut through vein minerals and wall rock. The crystal of analcime is in contact with the vein wall. The surface of the vein is encrusted with small crystals of adularia, which are absent beneath the analcime. The outer growth layers of the latter are zoned, show variable transparency, and have planar cavities. A vein of adularia cuts the wall rock and meets the base of the analcime; the pinkish-orange mottling (grey in the fig.) may indicate that replacement of analcime by adularia took place through the action of solutions entering from the vein. × 3·2.

layers are distinguishable from the interior. In many cut sections planar cavities exist of which there is no evidence on the exterior and the internal cavities are often larger than the superficial holes.

Pseudomorphs of adularia after analcime

Widespread formation of adularia succeeded analcime, the two minerals occurring in the following relationships: growth of adularia around or on analcime, without replacement; partial replacement of analcime by adularia, either superficially or internally; and complete replacement of analcime by adularia.

Surrounding growth without replacement. Numerous small crystals of adularia grew upon the vein wall and surrounded the larger crystals of analcime, but very rarely nucleated upon it. Only one crystal of analcime has been observed with a few crystals of euhedral adularia that grew *outwards* from its surface.



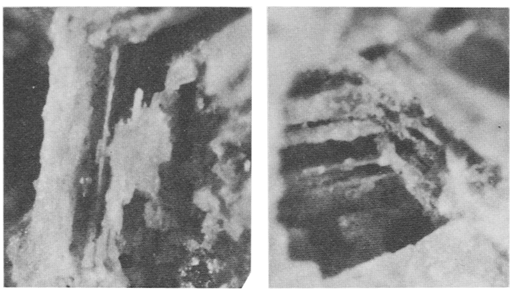
FIGS. 4–7, Porthkerris: FIG. 4 (*top left*). Broken crystal of analcime on matrix. The pinkish-orange interior (here mottled-grey) extends to inner surface of white coherent outer zone, which is more resistant to replacement. The analcime grew over a euhedral crystal of calcite (the dark triangle, arrowed), which remains unaffected. × 1·4. FIG. 5 (*top centre*). Adularia after analcime. The smaller pseudomorph shows the common rounded form. The larger broken pseudomorph has clusters of euhedral adularia crystals within, and colour zoning by lower edge, which is probably related to zoning in the outer layers of the original analcime. × 6·3. FIG. 6 (*top right*). Adularia after analcime. Typical group of small trapezohedral pseudomorphs. Note planar cavities in the more coherent outer growth zone, and lack of adularia crystals projecting from the crystal faces. × 1·6. Specimen kindly lent by the Revd. V. A. D. Holyer. FIG. 7 (*bottom*). Pseudomorph of adularia after analcime. The small white patches show the domains of individual adularia crystals, which grow inwards from the smooth surface. Euhedral adularia is present within the pseudomorph. The large white patch is a crystal of calcite, which grew before analcime, was partially enclosed by it, and relatively little affected by the removal of much of the analcime and the replacement of the rest by adularia. × 2·1.

A thin film of adularia has been found *replacing analcime superficially*.

Partial internal replacement of analcime by adularia occurs in some white, sub-translucent crystals. There is little or no indication of this replacement from the external appearance, but the crystals have a pinkish-orange mottling on fractured surfaces. Adularia was identified within these crystals of analcime by X-ray diffraction and staining in thin section. The mottled areas are usually irregular in shape and limited in extent, but may fill the interior up to the coherent outer zone (fig. 4). The mode of entry of the solutions precipitating adularia has not been definitely established. The distribution of the coloured area in the slices is usually irregular, and shows no sign of having spread inwards from the faces or holes in the surface. The pinkish-orange area, which is grey in fig. 3, suggests that replacement may have occurred through solutions entering this crystal from beneath, via the adularia vein, which cuts the wall rock.

Complete replacement of analcime by adularia occurs in specimens over a larger area than partial pseudomorphs or crystals of analcime. Complete pseudomorphs have been traced from Porthkerris Point northwards for about 200 m and southwards about 0·7 km, just south of Pencra Head. Specimens up to 10 mm in diameter, with unmistakable trapezohedral morphology, occur near Porthkerris Point. Further south they were usually about 1–3 mm in diameter, somewhat rounded (fig. 5), with a hint of trapezohedral shape, and often occurred in clusters (fig. 6). It would not have been justifiable to identify them as pseudomorphs after analcime unless much better specimens had been found. Some of the pseudomorphs are virtually filled with adularia, but others contain voids. Individual crystals of adularia grew *inwards* from the surface of the analcime, and developed euhedrally in the internal cavities. Although the trapezohedral faces are nearly plane, light is reflected from numerous small areas representing the domains of individual adularia crystals (fig. 7), one of which may form part of the surface of two adjacent trapezohedron faces. No euhedral adularia has been observed that grew *outwards* from these faces. Random clusters of euhedral adularia crystals may also occur within the partially hollow pseudomorphs (fig. 5). Broken pseudomorphs display varied internal structures. Only the outer growth zone is preserved in some cases. The most remarkable specimens are those that replace and preserve in detail the delicate tabular dissolution structures of analcime.

The white line near the lower edge of the broken crystal in fig. 5 is in a region with slight gradations in shades of orange. This colour zoning probably represents variations in resistance to replacement in the outer growth horizons of analcime. Figs. 8 and 9 are outstanding examples of the selectivity of the process of dissolution. In fig. 8 several growth planes have been removed, leaving a wafer-like wall of adularia 1·5 mm long and approximately 0·03 mm thick. The total depth to which dissolution originally proceeded (normal to the plane of the figure) cannot be determined in a broken crystal, but it must have exceeded the thickness of the remaining wafer by a very large factor. In fig. 9 the



FIGS. 8, 9, Broken pseudomorphs of adularia after analcime, Porthkerris. FIG. 8 (*left*). Strong differential dissolution of the outer growth layers of analcime has preceded complete replacement by adularia, the thinnest plate of which is *c*. 0·03 mm thick. × 18·8. FIG. 9 (*right*). Similar to fig. 8. Through a hole, the interior of the crystal is viewed parallel to two trapezohedron faces; the outer 1 mm of the original analcime had fourteen layers varying in their physical or chemical characteristics. × 23·5.

extensive development of tabular dissolution structures parallel to two adjacent trapezohedron faces is seen through a hole in the crystal. In a depth of 1 mm from the surface at least fourteen successive plates of adularia and intervening voids are present, representing fourteen layers of differing character in the last millimetre of analcime to be deposited. Some of the narrowest gaps are *c*. 0·01 mm wide.

The identification of these specimens of adularia as pseudomorphs after analcime appears to be adequately supported by the following evidence. The pseudomorphs have trapezohedral morphology, which is only known to occur in analcime at this locality, and is an uncommon habit among hydrothermal minerals. Structures identical with the very unusual planar dissolution features of the local analcime are present in adularia. Some analcime in the vicinity is partially replaced by adularia.

Discussion

This study of the dissolution of analcime from the east coast of the Lizard has shown that the interior of the crystals differs in some properties, physical or chemical, from the last portion of the crystal to grow. This outer zone, up to 1 mm thick, also has a composite structure, with markedly different reactivity or solubility along about fourteen growth horizons. Since these very unusual properties of growth and dissolution occur in crystals of analcime from the gabbros of Dean quarry and the amphibolites and granulites in the neighbourhood of Porthkerris Point, it seems justifiable to assume that the analcime in both localities, in different rock suites, was formed simultaneously from hydrothermal solutions having the same character and undergoing the same changes with time. Similarly, it may reasonably be assumed that the zonal dissolution and formation of boxworks occurred in both localities simultaneously, through the agency of solutions having the same properties.

Halliday and Mitchell (1976) comment on the pseudomorphs at Porthkerris Cove that 'The adularia appears to have encrusted the analcime first, and then, after dissolution of the analcime, further coarser adularia has infilled the cavity. Apart from this there is no known geological evidence for more than one adularia mineralization in the Lizard peninsula'. The evidence in this paper is at variance with their conclusions. No adularia has been found by the author 'encrusting' adularia pseudomorphs, in the sense that adularia nucleated on the surface of analcime and grew outwards from it. In all the pseudomorphs studied the adularia had grown *inwards* from the surface of analcime, and no evidence was found that the 'coarser' adularia within formed at a different time. Further, the complex dissolution structures in analcime must have been developed *before* adularia was deposited, otherwise they would not have been preserved as pseudomorphs in adularia. It is necessary to establish the correct paragenesis, in order to determine the number of phases of adularia mineralization in the Lizard. Since analcime suffered dissolution before the formation of adularia there is no need to invoke two episodes of adularia mineralization at Porthkerris. This subject is discussed in more detail elsewhere (Seager, Fitch, and Miller, 1978, in press).

It has not yet proved possible to date the growth of analcime or its dissolution, but the subsequent formation of adularia has been dated. At Dean quarry, as well as Porthkerris Point, the adularia is later than analcime. Exceptionally fresh adularia from Dean quarry and near Porthkerris Point gave apparent ages of 201 ± 4 Ma (Seager, Fitch, and

Miller, 1975) and 211 ± 2 Ma (Seager, Fitch, and Miller, 1978, in press), respectively. Halliday and Mitchell (1976) have determined the age of fifteen specimens of adularia from twelve localities in the Lizard, including Dean quarry, Porthkerris Cove, and Porthkerris quarry. They conclude that (adularia) mineralization in the Lizard occurred approximately 210–20 Ma ago, apart from one discrepant date. Therefore the growth and dissolution of analcime must have occurred over *c.* 220 Ma ago.

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