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# DAWSONITE AND ANALCITE IN THE SINGLETON COAL MEASURES OF THE SYDNEY BASIN

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## Abstract

Dawsonite, associated with minor amounts of analcite and nordstrandite, is relatively abundant in the Singleton Coal Measures of the Sydney Basin. It occurs as a replacement of feldspars and quartz, as an interstitial cement in sandstones and conglomerates, and as cleat, joint, and fissure infillings in coal and various clastic sediments. The origin of the mineral is discussed and, although incompletely understood, it is concluded that there is little evidence to suggest that widespread aridity, which characterised formation of dawsonite in the Green River Formation of Colorado and at Olduvai Gorge in Tanzania, accompanied deposition of the mineral in the Singleton Coal Measures.

## Introduction

Until little more than a decade ago dawsonite ($NaAlCO_3(OH)_2$) was believed to be a particularly rare mineral known only as an alteration product of alkali feldspars in certain hydrothermal environments (Palache *et al.*, 1960). In the intervening period, however, abundant dawsonite has been found in the extensive varved dolomites and oil shales of the Eocene Green River Formation of Colorado (Smith and Milton, 1966) and in the altered Pleistocene ash deposits of the Lake Natron–Olduvai Gorge region of Tanzania (Hay, 1963). Analcite, other zeolites, various carbonates of sodium, magnesium, and calcium, and an array of rare silicate minerals are associated with the dawsonite. Moreover, there appears little doubt that, in these occurrences at least, the mineral is authigenic and has developed under arid and strongly alkaline conditions. The presence of dawsonite in the Green River Formation has provoked much interest, for the mineral, although rarely detectable in hand specimen, is nevertheless sufficiently abundant to warrant consideration as a potential ore of aluminium. In fact, according to Hite and Dyni (1967), one square mile of these deposits could yield more aluminium than that obtainable from the total reserves of bauxite in United States.

More recently, the presence of dawsonite in the thick Permian–Triassic sequence of the Sydney Basin of eastern New South Wales has been recorded (Loughnan and See, 1967; Goldbery and Loughnan, 1970; Nicholas and Ozimic, 1970). The mineral occurs not only in coal measure and other non–marine strata, but also in sediments believed to be of marine origin. However, to date, zeolites have not been found accompanying the dawsonite and there has been very little independent evidence to suggest that strongly alkaline conditions prevailed during deposition of the sediments. Consequently, the discovery of analcite in association with dawsonite in the Singleton Coal Measures is of interest particularly since its relationship to the dawsonite shows a number of features which may assist toward an eventual understanding of the origin of the sediments in the Sydney Basin.

## THE SINGLETON COAL MEASURES

The Sydney Basin of eastern New South Wales is a structural unit that contains both Permian and Triassic sediments in addition to volcanic and alluvial deposits referrable to the Tertiary. The Permian succession consists of two thick groups of marine strata, each succeeded by coal measure sequences (Table 1). The Dalwood Group at the base is composed essentially of marine shales and sandstones with basaltic lavas and sporadic conglomerates. The overlying Greta Coal Measures consist of lenticular beds of conglomerate, shale, lithic sandstone, coal, and, in the Upper Hunter Valley, unusual thicknesses of kaolinite claystone (Loughnan, 1971). The first recorded occurrence of dawsonite in the sediments of the Sydney Basin was from these measures where the mineral forms a cement in lithic sandstones (Loughnan and See, 1967).

Siltstones, sandstones, and conglomerates predominate in the Maitland Group, which has a probable maximum thickness of 4,000 feet

TABLE 1. PERMIAN-TRIASSIC SUCCESSION IN THE SYDNEY BASIN

| Upper Hunter Valley | | Lower Hunter Valley | Southern and Western |
|---|---|---|---|
| TRIASSIC | Wianamatta Group<br>Hawkesbury Sandstone<br>Narrabeen Group | | |
| PERMIAN | Singleton Coal Measures<br>Maitland Group<br>Greta Coal Measures<br>Dalwood Group | Newcastle Coal Measures<br>Tomago Coal Measures<br>Maitland Group<br>Greta Coal Measures<br>Dalwood Group | Illawarra Coal Measures<br>Shoalhaven Group<br>Clyde Coal Measures |

(McKellar, 1969). In places the strata contain abundant marine fossils but nevertheless it is possible, indeed probable, that some non-marine sediments are present. Calcite pseudomorphs after glauberite, known as *glendonites* (Palache *et al.*, 1960), and lenticular beds of dolomite occur at several horizons near the top of the group, whereas coarse erratics, which generally have been attributed to ice-rafting during periods of glaciation, are common in the thick sequences of siltstone and shale. Nicholas and Ozimic (1970) have recorded the presence of dawsonite in these sediments and Goldbery and Loughnan (1970) have described occurrences of the mineral as pseudomorphs after glauberite and as spherulitic masses in dolomite and siltstone from the Shoalhaven Group which is the approximate equivalent of the Maitland Group in the western sector of the basin.

In the lower part of the Hunter Valley the Maitland Group is succeeded by the Tomago and Newcastle Coal Measures, whereas further up the valley, the Singleton Coal Measures form the uppermost unit of the Permian. As Robinson (1969) has pointed out, although the Tomago and Newcastle Coal Measures are undoubtedly the time equivalent of the Singleton Coal Measures, correlation between the sediments of the two areas has not been effected with certainty. The sediments comprising the Singleton Coal Measures are predominantly fluvial, nevertheless they range from bentonitic clays and deltaic laminites to coarse alluvial fan deposits. Most of the beds including the coal seams are lenticular and coupled with the widespread intrusion of Tertiary alkaline sills; correlation within the unit is difficult. In the Doyles Creek No. 9 Bore (for location see Fig. 1), the measures have a thickness slightly in excess of 3,100 feet and contain 60 coal seams, the majority of which, however, have little commercial potential. Deltaic laminites and siltstones with minor quantities of sandstone, shale, and claystone predominate in the basal 800 feet of the measures, whereas the overlying 2,300 feet of sediments consist essentially of fluvial sandstones and siltstones with intercalated claystones apparently of tuffaceous origin, and, to a less extent, conglomerates, shales, and coal seams. A massive, quartz-rich sandstone that is believed the equivalent of the basal formation (Waratah Sandstone) of the Newcastle Coal Measures in the lower Hunter Valley occurs approximately 650 feet below the top of the measures in the Doyles Creek bore and is underlain by a prominent laminite horizon.

A similar sequence of sediments was encountered in a bore sunk in the vicinity of Bulga (See Fig. 1) approximately 9 miles to the northwest of the site of the Doyles Creek bore.

The sandstones, siltstones, and conglomerates that comprise the

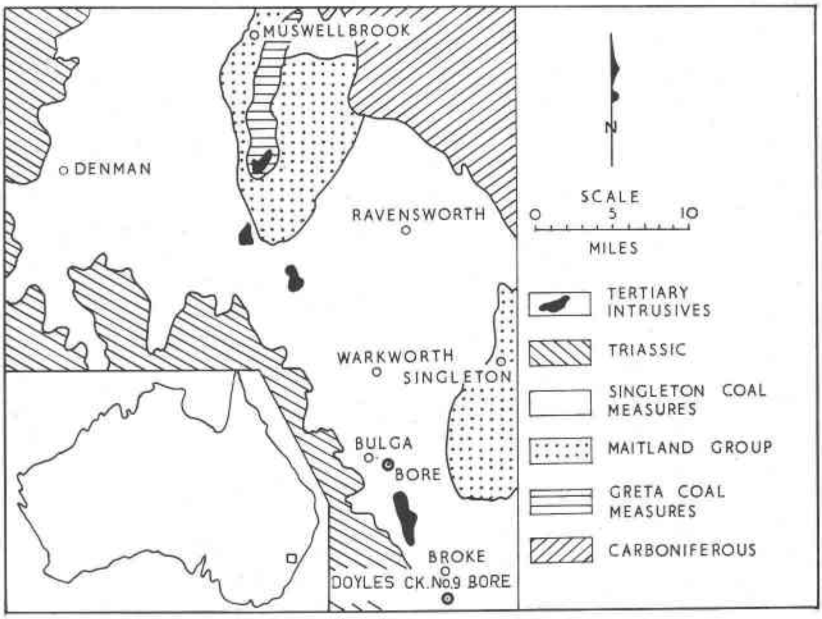


FIG. 1. Geological sketch map of the upper Hunter Valley showing the outcrop of the Singleton Coal Measures and the location of the two bores.

bulk of the Singleton Coal Measures are for the most part lithic with volcanic and chert fragments predominating. Bunny (1967) considered that the fragments were derived primarily from the Carboniferous lavas and sediments which lie to the northeast, but there is a strong possibility that much of the detritus, particularly the chert fragments, is of intraformational origin. Angular to subangular quartz grains are invariably present and all gradations into quartz–rich rocks can be observed. Fresh to highly altered feldspar grains that have generally retained some semblance of their euhedral form, are common but rarely exceed 10 percent of the constituents. Plagioclase which ranges from oligoclase to labradorite, is much more abundant than K–feldspar. Flakes of partly decomposed biotite are evident in some thin sections.

The grains are set in an abundant clay matrix which frequently comprises more than 30 percent of the rock. Both kaolinite and expandable lattice minerals are present, but whereas kaolinite is prevalent in the upper part of the measures, degraded illite, montmorillonite, and mixed layered minerals predominate toward the base.

Claystones ranging up to 2 feet thick are commonly associated with the coal seams, particularly in the upper part of the section, *i.e.*, the equivalent of the Newcastle Coal Measures, but nevertheless they also occur interspersed with the thicker beds of coarser grained sediments throughout the entire succession. The claystones are generally light colored, lack bedding, and contain a high proportion of montmorillonite either as the discrete mineral or interlayered with illite or chlorite. Euhedral grains of feldspar are commonly present and may be relatively abundant whereas quartz is either rare or absent. Nevertheless, all gradations into fine–grained sediments rich in quartz and kaolinite are evident. There seems little doubt that many of these claystones are true bentonites having formed from the alteration of volcanic ash either in a coal swamp or floodplain environment and possibly some of the feldspars and volcanic rock fragments in the coarser grained sediments are the product of contemporaneous ash showers.

In contrast to the claystones, the shales tend to be dark colored, well–laminated, and contain abundant quartz, kaolinite, and illite, whereas feldspars are generally absent and expandable lattice clay minerals sparse.

## Occurrence of Dawsonite and Analcite

Dawsonite is widely distributed in the Singleton Coal Measures. In the Bulga bore the mineral is not restricted to a particular rock type, but occurs in deltaic laminites and bentonitic claystones, as well as in fluvial conglomerates and sandstones. Nor does dawsonite appear to be associated with any particular clay mineral, since it is just as prevalent in the sediments toward the upper part of the measures where kaolinite predominates as it is in those located near the base where illite and expandable lattice clay minerals are relatively more abundant.

Dawsonite occurs in the Singleton Coal Measures in a variety of forms, (a) as an alteration product of feldspars and quartz, (b) as an interstitial cement in sandstones and conglomerates, (c) as joint and fissure infillings in various clastic rocks, and (d) as facings in cleats and other microfractures in coal.

In the coarse–grained sediments and to a less extent in the siltstones, dawsonite tends to replace feldspars which are present as discrete grains and as phenocrysts in the volcanic rock fragments. Both plagioclase and K–feldspar have been affected and frequently the alteration has been selective with only some of the twin laths replaced but elsewhere complete pseudomorphs of dawsonite are apparent and may abut fresh feldspar grains. In the claystones, however, the feldspar grains tend to be altered to the same degree. Very fine, rhomb–

shaped euhedra of nordstrandite ($Al(OH)_3$) are frequently associated with dawsonite in the sandstones (Fig. 2) occurring both within and along the margins of the altered areas. However, nordstrandite is generally not detectable by X-ray diffraction indicating that it rarely comprises more than 1–2 percent of the rock. Replacement of quartz by dawsonite is not so common. Only a few fragments show extensive alteration (Fig. 3) and mostly the attack has been restricted to incipient dissolution around the grain boundaries.

Although the presence of cement is precluded to some extent by the high matrix contents of the sediments, in many of the coarser grained sandstones and conglomerates, partial cementation by calcite and dawsonite can be observed. In this form, however, dawsonite rarely becomes a major constituent of the rock.

By far the most prevalent form of dawsonite in these measures is as facings and encrustations along the cleats in the coal and as infillings of joint and other fissures in the sediments. Of the 60 coal seams encountered in the Doyles Creek bore, more than half the number contain dawsonite within the coal (Fig. 4), yet the sediments comprising the floor, roof, and bands of the seams generally are devoid of the mineral. In this bore, dawsonite is virtually absent from the section forming the equivalent of the Newcastle Coal Measures and

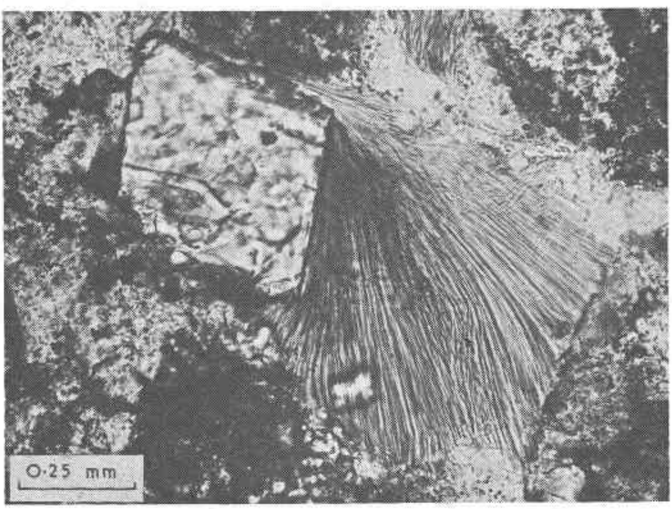


FIG. 2. Photomicrograph showing the association of euhedral nordstrandite and fibrous dawsonite in a feldspathic–lithic sandstone from the Singleton Coal Measures.

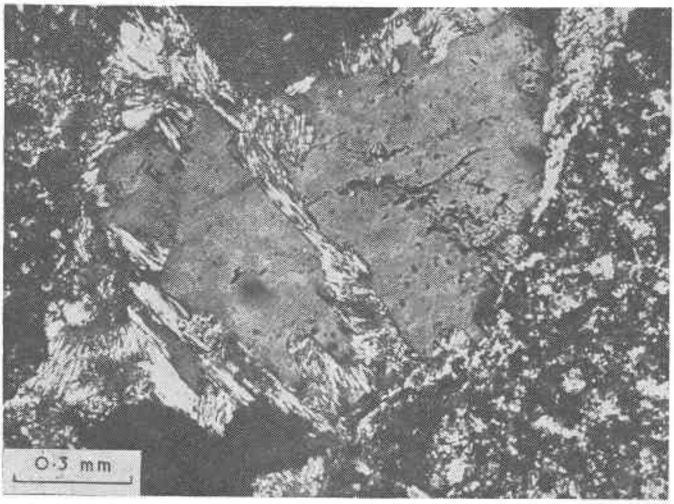


Fig. 3. Photomicrograph showing the replacement of quartz by dawsonite in a quartz–lithic sandstone from the Singleton Coal Measures.

the mineral tends to be concentrated in the coal seams that correspond to the upper part of the Tomago Coal Measures. However, in the Bulga bore and several others that penetrated the measures in the area to the west of Muswellbrook, dawsonite, although present in the coal seams, is much more prevalent as joint and fissure infillings in the sediments somewhat removed from the seams (Fig. 5). In these occurrences the mineral has a spherulitic habit and maintains sharp contacts with the enclosing sediments which range from bentonitic claystones to coarse–grained sandstones and conglomerates.

Analcite of apparent authigenic origin has been described from the Newcastle Coal Measures of the lower Hunter Valley (Loughnan, 1966; 1967), where, with abundant chalcedony, it forms pseudomorphs after the groundmass and shards in devitrified tuffs. Moreover, crystalline masses of the mineral have recently been found in carbonates within the Maitland Group. Apart from these occurrences, however, analcite has not been recorded previously in the sediments of the Sydney Basin and, consequently, the recent discovery of analcite–bearing cherts in the Singleton Coal Measures, although of relatively minor extent, is nevertheless of interest because of their association with dawsonite. The analcite bearing cherts were encountered in the Doyles Creek bore in the interval representing the upper part of the Tomago Coal Measures where they occur as thin beds, rarely exceed-

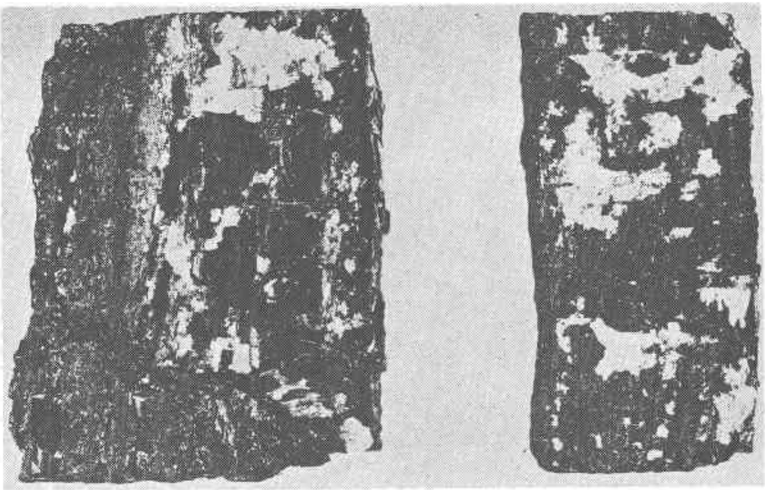

FIG. 4. Showing the occurrence of dawsonite (white) in coal cores from the Singleton Coal Measures. The cores measure 1¾ inches across.

FIG. 5. Dawsonite infilling a joint in a quartz lithic sandstone from the Singleton Coal Measures. The specimen measures 1¾ inches across.

ing an inch in thickness, within a succession of bentonitic and tuffaceous claystones. The cherts are hard, particularly dense, and in thin section are essentially devoid of textural features. Analcite, which comprises as much as 20 percent of the cherts, is present as isolated masses up to 0.5 mm across and as infillings of contraction fractures, and as such is similar in occurrence to the deposits in the Lockatong Formation of New Jersey (Van Houten, 1960). The claystones immediately above and below the chert bands generally show the characteristics of devitrified tuffs with calcite, chalcedony, and, to a lesser extent, analcite and dawsonite replacing the shards and groundmass.

## Discussion

According to Chesworth (1971), who synthesised dawsonite by immersing aluminum amalgam in a saturated solution of sodium carbonate at 25°C, a solution of 0.4 *M* $Na_2CO_3$, equivalent to a pH value of approximately 12, is necessary for the formation of the mineral. If this is correct, it is not surprising that dawsonite is a rare mineral. What is difficult to comprehend is the presence of the mineral in sediments of the Sydney Basin where independent evidence of unusual pH conditions is lacking and minerals such as nahcolite ($NaHCO_3$) and trona ($NaHCO_3Na_2CO_3$), which in the Green River Formation and at Olduvai Gorge are intimately associated with dawsonite, are absent. Moreover, the occurrence of dawsonite as cleat, joint, and fissure infillings in the Singleton Coal Measures indicates that solutions, apparently capable of maintaining these high pH values, migrated through the consolidated or partly consolidated sediments and peat material. The distance of migration may not have been very great although the relative abundance of dawsonite in the coal seams and its absence or paucity in the enclosing sediments tends to suggest the contrary. The prevalence of the mineral in the coal could be attributable to locally-high partial pressures of $CO_2$ and this is supported to some extent by the experimental work by Bader (1938) who found a considerable excess of $CO_2$ is necessary to precipitate dawsonite from solutions of sodium carbonate and sodium aluminate. Nevertheless, the occurrence of the mineral in sediments essentially devoid of organic matter suggests that factors other than the partial pressure of $CO_2$, have played a significant role in the formation of dawsonite.

Another puzzling aspect of the occurrence of dawsonite in the Singleton Coal Measures is the preponderance of the mineral over analcite. Since silica is readily mobilised at pH values above 9.5 (Krauskopf, 1959), high concentrations would be expected in these strongly alkaline solutions and there is much evidence in the form of altered feldspars and quartz to support this conclusion. Consequently, precipitation in the sediments, particularly those removed from the coal seams where the partial pressure of $CO_2$ was somewhat lower, should have yielded a silicate rather than the carbonate of sodium and aluminum. Yet, analcite is a rare constituent in these measures, being restricted in occurrence to thin chert beds that apparently were derived from the devitrification of glassy tuffs. Brobst and Tucker (1972), in discussing the origin of analcite and dawsonite in the Green River Formation, suggested that at high pH values analcite tends to alter to dawsonite and quartz. However, since dawsonite in the Singleton Coal Measures apparently formed at various $CO_2$ concentrations, and hence, over a range of pH values, pH does not appear to have been such a particularly critical factor in controlling development of the respective phases in these sediments.

The occurrence in the sandstones of fresh fragments of feldspar in juxtaposition with similar grains showing extensive replacement by dawsonite suggests that the alteration did not take place *in situ,* rather, that both fresh and altered grains were deposited contemporaneously. This could also account for the variation in composition of the associated clay minerals. Possibly alteration of the feldspars occurred in the parent lavas as a result of hydrothermal activity although evidence in this respect is lacking. Alternatively, the altered grains may be of intraformational origin having been derived from volcanic ash deposits of composition similar to the bentonitic claystones, and, pertinent in this respect, in those claystones where alteration of feldspar to dawsonite is evident, all grains have been affected to much the same degree.

Loss of soda from the dawsonite would seem the most obvious explanation for the origin of nordstrandite.

## Conclusions

In the present state of knowledge the only conclusion that can be reached concerning the origin of dawsonite in the sediments of the Sydney Basin in general and in the Singleton Coal Measures in particular, is that the conditions which accompanied the laying down of these rocks certainly differed from those that prevailed during formation of the Green River and Olduvai Gorge deposits. Not only does the mineral in the Sydney Basin occur in sedimentary rocks of diverse origin including some formed under marine conditions, but, moreover, with the possible exception of the bentonitic claystones, the strata lack independent evidence of having been subjected to unusual pH conditions.

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