ON THE OCCURRENCE OF GLENDONITES IN NEW SOUTH WALES, WITH NOTES ON THEIR MODE OF ORIGIN.*

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This paper deals mainly with the stratigraphical distribution of glendonites in the Permian sequence in New South Wales. This sequence, with the principal subdivisions and horizons referred to, are illustrated on page 337.

It should be noted that the term "Permian" as used in this paper is synonymous with the Kamilaroi of T. W. E. David. The reasons for regarding this sequence as Permian have been given in a recent paper.\(^{(13)}\)

**Review of Literature and Correction of Stratigraphical Position of Some Previously Recorded Horizons.**

The well known paper by David, Woolnough, Taylor and Foxall\(^{(4)}\) gives a complete bibliography of previous work on glendonites, and records four occurrences in the Upper Marine series of the Permian System in New South Wales, as follows: (1) Glendon, (2) Singleton Railway Bridge, (3) Near Mount Vincent, (4) Huskisson.

These authors considered three of these horizons to be at stratigraphical intervals above the Muree beds of (1) 200 feet, (2) 1,000 feet, and (3) 700 feet. The Huskisson occurrence has been discussed by Dr. Ida Brown,\(^{(3)}\) and is referred to below. As a result of geological work in the Hunter Valley during the years 1922–1930, the stratigraphical position of the three horizons referred to may be more accurately described than was previously possible.

* Published by permission of the Under Secretary for Mines.
The Glendon horizon is on the western limb of the Belford Dome and is about 250 feet above the Muree beds. The Singleton occurrence lies in a syncline between the Loder and Sedgefield Domes, and is about 750 feet above the Muree beds.* So far as the Mount Vincent horizon is

**STRATIGRAPHICAL COLUMN**

of part of Permian Sequence in
Hunter Valley, N.S.W. showing

Glendonite Horizons

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The structures referred to are illustrated and briefly described in a previous paper (Raggatt, H. G. [12]).

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concerned, Mr. L. J. Jones places this at about 500 feet above the Muree (verbal communication).

In 1908, Carne\(^{(4)}\) recorded glendonites from two horizons in the Upper Marine Series at Muswellbrook, one, which he noted in Muscle Creek, 350 feet above the Greta Series, and one on the left bank of the Hunter River near the present railway bridge on the Muswellbrook-Merriwa line. The latter he thought to be 1,000 (?) feet above the Greta. (This record by Carne appears to have been overlooked hitherto.) The recent work indicates that the latter horizon is immediately above the Muree beds and about 1,600 feet above the Greta. The lower of these two horizons has previously been referred to as the Muswellbrook, but, if this is done, no suitable name remains for the higher. It is, therefore, proposed to name the lower the Muscle Creek and the higher the Muswellbrook horizon.

In 1910 Woolnough\(^{(20)}\) recorded a glendonite zone in an argillaceous limestone bed of the Upper Marine Series in Wattle Ponds Creek adjacent to the Dyrring road, about three miles north from Singleton. Dr. Woolnough tentatively estimated this horizon to be 1,480 feet below the Muree. The recent detailed mapping of the Sedgfield Domes, however, indicates that this horizon is about 800 feet below the Muree, and about 2,000 feet above the Greta. (See also p. 342.)

Dr. Woolnough also found glendonites in the topmost beds of the Upper Marine Series at Wollongong in 1912. (See Walkom,\(^{(18)}\) p. 162). As the glendonites at this locality have not been previously described, and as geological excursions are frequently made there, some notes concerning it are given on page 339.

In 1911, Twelvetrees\(^{(16)}\) referred to the occurrence of glendonites in the Mersey Valley, at an horizon about 350 feet above the Tasmanian equivalent of the Greta coal measures.

Glendonites were recorded for the first time (in New South Wales) in a series other than the Upper Marine, by Walkom in 1913. This is the Harper’s Hill horizon, which is in the Lochinvar Stage of the Lower Marine, about 150 feet below the Harper’s Hill sandstone, and about 2,000 feet below the base of the Greta coal measures.

In 1925, Dr. Ida Brown\(^{(3)}\) published a note recording glendonites at Ulladulla. These she considers to be correlative with the Huskisson horizon, 100–200 feet
below the base of the Nowra Grits, which are considered to be the equivalent of the Muree.

In 1932, Whitehouse(19) noted the occurrence of glendonites in the Dawson Valley, nine miles north-northeast of the village of Theodore. This constitutes the first record of the existence of glendonites in Queensland. They occur in a soft yellowish mudstone, which is a member of a fossiliferous marine sedimentary series overlying the Lower Bowen volcanics. The Dawson Valley glendonites have much in common with those from some of the well-known localities in New South Wales. No glacial erratics were observed in their vicinity.

NEW AND UNDESCRIBED LOCALITIES IN NEW SOUTH WALES.

During the course of field work, glendonites were found at a number of new localities. None of these occurrences shows any marked divergence in stratigraphical position from those previously known. Prefacing these descriptions some notes are given on the well-known but undescribed glendonites at Wollongong and Gerringong. The localities are described below in descending stratigraphical order.

Wollongong.

From the south side of Flagstaff Hill to the North Wollongong surf sheds the thickness of Upper Marine beds exposed in cliff sections and on the rock platform is about 100 feet. Of this thickness about 40 feet are exposed at the Flagstaff Hill, made up as follows:

Descending Order.

<table>
<thead>
<tr>
<th>Feet</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Sandy shale.</td>
</tr>
<tr>
<td>5</td>
<td><em>Charonoma</em> <em>audax</em> abundant</td>
</tr>
<tr>
<td>2</td>
<td>Numerous glendonites and concretions.</td>
</tr>
<tr>
<td>15</td>
<td>Sandy mudstone — fossils and erratics scarce.</td>
</tr>
<tr>
<td>8</td>
<td>Ferruginous argillaceous sandstone with discontinuous joints infilled with calcareous material; weathers spheroidally.</td>
</tr>
<tr>
<td>6</td>
<td>Carbonaceous sandy mudstone. Concretions at top and glendonites two feet from base.</td>
</tr>
</tbody>
</table>

The glendonites of the lower horizon occur as single individuals up to three inches in length, as groups of three or more such individuals, and as clusters of about an inch
radius with as many as fifty small crystals in each cluster. Marine fossils and erratics are present in this bed, the largest erratic noted being one foot in diameter.

In the upper zone the glendonites are about $1\frac{1}{2}$ inches in length, quite a large number consisting of an intergrowth of from two to four individuals. Glendonites form the nuclei of many of the concretions. The zone is fossiliferous, but erratics are scarce.

In addition to the exposures at the top of the cliff, the upper zone is also revealed on an almost isolated outcrop 200 yards easterly from the lighthouse. Here also the glendonites occur in groups with diameters up to five inches. In some instances, concretions have formed around the glendonites. A number of the concretions have iron pyrites arranged peripherally; in the others, pyrites appears to form the nucleus.

This zone, or one very close to it in stratigraphical position, outcrops on the rock platform about 100 yards north of the small beach at the boat harbour. The association of glendonites, fossils, and concretions is most marked at this point.

Eight chains northerly from the last mentioned outcrop, i.e. 15 to 20 feet higher stratigraphically, there are more glendonites and concretions, but as they are submerged at high water they are much eroded. Above this occurrence there are about 30 feet of arenaceous muds exposed, with abundant concretions and lenticular calcareous beds. There is a good cliff section and railway cutting through these beds at the south end of the North Wollongong beach.

It is difficult to determine accurately the stratigraphical position of the glendonites in relation to some known horizon such as the base of the Upper Coal Measures, since the dip is very gentle and the nearest outcrops of the Upper Coal Measures are about a mile away. Applying the observations made, to L. F. Harper's geological map of the area, and to the military contour map, the highest horizon of glendonites appears to be about 75 feet below the base of the Upper Coal Measures. As three glendonite horizons have been observed within such a small stratigraphical interval, and with such limited exposures, it is highly probable that many more such zones exist in the Upper Marine beds of this locality.
Plashett.

In Pringle’s Saltwater Creek on the Plashett Holding, 3\(\frac{1}{2}\) miles north-north-west from Jerry’s Plains.

The glendonites occur at the top of the Mulbring beds (about 1,350 feet thick at this locality), and may be correlated with the uppermost of the Wollongong horizons. They are the small multiple variety, and are associated with *Chaenomysa etheridgei*.

Bickham.

Glendonites occur in blue mudstone on the right bank of the Pages River near the Bickham Homestead, 1\(\frac{3}{4}\) miles south-east from Blandford Railway Station. The glendonites are not plentiful, and consist mainly of single individuals or small groups. Fossils are present, but are not abundant.

The section of the Upper Marine Series in this area (Scone-Murrurundi) is markedly different from that exposed in the Lower Hunter. Measured with reference to the local equivalent of the Muree beds, the glendonite horizon is 250 feet above the top of that stage, but it is also very close to the base of the Upper Coal Measures, and is, therefore, preferably correlated with one of the Wollongong horizons.

Minimbah.

Good sections of the Mulbring beds can be examined in the railway cutting 2 miles north-west from Minimbah platform on the main northern railway. The glendonites occur about 850 feet above the Muree beds, and are thus on approximately the same horizon as the Singleton Railway Bridge occurrence. The glendonites are of the large type and occur both singly and in small groups. Both glendonites and marine fossils are particularly abundant at this locality. The glendonites occur in two zones about five feet apart, the lower ones being developed in groups, in close association with numbers of *Warthia micromphalus*. Other common fossils are *Stenopora crinita-ovata* and *Chaenomysa etheridgei*.

Gerringong.

It has been known for some years that glendonites occur at Red Bluff on the New South Wales coast 1\(\frac{1}{2}\) miles northerly from Gerringong. Dr. Ida Brown informs me
OCCURRENCE OF GLENDONITES.

Correlation of Horizons.

The method of correlation by reference to the stratigraphical interval above or below a known bed such as the Muree (18), Fig. 2) may give an erroneous impression because it takes no account of the thickness of the containing beds at the various localities. Where this thickness is variable it is obvious that different correlations may be obtained depending upon the datum horizon selected.

Dr. Ida Brown(3) has referred to this point in discussing the Ulladulla occurrence.

Another method of correlation that might be adopted is to express their position as a ratio between the interval of the horizon above or below a known datum, and some other factor such as the thickness of a stage. For this method to be exactly applicable, however, it would be necessary to assume that sedimentation was proceeding continuously, if unequally, at all the localities under consideration.

The correlations suggested in the foregoing brief description of new localities and on p. 337 take into consideration the general nature of the Permian sequence at each place, but it is not suggested that anything more than an approximate picture of their distribution in the stratigraphical column is given thereby.

The number of known glendonite occurrences in the Permian of New South Wales has increased so much during the past few years that it is almost certain that they are not referable to horizons which can be closely correlated from place to place.

On p. 337 average thicknesses of the formations as they are developed in the Lower Hunter Valley are given, and the correlations with localities outside that area, namely Wollongong, Ulladulla, Mersey Valley (Tasmania) are approximate only. They cannot be otherwise. Dr. Ida Brown's correlation between the Huskisson-Ulladulla and the Muscle Creek horizon is accepted.

Twelve horizons are represented, eight of which are in the Mulbring Stage, three in the Branxton Stage, and one in the Lower Marine Series. This may not give quite a true picture of the distribution of glendonites for several reasons. The Lower Marine Series has not been examined in detail for many years, and the beds of the Upper Marine below the Fenestella shales are exposed over only a relatively small part of the area occupied by beds of Permian age in the Hunter Valley. Further, in geological

Loder's Creek.

Seven miles south-westerly from Singleton. The glendonites occur on the main concretion horizon and, therefore, correspond to the type locality at Glendon. (Raggatt.111) Stenopora erinita occurs, associated with the glendonites, in a bluish-grey micaceous mudstone.

Edenglassie.

On the Edenglassie holding, six miles southerly from Muswellbrook in portion 77, Parish of Vaux, County of Durham. Only a few individuals were noted in a sandy shale.

It may be noted that the Muree beds are absent from the Upper Marine section over the greater part of the western limb of the Muswellbrook Dome, the total thickness of the Series there developed being not more than 1,600 feet. The glendonites occur 800 feet above the top of the Greta Series, and approximately at a stratigraphical position which is equivalent to the base of the Mulbring stage. They may be correlated with those originally noted by Carne in the Hunter River at Muswellbrook.

Sedgefield.

Glendonites were noted in a blue micaceous mudstone of the Branxton Stage in portions 37 and 38, Parish of Sedgefield, 1 1/4 miles north of the village of the same name. At first it was thought that these glendonites might be correlated with those originally noted by Woolmough at Wattle Ponds Creek, but as measurement indicates that they are 1,050 feet below the Muree beds this is improbable.

It will be observed that at five of the six new localities the glendonites occur in the top stage of the Upper Marine Series, namely the Mulbring beds.
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mapping it is the upper and lower parts of the Mulbring beds which receive most attention, the latter because of their nearness to a recognisable key horizon, the Muree Stage, and the former because of the economic importance attaching to the delimitation of the base of the Upper Coal Measures as accurately as possible. It may well be, therefore, that new horizons of glendonites will be found in the course of future field work.

CONDITIONS OF FORMATION OF GLENDONITES.

David, Woolnough, Taylor and Foxall(6) summarised the results of their research under ten headings. The majority of these are in support of their principal conclusion that glendonites are formed under marine conditions and are pseudomorphous after glauberite (i to iv, ix and x in part). This conclusion has been well supported by later work, but certain others relating to their mode of origin have been somewhat modified.

These authors considered that “The fact that the longest axes of the pseudomorphs trespass across the planes of lamination in the mudstone and have flattened themselves at their extremities where they grew against a coral or pebble; and the fact too that they sometimes enclose fossil brachiopod shells implies that they were not originally developed upon the surface of the mudstone (where their crystallographic force would have enabled them to have displaced small objects, as small pebbles and brachiopod shells) but at some depth below the surface ”.

In the first place the transgression of the bedding-planes by the long axes of the glendonites does not prove the intrusion of the former by the latter. This would appear to be the case whether it had actually happened or the glendonites had simply grown at the surface and become covered by the later sediments. The same might be said of any small object with a vertical dimension greater than the distance between any two bedding-planes.

In the second place the relationship existing between the glendonites and other objects such as pebbles and shells might be expected to arise whether the glendonites grew at the surface or beneath it. A crystal growing under quite normal circumstances would enclose or grow around any considerable object it might encounter, and if this process were arrested for any reason whatsoever, it would appear to terminate against such object. Obviously, where a number of crystals are growing in the same environ-
ment, there must be examples showing all stages in such an enveloping process. The principles controlling the growth of crystals are well set out by Taber,\textsuperscript{(14)} and as bearing on the present inquiry the most important is as follows: "Most crystals are unable to overcome external pressure resisting growth because there is no provision for supersaturating the solution with respect to the faces that are under pressure and that are thereby rendered more soluble."

Therefore, the fact that glendonites enclose fossils or terminate against them does not appear to support the view that glendonites necessarily formed at some depth below the surface of the muds in which they are found. It has been pointed out elsewhere that glendonites form the nuclei of small discoid concretions on the main glendonite horizon of the type locality (\textsuperscript{(11)}, p. 150), and it has been shown above that glendonites form the nucleus of concretions at other localities, as at Wollongong. Concretions showing well marked zoning are exposed in the railway cuttings two miles north-westerly from Minimbah platform. A small group of glendonites occurs between two zones of growth in one of these concretions. If the author\textsuperscript{(11)} has succeeded in proving that the concretions are contemporaneous, then the glendonites must have been formed contemporaneously also.

David and others\textsuperscript{(6)} have suggested that (No. x) "possibly sulphate-forming bacteria may have existed in the black muds of the matrix ", and these authors also refer elsewhere to the glendonites occurring in every case in "a dark grey, rather carbonaceous mudstone " (No. vii), a statement which is true in a general way of the new localities, though the mudstones are typically calcareous, and blue or grey depending largely upon the freshness of the exposed surface. Fresh exposures and bore cores are almost invariably blue in colour. It is also true, however, that apparently exactly similar beds contain no glendonites. Bacteria may certainly have played their part, but there is no reason for supposing that they may have been any more active at these horizons than at many others of similar lithology which are barren of glendonites.

Dr. Ida Brown (\textsuperscript{(3)}, p. 29) states that "it is noteworthy that where glendonites occur . . . abundant fossils are frequently associated with them ". She considers the sulphur necessary for the formation of glauberite "may have been derived from the decomposition of the soft
parts of the abundant marine organisms with or without the aid of bacterial action”. The reference to the presence of marine organisms in abundance is borne out at only one of the new localities recorded in this paper, but fossils certainly do appear to be present wherever glendonites occur; and, moreover, where the fossils are abundant the glendonites are plentiful, where the fossils are not common, there are few glendonites. Of course there is not necessarily any causal connection between these facts.

The association of glendonites with concretions and the alternations of these in zones has been stressed before. In regard to these it was pointed out (111, p. 156) that it is generally agreed that the amount of calcium carbonate held in solution by the waters of the ocean approximates saturation, at least in the warmer seas, and that the actual quantity of calcium carbonate held in solution at any time varies inversely as the temperature. On the other hand deposits of glauberite forming at the present time (as in the Gulf of Karabughaz) are thicker in winter than in summer (Twenhofel,17 p. 367).

If, therefore, one assumes a shallow arm of the sea the waters of which have reached saturation with respect to calcium carbonate under very cold conditions, slow warming is all that is necessary to induce the deposition of the calcium carbonate which forms the concretions. A renewal of cold conditions would lead to cessation of such deposition, and in extreme cases to the death of numerous organisms. This might be a local phenomenon and might be brought about by the advent of floating ice. The presence of numerous glacial erratics is clear evidence that ice rafts had access to arms of the sea in many places, but it may readily be supposed that bars precluded this happening in others.

Such conditions would be favourable for the formation of glauberite, the decomposition of the soft parts of marine organisms perhaps providing sulphur, and the cold conditions favouring the deposition of glauberite as in the Gulf of Karabughaz. The close association of glendonites with marine fossils over limited areas, e.g. with Warthia at Minimbah, supports this hypothesis.

Intermittency in this process would give rise to the alternating succession of concretion and glendonite zones observed in some localities, and to the formation of calcareous concretions with glendonites as nuclei.
This explanation is open to the objection already mentioned, that beds containing abundant fossils and apparently similar lithologically to those in which the glendonites occur are barren of the latter, and that with such a relatively simple mode of origin it is perhaps curious that glendonites, which have been recorded from so many localities in New South Wales, are of rare occurrence in beds of similar geological age in other States of the Commonwealth. (The writer has recently had the opportunity of examining much of the Permian in North-West Basin, Western Australia; no glendonites were noted.) It must be borne in mind, however, that the origin postulated requires a rather nice adjustment between the degree of concentration of the necessary salts and temperature, and that in any case the objection is a negative one.

It is worth while reiterating that there is a concentration of glendonite occurrences in the Mulbring Stage, and particularly towards the top of that Stage. This may be interpreted as being due to the fact that the Upper Marine sea was becoming shallower and divided into more or less isolated basins with approach to Upper Coal Measure time, its salts more concentrated, and chemical equilibrium in its waters more readily liable to be upset by temperature changes.

PERMIAN GLENDONITES AND CRETAEOUS PSEUDOMORPHS.

The evidence afforded by the Permian glendonites suggests that they can be expected to occur only on fossiliferous horizons in marine glacial deposits. Apart from the Permian the only other beds in New South Wales which satisfy these conditions are the Cretaceous of the Great Artesian Basin. These beds, which outcrop typically at White Cliffs and Tibooburra, are now considered to be glacial (Andrews,\(^2\) p. 96; Kenny,\(^19\) p. 99). In them occur the "fossil pineapples" first recorded by Jaquet \(^8\) p. 141). These, Anderson and Jevons \(^1\) p. 34) consider to be opalised pseudomorphs after glauberite.

The authors \(^6\) pp. 5 and 6) of the 1905 paper on glendonites referred to the White Cliff pseudomorphs, and in 1926 David and Woolnough \(^7\) pp. 346-347) put forward the occurrence of pseudomorphs after glauberite as "possible evidence of the seas having been cold in Australia in Cretaceous time ", and in his Explanatory Notes, David (1932, p. 84) states that the pseudomorphs
"resemble the glendonites associated with erratics in the sediments of the cold Middle Permian seas of Australia".

So far as can be observed, the only difference between the pseudomorphs from the Permian and those from the Cretaceous is their present chemical composition. Groups of glendonites may be seen at several localities in the Hunter Valley and at Wollongong which are very similar to the figures published by Anderson and Jevons, and Ida Brown (loc. cit.) has described glendonites from the South Coast as occurring as a dozen or more individuals. (Compare Plate XV, Proc. Linn. Soc. N.S. Wales, Vol. 7, Part 2, and Plate XI, Rec. Austr. Mus., Vol. VI, No. 1.)

Having regard to the fact that opalised shells are found in these deposits, the Cretaceous pseudomorphs may have suffered two changes, the first early in their history when the glauberite was replaced by calcium carbonate, and the second in Tertiary or later times when they became opalised. It is probably significant that erratics and opalised fossils are associated with the pseudomorphs at White Cliffs. Mr. Kenny has compiled a list of these fossils which the late W. S. Dun states are all shallow water forms. (See also Pittman (10) re association of pseudomorphs and fossils.) The Cretaceous "glendonites" thus appear to offer rather striking confirmation of the conclusions reached regarding those from the Permian.

**Summary.**

The stratigraphical position of a number of previously mentioned glendonite horizons has been defined, and six new localities have been briefly described.

The paper is believed to constitute a complete record of glendonite occurrences in Australia.

Glendonites are known to occur on at least twelve horizons in the Permian in New South Wales, and no less than seven of these are in the Mulbring Stage of the Upper Marine Series. It is considered that this indicates that the Upper Marine sea was becoming shallower and divided into more or less isolated basins as Upper Coal Measure time was approached. This led to concentration of salts, with the result that chemical equilibrium in its waters was more readily liable to be upset by temperature changes than previously.

The presence of numerous erratics shows that glendonites were formed, at least in many instances, under cold conditions, and the absence of erratics from some places is
NOTES ON THE STEATIGEAPHY AND PHYSIOGEAPHY OF THE TALBBAGAE "FISH-BED" AREA.

By J. A. Dulhunty.

(With two text-figures.)

(Manuscript received, October 18, 1937. Read, December 1, 1937.)

Introductory.

The Talbragar Fossil Fish Beds are situated 20 miles north-east from Gulgong on Portion No. 14, Parish of Bligh. The general stratigraphy of the area surrounding the Fish-Beds is described in the present paper, with a view to elucidating the relation which the fossiliferous cherty shales of the Fish-Beds bear to the associated strata. The physiography of the area is also important as it is intimately connected with the physiographical development of the Merriwa-Ulan district, described by the present writer in a previous paper (This Journal, 1937, 77, 297).

Topography.

The principal topographical feature is the Main Dividing Range, trending approximately north-east to south-west across the area, and consisting of a low ridge or slightly elevated portion of the old peneplain surface which extends to the east and west. The average elevation of the Dividing Range at this particular point is some 1,800 feet above sea level. The peneplain surface has been developed in sandstone strata and now forms a plateau extensively dissected by shallow and mature valleys carrying the headwaters of the Goulburn River on the east and the Talbragar River on the west. The floors of these valleys lie some 300 feet below the plateau surface. Basalt-flows have produced rounded hills which stand out above the general surface, as at Cockabutta Mountain. These flows are olivine-basalt of late Tertiary age, and in several places occupy positions on the sides of the valleys, and Fletcher, H. O.: Rec. Austr. Museum., 1937, 29, 150-184.

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