RIPPLE-MARKS IN THE NARRABEEN SERIES ALONG THE COAST OF NEW SOUTH WALES.

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(With Plate V and five text-figures.)

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The Narrabeen Series is the lower division of the Triassic System in New South Wales and overlies rocks of Kamilaroi Age; above, the Narrabeen beds pass into the middle division of the Triassic—the Hawkesbury Series.

The study of the ripple-marks in the Narrabeen Series was undertaken with the hope of gaining information as to their mode of origin.

Short Notes on the Formation and Interpretation of Ripple-marks.

A short description of the method of formation and interpretation of the main types of ripple-marks seems necessary at this stage. Reference for this has been made to papers by Kindle,(4) Bucher,(1) Hunt,(2) Twenhofel.(5)

Fossil ripple-marks are exposed on the surface of some sedimentary rocks. They are marks or corrugations which suggest water ripples and are formed by water or wind action at the time of deposition of the sedimentary rocks.

Ripple-marks can be classified into three main types, (*a*) wave ripple, (*b*) water-current ripple, (*c*) wind-current ripple. Complex ripple-marks are variations of one or more of the above.

Wave ripples may be formed on the floor of a body of water which is tideless and also free from currents. Such a body may be a lake or an arm of the sea cut off from the main ocean. Wind blowing over the water surface produces an orbital motion of the water particles. This motion is circular in deep water but grades through elliptical motion to an almost horizontal to-and-fro oscillation in shallow water. Where the water is sufficiently shallow the movement of the water particles induces a corresponding oscillation in the loose sediment beneath. The continued motion causes a series of parallel ridges to be built up, their distances apart being proportional to the major axes of the oscillation ellipses. The production of vortices on either side of the ridges gives them a symmetrical profile with sharp crests and rounded troughs. Occasionally the crests may be rounded.

The direction of the ripples, then, is dependent on the direction of the wind, but in shallow water there is a tendency for the waves to wheel round parallel to the contour lines of the bottom, and thus the ridges become approximately parallel to the shore-line, no matter what the direction of fetch of the wind.

Considerable confusion exists as regards nomenclature in the study of ripple-marks. In this paper the spacing of the ridges will be termed the wave length, and the height from trough to crest the amplitude.

The actual effect which depth of water and wave amplitude have on the wave length and amplitude of the ripple-marks has not yet been ascertained, but Kindle, from observations made on the shore of Lake Ontario, gives us the following table:

Depth of Water.	Wave Length of Ripple-marks.
6 inches	1 – 2 inches
1¼ feet	2 – 4 ,,
2½ ,, ...	3½– 4 ,,
10 ,, ...	4 – 6 ,,
11 ,, ...	4½ ,,
20 ,, ...	4 – 5 ,,

Also, he states that to his knowledge ripple-marks with a wave length of less than two inches are formed only in water having a depth of less than one foot.

Bucher[1] (p. 188) reports that Forel has conclusively shown that wave length diminishes with increasing depth of water; Kindle's observations for shallow water are contrary to this.

The relationship of depth of water to wave length may be summarised: (*a*) For shallow depths, as given in Kindle's table, there appears to be an increase of wave length with increase of depth. (*b*) "For moderate depths the size of the ripples is not very sensitive to variation of water depth." (*c*) For greater depths there is a decrease of wave length to a very small size.

Kindle refutes the idea fairly commonly accepted, that ripple-mark of any dimension, in itself, is sufficient criterion for shallow water deposition. He gives examples of ripple-mark produced at great depths.

Current Ripple-mark.—The continued flow of a current (water or air) over loose sediment is likely to set up ripple-marks, the ridges being at right angles to the direction of the current. Both water and wind ripple-marks have characteristic asymmetric profiles with a gentle stoss-side and a steep lee-side. Water-current ripples are formed along shores with a coastal current, in water bodies under tidal influence, and as local occurrences in fresh-water lacustrine sediments.

According to Bucher, *cross ripples* are formed when one set of ripples intersects a previously formed set. The component ripples may be either symmetrical or asymmetrical. There are two classes of cross ripples—hexagonal, when the crests of the two sets of ripples intersect at an angle less than 90°, and rectangular, when they intersect at 90°. Accepting Bucher's theory of their formation, cross ripples can form anywhere where conditions are favourable for the formation of simple ripple-mark; but Kindle's theory demands very shallow water, and a barrier to set up the component systems.

Method of Measurement.

A very satisfactory and quick method of measurement of ripple-marks was suggested by Professor L. A. Cotton, M.A., D.Sc.

An ordinary pantograph was adapted (Fig. 1). The pantograph was attached by means of the screw "A" to

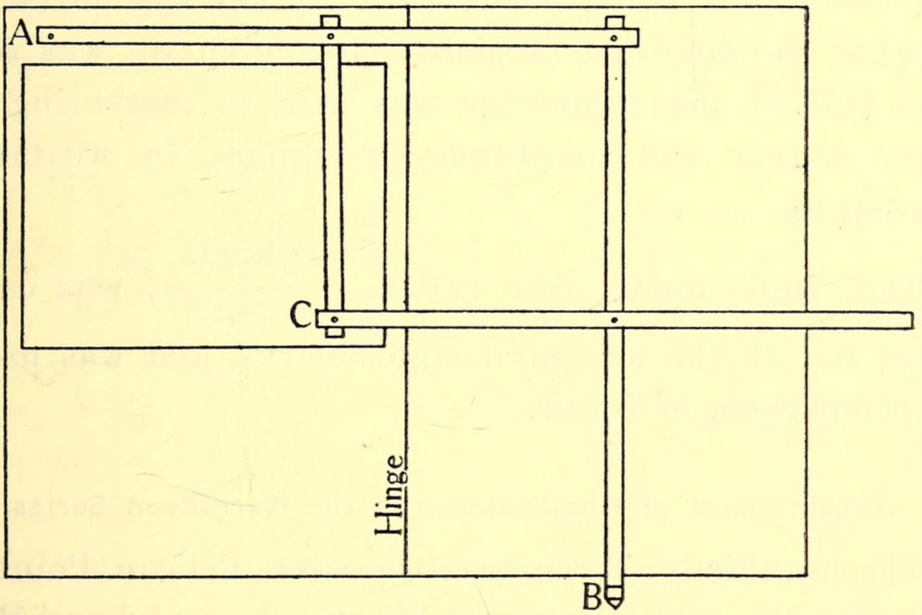


Figure 1.

a light board. The board was of 3-ply wood, and in order to make it more convenient for carrying, it was cut along a central line and hinged so that it could be folded into a convenient size. The usual tracer was replaced by a hard metal point "B," which could be drawn over the surface of the rock. To obtain traces of the profiles of the ripple-marks, the board was held vertically at right angles to the direction of the crests of the ripples, the tracer was drawn over the rock surface, and the pencil "C" traced the profile of the rippled surface on paper pinned on the board.

With the pantograph thus altered, only reduced drawings could be made. There was no necessity for varying the amount of reduction, so to facilitate comparison of ripple forms, all the measurements were done to half-scale.

The symmetry of the profiles obtained is sufficient to show whether they are formed by wave action, water current, or air current.

The directions of the ripple crests were measured by the compass of a clinometer rule. In the case of curved ripples, the direction tangential to the curves was read. The rule of the clinometer was used in measuring the wave length and amplitude of ripples in weathered exposures.

The ripple index, (the ratio $\frac{\text{wave length}}{\text{amplitude}}$), was calculated for all the measured ripple-marks, and was useful in comparison of forms.

Measurement of Ripple-marks in the Narrabeen Series.

The headlands of the coast between Pelican Point (7 miles north of The Entrance, Tuggerah) and Long Reef, and also the coastal exposures between Garie and Stanwell Park, were examined for ripple-mark.

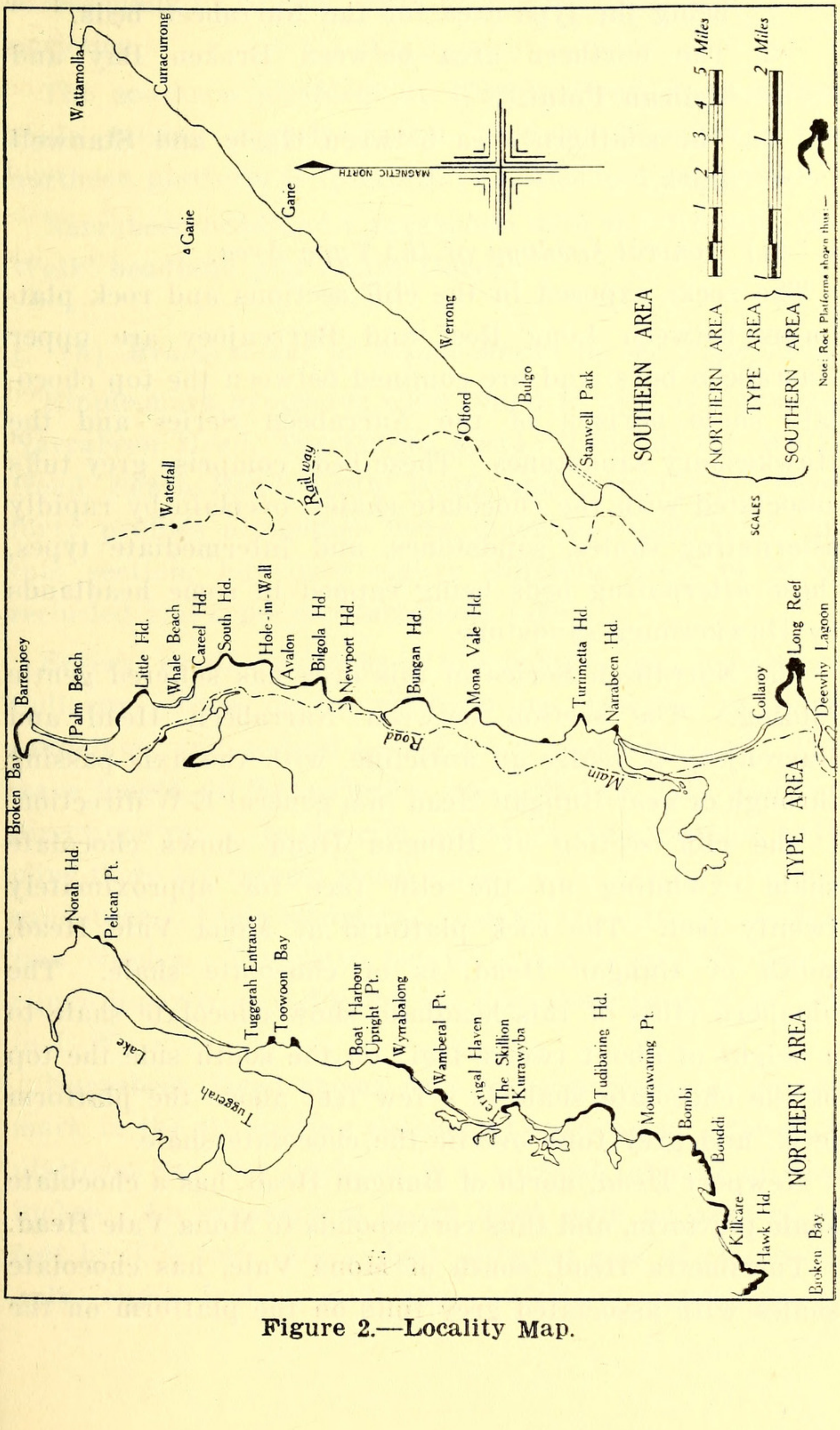


Figure 2.—Locality Map.

The work will be dealt with in three sections:

1. The area between Long Reef and Barrenjoey, being the type area for the Narrabeen beds.
2. The northern area between Broken Bay and Pelican Point.
3. The southern area between Garie and Stanwell Park.

1. (*a*) *General Geology of the Type Area.*

The rocks exposed in the cliff sections and rock platforms between Long Reef and Barrenjoey are upper Narrabeen beds, and are confined between the top chocolate shale horizon of the Narrabeen Series and the Hawkesbury sandstones. These beds comprise grey tuffs associated with the chocolate shales, overlain by rapidly alternating shales, sandstones, and intermediate types, these alternating beds being capped in some headlands by Hawkesbury sandstone.

The Narrabeen Series in this area has suffered gentle folding. The section between Narrabeen Head and Barrenjoey is really an anticline, with the axis passing through or near Bungan Head in a general E-W direction.

The cliff section at Bungan Head shows chocolate shale extending up the cliff face for approximately twenty feet. The rock platform at Mona Vale Head, south of Bungan Head, is of chocolate shale. The northern cliffs of this headland show chocolate shale to a height of about twelve feet; on the south side the top of the chocolate shale is a few feet above the platform level, and grey tuffs overlie the chocolate shale.

Newport Head, north of Bungan Head, has a chocolate shale platform, and thus corresponds to Mona Vale Head.

Turrimetta Head, south of Mona Vale, has chocolate shales with associated grey tuffs on the platform on the northern side, but these give place to interbedded sandstone and shales on the southern side. This headland corresponds to Bilgola Head on the northern arm of the anticline.

The southern platform at Bilgola Head is chocolate shale (rising slightly higher than at Newport); the northern platform is interbedded shales and sandstones.

Narrabeen headland corresponds with the "Hole in the Wall" headland and South Head.

1. (*b*) ***Measurement of Ripple-marks in the Type Area.***

Ripple-mark exposures were found *in situ* at Collaroy, Narrabeen Head, Turrimetta Head, "Hole in the Wall" Head, South Head, Little Head, and Barrenjoey. Over forty profiles altogether were taken of ripple-marks in this section, but over eighty different horizons were recorded and some measurements taken.

Several small exposures of ripple-mark may be seen at Collaroy. Those on the platform are preserved in a fine sandstone, and several horizons are ripple-marked. The wave length of these ripples averages one inch, and the directions vary. In the cliff section at the hydration anticline there are several small exposures in medium-grained sandstone. Their symmetry is definitely that of oscillation ripples. The wave length varied from 2–3 inches, ripple index from 6–12, and the directions from N 20° W, to E-W.

Narrabeen Head shows very many horizons of ripple-mark in the alternating shales and sandstones. The rock platform has four horizons in a vertical interval of four inches. An exposure at beach level, with an area of 42 feet by 37·5 feet, shows eight different sets of ripples in only eight inches vertically. Various exposures of ripple-mark are found in grey shales and fine sandstones in the cliff ledges.

The directions range over a very wide angle, but in the cliff exposures there is a progressive change in a W-E direction from N 51° W to N 55° E.

Three sets of cross ripples are present—one in the rock-platform and the others in the exposure at sand-level. The direction of the sharper component in one case is the same as that of the simple ripples two inches below, and in a second instance, the same as simple ripples on the same horizon. This appears to be in favour of Bucher's theory that cross ripples are formed by one set of ripples interfering with a previously formed set, and not simultaneously by component current systems as suggested by Kindle. The directions of the stronger components are N 55° W, N 58° W, and N 32° W.

The ripples at Narrabeen Head are all of the oscillation type, with the exception of one set, which is asymmetric. The wave length averages 2·35 inches, with minimum and maximum limits of 1·7 inches and 3·4 inches, and the ripple index varies between ·9 and 15, the higher values generally obtaining for the finer sandstones and shales.

About one chain beyond Narrabeen Head, on Turrimetta beach, some grey sandstone ledges show ripple-marks of wave length 2 inches and 2·9 inches. Although these are separated by one foot vertically, they trend in the same direction, *viz.*, E-W, indicating stable conditions of sedimentation between these two horizons.

At the most southerly point on the Turrimetta Head platform cross ripples occur in a fine shaly sandstone. The strongest set of ripples trend N 20° W, and have a wave length of 3·5 inches approximately. The weaker ripples have a wave length of 4 to 4·5 inches. Both sets are wave formed. No other ripples observed on Turrimetta were *in situ*, but two boulders showed asymmetrical ripple-marks, both in shale, and having values of 15 and 18 for the ripple index. The other ripples are all of the oscillation type, and one boulder with three layers of ripple-marks, shows a progressive change in direction. Two sets of ripples in sandstone have wave lengths of 3·5 inches and 3·6 inches, which is much greater than the average of 2·28 inches. Many of the ripples are in close association with abundant fossil worm burrows.

At the headland north of Mona Vale beach no ripples were found *in situ*, but several rippled boulders of sandstone had fallen from above the chocolate shales which formed the platforms and the lower portion of the cliff. One was particularly interesting in showing intimate association of ripple-marks with *Phyllotheca*. A stem of *Phyllotheca*, about five-eighths of an inch wide, has been preserved lying on the rippled surface, making an angle of almost ninety degrees with the ripple crests. The wave length of the ripples is 1·5 inches, and the amplitude 0·15 inch, and the fact that the *Phyllotheca* stem has produced no noticeable distortion of the ripple forms, testifies to the flexibility of the plant stem.

Oscillation ripples are found in grey shale and sandstone boulders at Bungan Head.

Ripple-marked boulders are present at Newport. The sandstones show ripple-mark of greater wave length than usual, ranging from 2·6 inches to a maximum of 4·5 inches. A grey shale boulder, besides being rippled, contains abundant plant fossils (mainly *Phyllotheca*), and also has worm-burrows on the same surface as the ripples.

From south to north round Bilgola Head, the chocolate shales give place to fine sandstones and sandy shales. It is in this horizon, on the northern platform, that abundant ripple-marks occur. The rocks are finely laminated, and in a vertical interval of only a few inches ripple-mark directions N 8° W, N 13° W, N 20° E, N 70° E, N 64° E, N 70° E, and N 75° E were measured. The wave length averages one inch, but reaches a maximum of two inches.

Ripple exposures are found *in situ* and in boulders at the "Hole in the Wall" rock platform. Both simple and cross ripples occur. The best defined set in the cross ripples trends in a direction N 70° W, the other set almost at right angles to this. The wave length of the ripples varies vetween 2 inches and 3·5 inches, and the direction between N 40° W and N 40° E.

The rock ledges at the base of the cliffs between South Head and the "Hole in the Wall" show an astonishing number of ripple-marked horizons. In a vertical interval of three feet nine inches eighteen different horizons were noted. The ripple-marks occur in very rapidly alternating beds of very fine sandstone, sandy shales, or finer shales. Almost all the sandy material is rippled and the directions are variable, although some ripples, trending E-W, are superimposed throughout a few inches. While the ripples vary greatly in size, they are all of the oscillation type. It is in a sandstone boulder from here that the ripples occur which have the maximum wave length observed, *viz.*, 5·2 inches.

The only other ripple-mark exposures in this section are two small isolated exposures. The first is in sandstone which forms the headland south of Palm Beach. Indications of ripple-marks are seen in the cliff faces above this sandstone. The second is at the eastern point of Barrenjoey. The exposure is small, and in massive sandstone. Again, indications of ripple-marks can be seen in the sandy shales in the cliff face.

2. (*a*) *General Geology of the Northern Area.*

Between the Hawkesbury River and Pelican Point we have the entire sequence of the Narrabeen Series from the Hawkesbury sandstones to the base, overlying conglomerates at the top of the Kamilaroi system.

The headlands between Terrigal and Killcare expose the same sequence as between Narrabeen and Barrenjoey. The general nature of the Killcare rocks is very similar to those at and near South Head.

To the north, Wamberal headland gives the first exposure of the upper chocolate shales, which are associated with grey tuffs and grey shales.

The southern portion of Wyrrabalong rock-platform consists of a fine tuffaceous sandstone, greenish grey in colour. This is in part weathered brown, the resultant rock looking very like the chocolate shales but being more sandy in character. These beds, dipping S 24° W at about 5°, are finely bedded, and form a very level platform, eroded edges showing at intervals. The chocolate shales outcrop at beach level and at the base of the cliff on the southern side of Wyrrabalong. The northerly cliff section of Wyrrabalong exposes a much greater thickness of chocolate shales. A rough estimate was made of one hundred feet of chocolate shales with subordinate greenish sandy tuff interbedded, these being overlain by approximately one hundred feet of a flaggy tuffaceous sandstone. The chocolate shales are covered with grass as is often the case with chocolate shale cliffs.

There are two bands of chocolate shale exposed at Point Upright, one at reef-level, the other about nine feet up the cliff, separated from the lower by tuffaceous sandstone.

The small headland north of Boat Harbour shows weathered exposures of chocolate shales. The lower shales are not typical chocolate shales, but their sandy nature is no doubt due to their being near the edge of the basin of deposition. They are associated with green tuff and one sedimentary type grades into the other. These are separated from the upper band by about twelve feet of sandstone.

The most northerly coastal exposure of chocolate shales is found at Toowoon Bay, where a vertical thickness of ten feet was estimated. This is underlain by massive tuffaceous sandstone and conglomerate which lie near the base of the Narrabeen Series.

The beds in the northern area have a general gentle southerly dip, and no definite folding is apparent.

2. (*b*) *Measurement of Ripple-marks in the Northern Area.*

The rock platform south of Killcare exposes shaly sandstones (purplish in colour), similar in appearance to those of Narrabeen Head. The alternating beds in the cliff section are capped by Hawkesbury sandstone. The platform has many ripple-mark exposures, but all are badly weathered, and only the crests remain in many cases. The wave length averages between 1 inch and 2 inches, and direction readings are varied for the ripples at different horizons. One set of cross ripples has components N 10° W and N 78° E.

The stretch of coast between Killcare and Mourawaring Point is inaccessible.

Mourawaring Point shows numerous weathered ripples in the fine sediments exposed. The wave length of the ripples averages 1·5 inches, few being only 1 inch, and others reaching a maximum of 2 inches. In a vertical interval of about four feet fairly good exposures were noted in sixteen different horizons, the directions varying between N 70° W and N 53° E.

Tudibaring Head, north of Tudibaring beach, exposes more sandstone than the more southerly headlands, and in this the ripple-marks are more rare and very badly preserved. Only a few very poor exposures were observed, and directions noted were N 7° E and N 85° E.

Sandstones are again more prominent in the headland south of Avoca, and no ripple-marks were found in these.

On the northern platform of the Skillion, Terrigal, a few exposures of ripple-marks occur. One set of markings, having a wave length of 1·5 inches, and a direction of N 34° E, is persistent over two inches vertically, and in a slightly lower horizon other ripples occur trending N 40° E, indicating constant conditions of ripple formation over a time sufficient for the consolidation of the lower ripples, and subsequent deposition of sediment.

But it is on the southern side of the Skillion towards Kurrawyba Head, that some excellent exposures occur. Many of these are very well preserved. The average direction readings on twenty-five different exposures is N 30° E, the limiting readings being N 25° W and N 84° E. The average wave length is about 1 inch, and ripples were recorded from here with wave lengths of only 0·5 inch and 0·7 inch, each being in fine sediment. The component directions of a cross ripple exposure are N 15° E and N 62° W.

Proceeding south from the Skillion the alternating shale and sandstone give way to more massive sandstone ledges which are practically free of ripples, but those which do occur have a wave length of 3–3·3 inches. Also, in this sandstone, interference ripple-marks of large size and irregular pattern can be seen. They are similar to those formed in water bodies under the influence of current action.

Ripple-marks were not observed at Wamberal Point, but many were found on the rock platform at Wyrrabalong. Here greenish grey tuffs form the platform, and these are intimately associated with chocolate shales. On the platform are many exposures, but most of the platform is covered with algæ, leaving only a few rocks exposed. The directions are variable, mostly being between the limits N 35° W and N 24° E. The wave length averages one inch, and the limits observed were 0·8 inch and 1·05 inches.

The chocolate shale at Wyrrabalong is interbedded in narrow bands of eight inches or less with green tuffs. In several instances these interbedded tuffs are rippled. Specially interesting is a junction surface between tuff and chocolate shale, where the shale rests on the rippled tuff surface.

Also, in this tuff are irregular interference ripples similar to those at Kurrawyba, and evidently due to some current or tidal action. Worm burrows and sun cracks are found in the tuff close by these ripples.

Only two other exposures of ripple-marks are noted and these are on the small rock platform north of Boat Harbour. In some sandy chocolate shale some shallow ripple-marks of wave length 1·3 inches occur. These are particularly interesting in being the lowest observed in the series—being at the base of the lower chocolate shales.

3. *The Southern Section.*

The headland north of Garie Beach exposes the upper chocolate shale horizon, which has here a thickness of about forty-five feet, overlain by alternating grey shales and sandstone. Below are shales and sandstones and about one hundred and fifty feet lower than the chocolate shales is a horizon of cupiferous basic tuff.

Much of the coast is inaccessible south of Garie, with truncated headlands covered with vegetation and comparatively few rock platforms.

A little south of Otford rock platforms are developed, but there the rock formation is coarse sandstone and conglomerate, forming the lower beds of the Narrabeen Series. The upper chocolate shales are exposed at Otford, and the cliffs between here and Stanwell Park would, if not covered so heavily with vegetation, show the sequence between the top chocolate shales and the base of the Narrabeen Series. No detailed work could be done in this section.

The rock platforms, being of coarse sediment, do not show any ripple-mark.

In fact, no ripple-marks were found by the writer, in the southern section of the Narrabeen Series, other than at Waterfall. The ripples here are exposed in the cliff section and on fallen boulders at the Lower Falls, two miles along the Lady Carrington Drive from Waterfall. Here, in the cliff face, Narrabeen grey shales with abundant *Phyllotheca,* and fine sandstones are exposed, overlain by more massive coarse Hawkesbury sandstone. Boulders show weathered ripple-marks with a wave length of about one inch. Some grey shale shows ripple-mark of wave length three inches. The ripples are symmetrical and therefore wave formed; and the upper ones are only fifteen inches below the Narrabeen-Hawkesbury junction.

Reference has been made in *N.S.W. Geol. Surv. Mem.,* 7, to ripple-marks in the Corrimal-Balgownie colliery, formed in a horizon two feet six inches above the coal, and to a rippled horizon between Bellambi and Mount Keira. But "Palæontological evidence available does not permit of a definite age being assigned to this horizon, and it may be either early Triassic or late Permo-Carboniferous."

Summary of Data Acquired.

From information now available the facts may be listed as follows:

1. Ripple-marks are developed in the Narrabeen beds at various levels in the series.
2. The lowest ripple-marks noted are at the base of the chocolate shales, north of Boat Harbour. Only a few exposures were observed at, and near, this level.
3. More numerous exposures were found in the tuffs associated with the chocolate shales, higher in the series, at Wyrrabalong.
4. The ripples are best developed in the alternating shale and sandstone formation between the upper chocolate shales and the massive Hawkesbury sandstone. The individual beds vary from as little as $\frac{1}{8}$ inch to several feet, many of the beds being 1 foot or less in thickness. One bed may grade into another, and they are not persistent. Apparently most of the individual beds are ripple-marked.
5. From these facts one sees that the ripples are not confined to a narrow limit in the Narrabeen beds, but are developed over quite a large vertical range, from at least the base of the lower chocolate shales (north of Boat Harbour), to within

15 inches of the Hawkesbury sandstone (as seen at Waterfall).

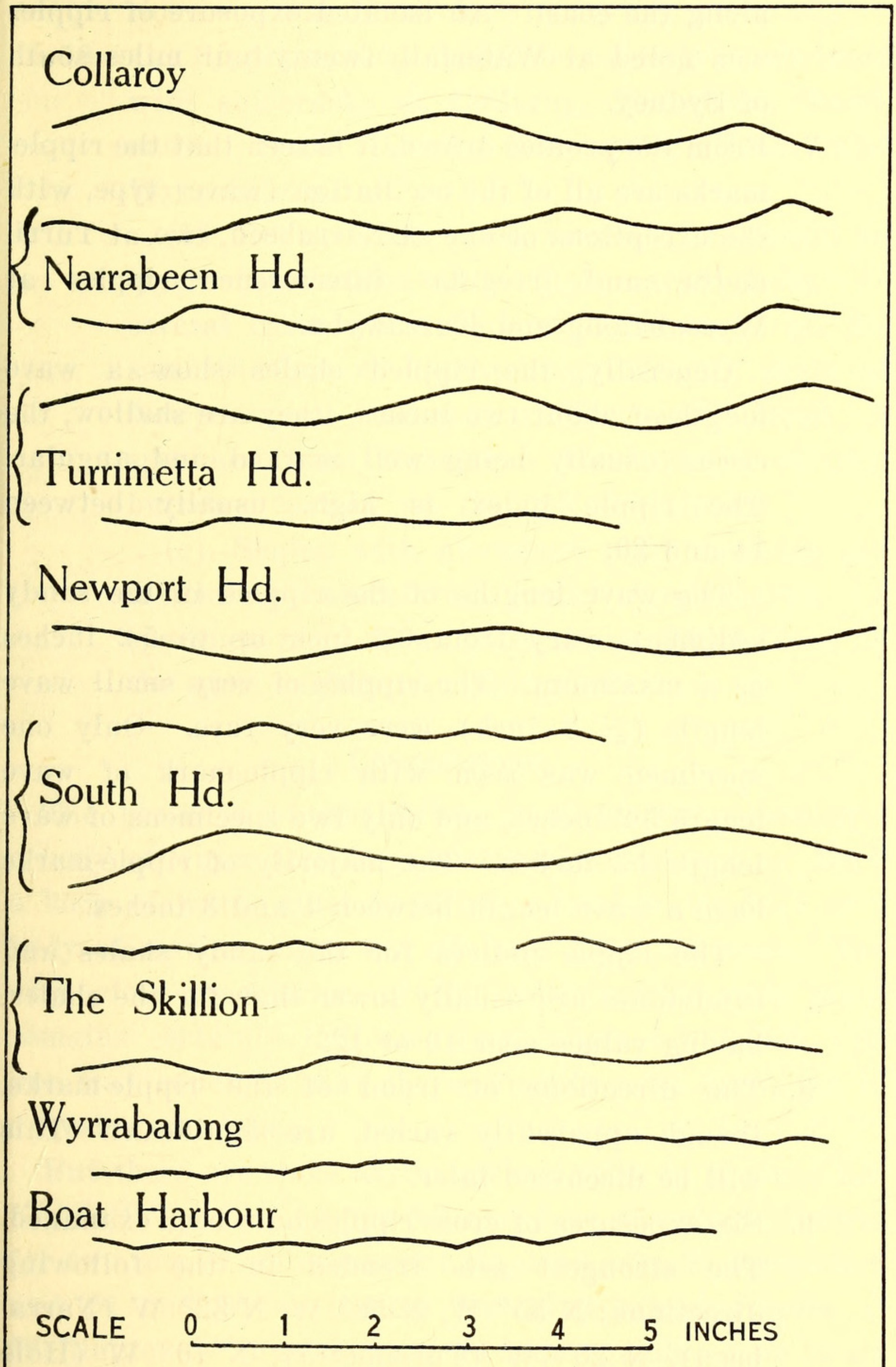


Fig. 3.—Selected profiles of ripple-marks.

6. The rippled beds extend from near Boat Harbour to Collaroy, a distance of about thirty miles along the coast. An isolated exposure of ripples was noted at Waterfall, twenty-four miles south of Sydney.

7. From the profiles drawn, it is seen that the ripple-marks are all of the oscillation (wave) type, with the exceptions of one at Narrabeen, two at Turrimetta, and irregular interference ripples at Wyrrabalong and Kurrawyba.

   Generally, the rippled shales show a wave length of about two inches—they are shallow, the crests usually being well marked and angular. The ripple index is high, usually between 14 and 20.

   The wave lengths of the ripples in the sandy sediments vary from 0·5 inch up to 5·2 inches as a maximum. The ripples of very small wave length ($\leqq$ 1 inch) were very rare. Only one specimen was seen with ripple-mark of wave length 5·2 inches, and only two specimens of wave length 4·5 inches. The majority of ripple-marks have a wave length between 1 and 3 inches.

   The ripple indices for the sandy shales and sandstones are usually lower than for the shales, having values near 10 or 12.

8. The directions of trend of the ripple-marks, though apparently varied, are significant. This will be discussed later.

9. Six exposures of cross ripples have been examined. The strongest sets trended in the following directions: N 55° W, N 58° W, N 32° W (Narrabeen), N 20° W (Turrimetta), N 70° W (Hole in the Wall). In the case of the cross ripples at

the Skillion, the two component directions seemed to be equally marked, and of these directions one was N 62° W.

10. (*a*) Ripple-marked beds are closely associated with sun-cracks at Collaroy, Narrabeen, Turrimetta, South Head, Kurrawyba Head, and Wyrrabalong.

(*b*) Horizons of worm burrows are found in layers interbedded with ripple-marked beds. In several cases worm burrows were found on the same surface as ripples, *e.g.*, in grey shale at Newport, and sandstone at Kurrawyba Head. A specimen from Narrabeen Head shows vertical burrows cutting up through the ripples.

(*c*) Shales with abundant plant remains are intimately associated with ripple-marks. A specimen from Mona Vale shows *Phyllotheca* on the same surface as ripple-marks.

Conclusions.

The presence of oscillation ripple-marks necessitates a body of water free from current or tidal action. Such a body of water must be either a fresh-water lake or a body of marine water cut off from tidal influence. The very close association of the ripple-marks with plant remains certainly indicates fresh-water conditions. So one may conclude that the sediments were deposited in a fresh-water lake.

But there are some asymmetric ripples to account for. Kindle[4] (p. 12), quotes 6·3 and 4 as the ripple indices for two sets of water-current ripples in the St. Lawrence, and 24 and 25 as indices for wind-formed ripples at Wellington—"Thus showing an index number four to six times greater than that of the water-made ripple-marks."

The indices (15, 18, 19) of the measured marks at Narrabeen and Turrimetta indicate wind agency. This is quite possible, for a shallow lake could easily be drained in part and wind ripples could then develop. Even if the inference from the ripple indices is not correct, and the ripples are water formed, there is no need to postulate other than lacustrine conditions. A local disturbance (*e.g.,* a storm), or local features (*e.g.*, a stream flowing into a lake), may produce local currents which may leave their record in fossil asymmetric ripple-marks. The irregular interference ripples at Wyrrabalong and Kurrawyba are undoubtedly water formed.

The presence of ripple-marks at intervals between the lower and upper chocolate shale horizons indicates shallow water conditions of deposition at these intervals. Ripples were not noticed in these sufficient to establish a conclusion that there was continuous shallow water sedimentation, but it can be seen that even if such conditions were not continuous, there was repeated occurrence of shallow water conditions. The presence of ripple-marks in the tuffs interbedded with the chocolate shales would suggest shallow water deposition of the latter.

The ripple-marks occur so abundantly in so many horizons in the upper Narrabeen beds between the upper chocolate shales and the Hawkesbury sandstones that it seems quite reasonable to assume shallow conditions during the whole period of accumulation of these alternating beds.

From a number of observations Kindle[4] (p. 29) concluded that:

(1) Ripple-marks with a wave length less than two inches formed only in water having a depth of less than one foot.

(2) Ripples of wave length between one and two inches were common in water six inches deep.

(3) Ripples of wave length between three and a half inches and six inches formed in water of depth about ten feet.

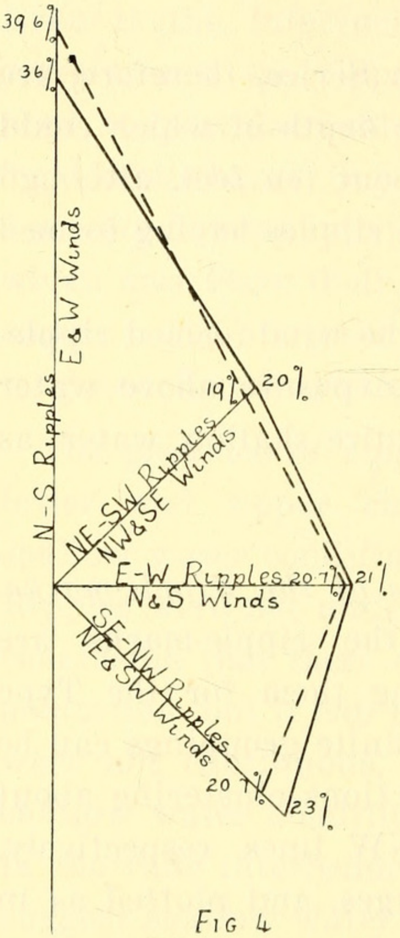
All the ripples of the Narrabeen Series, therefore, are likely to have formed in water the depth of which could vary between a few inches and about ten feet, although there is a possibility of some of the ripples having formed at a greater depth.

The presence of sun-cracks and the wind-formed ripple-marks would indicate temporary exposure above water level at times. Worm-burrows require shallow water, as do terrestrial plants.

The Significance of the Directions of the Ripple-marks.

The directions of trend of the ripple-marks are apparently varied, but on plotting them for the Type and Northern Areas separately definite groupings can be seen. The numbers of ripple directions clustering about the N-S, NE-SW, E-W, and SE-NW lines, respectively, were counted, reduced to percentages, and plotted as in Figs. 4 and 5.

Similarly, a diagram (Fig. 4) was drawn showing quantitatively, in time, the wind directions at Sydney (Type Area), for the past twenty years. Winds from opposite points of the compass form symmetrical wave-ripples trending in the one direction at right angles to the directions of the winds, *e.g.,* ripple-marks trending N-S are formed by winds either from the east or west. Therefore the duration in hours of the winds from opposite points were added and plotted as a percentage of the total wind duration along the corresponding direction for the ripples. A very striking similarity was noticed between the ripple diagram and wind diagram for the Type Area. This suggests that the planetary wind systems of lower Triassic time were the same as those prevailing at the present time in this area.



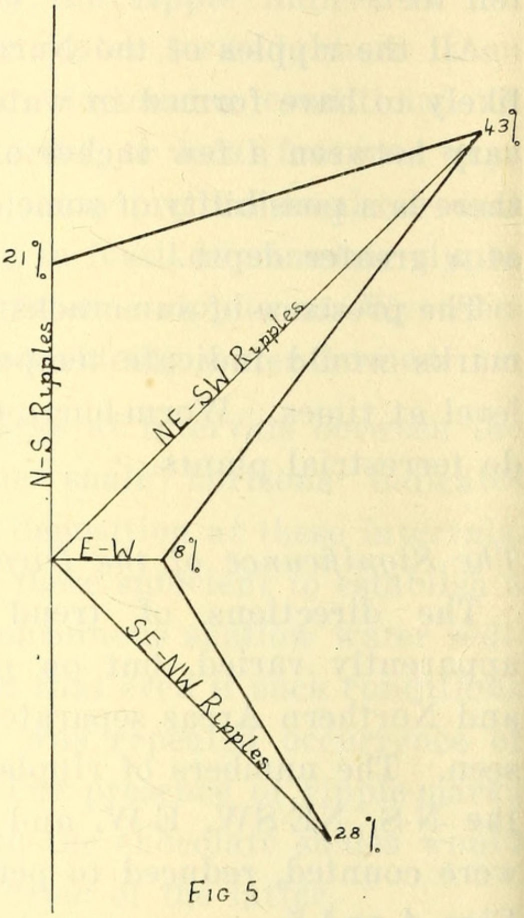


Fig. 4.—The diagram drawn with the heavy line is the ripple mark diagram for the Type Area. It is based on 66 measured directions. The diagram drawn with the broken line is the wind diagram for the Type Area (Sydney), based on the records for the years 1911-1930.

Fig. 5.—Ripple-mark diagram for the Northern Area, based on 45 measured directions.

The figure (Fig. 5) drawn for ripples in the Northern Area was of a different character, and unfortunately quantitative observations for the wind systems were not available for a comparison diagram. However, comparison of general observations of the prevailing winds at Sydney and Newcastle shows a marked dissimilarity in the summer winds. The area in question lies approximately half-way between Sydney and Newcastle. At Sydney the prevailing directions are east and north-east, while at Newcastle the south winds are predominant. So, although from this diagram one has nothing to add in support of conclusions formed from the study of diagrams for the Type Area, the different nature of the ripple diagram cannot be taken as evidence against similar planetary wind systems. The difference could probably be explained by the change of wind systems with change of locality.

From the conclusion that the planetary winds of early Triassic and the present time, are the same, one may deduce that the poles were in the same position then as now. Since the Type Area is in the anticyclone belt, a critical position, a movement of the pole of only a few degrees would probably result in a marked change of wind direction, as from the SE Trades to the Roaring Forties, or *vice versa*. This eliminates the possibility of any notable difference of the position of the pole in Triassic times.

In the case of the cross ripples it is noticed that the directions of the strongest ripples are confined between N 20° W and N 70° W. The strongest ripples are formed by the strongest waves, usually, and the strength of the wave is influenced by the shape of the lake, or by the distance of fetch. It seems possible that these directions indicate the direction of greatest fetch, which would be between N 20° E and N 70° E. This would mean that the lake would be elongated in a NE-SW direction.

Concluding, one may imagine the Triassic Narrabeen Lake as a shallow, subsiding, fresh-water lake, probably elongated in a NE-SW direction. Surrounding it one would see areas of low relief from which the sediments are brought down and deposited quietly in the lake, the prevailing calm being interrupted by local disturbances and ejections of tuffs, followed again by quiet sedimentation.

Finally, the writer would like to thank those who have helped with this paper; particularly Professor L. A. Cotton, M.A., D.Sc., for many helpful suggestions, and also Mr. D. J. Mares, of the Meteorological Bureau, Sydney, for making available wind data of Newcastle.

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