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OBSERVATIONS ON THE NATURE AND ORIGIN OF THE COW HEAD BRECCIAS OF NEWFOUNDLAND

INTRODUCTION

Unusual limestone breccias occur widely in a belt of sedimentary rocks on the west coast of Newfoundland, from Pistolet Bay on the north to the Port au Port peninsula on the south. The best exposures lie in the middle of the belt, between Daniels Harbour on the north and Green Point on the south. The breccias are named from Cow Head where excellent exposures are easily accessible along the sea-coast. These breccias have long attracted interest because of the unusual coarseness in some facies with boulders of limestone, interbedded limestone and dolomite, and shale, as much as several hundred feet long. They are unusual also because of the preservation within the apparently chaotic masses of angular boulders, of delicate fragments and plates of limestone. These fragments may be several square feet parallel to the bedding of the original limestone and only one inch thick. Furthermore, on the headlands and points formed by the breccias along the sea-coast, weathering produces spectacularly rough surfaces, with the original boulders sticking out of the matrix in chaotic jumbles.

PREVIOUS WORK

Richardson visited the region in the early days of the Geological Survey of Canada and the results of his study are reported by Logan (1863, pp. 291-292)[1]. Logan does not give an explanation of the origin of these massive breccias but does say of some very large blocks in the breccia, "It is difficult to decide whether these are sediments deposited in the bed, or enclosed transported masses, notwithstanding that they are divided into beds with partings of black shale".

Four expeditions were made to western Newfoundland between 1910 and 1933, and the resulting report by Schuchert and Dunbar (1934) has been the foundation for stratigraphic work in the region since its publication. In reviewing the problem of the Cow Head breccia, they suggested (p. 84) that the following have to be kept in mind "... in contemplating the origin of this phenomenal breccia:

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1 Names, dates and page numbers in parentheses refer to publications listed in the References, p. 25.

" (1) It consists of angular blocks of various kinds of dolomite and limestone of Upper Cambrian, Lower Ordovician and early Middle Ordovician ages;

(2) It includes no boulders of older rocks or of crystallines, in spite of the fact that the sandstones of the immediately underlying and overlying formations were derived from crystalline sources and are more or less arkosic;

(3) The blocks of limestone vary enormously in size, and commonly include rolled, jagged blocks, over five feet across, and locally, slablike masses hundreds of feet long;

(4) The cement is of finely crushed limestone, not foreign sand or mud;

(5) The underlying rocks, several thousand feet in thickness, are fine-grained and largely calcareous;

(6) The overlying series is almost entirely detrital, largely unfossiliferous, enormously thick, and obviously of rapid accumulation;

(7) The breccia attains considerable thickness but is local and irregular in its occurrence;

(8) In places a series of lesser breccias succeed the main mass and are interbedded in the basal part of the Humber Arm series."

They concluded that the breccias were formed of the materials of talus and landslides formed along a fault scarp that came into existence during mid-Ordovician orogeny, and, further, that the breccia formed at the noses of thrust sheets which were in movement during the Middle Ordovician. They noted (p. 81), "that in any one locality most of the blocks are of a single formation".

Sullivan (1940, p. 52), in describing the detailed geology of the Port au Port peninsula, concluded that there are "... two distinct types of conglomerates which may easily be confused with one another, since often times they are found together in the same vicinity: (1) Angular breccias with large constituent fragments, of variable thickness and of limited extent, being found only along tectonic lines; and (2) finer textured and subround conglomerates of variable thickness and of widespread extent, marking a hiatus, and in part being of landslide origin, and which now make up the basal beds of the Humber Arm group". The first class is due, Sullivan believed, to movement and breakage along thrust faults as Schuchert and Dunbar originally suggested. The second class he believed to be the result of shoaling of the sea and its readvance, local landslides and contributions from small thrusts. Sediments which were deposited earlier were broken up to form widespread limy gravels which were thickest and coarsest nearest local upwarps, and which had incorporated and intercalated in them talus and tectonic breccia material.

Johnson (1941, p. 143) concluded that a lower to middle Ordovician sequence of shale, sandstone and limestone occupies the coastal area between Western Brook Pond and St. Pauls Inlet. He notes that, "Within this shale-sandstone-limestone complex appear several horizons of breccia or intraformational conglomerate, as well as the spectacular Cow Head breccia". This would seem to indicate a distinction between the widespread breccias found generally through the sequence and those typified by the Cow Head exposures, although Johnson makes no comment on the origin of either class.

Oxley (1953, pp. 30-33), generally accepted the mode of origin suggested by Schuchert and Dunbar but recognized that the correlation of the breccia from place to place as a stratigraphic unit was not tenable. He suggested that the exposures of the breccia should be treated as separate units and that the boulders within the masses should not be used to correlate the masses which incorporated the boulders. Thus he says (p. 33), "It seems reasonable to suggest correlation, where evidence for it exists, also to map separated occurrences of thrust breccias as tectonic phenomena which demand special treatment and not as sedimentary rock units".

Nelson (1955, p. 41) clearly recognized that the boulders of any one part of the breccia were largely derived from one rock unit, with only a few from overlying and underlying formations. At the Cow Head locality, he found (p. 41) "The northern part of the peninsula is composed mainly of Upper Cambrian sandy limestone phenoclasts and the southern part of Lower Ordovician (St. Paul group) dolomite blocks. From Cow Head north to Daniels Harbour, the breccia is mainly composed of Table Head limestone." He describes typical breccias in the region north of Portland Creek, including localities where the breccias grade into little-disturbed rocks of the Table Head group and into shaly sandstone of the Humber Arm group. Nelson suggested that the following should be noted (p. 44):

" (1) At nearly every locality visited it was found that the phenoclasts have interlocking textures.

(2) At Daniels Harbour the Cow Head breccia was seen to cut a large Middle Table Head exotic as a dyke-like

intrusion. This exotic, which consists of thinly interbedded shale and limestone shows drag folding, presumably caused by the force of intrusion.

(3) The matrix surrounding exotic shale fragments is higher in clay content than that around limestone phenoclasts."

Thus, on the basis of evidence from the area he studied, Nelson (p. 44) was "inclined to attribute the formation of the breccia to localized earthquakes affecting semi-consolidated limestone muds". He shows, however, that at two other localities in his area, faults in the Table Head limestones produced similar breccias. After noting that Schuchert and Dunbar had been able to examine the whole coast-line and most of the known outcrops of the breccia, Nelson stated (p. 45) that he was "inclined to the view that their hypothesis of origin is probably the best so far presented".

Recently Dunbar (1957, p. 176) stated, "The breccia occurs discontinuously over a distance of more than 200 miles along the coastal belt in front of the Long Range Mountains, and it is probably a series of lenses not strictly contemporaneous. It is therefore not a geologic formation but a facies of the Humber Arm group (Middle Ordovician)." He regarded all the coarse facies of the breccias as directly connected with submarine faulting, but in the following (p. 177), he appears to allow for other origins for some facies in some places, "The largest and coarsest mass at Cormorant Head appears to be a simple talus deposit, but the higher beds are probably lenses formed by landslides, and in other places spasmodic turbidity currents may have played a part".

Kindle and Whittington (1958, p. 317), from a detailed palaeontological study of the Cow Head breccia at Cow Head, Lower Head, Martins Point and nearby localities, found that the breccia at these localities is not a single bed or zone but is a series of "thin-bedded limestones with shale partings and interbedded shales, and rarely, sandstones; at intervals throughout the sequence occur spectacular beds of limestone conglomerates". Fossil evidence shows that in any one layer, the fossiliferous boulders are all of about the same age and that the beds on which any layer rests are of about the same age as the boulders within the bed. Kindle and Whittington thus concluded (p. 317) that "the conglomerate layers are intraformational and were brought into place periodically during Middle Cambrian to Middle Ordovician time".

Kindle and Whittington did not accept the view of Schuchert and Dunbar of an origin along mid-Ordovician thrust faults but instead proposed (p. 341) that the materials of the limestone

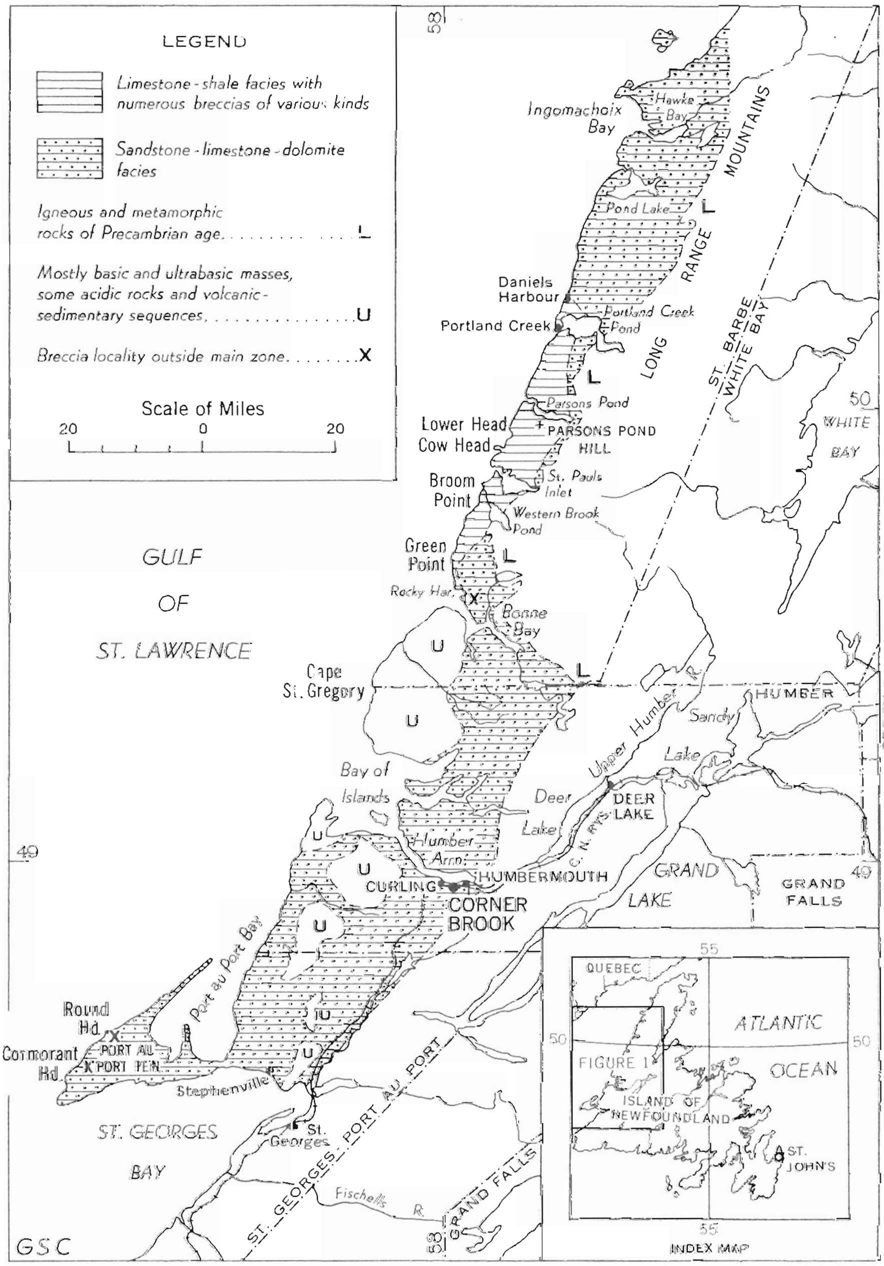

Figure 1. Location of principal occurrences of Cow Head type breccias

<table>
<tr><th rowspan="2"></th><th colspan="2">OXLEY, 1953</th><th>KINDLE AND WHITTINGTON, 1958</th><th colspan="4">THIS PAPER</th></tr>
<tr><th>WESTERN SHORE (including Cow Head)</th><th>INLAND (north and south of Cow Head Belt)</th><th>COW HEAD REGION</th><th colspan="3">WESTERN SHORE (Daniels Harbour Bakers Brook)</th><th>INLAND (north and south of Cow Head Belt)</th></tr>
<tr><td>MIDDLE ORDOVICIAN</td><td>HUMBER ARM GROUP</td><td>HUMBER ARM GROUP</td><td>UNNAMED GREEN SANDSTONES</td><td colspan="3">HUMBER ARM GROUP Not divided</td><td>HUMBER ARM GROUP Not divided</td></tr>
<tr><td>LOWER ORDOVICIAN</td><td>COW HEAD BRECCIA
GREEN POINT-ST. PAUL GROUP</td><td>TABLE HEAD GROUP
ST. GEORGE GROUP</td><td rowspan="2">COW HEAD GROUP</td><td rowspan="2">COW HEAD TYPE BRECCIA</td><td rowspan="2">COW HEAD GROUP Not divided</td><td>GREEN POINT-ST. PAUL GROUP</td><td>TABLE HEAD GROUP
ST. GEORGE GROUP</td></tr>
<tr><td>MIDDLE AND UPPER CAMBRIAN</td><td>Unnamed, but recognized in boulders</td><td></td><td>Not named</td><td>EAST ARM GROUP Undivided (south only)</td></tr>
<tr><td>LOWER CAMBRIAN</td><td></td><td>LABRADOR GROUP</td><td></td><td colspan="3"></td><td>LABRADOR GROUP</td></tr>
</table>

Table 1. Stratigraphic distribution of breccias

breccias were intermittently discharged as landslips down submarine slopes onto the sediments accumulating there. They did, however, admit (p. 340) the possibility of a tectonic trigger action along submarine faults of minor displacement.

NAMING OF THE BRECCIAS

Schuchert and Dunbar (1934, p. 73), in the original and classic description of the breccias, proposed the name "Cow Head Limestone Breccia", for the complete sequence at Cow Head and considered it to be of Middle Ordovician age. Oxley (1953, p. 30) used the term "Cow Head Breccia" but did not discuss the nomenclature, although his suggestion that the occurrences of breccia must be considered separately carries with it the corollary that it is not of group or series status. Nelson (1955, p. 40) also used the term "Cow Head Breccia" without comment on the stratigraphic terms to be used. Kindle and Whittington (1958, p. 335), after concluding that the breccias are intraformational and that the Cow Head and other occurrences of the breccias are from Middle Cambrian to Middle Ordovician in age, proposed the term "Cow Head Group" for the whole sequence of breccias and interbeds. They suggested (p. 317) the term as an "emendation of Schuchert and Dunbar's Cow Head Limestone Breccia".

To the present writer it appears that two separate and independent problems are intermingled in previous nomenclature. A facies of sedimentation different from time equivalents on all sides is represented in rocks which occupy a coastal strip centred more or less at Cow Head, (See Figure 1). These rocks should be subdivided as any other sedimentary sequence is subdivided. In addition, a series of unusual breccias occurs in western Newfoundland. These too, are more or less centred at Cow Head where they reach their most spectacular development, but they are not confined to the beds at Cow Head or to their equivalents. It thus seems necessary to have two distinct names for two distinct features.

"Cow Head Group" as proposed by Kindle and Whittington refers, thus, to the whole sequence of Cambrian and Ordovician rocks exposed at Cow Head and adjacent localities. In many ways the writer prefers to follow Oxley in his use of "Green Point - St. Paul Group" for the Ordovician part of the sequence and to leave the Cambrian section unnamed until more is known about it.

Through the Cambrian - Ordovician sequence occur many breccias which the present writer will refer to as "Cow Head type breccias" as a general term. In this way the breccia beds are recognized as structural-stratigraphic occurrences in otherwise normal sequences. With separation of ideas and distinct terms the occurrence of breccias over a wide time range makes no complication. The occurrence of the breccias in rocks which are subdivided and already named elsewhere is allowed for.

A clear threefold distinction may be made, with the dominantly clastic, middle Ordovician rocks (Humber Arm group) in which some limestone breccias of the Cow Head type occur; an older but perhaps partly equivalent sandstone-shale-limestone sequence in which the breccias are abundant; and Cambrian strata which have not as yet been studied in detail but are known from fossils in several localities. Rocks of very different facies may be grouped according to those facies, instead of on the basis of occurrence in them of the Cow Head type breccia. Stratigraphic distribution of breccias is shown in Table I.

DESCRIPTION OF THE BRECCIAS

Many kinds of limestone breccia occur in the Cow Head peninsula and in other localities in the coastal plain below the front of the Long Range Mountains. These breccias vary from tightly packed parallel chips of limestone 1 inch long and 1/2 inch thick in a light grey limestone matrix, to chaotic assemblages of great boulders of interbedded shales and limestones, limestones, cherty beds, arenaceous limestone and dolomite, embedded in an arenaceous limestone cement. The following types can be recognized:

Chaotic Megabreccia

At several places in the area, notably at Cow Head and Lower Head, breccias are composed of a wild jumble of large chunks of various limestones, with little evidence of bedding in the breccia. The cementing material is fine-grained limestone or sandy limestone and smaller fragments of limestones.

The appearance of the breccia varies from bed to bed because the fragments in any one breccia zone come almost entirely from a single source bed and different beds are made up of fragments from different source beds. Sedimentary rocks interbedded with the breccias are commonly of entirely different facies from those of the preponderant fragments in adjacent breccia beds.

Shingle Breccia

Flat chips of light-coloured limestone, from 1/4 to 1 inch thick and up to about a foot in greatest dimension, commonly are cemented in a light, yellow-grey, arenaceous or dolomitic limestone matrix. Commonly they show a marked parallelism of the fragments to the bedding of the breccia and adjacent sedimentary rocks, from which they are divided along contacts that are generally sharp and smooth. This type of breccia is common on the points that project into Parsons Pond and St. Pauls Inlet. It is found interbedded with other breccias at Cow Head and other places.

Erratic-boulder Breccia

Normal sandstone-shale-limestone sequences in the breccia areas are interrupted in some places by the presence of erratic boulders, seemingly dropped into a mass of normally accumulating sedimentary material. These boulders may be unique in exposures which show a strike length of hundreds of feet and a stratigraphic thickness of several tens of feet, or they may occur scattered through normal sequences, more common at one horizon than another, or at apparent random throughout. Some fine-grained breccias, made up of small chips and fragments of limestone, contain large boulders scattered in them. Excellent examples of erratic-boulder breccias are in the shore exposures on the northwest-facing shore of Cow Head; on the southern part of Broom Point; and in exposures on the points which protrude into Parsons Pond and St. Pauls Inlet.

Common Limestone Breccia

Common breccias with subrounded fragments of limestones of mostly the same type within any one bed are found throughout the breccia-bearing area. These have little apparent organization within any one breccia mass, and the fragments, from 1/8 inch to 1 foot in greatest dimension, are packed together in a jumble, with the interstices filled with light grey sandy limestone, limestone, or dolomite. At Cow Head some of these breccias have a sandstone matrix.

ORIGIN OF THE BRECCIAS

Theories of origin must take into account many factors which come broadly under the following headings:

Areal distribution

Relationships of breccias to beds above and below

Internal structure

Nature of fragments

Broad stratigraphic relations

Areal Distribution

Cow Head type breccias have been observed along the whole length of the belt of sedimentary rocks which stretches from Port au Port peninsula in the south to Pistolet Bay in the north, about 200 miles. The main concentration is near the middle of this belt, from Green Point in the south to Daniels Harbour in the north, a distance of some 40 miles. In this central area the breccias occur through the entire width of the coastal belt, from the present sea-coast on the west to the vicinity of the Long Range fault and the escarpment of the Long Range Mountains on the east, a distance of 4 to 8 miles.

Masses of chaotic megabreccia seem to be largely at or near the present sea-coast. Everywhere these interbedded rocks are known, they stand out as prominent erosion-resistant headlands such as Cow Head, or as hills such as Parsons Hill. It thus seems improbable that other large masses of megabreccia are hidden in the lowlands. Their real distribution is thus probably parallel to and along the present coast-line.

Units of shingle-breccia, from a foot to 20 feet thick, occur with the megabreccias and interbedded rocks on the coast and extend eastward into the limestone, shale, and clastic sequences of late Cambrian to middle Ordovician age. These breccias occur over large areas in the flat lowlands between Western Brook Pond and Portland Pond where they underlie long, low ridges which mark their upturned edges.

The dominant factor in the physical features at the time of the breccia formation was probably a north-northeast-trending structure, generally parallel to, and perhaps the same as, the present-day control, the Long Range uplift and fault system. The writer has long believed that the major breaks through Newfoundland, like the Long Range fault system, are very old and that late movements along them are but renewals of movement along old fractures (Baird, 1947, p. 227). That the Long Range fault system is at least pre-Carboniferous is shown in several ways.

The Long Range highland provided the coarse sediments for the blanket of Carboniferous rocks in the lowland south of the Port au Port peninsula, as shown by the enclosed boulders of anorthosite, titaniferous magnetite, granite gneiss and metamorphosed sedimentary rocks - all of kinds identical to those now exposed in the Long Range. The orientation of current-ripple marks and the general grain gradation, from coarse to fine towards the west and southwest, support this view. Thus, the highland certainly seems to have been there in Carboniferous time and it seems reasonable to suggest that it was controlled by the same major fault systems we know today. Re-occurrence of coarse conglomerates in finer-grained clastic sequences and alternating marine and non-marine sequences suggests repeated renewal of action along it during Carboniferous sedimentation.

The presence of numerous northeastward-trending diabase dykes, which occur only in the Precambrian rocks of the nearby Long Range complex, further shows the development of strong structural trends in that direction in pre-Ordovician time.

It thus seems possible that the controlling feature of the topography, and therefore of the sites of sedimentation, at the time of formation of the breccias, was a north-northeast-trending structure that may have been the Long Range fault system or its ancestor, or possibly, a parallel structural system.

Relationships of Breccia Beds to Beds Above and Below

The mass of rocks at Cow Head is a layered sequence, as is clearly shown by the detailed stratigraphic and palaeontological work of Kindle and Whittington (1958), and confirmed by the writer. It seems clear also that Schuchert and Dunbar (1934, p. 77) mistook some of the zones of interbedded rocks for large boulders within the mass. This was natural, according to Logan's (1863, p. 291) observation that he was in doubt as to whether these were interbeds or transported masses. To add to the confusion, small cross-faults make parts of limestone beds that have been moved only a few feet transverse to the bedding, appear as very large boulders.

A complete gradation is found between units of breccia, which are clearly individual beds of breccia between layers of other sedimentary rocks, and zones of breccia with little apparent internal structure and ill-defined relations to beds found above and below them. Shingle breccias and common breccias, from a foot to 20 feet thick, are clearly distinguishable from the shales and alternating thin limestones and shales with which they are interbedded, particularly in areas away from zones of megabreccia. Beds like these are found, however, even in the areas of coarsest breccias, at Cow Head and Lower Head. In zones of coarse megabreccia such clear bedding is less evident.

Relationships at the bedding planes which separate breccias from adjacent beds are various. In most places the bottoms of the breccia beds are sharply marked by abrupt changes of rock types. Fragments of limestone extend right to the boundary, where cementing materials also terminate abruptly, as though inseparable from the fragments they enclose. Channelling of underbeds was absent in most of the contacts examined, although in some places crosscutting was observed. (See Kindle and Whittington, 1958, Pl. 1, Fig. 2). At one place, near the eastern end of Beachy Cove, Cow Head, bedded limestones with thin shales pass laterally into breccia and give the appearance of having formed a wall which was torn into by the moving breccia which incorporated into it loose material from the wall. (This locality is shown by Kindle and Whittington, Pl. 1, Fig. 1).

In some places very large boulders in the breccias appear to have bowed the sediments down under them, but in others they seem to have had little effect. Nowhere did the writer observe strong "splash effects" such as might be expected if boulders dropped into soft, liquid mud. Even erratic boulders of limestone several feet in diameter seem to have bowed the sediments under them rather than splashed through. Bedding, though broken and disturbed, is preserved on all sides of such boulders.

One bed of breccia, at Lower Head, shows a coherent mass of more or less homogeneous breccia about 20 feet thick, which seems to have caught up fragments of the immediately underlying bed. It gives the impression of having been emplaced as a mass coherent enough to hold together but mobile enough to move and to pick up fragments in its base.

Beds of breccia with smooth bottoms and tops and consisting exclusively of limestone fragments in limestone matrix may be overlain and underlain by normal sedimentary sequences of thin-bedded shales with minor limestones. Transitional zones or partly broken zones are rare.

Breccias on the south side of Green Point are interbedded with a sequence of shales, thin limestones and sandstones which show crossbedding, current-ripple marks, and polygonal shrinkage cracks of several types and pebbly facies in fine sandstones. Thin limestone layers are folded and broken by deformation which must have been contemporaneous with sedimentation for the structures are confined to a few beds in an otherwise evenly layered sequence. Some of this deformation may be due to sliding on submarine slopes as suggested by Kindle and Whittington (1958, p. 327), although it is difficult to understand how such sliding could be confined to individual layers as small as 1 inch thick, lying on little-disturbed shales which must have been soft muds at the time of sedimentation. Also found are bulging concretionary masses and layers which show a coarse wrinkling of patterns similar to those formed by interfering current-ripples.

Breccias range from evenly bordered, tabular beds of smooth outline, to gradually lensing beds, to bulging masses joined by much thinner zones of breccia, to separated bulbous masses. This great variety of breccias is well shown on the south side of Broom Point in a rock bench exposed at low tide, and at most other localities where breccias are abundant. In some places, only a few isolated, lensing or bulbous masses of breccia occur in otherwise normal, sedimentary sequences, such as on the south side of Rocky Harbour where they occur in shales and sandstones at present classed with the Humber Arm group.

On the other hand, breccias, mostly of the shingle type, are remarkably uniform over large areas in the region of Parsons Pond and St. Pauls inlet. Here, beds maintain even thicknesses of 2 to 20 feet, with smooth tops and bottoms against shales and interbedded shales and limestones, even though they consist internally of a mixture of angular sheets and fragments of different kinds of limestones.

Internal Structure

In any of the breccias the fragments tend to lie parallel to the bedding, although a complete gradation may be found from almost complete disorganization to almost complete parallelism. In coarse megabreccias, close inspection may show very little preferred orientation parallel to the bedding. More distant views, however, show that, of the fragments of various shapes, those with one dimension smaller than the other two generally lie parallel to the bedding and give a faint grain to the breccia.

Parallelism is generally evident in units less than 15 feet thick. However, in some facies, such as the Ordovician beds on the shore of Cow Head on the south side of the junction with the tombolo, thin units of even outline are highly disorganized within.

Shingle breccias commonly show a very high degree of parallelism, as would be expected from the fact that fragments as much as 3 square feet in plan may be only 1 inch thick.

The fragments in any one bed are derived principally from one source horizon. Some of these source beds tend to break into more or less equidimensional fragments and others into flat and tabular fragments. There is thus a broad correlation between the kind of rock fragments and the degree of parallelism. Breccias derived dominantly from the Table Head limestone tend to show poorly developed internal parallelism, whereas beds derived from Cambrian and lower Ordovician beds, made up of interbedded shales and limestones, tend to show a higher degree of parallelism.

No sorting was noted within breccia beds. Chaotic megabreccias consist of fragments which range from tens of feet in diameter to finely ground particles. In shingle breccias the distribution of the size of fragments appears to be the same at the boundaries as in the interiors. In some places, zones of different coarseness were noted, but these appear more as different breccias which are interbedded than as sorting within single breccia zones.

Erratic boulders occur in shale and interbedded shale and sandstone in many places, but generally in parts of the sections which contain breccias. It is rare, however, to find smaller chips, or zones or layers of fragments within beds that are not fully developed breccia beds. An exception to this generality is on the northwest-facing shore of Cow Head, where fragments and chips of limestone occur scattered through, or as layers in calcareous sandstone.

Nature of Fragments

Almost all fragments within the breccias are of limestones of various kinds. It has already been pointed out that in any one bed the fragments come largely from the same source but that different beds draw from different sources. This results in breccias of different appearances— for example those made up almost entirely of small fragments of light-coloured, very fine grained limestone that is recognizable as being of Table Head derivation, as at Daniels Harbour; or those in which boulders of very rough outline are almost entirely of light grey and mottled-white and grey limestones, as on the shore on the south side of the place where the tombolo joins the mass of Cow Head.

On the other hand some of the breccias are made of a variety of limestones. One of these, on the west shore of St. Pauls Inlet about half-way from the Inner Tickle to the west end of the south shore, shows boulders of the following: wizened-weathering, fine-grained, grey to white, lithographic limestone; sugary, pale-brown, granular limestone or dolomitic limestone; cherty, limestone breccia; white-weathering, grey limestone; crossbedded, arenaceous grey limestone; buff-weathering, dolomitic limestone; and yellow-weathering argillite. Boulders in this occurrence are as much as 3 feet long, generally flat, and sharply angular to slightly rounded on the corners.

Fragments of limestone within the breccias are sometimes broken and healed with calcite that is later than the breccias for it cuts across both cement and fragments. On the other hand, many of the phenoclasts were broken and recemented before they became fragments. Stylolites similarly occur both in individual fragments and in the breccias proper. Polished sections show that stylolitic solution boundaries are very common on boundaries between fragments and cement, and between the fragments themselves.

Occasional boulders of sandstone occur in the younger breccias. These may be seen at several occurrences on the south shore of St. Pauls Inlet. Pieces of black, brown and yellow-brown chert occur widely in breccias which are made largely of Ordovician boulders such as those at Lower Head or on the west end of St. Pauls Inlet. At Lower Head the weathered surface of the megabreccia is speckled with well-rounded fragments of black, highly petroliferous, argillaceous limestone and cherty limestone. Yellow-weathering, light grey argillite, of a type known in the Humber Arm rocks on the north side of Rocky Harbour, is present in boulders as much as 2 feet long at Lower Head, and in breccias on points on the west end of St. Pauls Inlet. Large angular boulders of different kinds of limestone breccia occur within the megabreccia at many places but are particularly well shown at Lower Head. Boulders of earlier breccia which consist of angular fragments of chert in a limestone matrix also occur here. Boulders of limestone breccia are found in shingle breccias at several places in St. Pauls Inlet and Parsons Pond.

Well-rounded grains of quartz, 1 to 2 mm in diameter, which show a high degree of sphericity occur very commonly in the cement of the breccias. These grains may be scattered sparingly throughout a limestone cement and show as tiny dark eyes on light grey, weathered surfaces, as in beds on the shore about a mile northeast of the end of Broom Point; or they may make up as much as 80 per cent of the rock, as in the calcareous sandstones on the northwest-facing shore of Cow Head, below the lighthouse. Here, a complete gradation may be observed; from quartz sandstone containing scattered chips of limestone, to limestone breccia with a matrix of sandy limestone.

The grains of quartz are heavily frosted, suggesting that they are wind-blown. Supporting this view are the absence of larger pieces of quartz, and the discrepancy between the environments necessary to produce and transport frosted quartz grains, on the one hand, and fine-grained calcareous mud in which they occur, on the other.

The quartz grains are commonly of bluish cast, identical to that of the bluish quartz that is characteristic of the gneisses of the Long Range complex to the east.

In addition to the quartz, the sandstones below the lighthouse at Cow Head have rare grains of reddish or greenish chert or fine-grained volcanic rock.

Fragments in the breccias are set in pastes made of limestone, argillaceous limestone, finely ground fragments of limestone of various kinds, calcareous sand, dolomitic limestone and quartz grains in varying proportions. Weathering of breccias tends to produce even-white or light grey surfaces across both fragments and matrix, except where dolomitic and cherty limestone matrices produce yellow-brown surfaces that contrast with the grey limestone fragments.

In many of the breccias the matrix is darker than the limestone fragments, and in some of these at least, it is because it is petroliferous.

Broad Stratigraphic Relations

Middle and Upper Cambrian beds on the Port au Port peninsula consist largely of sandstone at the base and grade upward into dolomite and shale. These are succeeded by Lower Ordovician dolomite, limestone and interbedded shale, of the St. George group, which have an aggregate thickness of 2,000 to 3,000 feet. Above the St. George group, limestones of the Table Head group are about 800 feet thick. This dominantly calcareous sequence is succeeded by the Humber Arm group which is of Middle Ordovician age and consists largely of sandstone and shale with some conglomerate and rare, thin limestone beds.

In the Bonne Bay area, Cambrian rocks include a thick section of quartzite, slaty shale and thin limestone beds. These are succeeded, probably conformably by Ordovician dolomite and limestone of the St. George group, followed by Table Head limestone and the Middle Ordovician Humber Arm sandstone, shale and conglomerate. This sequence extends northward along the coast, but in the lowland region between Green Point and Portland Creek the rocks of this sequence, except the Humber Arm group which is more widely exposed, are found only as thin, fault slices, tight up against Precambrian rocks along the Long Range scarp.

The coastal belt from Portland Creek northward to Hawke Bay is occupied largely by Ordovician limestone, dolomitic limestone and dolomite of the St. George and Table Head groups, with Lower Cambrian quartzite, shale and dolomite occupying wedges faulted against Precambrian rocks to the east. North of Hawke Bay the same general sequence prevails but the Lower Cambrian quartzites and other clastic rocks underlie large areas with only a fringe of Ordovician calcareous rocks along the coast.

Cambrian and Ordovician sequences in the coastal belt between Green Point and Portland Creek are not fully understood. The succession is characterized by grey to black shale, thin-bedded limestone and interbedded limestone and shale, occasional massive limestone beds up to 10 feet thick, and abundant limestone breccias of a variety of kinds.

Schuchert and Dunbar (1934, p. 35) speculated on the possible occurrence of Upper Cambrian strata in the Cow Head area because of the large blocks of fossiliferous, thin-bedded, Upper Cambrian limestone in the breccias there.

Johnson (after Kindle and Whittington, 1958, p. 329) identified Cambrian rocks among the faulted shales and limestones of the coastal belt between Western Brook Pond and Portland Creek. Oxley (1953, pp. 10-12) believed Cambrian rocks to be present in the area on the basis of fossils in breccia boulders. Kindle and Whittington (1958) date many breccias in coastal exposures between Lower Head and Green Point as Cambrian on the basis of their enclosed boulders which are invariably all of the same age in any one bed. From limited work in the St. Pauls Inlet area it appears that similar reasoning will also establish some of the breccias there as of Cambrian age (Kindle and Whittington, 1958, pp. 326-329).

Ordovician beds are widely known in the same region from graptolite faunas in dark shale and interbedded limestone-shale sequences, as well as from the previously mentioned fossiliferous St. George and Table Head groups near the Long Range scarp. Trilobite faunas in Ordovician limestones are also well known from boulders in the Cow Head type breccias.

The writer believes that detailed investigation of the stratigraphy of the lowland belt will reveal a basis for a subdivision into various groups. In the meantime the somewhat non-committal term, "Green Point - St. Paul group", used by Oxley (1953) on his map is preferred by the writer to designate all the Ordovician members of the sequence, with the Cambrian left unnamed pending separation and diagnostic description. Thus it appears that the rocks of the coastal plain between Rocky Harbour and Daniels Harbour are of a different facies from their time equivalents both north and south, a possibility first recognized by Schuchert and Dunbar (1934, p. 40).

Coarse megabreccias and other types, however, are not restricted to this facies, for on the Port au Port peninsula coarse breccias are directly associated with the St. George - Table Head sequences. Breccias are known in several places in the Humber Arm group. Nelson (1955, p. 43) reports breccia grading into Table Head limestone at Portland Creek Pond.

Mechanism of Formation

Several different kinds of breccias occur in the coastal belt of Newfoundland, centred about Cow Head. From the foregoing descriptions and from the work of previous writers it appears that several different factors contributed to the origin of the breccias. Sullivan (1940, p. 52) was the first to clearly distinguish breccias of different types.

Thus it is felt that no single mechanism is adequate to explain all the breccias. Kindle and Whittington have clearly shown that the formation of breccias took place over a long period of time, bearing out what was suspected by Oxley and others when they suggested that breccias can not be correlated from place to place merely because they are breccias. Thus the accumulation of the breccias along mid-Ordovician thrust faults as proposed by Schuchert and Dunbar cannot be accepted as an overall explanation of the origin of the breccias from Port au Port peninsula to the northern tip of Newfoundland.

It is clear that faulting has produced, directly, some breccias in the area. At Cow Head small cross-faults have made narrow zones of quantitatively unimportant breccia which cut across the general bedding pattern. Nelson (1955, p. 45) describes fault breccia in Table Head limestone at two localities in the general vicinity of Portland Creek Pond. He notes that the resulting breccias look very much like the Cow Head type breccias south of Daniels Harbour. Sullivan (1940, p. 51) found breccias at Round Head, on Port au Port peninsula, which he explains as having formed along a fault plane and at the nose of a thrust sheet. However, he realized that this explanation does not hold for other breccias in the region. Schuchert and Dunbar (1934, p. 85) explained the formation of the Cow Head breccias generally as the result of thrusting and the accumulation of rubble along the fronts of thrust sheets during movement in middle Ordovician times. While it appears that this explanation is not generally suitable because of the time limitation, the mechanism of origin may be valid locally. The position of the coarse megabreccias along a clearly marked line strongly suggests that some such tectonic control was effective. From all the evidence at hand it appears very likely that this took the form of triggering submarine landslips, as agreed by Kindle and Whittington (1958, p. 340).

Landslip debris from such faults and from the steepening of contours caused by such faults would be discharged downslope into greater depths. Movement along such faults was probably intermittent and was perhaps sudden enough to make earthquake shocks, which would not only make for intermittency of discharge, but would also tend to make large blocks. Minor shocks or movement would perhaps result in a few blocks being broken off along submarine scarps or steepenings and moving alone to provide the erratic blocks encountered through the belt.

In a diagram to illustrate the formation of Cow Head type breccias at Cormorant Head on the Port au Port peninsula, Dunbar and Rodgers (1957, p. 177) picture a mass of Table Head limestone moving on a low-angle fault which dips southeast. A bedded series of graptolite-bearing shales and breccias dips northwestward away from the toe of the fault at about 50 degrees.

Dunbar and Rodgers propose that the breccias were formed as talus and landslide accumulations related to the faulting, with some assistance from spasmodic turbidity currents. The present writer finds that the diagram and the explanation do not fit one another.

If the fault surface had originally extended farther to the northwest than shown, then it would have been impossible to have the breccias derived from the faulting with the attitudes shown and with the interbedded shales. If the fault provided movement only as far as shown, it is difficult to see how the beds which succeed the initial breccias could have been laid down, particularly with such steep initial dips. If the original movement on the fault had not been as much as shown then the breccias could not have formed in their present positions.

Dunbar and Rodgers point out that the fossils in the upper part of the breccia-shale sequence are of uppermost Table Head age. It would seem reasonable that the beds underlying this zone would be partly equivalent to the Table Head limestones above the plane of the fault.

Thus it seems likely that the massive Table Head limestones and underlying beds have been faulted against a tilted, breccia-bearing sequence, partly equivalent in time, and that the faulting accounting for this juxtaposition is not directly related to the formation of the breccias. Kindle, who recently visited the Cormorant Head area, states that from his preliminary reconnaissance this seems to be the relationship (personal communication). Similar juxtaposition of the two facies of sedimentary rocks by faulting, which clearly post-dates their formation, is probable in many other places in front of the Long Range Mountains.

Thus the writer believes that clearly defined, simple, talus accumulations below fault scarps have not yet been identified among the Cow Head breccias. The role of faulting seems much more likely to have been that of a trigger which set off sliding and slumping with resultant turbidity currents, and, possibly, earthquake shocks that caused a violent disturbance in adjacent shallow-water areas, contributing fragmented, partly consolidated sedimentary materials and perhaps turbid waters there as well.

Sedimentary materials being deposited along steep fronts leading to greater depths, when disturbed, would be expected to collapse and slide to the foot of the slopes or where the gradient becomes too slight to permit further sliding. If the materials were quickly consolidating varieties one would expect from such slides, mixtures of fragments of sedimentary materials in various degrees of consolidation, from soft to solid.

Slide breccias might be produced in front of fault scarps or the flanks of rising ridges where movement would be directly responsible. In the Cow Head type breccias, theories of origin by sliding on steep slopes have many attractions as shown by Kindle and Whittington (1958, p. 340). Boulders of massive and thin-bedded limestone, sometimes large, could thus have been deposited on the dark graptoliferous shales. Fossiliferous limestones of shallow-water derivation could thus have mixed with other limestones of various types and the whole have been dumped together at the foot of a steep slope on top of deep-water sediments. Even sliding, however, requires a mechanism to fragment the original limestone. It thus seems that before the sliding of materials down a submarine slope took place, the whole process must have been initiated by faulting, earthquake shocks, or gradual uplift with steepening beyond capacity to hold.

While applicable to certain of the chaotic megabreccias, this theory of origin is not suitable to account for the widespread chip and shingle breccias which are exposed along the sea-coast, and on the points which stick out into St. Pauls Inlet, Parsons Pond and Western Brook Pond. The even thickness of the beds over large areas, the narrow range of fragment sizes, the parallelism of fragments within beds to each other and to the boundaries of the beds, the sharp definition of the beds on top and bottom along boundaries parallel to the regional bedding - all of these suggest a mechanism other than direct slipping on steep submarine slopes.

It seems certain that masses of consolidated and partly consolidated limestone and interbedded limestone and shale collapsing and moving suddenly down submarine slopes would set up powerful turbidity currents which would transport finely divided debris and small fragments. Further, deposits made directly by collapsing and sliding would be expected to grade imperceptibly into those made by current transportation. Turbidity currents might be started in an area of lime and mud accumulation by earthquake shocks and resulting heavy wave and current action.

In recent years, studies of turbidity currents and their deposits (Kuenen and Sanders, 1956; Kuenen and Carozzi, 1953) have resulted in the setting up of some criteria for recognition in the field of deposits from turbidity currents.

Certain of the chip and shingle breccias show many of the features described by Kuenen and Carozzi (1953, p. 363) as being typical of those in turbidity-current deposits. These include interstratification of fine-grained deposits with coarse-grained beds (the breccias); regular bedding; absence of wave-ripple marks and channel scour; absence of shallow benthos fossils in the fine-grained members of the series; coarser beds being commonly the thickest individual beds of the sequences; and individual coarse beds maintaining their individual characteristics over wide areas.

A heavily emphasized feature of turbidity-current deposits, however, is graded bedding, not noted in the Cow Head area as being a prime feature. Again, the breccias of the chip and shingle variety are generally of coarser grain than the sediments dealt with by Kuenen.

It would seem therefore not unlikely that the chip and shingle breccias are intermediate between direct falling or sliding breccias and the straight turbidities. If the coarse-grained, direct-falling and sliding Cow Head breccias and the chip and shingle breccias were directly related in origin, then one would expect the latter to be intermediate in position between the zones of coarse megabreccia and the more-distant and finer-grained turbidity sediments. On the other hand, the directional relationship would be reversed if the chip and shingle breccias were produced by breakage and minor sliding in a shallower coastal zone, with turbidity currents of a more local nature being developed on slopes leading to a break in profile lower down the slope.

If the former were the case then the principal falls and slides took place west of the present coast-line where the chaotic megabreccias are found and the chip and shingle breccias were formed downcurrent to the east. Finer turbidity sediments with graded bedding, minor-slump structures, pull-apart structures, load casts and the rest must have been lost in the faulting, uplift and erosion of the Long Range fault system.

If the latter were the situation then the finer turbidity sediments are now in the area covered by the sea to the west of the present coast-line.

Cutting of steep gullies by currents, either on exposed mudflats or on the sea bottom, would produce slumping and breakage of partly consolidated sedimentary materials, without transportation for long distances. The breccia which grades into interbedded limestone and shale on the east end of Beachy Cove, Cow Head, gives the impression of having been formed partly in this way. Scouring by extended streams on mudflats exposed at low tide, would be expected to result in formation of numerous angular fragments from the walls, particularly if the muds were thinly layered and semi-consolidated. Leathery sheets of partly solidified limy mud would thus be added to finer-grained sedimentary materials being transported to the sea. Scouring by turbidity or other currents on the sea bottom would be expected to produce slumping of the walls of eroded channels.

Nelson (1955, p. 44) suggested that localized earthquakes might have partly fragmented semi-consolidated limestone muds. He thus accounted for the interlocking textures he observed in some of the breccias in the Portland Creek - Daniels Harbour area north of Cow Head. It seems possible that earthquake shocks could very well shake up accumulating and partly consolidated muds to the extent of breaking them, but it does not seem likely that such action would produce the mixtures of materials found in most of the breccias. Nor are interlocking textures general. Thus the writer believes that this effect of localized earthquakes, as proposed in Nelson's hypothesis, should be looked upon as a possible contributing factor to the formation of breccias generally and perhaps a causative factor locally.

If the present structures in the Palaeozoic sedimentary rocks are but continuations of ancient basement structures, then it is possible that the foundation on which sedimentation was taking place was already broken into a number of fault slices. If movement along these was intermittent during the period of sedimentation then one might expect that the entire region was broken by linear fault ridges and folds. If this kind of site of sedimentation were to be in shallow-water, the effects of earthquakes would be violent and perhaps result in the wide distribution of fragmented sedimentary rocks in different stages of consolidation. In the turmoil, argillaceous fractions of interbedded limestone and shales might be washed out and deposited elsewhere, particularly if the calcareous beds were quick-setting and the muds were not. If the whole zone were sloping, turbidity currents might be set up by this action.

On gentle submarine slopes, masses of partly consolidated materials might well slide very slowly, picking up material from below and leaving behind a more or less even blanket of debris, rather like a drop of water on a mist-covered glass.

Sullivan (1940, p. 52) and others have attributed certain chip and shingle breccias to breakage of partly consolidated beds during upwarping of the area with exposure and readvance of the sea. Sullivan also suggested that landsliding may have assisted. The writer agrees that some of the shingle breccias could have been developed in shallow water and that it is possible that exposure and wave breakage contributed to their origin. At the same time it is difficult to account for the sharp delineation of the beds in this manner and the rarity of partly broken beds. The close association of the cement with the fragments in many cases suggests that they were brought in together from another place.

SUMMARY

Picture then a shallow marine shelf zone with a lowland to the east in which Precambrian or other crystalline rocks were exposed. The shoreline of the day was much farther east than that of today. On the shallow shelf zone great quantities of limy muds were accumulating in shallow warm waters. Rates of accumulation were not uniform, for variations in the sea water and in the shape of the sea floor produced variations in the rate and kind of sedimentary accumulation. In quiet areas to the north, south and east of the Cow Head region, but generally on the eastern edge of the sedimentary belt, great thicknesses of sedimentary materials were accumulating. In St. George and Table Head times, several thousand feet of almost featureless and almost unfossiliferous calcareous sediments gathered. In the region of Cow Head, a re-entrant in the northeast-trending shoreline was marked by instability. Here, accumulation of thick limy muds was interrupted periodically by slumping in the partly consolidated materials that included lime from the sea, some windblown sand from distant coastal regions and small amounts of argillaceous clastics. Slumping, which may have been triggered by fault movements with resulting earthquake shocks or simple oversteepening, produced much breakage in the thin-bedded limy sediments and perhaps set up turbidity currents. These currents, gathering force as they continued down the slope tore more deeply into the disturbed limy sediments. Thus a mixture of limy-mud-rich waters and flat fragments of thin-bedded limestones spread out over the sea floor, in a few places disturbing the beds underneath, but for the most part depositing their load directly on whatever was there, without disturbance. Turbid currents cascaded over the edges of deeper parts of the basin, cutting into and undermining large blocks of the new sediments there and incorporating them into the chaotic mass below. Occasional fault scarps contributed to the formation of breccias throughout the basin but most spectacularly along the edges of steeper slopes where submarine landslips of shallow stratigraphic penetration were triggered by the steepening or by the actual shock of movement. Very locally, in parts of the basin where warping or fault movements produced very marked shallowing, wave and shore currents produced local intraformational conglomerates.

After any one series of movements quiet conditions prevailed for a time so that ordinary sedimentary rocks accumulated in all parts of the basin. Shallow areas on the sea bottom, made by uplifted fault blocks or upfolds, made favorable areas for life, away from the stifling effects of massive limestone deposition. When shaken, broken by faulting, or oversteepened by progressive warping, these areas contributed fragments of fossiliferous limestone.

At the same time as this was going on, great masses of volcanic rocks were being poured out onto the sea bottom and over the landscape of the Notre Dame Bay region to the east. Their presence in the geological column shows the marked tectonic instability of the northern end of the Appalachian geosynclinal belt at this time. Volcanic activity in the region south of Bonne Bay was limited in extent and time, but further shows the marked tectonic activity of the region.

Limestone accumulation was terminated gradually as the region was uplifted and the clastic sediments of the Humber Arm group spread thickly over the area. Short-lived periods of lime deposition with some breccia formation took place after the initial floods of clastic materials came in. Masses of ultrabasic rocks and related basic intrusives were emplaced near the centre of the eugeosynclinal area, (cf. Smith, 1958, map 2). These were probably followed shortly by granitic intrusions, folding and uplift, and the close of a chapter in the tectonic history of western Newfoundland.

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