

POSSIBLE "TACONIC" KLIPPEN IN WESTERN NEWFOUNDLAND†

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ABSTRACT. The Lower Paleozoic strata of western Newfoundland belong to two separate but contemporaneous terranes, each many thousands of feet thick. One contains a well established sequence of shallow-water dolostone, limestone, and sandstone units, here called the carbonate sequence; the other is a clastic terrane consisting of deep-water shale, sandstone, conglomerate, and lime-breccia, associated with mafic volcanic rocks and mafic and ultramafic intrusions. Both appear to range in age from Early Cambrian to Middle Ordovician, but structurally the clastic terrane is surrounded on three sides by and generally seems to lie above the carbonate sequence. The carbonate sequence rests unconformably on Precambrian rocks and is certainly autochthonous. If the clastic terrane is also autochthonous, then invisible unconformities or rapid facies changes must separate the two. We prefer the hypothesis that it is allochthonous and forms two large klippen, one extending along the west coast from Port au Port Peninsula to Daniels Harbour and the other at the tip of the Great Northern Peninsula between Canada Bay and Pistolet Bay; that these allochthonous masses originated east of the carbonate sequence in an area where large bodies of Lower Paleozoic clastic-volcanic strata occur as remnants in a now dominantly granitic terrane; and that they were emplaced during Middle Ordovician time, being first squeezed up and out of their original depositional basin and then sliding by gravity westward into a basin where shale was being deposited upon the autochthonous carbonate sequence.

The numerous and close similarities in lithology, stratigraphic succession, and structural arrangement between western Newfoundland and the Taconic region of New York, Vermont, and Massachusetts, are remarkable.

INTRODUCTION

The purpose of this paper is to point out stratigraphic and structural similarities between the Lower Paleozoic rocks of western Newfoundland and those of the Taconic region in New York, Vermont, and Massachusetts, and to place in discussion the hypothesis that two large klippen exist in Newfoundland that resemble the much-debated Taconic klippe.

In western Newfoundland, as in the Taconic region, there are two contrasting terranes of Cambro-Ordovician strata, one dominated by carbonate rocks and certainly autochthonous, the other dominated by clastic rocks, principally shale and slate. At first it was thought that the whole clastic terrane overlies in normal succession the reasonably well known stratigraphic sequence in the carbonate terrane, but fossils have shown that at least parts of the two are contemporaneous. To explain these relations, the fossiliferous parts of the clastic terrane have generally been interpreted as relatively local facies variations of the carbonate sequence, but in 1941 Helgi Johnson published the suggestion (see also Kay, 1945, p. 442) that some of the clastic strata were thrust into their present position, perhaps from a depositional site far to the east. To date, however, neither he nor anyone else appears to have worked out the implications of this hypothesis in print.

Rodgers has long been interested in the problems of the Taconic region, for which the klippe hypothesis was proposed some 50 years ago, and a re-reading in 1959 of Schuchert and Dunbar's classic study (1934) of the west coast of Newfoundland led him to entertain a klippe hypothesis for that area

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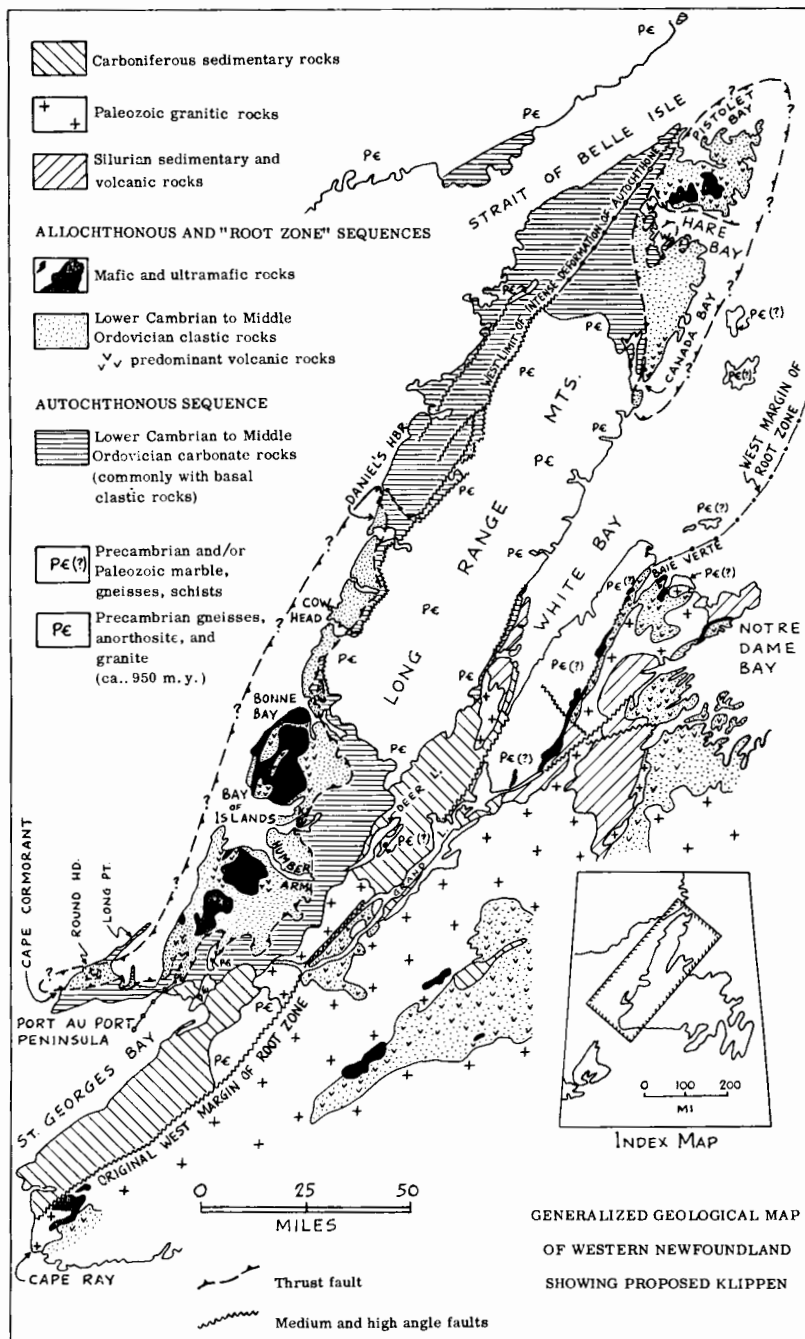


Fig. 1.

as well and to plan a visit to the island. Independently, in informal talks to the Appalachian Discussion Group at the Geological Survey of Canada, Neale had suggested thrusting from the east as a plausible explanation for the juxtaposition of the contrasting facies of the two sequences. This paper is the result of the exchange of ideas between us in 1961 during a joint field trip to Newfoundland, where we were subjected to the lively, informed, and entertaining criticisms of David M. Baird. Many people have kindly criticized drafts of the manuscript for us—Baird, Wallace M. Cady, A. H. Chidester, P. M. Clifford, L. M. Cumming, Carl O. Dunbar, Cecil H. Kindle, William H. Poole, Charles H. Smith, Harry B. Whittington, and E-an Zen; we are heartily grateful to them all, but we do not mean to imply by naming them that they necessarily accept the hypothesis.

STRATIGRAPHY

When Schuchert and Dunbar (1934) summarized the stratigraphy of western Newfoundland, they attempted to set up a single stratigraphic column including all the stratigraphic units in the region, but to do so, particularly in the Ordovician, they had to dovetail several units that were not actually in sequence anywhere and that seemed rather to be in part contemporaneous. Further work has shown more and more clearly that the rocks present belong to at least two separate and largely contemporaneous stratigraphic sequences.

The carbonate sequence.—Much the clearest sequence of units in western Newfoundland forms what is here termed the carbonate sequence because carbonate rocks dominate its middle part; it is summarized in the left-hand column of table 1, and its distribution is shown in figure 1. This sequence, with some variations in unit names and thicknesses, has been recognized from the Strait of Belle Isle to Port au Port Peninsula, wherever the Lower Paleozoic rocks have been mapped. Rocks belonging to it crop out all around the Precambrian core of the Long Range Mountains—the backbone of the Great Northern Peninsula of Newfoundland (Clifford and Baird, 1962)—except where cut out by faults or overlapped by Carboniferous strata or the sea, and also in a somewhat sinuous belt extending southwestward from the south end of that core to the tip of Port au Port Peninsula. Along the coast northwest of the north half of the core of the Long Range Mountains, the strata lie relatively flat, though cut by high-angle faults. Farther south along the west side of the core, the sequence is largely cut out by a thrust fault; slivers of carbonate rock show however that it was originally present. In the exposures east and south of the Precambrian core of the Long Range, the carbonate strata are highly deformed and partly metamorphosed to marble, but on and near the Port au Port Peninsula they are again only locally folded, though broken by several faults.

Sedimentary features, such as cross-bedding in sandstone and limestone, and fossils, such as trilobites, gastropods, cephalopods, and brachiopods, show that all but the uppermost shaly part of the carbonate sequence was deposited in shallow sea water, probably on wide shoal banks similar to those along the present coasts of Florida and Yucatán. A very similar sequence of strata, with resemblances extending to details, is known not only in the Taconic region (right-hand column of table 1; for distribution see fig. 2) but also along the

TABLE 1
Carbonate sequences

Western Newfoundland	Taconic region
Middle Ordovician:	Middle Ordovician:
Part of Humber Arm group*—shale and sandstone, upper limit uncertain	Canajoharie shale (and part of Hortonville formation) — black graptolite shale, limy near base, some sandstone in upper part; upper limit uncertain in much of region
thickness uncertain	to 1000'?
Table Head group—thin-bedded fossiliferous limestone, shale in upper part, some dolostone in lower part	Several units—thin-bedded fossiliferous limestone, some shaly, some calcarenitic, some dolomitic
500-1500'	0-400'
Disconformity	Disconformity
Lower Ordovician:	Lower Ordovician:
St. George group—massive dolostone, a few limestone and sandstone beds	Beekmantown group—massive dolostone and limestone (limestone especially to east); thin sandstone beds
2000-3000'	1000-1500'
Middle and Upper Cambrian:	Upper Cambrian (Middle not recognized):
Several units—massive dolostone, some shale and oölitic limestone, thick sandstone in lower part	Several units—massive dolostone, local limestone, quartzite toward base (especially to west where it rests directly on Precambrian)
500-1500'	300-600'
Lower Cambrian:	Lower Cambrian:
Labrador group, etc.—sandstone (especially quartzite and arkose), some units of shale and limestone	Several units—Massive dolostone, units of pink quartzite and slate in upper part
1000-3000'	1500'
	Cheshire quartzite and Mendon group—pure quartzite near top, phyllite, graywacke, and conglomerate in lower part
	200-2000'
Unconformity	Unconformity
Precambrian rocks of Long Range Mountains and Labrador	Precambrian rocks of Green and Adirondack Mountains

* The Long Point formation, which crops out only on Long Point and adjacent parts of the western Port au Port Peninsula, is not listed here because its relation to the other rocks in the region has never been clarified and because we have a special hypothesis to propose for it (p. 727-728).

west side of the entire Appalachian chain as far as Alabama. These rocks were evidently deposited upon the slightly submerged eastern margin of the central platform of the North American continent, over which shallow seas transgressed more and more during the Cambrian and early Ordovician.

On the other hand, Middle Ordovician shale and sandstone units that overlie Cambro-Ordovician carbonate strata all along the west side of the Appalachians show quite different features; graded bedding and graptolitic faunas testify to a change of environment, with the appearance of a flood of clastic material from the east and probably also rapid subsidence of at least

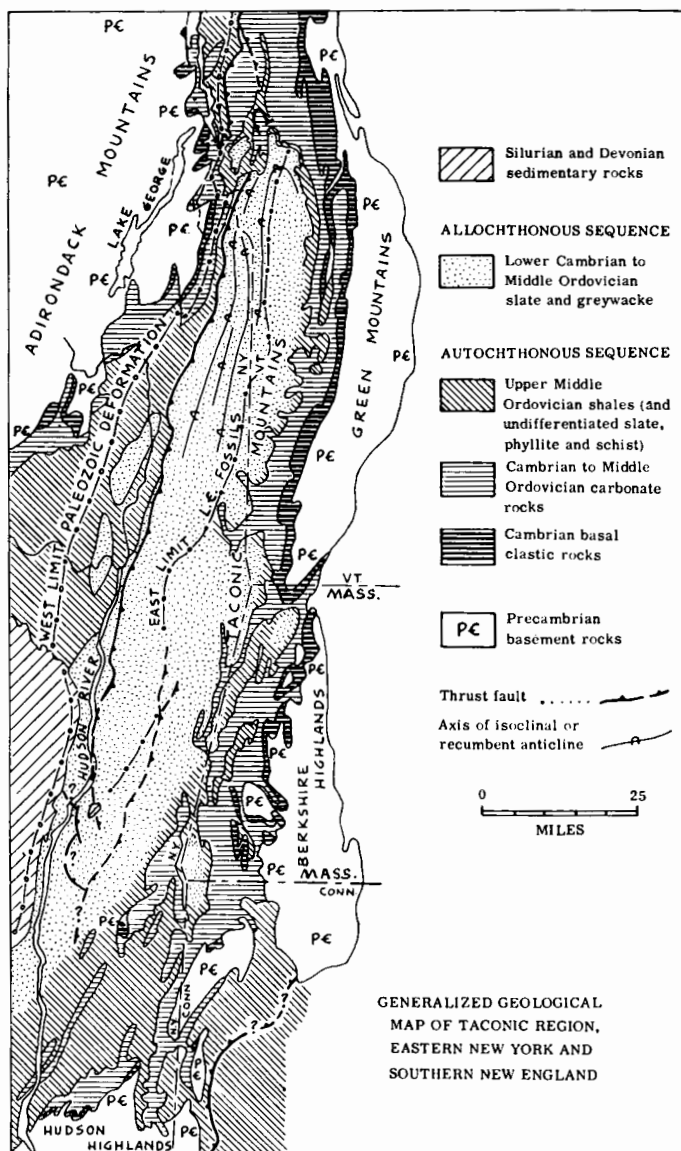


Fig. 2.

part of the former bank area into deep water. The same change seems to have taken place in western Newfoundland, though it is difficult to draw a consistent boundary separating these Middle Ordovician clastic strata, which form the summit of the carbonate sequence, from adjacent but older clastic strata that do not form part of that sequence; similar difficulties are encountered in the Taconic region.

The clastic terrane.—Those strata in western Newfoundland that do not find a natural place in the carbonate sequence have been more difficult to classify. Originally they were all lumped in a single unit, the Humber Arm group, but progress has now been made in several areas toward recognizing a stratigraphic succession; ultimately more than one succession may have to be distinguished. The dominant rock type is shale, slate, or phyllite, mainly gray, black, or green, but also including red and purple. In addition there are numerous thin to thick beds of siltstone, sandstone, and conglomerate, mainly of graywacke affinities and commonly graded, and likewise beds of limestone, ranging in texture from lime-mudstone to lime-breccia and also commonly showing grading. Also included in the Humber Arm terrane in places are large bodies of mafic volcanic rocks, including pillow basalt, and even larger intrusive masses of mafic and ultramafic rocks, which form the high mountains near the coast on either side of the Bay of Islands. Rocks of these types underlie two large areas in western Newfoundland (fig. 1), one north and west of the outcrop belt of the carbonate sequence extending along the west coast from Port au Port Peninsula to Daniels Harbour, and the other east of the carbonate rocks at the northeastern end of the Great Northern Peninsula between Pistolet Bay and Canada Bay.

These two areas of the clastic terrane are framed within outcrop belts of the carbonate sequence, except where the Precambrian rocks are locally thrust against them or they are overlapped by Carboniferous strata or by the sea. The upper strata of the carbonate sequence dip under the clastic strata nearly everywhere along their common boundary. Hence the entire Humber Arm group was originally considered to overlie the carbonate sequence conformably and to be Middle (or Middle and Late) Ordovician in age. When older fossils were found in the clastic rocks, however, the units containing them were generally removed from the Humber Arm, but some of these units were defined only by their fossils and contain no distinctive rock types. They are not part of the carbonate sequence, but their relation to it and to the unfossiliferous part of the Humber Arm has remained enigmatic. The prominent layers of lime-breccia (calcirudite) posed additional problems; at first they were all classified as a single Middle Ordovician unit, the Cow Head breccia, lying at the base of the Humber Arm group just above the top of the carbonate strata. Recent work (Kindle and Whittington, 1958, 1959) has shown however that in the area around Cow Head they range in age from Middle Cambrian to Middle Ordovician and form, with the interbedded shale and thin-bedded limestone, an unbroken consistent sequence about 1000 feet thick. In that area, this sequence of strata is repeated, apparently by imbricate thrust faults, in some 6 to 8 parallel belts trending north-northeast and separated by shale and sandstone assigned to the Humber Arm (Oxley, 1953; Baird, 1959). Moreover, both the total thickness of breccia and the size of the largest blocks increase belt by belt from southeast to northwest, reaching a maximum along the shore at Cow Head and vicinity.

Some of the blocks in the lime-breccia beds are fossiliferous, and many can be identified as coming from units in the carbonate sequence. Except in such blocks, however, fossils are relatively rare everywhere in the clastic ter-

rane. In the Ordovician the fossils are principally graptolites; in the Cambrian, they are trilobites but partly of different groups from those in the carbonate sequence. In general this fauna appears pelagic. Coupled with the grading evident in some of the sandstone and lime-breccia beds and with the graywacke affinities of the non-calcareous sandstone, the fauna suggests that the rocks of the clastic terrane were deposited in relatively deep water, where slow mud deposition was sporadically interrupted by turbidity currents from two sources: on the one hand from the banks where the carbonate sequence was being contemporaneously deposited, and on the other from an area of incomplete chemical weathering or rapid erosion or both. Such deeper water might have lain just east of the margin of the continental platform or in embayments within it.

The Taconic sequence of the Taconic region (see fig. 2) consists of precisely similar strata (except that igneous rocks are virtually absent) and has presented precisely similar problems. At first it was all lumped into the Hudson River "group" and considered to overlie the top of the carbonate sequence conformably. Then as more and more fossils were found, ranging in age from Middle Ordovician to Early Cambrian, the fossiliferous units were removed one by one from the Hudson River, which remained a dump-box for undated strata. Lime-breccia units are common, especially near the west edge of the outcrop belt of the Taconic sequence, and a few studies of the fragments (Ruedemann, 1901; Ross, 1949) have shown that they come in part from the carbonate sequence. At first the breccias were all classified as a single Middle Ordovician unit (Rysedorph or Rysedorph Hill conglomerate), but it is now clear that they occur in units of several ages, from Early Cambrian to Middle Ordovician. Because the region is structurally complex, even the main outlines of the stratigraphy were long in doubt, but recent painstaking work has finally established a satisfactory sequence of units (Zen, 1959, 1961; Theokritoff, 1959; Fisher, 1961; Bird, 1961, 1962). The depositional environment must have been very similar to that of the clastic terrane of western Newfoundland.

STRUCTURAL INTERPRETATION

Statement of hypothesis.—As already mentioned above, the original and the simplest structural interpretation of the Humber Arm terrane is that it was deposited in normal succession at the top of the carbonate sequence and was deformed with it; thus it would be Middle (and possibly partly Upper) Ordovician. This was the hypothesis of Schuchert and Dunbar (1934); to accept it however they had to exclude from the Humber Arm all beds with older fossils. Thus when lowest Lower Ordovician graptolites were discovered at Green Point and elsewhere, they felt compelled to separate the fossiliferous beds as a new formation, the Green Point formation, and to postulate major faults separating it from the "true" Humber Arm, though they stated (1934, p. 38): "Throughout our field work it [the Green Point] was supposed to be part of the Humber Arm series". Later Johnson (1941) and Oxley (1953) separated additional shales (St. Paul group of Oxley) from the Humber Arm, simply because they are older than its presumed age.

The presence of contemporaneous carbonate and clastic units in the region can be explained in several ways, and one's choice of explanation is apt to be

conditioned by one's conception of the magnitude of the problem, i.e. by how much of the clastic terrane one conceives to be contemporaneous with and how much subsequent to the end of carbonate deposition in the carbonate sequence. The general tendency has been to admit contemporaneity only where the fossils demand it, and to view all other clastic strata as subsequent to the carbonate rocks and hence conformably above them, expressing this view by assigning them to the Humber Arm Group, considered as the top unit of the carbonate sequence.

Even apart from the fossiliferous clastic units, however, which all agree cannot be so assigned, the "Humber Arm" consists largely of rock types—e.g. turbidites and volcanic rocks—that seem out of place as part of the carbonate sequence and more akin to the fossiliferous clastic strata. Furthermore many of these rock types are remarkably similar to strata in the Taconic sequence in Vermont and New York, strata that are associated with fossiliferous Cambrian and Lower Ordovician slate and hence are excluded from the carbonate sequence there. We suggest therefore that the bulk of the rocks in the clastic terrane of western Newfoundland are not younger than or conformable above the carbonate units of the carbonate sequence but contemporaneous with them.

To explain the structural position of those clastic strata that are not part of the carbonate sequence (whether or not one includes in this category the bulk of the unfossiliferous clastic rocks), one has several hypotheses to choose from (exactly the same hypotheses are available to explain the relations of the Taconic sequence to the contemporaneous strata of the carbonate sequence in the Taconic region). One such hypothesis, though admitting the overall contemporaneity of the two terranes, holds that units in the one are not exactly correlative with units in the other but are typically represented in it by disconformities; thus units of each sequence either were never deposited in or were removed by erosion from the present outcrop area of the other. This hypothesis was hinted at by Schuchert and Dunbar (1934, p. 40) for the Green Point formation, but now that several faunas, ranging from Middle Cambrian to Middle Ordovician, are known in the clastic sequence, especially in the Cow Head area, it seems untenable. (For the comparable hypothesis in the Taconic region, see Bucher, 1957.)

Another more satisfactory hypothesis accepts the contemporaneity of the two terranes as indicated by the fossils and interprets their present distribution as original, the carbonate sequence having been deposited on a shelf separating two deep-water embayments in which the clastic strata accumulated. According to this hypothesis, the fossiliferous succession in the Cow Head area must have been virtually surrounded by shallow carbonate banks; the carbonate sequence crops out to the east and north and, though it is not now visible to the west, its former presence there may be inferred from the westward thickening and coarsening of the lime-breccia beds. This hypothesis corresponds to the most widely held autochthonous hypothesis for the Taconic sequence, which has been carefully worked out by Lochman-Balk (1956) in connection with a detailed restudy of the Lower Cambrian Taconic fauna. It demands a rapid facies change between the carbonate and clastic sequences;

perhaps the abundant lime-breccias along the western side of each of the large areas of the clastic terrane point to such a change, but otherwise no transitional rocks have been observed, either in western Newfoundland or in the Taconic region.

We propose, on the other hand, to follow up Johnson's and Kay's original lead and develop the hypothesis that the clastic terrane, comprising most of the unfossiliferous rocks now assigned to the Humber Arm as well as the fossiliferous units generally separated from it, was originally deposited in deep water entirely east of the continental platform on which the carbonate sequence accumulated and from which the fragments in the lime-breccia beds were derived. When deposition of both terranes was essentially complete, the clastic rocks to the east were transported westward by large-scale tectonic displacements until they lay on top of the carbonate sequence, with which they were later deformed and locally metamorphosed. This hypothesis does not require the separation of the fossiliferous clastic strata from the rest of the Humber Arm terrane, but it does require a separation of the main body of that terrane from the shale and sandstone that lie conformably at the top of the carbonate sequence. If it is correct, then the two large areas of the Humber Arm and related rocks in western Newfoundland are klippen, the larger one—roughly 130 miles by 30 miles—being about the size of the Taconic klippe.

In order to maintain that the structure is relatively simple, or at least that the clastic terrane is still roughly where it was deposited, the autochthonous hypotheses must postulate complex stratigraphic relations, such as invisible unconformities or facies changes. On the other hand, in order to avoid these problems and present a simple and logical stratigraphic picture, the allochthonous hypothesis must postulate complex structural relations, and it thus raises a whole series of other problems. Among these problems are: How closely can the boundaries of the supposed klippe be located? Where was the source of the far-travelled mass, and can we recognize anywhere to the east the correlative rocks that stayed at home? What forces caused the movement, and how were they transmitted through the notably incompetent materials of the clastic terrane? These problems we now discuss in order.

Boundary of the proposed klippen.—Figure 1 shows our best present guess as to the outlines of the two supposed klippen. In a number of places it is clear that the uppermost carbonate unit in the carbonate sequence, the lower Middle Ordovician Table Head group, grades upward into black graptolitic shale, which locally contains graded beds of greenish sandstone and also of lime-breccia (e.g. just north of Cape Cormorant and elsewhere in the west part of Port au Port Peninsula); thus the klippen boundary cannot in general coincide with the carbonate-clastic contact but must lie somewhere within the area of clastic rocks. Believing nevertheless that most of the Humber Arm group is allochthonous, we were forced in the absence of information over most of the area to show the boundary of the klippen approximately at the boundary of that group and its equivalents—that is, generally close to the carbonate-clastic contact.

In the northward projection of the west coast klippe north of Bonne Bay, however, better information is available, thanks to the work of Johnson, Oxley,

Baird, and Kindle and Whittington, and our procedure can be to some extent justified. Along the east side of this projection of the klippe, late thrusting, presumably associated with the rise of the Precambrian core of the Long Range Mountains, has brought slivers of the carbonate rocks *over* the clastic terrane, whereas at the north end of this klippe, strata of the lower Middle Ordovician Table Head group dip fairly gently under it. Within the clastic terrane, as mentioned above (p. 718), a succession of lime-breccia, thin-bedded limestone, limy shale, black graptolite shale, and graywacke sandstone is repeated 6 to 8 times, apparently by east-dipping thrust faults. In the western part of the area, as around Cow Head, the lime-breccia beds become spectacularly coarse (Cow Head breccia), and according to Kindle and Whittington (1958, 1959) the fossils in the boulders in each bed of breccia are all about the same age, which is that of the immediately underlying unit of shale or shaly limestone wherever fossils can be found in that unit. Here the age span indicated by the fossils extends from the Middle Cambrian to the Middle Ordovician; even to the east, where the lime-breccia beds are fewer and finer-grained, they suggest that Middle Cambrian is present, and graptolites in the upper part of the succession prove that it spans much of the first half of the Ordovician. In other words, the bulk of the clastic terrane here is clearly contemporaneous with the typically developed carbonate sequence exposed nearby to the east and north, and even if younger rocks are present they are part of the succession in the clastic terrane. By our hypothesis, therefore, it is all allochthonous. Only at the extreme north end of the projection is there shale and sandstone that might be in normal succession above the carbonate rocks of the carbonate sequence.

Elsewhere in the region, wherever indigenous fossils such as graptolites show that the clastic strata containing them are as old as or older than the Table Head group, these strata must by our hypothesis be part of the klippe, but such fossils are seldom common enough to provide much help in locating the klippe boundaries. If however the conclusions of Kindle and Whittington concerning the ages of the lime-breccia beds can be generalized for the rest of the region, then large parts of the Humber Arm terrane would be allochthonous, for lime-breccia beds with Cambrian fossils are known in several parts of it; thus in the vicinity of Humber Arm, Lower Cambrian fossils have been found in breccia fragments at two different localities (see Walthier, 1949, p. 25, and McKillop, ms).

Where fossils are absent we have fallen back on rock type as a criterion, reasoning that those rock types which, according to the hypothesis, are allochthonous north of Bonne Bay are probably allochthonous elsewhere. Thus the presence of unfossiliferous lime-breccia and graywacke sandstone nearly everywhere in the clastic terrane and their general absence from the carbonate sequence (though perhaps they occur at its top) is part of the argument for assigning most of the clastic terrane to the klippe. Similarly, several common rock types in the Humber Arm group (well displayed along Humber Arm), such as purple and green slate, greenish impure quartzite, and brown-weathering ankeritic sandstone, are typical of Cambrian units in the Taconic sequence;

as we accept the allochthony of the latter, we have used the distribution of such rock types in Newfoundland as evidence for drawing the klippe boundaries.

Furthermore, we interpret both the volcanic rocks and the mafic and ultramafic intrusions as more probably allochthonous, because there is no evidence that feeders for either cut the carbonate rocks; thus Smith (1958, p. 11), who studied the ultramafic rocks in detail, states: "There is no indication that primary ultrabasic rocks were intruded into the pre-Humber Arm rocks [in our terms, the autochthonous carbonate sequence], although later deformation has brought them into contact in places".

Nevertheless, it is obvious that, if one accepts the klippe hypothesis as we have done, many problems remain in drawing the klippe boundaries. For example, between Humber Arm and Bonne Bay, the clastic terrane (Humber Arm group) has been divided into four lithologic units, which Troelsen (ms), Weitz (ms), and Lilly (ms) regard as progressively younger westward, the lowest resting upon the Table Head group. Troelsen has stressed that the relative ages of these unfossiliferous units are difficult to determine because of intense deformation, and that the boundary with the carbonate sequence is drawn arbitrarily: thus he used cleavage type to distinguish slate at the top of the Table Head (slate with flow cleavage) from slate at the base of the Humber Arm (slate with bedding cleavage). Again, Lilly (ms, p. 78-79) remarks that the contact zone between the carbonate and clastic terranes is commonly marked by lime-breccia that contains fragments resembling the Lower Ordovician St. George group, west of which come sandstone and conglomerate that contain fragments of probable Cambrian rocks. Perhaps these strata represent a sequence that ranges from the Cambrian into the Ordovician, like the sequence farther north studied by Kindle and Whittington, and much or all of it may belong in the klippe.

Other difficulties concern the interpretation of the sedimentary environment. To us the descriptions of most of the unfossiliferous clastic strata between Bonne Bay and Port au Port Peninsula strongly suggest deep-water deposition, yet several authors (e.g. Schuchert and Dunbar, 1934; Sullivan, ms; Walthier, 1949; Lilly, ms) have called attention to cross-bedded and ripple-marked sandstone and to mudcracked shale and from these have interpreted the entire section as deltaic. No detailed descriptions of these sedimentary structures have been published, so that it is possible that some of the cross-bedding and ripple marks are of the varieties commonly associated with turbidites (Kuenen and Sanders, 1956). Mud cracks are more difficult, and we would have to explain any sedimentary features that do represent shallow-water or fluvial deposition as produced either in Early Cambrian time before deep downwarping of the depositional basin or on or near islands within it.

Most of our reasoning about the klippen is based on the west coast area of Humber Arm rocks, for we have seen this area, and fairly detailed descriptions covering most of it are available in published reports and unpublished theses (from south to north: Sullivan, ms; Riley, 1962; Walthier, 1949; McKillop, ms; Weitz, ms; Lilly, ms; Troelsen, ms; Oxley, 1953; Baird, 1959; Kindle and Whittington, 1958, 1959; Nelson, 1955). For the area of similar rocks at the northeastern tip of the Great Northern Peninsula, however, we

have the reports of Cooper (1937) and Betz (1939) but no first-hand knowledge. Hence we merely wish to suggest that in a consistent application of the klippe hypothesis these rocks also would be allochthonous. As shown on figure 1, the clastic strata here lie east of the exposed rocks of the carbonate sequence. On the west shore of the head of White Bay, however, Lower Paleozoic marble flanks the Precambrian core of the Great Northern Peninsula. Furthermore, Neale (1959) and Neale and Nash (1963) have suggested that the metamorphic rocks east of White Bay—schist, gneiss, and marble of the Fleur de Lys group—may also be partly of Early Paleozoic age. If Paleozoic carbonate rocks extend northeastward beneath the sea, then the clastic terrane between Canada Bay and Pistolet Bay might also be a klippe. Certain structural features recorded by Cooper and Betz might fit reasonably well with an allochthonous hypothesis, for example the thrust fault mapped by Cooper along the north shore of Hare Bay, on which ultramafic rocks and associated clastic and volcanic rocks have overridden members of both the clastic and carbonate sequences, but obviously they provide no proof.

Source area for the klippen.—Baird's (1954) map of Newfoundland shows that an adequate source area for the clastic and volcanic rocks of the postulated klippen lies to the east of the carbonate sequence. Subsequent mapping (Neale and Nash, 1963) has provided additional information on the variety and structural setting of this area, and Riley (1957) has outlined an additional outcrop area of such rocks which, in places, lies only 8 miles east of rocks mapped as Humber Arm group.

Rocks much like those of the west coast clastic terrane occur in the region east of White Bay, east of a line that extends south-southwest from Baie Verte (Watson, 1947; Neale and Nash, 1963). These rocks, the Baie Verte group, include mafic pillow lava, graywacke, black slate, chert, and thin-bedded limestone. They contain no fossils in their westernmost outcrops, but a short distance to the east, on the western shores of Notre Dame Bay, similar rocks contain both Early and Middle Ordovician graptolite faunas. Along its western margin, the locus of a major fault zone, this clastic-volcanic terrane is intruded by a linear belt of ultramafic and associated plutonic rocks. Neale and Nash interpret the schist, gneiss, and marble of the Fleur de Lys group, which crops out immediately west of the fault zone and line of ultramafic intrusions, as partly of Early Paleozoic age. They suggest that the faulting and ultramafic intrusion took place along the eastern margin of a broad shelf zone that extended across the Northern Peninsula and the entire White Bay area and was the site of carbonate deposition in Cambro-Ordovician time. An alternative view is that the Baie Verte clastic-volcanic strata originally extended as far west as the central part of White Bay and that the Fleur de Lys group is older, perhaps Precambrian, and represents a welt of the basement that underlay the eugeo-synclinal trough in which the Baie Verte group was deposited. Thin mafic and ultramafic dikes and sills in the Fleur de Lys group, which may have acted as feeders to volcanic and intrusive rocks in the overlying Baie Verte group, tend to support this second view. Depending on the interpretation of the Fleur de Lys group, a minimum transport of 40 or 60 miles is required if the Baie

Verte group represents the source area for the clastic terrane north of Bonne Bay.

The linear belt of ultramafic rocks and the associated fault zone terminate against or merge with a major zone of faulting that extends southwestward to the southwest tip of Newfoundland (Betz, 1943). Immediately southeast of this fault zone, granitic intrusion has largely obscured the nature of the country rocks. Rocks that might represent a source for the klippen have been mapped by Baird (1959) along the east shore of the northern end of Grand Lake. He described these rocks as pre-Carboniferous, possibly Ordovician, amygdaloidal mafic volcanic rocks and associated silicic porphyries. In adjacent areas, however, Riley (1957) and Neale and Nash (1963) interpret these rocks as post-Ordovician on petrographic evidence. In the southern part of Grand Lake basin, Riley (1957) has mapped a mafic volcanic sequence, the Glover formation, that strongly resembles the volcanic members of the Humber Arm group. Southeast of the Glover formation, and separated from it by 10 to 20 miles of intervening granitic rocks, are outcrops of similar mafic pillow lavas associated with green sandstone and black shale that resemble sedimentary members of the Humber Arm group. These rocks are intruded by large bodies of gabbro. The westernmost exposures of the Glover formation are only 4 or 5 miles east of metamorphosed Cambrian formations of the west coast carbonate sequence and only 8 miles from shales of the Humber Arm group. However, they are roughly 25 miles east of the nearest outcrops of Humber Arm volcanic rocks.

No ultramafic rocks have been mapped in the region around Grand Lake. On the east shore of Deer Lake, however, Grossman (ms) and Baird (1959) report small bodies of serpentinized ultramafic rocks and metagabbro in schists and gneisses of clastic origin that Baird interprets as Cambrian. These rocks are analogous to the Fleur de Lys group mentioned above, and possibly they formed the floor of a eugeosynclinal trough in which the clastic-volcanic sequence accumulated, the small mafic and ultramafic bodies being feeders to large sills in the overlying rocks.

Phair's (ms) study of the dominantly granitic terrane at the southwest tip of Newfoundland shows the presence of ultramafic rocks and metagabbro, and of schist, gneiss, and amphibolite derived from a clastic-volcanic sequence. Small patches of silicated marble are also shown on Phair's map.

Summing up, it is reasonably certain that a belt of Humber Arm-like rocks originally extended from Baie Verte to Cape Ray. In places, for reasons cited above, the western margin of this belt may have lain 10 to 20 miles farther west than the present outcrop. In the region south of Bonne Bay, where the proposed klippe contains the greatest thickness and variety of rocks, the adjacent source area to the east consists of only a few "islands" in a granitic terrane. In contrast, north of Bonne Bay, the "klippe" sequence is thinner, and the corresponding source area contains all the rock varieties that characterize the terrane south of Bonne Bay. One may suggest that more of the potential klippe material was expelled from the source belt in the one area than in the other.

If the klippe hypothesis is valid, then the ultramafic and related intrusive rocks within the area of the proposed klippe (e.g. the Bay of Islands complex) must have been emplaced in the original depositional site of the clastic sequence. Thrusting and gravity sliding of these intrusive rocks would present no problems if they were laccoliths as interpreted by Ingerson (1935) or fault-disrupted segments of a single lopolith as interpreted by Cooper (1936) and Buddington and Hess (1937). Both laccoliths and lopoliths should have thin necks that would be amenable to "beheading". Smith's (1958) later, detailed studies of the Bay of Islands ultramafic plutons suggests, however, that they are parts of either one or two wedge-shaped bodies that thicken at depth. Such bodies would require considerable force to cut them loose from their roots prior to sliding 25 to 40 miles westward. We prefer to refrain from further discussion of this problem until a projected gravity survey by the Dominion Observatory of Canada establishes whether or not these plutons are "rootless" in their present locale.

Emplacement of the klippen.—The hypothesis that the clastic and volcanic rocks now forming the supposed klippen were transported to their present position from the east requires not only a plausible source area but also a plausible mechanism. One might suggest that they are merely remnants of a great thrust sheet that was once continuous over the whole area of the Great Northern Peninsula and extended to the south and east as far as the source area, having been pushed laterally from there by tangential orogenic forces. If, however, one attempts to restore the materials of so vast a thrust sheet to their original position, the amount of shortening in the source area becomes extreme. Moreover, the materials seem too weak to have transmitted tangential forces all the way from that zone to the leading edge, a distance of 40 miles or more.

As an alternative, we suggest that the orogenic forces, acting on the trough to the east in which the clastic and volcanic rocks were deposited, squeezed the main mass of those rocks a relatively few miles (ten to fifteen perhaps) out over one side of the trough, and we would explain the rest of the transport by gravity sliding of parts of this mass into a new basin of active deposition that had formed to the west. We infer that such a western basin appeared in Middle Ordovician time on the former site of the shallow bank where the main body of the carbonate sequence had been accumulating, because the lower Middle Ordovician Table Head limestone of that sequence grades upward into graptolite shale that suggests deep water into which turbidity currents brought clastic materials. We suggest that the allochthonous masses made this part of the journey not as normal thrust sheets—hard rock against hard rock—but as great landslides of weak older sediment slipping into the midst of the still arriving fresh sediment, itself probably the result of erosion of the forward moving mass. Under these circumstances, one can understand that the boundary between autochthonous and allochthonous strata would be difficult to locate, especially in view of the later deformation of the rocks involved.

The masses that slid into the new basin need not have remained continuous either with each other or with the rocks left behind in what remained of the original depositional trough—the source area—nor would they need to have been competent enough to transmit any forces, for gravity would operate

on each particle separately. What they would need would be gravitational potential; somehow they would have to start their slide from a higher position. Part of this height might be given them by the compression of the original trough, squeezing them up and out, part by uplift of segments of the underlying crust, as in areas where Precambrian rocks are now exposed at the surface, such as the core of the Great Northern Peninsula and possibly the outcrop area of the Fleur de Lys group. The later deformation of the new (Middle Ordovician) basin, now including the allochthonous masses that had slid into it, would downwarp them enough to preserve them through all subsequent erosion to the present.

Just this interpretation has recently been emerging to explain the emplacement of the Taconic klippe, for the original, more "orthodox" thrust sheet hypothesis had been unable to provide satisfactory solutions to the three problems mentioned above, those of boundaries, roots, and forces. For that klippe, Cady (1945, p. 578) suggested an analogy with tar and questioned whether it had remained attached to a root. Thompson (in Billings and others, 1952, p. 20) more explicitly suggested gravity gliding off the site of the present Green Mountain anticlinorium just to the east at the time of known Middle Ordovician uplift along it, obviating the root problem in part and the competence problem entirely. Rodgers, influenced by new ideas on the Pre-Rif nappe of northern Morocco and the *argile scagliose* ("Liguride nappe") of north-central Italy, and Zen (private conversations between them; Zen, 1961) further suggested that the mass slid off the anticlinorium into the Middle Ordovician sea *during* the deposition of the shale at the top of the carbonate sequence, perhaps into relatively deep water in a depression complementary to the anticlinorial uplift. Deposition of shale and sandstone probably continued, locally at least, even after the arrival of the sliding mass; both Zen and Rodgers found breccias containing Taconic blocks in apparently autochthonous shale close to the west edge of and just below the allochthonous mass (see also Berry, 1962, p. 713).

A final question is that of the time of emplacement of the allochthonous masses. A lower limit is fixed by the age of the clastic rocks immediately above the carbonates—early Middle Ordovician. An exact upper limit could be determined only if sediments deposited in this basin *after* the arrival of the allochthonous masses could be recognized and dated. In any case, the deformation that folded the two sequences jointly into their present structural position would be later, perhaps several periods later.

Now the Long Point formation, which contains the youngest well characterized Ordovician fauna in western Newfoundland, is very insecurely placed in the stratigraphic succession. In its type locality, the northern point of Port au Port Peninsula, it is reported to be faulted against all surrounding formations (Sullivan, ms; Riley, 1962). Schuchert and Dunbar (1934, p. 72-73, 79-80) considered it older than the Cow Head breccia, and hence than the Humber Arm, because of sandstone in the Cow Head region which they interpreted as Long Point underlying the lime-breccia, though no fossils were found in the sandstone. Later workers have not accepted the correlation (Oxley, 1953) and have indeed considered that the sandstone overlies the breccia (Kindle and

Whittington, 1958, p. 334-335). Likewise Sullivan (ms) reported fragments of the Long Point in the lime-breccia within the Humber Arm at Round Head on Port au Port Peninsula, but he mentioned no fossils in these fragments and stated on the other hand that the fossils from the true Long Point are younger than any found in the Humber Arm.

In the type area, the Long Point dips northwestward (except where overturned) and is succeeded in that direction by the Clam Bank formation. The Clam Bank consists largely of redbeds, but limestone beds in its upper part contain marine fossils that suggest a Late Silurian or Early Devonian age (L. M. Cumming, written communication, 1961). The contact of the Long Point and Clam Bank formations has been interpreted as a fault, but at Clam Bank Cove at least, where we saw it in 1961,¹ we believe that the Long Point, which contains limestone (lime-sandstone) below and becomes shaly and then sandy upwards (Middle Ordovician graptolites were found in the sandstone near the top), simply grades up into the redbeds, which might therefore represent Late Ordovician and much of Silurian time. Certainly the two formations appear structurally parallel here: both are vertical or overturned. If the Long Point is really part of a sequence that continues up into the Silurian and was deformed along with it, then it must represent an autochthonous (strictly, neo-autochthonous) deposit on top of the klippe *after* emplacement, and it provides a closer dating of the gravity sliding, which would be Middle Ordovician. Presumably the deformation of the Long Point would be contemporaneous with that of the klippe and substratum—possibly Devonian. Proof or disproof of this speculation should be available in the area where the base of the Long Point formation is in contact with the Humber Arm terrane.

CONCLUDING REMARKS

In conclusion, what we have tried to do is to raise for serious consideration the hypothesis that the Humber Arm group and its equivalents in western Newfoundland are not in place but form two large klippen, derived from a clastic-volcanic (eugeosynclinal) trough well to the east and transported westward, probably by a combination of lateral compression and gravity sliding, into a basin where shale was already being deposited on top of a (miogeosynclinal) sequence of carbonate rocks. The allochthonous masses were probably emplaced during the Middle Ordovician: carbonate and clastic-volcanic terranes were later deformed together (in the Devonian?), forming synclinoria marginal to the Long Range anticlinorium and related uplifts; the klippen owe their preservation to their synclinal position. Final evaluation of this hypothesis will demand much more work in the region, both field mapping and geophysical work, which hopefully will be carried out with the hypothesis and its alternatives in mind.

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