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THE LATE PROTEROZOIC "H. D. LILLY UNCONFORMITY" AT RED HEAD, NORTHEASTERN AVALON PENINSULA, NEWFOUNDLAND

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ABSTRACT. At Red Head, on the northeastern coast of the Avalon Peninsula of Newfoundland, intricately folded and irregularly eroded marine sandstones of the lower Conception Group are unconformably overlain by red terrestrial breccias belonging to the upper part of the Cabot Group; both groups are of late Proterozoic age. At this contact, a sequence some 2 to 3 km thick is missing, which everywhere else in eastern Avalon is intercalated conformably between the rocks making contact at Red Head (upper part Conception Group, St. John's Formation, and most of Signal Hill Formation of Cabot Group). In memory of their late colleague, Hugh D. Lilly, who was the first to recognize the unconformable nature of this contact, the authors propose to call it the "H. D. Lilly Unconformity".

This contact is proof that a tectonic event of some magnitude, probably a thrust fault, affected the Red Head area during an interval of the late Proterozoic that is stratigraphically definable as middle to upper Signal Hill Formation time. This suggests that other, less exactly definable late Proterozoic deformations recognized elsewhere within the Avalon Peninsula region developed at about the same time.

The Red Head area, like the whole of southeastern Newfoundland, was also affected by Paleozoic (Devonian?) diastrophism. The main features of the younger orogeny are two thrust faults and a few large open folds.

INTRODUCTION

The purpose of this paper is to substantiate a discovery made by the late Professor Hugh D. Lilly and to discuss its significance in eastern Avalon Peninsula geology.

In the north-facing cliff of Red Head, about 17 km north of the city of St. John's (fig. 1), one of us (W.D.B.) had noted, in 1961, an unusual, highly irregular contact between older and younger late Proterozoic rocks that everywhere else in the eastern parts of the Avalon Peninsula are separated conformably by a sedimentary sequence some 2 to 3 km thick. Later in that year, Mr. Lilly, following a descent of the cliff face to examine the contact, declared that it was an unconformity. Because of its location next to a well-known thrust zone, however, a tectonic explanation of the contact seemed to be more probable, and this tectonic interpretation was adopted later by Keats (ms) after detailed mapping of the area.

In recent years, the four authors of this paper have restudied the Red Head area and its critical cliff section, from the sea (J.B.M., 1970; A.F.K., 1972) and on the ground (M.M.A., W.D.B., J.B.M., 1971; W.D.B., 1972). Their results are reported here.

REGIONAL SETTING

The overall structure of the Avalon Peninsula Proterozoic socle east of a line from Trinity Bay to St. Mary's Bay is considered to be that of

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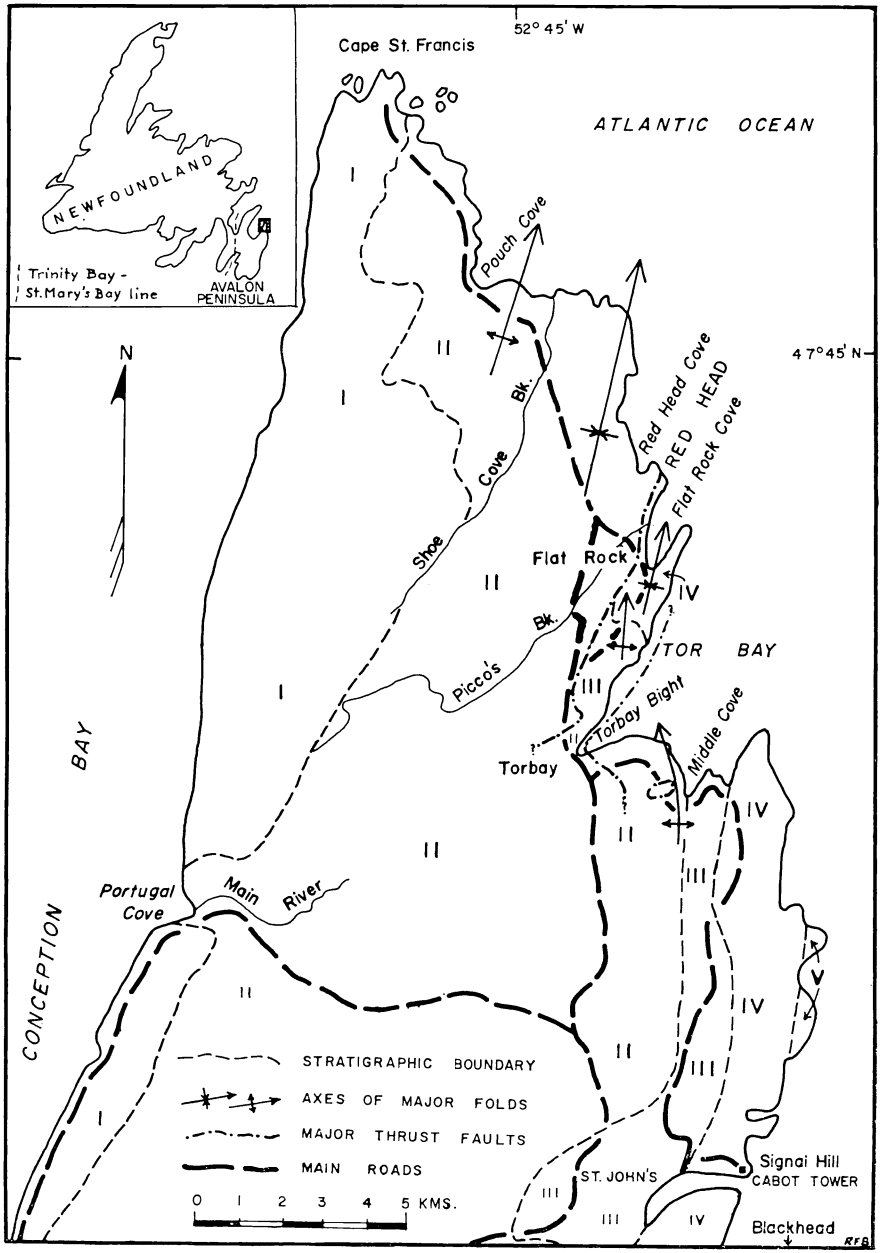


Fig. 1. Sketch map of "St. John's Peninsula", showing locations mentioned in the text and major geological features. I. Harbour Main Group, II. Conception Group, III. St. John's Formation, IV. Signal Hill Formation, V. Blackhead Formation (III to V = Cabot Group).

an elongated, north-south trending dome (King, 1972); this is reflected in the outcrop pattern of the stratigraphic units as can be seen clearly in historical as well as more recent geological maps of Newfoundland (Murray and Howley, 1881; Baird, 1954; Williams, 1967). The so-called St. John's Peninsula, that is, the tip of land separating Conception Bay from the open Atlantic (fig. 1), belongs to the eastern flank of this dome, and it embraces three major stratigraphic units in generally conformable succession (Rose, 1952; Brückner, 1969; King and others, 1974). These units are, from west to east, the dominantly volcanic Harbour Main Group (I in fig. 1), the marine volcaniclastic strata of the Conception Group (II), and the marine to terrestrial epiclastic rocks of the Cabot Group (III to V). The Harbour Main and Conception Groups represent different facies that developed side by side (Hughes and Brückner, 1971); these groups together with the Holyrood plutonic series exposed in central parts of the dome (McCartney, 1967) constitute the "Lower Assemblage" of Avalon Peninsula rocks (Brückner, 1974). The Cabot Group belongs to the overlying "Middle Assemblage". (Rocks of the "Upper Assemblage", of lowermost Cambrian to lower Ordovician age, are not represented on the St. John's Peninsula.) The Harbour Main-Conception sequence exposed between Cape St. Francis and the Red Head area is nearly 3 km thick (Maher, ms). The maximum preserved thickness of the Cabot Group ranges from about 3 km around Tor Bay to over 5 km south of St. John's (King and Brückner, 1972b).

Although regarded above as forming the flank of a structural dome, the St. John's Peninsula is not underlain merely by an east-dipping sequence of rocks as its structure is complicated by several major folds, zones of thrusting, and numerous faults and minor folds (Rose, 1952; see also fig. 1). The rocks were subjected, moreover, to low-grade metamorphism of the prehnite-pumpellyite facies (Papezik, 1972), and slaty cleavage is developed locally. Most structural deformations of the region appear to have occurred after the deposition of the Cabot Group and have tentatively been attributed to a Devonian orogeny; some evidence for pre-Paleozoic tectonic events, however, is also known (McCartney, 1967, p. 80; Brückner, 1974; see also below).

LOCAL SETTING

Before describing the Red Head area, details of the local setting, that is, the main geological features of the surrounding area, between Pouch Cove and Tor Bay, must also be mentioned (fig. 1). Only rocks of the Conception and Cabot Groups are present here.

The Conception Group comprises a lower part consisting of thin-bedded to laminated, fine to coarse-grained sandy arkosic rocks with a maximum exposed thickness of about 800 m (anticline plunging into Pouch Cove) and an upper part of siliceous siltstones and mudstones grading into cherts, with some intercalated volcaniclastic graywacke beds and acidic air-fall tuffs, of which a similar thickness is preserved (syncline west of Red Head Cove; Keats, ms). These two parts are separated by a

glacial member (Brückner and Anderson, 1971; Brückner, 1974). Diabase sills and dikes cut the Conception rocks at several localities in the area concerned (Keats, ms).

Between Tor Bay and Flat Rock, the Cabot Group is divisible into an older part consisting of marine deposits in which black slaty shales dominate over generally thin, fine-grained sandy or silty interbeds (St. John's Formation, III in fig. 1) and a younger part made up of coarser-grained clastic rocks, in which greenish gray, still marine sandstones with some shale interbeds grade upward into red fluviatile sandstones and red and whitish pebble conglomerates (Signal Hill Formation, IV in fig. 1). Going north along the west side of Flat Rock Cove to Red Head, the pebbly Signal Hill beds are first interlayered with, and then overlain by, breccias with subordinate sandstones and mudstones, all dark red in color, which reach a thickness of about 400 m (included in IV of fig. 1). This breccia unit clearly belongs to the upper part of the Cabot Group, but because of the intervening large exposure gap it is impossible to say whether or not it is the lateral equivalent of the dominantly red sandstones of the Blackhead Formation overlying the Signal Hill rocks to the south of Tor Bay (V in fig. 1). In this paper, it will informally be called the "Upper Cabot Group Breccia".

A zone of thrust faulting divides the terrain between Pouch Cove and Tor Bay into two distinct areas (fig. 1). To the west of the thrust zone only rocks of the Conception Group are preserved; to the east only rocks of the Cabot Group (except near the town of Torbay where the underlying Conception rocks are also exposed). The dividing zone of thrust faulting ("Flat Rock thrust zone"), first recognized on the west side of Flat Rock Cove (Rose, 1952, p. 41, pl. VA), has since been traced from a hill about 1.5 km northeast of the center of Torbay (town) northeastward to Red Head, where it strikes out to sea (Gale, ms; Keats, ms). Another significant thrust fault, recognized to the south of Torbay Bight (Cull, ms), apparently continues northeastward beneath Tor Bay. The rocks between the Flat Rock thrust zone and Tor Bay thus constitute a thrust slice rather than, as formerly believed, an autochthonous complex.[1]

Along the whole of the Flat Rock thrust zone, west-dipping strata of the Conception Group, including the glacial member near their base, are thrust over shales of the St. John's Formation. In the south, that is, on the north side of Tor Bay, the thickness of the shales appears to have been little affected by the thrust fault, and they occupy their regular place within the Conception-Cabot Group sequence; only close to the thrust contact are they markedly crushed. Toward the north, however, the shales are squeezed and crushed into a slice of irregular shape with a thickness varying from almost nothing to about 35 m. This shale slice overlies beds of the Signal Hill Formation and the Upper Cabot Group

[1] W. D. B. has recently found that a major thrust fault is not present at the Conception-Cabot contact on the north side of Torbay Bight as had been assumed on the basis of work by Gale (ms). Thus, the "Torbay thrust slice" (King and Brückner, 1974, p. 22) does not find its northern end at this contact but comprises the whole strip of land southeast of the Flat Rock thrust zone, from Torbay to Red Head.

Breccia at a secondary thrust contact, along a surface that, because of its irregular, locally jagged shape, is suggestive of an erosional origin. Figure 2 gives schematic sections across the Flat Rock thrust zone at the mouth of Picco's Brook, the locality described by Rose (1952).

GEOLOGY OF RED HEAD

As noted earlier, the area of Red Head (fig. 3) is traversed by the Flat Rock thrust zone with its two thrust contacts above and below a slice of crushed St. John's shales. In the coastal cliff south of Red Head (pl. 1-A), the St. John's slice directly overlies beds of the Upper Cabot Group Breccia, as it does at Picco's Brook farther south. On the surface and in the northern cliff of Red Head, however, these units are separated by a band of folded, thin-bedded arkosic sandstones belonging to the lower part of the Conception Group. The significance of this band of lower Conception sandstone can best be appreciated from the description given below of the whole section visible in the coastal exposures from Red Head Cove to Red Head proper (figs. 3, 4, and 5).

The main mass of Conception rocks west of the Flat Rock thrust zone dips to the west, steeply near the contact and more gently farther to the west. It includes the top portion of the lower part, the glacial member (here 50 to 75 m thick), and the lower portion of the upper part of the Conception Group. In the cliffs of Red Head Cove, two minor thrust faults, approximately parallel to the bedding planes, are accompanied by zones of crushed rock, the weakness of which has apparently guided erosional agents in excavating the cove. On the inaccessible west side of the cove, the well-bedded Conception sequence is interrupted at one point by a massive rock believed to be a diabase intrusion.

The surface separating the main Conception mass from the band of crushed St. John's shale to the east and beneath it is a sharp thrust fault plane dipping about 45°W (pl. 1-B). The rocks immediately above and below it are strongly sheared and crushed and have hence allowed a deep gash to be eroded by the sea (fig. 3). The shaly St. John's rocks are de-

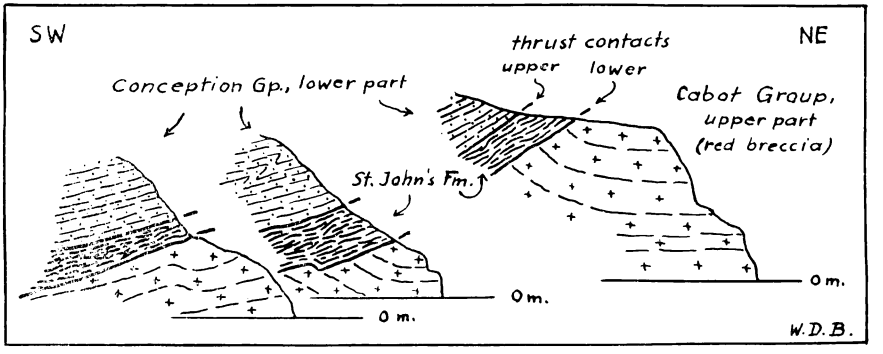


Fig. 2. Diagrammatic sections across the Flat Rock thrust zone exposures north of the mouth of Picco's Brook in Flat Rock Cove.

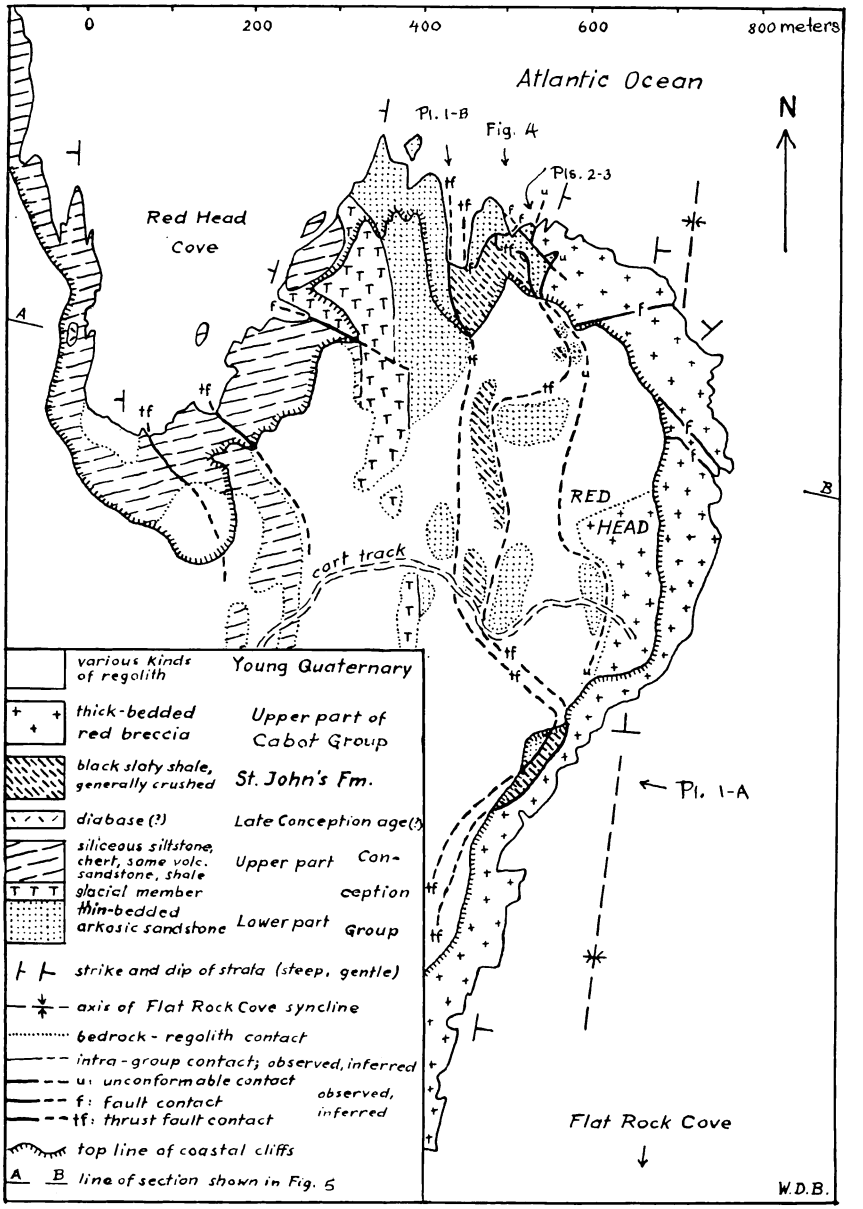
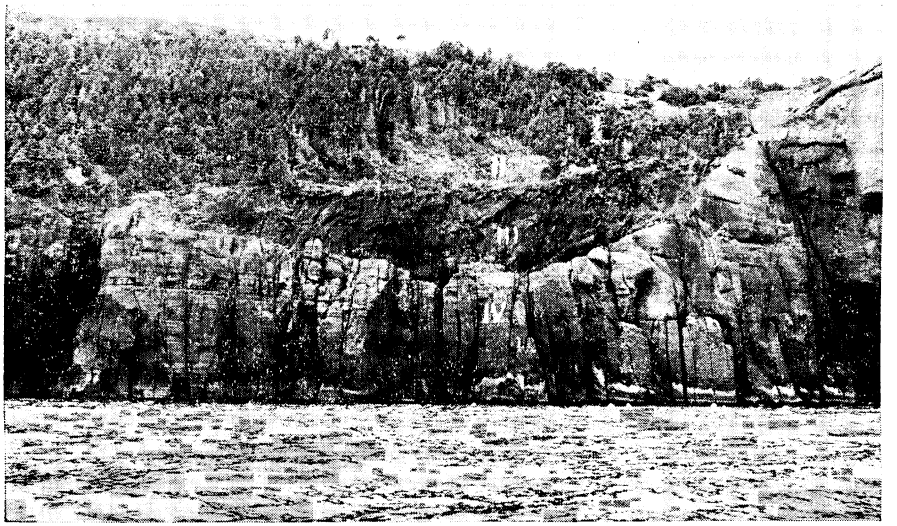
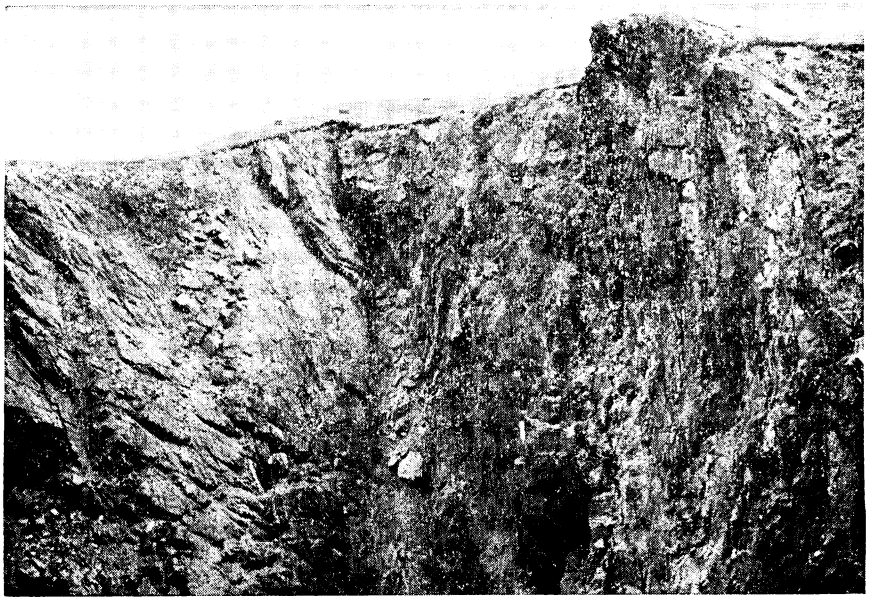


Fig. 3. Geological sketch map of the Red Head area north of Flat Rock.

PLATE 1



A. Flat Rock thrust zone south of Red Head, seen from the east. Massive beds of red Upper Cabot Group Breccia (IV) are tectonically overlain, along an irregular contact probably resulting from ancient erosion, by a slice of dark St. John's shales (III) which are in turn overlain, tectonically, by Conception strata of the main thrust mass (II).



B. Main thrust fault in northern cliff of Red Head area. Shales of St. John's slice on left (east) side, lower Conception Group strata of main thrust mass on right (west) side of fault.

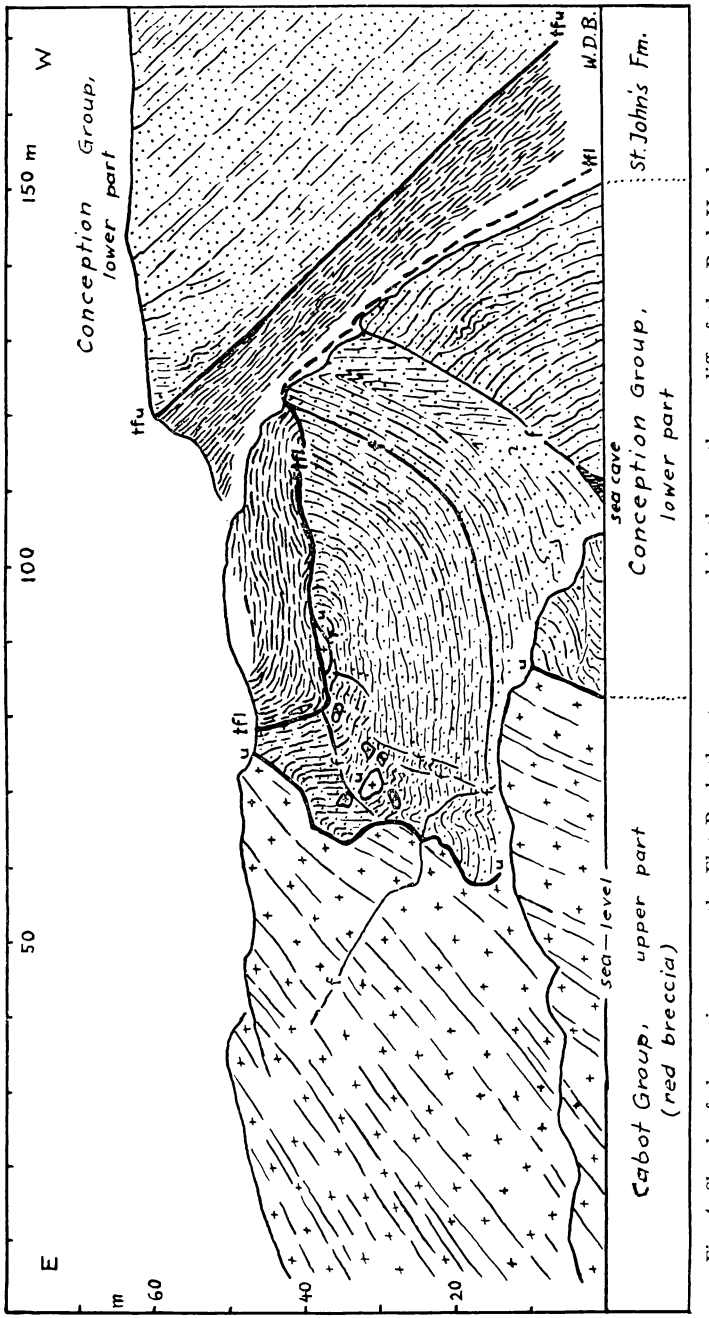


Fig. 4. Sketch of the section across the Flat Rock thrust zone exposed in the northern cliff of the Red Head area. u. unconformable contact, tfl. and tfu. lower and upper contacts of Flat Rock thrust zone, f. other faults. Scales shown are approximate.

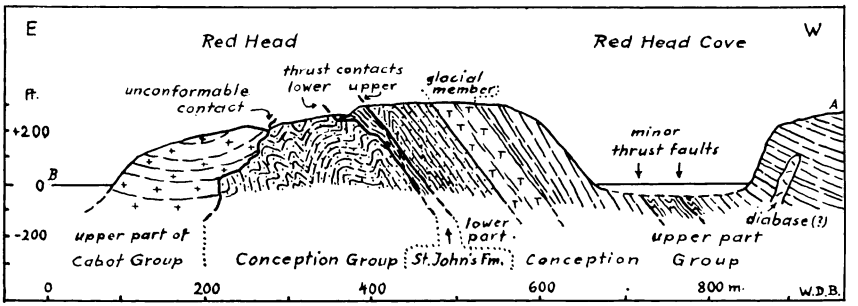


Fig. 5. Diagrammatic cross section through the Red Head-Red Head Cove area along the line A-B indicated in figure 3.

formed to such an extent that their bedding planes are almost indistinguishable. The lower surface of the St. John's shale slice is more irregular than the upper one, and the intensity of crushing and shearing associated with this level indicates that there has been tectonic movement along it. Fragments of the underlying Conception rocks are, moreover, locally included in the crushed basal shale, and they have apparently been dragged along eastward for some distance, though probably not very far.

The upper surface of the St. John's slice is clearly the main thrust fault, and the overlying Conception rocks the main thrust sheet in this area, whereas the St. John's shales, though also transported, were molded beneath the main thrust sheet so as to fit the various and in part substantial irregularities in the surface of the underlying rocks. The existence of an eastward-transported St. John's slice indicates that this formation was, and presumably still is, present beneath the main thrust mass at some distance west of the Red Head area, that is, where it would be expected following the northerly strike of the broad exposures on the north side of Tor Bay.

The Conception and upper Cabot Group rocks beneath the St. John's slice are traversed by several faults. A concave bedding fault in the central part of the Conception exposures is quite obvious (fig. 4), and so is an approximately west-east trending vertical fault in the lower part of the cliff section (fig. 3); both these fractures are, however, of little importance, and they give way eastward to splinter faults trending in various directions and causing only very minor displacements. In addition, a southeast-dipping (strike-slip?) fault with a northeast-southwesterly trend cuts across the base of the Conception spur east of the main thrust fault gash in the cliff, and a low tunnel has been excavated along it by wave erosion from the two sides of the spur (fig. 4). Farther east, in the massive Upper Cabot Group Breccia, only a few small faults are present.

The dip of the breccia beds near the contact with the Conception rocks to the west is about 45°E, but it decreases rapidly eastward and then becomes westerly because the axial plane of the Flat Rock Cove syncline strikes through Red Head (fig. 3).

Some minor fault movement has also affected parts of the contact between the early Conception and the Upper Cabot Group rocks, as crushing can be seen for short stretches or in lenses connected with the splinter faults mentioned above. Generally, however, this contact is not disturbed tectonically. At some places it is straight or only slightly irregular (pl. 2), but locally, the Conception surface has pockets of various shapes and sizes that are filled with Upper Cabot Group Breccia. Indeed, several irregular breccia-filled pockets of this kind are still preserved on the Conception surface in the upper part of the cliff (fig. 4). Clearly, the folds in the Conception rocks were formed at some earlier time, because erosion cut deeply and quite irregularly into these folded rocks before they were covered by the breccia layers.

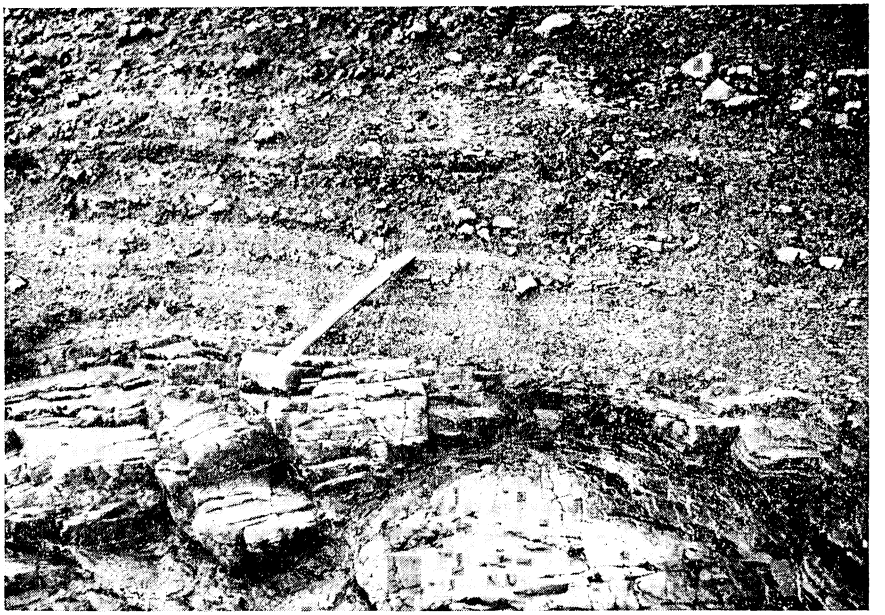
The irregular surface of the early Conception rocks must have been littered, at least locally, with fragments of its laminated sandstones, as large and small fragments of this derivation are dominant in the Cabot Group Breccia at the contact. In a contact sample collected by J.B.M. from the lower part of the cliff (pl. 3), the lowest four centimeters of the breccia consist almost exclusively of fragments of such laminated sandstone, but above this level the sandstone clasts are much less abundant and associated with fragments of chert, siliceous siltstone, and other rock types common in stratigraphically younger parts of the Conception sequence to the west. This association is then dominant throughout the Upper Cabot Group Breccia. (A few isolated pieces of igneous rocks in the breccia have probably been reworked from the glacial member in the Conception Group rather than directly from igneous source rocks some distance away.)

In memory of the discoverer of this unconformable contact, who died accidentally in 1966, in the middle of a promising career, the authors propose to call it the "*H. D. Lilly Unconformity*".

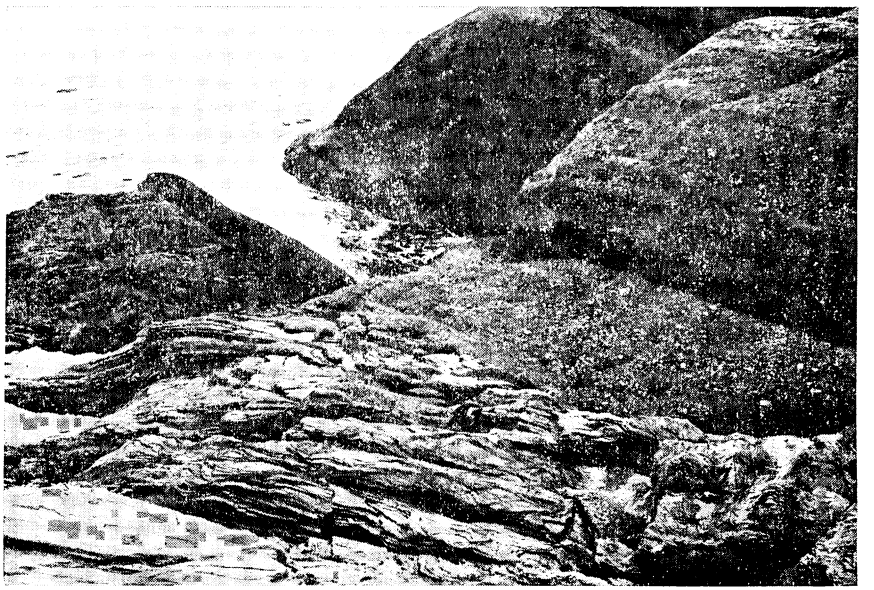
SIGNIFICANCE OF H. D. LILLY UNCONFORMITY, CONCLUSIONS, AND RELATED CONSIDERATIONS

As mentioned briefly above, diastrophic deformation affected the Avalon Peninsula not only after the deposition of its "Upper Assemblage" rocks, that is, at some time after the lower Ordovician, but also in late Proterozoic time, preceding Upper Assemblage sedimentation (Rose, 1952; Hutchinson, 1953; Poole, 1967; McCartney, 1967; Hughes and Brückner, 1971; Fletcher, ms). Opinions as to the dating, types, and magnitudes of the late Proterozoic tectonic deformations, however, have differed considerably as unequivocal evidence is so far known only from a few localities (Brückner, 1974). Among these bits of evidence, the H. D. Lilly Unconformity at Red Head provides the most precise information with regard to stratigraphic dating, although the type and magnitude of the deformation concerned remains uncertain. The following discussion is intended to amplify this statement.

PLATE 2

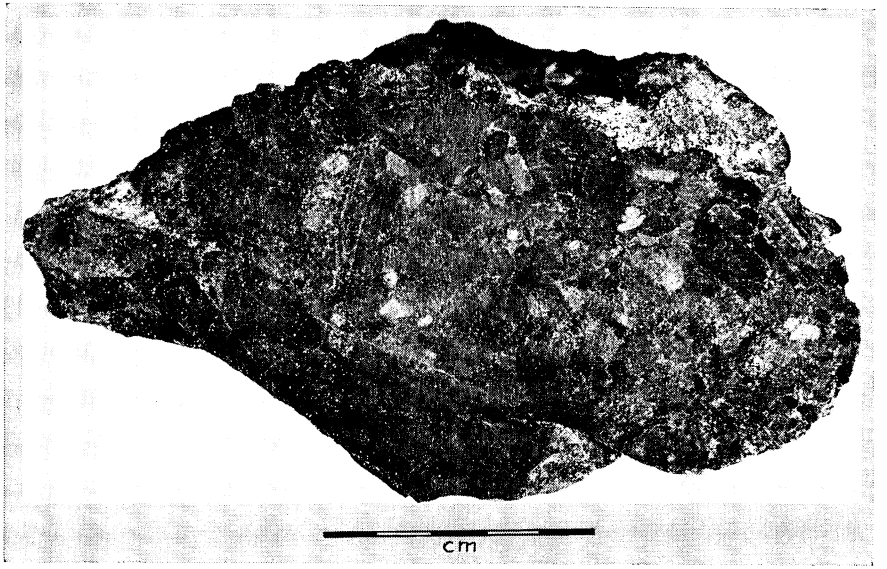


A. Close-up of unconformable contact between thin-bedded sandstones of lower Conception Group below and beds of red Upper Cabot Group Breccia above. Lower part of northern cliff of Red Head area.



B. Another view of unconformable Conception Group—Upper Cabot Group Breccia contact. Base of northern cliff of Red Head area.

PLATE 3



Polished specimen showing the unconformable contact between laminated sandstone of the lower Conception Group (in lower left of section) and red Upper Cabot Group Breccia. Note that clasts of light-colored chert and dark-colored siliceous mudstone derived from the upper Conception Group are restricted to the upper part of this section, whereas the basal breccia consists only of laminated sandstone fragments derived from the underlying lower Conception Group.

The major geological events in the Red Head area inferable with confidence from the observations reported above can be summarized as follows:

1. A conformable sequence of great thickness comprising Conception, St. John's, and most of the Signal Hill strata was deposited here in much the same manner as elsewhere in the eastern coastal belt of the Avalon Peninsula.

2. Then a tectonic event disturbed the uniform progress of sedimentation in this area, bringing rocks of the Conception Group into a position so high that vigorous erosion laid bare the lower portion of the group. A hill of irregular shape was thus formed and subsequently protected from further degradation by gradual accumulation of the erosional debris that now constitutes the red breccia beds of the Red Head-Flat Rock area. As the breccia is laterally interfingered, in Flat Rock Cove, with conglomeratic beds of the upper part of the Signal Hill Formation, it can be inferred that the tectonic event, and the erosion it initiated, occurred preceding, and penecontemporaneous with, deposition of the red breccia beds. Hence, the age of these events, which included the formation of the H. D. Lilly Unconformity, was middle to upper Signal Hill time.

3. The next ascertainable stage was uplift of the whole area in which the upper strata of the Cabot Group had been deposited and erosive removal of substantial portions of the Cabot sequence, probably progressing dominantly, though irregularly, from west to east and leaving a kind of west-facing escarpment in the more resistant Signal Hill conglomerates and upper Cabot Group breccias.

4. This escarpment was then approached and overridden when a major Conception Group thrust slice advanced from the west, dragging along beneath it a slice of St. John's shales that had earlier been brushed off the main body of this formation at some distance to the west.

5. Of later events only erosive lowering and modification during many millions of years can be inferred with certainty, a development the Red Head area shared with the whole island of Newfoundland.

This brief five-stage geological history of the Red Head area leaves three important questions unanswered. These are discussed below in an attempt to provide possible answers.

(i) What was the nature of the tectonic event that took place during stage (2)?

The intricate and irregular folds in the lower Conception sequence beneath the Lilly Unconformity seem to indicate that they formed under a considerable load, exercised in all probability by the younger Conception Group members that furnished the fragments in the red breccia. Lack of lower Cabot Group clasts in the breccia could mean that these rocks were eroded from the rising tectonic unit without leaving a trace in the environment, or else that they were never deposited there, or possibly that they were eroded elsewhere before the lower Conception sequence was emplaced tectonically in the Red Head area. In the last case, transportation of a thrust mass from the west would have to be assumed. This appears to be a distinct possibility because the style of the folds resembles that observed in the well-exposed basal part of the "Torbay thrust slice" in Torbay Bight (King and Brückner, 1974, p. 22) and differs from the more regular pattern of upright, though tight, folds that characterizes the cores of large Conception anticlines such as those east of Pouch Cove and in Middle Cove (fig. 1). If these inferences are correct, then a low-angle thrust fault exists at some depth below present sea level, separating the folded lower Conception rocks from Signal Hill rocks slightly older than the basal beds of red breccia, and beneath it there is probably an essentially undisturbed sequence comprising the lower part of the Cabot Group and the Conception Group, down to the base of the Torbay thrust slice.

(ii) During what period of time did the erosion of stage (3) take place, and when did the Flat Rock thrust zone (stage 4) develop?

It is not known, but possible, that members of the Cambrian to lower Ordovician "Upper Assemblage", now preserved only as remnants west of the "St. John's Peninsula", were also deposited within the area of this peninsula. Such an assumption may be supported by the presence of prehnite in lower Signal Hill rocks near St. John's, as this mineral is in-

dicative of load pressures possibly greater than that exercised by a complete Cabot Group sequence alone (Papezik, 1972). In the event that older Paleozoic sediments were present, erosion of Cabot rocks might not have been possible until some time after the lower Ordovician.

The younger tectonic deformations of the Avalon Peninsula rocks are usually assigned to the "Acadian Orogeny" of Devonian age, extrapolating from the age of intrusive rocks on the western side of the Avalon region. Following this kind of conventional reasoning, the erosive relief of the Cabot Group rocks beneath the Flat Rock thrust might have been carved between lower Ordovician and Devonian time, and the Flat Rock thrust would then be Devonian in age. Probably, the two open, north-plunging Cabot Group folds in the Flat Rock area, that is, the anticline southwest of the town and the syncline striking through Flat Rock Cove and Red Head (fig. 1), were formed at the same time as the Flat Rock thrust, as they are part of the Torbay thrust slice which presumably moved contemporaneously with the mass above the Flat Rock thrust zone. It is even conceivable that all the open folds in the belt of Cabot Group rocks farther south were formed at the same time.

(iii) Do the complex geological events recorded in the rocks of the Red Head area have only a local significance or are they an indication that similar events affected the whole belt where Conception and Cabot rocks are in contact along the east coast of the Avalon Peninsula?

There is no evidence known at present that would favor an extension of the Red Head sequence of events to the whole belt concerned, but considering the scarcity of inland exposures and the fact that little detailed mapping has yet been carried out to the south of St. John's, it is possible that such evidence may still come to light. It has been established, in any case, that a fair amount of deformation and penecontemporaneous erosion affected more westerly parts of the Avalon Peninsula during late Proterozoic time, because in the Conception Bay area lower Cambrian beds unconformably overlie deformed Harbour Main volcanics, Holyrood intrusive rocks, and deformed Conception Group strata (McCartney, 1967; Hughes and Brückner, 1971; King and Brückner, 1972a; Brückner, 1974). It seems reasonable, therefore, to assume that the tectonic event that affected the Red Head area in middle to upper Signal Hill time was not unique and localized but part of a series of diastrophic deformations that developed in various sectors of eastern Avalon.

Following a suggestion by Rodgers (Lilly, 1966), deformations of late Proterozoic age observed locally in southeastern Newfoundland, and also elsewhere in the belt along the east side of the Appalachian orogenic system, have been interpreted as indicating an "Avalonian" orogeny (Poole, 1967; Rodgers, 1967, 1970). However, Hughes (1970) has defined the Avalonian orogeny in a different way. It would seem advisable, therefore, to exercise caution in the use of this term until it has been defined unequivocally.

ACKNOWLEDGMENTS

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