Silurian Roundstone Conglomerates of Coastal Maine
and Adjacent New Brunswick

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ABSTRACT

Six roundstone conglomerates of uncertain but probable middle to late Silurian age at Oak Bay, New Brunswick, and at Wesley, Addison, Douglas Islands, Turtle Island, and Flanders Bay, Maine, consist of rounded to subangular pebbles, cobbles, and boulders of unfoliated and little metamorphosed felsic and mafic volcanic rocks, collectively several varieties of granitoids, and a suite of generally arkosic volcanogenic sandstones and siltstones. Clasts from the generally foliated schists and metavolcanic rocks of the pre-Silurian Ellsworth, Columbia Falls, and Cookson Formations in the coastal volcanic belt of Maine are absent.

Except for that at Wesley, the conglomerates are unstratified and some are at least several hundred meters thick. At Oak Bay and Addison the matrix is clast-supporting; the others are generally clast-supported. These disorganized conglomerates were emplaced as debris flows, subaqueous except perhaps for the Douglas Islands. The conglomerates originated as stream gravels in a volcanic upland and eventually were deposited in thick alluvial fans or fan deltas along the fault-bounded border of the upland. An episode of faulting, perhaps associated with earthquakes, and further uplift destabilized the fans, initiating landslides which moved downslope towards and into the neighboring basin as debris flows.

Within the coastal belt of Maine and New Brunswick, two lithologic provinces qualify as possible provenances of the clasts. One is uplifted Silurian volcanic terrain, in which Silurian granites have recently been identified in addition to the much more widespread Devonian ones. The other possibility is the Precambrian-Cambrian rocks of the Avalonian terrane of the Long Reach-Saint John area, New Brunswick which have the requisite volcanic and granitic rocks, many of them unfoliated. A third alternative underlies the Gulf of Maine. Gravitational and aeromagnetic signatures and deep seismic profiling have identified Avalonian terrane flooring the gulf, a possible source for clasts in the Addison and Douglas Islands conglomerate near the coast.

The uplift and faulting to which the conglomerates testify may reflect block faulting in an extensional tectonic regime during Silurian volcanism. Alternatively, they may have resulted from crustal strains imposed during the final stages of emplacement of the suspect Avalonian terrane.

INTRODUCTION

Of the eight known Silurian conglomerates in the Silurian-Lower Devonian coastal volcanic belt of Maine and adjacent New Brunswick, six are composed of rounded pebbles, cobbles, and boulders of non-foliated sedimentary, volcanic, and granitic rocks. Clasts derived from nearby pre-Silurian, generally foliated formations such as the Cookson, Columbia Falls, and Ellsworth Formations, which unconformably underlie the Silurian-Lower Devonian volcanic pile in coastal Maine have not been identified in outcrop or in thin section. This paper describes the six conglomerates and discusses their origin and possible provenances.

The other two conglomerates, one near Castine on the Bagaduce River (Wingard, 1961; Stewart and Wones, 1974) and the other at Ames Knob on North Haven Island in Penobscot Bay...
Figure 1. Geologic map of the area from Penobscot Bay to Passamaquoddy Bay, Maine and New Brunswick (sources: Osberg et al., 1985; Potter et al., 1979).
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(Smith et al., 1907; Dow, 1965; Brookins et al., 1973), will not be discussed here. They were deposited on the angular unconformity between the overlying Silurian-Lower Devonian volcanic section and the underlying Cambrian? to Ordovician? Ellsworth schist and North Haven greenstone and contain clasts of the latter formations.

Because the ages of most of the conglomerates within the Silurian are poorly constrained stratigraphically, informal lower case terms early (lower), middle (middle), late (upper) are generally used to indicate uncertainty within the Silurian. All Rb-Sr dates use the $\lambda = 1.42 \times 10^{-11}$/year decay constant. Used in conjunction with the Decade of North American Geology 1983 Geological Time Scale (Palmer, 1983), it results in ages about 12 million years younger than those based on fossils, further compounding the age uncertainty.

Only the conglomerate of the Oak Bay Formation has a formal formation name. The other conglomerates are informally designated by geographic location for convenient reference.

This paper has three principal sections: (1) descriptions of the various conglomerates, (2) a proposed genetic model, and (3) discussion of provenance and regional tectonic significance.

DESCRIPTION

Oak Bay Formation

The Oak Bay Formation (Figs. 1, 2) is the best exposed of the conglomerates described in this paper. Exposure is continuous along the west shore of Cookson Island from the unconformably underlying Cookson Formation to the conformably overlying Silurian Waweig Formation. Originally described by Bailey and Matthews (1872), it has been most recently studied by Cumming (1967), Ruitenberg (1967), Stringer and Pajari (1982), and Stringer and Burke (1985). The conglomerate, its contiguous rocks, and the structure of the Oak Bay area deserve a much more detailed study than this paper attempts.

The conglomerate forms a broad lens which thins to the northeast and southwest from its greatest thickness on Cookson Island between the unconformably underlying Cookson Formation and the conformably overlying Waweig Formation. The Cookson Formation consists of tightly folded graphitic phyllite and thin quartzite beds which have an early foliation parallel or subparallel to bedding that is cut by several younger cleavages, the youngest being axial-planar to upright folds (Stringer and Burke, 1985). The bedding-parallel foliation is probably Taconian, and the upright folds and axial plane cleavage are the imprint of the Acadian orogeny (Stringer and Burke, 1985). The graptolite Clonograptus tenellus Linnarson indicates a Late Tremadocian age (Fyffle et al., 1983) for the Cookson Formation.

I collected hitherto unreported small linguloids, undiagnostic of age (Pickerill, pers. commun., 1987) together with Clonograptus within 30 cm of the base of the conglomerate of the Oak Bay Formation.

Figure 2. Geologic map of the Oak Bay area, New Brunswick (mapping by Gates supplemented by mapping by Ruitenberg, 1967; Stringer and Burke, 1985; Stringer, pers. commun., 1987).
Most of the Waweig Formation, which conformably overlies the Oak Bay Formation, is a feldspathic graywacke and slate (Ruitenberg, 1967, 1968). Pickerill (1976) noted dominant homogeneous and bioturbated bedding, locally having flutes, grooves, and cross-bedding. Ruitenberg (1967) suggested a thickness of 5 km, a very tentative figure due to lack of marker beds and uncertainty as to the amount of isoclinal folding. Pickerill (1976) concluded that its Salopina faunal community indicates a shallow water shelf environment of deposition. Its general lithologic uniformity and great thickness, if real, imply continuous subsidence during deposition over considerable geologic time.

Boucot et al., (1966) assigned an age somewhere in the Late Llandovery through Wenlock range to a poorly preserved unzonable brachiopod collection of the Waweig Formation from the east shore of Oak Bay primarily because the collection was stratigraphically below loose blocks having a Salopina fauna. Pickerill (1976) found a large well preserved Salopina fauna in place to which he assigned an uppermost Ludlow-Pridoli age. However, the stratigraphic position of the collection above the base of the Waweig Formation is not known.

The conformable contact of the Waweig Formation on the conglomerate of the Oak Bay Formation, the finding of an early Silurian pentameroid brachiopod in a limestone clast (Cumming, 1967), the apparent great thickness of the Waweig Formation, and the Pridoli age for at least part of it suggest a Ludlow to Pridoli age for the Oak Bay Formation.

The contact between the Oak Bay Formation and the Cookson Formation on Cookson Island is a complex fault zone associated with the Carboniferous Oak Bay fault (Fig. 2). A sedimentary contact is preserved only in two fault blocks on the west shore of the island. The conglomerate dips about 70 degrees to the south and has an east-striking cleavage that also dips steeply southward. Figure 3a illustrates the contact relations. The only clearly sedimentary contact is in block II of Figure 3a. Here the upward succession is foliated phyllite of the Cookson Formation, then a barely perceptible bedding plane beneath a mudstone that carries scattered rounded pebbles, then a 5 cm thick bed of laminated mudstone, and finally the massive conglomerate. In block I the contact between fossiliferous phyllite of the Cookson Formation and a mudstone with scattered pebbles is a plane which can be interpreted either as a bedding plane or a fault. The lowermost conglomerate clasts appear to have been deposited on and sunk into a thin layer of mud overlying the eroded phyllite. The thin bed of laminated undisturbed mudstone in block II within the base of the conglomerate suggests that the initial phase of emplacement of the conglomerate was not turbulent. Rotation of the conglomerate of the Oak Bay Formation of block I to horizontal as originally deposited (Fig. 3b) suggests that faults formed in the Cookson Formation prior to, or contemporaneous with, deposition of the Oak Bay Formation. Subsequent faulting involving both formations folded the older faults.

The conglomerate dips consistently south along the west shore of Cookson Island exposing an apparent thickness of about 300 m, but several faults of unknown displacement may repeat some of the section. Above the basal zone, the conglomerate is massive, without discernible bedding contacts, but there are subtle gradational changes in median clast size. The amount of matrix, from clast-supporting to clast-infilling, also varies. Deposition apparently was a continuing, uninterrupted, but slightly varying process.

Clasts are well-rounded to subrounded and range through the pebble-cobble-boulder scale (Fig. 4). Modal size from outcrop estimates is 4-8 cm with scattered boulders up to 30 cm, particularly in the lower one-third of the formation. The matrix is a poorly sorted mixture of small pebbles, grit, and sand of albite, quartz, volcanic rock fragments, and minor chlorite (Fig. 5). In most places it is clast-supporting.
Figure 4. Oak Bay conglomerate at the south end of Cookson Island. Note the good rounding and poor sorting. Here the matrix is not abundant enough to be fully clast-supporting. The largest clasts are about 6 cm long.

Figure 5. Thin section (uncrossed nicols) of the matrix of the Oak Bay conglomerate. Note the poor sorting, angularity, and generally immature aspect. Quartz grains are white; dusty albitized feldspar grains and fragments of once glassy porphyries are gray; and basalt fragments are black. Field of view is 7 x 5 mm.

Figure 6. Thin section (crossed nicols) of a granophyre clast in the Oak Bay conglomerate. Field of view is 10 x 7 mm.

Figure 7. Thin section (crossed nicols) of a devitrified porphyry clast in the Oak Bay conglomerate. Field of view is 7 x 5 mm.

Several clast counts on the outcrop and on polished slabs indicate that about 70 percent are volcanic, perhaps 1-2 percent granitic, and the rest sedimentary. Thin sections of 25 clasts chosen to be representative of the various clast lithologies showed only one granite type, a fine to medium grained granophyre (Fig. 6); a variety of dacite to rhyolite porphyries, (Fig. 7), some flow-banded; two varieties of basalt, one amygdaloidal, the other diabasic (Fig. 8) possibly from dikes; and several crystal lithic tuffs. The sedimentary clasts are of pebble conglomerates, and lithic arkosic grits, sandstones, and siltstones. No clasts of the Cookson Formation were found. Feldspars are dusty weathered albite; and ferromagnesian minerals are altered to chlorite and epidote. The entire suite indicates erosion of a bimodal volcanic terrane, weathered and hydrothermally altered, but not penetratively deformed or thermally recrystallized.

The contact with the overlying Waweig Formation is exposed in the small cove at the neck of the peninsula at the southwest corner of Cookson Island. A lens of unbedded arkosic sandstone in the conglomerate is succeeded by bedded arkosic sandstones, a coarse debris flow with mud chips, and then a section of well-bedded siltstone and argillite. A thicker, more complete section of argillite, siltstone, arkosic sandstone, graywacke, pebble conglomerate, debris flows, and slumped pebbly mudstones overlies conglomerate of the Oak Bay Formation along the west shore of Oak Bay, and was considered by
Ruitenberg (1967) to be the gradational contact zone from the Oak Bay into the Waweig Formation.

Ruitenberg (1967) concluded that the Oak Bay Formation is a reworked conglomerate. An unsorted mixture of clasts of various sizes, a muddy, silty, and sandy matrix, and an absence of internal stratification are characteristics used to classify conglomerates as disorganized (Walker, 1975; Pickering et al., 1986), or with genetic implications, as debris flows (Fisher, 1971; Hampton, 1972). The other massive conglomerates of this paper are also disorganized ones. A brief review of such conglomerates, debris flow mechanisms, and their application to the origin of the Oak Bay and the other conglomerates are postponed until all have been described.

**Conglomerate at Wesley**

This conglomerate (Westerman, 1978, 1981) crops out in the bed of Old Stream in the west-central part of the Wesley 15 minute quadrangle (Figs. 1, 9). It is probably in fault contact with the Cookson Formation to the north and underlies metasedimentary and metavolcanic rocks believed to be Waweig.
Formation to the south. The following description repeats with minor changes that of Westerman.

The conglomerate lies along the south side of a major northeast-trending fault that continues eastward across the quadrangle, apparently separating Cookson Formation to the north from chlorite grade probably Silurian-Lower Devonian volcanic rocks to the south. Although the nature of movement on this fault appears to have varied along strike and through time, the intense deformation and stretching of the conglomerates and associated metatuffs and metasedimentary rocks is presumed to reflect strain along the fault.

Bedding in the 2 km wide section of conglomerate and associated rocks consistently dips gently to the south, with rare graded beds and cross-beds indicating younging to the south. Outcrops in Old Stream suggest that the conglomerate grades upwards into and is interbedded with feldspatic metatuffs, metasiltstones, and metashales. Farther south the stream cuts through volcanic breccias that are part of an extensive terrane of bimodal volcanic rocks and minor associated redseds. The redseds have yielded an invertebrate fossil assemblage of favositid corals, comulitid tubes, pterineoid bivalves, and a few gastropods, possibly representing a very shallow, intertidal environment with low turbulence of probable Late Silurian age (Boucot, pers. commun., 1978).

Although the conglomerates and associated rocks at Wesley are more deformed and metamorphosed than those at Cookson Island, Westerman concluded that the succession of Cookson Formation, Oak Bay Formation, and Waweig Formation is duplicated at Wesley. The volcanic section of probable Late Silurian age overlying and perhaps interfingering with the presumed Waweig Formation at Wesley lends credence to Westerman’s stratigraphic interpretation. The Wesley conglomerate, thus, is of Ludlow to Pridoli age if the correlation with the Oak Bay Formation is valid.

Conglomerate beds make up approximately 30 percent of a .5 km wide zone in Old Stream. The coarsest, with clasts up to 25 cm, occur near the northern margin of the section close to the unexposed fault where they are the dominant lithology. Schists of the Cookson Formation crop out about 400 m upstream to the north. The grain size of the conglomerate beds decreases southward as the ratio of conglomerate to highly deformed metatuffs, metagraywackes, and metapelites decreases. These finer grained rocks crop out intermittently for an additional 1.5 km downstream from the southernmost exposure of conglomerate.

The conglomerate carries clasts of a wide variety of lithologies: quartzite, calcareous metasiltstone, siliceous metapelite, vein quartz, amygdaloidal basalt, massive basalt, various felsic lavas and tuffs, white medium-grained granite, and pink vitrophyre. Thin sections of 4 randomly selected clasts show granophyre, devitrified flow-banded dacite porphyry (Fig. 10), and an unfoliated quartz-feldspar-chlorite greywacke with fine-grained metamorphic biotite. Although the clasts locally have been tectonically elongated and thermally metamorphosed, they lack foliation resembling that of the adjacent metapelitic rocks of the Cookson Formation. Presumably their metamorphism is entirely post-depositional, in common with that of the overlying Waweig Formation.

The matrix is clast-supporting in most places, but may locally constitute less than 20 percent of the rock. It is schistose, fine-grained, and predominantly of quartz and chlorite.

**Conglomerate at Addison**

The conglomerate at Addison (Gilman, 1966) crops out in three widely separated areas (Fig. 1, 11): on a ridge west of Addison, in a quarry in a contact zone of a hornblende granophyre east of Pleasant River, and on two knobs north and south of Route 1 east of Addison. Because of the scarcity of outcrops in the general region, its stratigraphic setting and age are poorly constrained.

The stratigraphic base of the conglomerate is not exposed. An outcrop of mylonite between Addison and Marshville close to the lowermost outcrop of conglomerate on the ridge, a strong fracture cleavage in the conglomerate parallel to the presumed fault indicated by the mylonite, and the absence of clasts from the adjacent Columbia Falls schist (Gilman, 1961) of probable Cambro-Ordovician age suggest that the base of the conglomerate is in fault contact with the schist rather than unconformably overlying it as proposed by Gilman (1966).

Evidence bearing on the stratigraphic position of the conglomerate is meager. On the ridge west of Addison the conglomerate is overlain by bedded siltstone which dips to the southeast and is metamorphosed by the adjacent granite. Thinly bedded siltstone and quartzite beds on the east shore of Pleasant Bay dip and young to the northeast. Alignment of conglomerate outcrops north and south of Route 1 and of basalts further east.
suggests northerly strikes. A small outcrop of volcanic rocks between Addison and Columbia Falls has a fracture cleavage parallel to the inferred fault, but no measurable attitude. Fossilsiferous Silurian rocks along the east shore of Chandler Bay dip east. Black shales beneath east-dipping tuff-brecchas north of Centerville and north of the inferred fault carry Wenlock gaptolites. The Addison conglomerates thus probably are within an east-dipping section of siltstones and volcanic rocks of middle Silurian age. Tilting of the section and subsequent intrusion of Acadian granites indicate an age older than the Acadian orogeny. Gilman (1966) noted that the conglomerate north and south of Route 1 has better rounded clasts and different proportions of clast lithologies than that on the ridge west of Addison, and thus it probably represents a separate episode of emplacement rather than repetition by folding or faulting.

The most instructive exposures are on the ridge west of Addison where numerous, but discontinuous, outcrops indicate a thickness of about 900 m assuming no repetition by undiscovered faulting or folding. Individual outcrops appear massive without visible bedding, but in some outcrops the median grain is noticeably less than in others, suggesting that the conglomerate is not homogeneous. Sorting of clasts is poor, ranging from pebble size to 25 cm for the largest clasts. Most clasts are in the 3-10 cm range. Based on a study of slabs, Gilman (1966) showed that clasts are rounded to subrounded, but that matrix fragments are subangular to angular. The matrix consists primarily of silt together with fragments and grains of rocks like those that make up the clasts and is clast supporting except where pebbles are numerous (Gilman, 1966). Thermal metamorphism, probably from the adjacent granite, has recrystallized the matrix to the epidote-amphibolite facies.

Gilman's (1966) analysis (Fig. 12) illustrates the mixture of volcanic, sedimentary, and granitic clasts, notably devoid of foliated rocks. Quartzite and siltstone together make up about one half the clasts examined on slabs or in thin sections, and granite and granophyre about 20 percent. Thin section examination of a random sampling of clasts much less thorough than Gilman's identified granophyre, quartz diorite, poorly sorted quartzite (Fig. 13), devitrified, flow-banded, quartz-feldspar porphyries, and basalt.

East of Pleasant River in the quarry within the contact zone of a hornblende granophyre, Gilman (1966) described rounded cobbles and boulders up to 60 cm in diameter of granophyre and an equigranular plagioclase-hornblende rock in a matrix of quartz, dark gray aphanitic fragments, and metamorphic hornblende and minor pyroxene. At the present quarry levels, deepened since Gilman examined it, numerous granophyre dikes together with brecciation, flowage, local melting, and thermal
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Figure 12. Histograms of pebble distributions in the Addison conglomerate (reproduced from Gilman, 1966, Fig. 3). (a) Determined from thin section analysis. A - equigranular plagioclase and hornblende; B - diabase; C - equigranular quartz and feldspar; D - felsite showing volcanic texture; E - quartzite; F - granite; G - granophyre; H - diorite; I - silt. (b) Determined from analysis of cut slabs. 1 - aphanitic, black; 2 - diabase; 3 - felsite, general; 4 - felsite, volcanic texture; 5 - quartzite; 6 - granite; 7 - granophyre; 8 - diorite; 9 - silt.

Figure 13. Thin section (crossed nicols) of a poorly sorted immature quartzite clast from the Addison conglomerate. Field of view is 10 x 7 mm.

metamorphism associated with intrusion of the adjacent granophyre and possibly the large gabbro to the south have severely disrupted and obscured the original rocks.

The conglomerate south of Route 1 is massive, but has more rounded clasts and relatively fewer granite and granophyre clasts than the conglomerate on the ridge west of Addison (Gilman, 1966).

Gilman (1966) concluded that the Addison conglomerate was deposited as subaqueous debris flows of unconsolidated gravels, sand, silt, and mud which moved down the marginal slope of a sedimentary basin floored by silt and mud. He cited the absence of bedding, poor sorting, and the clast-supporting matrix that includes silt and mud incorporated during emplacement. The finely laminated siltstone and mudstone represent muds that floored the basin. He attributed the different clasts to different sources; volcanic to the Silurian section, quartzite to pre-Silurian (Cookson?) rocks inland, and granitic to unknown sources.
**Conglomerate at the Douglas Islands**

The three Douglas Islands at the mouth of Narraguagus Bay (Figs. 1, 14) provide excellent exposures of a coarse, massive polymict roundstone conglomerate (Gates, 1984). The conglomerate overlies volcanic rocks on Pond Island and is intruded by granite on Bois Bubert Island.

Pond Island consists of rhyolite, commonly porphyritic and locally flow-banded, which is intruded by gabbro at the south end and by granite at the north. Along the west shore the rhyolite is overlain along an unexposed contact by a section of bedded siltstones, arkosic sandstones, and pebble conglomerates displaying cross-bedding, cut-and-fill structures, grading, and lensing of beds. The section dips and youngs to the west. Pebbles are angular and of pink granite and red and black rhyolite. The matrix sand grains are primarily of feldspar and quartz.

The contact between this bedded section and the Douglas Islands conglomerate lies in the gap between Pond Island and Turkey Island. The conglomerate on Turkey Island contains rhyolite and pink granite clasts like the pebbles on Pond Island and has an arkosic matrix suggesting that the conglomerate is a continuation of the underlying bedded sequence.

Assignment of an age to the conglomerate depends on the assumption that the rhyolite on Pond Island belongs to the same volcanic section as the rhyolite on Flint Island about 3 km to the northeast. There, two collections of unzonable brachiopods from shale and siltstone beneath the rhyolite give an age somewhere in the range from Late Llandovery to Ludlow (Boucot, pers. commun., 1983). Metzger et al. (1982) reported a Rb-Sr whole rock age of 396±17 Ma for the rhyolite on Flint Island, middle Early Devonian according to the DNAG Geologic Time Scale (Palmer, 1983).

Assuming an average dip of 45°, the thickness of conglomerate from Turkey Island to Bois Bubert Island is an astonishing 1.5 km. Lack of marker beds precludes determination of possible faults or folds that might repeat the section. A strong fracture cleavage that trends N10-20°E and dips 60-70° east has flattened small clasts and pebbles in the matrix and produced anastomosing zones of shear that envelop the large clasts. It may be an axial plane cleavage due to folding of the conglomerate, indicate a nearby major shear zone, or have been imposed by intrusive forces of the neighboring granitic plutons.

The conglomerate is unstratified, but has vaguely defined areas several square meters in size in which clasts in the 2-8 cm range predominate and others in which clasts of 10-15 cm are common. In addition, irregular tabular lenses up to 5 m long and a meter or so wide of cross-bedded sandstone and pebble conglomerate have gradational to sharp, ragged contacts with the enclosing conglomerate (Fig. 15). These are interpreted to be disrupted, originally continuous bedded sequences. The Douglas Island conglomerate is less homogeneous than the Oak Bay and Addison conglomerates.

Clasts range from well rounded to subangular (Fig. 16). As a whole, rounding is poorer than in the Oak Bay and Addison conglomerates. Sorting is poor, ranging from pebble sizes to boulders as large as 35 cm in diameter. Most clasts are in the 5-15 cm range, reflecting proportionately more large clasts than in the Oak Bay and Addison conglomerates.

The conglomerate is clast-supported. The interstitial matrix consists of an unsorted mixture of sand, grit, and pebble sizes...
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Figure 15. Irregular tabular block of sandstone, probably a remnant of a disrupted sandstone layer, in the Douglas Islands conglomerate. Hammer is 15 cm long.

Figure 16. Conglomerate at the Douglas Islands. Note mixture of rounded and subangular clasts, poor sorting, and pebbly matrix. Hammer is 15 cm long.

largely of quartz, albite plagioclase, vein quartz, and lithic fragments of rocks like those of the enclosing clasts.

Counts on the outcrop using hand lens identification give average clast compositions of 50% felsic volcanic rocks, 10% mafic volcanic rocks, 20% granitic rocks of several varieties, and 20% quartzite, arkosic sandstones, siltstones, vein quartz, and unidentified. Study of 20 thin sections chosen to be representative of the clasts and matrix identified the following rocks:

quartz-albite-hornblende granophyre (Fig. 17); medium grained allotriomorphic granite; several varieties of devitrified volcanic prophyries, some flow-banded, with phenocrysts of quartz and/or feldspar; amygdaloidal basalt; basalt with a diabasic texture of plagioclase laths, possibly dike rock; poorly sorted recrystallized quartzite with sutured grain contacts; vein quartz mosaics; and sheared shale and siltstone. Many of the clasts, including granitic ones, are cataclastically deformed and recrystallized, suggesting derivation from a major shear zone. The feldspars are largely dusty albite plagioclase; once glassy volcanic rocks are devitrified, and original ferromagnesian minerals are now chlorite and epidote. Some late epidote and recrystallization of quartz may reflect thermal metamorphism from the neighboring granitic plutons.

The general mixture of clast lithologies is like that of the Oak Bay conglomerate, but with more varieties of granitic rocks and fewer arkosic clasts. The Addison conglomerate also has a variety of granitic clasts. The Addison and Douglas Island conglomerates are separated by only about 15 km of granitic and gabbroic plutons and might well be parts of the same conglomerate body.

Conglomerate at Turtle Island

The conglomerate on Turtle, Flat, and Heron Islands west of Schoodic (Figs. 1, 18) rests unconformably on a basalt of uncertain age and is overlain conformably by thick arkosic sandstones interpreted to be the lower part of the Bar Harbor Formation (Metzger, 1979).

The age of the Turtle Island conglomerate is uncertain. The stratigraphic position of the underlying amygdaloidal basalt is unknown. Similar basalts do not occur in the Lower Devonian (Brookins et al., 1973) Cranberry Island volcanic section 15 km
to the southwest. Very similar basalts crop out along the shore south of Steuben 15 km to the northeast, but are isolated in granite. The greenstone of Flanders Bay (Gilman and Lash, 1988) may be correlative. Basalts within the Cambrian? to Ordovician? Ellsworth Formation to the north are completely recrystallized to well foliated amphibolites.

The overlying Bar Harbor Formation has yielded no fossils. Metzger and Bickford (1972) correlated it on lithologic resemblances to the fossiliferous mudstones and siltstones on Flint Island and concluded it was of middle Silurian age. Metzger et al. (1982) reported a Rb-Sr whole rock age of 408±27 Ma for a felsite in the Bar Harbor Formation at Ireson Hill on Mount Desert Island, an age about on the Silurian-Devonian boundary according to the DNAG Time Scale (Palmer, 1983). However, Lux (pers. commun., 1988) reported a 418-420 Ma argon release age (Ludlovian according the DNAG 1983 Geologic Time Scale) for the Somesville and Cadillac granites on Mt. Desert Island. The Cadillac intrudes the Bar Harbor Formation which, thus, should be no younger than Ludlow.

The basal unconformity of the conglomerate is well exposed on the southwest corner of Spectacle Island. The underlying basalt has numerous amygdules of quartz and epidote, replacement clots of epidote, and numerous veins of quartz and epidote. Thin section study shows that the basalt consists of an unfoliated mass of finely granular epidote and felty intergrowths of actinolite. The absence of evidence of original textures suggests that the basalt originally was largely glassy. In several places on Spectacle Island, very amygdaloidal flow tops define open, upright folds with axial planes parallel to a northeast-striking vertical fracture cleavage which is marked also by flattening of the amygdules locally.

The very irregular erosion surface on the basalt has a relief of up to one meter (Fig. 19). The conglomerate immediately above the unconformity has angular blocks of the basalt up to a meter long in a very unsorted matrix of smaller angular blocks, subangular pebbles and cobbles of epidote clots and vein quartz from the basalt, plus a few well-rounded felsic pebbles like those in the bedded conglomerate on Flat Island.

The bulk of the conglomerate crops out along the shores of Flat, Heron, and Turtle Islands and has two markedly different facies. On Heron and Turtle Islands the conglomerate is coarse and unstratified. On Flat Island a well bedded sandstone, grit, and pebble conglomerate facies underlies the massive facies.

The bedded facies on Flat Island displays lensing beds, some cross-bedded, of sandstone, grits, and pebble conglomerate. In general, the larger the grain size the thicker the lens. Sandstone and grit beds are under 20 cm thick, whereas pebble conglomerate beds with clasts up to 6 cm range to a thickness of 40 cm. Sorting within pebble beds is good, sizes generally remaining within two or three magnitudes. The pebbles and small cobbles are very well rounded and some of the latter are discoid and have a consistent imbrication. The pebbles and small cobbles are closely packed, the sandy matrix filling the interstices.
making up only about 10 percent of the total volume. I interpret this well bedded facies to be a gravel beach deposit.

This lower section grades over a distance of a meter or so by decreasing stratification and increasing clast size into a massive boulder conglomerate that also has well rounded clasts tightly packed with minimal sandy to gritty matrix. However, sorting is poor, a mix of pebbles, cobbles, and boulders up to 40 cm in diameter.

The well-bedded conglomerate and the overlying massive conglomerate on Flat Island share the same clast lithologies. Hand lens and thin section study indicate that about half the clasts are felsic quartz and/or feldspar devitrified porphyries, while the remainder is a mixture of fine-grained mafic dike rocks, vein quartz, granular vein epidote, and small-pebble conglomerate. The absence of clasts derived from basalt like that on Spectacle Island indicates that the latter had not yet been uncovered, although perhaps some of the quartz and epidote veins had penetrated the overlying felsic volcanic rocks and were eroded with them.

The massive conglomerate on Heron Island is an upward continuation of that on Flat Island. The two massive conglomerates together are about 30 m thick. The Heron Island conglomerate is unstratified, except for a few thin and discontinuous lenses of pebble conglomerate. Clasts are well rounded to subangular, range from pebble size to boulders 60 cm in diameter, and form a tightly fitting clast-supported framework. The matrix is composed of grains of quartz and feldspar together with lithic fragments reflecting the lithologies of the clasts. Unlike the massive conglomerate on Flat Island, the clasts on Heron Island are largely of amygdaloidal basalt and epidote clots derived from basalt like that on Spectacle Island, mixed with clast lithologies like those on Flat Island. Apparently the basalt was suddenly uncovered and exposed to rapid erosion.

The conglomerate (Fig. 20) on Turtle Island is mapped as a continuation of that on Heron Island offset by a fault (Fig. 18). It has the same overall lithology except that boulders of basalt reach a maximum size of 95 cm. Exposed stratigraphic thickness along the shore is about 10 m.

The overlying arkosic beds of the Bar Harbor Formation drape over boulders protruding from the top of the conglomerate. Emplacement of the latter ceased abruptly. On Turtle Island the massive and generally homogeneous beds of arkosic sandstone are up to 4 meters thick and are delineated by intervening 10-50 cm thick composite beds of laminated siliceous siltstone and bedded sandstone. Some of the thick beds contain scattered rounded pebbles of vein quartz, felsic volcanic rocks, and fine-grained pink granite as well as scattered discontinuous lenses of slump-deformed pebbly mudstone, sandstone, and pebble conglomerate. Similar, but less thickly bedded sedimentary rocks overlie the conglomerate on Heron Island. These massive arkose units have some of the properties of grain flows (Stauffer, 1967).

Study of thin sections shows that the coarse sandstones are poorly sorted mixtures of angular quartz, albitized plagioclase, and much altered perthite (?) grains plus granules of granophyre, vein quartz, and an enigmatic granular quartz-epidote-hornblende rock that may be a contact metamorphosed carbonate.

The conglomerate has an inherited hydrothermal alteration in the felsic volcanic clasts and a thermal metamorphism in the basaltic clasts like that of the underlying basalt. A post-depositional thermal metamorphism has produced fine grained biotite, epidote, and blue-green hornblende in some clasts and in the matrix. This later metamorphism also has produced epidote and hornblende in the arkosic sedimentary rocks. It is probably related to intrusion of the Schoodic granite exposed on Grindstone Neck.
Conglomerate at Flanders Bay

Gilman and Lash (1988) describe a Silurian roundstone conglomerate at Flanders Bay. A brief summary of their paper is included here for the sake of completeness.

The conglomerate and associated pebbly siltstones unconformably overlie a greenstone composed largely of actinolite and epidote having numerous epidote veins and a faint foliation. It is considered to be Silurian, but has not as yet been identified elsewhere in coastal Maine. Siltstones of the Bar Harbor Formation stratigraphically above the conglomerate crop out along the shore within 100 meters and have a dip and strike parallel to that of the unconformity.

The conglomerate, a few meters thick and apparently discontinuous along the contact with the greenstone, has well-rounded clasts mostly smaller than 6 cm in diameter along with a few as large as 30 cm in a clast-supporting matrix of mudstone and siltstone. It is unstratified. Clasts of the underlying greenstone are absent.

Gilman and Lash (1988) concluded that the clasts originated from erosion of a volcanic upland and were transported by stream systems to the margin of a down-faulted basin in which the turbidite sediments of the Bar Harbor Formation subsequently were deposited. Debris flows carried the well-rounded clasts down across the marginal fault scarp and out onto the greenstone floor of the basin.

They note that the conglomerate at Flanders Bay occupies the same stratigraphic position at the base of the Bar Harbor Formation as the Turtle Island conglomerate. There is some basis for speculation that the correlation is even more direct. The faintly foliated greenstone at Flanders Bay has a mineralogy like, and a foliation parallel to, that of the basalt at Spectacle Island. The Flanders Bay conglomerate may be the distal part of the Turtle Island conglomerate, particularly the lower bedded pebble conglomerates on Flat Island which have largely felsic clasts. If so, the basin in which the Bar Harbor Formation accumulated has a common mafic greenstone-basalt floor at least 15 km across that matches no known section of mafic pre-Silurian, Silurian, or Lower Devonian rocks in coastal Maine.

ORIGIN OF THE CONGLOMERATES

Properties common to the roundstone conglomerates imply that they share some common genetic history. The variety of clast lithologies indicates erosion of a volcanic province sufficiently large to encompass a variety of volcanic rocks, subjacent granites, and volcaniclastic feldspathic sedimentary rocks. These many kinds of clasts must have been brought together and mixed. These processes require a fluvial drainage network. The generally large size of the clasts necessitates mass-wasting such as talus accumulation and creep to deliver large blocks to the drainage system, suggesting steep valley slopes. Transportation of cobbles and boulders require fast moving streams on steep gradients; and the excellent rounding implies residence in a high energy environment such as mountain streams. The pebbles, cobbles, and boulders of the roundstone conglomerates must have begun life as fluvial gravels in a highland terrain where streams cut steep-sided valleys into a volcanic landscape.

Most of the conglomerates also share some lithologic characteristics that suggest some common elements in the mode of emplacement. Except for the basaltic clasts in the Turtle Islands conglomerate and perhaps some rhyolite pebbles in the Douglas Islands conglomerate attributable to the Pond Island rhyolite, the clasts represent detritus imported from elsewhere, not locally manufactured from the rocks on which the conglomerates rest. All carry a poorly sorted mixture of generally well rounded clasts in a thick unstratified depositional unit without sedimentary structures except for vaguely defined areas of slightly different grain size or disrupted bedded sandstones. There are some differences in matrix materials and amount. The Oak Bay conglomerate has a feldspathic sandy to gritty matrix which, in most places, is clast-supporting; the Addison conglomerate has a clast-supporting matrix richer in silt than the Oak Bay conglomerate; and the Douglas Islands conglomerate has a relatively sparse, coarsely clastic infilling rather than a clast-supporting matrix. These disorganized-bed conglomerates (Walker, 1975) or disorganized gravels (Pickering et al., 1986) are generally attributed to transportation and deposition as gravity-powered mass movement debris flows (Larsen and Steel, 1978; Gloppin and Steel, 1981; Wescott and Ethridge, 1980, 1983; Pickering et al., 1986). The general mechanism of debris flowage applies to mass movement of a variety of materials including muds, sands, and pebbly muds as well as disorganized gravels.

In debris flows, clast dispersion by collision, pore fluid pressures, and matrix mud, silt, and sand provide support and lubrication during movement; flowage on the scale of the whole moving mass has been termed viscous, plastic, or laminar; and deposition occurs by frictional freezing when the shear strength of the moving mass exceeds the gravitational shear stress because of decrease of slope, expulsion of pore fluids, or increase of pressure due to an increase in thickness (Dott, 1963; Fisher, 1971; Hampton, 1972; Lowe, 1982; Pickering et al., 1986). Among reworked conglomerates, disorganized ones are a minority, and many have some stratification such as normal grading or inverse-to-normal grading as well as alignment or imbrication of clasts (Walker, 1975).

Environments of deposition for disorganized and other reworked conglomerates include alluvial fans and fan-deltas (Hooke, 1967; Gloppin and Steel, 1981; Wescott and Ethridge, 1980, 1983; Flint et al., 1986), delta marine slopes (Wescott and Ethridge, 1980, 1983; Carter and Norris, 1977), and submarine deep water fans and braided channels at the base of continental or regional slopes fed by turbidity currents (Walker, 1975; Hein and Walker, 1982). The coarsest, least organized conglomerates occupy proximal positions at the apex of the various types of fans. The reworked conglomerates are only one facies in the package of bedded pebble conglomerates, sandstones, siltstones, and mudstones that constitute any particular fan.
Alluvial fans and fan-deltas associated with disorganized conglomerates send a tectonic signal because they form along normal faults or strike-slip faults dividing a source highland from the adjacent basin (Nemec et al., 1980; Gloppin and Steel, 1981; Wescott and Ethridge, 1980, 1983; Pickering, 1984). Alluvial fans may also border highlands riding on thrust faults (Decelles et al., 1987).

The three thick massive conglomerates, the Oak Bay, Addison, and Douglas Islands, have the characteristics of debris flows, but differ from those described in the literature in several ways. They are much thicker single depositional units than commonly present in the various fan types which are generally within the 1-10 m range and rarely as much as 50 m. They also are not interlayered with an associated package of finer-grained, well-bedded clastic sediments. Furthermore, emplacement apparently began abruptly, was continuous, and ended abruptly. Deposition of the Oak Bay conglomerate began on a thin skim of mud over bedrock without precursor sedimentation. The undisturbed basal pebbly mudstone and thin mudstone lens at its base suggests that the clasts at the base of the debris flow were fully suspended in and dropped out of the matrix when motion had stopped or almost stopped. The base of the Douglas Islands conglomerate is a narrow transition zone from well-bedded arkosic sandstones and pebble conglomerates to the overlying coarse massive conglomerate. Bedded arkosic sandstones cap the conglomerate of the Oak Bay Formation, and thinly bedded siltstones overlie the Addison conglomerate. Although the intervening rocks are not exposed, the bedded pebble conglomerate and mudstone on Bois Bubert Island overlying the Douglas Islands conglomerate may also indicate a relatively abrupt end to conglomerate emplacement.

Figure 21 illustrates the proposed model for the origin of the three thick unstratified conglomerates. Accumulation of thick alluvial fans or fan deltas along fault scarps and fed by streams eroding a volcanic highland was followed by an episode of renewed faulting, possibly with associated earthquakes, and uplift that destabilized the fans. They slid towards and into the adjacent basins as debris flows, mixing the various facies of the parent fans and absorbing water as lubricants when they became subaqueous. The conglomerates thus began as landslides or a series of landslides of unconsolidated coarse fan detritus.

The Addison debris flow went furthest into the muddy floor of a marine basin, stirring in muds and silts to build up its predominantly silty clast-supporting matrix. After emplacement, the deposition of muds and silts continued. The benthonic, relatively shallow water brachiopod fauna of the Waveig Formation suggests that the underlying Oak Bay debris flow moved down a proximal marine shelf or slope coming to rest on a submarine exposure of phyllite of the Cookson Formation that perhaps prior to the faulting was eroded and swept clean by wave action above wave base. The largely sandy to gritty matrix of the conglomerate of the Oak Bay Formation is a mixture of fan components and shallow water sand sediments. The Douglas Islands conglomerate moved the least, perhaps only enough to override the outer slope of the parent fan preserved as the underlying coarse bedded clastics on Pond Island. Mixing of fan facies and incorporation of fine grained clastic sediments to build up a matrix was less than in the Addison and Oak Bay debris flows.

Reduction of the parent fans to stable dimensions by the landsliding and the return of relative tectonic quiescence presumably brought the debris flow activity to an abrupt halt. The three thick conglomerates represent continuing, relatively brief, and localized episodes of landsliding. Figure 21 illustrates the proposed geologic processes and events responsible for the thick conglomerates, but is not meant to imply that they all were once part of a single system in space or time.

A somewhat different model (Fig. 22) applies to the Turtle Island conglomerate, although like the conglomerates of the previous model, deposition occurred in a single continuing episode initiated by faulting. An initial pebbly beach, perhaps along the margin of a fan delta fed by streams eroding a felsic volcanic area, was abruptly down-dropped along a fault that exposed the basaltic bedrock originally beneath the beach in a fault-scarp cliff on the upthrown block. Initially, felsic cobbles and boulders of the beach or fan, if present, were swept seaward over the now submerged pebble beach by increased stream velocities and perhaps wave erosion and transport. Soon, however, waves began eroding the basaltic cliff and the resulting coarse basaltic debris spread as subaqueous talus and scree over

Figure 21. Sketch illustrating the proposed origin of the Douglas Islands, Oak Bay, and Addison conglomerates. In (a) a thick alluvial fan or fan delta accumulates along a fault scarp bordering a highland. In (b) an episode of renewed faulting destabilizes the fan, initiating landslides that become debris flows. It is very unlikely that the three conglomerates were emplaced at the same time as parts of the same down-slope transportation system. No scale.

Figure 22. Diagram illustrating the various factors contributing to the emplacement of the three thick unstratified conglomerates. 1-10
the original beach deposits. Submergence of the cliff abruptly halted deposition of the coarse basaltic material.

The poorly exposed Wesley conglomerate appears to be part of a package of bedded pebble conglomerates, volcanically derived sandstones and tuffaceous sediments, and siltstones that grades upward into the overlying chlorite schists of the Waweig Formation. It may be a relatively intact part of a fan delta complex.

**TECTONIC IMPLICATIONS**

The provenance of the roundstone conglomerates was a bimodal volcanic highland with subjacent granitic rocks which had not been recrystallized and penetratively deformed regionally, was close enough to supply large boulders, and was older than middle to upper Silurian.

Two presently exposed lithologic provinces in coastal Maine and southwestern New Brunswick meet these specifications. The roundstone conglomerates may testify to erosion of lower to middle Silurian volcanic and associated sedimentary rocks of the coastal volcanic belt. Although most dated granite plutons of the coastal belt are Early to Middle Devonian (Acadian) in age, recent dating has confirmed Silurian granites. The argon release ages of 418–420 Ma (Ludlow) for the Somesville and Cadillac granites (L. Pers. commun., 1988) on Mt. Desert Island suggest that dating of more granites may identify others of Silurian age that might have contributed granitic clasts.

An alternative provenance is the Avalonian terrane of the Long Reach–Saint John area of southwestern New Brunswick (Nance, 1986; McCutcheon and Ruitenberg, 1987; Currie, 1988). Late Precambrian to Cambrian rocks include a variety of felsic, basaltic, and generally feldspathic volcaniclastic sandstones together with Precambrian granitic plutons and granophyric dikes, many of which are of low metamorphic grade and not penetratively deformed. Clasts in both Cambrian and lower Silurian conglomerates include felsic and basaltic volcanic rocks and sparse granophyres, a mix much like that of the conglomerate of the Oak Bay Formation. These rocks of southwestern New Brunswick would provide a nearby source for clasts in the Oak Bay Formation and the conglomerate at Wesley.

The Avalonian rocks of the Boston Basin also have a variety of late Precambrian and Cambrian felsic and mafic volcanic rocks, sedimentary rocks, and granitic rocks that have low metamorphic grade and little deformation (Billings, 1976; Kaye, 1980, 1984; Hepburn et al., 1987; Socci and Smith, 1987). Gravity and aeromagnetic signatures and deep seismic profiling indicate that the Avalonian rocks of the Boston Basin trend northeastward beneath the Gulf of Maine, linking up across a zone of multiple faults with the Avalonian rocks of southwestern New Brunswick (Hutchinson et al., 1988). This offshore belt of Avalonian rocks conceivably might be the provenance of the Addison and Douglas Islands conglomerates.

The conglomerates testify to uplift and faulting in or adjacent to the coastal volcanic belt in the Silurian, but more definitive conclusions about the tectonic regime await additional field research into the provenance of the conglomerates. Until then, two alternative tectonic implications are viable. The conglomerates may point to block faulting in an extensional tectonic setting during Silurian volcanism, confirming the conclusions of Gates and Moench (1981). On the other hand, the conglomerates may be clues to major regional faulting within or marginal to the suspect Avalonian terrane during its final emplacement.

**ACKNOWLEDGMENTS**

The Maine Geological Survey funded the field work. I am very much indebted to Peter Stringer for his counsel in the field on Cookson Island and the detailed unpublished information he gave me. I have profited also from discussions on Cookson Island with L. R. Fyffe and David B. Stewart. I am greatly indebted to David B. Stewart who lent me some thin sections of the Wesley and Addison conglomerates and carefully reviewed an early draft, and to Richard A. Gilman and Arthur M. Hussey II who did so for successive versions.

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Silurian roundstone conglomerates


