An Ensismatic Island Arc and Ocean Closure in the Grenville Province of Southeastern Ontario, Canada

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Summary
Within the Grenville Province of Southeastern Ontario geological data may be interpreted in the light of plate tectonic theory. An early cycle involving subduction of oceanic lithosphere, generation of an island arc complex together with partial melting of the downgoing slab to produce calc-alkaline volcanism and granodioritic intrusions, was followed by a second cycle during which the island arc was uplifted, eroded and covered by miogeocline sediments. Subsequently the miogeocline was deformed presumably during continental collision. The evolution from early island arc phase to ocean closure and consolidation took approximately 250 m.y.

Introduction
A generally acceptable tectonic model for the evolution of the Grenville structural Province has yet to be proposed; the diversity of opinion has been recently outlined in this journal by Baer et al. (1974).

Much of the province is pparently underlain by reactivated older sialic basement (Wynne-Edwards, 1972), and lack of evidence of belts of ensismatic rock has favoured interpretations which would place a suture southeast of the exposed Grenville terrain (Wynne-Edwards, 1972; Dewey and Burke, 1973). On the other hand paleomagnetic results suggest a possible suture lying well within the exposed part of the Grenville Province (e.g., Irving et al., 1974; Ueno et al., 1975).

It is the purpose of this communication to call attention to published information and new data which in our opinion point to the former existence of ocean floor and island arc volcanism in part of the Grenville Province in southeastern Ontario (Fig. 1), and to present a tectonic model compatible with these results.

The model rests on four main points of evidence: a) relict oceanic lithosphere is preserved in the terrain northeast of Madoc, Ontario (Fig. 1, 2); b) granitic to dioritic batholiths were intruded into the oceanic crustal material; c) platformal sediments were deposited unconformably over intruded oceanic crust; d) the basement and cover then became involved in intense regional deformation and metamorphism.

a) Evidence of Relict Oceanic Lithosphere.
The petrology of the metavolcanic rocks has been described by Sethuraman and Moore (1973), and their geochemistry has recently been considered by Condie (1975). An apparent thickness of 7 km is exposed in the vicinity of Bishop Corners (Fig. 2) and top determinations from pillow lavas indicate an essentially unmetamorphosed, easterly facing stratigraphic sequence. The lower part of the succession (A - B, Fig. 2) comprises mainly pillowed and massive tholeiite flows; the eastern upper part (C - D) includes the top of the batholiths and ranges upwards from andesite flows and pyroclastic rocks to ryholite pyroclastics with intercalated carbonates at the top. All the basalts contain less than 0.6 percent K₂O; half contain 0.1 percent or less. Sethuraman and Moore (1973) pointed out that the low potassium content of the basalts implies that they were extruded on oceanic crust, and that the succeeding calc-alkaline activity is consistent with development of the entire assemblage at a consuming plate margin. Figure 3 summarizes some of the chemical data of the volcanic rocks (see also Sethuraman and Moore, 1973).

New evidence for the existence of ocean floor material has recently been found by one of us (J.F.C.). Near Flinton, the lower lavas are in contact with mafic and untramanic meta plutonic rocks, which are also enclosed as fragments in the basalt flows (locality 1, Fig. 2). In addition, pods of ultramafic material up to 1 m in diameter are incorporated in metagabbro (locality 2, Fig. 2). Several lenses of ultramafic rock have been tectonically emplaced in the volcanics, granitic rocks and overlying metasediments, but the evidence indicates that at least some of the ultramafics are the oldest rocks in the area, and are followed closely by mafic plutonic rocks which predate the early basalts.

Lead isotope ages of 1310 ± 15 m.y. have been reported by Silver and Lumbers (1966) for zircons from metaharlyte which is probably correlative with the upper part of the volcanic succession in the region.

b) Origin of Granodiorite Batholiths.
The intrusive nature of granitic rocks in the region was first pointed out by Miller and Knight in 1914. Although in much of the region contact relationships between sialic rocks and pillow lavas have been obscured by later deformation, several excellent exposures have been located which unequivocally demonstrate that the granodioritic and gneissic rocks of the Elzevir and Westemkoon batholiths respectively are intrusive into the metavolcanic rocks (localities 3, 4, 5, Fig. 2). Xenoliths of mafic metavolcanics are common within the granodiorite, dykes similar in composition to the Elzevir batholith cut the mafic volcanics and associated mafic intrusive rocks.

Zircons from granodioritic intrusions in the area yield lead isotope ages of 1250 ± 25 m.y. (Silver and Lumbers, 1965). The tholeiitic volcanic rocks and associated mafic/ultramafic rocks thus comprise the oldest known rocks in the region.

c) Deposition of Platformal Sediments.
Evidence for the deposition of clastic and carbonate sediments (Flinton Group) unconformably over the intruded volcanic sequence has previously been documented (Sethuraman and Moore, 1973; Moore and Thompson, 1972; Thompson, 1972). Stratigraphic
boundaries in the volcanic-marble succession are truncated by the base of
the Flinton Group (locality 6, Fig. 2); contacts between volcanic and plutonic
rocks are also transected.
Conglomerates of the Flinton Group
consist mainly of quartzite clasts, but
locally contain clasts of the underlying salic plutonic rocks. There is no
evidence of large mafic or granitic
intrusions postdating the Flinton Group
in the area.

d) Deformation
With the exception of a weak fabric seen
in the volcanic rocks at several localities
(Thompson, 1972), folds and penetrative
fabrics recognized in the intruded
oceanic crustal material and
unconformably overlying platformal
sediments were formed after deep burial
of the platformal rocks. Large scale
isoclinal folds developed at this time in
an intermediate-pressure regional
metamorphic environment (Moore and
Thompson, 1972). The isoclines now
exhibit steeply dipping axial surfaces
and non-cylindrical hinge lines. In detail,
the geometry is complex due to the
rotation of planar and linear elements
during progressive deformation, and
superposition of two phases of refolding
(Thompson, 1972).

Although a low-angle discordance at
the base of the Flinton Group is regional
in extent, high-angle unconformity is
present only around Bishop Corners and
Flinton (Fig. 2). Lack of evidence of
important penetrative deformation
predating deposition of Flinton Group
rocks, and the spatial association of the
high-angle unconformity with the Elzevir
suggest to us that pre-Flinton
deforation was probably restricted to
local arching and perhaps faulting
related to diapiric emplacement of the
salic plutonic rocks.
Discussion

The similar ages of the oceanic volcanic rocks and intruded mafic plutons together with the marked transition from tholeiitic to calc-alkaline volcanism suggest a related cause. The chemistry of the volcanic rocks and the observation that they are underlain by mafic and ultramafic rocks, and pass upwards into pyroclastics and carbonate sediments, lead us to propose an ensimatic island arc environment. If subduction of oceanic lithosphere is accepted as the cause of oceanic island arcs it is most likely that the associated granodioritic intrusives were generated at depth by partial melting of the subducted slab.

The earliest evidence of sediments possibly derived from a continent appears in the Bishop Corners Formation, at the base of the

unconformably overlying metasedimentary rocks of the Flinton Group (Moore and Thompson, 1972). Some of the clastic material is clearly of local derivation, but a large proportion of the Formation consists of hemitic quartzites and quartzite pebble metaconglomerates. As there is however no other evidence of an adjacent pre-volcanic volcanic terrain, these clastics may imply local uplift and erosion of sedimentary rocks derived from the unroofed plutons in the area. The paucity of local pre-Flinton rocks in the conglomerates, and the oxidized character of the base of the Flinton Group, suggest deep weathering and intermontane deposition.

Locally derived clasts of underlying plutonic material are extremely coarse in places, and are indicative of a rejuvenated terrain induced perhaps by block faulting. This was followed by subsidence and the accumulation of a thick miogeoclinal clastic-carbonate shallow marine sequence.

We appear to be dealing with a two-phase orogenic cycle. The regional strain and metamorphism occurred late in the tectonic history of the region and cannot have resulted from early subduction of oceanic lithosphere, but rather must be related to the final closing of the ocean. This closure was followed by consolidation and uplift (about 1050 m.y. Silver and Lumber, 1966; Krogh and Hurley, 1968).

The region of Figure 1 is interpreted to be underlain by a collision zone. The continental margins to the relict “Grenville ocean” are likely to be northeast-trending lines lying just northwest of Bancroft and somewhere southeast of Westport respectively (Fig. 1).

Summary of Conclusions.

A model of tectonic evolution for part of the Grenville Province in Eastern Ontario comprises: 1) Generation of pillow lavas in an island arc environment involving subduction at converging oceanic lithosphere plate margins (about 1300 m.y.). 2) Calc-alkaline volcanism coincident with the generation of granodioritic magma derived at depth by partial melting of the subducted slab of oceanic lithosphere. 3) Diapiric intrusion of the granodioritic plutons, locally deforming the overlying oceanic crust and arc (about 1250 m.y.).
Erosion of uplifted basement terrain together with influx of externally derived mature clastics to provide material for the unconfomable deposition of a clastic-carbonate succession (Flinton Group). 5) Continental collision to produce isoclinal folding and refolding, together with regional metamorphism of the basement and cover yielding the present complex (about 1050 m.y.).

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References

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