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TIMING OF OPHIOLITE EMPLACEMENT ONTO THE GANDER ZONE: EVIDENCE FROM PROVENANCE STUDIES IN THE MOUNT CORMACK SUBZONE

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ABSTRACT

Two small exposures of late Llanvirn to early Llandeilo limestone conglomerate occur within the outcrop of quartzitic sandstones of the Spruce Brook Formation, which has recently been interpreted as a tectonic window of the Gander Zone (Mount Cormack Subzone). The conglomerate was formed by resedimentation of shallow-marine, semilithified limestones and calcarenites that were themselves supplied from three main extrabasinal sediment sources. Fragments of quartzite and finer grained, siliciclastic rocks, including recycled monocrystalline grains, are likely to have been derived from the surrounding Spruce Brook Formation. Ubiquitous, little abraded, accessory chromite, rare fragments of serpentinized peridotite and possible trace volcanogenic detritus reflect erosion of nearby ultramafic and associated volcanic rocks of the Dunnage Zone (Coy Pond and Great Bend complexes), that were emplaced onto the metasedimentary rocks of the Spruce Brook Formation. The provenance evidence and stratigraphic considerations suggest that the craton-derived, quartz-rich sediments of the Spruce Brook Formation are of Arenig or older age, and that the limestone conglomerate was unconformably deposited upon them, following the ophiolite emplacement in the Llanvirn.

INTRODUCTION

The island of Newfoundland was divided into the Humber, Dunnage, Gander and Avalon tectonostratigraphic zones by Williams (1978). Of the three resulting zone boundaries, the Dunnage–Gander boundary has been the most contentious, with disagreement on its location, nature and age. This paper addresses the problem of age and applies techniques of sedimentary provenance to its resolution. The zonal distribution of Williams *et al.* (1988; Figure 1) is followed here. Much of the boundary is tectonic, and most clearly so, where it is marked by ophiolites (Blackwood, 1982; Colman-Sadd and Swinden, 1984; Colman-Sadd, 1985, 1987; Piasecki, 1988), but suggestions that parts of it are either unconformable (Kennedy and McGonigal, 1972) or conformable (Jenness, 1963; Currie *et al.*, 1979; Blackwood, 1982) have not been conclusively disproven.

Any Dunnage–Gander boundaries that are stratigraphic are likely to be Middle Ordovician or earlier, since Dunnage Zone rocks close to the zone boundary contain early and middle Ordovician fossils (Stouge, 1980; Boyce, 1987) and fossils associated with the supposed Dunnage outlier in the Gander Zone at Indian Bay Big Pond, are probably late Arenig (Wonderley and Neuman, 1984). The possible age of tectonic contacts, however, has a much greater range, from Middle Ordovician (Currie *et al.*, 1979) to Middle Silurian or later (Colman-Sadd, 1980; Colman-Sadd and Swinden, 1984). Since most of the Dunnage–Gander boundary is tectonic, and it has been proposed that the Dunnage Zone forms an allochthonous sheet on the Gander Zone (Colman-Sadd and Swinden, 1984), the age of these contacts is of paramount importance. Of particular interest is the age of emplacement of ophiolitic rocks onto the Gander Zone, because the ophiolites form the basal units of the proposed allochthon and it is their contacts with the Gander Zone that are most likely to be the earliest.

The sedimentary provenance studies reported in this paper tightly constrain the timing of ophiolite emplacement. In so doing, they provide the earliest known link across a Dunnage–Gander tectonic boundary.

SAMPLE LOCALITIES

Two suites of samples have been collected from the Mount Cormack Subzone, and their locations are shown in Figure 2. The first suite consists of samples of fossiliferous limestone conglomerate, taken from two localities near the confluence of the Northwest Gander and Little Gull rivers. The second suite, made up of thirteen samples of quartzitic sandstone, was collected from interbedded sandstone and pelite of the Spruce Brook Formation in the general area around the limestone localities. Colman-Sadd and Swinden (1984) included the limestone conglomerate in the Spruce Brook Formation; for reasons that will become apparent, it is here excluded from the formation. The sampled area is bordered to the southeast by a continuous belt of ophiolitic rock, constituting the Coy Pond and Great Bend complexes (Colman-Sadd, 1985; Zwicker and Strong, 1986; Geological Survey of Canada, 1968a,b). The Spruce Brook Formation is considered to be a characteristic lithofacies of the Gander Zone and the ophiolites are typical components of the

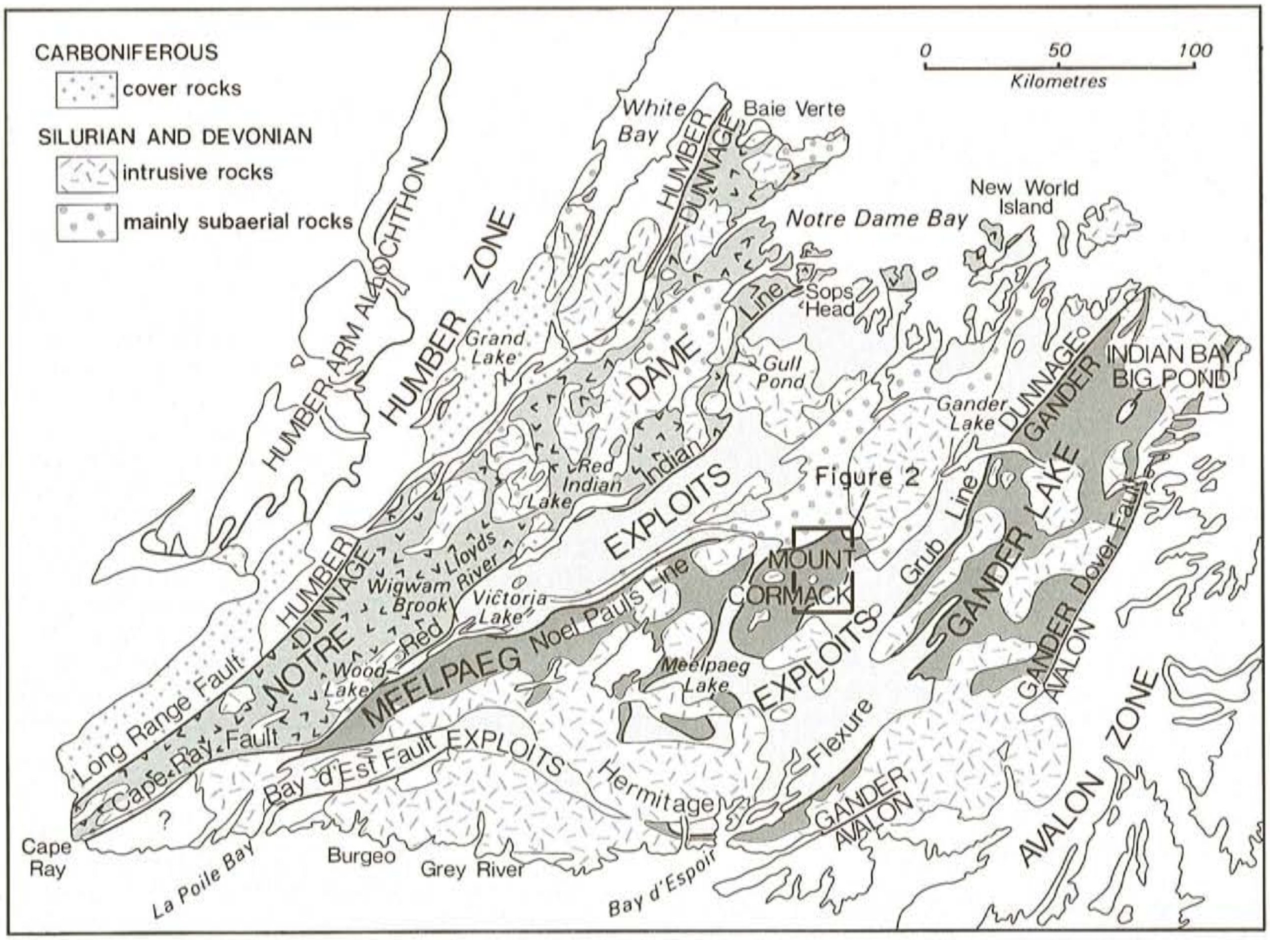


Figure 1. *Geological zones and subzones of central Newfoundland (from Williams* et al., *1988), showing the location of Figure 2.*

Dunnage Zone (Williams *et al.*, 1988); the contact between the two is the zone boundary and is clearly tectonic.

Quartzitic Sandstones of the Spruce Brook Formation

All samples of quartzitic sandstone were taken from exposures of typical Spruce Brook Formation with a maximum metamorphic grade in the biotite zone. The sandstone beds are mostly about 30-cm thick, but vary between 10 cm and 2 m (Plate 1). The sandstone is well sorted with a grain size that is generally less than 2 mm. The lower parts of many beds show grading above a sharp and commonly loaded base. The upper parts have parallel- and cross-lamination defined by a slight increase in phyllosilicate content. The sandstone beds are interbedded with dominantly dark-grey, parallel-laminated pelite divisions varying from a few centimetres to several metres in thickness. The pelite contains numerous thin beds and laminae of sandstone and siltstone, which are mostly crosslaminated and in some cases show lenticular lamination. It has a penetrative cleavage, which is generally but not exclusively, parallel to bedding, and this is locally intersected by a second, spaced cleavage.

The sandstone is composed mainly of angular to subangular, mono- and poly-crystalline quartz and accessory plagioclase, microcline, muscovite, chlorite (after biotite?), zircon, tourmaline and opaque grains. Rock fragments are present in minor amounts and are represented by shale and phyllite (possible rip-up intraclasts), showing a post-incorporation, sericite foliation. There are also ubiquitous aggregates of quartz ± muscovite ± chlorite (after biotite?) ± albite, which probably represent fragments of two-mica schist. They appear discordant with the sericite–muscovite foliation. Although contacts between the detrital grains are welded, quartz overgrowths are commonly preserved. Secondary sericite, muscovite and locally biotite are widespread, usually defining a foliation. Epidote, granular sphene, apatite, calcite, chlorite, magnetite and pyrite are other low-grade, metamorphic phases. There are also common veins of quartz ± calcite ± iron-oxide and quartz ± vermicular chlorite ± K-feldspar.

Sedimentary structures suggest that the sandstone and shale were deposited from turbidity currents (Colman-Sadd and Swinden, 1984).

Limestone Conglomerate

The two limestone localities were described by Colman-Sadd and Swinden (1984) as being interbedded with the siliciclastic rocks of the Spruce Brook Formation. The interpretation was based on bedding attitudes in the limestone conglomerate being similar to those in the siliciclastic rocks, exposed within 500 m in both directions across strike. However, the contacts of the limestone with the siliciclastic rocks are not actually exposed, so their true nature remains uncertain.

The conglomerate consists of about 60 percent clasts, generally surrounded by a calcarenite matrix (Plate 2). Calcarenite also forms beds in locality L2 (Figure 2) that are up to 60-cm thick and interbedded with the conglomerate. The clasts, formed principally of sparry limestone, are subangular to subrounded, up to 15-cm across and very poorly sorted.

Brachiopods collected from locality L1 (Figure 2) have been identified by R. Neuman of the U.S. Geological Survey and were reported by Colman-Sadd and Swinden (1984). They indicate an age between the late Arenig and early Caradoc, but are most likely in the Llanvirn. A collection from locality L2, has yielded a rich trilobite fauna of late Llanvirn to early Llandeilo age (Boyce, 1987) and brachiopods, which are consistent with this determination (R. Neuman, personal communication, 1987).

Petrography of the Limestone Conglomerate. Three main components of the limestone conglomerates have been identified, and these in turn contain smaller detrital phases.

1) *Limestone and calcarenite* fragments are composed of mainly drusy, sparry calcite and dolomite containing abundant chalcedony–calcite–dolomite–pyrite nodules that vary between 0.25 and 2.00 mm in size. Euhedral to subrounded grains of chromite and angular to rounded quartz represent accessory extraclasts.
2) *Siliciclastic calcarenite* fragments (Plate 3) are characterized by poor internal sorting of angular sand grains, cemented by sparry carbonate. Monocrystalline quartz showing straight to undulose extinction is the dominant detrital component. Many of the round, slightly embayed quartz grains appear to be of volcanic provenance. Rare, polycrystalline quartz grains are either massive and polygonal or foliated and sutured. The calcarenite clasts also contain fragments of intermediate-mafic volcanic rocks, extramicrite, phyllite and quartzite (Plate 4a); the latter containing accessory detrital plagioclase, muscovite, zircon and sphene. Conspicuous accessory chromite is also present.
3) *Bioclastic calcarenite* fragments (Plate 5) contain abundant carbonate grains of organic and non-organic origin. Internal sorting varies from very good to poor and the constituent grains are predominantly very well rounded, reaching up to small-pebble size. Monocrystalline quartz showing straight to undulose extinction and carbonate clasts form over 90 percent of the detrital phase. Some of the round monocrystalline grains display deep corrosion embayments, indicative of a volcanic origin (Plate 5). Polycrystalline quartz is subordinate and occurs as foliated and unfoliated aggregates, locally in association with muscovite. Abraded overgrowths have been found on some of the monocrystalline quartz grains (Plate 6).

The fragments of bioclastic calcarenite contain clasts of felsic–mafic volcanic rocks, quartz arenite, quartzite (Plate 4a) and quartz–muscovite schist (Plate 7) as well as accessory grains of chromite, zircon, tourmaline, epidote, feldspar (albite), muscovite, biotite and chlorite. Zircon and tourmaline are also locally found in the quartz and quartzite clasts (Plate 4).

The bioclasts are represented by calcareous, blue-green algae *Girvanella* and *Nuia*; Plate 8) and red algae (probably *Solenopora*). Other fossil detritus includes brachiopods, trilobites, pelmatozoan plates, gastropods, ostracods and bryozoa (for detailed lists of the remaining fossils see Colman-Sadd and Swinden, 1984, and Boyce, 1987). Grains of extramicrite and peloids are also present. All carbonate grains normally display irregular micritic encrustations and envelopes (Plate 5), locally accompanied by micritised micro-burrows. These features are characteristic of the degrading action of micro-organisms. The faunal assemblage is indicative of a shallow-marine (less than 50 m), warm-water, agitated environment (Wray, 1977).

Boundaries of the limestone and calcarenite fragments are normally poorly defined as a result of carbonate recrystallisation, and presumably also because of mutual remoulding of semilithified particles during resedimentation. The remoulding has also produced a texturally heterogeneous, coarse grained, calcarenite matrix, reflecting the mixed sedimentary rock types making up the conglomerate.

The conglomerate contains subordinate, very well-defined, angular pebbles of dark organic matter, and/or iron-oxide-stained micritic limestone containing brachiopods, gastropods and abundant quartz extraclasts.

Apart from secondary calcite and dolomite, which are most abundant, authigenic quartz, albite, pyrite, galena, sericite and muscovite are widespread in the conglomerate. Pyrite commonly outlines the rounded carbonate grains and locally forms cement in quartz arenite grains. The conglomerate is essentially undeformed. Microstylolites and dissolution seams are developed in a few places.

Chromite and Ophiolitic Detritus

Chromian spinel is the most conspicuous accessory component of the limestone conglomerate, being present both in the majority of the clasts as well as in the matrix. Its frequency (determined by point counting of 400 detrital sand and larger grains) in the bioclastic calcarenite fragments and in the matrix, is 2.1 and 1.5 percent respectively. The chromite grains are predominantly translucent, cherry-red to brown with a few opaque areas. Some entirely opaque chromites have also been found.

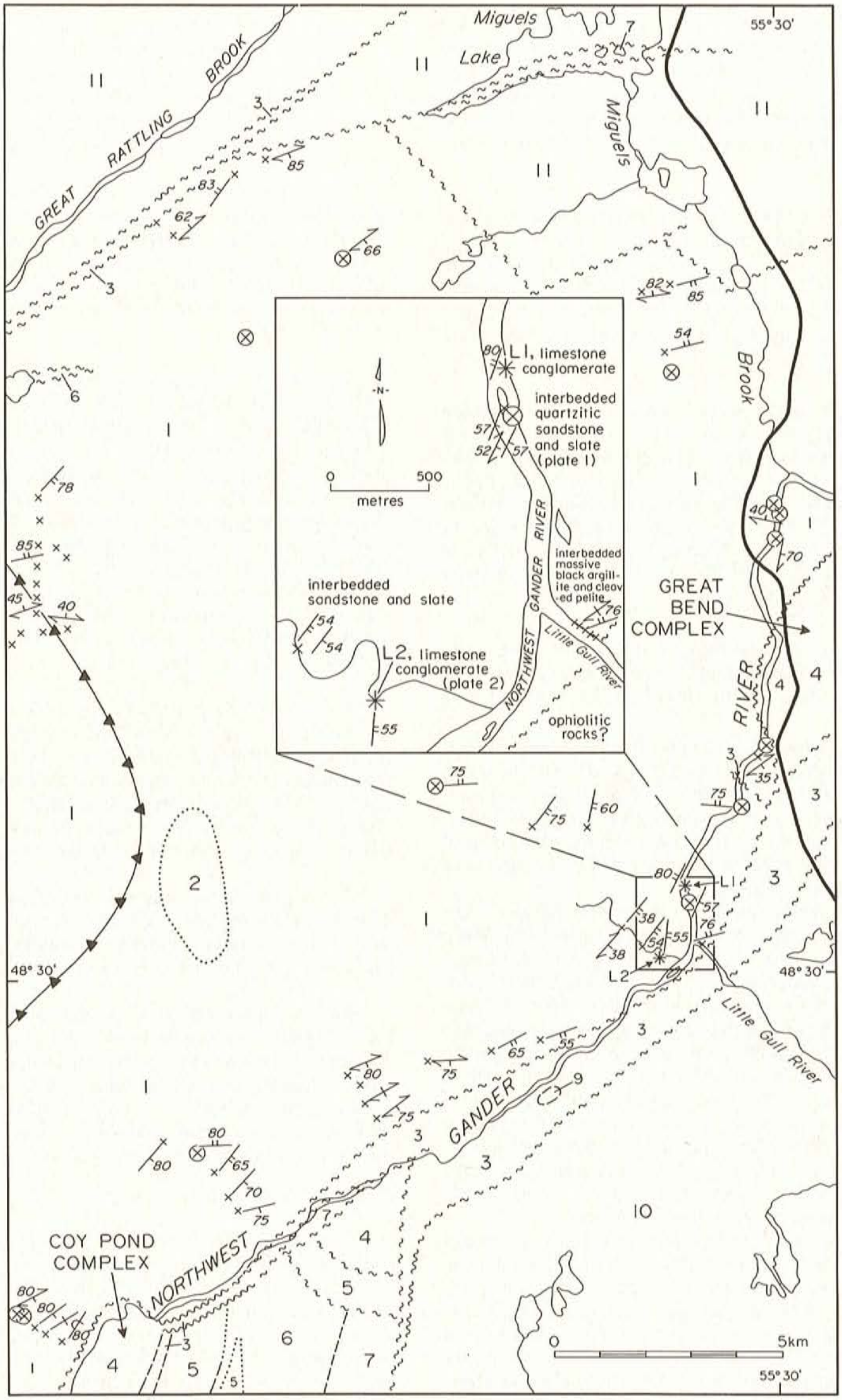


Figure 2. *Geological map of the northwestern part of the Mount Cormack Subzone showing sample localities (after Colman-Sadd, 1985; Colman-Sadd and Russell, 1988; Zwicker and Strong, 1986).*

Legend

SILURIAN

OVERLAP SEQUENCES

11 Botwood Group: *green-grey and maroon interbedded sandstone, siltstone and shale containing ripple marks and mud cracks*

MIDDLE (AND LATE?) ORDOVICIAN

DUNNAGE ZONE

10 North Steady Pond Formation, Baie d'Espoir Group: *felsic crystal and lapilli tuff, conglomerate, and green-grey, graded arkosic sandstone interbedded with siltstone and shale*

MIDDLE ORDOVICIAN OR YOUNGER

9 *Conglomerate composed mainly of ultramafic clasts*

MIDDLE ORDOVICIAN (LATE LLANVIRN–EARLY LLANDEILO)

✳ (8) *Fossiliferous limestone conglomerate, containing detrital chromite*

EARLY ORDOVICIAN

Ophiolitic Rocks–Coy Pond and Great Bend complexes

7 *Pillow lava and conformably overlying conglomerate, sandstone and shale*

6 *Diabase, gabbro, trondhjemite and keratophyre*

5 *Pyroxenite*

4 *Peridotite*

3 *Altered and sheared ultramafic rocks, and shale-matrix ophiolitic mélange*

EARLY ORDOVICIAN OR YOUNGER

GANDER ZONE

2 *Pegmatitic, garnetiferous muscovite granite*

EARLY ORDOVICIAN OR OLDER

1 Spruce Brook Formation: *interbedded grey quartzitic sandstone and grey to black shale; metamorphic derivatives*

SYMBOLS

Limestone conglomerate exposure

Exposure of Spruce Brook Formation examined for provenance

Other exposures of Spruce Brook Formation

Bedding, tops known (inclined, overturned)

Bedding, tops unknown (inclined, vertical)

Cleavage (inclined, vertical)

Geological contact (approximate, assumed)

Fault (defined, approximate, assumed)

Sillimanite isograd

Unit 8

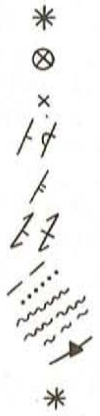


Plate 1. *Bedded quartzitic sandstone of the Spruce Brook Formation, showing grading, lamination and loading. Exposure is located 300 m south of limestone locality L1 on the Northwest Gander River (see Figure 2 inset).*

Plate 2. *Limestone conglomerate at locality L2, on east flowing tributary of the Northwest Gander River (see Figure 2, inset).*

The chromite grains are mostly euhedral or slightly rounded; well-rounded grains being least common (Plate 9). In the clasts of bioclastic calcarenite, the chromite grains range in size between 0.03 and 0.85 mm, averaging 0.13 mm. In the matrix they are as large as 1.2 mm, averaging 0.28 mm.

Scanning electron microscope examinations of the chromite grains have revealed common dissolution features, often associated with microfractures (Plate 9). Some of the dissolution must have taken place prior to the abrasion, since many rounded surfaces are smoother than the alteration-pitted crystalline faces (Plate 9c). Many grains have intact, unaltered surfaces, regardless of their degree of roundness. The cracked chromite grains have a distinctive 'jigsaw-puzzle' pattern, with calcite, dolomite, mica, pyrite and galena sealing the fractures.

Well-preserved, euhedral chromite is also present in a pebble within the conglomerate. The pebble appears to be

Plate 3. *Photomicrograph from a fragment of siliciclastic, poorly sorted calcarenite: 1–clast of intermediate–mafic volcanic rock, composed of plagioclase laths; 2–clast of quartzite containing sphene and zircon (arrowed; see also close up in Plate 5a); 3–chromite grain; plane-polarized light; scale bar = 0.05 mm.*

a strongly altered fragment of serpentinised ultramafic rock (Plate 10). A 'ghost' mesh texture of serpentinized rock is preserved in secondary silica, calcite and dolomite. The dominant secondary quartz is mostly polycrystalline, showing complex, often sutured intercrystalline boundaries. Crypto- and mono-crystalline silica is also locally present. The secondary quartz usually has a dusty appearance, but the actual identity of the tiny, dark specks causing it, except for minor magnetite (?), has not been determined. The dusty silica commonly encloses minute (up to 0.05 mm) variolitic and bow-tie aggregates of colourless to greenish mica. The dustiness, together with the post-silica carbonate, and locally with pyrite, highlights the primary mesh texture, with the dustiest silica replacing early fracture-filling serpentine. The 'ghost' olivine or pyroxene are commonly outlined by thin, dusty rims, and are represented either by clear crypto- to polycrystalline quartz or by carbonate.

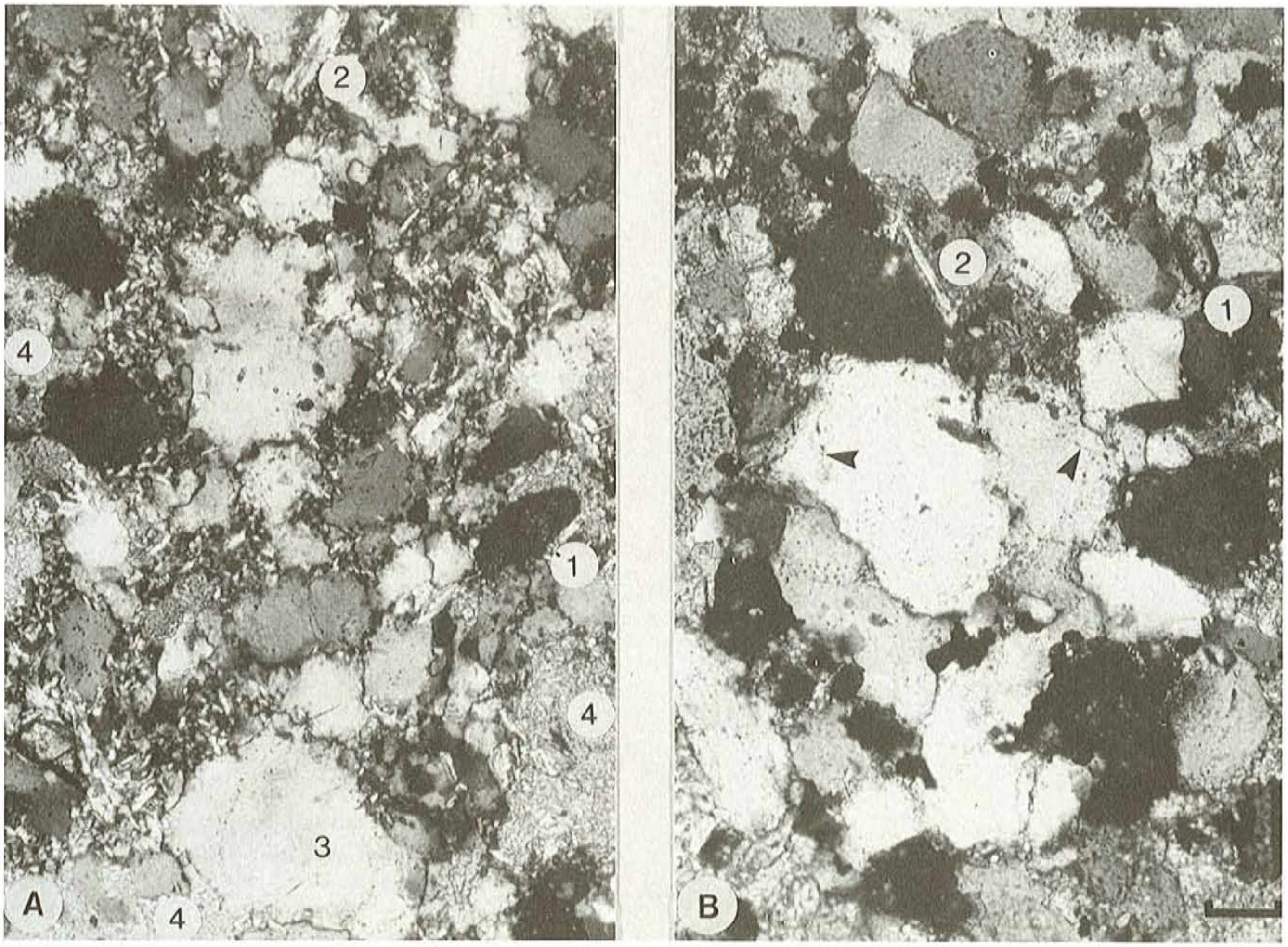


Plate 4. *A: Close up photomicrograph of a quartzite fragment from Plate 3: welded contact between the quartz grains and authigenic mica are widespread; 1—sub-euhedral sphene grain; 2—possible detrital muscovite; 3—rounded quartz grain with an overgrowth; 4—carbonate replacement. B: Photomicrograph of another fragment of quartzite: welded contacts; quartz overgrowths (arrowed); 1—zircon grain; 2—detrital muscovite; cross-polarized light; scale bar = 0.05 mm.*

Provenance of the Limestone Conglomerate

The limestone conglomerate is interpreted to have formed through downslope resedimentation of partially lithified limestones and calcarenites, which had been deposited in a shallow-marine environment. This depositional setting of the source sediments is indicated by the faunal assemblage (Wray, 1977) and supported by the textural features in the calcarenite fragments, such as very good internal sorting and generally good grain roundness. The petrographic investigations suggest that the original limestone and calcarenite deposits had been supplied in various proportions by four main sediment sources, and these are represented by the following detrital components:

a) chromite detritus, derived from ultramafic rocks, exposed in the vicinity and/or within the marine basin;
b) fragments of quartz arenite, quartzite, phyllite and schist, representing siliciclastic formations of possible cratonic derivation (Graham *et al.*, 1975);
c) felsic to mafic volcanogenic detritus; and
d) intrabasinal fossil debris and non-organic carbonate grains.

The source rocks exposed during deposition of the primary carbonate sediments (and presumably also during their remobilization and resedimentation as a limestone conglomerate) are represented by the extrabasinal chromite, sedimentary, metasedimentary and volcanogenic detritus.

The overall abundance and generally limited roundness of the euhedral chromite grains suggest that deposition of the primary limestones and calcarenites occured close to exposed ultramafic rocks. The ophiolitic complexes of Great Bend and Coy Pond, outcropping in the vicinity of the two conglomerate outcrops, are the candidates for the source of the detrital chromite. The colour range and grain-size distribution of the detrital chromite are compatible with *in situ* chromite in serpentinized peridotite of the Great Bend Complex (Figure 2). The 120 chromite crystals measured in two thin sections from the complex range between 0.07 and 1.5 mm, averaging 0.32 mm.

Except for one chromite-bearing, silicified pebble (Plate 10), no other ultramafic detritus has been identified in thin sections. It is likely, however, that some of the polycrystalline quartz grains may actually represent small, silicified ultramafic fragments, which are impossible to distinguish from polycrystalline aggregates derived, e.g., from siliceous schists.

The conspicuous presence of quartz arenite and quartzite fragments (containing quartz overgrowths, sphene, detrital zircon, tourmaline, muscovite and plagioclase) as well as the recycled mono- and poly-crystalline quartz grains suggest that a significant proportion of the siliciclastic detritus came from erosion of quartzose sedimentary and metasedimentary rocks. The petrographically very similar Spruce Brook Formation, which probably forms a basement to the limestone conglomerate (see below), is a likely source of the siliciclastic component. A fraction of the polycrystalline quartz, as well as the fragments of phyllite and quartz–muscovite schist, together with epidote and biotite, may represent the pelitic and metamorphosed portions of the Spruce Brook Formation. A relative scarcity of the metasedimentary detritus in the limestone conglomerate, in spite of proximity of the proposed source, can be explained in terms of carbonate-dominated sedimentation of the primary limestones and calcarenites.

The derivation, of at least a proportion, of the siliciclastic detritus from the Spruce Brook Formation is mainly inferred from the presence of quartz arenite and quartzite fragments. No such unambiguous quartzite clasts nor recycled quartz have been found in the sandstones of the Spruce Brook Formation, and, therefore, there is no compelling evidence to suggest that the siliciclastic component of the limestone conglomerate might have been entirely derived from the same cratonic source as the Spruce Brook Formation. The metamorphic clasts, however, might have either come from erosion of the Spruce Brook Formation and/or some other metamorphic source.

The perfectly rounded, embayed, monocrystalline quartz grains, some of the plagioclase and epidote, as well as felsic to mafic volcanic fragments, must have been derived by erosion of volcanic rocks, possibly similar to those associated with the Coy Pond Complex (Colman-Sadd, 1985).

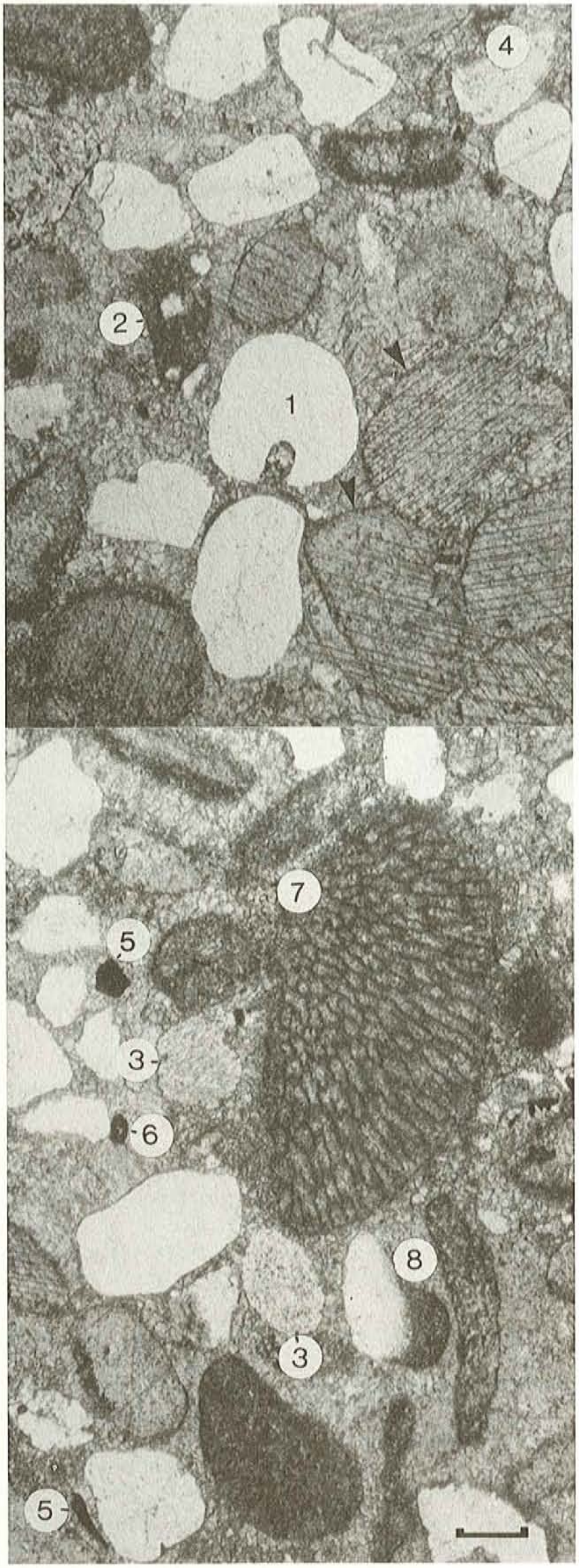


Plate 5. *Photomicrograph from a fragment of bioclastic calcarenite showing very good sorting and roundness of the grains. 1–embayed, volcanogenic quartz; 2–clast of extramicrite; 3–feldspar (albite); 4–polycrystalline quartz; 5–chromite grains; 6–ilmenite (?); 7–fragment of bryozoa; 8–quartz grain with* Girvanella *encrustation; other unidentified carbonate fragments are represented by sparr and micrite; micritic rims developed on the clastic grains as a result of bacterial degradation are marked with arrows; cement in the rock is represented by calcite and dolomite spar and micro-spar; plane-polarized light; scale bar = 0.25 mm.*

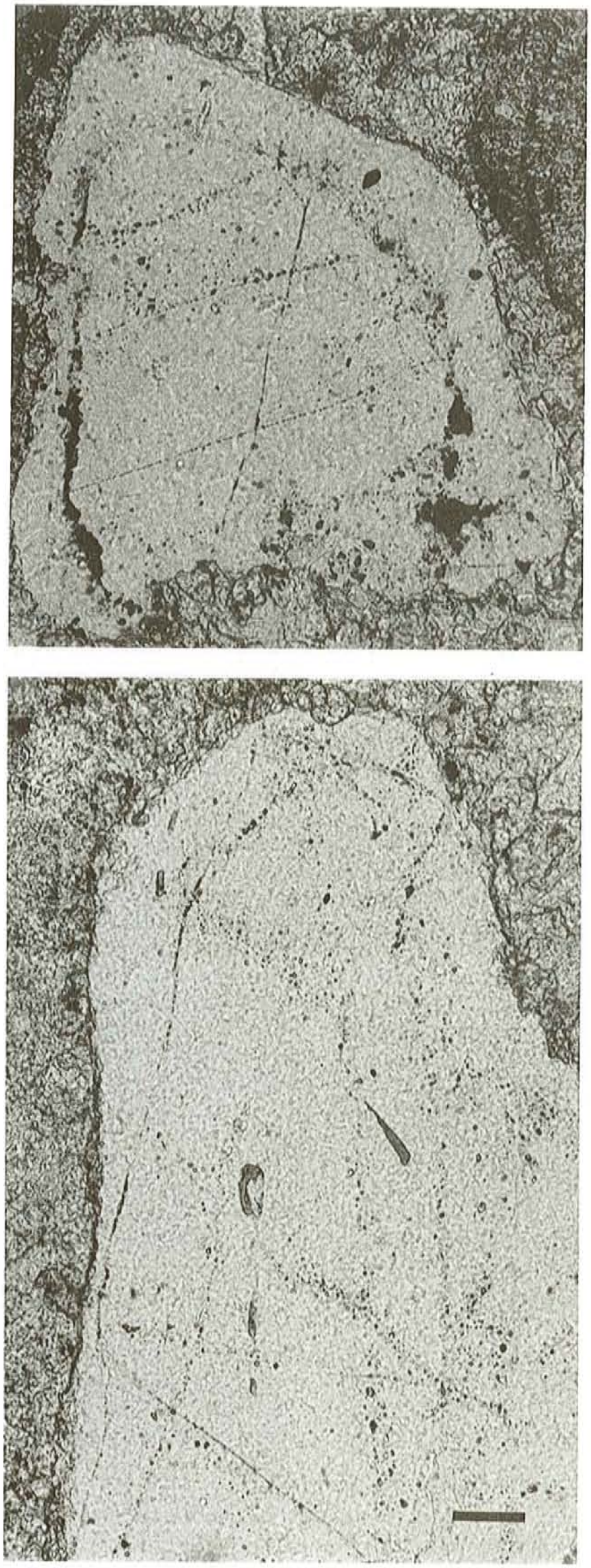


Plate 6. *Photomicrographs of recycled quartz grains, showing abraded overgrowths; plane-polarized light; scale bar = 0.05 mm.*

DISCUSSION

Both limestone localities contain detrital chromite that, in general, shows very little abrasion and has most likely been derived from the ophiolitic rocks of Great Bend and Coy Pond complexes. The fossils contained in the limestone conglomerate indicate that deposition of the original carbonate rocks occurred during late Llanvirn to early Llandeilo. The texture of the limestone conglomerate (i.e., remoulded, irregular fragments) indicates that the original fossiliferous limestones and calcarenites were not fully lithified before resedimentation and, therefore, the age of fossils should approximate the age of the resedimented deposits.

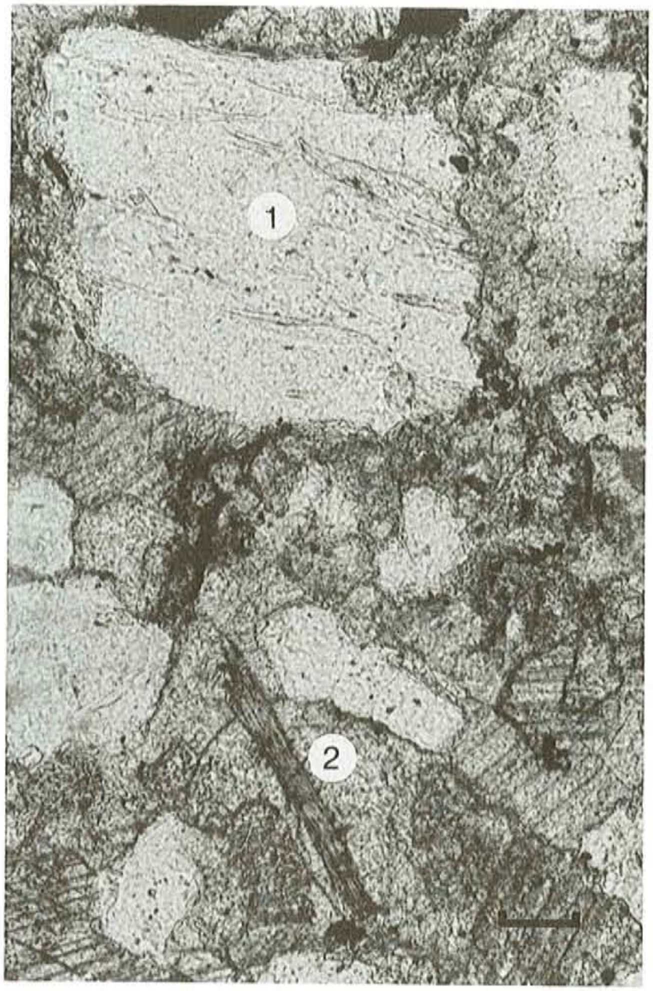
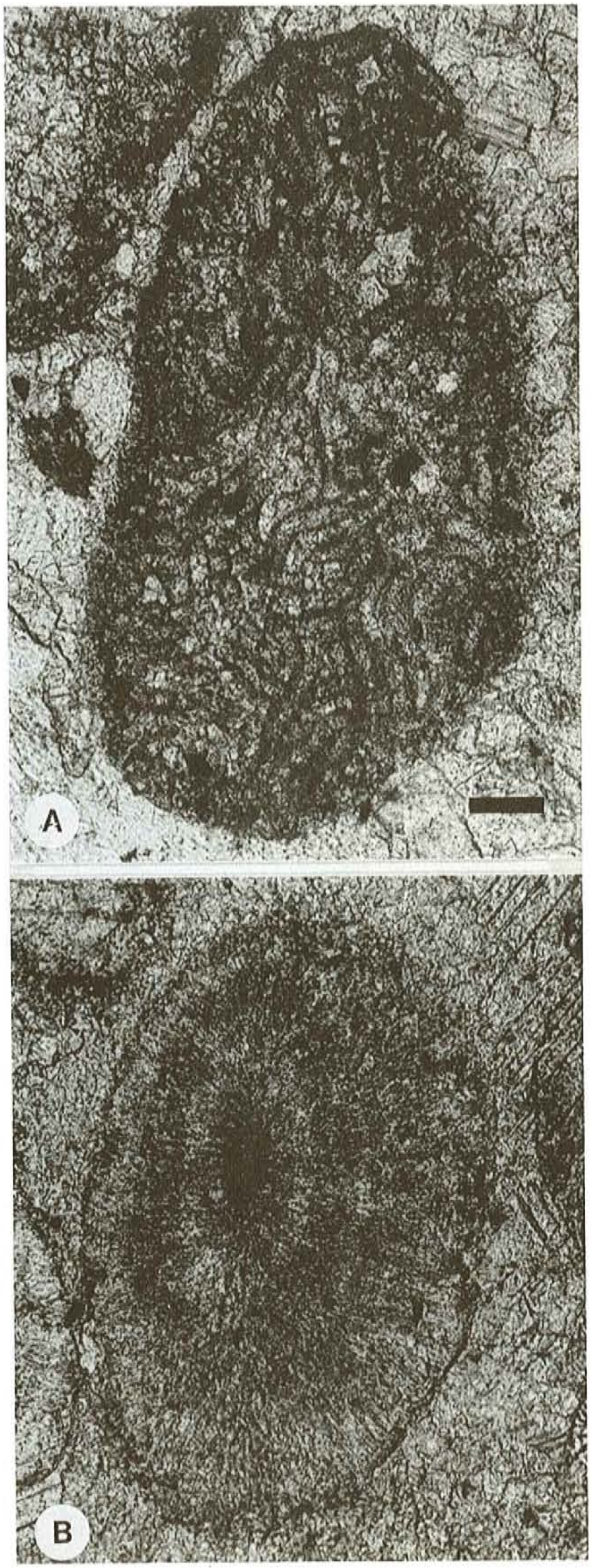


Plate 7. *Photomicrograph from a calcarenite matrix showing a fragment of quartz–muscovite schist (1) and unaltered detrital biotite (2), which might have been derived from the metamorphosed Spruce Brook Formation; plane-polarized light; scale bar = 0.05 mm.*



No chromite or other ophiolitic detritus, including volcanic clasts, has been found in the samples of quartzitic sandstone from the Spruce Brook Formation, which has a distinctly cratonic provenance. Furthermore, it is thought that at least a proportion of the siliciclastic, sedimentary component of the limestone conglomerate, best represented by quartz arenite and quartzite fragments, has been derived from the quartz-rich, metasedimentary rocks of the Spruce Brook Formation. Both conglomerate localities lie within the outcrop area of the Spruce Brook Formation and there are exposures of siliciclastic rocks that project along strike between the limestone localities and the ophiolite belt.

There are essentially three possible ways of interpreting the relationships of the limestone conglomerate. It may be tectonically emplaced, it may be an interbedded and conformable part of the Spruce Brook Formation, or it may overlie the Spruce Brook Formation unconformably. Each hypothesis has different implications for the timing of ophiolite emplacement. Since the contacts of the conglomerate are not exposed, none of the hypotheses can be positively excluded, but evidence from the clast composition and indirect stratigraphic evidence favour an unconformable relationship.

Tectonic Emplacement

If the limestone has been tectonically emplaced into the Spruce Brook Formation, the only conclusion that can be drawn from the provenance studies is that ultramafic and siliciclastic rocks were exposed near where the limestone was deposited during the late Llanvirn to early Llandeilo. Therefore, the time of emplacement of ophiolite against the Spruce Brook Formation would remain as obscure as the time of emplacement of the limestone. Tectonic emplacement of exotic units into the Spruce Brook Formation has clearly occurred, the ophiolite belt being the prime example. In particular, a linear zone of altered, magnesite-rich ultramafic rock is crossed by the Northwest Gander River, 2.5 km northeast of locality L1, and is bounded on both sides by siliciclastic rocks of the Spruce Brook Formation (Colman-Sadd and Russell, 1988). Unlike the ultramafic rocks, however, the limestone conglomerate is essentially undeformed and unaltered. The lack of deformation contrasts with the slaty cleavage in the pelite beds and the foliation in the psammite beds of the Spruce Brook Formation. Tectonic emplacement is, therefore, considered unlikely.

Conformity

Colman-Sadd and Swinden (1984) considered that the limestone was most likely to be conformable within the Spruce Brook Formation. If this is so, detrital chromite, restricted to the limestone, would show that ultramafic rock

Plate 8. *Grains of commonly found blue-green algae:* Girvanella *(A) and* Nuia *(B); plane-polarized light; scale bar = 0.05 mm.*

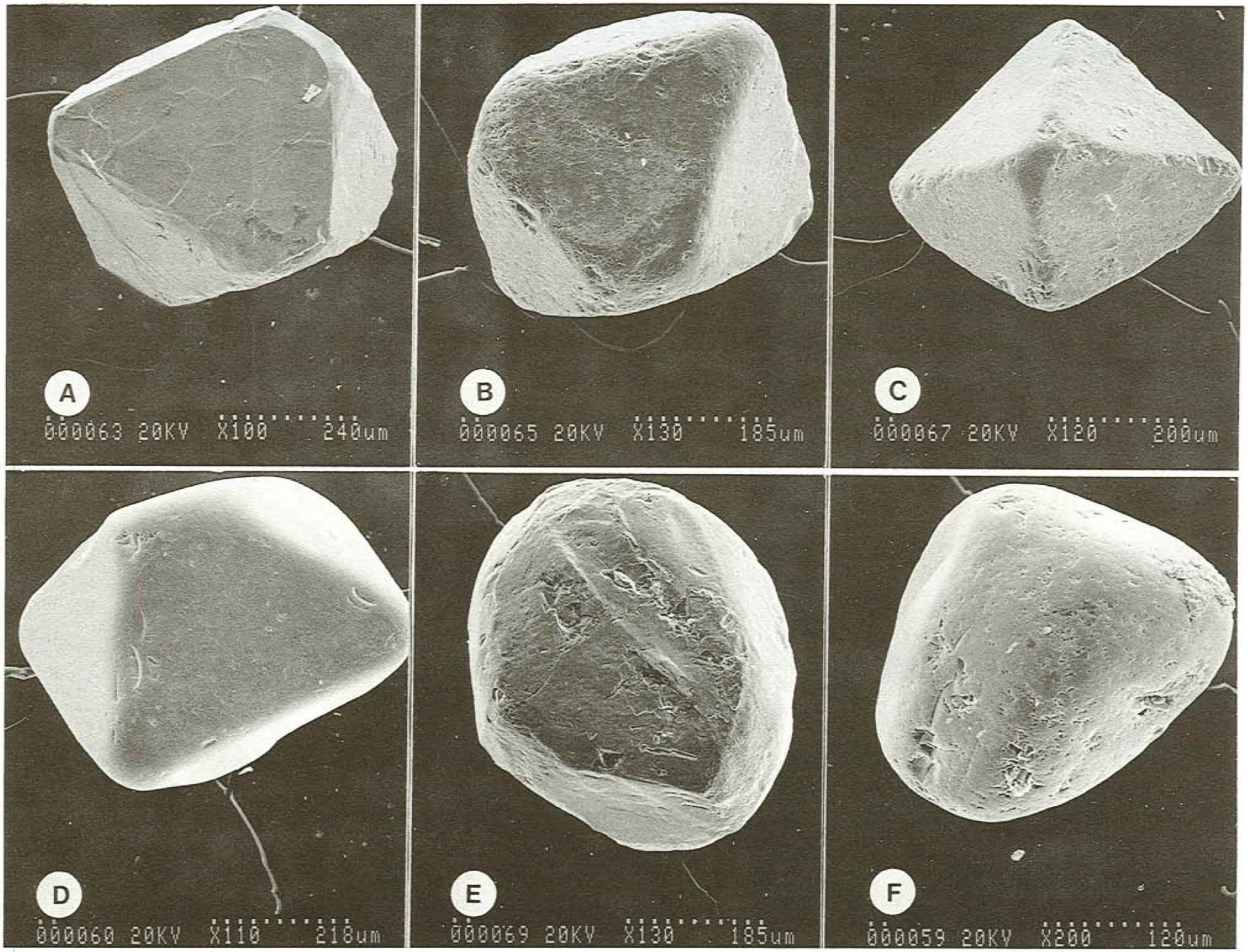
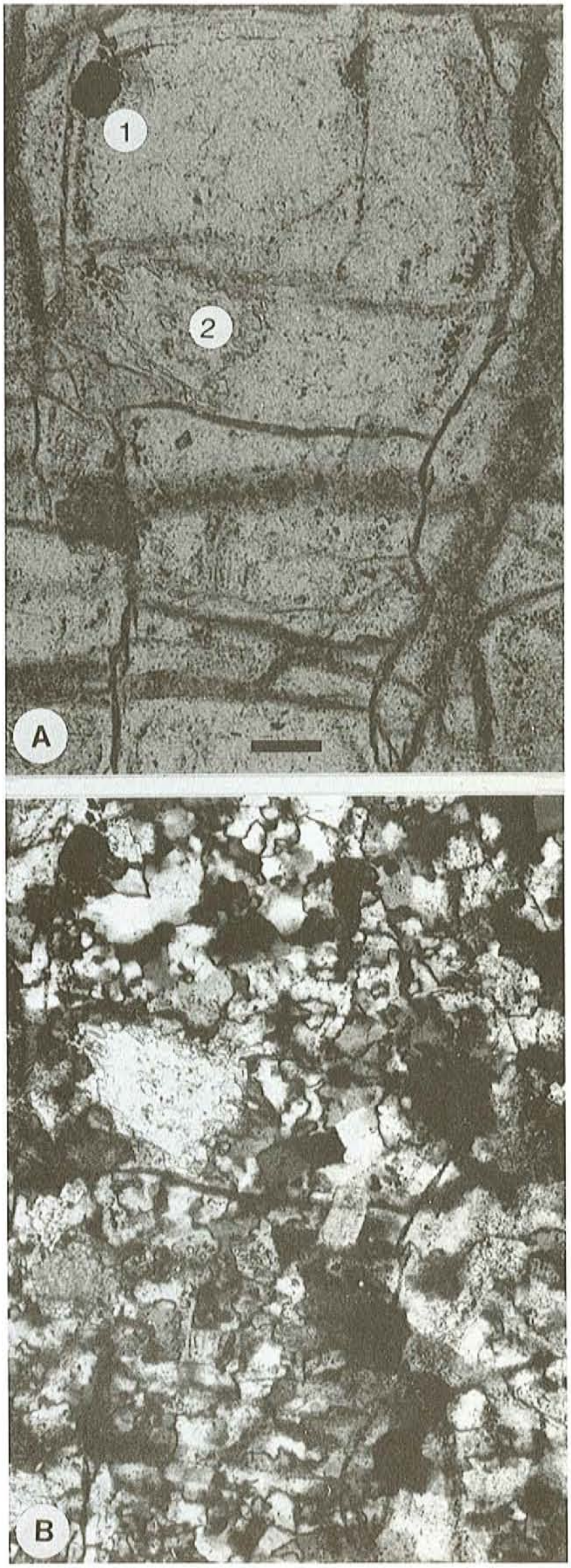


Plate 9. *SEM images of chromite grains separated from the limestone conglomerate. The grains generally show little or no mechanical abrasion (A−C). Dissolution features are common on both rounded and unabraded grains and are commonly associated with micro-fractures (E) and percussion marks (F). Note that abraded edges of the grain C are less corroded than its original, crystalline faces, suggesting that transport of some of the chromite grains postdated the dissolution.*



was only temporarily shedding detritus into the basin and that the remaining quartz-rich sediments of the Spruce Brook Formation were derived from an entirely different, cratonic source. Such dramatic changes in provenance are possible, and a model for contrasting provenance in coeval sedimentary rocks has been presented by Blackwood (1982) for Dunnage–Gander relationships in the Gander area. In the case of the Northwest Gander River area, there are two main difficulties with this hypothesis. The first is that the limestone conglomerate contains quartzite, phyllite and schist detritus, derived from a strongly lithified and metamorphosed source. If, as seems likely, this source was, at least in part, the Spruce Brook Formation, a conformable relationship would be excluded.

The second difficulty is that conformity requires the Spruce Brook Formation to be, at least partly, of late Llanvirn–early Llandeilo age. This is anomalously young, when compared with probable correlatives elsewhere in Atlantic Canada. In the Gander Lake Subzone, the Jonathans Pond formation, which is of similar composition to the Spruce Brook Formation, appears to pass conformably upward into black shale, dark-grey sandstone and minor volcanic rocks of the Indian Bay formation (O'Neill and Knight, 1988). The Indian Bay formation is dated by fossils in associated boulders as probably late Arenig (Wonderley and Neuman, 1984; Boyce *et al.*, 1988). In New Brunswick, the lower part of the Tetagouche Group consists of Gander Zone rock types (Rast *et al.*, 1976; Williams, 1979) and is overlain conformably by rocks containing late Arenig–early Llanvirn fossils (Nowlan, 1981; van Staal *et al.*, 1988). The upper part of the Tetagouche Group is more characteristic of the Dunnage Zone (van Staal, 1987). Thus, from a regional perspective, the Arenig–Llanvirn boundary seems to mark the end of quartz-rich Gander Zone sedimentation, and a late Llanvirn–early Llandeilo age for the Spruce Brook Formation would be in conflict with this.

Unconformity

If the limestone conglomerate rests unconformably on siliciclastic rocks of the Spruce Brook Formation, the latter can be any age older than late Llanvirn to early Llandeilo. The absence of ophiolitic detritus in the sandstone, and the presence of recycled, quartz-rich sandstone detritus in the chromite-bearing conglomerate probably indicate that the Spruce Brook Formation predates the emplacement of ophiolitic rocks. If it is valid to assume termination of quartz-rich sandstone deposition at about the Arenig–Llanvirn boundary, the time of ophiolite emplacement can be fairly tightly constrained to the Llanvirn. The structural and stratigraphic relationships, using the unconformity hypothesis,

Plate 10. *Photomicrographs in plane-polarized (A) and cross-polarized light (B) showing texture of an altered ultramafic pebble: the 'ghost' mesh texture is defined by clear and dusty, mainly polycrystalline, quartz; 1–magnetite; 2–post-silica calcite replacement; scale bar = 0.05 mm.*

are similar to those at Weirs Pond, where the Gander River Ultrabasic Belt abuts the Jonathans Pond formation of the Gander Group (Blackwood, 1978; O'Neill, 1987). At Weirs Pond, bioclastic limestone, containing ophiolitic and other detritus, unconformably overlies serpentinized ultramafic rock. Stouge (1980) used conodonts to date the limestone as late Llanvirn—early Llandeilo, the same age as the Northwest Gander River limestone conglomerate. The critical difference between the two areas is that, at Weirs Pond, limestone overlies Dunnage Zone ophiolite, whereas near the Northwest Gander River it is interpreted to overlie Gander Zone rocks. The Weirs Pond limestone might reasonably be expected to contain Dunnage Zone detritus and, as pointed out by Colman-Sadd (1982), demonstrates nothing about Dunnage—Gander relationships. If, however, the Northwest Gander River limestone is indeed unconformable on the Spruce Brook Formation, it would satisfy the requirement shown in Figure 1 of Colman-Sadd (1982) for onlap of the unconformity onto the Dunnage Zone metasedimentary rocks. It would then prove Middle Ordovician thrusting of ultramafic rocks onto the Gander Zone, as proposed by Currie *et al.* (1979).

CONCLUSIONS

Ophiolitic detritus occurs in late Llanvirn—early Llandeilo limestone conglomerate near the Northwest Gander River, but is absent from surrounding quartz-rich sandstone and shale of the Spruce Brook Formation. Siliciclastic detritus (represented primarily by the quartz arenite and quartzite clasts), recycled into the conglomerate is likely to have been derived from the Spruce Brook Formation. The most probable explanation for the clast composition is that the limestone conglomerate lies unconformably on the sandstone and shale, and that tectonic emplacement of the Coy Pond and Great Bend ophiolites took place in the time interval represented by the unconformity. Comparison with the Gander and lower Tetagouche groups suggests that deposition of the Spruce Brook Formation ended at about the Arenig—Llanvirn boundary, thus limiting ophiolite emplacement to the Llanvirn. On this assumption, rocks of the Exploits Subzone that are younger than Llanvirn were either deposited on, or thrust across, a composite crust that included Dunnage Zone ophiolite and Gander Zone craton-derived sedimentary rocks. Any stratigraphic contacts between this composite crust and overlying rocks are likely to be unconformities. Post-Llanvirn units include parts of the Davidsville and Baie d'Espoir groups (Bergstörm *et al.*, 1974; Williams, 1989a), the Middle Ordovician black shales (Dean, 1977; Williams, 1989b), the Sansom Greywacke, Goldson Conglomerate and equivalent rocks (Neuman, 1968; McKerrow and Cocks, 1981), and the Botwood Group (Williams, 1962). The relationships between these units, the ophiolites and the sedimentary rocks of the Gander Zone are essentially the same as those described by Kennedy (1975).

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