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CLASTIC DYKES IN THE DUNNAGE MELANGE, HALFMOON BAY, NORTHEAST NEWFOUNDLAND

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ABSTRACT

Recent studies have examined the presence and significance of clastic dykes in the Dunnage Melange, at Halfmoon Bay. They resemble pebbly shale, polymictic dykes that are between 2 and 30 cm wide and are up to 10 m in length. Grain size varies from fine to coarse, having equant and irregular clasts that include native and/or exotic rock types. The dykes cut both the shale melange matrix and volcanic blocks, as well as all cleavages in the melange. Injections of dyke matrix into internal joints and fractures in the clasts indicate that at some stage, the matrix was highly fluidized. The variety and irregular shape of clasts requires significant flow and mixing, probably over distances of hundreds of metres. The Dunnage Melange is the locus for intrusions, especially small bodies of the Coaker Porphyry that occur throughout the entire melange and make up about one third of the Dunnage Melange area. Intricate patterns of melange matrix shale and Coaker Porphyry have been interpreted as mud–magma mixtures. Clastic dykes in localities such as Halfmoon Bay are most plentiful and obvious where mud–magma mixing is most spectacular. The timing of clastic dyke emplacement has an important bearing on several structural and plutonic events in melange evolution. Injection is a more important process in the entire Dunnage Melange development than previously considered.

INTRODUCTION

The Dunnage Melange is the most distinctive feature of the central belt of the Newfoundland Appalachians, from which the Dunnage Zone takes its name (Williams, 1994). The Dunnage Melange is a heterogeneous deposit composed of blocks of mainly clastic sedimentary and mafic volcanic rocks enveloped in a dark scaly shale matrix (Figure 1). Its clasts vary in size from granules and cobbles to boulders and huge blocks up to a kilometre in diameter, producing a chaotic mosaic that contrasts sharply with nearby stratified volcanic and sedimentary rocks. Most blocks are indigenous to nearby volcanic sequences, however a few are exotic. A variety of small intrusions that are localized within the melange are rare or absent in surrounding country rocks (Williams, *op. cit.*).

Clastic dykes in the Dunnage Melange at Halfmoon Bay, Chapel Island, raises another problem in a long list of questions bearing on the genesis, evolution, and tectonic setting of the melange. Although recognized over 30 years ago, the timing of its commencement, termination, and controls are still unknown. Melange formation involves a lively history of deformation, sedimentation, recycling of blocks and matrix, and intrusion. Relationships between the clastic dykes and the melange at Halfmoon Bay set restraints upon the timing of these processes and the clastic dykes may hold profound clues to Dunnage Melange formation and development.

The clastic dykes went unnoticed by most early workers (e.g., Kay, 1970, 1972; Hibbard and Williams, 1979) but were highlighted by Williams *et al.* (1988). The latter viewed the dykes as tuffisites or gas-flow breccias, without concern for their formation and significance within the melange. More recently, numerous clastic dykes were recognized at Halfmoon Bay and Inspector Island (Williams, 1994). This study is the first systematic description of the clastic dykes at Halfmoon Bay and focuses on these easily accessible occurrences.

LOCATION

Clastic dykes in the Dunnage Melange are found in its northeast portion at, and near, Chapel Island in Dildo Run. The study area, at Halfmoon Bay, on the northwest shore of

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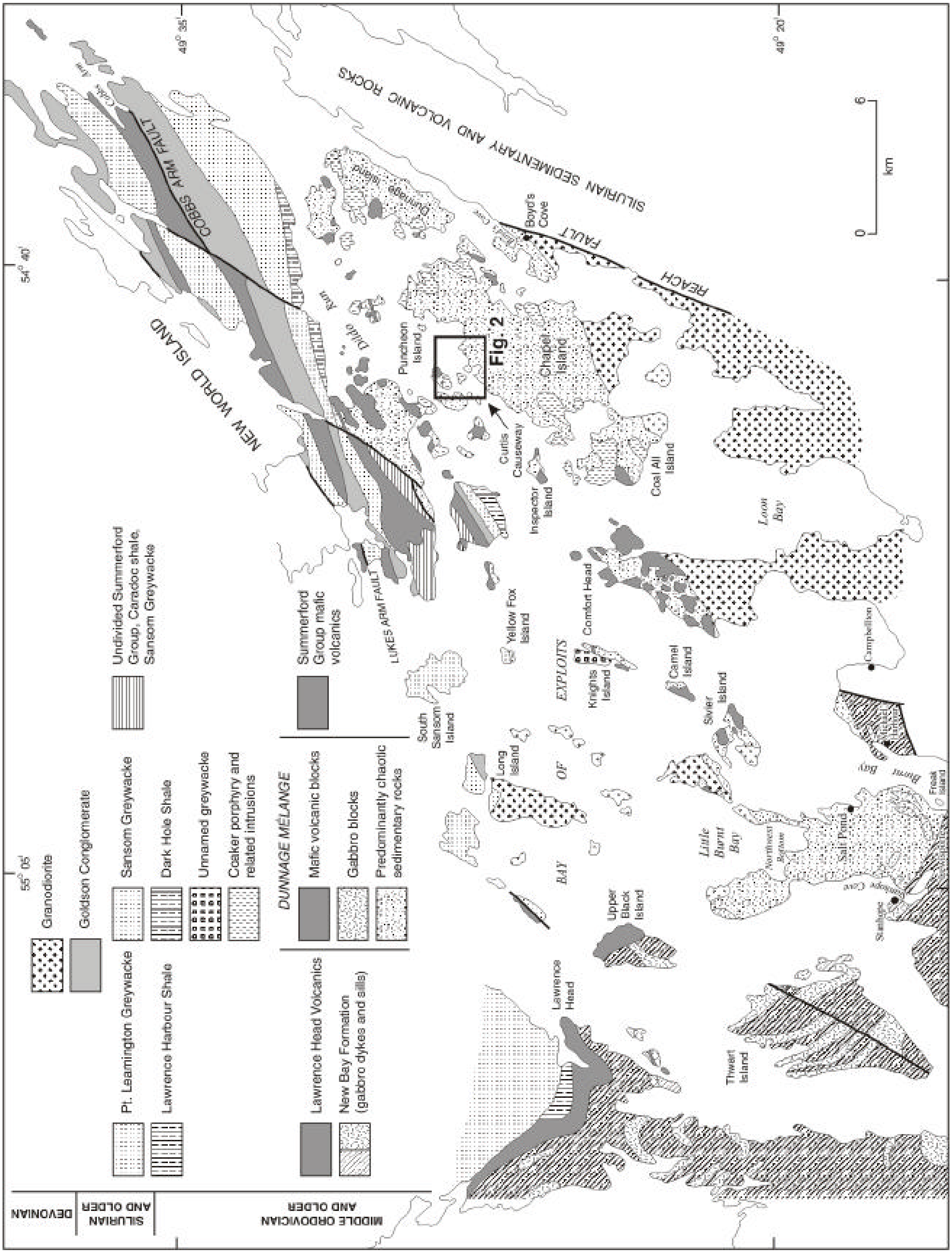

Figure 1. *Setting and internal makeup of the Dunnage Mélange (Williams, 1995). The area of Figure 2 is outlined*

Chapel Island is situated approximately 10 km northwest of the community of Boyd's Cove, in NTS map area 2E/07 (Figure 1). Halfmoon Bay is within easy walking distance from the intersection of The Road To The Isles (Route 340) and the eastern end of the Curtis Causeway; alternatively the area can be accessed by boat.

DESCRIPTION OF CLASTIC DYKES

DISTRIBUTION

The dykes exposed at Halfmoon Bay outcrop at two separate locations along the shoreline and at one locality on the island to the northeast (Figure 2). The westernmost occurrence of clastic dykes at Halfmoon Bay consists of four separate dykes that are exposed along the shoreline at low tide. Another locality one hundred metres to the east, has two clastic dykes. On the eastern end of the large island in Halfmoon Bay, one large clastic dyke is exposed.

PHYSICAL PROPERTIES

The dykes located at the western occurrence are irregular, ranging in thickness from 2 to 13 cm, and from 1 to 4 m in length (Plate 1). All of the dykes at this location trend northwest–southeast and are steeply dipping to vertical. The dykes are hosted by a fine-grained green- and buff-weathering shale of the Dunnage Melange matrix. They display straight, sharp, parallel contacts with the host rock and, in places, they bifurcate and abruptly pinch out, or reconnect farther along strike (Plate 2).

Of the two dykes located to the east of the previous occurrence, one dyke is 8 cm wide and 3 m long, whereas another, located 2 m north, is 6 to 10 cm wide and 2 m long. Both dykes trend east–west and are vertical. Eastward along strike, both dykes disappear under glacial cover and reappear 2 and 5 m farther east. Three and a half metres to the west, one of the dykes is exposed from underneath glacial cover and extends for 3 m, where it pinches out. This dyke is offset 45 cm along a sinistral fracture trending north–south. The dykes are enclosed by scaly black shale of the Dunnage Melange matrix. Unlike the western occurrences, contacts between the dykes and the shale are straight, smooth, and parallel, and do not exhibit branches.

The dyke exposed on the island is 30 cm wide and at least 3 m long, trending south-southeast–north-northwest and dipping 55° west. The dyke is contained in a fine-grained, pyrite-bearing, red- to buff-weathering melange matrix shale (Plate 3). Contacts between the dyke and host rock are subparallel, rough, and irregular. Three hundred metres north of the dyke, fine-grained Coaker Porphyry is intricately interlayered with black sedimentary mudstone (Plate 4). This mudstone is very similar in appearance to the material constituting the dyke matrix.

LITHOLOGY

The Matrix

The matrix of the clastic dykes at Halfmoon Bay is generally dark and fine grained and resembles shale. It consists of small clasts, surrounded by still smaller clasts; thus comprising a poorly sorted and texturally immature finely comminuted rock flour. There is nothing added by way of matrix material, it is just more finely comminuted material found in the rest of the dyke. In places, elongate clasts of black, graphitic shale disintegrate to generate elongate areas of black matrix.

The Clasts

Sedimentary rock fragments are the most abundant clasts in the clastic dykes. They include green-, grey- and buff-weathering shale of the host Dunnage Melange matrix, along with black graphitic shale and siltstone. Minor clasts are felsic (dacitic) fragments of the Coaker Porphyry, greywacke, limestone and fine-grained basalt. Serpentine and brown garnets are present in minor quantities.

The commonest, largest clasts are green-grey shale that constitute 70 to 80 percent of all clasts contained in the dykes. They range in length from a few millimetres up to 3 cm and are everywhere angular to rounded, with heterogeneous concentrations from around 30 to 70 percent in relation to the dyke matrix. Most are fine grained, with some containing coarser silty areas having recognizable quartz grains. Many display the same scaly cleavage as the Dunnage Melange matrix. Some clasts display polished surfaces, and many are internally brecciated with an intricate network of microfractures that are filled with matrix material.

The common dark clasts range in size from 0.1 to 1.5 cm and are present as angular to subangular fragments. These clasts consist of black, opaque, banded/foliated graphitic shale. Most of the black shale clasts contain a pronounced fabric, possibly a schistosity, parallel to their length.

Felsic volcanic clasts are present in the dykes, in amounts of approximately 30 to 40 percent. These clasts occur as angular to rounded grains ranging in size from 0.5 to 1.7 cm. The felsic volcanic clasts consist dominantly of fine- to medium-grained dacite, locally containing subrounded to rounded quartz phenocrysts. The felsic volcanic clasts have a very distinctive felted texture defined by the

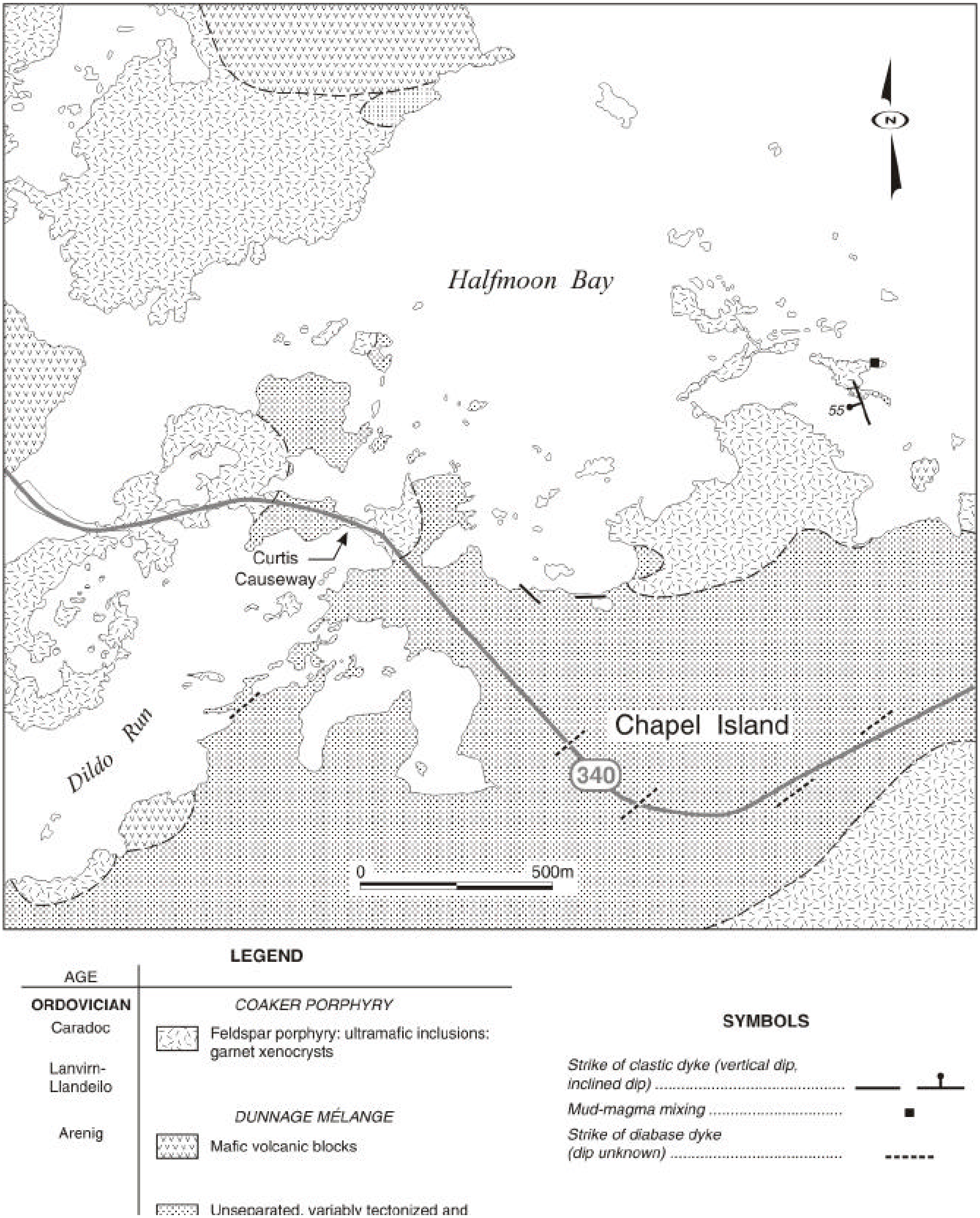

Figure 2. *Geological map of the Halfmoon Bay area, northwest Chapel Island (geology modified from Currie and Williams, 1995).*

radial orientation of elongate, euhedral alkali-feldspar laths. These clasts are considered to have originated from the nearby Coaker Porphyry.

Other clasts are greywacke, calcite, limestone and basalt. All occur in small quantities (<20%) and measure 0.2 to 2 cm in diameter. Grain sizes range from extremely fine in the basalt up to coarse silty in the greywacke. Most of the greywacke clasts appear massive; however, some display remnants of bedding. Most of the limestone clasts consist of a primary carbonate, with some examples displaying secondary carbonate overgrowths. Greywacke, limestone, and basalt are common blocks in the Dunnage Melange, so all of these clasts in the dykes are considered to be of local derivation.

Plate 1. *Clastic dykes exposed along the western shoreline at Halfmoon Bay.*

Clasts of garnet occur in two samples of the clastic dykes taken from the northeastern locality (Figure 2). The garnets are brown, euhedral crystals that measure 3 or 4 mm in diameter. Like the felsic volcanic clasts, the garnets are thought to have originated from the Coaker Porphyry. Garnets in the porphyry exist as xenocrysts, meaning that they have been introduced into the melt from some extraneous source (van Staal, personal communication, 1998). Mafic–ultramafic inclusions in Coaker Porphyry are interpreted as a sampling of an ophiolithic substrate beneath the Dunnage Melange (Lorenz, 1984). Garnets in the clastic dykes may be derived from the same substrate.

Serpentinite occurs in very minor quantities as small, <3 mm, crystals found in association with carbonate and chlorite. They are oval masses of small crystals suggesting that they formed as olivine or pyroxene pseudomorphs.

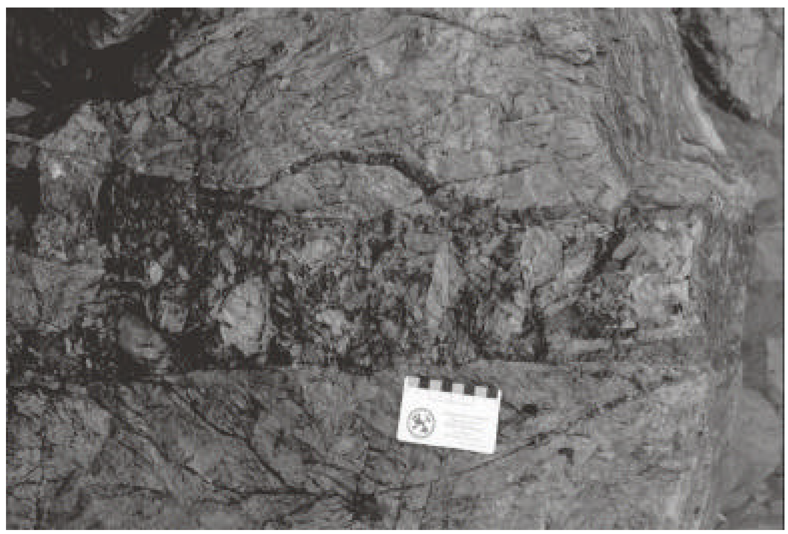

Plate 2. *Contact relationship between clastic dyke and host melange.*

TEXTURES

In the clastic dykes studied, clasts are everywhere matrix supported. Clasts of contrasting composition are rarely seen in contact, and all are separated by the rock-flour matrix. The clasts are typically irregular in shape and vary morphologically from angular to oval to spherical. Although many of the clasts are distributed randomly throughout the clastic dykes, almost everywhere, the elongate larger clasts are aligned in the direction of flow (Plate 5).

Many clasts in the dykes are in various states of disruption. They are composed of many closely spaced, isolated, angular to subrounded, joint bound fragments, separated by, and being dispersed in, the matrix. Many of these clasts formed at an intermediate stage of fragmentation and reflect the outline of once continuous larger clasts.

Mesoscopically, the matrix appears massive, however microscopically many areas show flow structures defined by elongate clasts aligned parallel to borders of larger clasts and aligned in confluences or constrictions between larger clasts (Plate 6). In other places, silty bands are aligned parallel to the margins of the dyke or diverge and pass between the suspended clasts. In situations where one dyke cuts another, boundaries are straight and sharp and the clasts in the younger dyke are aligned parallel to its boundary. All of these flow patterns are irregular in orientation and are controlled only by the presence of clasts.

In numerous places thin (<1 mm) discontinuous calcite and/or quartz veins from 0.5 up to 4 cm in length, cut the matrix and offset clasts. In addition, many of the clasts contain chlorite and carbonate alteration. Since chlorite and carbonate alteration halos are absent from the surrounding matrix, the clasts most likely underwent mild alteration before they were incorporated into the dyke.

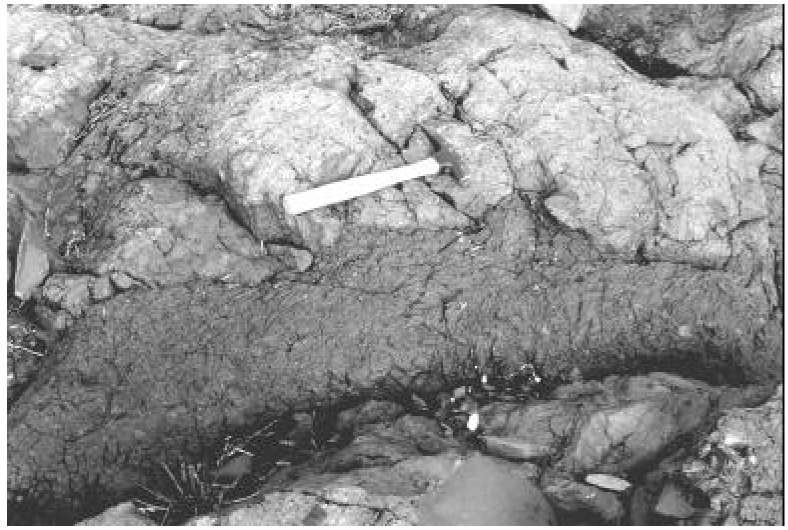

Plate 3. *Large clastic dyke exposed on the island in Halfmoon Bay.*

MODE OF EMPLACEMENT

Clastic dykes, similar to those at Halfmoon Bay, may be produced from a number of different processes. These include: (a) tuffisite dykes or a gas-flow from an igneous source; (b) neptunian dykes or sedimentary filing of existing fractures; and (c) injection dykes or movement of liquefied and fluidized sediments.

The results of this study support a liquefied fluid flow or injection model. This involved the upward movement of overpressurized fluid along with a poorly sorted mixture of more competent clasts of strata encountered during movement of the fluid (Lash, 1987). Fluids and fluidized sediments only need to follow local and regional pressure gradients and to flow from an over pressurized area to an overlying adjacent area of lower pressure to generate the conditions necessary for the liquefaction, fluidization, and injection of sediments (Cousineau, 1998).

Plate 4. *Interlayering and intricate commingling of Coaker Porphyry and black shale.*

The clastic dykes exhibit features of injection, which include brittle clast fragmentation, a granulated matrix, and the shape, variety and orientation of clasts. These dykes were not formed by a simple, *in situ* fragmentation, where the clasts are not far traveled. The angularity of small clasts and relationship between the intensity of matrix flow and variety of small clasts indicate that as the dykes intruded the melange they incorporated more clasts, and the longer the duration of intrusion, the greater number and more variety of clasts. The variety of clasts requires significant flow and mixing, probably over distances of hundreds of metres.

Other evidence for the injection origin of the dykes comes from the origin and composition of the matrix. The matrix was produced by the disintegration of sediments under locally high pore-fluid pressures, or by local pulverization of clast material during fluidization, in which the clasts are repeatedly fractured to reduce their size. The thin veins of matrix material contained in fractures in the clasts are present due to the forceful injection of highly pressurized matrix into competent clasts. This indicates that at some stage the matrix was highly fluid and that pore fluid pressure in the matrix was higher than that in the enclosed clasts. Flow features in the matrix are caused by fluid turbulence in the escaping mixture, which imparts a fabric on the matrix.

Perhaps the strongest line of evidence for the far-traveled origin of the clastic dykes in the Dunnage Melange, however, is the occurrence of exotic clasts of garnet, felsic volcanic Coaker Porphyry, and serpentinite. Exotic clasts present in the dykes provide evidence of clast transport and indicate movement over fairly large distances. Injection provides a mechanism by which exotic elements not otherwise available may be supplied to the system.

AGE OF EMPLACEMENT

The clastic dykes crosscut matrix, blocks, and all structures found in the Dunnage Melange. Williams *et al*. (1988) report a clastic dyke cutting the Coaker Porphyry, however, no examples of clastic dykes cutting the Coaker Porphyry at Halfmoon Bay were seen. The Coaker Porphyry dated at 467 ± 5 Ma (Elliott *et al.*, 1991) sets a lower limit on the age of the dykes.

The clastic dykes do not intrude the Loon Bay Batholith located to the southeast of the study area at Halfmoon Bay (Williams *et al.*, 1988). The Loon Bay Batholith postdates the Coaker Porphyry, and is unaffected by many mafic dykes found throughout the Dunnage Melange. This intrusion has been dated at 408 ± 2 Ma (Elliott *et al.*, 1991), and may place an upper age limit on the dykes. Therefore, the clastic dykes would appear to have been emplaced between 467 and 408 Ma.

Rocks of the melange matrix at Halfmoon Bay display the penetrative cleavage found throughout the entire melange. This cleavage has been interpreted as the regional northeast-trending cleavage present in adjacent Silurian rocks, which is younger than the Coaker Porphyry (Currie and Williams, 1993). However, Lafrance and Williams (1992) suggest that this cleavage is cut by the Coaker Porphyry. If the penetrative cleavage in the Dunnage Melange is pre-Coaker Porphyry, the clastic dykes may be as old as Mid-Ordovician. However, if this penetrative cleavage is the regional cleavage present in Silurian rocks, it implies a Silurian or younger age for the dykes.

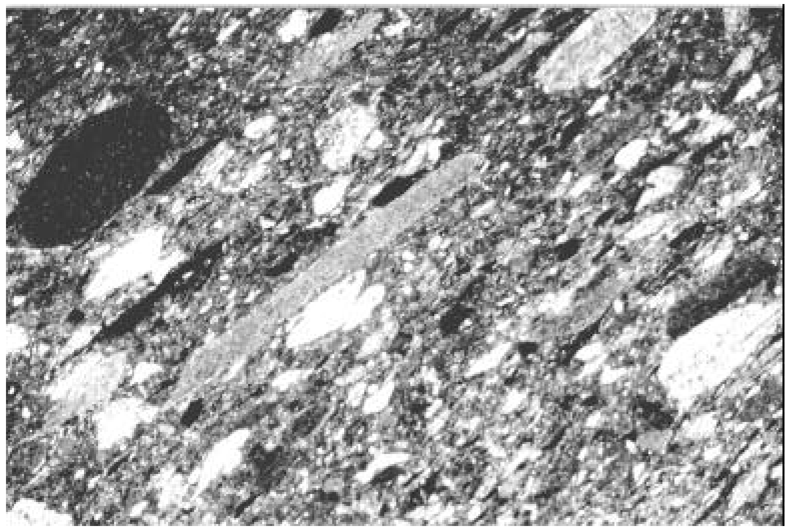

Plate 5. *Photomicrograph displaying flow alignment of clasts in clastic dyke matrix (crossed polars, magnification = 2.5 X).*

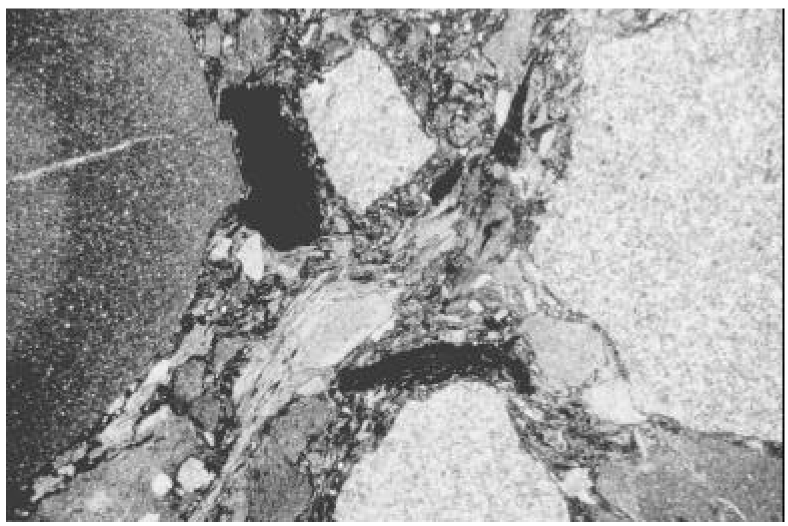

Plate 6. *Thin section displaying flow of matrix and small clasts around and between larger clasts (crossed polars, magnification = 10 X).*

SIGNIFICANCE OF THE DUNNAGE MELANGE

Since its initial recognition over 30 years ago, the Dunnage Melange has been viewed as, a) olistostromal (Hibbard and Williams, 1979), with major slumping favoured as the controlling mechanism of emplacement, and b) as the product of tectonic processes and brittle deformation (Karlstrom *et al.*, 1982). There has been little or no discussion of injection as a mode of emplacement although this process is suggested as the mode of emplacement of the possible correlative Carmanville Melange (Lee and Williams, 1995).

Features of the Dunnage Melange that favour injection are: a) emplacement of the Coaker Porphyry and other intrusions; b) melange exhibits intimate mixing relationships between muds and magma (Lorenz, 1985); c) recycling of deformed melange/psammites into less deformed melange (Williams, 1994); d) web textures in greywacke blocks shows black shale injecting matrix (Hibbard, 1976); e) foreign blocks in Dunnage Melange with respect to nearby groups (Williams, 1994); and f) alternating layers of melange and shale in bedded sections (Hibbard and Williams, 1979).

An injection mode of emplacement of the Dunnage Melange is compatible with many of the above features. The clastic dykes are another injection phenomenon within this list of injection features. The absence of Coaker Porphyry and other intrusions in surrounding rock units may indicate the existence of a conduit that might have been established by injection of the melange itself. The localization of these intrusions within the confines of the melange imply deep connections and that the melange was not entirely controlled by surficial processes.

The Dunnage Melange contains many metamorphic blocks, the most deformed of which are psammitic schists, that mainly occur in a narrow zone crossing the interior of the melange in a northeast direction (Williams, 1994). These rocks are analogous to areas of recycled Teakettle Melange, which occurs as blocks in the correlative Carmanville Melange (Lee, 1994). By analogy with the Carmanville Melange and its injection model, the metamorphic rocks in the Dunnage Melange are related to processes that produced the melange rather than erosion from some bordering landmass. If the Dunnage Melange was formed by injection, this mode of emplacement might explain the presence and localization of these metamorphic blocks.

Lee and Williams (1995) proposed that injection and diapirism are controlling factors in the genesis and development of the Carmanville Melange. The Dunnage Melange displays all of the internal features of the Carmanville Melange and is the locus for intrusions and other features favoring injection. Therefore, an injection mode of emplacement is favoured for the Dunnage Melange.

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