THE SPRINGDALE CALDERA

A Field Guide for the Annual Field Meeting
of the

GEOLOGICAL ASSOCIATION OF CANADA,
NEWFOUNDLAND BRANCH

October 17-19, 1986

Marylou Coyle and D. F. Strong
Department of Earth Sciences and
Centre for Earth Resources Research
Memorial University of Newfoundland
St. John's, A1B 3X5

1. INTRODUCTION

Calderas are the topographic and volcanological manifestations of shallow magma chambers, resulting from deeper-seated thermal processes which ultimately reflect global scale tectonic activity. Accordingly, the documentation of ancient calderas and their products provides essential magmatic and tectonic insights into the evolution of ancient terranes. Volcanic-sedimentary sequences have been described at several localities in the Silurian-Devonian belts of the Appalachians from Scotland to Maine (Fig. 1), and in rare cases only have such sequences been interpreted as caldera or cauldron features, the best example being Glen Coe in Scotland. Caldera development in this belt has much to offer for understanding tectonothermal evolution of the orogen. However their characteristics are variable because of the differing structural levels at which they are now exposed, and the Springdale caldera is one of the few which exhibits the full range of features seen in more recent volcanic fields.

Similar-aged rocks in Quebec and northern New Brunswick contain a larger proportion of basaltic and andesitic rocks, and recent studies in Quebec have provided new interpretations. According to Laurent and Belanger (1984), Silurian-Devonian volcanism of the Gaspe area took place under an intracontinental or continental border regime of compression, and was controlled by strike-slip faults. They suggest that the volcanic rocks differ from those of arc-trench systems, being rich in Ti, P and other incompatible elements. They proposed a tectonic model analogous to that of the Alpine system in northern Anatolia and Iran, where Quaternary volcanism is associated with major transcurrent fault zones. This model provides an elegant resolution to the problem of contrasting Siluro-Devonian volcanic types, and is comparable to that suggested by Strong (1980) for similar-aged granitoid rocks throughout the orogen.

The Springdale Group occurs along the western margin of Newfoundland's lower Paleozoic Central Volcanic Belt (Figs. 1 and 3). Our geochemical data demonstrate that the volcanic rocks are calc-alkaline, somewhat comparable to orogenic calc-alkaline suites of circum-Pacific regions (cf. Ewart, 1982). However the Group also includes a suite of high-silica rhyolites which are similar to those derived from large layered siliceous magma chambers of continental regions such as the Basin and Range area of southwest U.S.A. (cf. Lipman et al., 1978). The Springdale caldera is unlike any found with orogenic calc-alkaline suites in that its large size, representing a minimum eruption volume between 10^3 and 10^4 km^3, is matched only by the largest of epicontinental calderas like those of the southwestern U.S.A. This implies a similar Silurian-Devonian tectonothermal environment for west-central Newfoundland, as do the high-silica rhyolite compositions.

Lipman (1984) has provided a thorough review of ash-flow calderas, with the generalized cycle shown in Figure 2 based on a composite of features from a number of calderas. Most of the features reviewed by Lipman are seen in the Springdale caldera, and the different field stops might be better understood by reference to Figure 2.

2. REGIONAL SETTING OF THE SPRINGDALE CALDERA

The Springdale Group correlates approximately with similar sequences of the area, including the Cape St. John, Mic Mac, Sops Arm and Sheffield Lake Groups and the King's Point and Topsails complexes, all of which we also interpret as different facies of caldera volcanism (Fig. 3). Age dates are sparse, but those available indicate that this activity extended through the Silurian and into the Devonian period. The Springdale and other sequences have received little exploration interest, but such rocks in the southwestern U.S.A. provide a rich source of precious and base metals, and there is every reason to expect the same in Newfoundland. Recent exploration in the Sops Arm Group lend encouragement for this expectation.

Williams (1967) recognized nine different belts of Silurian-Devonian rocks in Newfoundland, the largest of which are the Springdale and Botwood Belts of the Dunnage Terrane. The Springdale belt extends continuously for 60 km, and possibly a further 100 km southwestward if volcanic inliers within the Topsails complex are included (see Fig. 2.2 of Whalen and Currie, 1983), and reaches a maximum width of 35 km across the centre of the belt (Fig. 4). The Springdale Group is not fossiliferous, so that its Silurian age has only been indirectly inferred through correlation with lithologically similar fossiliferous rocks of the Botwood belt. More recently the Springdale Group has been correlated with rhyolites of southern Newfoundland which have yielded an Early Silurian U/Pb zircon date of 431 $\pm$ 5 Ma (Chandler and Dunning, 1983).

Basement Rocks to the Springdale Group include a variety of lithologies, all of which contribute clasts to the pyroclastic and sedimentary rocks. Unit A, are rocks which correlate with the Hungry Mountain Complex of Thurlow (1981), and range in origin from presumed Precambrian continental crust to Cambro-Ordovician ophiolitic and island arc material. They are characterized by foliated amphibolite and gabbro occurring as large screens and xenoliths in foliated diorite and granodiorite. Green and black, medium to fine grained diorite, with hornblende and biotite, are intruded or net veined by a pale fine-grained granite, with a typical tectonic fabric emphasized by amphibole alignment. These are intruded by variably deformed tonalite and amphibole-biotite granite.

Three groups of Lower Ordovician volcanic rocks form the basement along the northern margin of the Springdale Group. They are the Lushs Bight, Catchers Pond and Roberts Arm Groups, all dominated by submarine pillow lavas and pyroclastics. The Lushs Bight Group are derived from Iapetus oceanic crust, and it is assumed that these ophiolitic rocks were the source of ultramafic clasts within the ash flows of Units 1 and 10. Silicic pyroclastic rocks and intrusions are found with the pillow lavas of the Catchers Pond and Roberts Arm Groups, and they are generally interpreted as of island arc origin.

A number of types of intrusive rock are seen around the margin of the Springdale Group. Unit B is a black massive microdiorite which intrudes units A and 2, and is contemporaneous with or intruded by unit C. Unit D may also intrude it in the west, although this contact is obscured by faulting. Unit C is a rhyolite occurring as dykes, sills and domes with microphenocrysts of quartz and feldspar, and in some cases contains finely disseminated riebeckitic amphibole in the groundmass. These domes intrude Units 3, 6 and 8, as well as the microdiorite of unit B, and are all similar in composition and textures. They may be flow-foliated with extreme convolution seen as fluidal folds and disrupted flow banding, auto-brecciated, or contain zones of intense development of spherules and/or lithophysae along with other indications of gas-streaming. Curviplanar jointing and ductile flow-shear features are found within the body of the domes.

Units D and E, the younger granitoid rocks, were intruded along faults bounding the Springdale Group in the east and west, and truncate much of the stratigraphy in the south, as part of the Topsails Complex. These intrusions exhibit contact aureoles of major extent and intensity, although along the northwestern boundary with the volcanics, the granites tend to be highly sheared and altered along caldera marginal fault blocks.

Rocks of the Springdale Group generally show no penetrative deformation, except in local fault and possible thrust zones, but are folded about a main northerly-plunging synformal axis, which is sporadically marked by a steeply dipping spaced fracture cleavage. Sedimentary rocks of the group are gently dipping. If all units were folded to the same degree, this would indicate across-strike structural shortening of up to about 20%, which would have contributed to the present elongate distribution pattern of the group.

The eastern and western boundaries of the group (Fig. 4), although locally intruded by granitoid rocks, mark early basement-controlled boundary faults along which the group was down-dropped, and which partially controlled volcanism, sedimentation, and intrusion of resurgent domes along caldera fracture margins and possibly also to a central graben feature associated with resurgence.

FIELD STOPS

Set 0.00 km. at the Burnt Berry Motel, and drive east.

Turn right (south) on logging road at 6.7 km. Note andesites in low-lying outcrops on both sides of this road at 100 m from TCH. The next three km run approximately along the contact between granites to the east and the Springdale pyroclastic Unit 1 and debris flows of Unit 2. Don't stop!

Stop 1: 10.7 km, at sharp turn in road (in Unit A).

Hungry Mountain Complex, marking the eastern boundary of the caldera. Foliated amphibolite and gabbro screens and xenoliths in foliated diorite and granodiorite, intruded by variably deformed tonalite and amphibole-biotite granite; intruded and net-veined by pale fine-grained granite. These we interpret as partial melting features at the base of the Ordovician island arc sequences, not Precambrian basement rocks.

Reset to 0.00, turn around and go back 0.8 km

Stop 2: (in Unit 1)

Here is one of the rare examples of a penetrative fabric within the Springdale Group, possibly related to the SE-directed thrusting in the area, which is best evident on the Lobster Cove Fault. Unit 1 is the lowermost recognized of the volcanic units, has a fault-modified unconformable relationship with the older granodiorite (Unit A), and is intruded by younger granitoid rocks (unit E). It is a moderately welded, lithic-crystal tuff, commonly highly fractured or sheared along it's eastern margin. It differs from the other overlying ash-flows in that fractured and broken crystals of both plagioclase and K-feldspar are present, along with accessory biotite, quartz, and rare opaques. The lithic component includes clasts of plagiophyric basalt, andesite, ultramafics, red jasper, and granophyric to perlitic felsic fragments. The primary features are obscured here by the deformation, but it is a good place to see the basement clasts, including jasper and altered mafics, probably derived from the Roberts Arm Group.

Continue to 1.0 km, and take road on left at small wooden shed

Continue south to 2.0 km

Stop 3: (in Unit 2)

This unit can be termed mesobreccia, a distinctive and complex assemblage of clastic lithologies dominated by laharic flows, with tuffites and pepperites, volcanic conglomerates and local red sandstones, and volcanic explosion breccias. It is best developed along the eastern margin of the Springdale Group as elongate lenses and irregularly shaped lobate areas, and along the western margin as block-faulted ridges in contact with basement rocks. The distribution of these deposits indicates that they have been generated throughout the eruption and accumulation history of the Springdale Group (as would be expected from Fig. 2).

Unit 2 was produced by a variety of physical mechanisms. The predominant feature in all of it's lithologies is the large size of the clasts, suspended in a finer matrix, i.e. with a strongly bimodal size distribution. These lithologies represent facies developed during volcanic activity ranging from near-source explosion deposits, to more distal, fluvially reworked sediments. Some debris flows may have been activated on unstable slopes and rapidly deposited, whereas others could have had long periods of reworking. The lithologies of unit 2 are similar to those seen at caldera margins, and this unit is important as both collapse and topographic marginal facies markers for the Springdale caldera.

Continue through boulder field, keeping right. Turn right at 5.25 km.

Stop at 5.4 km

Stop 4: Johnson's Lookout

This outcrop is one of a number of domes within the caldera, and are thought to represent the filling of collapse ring fractures parallel to the topographic margin of the caldera, as shown on Fig. 2. This dome is dacitic in composition, and is marked by complex flow structures, cooling joints and a concentrically distributed emplacement fabric. This is clearly an emplacement feature, as clasts with the fabric are seen in the autobreccia apron which surrounds the Johnson's Lookout dome.

Return to main access road (wooden shed), set odometer to 0.00

Turn right, drive past Stop 1, continue past red shed @ 5.3 km, to 8.7 km

Turn left, continue for 5.4 km

Stop 5: Nutmeg Hill (in Unit 3)

Columnar-jointed andesite of Unit 3 is exposed in cliffs along the road here for several 100 m. Unit 3 includes aphanitic to plagioclase-phyric dacitic and andesite flows and flow breccias interbedded with Units 1, 2, 4, and 5, and massive andesite (diorite) intrusions in to Unit 5. They are mainly distributed along the eastern and southern margins of the volcanics in a belt about 24 km long and up to 3 km wide, and in a number of isolated exposures in the central and western parts of the caldera. Unit 3 represents a period of volcanism dominated by intermediate chemistry, and a minor phase of it consists of interbanded silicic and mafic compositions on the scale of centimetres or less, suggesting that some of these intermediate rocks may have been formed by mixing of more mafic and silicic magmas.

Continue, noting outcrops of conglomerate along the way, stop at 2.15 km beyond Stop 5

Stop 6 (in Unit 2)

This is another variety of the clastics of Unit 2, here being a well-sorted fluviatile conglomerate-sandstone, exposed for about 700 m along road. They differ from the facies seen at Stop 2 in that basement clasts of jasper, altered basalt (Roberts Arm?) and Hungry Mountain Complex are abundant. These probably indicate that they represent an older wedge of sediments formed during the earlier stages of collapse when the basement was exposed. These outcrops are interesting in that they are intruded by a mafic dyke which has produced a strong oxidation along the contact.

Return to main access road, turn left towards West Brook (9.6 km); Set to 0.00 at bridge.

Stop 7 (unmeasured - first road on right to west of Long Steady bridge)

Unit 6 consists of silicic ash-flow tuffs in conformable contact with basaltic flows of unit 5, exposed discontinuously over a strike length of about 44 km. A particular feature of these rocks seen in the northern exposures along Barney's Brook is a 1 to 2 m thick lithophysae-rich horizon resting on irregular flow tops of the basaltic Unit 5. The individual lithophysae may be as large as 10 cm in diameter, with central cavities partially or completely filled with radiating quartz crystals, microlites, and chalcedony. This horizon grades up over several metres into a partially welded crystal-lithic lapilli tuff and pyroclastic breccia. The phenocrysts are plagioclase, K-feldspar and quartz, commonly broken and concentrated in the matrix in preference to the pumice vitroclasts.

This unit is not exposed in readily accessible outcrops, but can be seen in superb boulders at this stop. Here one can see moderately welded crystal-lithic lapilli tuff with pumice bombs up to a metre long by several cm thick; clasts of silicic volcanics, andesite and rarely basalt; crystal fragments of plagioclase, K-feldspar and quartz.

Stop 8 (in Unit 7 at West Brook bridge)

The West Brook Dome is well-exposed in the river bed on both sides of bridge. It is part of Unit 7 (Fig. 4), which includes dacitic to rhyolitic massive, strongly welded vitric ash-flow tuffs, vitroclastic breccias and domes. The massive tuffs are locally porphyritic, with small euhedral flow-aligned plagioclase and rare quartz phenocrysts in a brown to maroon glassy matrix. Welding can be observed on weathered surfaces and is apparently flat lying in the southern exposures of this unit and becomes more steeply inclined towards the north. In the West Brook Dome of this unit, at this stop, curviplanar joint surfaces are very common and internal plastic shear zones and local brecciation can been seen, as well as flow folds. Vitroclastic auto-brecciated debris form cogenetic pyroclastic aprons of the dome in some areas.

At 5.1 km west of West Brook bridge, turn right, go north to 7.2 km.

Stop 9 (in Unit 8)

Unit 8 is a rhyolitic ash-flow tuff sequence extending via intermittent exposures throughout the centre of the caldera (Fig. 4). It includes an assemblage of devitrified, welded, pink and red rhyolitic ash-flow tuffs and breccias, displaying a variety of rheomorphic features. Certain parts of this unit are very massive due to intense welding, and others consist of unwelded vitroclastic tephra with large individually devitrified shards, each showing independent development of spherules, seen here at Stop 9. Other parts of the ash-flow breccias have internal auto- or gas-breccias with clasts of plastically deformed rhyolitic lava and pumice. Mixed magmas are found within the breccias, with alternating thin basaltic and silicic bands. Near central Burnt Berry Brook the silicic tuffs are intruded by the Burnt Berry rhyolite dome.

Return and set 0.00 at jct. Go west and turn south @ 4.45

Turn right at 6.65 km. Set 0.00 at this jct.

Stop 10

This is a series of stops going through the stratigraphic sequence from Units 8, 9 and 10.

At Stop 10A, 1.25 km from jct. is massive rhyolite of the Burnt Berry Dome (Unit C), and the pumice-bearing apron? of flow-banded rhyolite can be seen @1.75 . Stop 10B: At ~2.75 km, walk through scrub to lowermost finely laminated welded ash-flow tuff of Unit 8, with lithics and phenocrysts of quartz and orange K-feldspar. Stop 10B: Continue around the circle to the large hill (marked on topo. map by a benchmark of 825'). The hill is formed by the welded ash-flow tuffs of Unit 10, which overly red sandstones of Unit 9 exposed along the road.

Unit 9 comprises a sequence of redbed sedimentary rocks in the central portion of the synform (Fig. 4), and forms belts up to 25 km long, 3 km wide in the northeast and narrowing to 500 m at the inner fold closure. An outer band of sediments is disposed about the central synclinal axis over a distance of 20 km and map width between 0.5 and 2 km. Rock types include red conglomerate, sandstone, sandy siltstone,with local caliche horizons. Cross-bedding, ripples, laminations, rip-up horizons, scour channels, etc. indicate stream-flood and proximal and distal fluviatile origin. Clasts are essentially of volcanic provenance, with rare basement lithologies. These sedimentary rocks have been described in detail by Wessel (1975), who interpreted them as stream-flood and proximal and distal fluviatile deposits. They essentially represent the late caldera-fill detritus shown in Fig. 2c.

Unit 10 is an orange to brown densely welded crystal-lithic tuff found mainly in the interior of the central syncline, where it is presumably the youngest volcanic unit of the springdale Group, and in one other isolated exposure in the southwestern part of the caldera (Fig. 4). The crystal tuff is very massive and so strongly welded as to look like an intrusive porphyry. At this stop it can be seen to also exhibit good columnar jointing where very densely welded. It has clasts of mafic and ultramafic lithologies, and phenocrysts of quartz and zoned and fractured feldspar, which together can constitute up to 60% of the rock. The clasts are found in a red, brown or orange vitric aphanitic matrix, are commonly angular, and may have reaction halos, especially around the ultramafic clasts. This rock is indistinguishable from some intrusive porphyries of the King's Point Complex to the north (Fig. 3), which we take to be the source of Unit 10, i.e. from outside the Springdale caldera. In this regard, it would be mimicing a pattern typical of volcanic fields with nested calderas such as the San Juans (e.g. Steven and Lipman, 1976).

Stop 11: At Lobster Cove fault in town of Springdale

Here we see altered pillow lavas of the Lushs bight Group thrust over different units of the Springdale Group, i.e. upon the Springdale redbeds of Unit 9 behind the Trade School, and upon the crystal-lithic tuff of Unit 10 behind Cohens Furniture Store. If time permits, we will walk up to the latter.

Stop 12: King's Point Road:

Coarse conglomerates-debris flows begin on right (east) side of highway and continue intermittently past Terra Nova Pond to main outcrop for Stop 12 at 2.1 km. Start at conglomerates and continue to where they are overlain by ash-flow tuff at ~2.35 km. Note here that the tuff contains only feldspar phenocrysts (no quartz) with lithic and flattened pumice clasts. It is marked by a lithophysae-rich zone just above the base (resulting from gas-streaming), which is overlain by a more strongly welded zone with eutaxitic texture. Note that the ash flow and conglomerates strike sub-parallel to the highway and dip towards the east.

A little further north at 2.5 km begins a section passing down through a steeply-dipping south-facing conglomerate-sandstone sequence and underlying porphyritic basalt flows. Note the variety of clasts in the conglomerates, and the fact that this sequence is at a sharp angle to that of the ash flow and conglomerate to the south. We interpret this as resulting from rotation of separate blocks during thrusting of the Catcher's Pond and Lushs Bight Groups over the Springdale Group. The Catcher's Pond group can be seen across the bridge at ~2.8 km, where it consists of hydrothermally altered rhyolite and rhyolite breccia, with numerous small thrust faults reflecting the main southeasterly directed trend. These are less obvious in the Springdale block, but the basalt is altered along its northern limit, which we interpret as resulting from the overthrusting.

Turn around and proceed to Trans-Canada Highway.

Set 0.00 at jct. and proceed east

Stop 13: On north side of TCH @ 3.2 km east of Springdale junction:

Sandy redbeds of Unit 9 (see Stop 10 for description of Unit 9). Here the beds are dipping gently eastwards, marking the west limb of the Springdale syncline.

At 4.8 km: The sandstones dip to the west, i.e. on the eastern limb of the syncline.

At 5.8 km: Chocolate-coloured conglomerates dipping to the west.

Continue to the east for 9.3 km and take logging road to right at Forestry Improvement Area sign

Stop 14: @ 1.1 km south of highway:

This outcrop, at sharp bend in road, shows the contact between Units 3 and 4. See Stop 5 for a description of Unit 3. It is here represented by a rubbly topped vesicular andesitic flow with plagioclase phenocrysts with less abundant clinopyroxene, olivine and amphibole. A patch of polymictic conglomerate is also seen here, and they are overlain by Unit 4.

Unit 4 forms a narrow band of ash-flow tuff, overlying unit 3 and succeeded by basaltic flows of unit 5, and may be locally gradational into unit 6. It is predominantly dacitic but ranges in composition from rhyolite to andesite. At this locality it is represented by a welded ash-flow tuff with phenocrysts of feldspar (no quartz) and a variety of clasts. This unit is better exposed in cliffs and boulders on the left (west) side of the road about half-way towards the TCH, showing spectacular fiamme up to 30 cm long. We'll stop there if time permits.

Stop 15, at Goodyears Cove:

Along the western shoreline is exposed red feldspar-porphyritic andesites, with a strong trachytic texture and locally brecciated. It is overlain by coarse monomictic breccia formed of angular glassy rhyolitic clasts, which is in turn overlain by flow-banded rhyolite of exactly the same lithology. One can see from a distance that the breccia is grossly bedded, with a gently westward-dipping orientation which is parallel to that of the underlying andesitic flow and the strong flow-banding in the overlying rhyolite. On top of Wolf Head the rhyolite flow banding becomes random and internally sheared and broken, as is seen in all rhyolite domes, and we interpret them both to represent a dome which vented to the surface. This is one of a number of domes presently included within Unit 3 which extending in a discontinuous linear belt southward to include Johnson's Lookout, and probably representing the plugging of a collapse margin fracture vent.

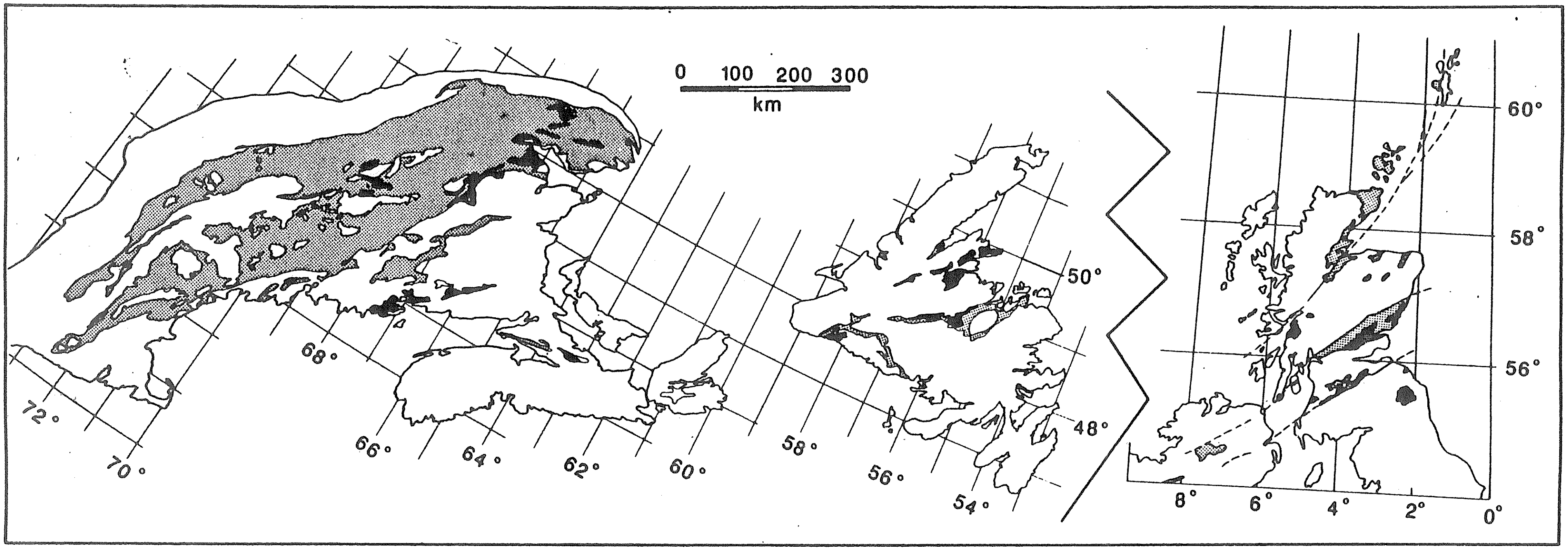


Fig. 1. Distribution of Silurian-Devonian volcanic, intrusive and sedimentary rocks in the northern Appalachians, and of correlative volcanic and sedimentary rocks of northern Britain. Data from Williams (1980) and Thirlwall (1981).

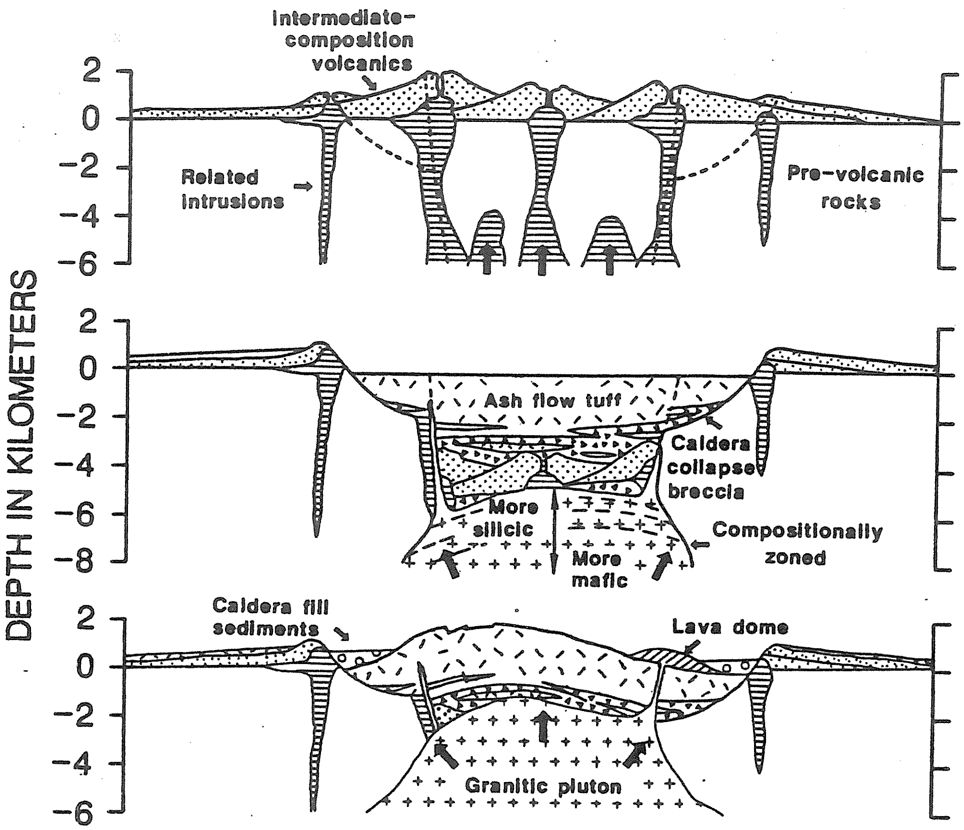
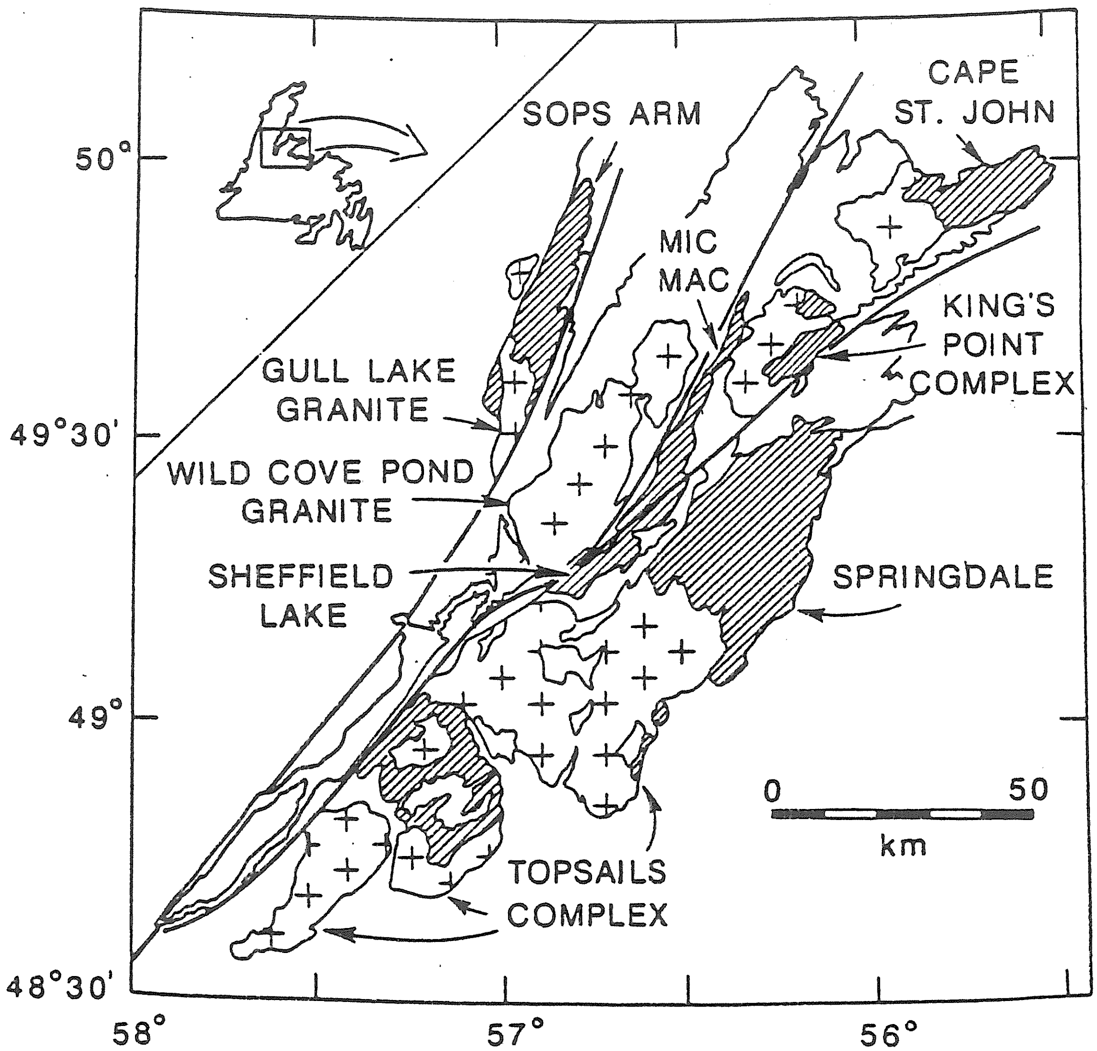


Fig. 2. A generalized ash-flow caldera cycle based on a composite of features from a number of calderas (after Lipman, 1984). A. "Pre-collapse volcanism. Clustered intermediate- composition strato-volcanoes form over isolated small high-level plutons that mark the beginning of accumulation of a batholith-sized silicic magma body that will feed ash-flow eruptions. Uplift related to emplacement of the plutons leads to the development of arcuate ring fractures which form the sites of subsequent caldera collapse (dotted lines). Heavy arrows indicate upward movement of magma. B. Caldera geometry just after ash flow eruptions and concurrent caldera collapse. Central area of clustered earlier volcanoes caves into collapsed caldera. Intracaldera tuff ponds during subsidence and is an order of magnitude thicker than cogenetic outflow ash-flow sheet. Initial collapse along ring faults is followed by slumping of oversteepened caldera walls and accumulation of voluminous collapse breccias that interfinger with ash-flow tuffs in the caldera fill sequence. Caldera floor subsides asymmetrically and is tilted to the left side of the diagram. Main magma body underlies entire caldera area and is compositionally zoned prior to eruption, becoming more mafic downward. C. Resurgence and post-caldera deposition. Resurgence is asymmetrical, with greatest uplift in area of greatest prior collapse. Extensional graben faults form over crest of the dome. Some resurgent uplift is accomodated by movement along ring faults in the sense opposite that during caldera subsidence. Magma body has risen into volcanic pile and intrudes cogenetic intracaldera welded tuff. Original caldera floor has been almost entirely obliterated by rise of the magma chamber to near the level of pre-volcanic land surface. Caldera moat is partly filled by lava domes and volcaniclastic sediments. Hydrothermal activity and mineralization become dominant late in the cycle.



. 3a. Distribution of the Springdale Group and correlative volcanic and plutonic rocks of west-central Newfoundland.

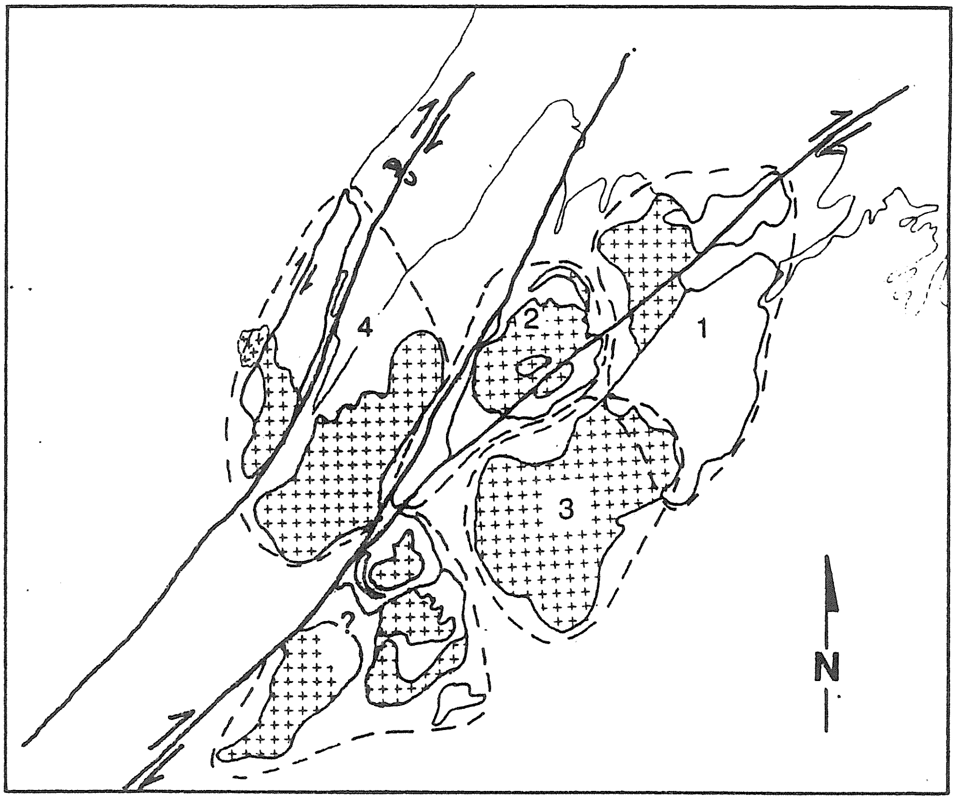


Fig. 3b. Proposed reconstruction of Silurian(-Devonian?) volcano-plutonic sequences of western Newfoundland. It is possible that the dominantly dextral strike-slip faulting which affected this area, although extending into the Carboniferous, was active during volcanism and provided some control of caldera development. This reconstruction allows for at least five large calderas and possibly a number of smaller nested ones. "Caldera No. 1" includes the Springdale and Cape St. John Groups and the Cape Brule Porphyry. No. 2 includes the King's Point Complex and Sheffield Lake Group. No. 3 is the mainly plutonic northern lobe of the Topsails Complex. No. 4 includes the Wild Cove Pond, Gull Lake and Devils Room plutons and the Sops Arm Group. The question mark area encloses a number of volcano-plutonic circular structures which may represent smaller nested cauldrons.

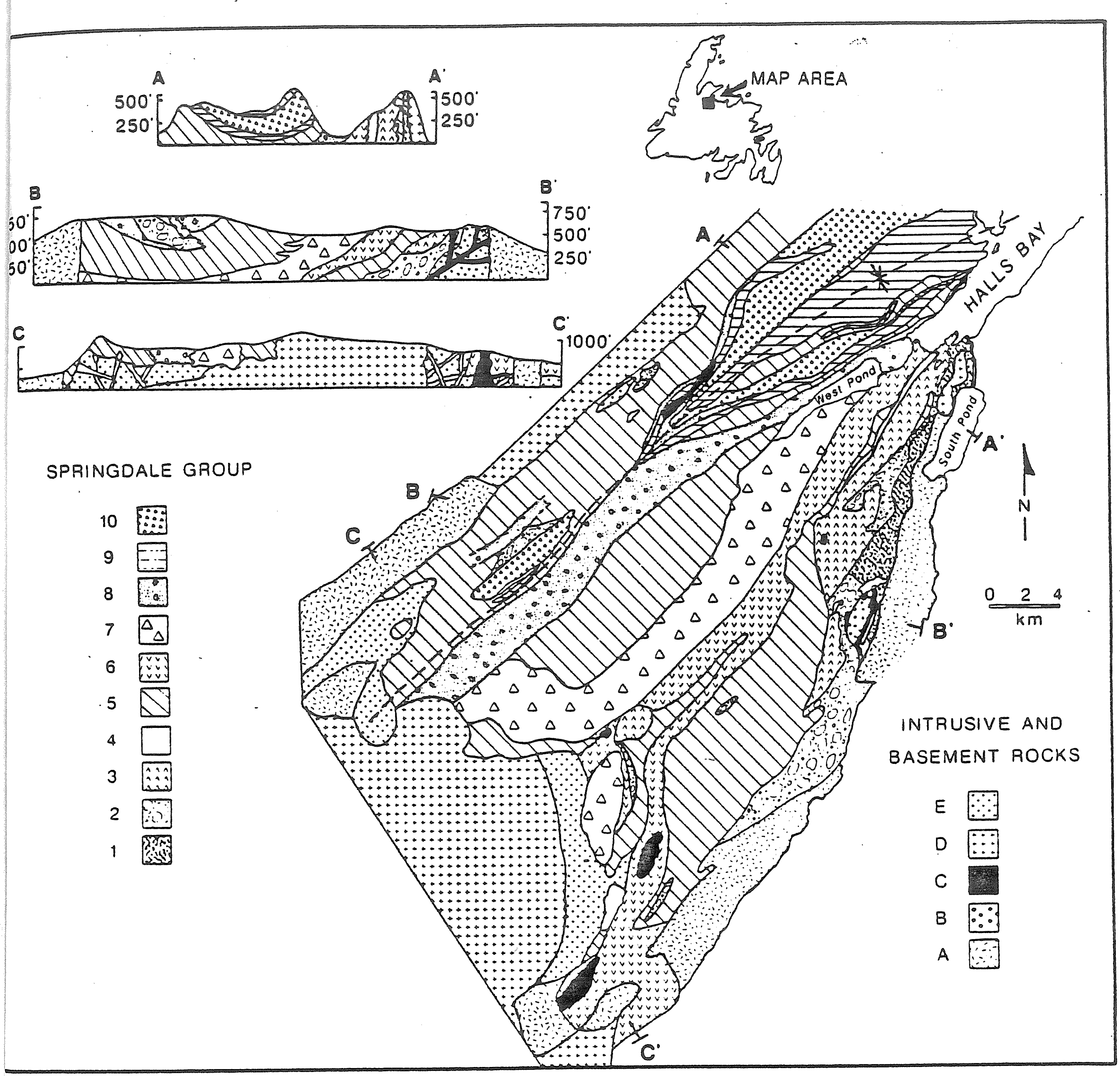


Fig. 4. Generalized geology of the Springdale Caldera, Newfoundland.

Legend for Figure 4

SPRINGDALE GROUP

10. CRYSTAL-LITHIC TUFF. Densely welded and massive; large phenocrysts of quartz and K-feldspar; clasts of mafic and ultramafic lithologies.

9. CLASTIC SEDIMENTARY ROCKS. Red conglomerate, sandstone, sandy siltstone, local caliche horizons; cross-bedding, ripples, laminations, rip-up horizons, scour channels, etc. indicate stream-flood and proximal and distal fluviatile origin; clasts are essentially of volcanic provenance, with rare basement lithologies, especially in the northwest.

8. RHYOLITIC VITRIC ASH-FLOW TUFFS AND BRECCIAS. Welded, devitrified, locally massive; areas of unwelded vitroclastic air fall scoria with large individually devitrified shards, locally passing into sandstone; alternating cm-thin basaltic and silicic bands may indicate magma mixing.

7. DACITIC TO RHYOLITIC ASH-FLOW TUFFS, VITROCLASTIC BRECCIAS AND DOMES. Massive, vitric, strongly welded; curviplanar joint surfaces in the domes with internal plastic shear zones, local brecciation and flow-folds; tuffs locally have crystals of plagioclase and rare quartz.

6. SILICIC ASH-FLOW TUFFS. Basal lithophysae-rich horizons grade upwards into partially weldedcrystal-lithic lapilli tuff; pumice bombs up to a metre long by several cm thick; clasts of silicic volcanics, andesite and rarely basalt; crystal fragments of plagioclase, K-feldspar and quartz.

5. FLOWS. Mainly basalt, some of intermediate composition; locally plagiophyric; variably altered to lower greenschist facies assemblages; amygdales of quartz, calcite and chlorite.

4. CRYSTAL-LITHIC AND LAPILLI ASH-FLOW TUFFS. Felsic to intermediate, but dominantly dacitic; clasts of andesite, dacite, rhyolite; angular and flattened pumice; variably welded.

3. FLOWS. Mainly andesite to dacite, both locally plagiophyric; massive to flow-foliated to brecciated; locally massive andesite may be small intrusions.

2. MEGABRECCIA. laharic flows, tuffites and pepperites, volcanic conglomerates and breccias; red sandstones.

1. WELDED LITHIC-CRYSTAL TUFF. Crystals of plagioclase and K-feldspar, accessory biotite, quartz and rare opaques; clasts of granophyre, plagiophyric basalt, ultramafics and jasper.

INTRUSIVE AND BASEMENT ROCKS

E. GRANITE. Medium to coarse grained, crystals of quartz and pink K-feldspar and finer grained black amphibole; intruded by finer grained grey-white granite, with local riebeckitic pegmatite and abundant amphibole-lined miarolitic cavities and fractures; offshoots of the Topsails complex.

D. GRANITE / QUARTZ SYENITE. Red, medium grained, with phenocrysts of quartz, K-feldspar, amphibole and biotite.

C. HIGH-SILICA DOMES, DYKES AND SILLS. Microphenocrysts of quartz and feldspar , with finely disseminated groundmass riebeckite; flow-foliated, autobrecciated, zones with intense development of spherules and other indications of gas-streaming.

B. MICRODIORITE. Black, fine grained and massive.

A. AMPHIBOLITE, GABBRO, DIORITE, GRANODIORITE, GRANITE. Foliated amphibolite and gabbro screens and xenoliths in foliated diorite and granodiorite, intruded by variably deformed tonalite and amphibole-biotite granite; intruded and net-veined by pale fine-grained granite.