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Structural Geology of the Bathurst-Newcastle District

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STRUCTURAL GEOLOGY OF THE BATHURST-NEWCASTLE DISTRICT

INTRODUCTION

The Bathurst-Newcastle district is composed of three regional structural units (Smith and Skinner, 1958):

(1) The Ordovician Folded Belt (including the highly deformed and regionally metamorphosed rocks of the Early to Middle Ordovician Tetagouche Group).

(2) The Silurian Folded Belt (corresponds to the Silurian-Devonian Folded Belt (Davies, 1966) and includes the Middle to Upper Silurian and Lower Devonian rocks north of the Ordovician Folded Belt).

(3) The Pennsylvanian Cover (flat-lying red beds of Carboniferous age that unconformably overlie all older strata).

This field trip is concerned with the structural evolution of the oldest unit, the Ordovician Folded Belt (Fig. 1), an area of approximately 1600 square miles corresponding to the northeastern end of the Miramichi geanticline of Poole (1967). The structural information conveyed in this guide is based on mapping of four areas by the present author (Fig. 1, 3: Table 1).

STRATIGRAPHY

The area is underlain by the Early to Middle Ordovician Tetagouche Group. The stratigraphic sequence adopted here (Helmstaedt, 1971, Helmstaedt and Skinner, in preparation) differs from previous lithologic subdivisions by distinguishing two sedimentary units, one at the base of the Tetagouche Group and predating the volcanic sequence, and the other interlayered with and overlying the volcanic rocks and partially derived from them (Fig. 2). The lower sedimentary sequence is characterized by light-colored arenaceous rocks ranging in composition from orthoquartzite to lithic and arkosic sandstones and feldspathic greywacke, all of which are interlayered with grey-colored slates. These relatively mature sedimentary rocks represent the substratum of the volcanogenic part of the Tetagouche Group and are correlated with Early to Early Middle Ordovician quartzites from Central New Brunswick (Poole, 1963) (Fig. 2). The volcanogenic sequence begins with acidic pyroclastics ("porphyries") and large volumes of rhyolitic rocks. Two major centers of rhyolitic volcanism can be distinguished (Fig. 1). Some intermediate to basic volcanics are interlayered with the rhyolitic rocks, but most basic rocks overly the rhyolitic volcanics. The volcanic pile is

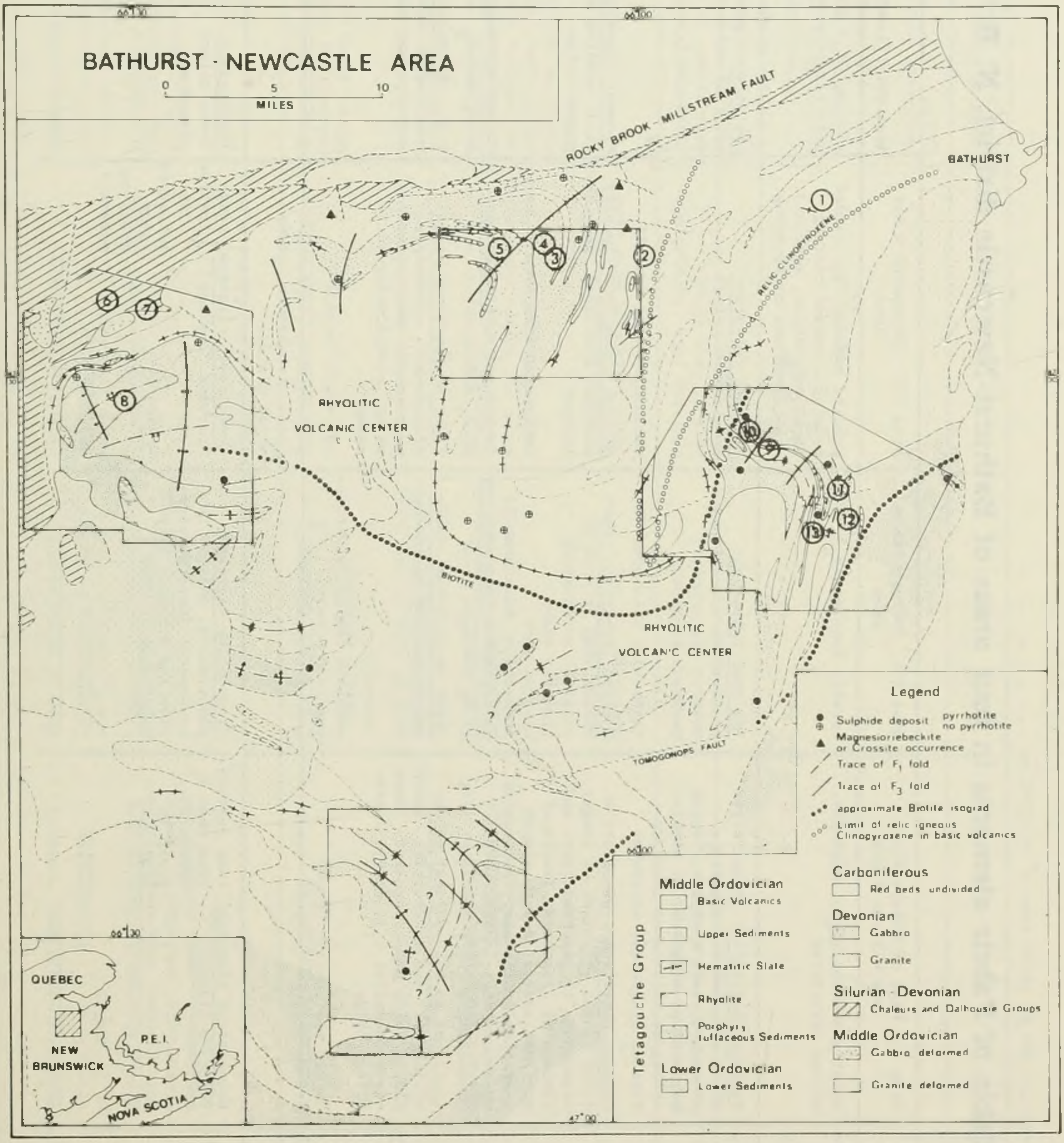

Fig. 1 Structural compilation map of Bathurst-Newcastle district by Helmstaedt and Skinner (manuscript in preparation). Areas outlined (see also Figure 3) are after Helmstaedt (1970, 1971, in press). Geology of Brunswick Mines area (Area III) modified after Boyle and Davies (1964), Stockwell and Tupper (1966) and D. Rutledge (unpublished maps). Remainder of the area modified after Davies (1968) and published maps of the New Brunswick Mineral Resources Branch and the Geological Survey of Canada.
Blank areas: no firsthand structural information.
Encircled numbers correspond to field trip stops in road log.

Table I Table of Fabric elements in four areas of Bathurst-Newcastle district, N. B.

Phase of Def.	Fabric element	Area I: Head of Middle River and Wildcat Brook	Area II: Portage Lakes Area	Area III: Brunswick Mines Area	Area IV: Clearwater Area
	Primary Structures	Locally bedding (S_0), amygdules, pillow structures	Locally bedding (S_0)	Locally bedding (S_0) graded bedding, crossed bedding, local sole marks, possible pre-lithification slumping	Bedding (S_0) graded bedding very rarely preserved
First (D_1)	Planar Fabric (S_1)	Regional foliation: penetrative steep schistosity, phyllitic cleavage, slaty cleavage, caused by parallel alignment of phyllosilicates, flattened porphyroclasts, fragments, amygdules	Regional foliation: penetrative (except in massive greenstones) moderate to steep (otherwise like Area I)	Regional foliation: penetrative, steep (otherwise like Area I)	Foliation: penetrative, original orientation probably steep, in many instances transposed along S_2
	Linear Fabric (L_1)	Mineral Lineation: penetrative, steep linear alignment of longer dimensions of porphyroclasts and lenticular fragments, trails of phyllosilicates, and in places C-axes of amphiboles. Rodding of quartz veins. In sediments intersection of S_1 and S_0	Mineral lineation: less common than in Area I, original orientation probably steep (otherwise like Area I) In sediments intersections of S_1 and S_0	Mineral lineation: locally strongly developed, generally steeper (otherwise like Area I) In sediments intersections of S_1 and S_0	Mineral lineation: rarely seen, local rodding of quartz veins In sediments intersections of S_1 and S_0
	Folds (F_1)	Isoclinal to subisoclinal folds: microscopic and mesoscopic: macroscopic folds not recognized. Axes steep (parallel L_1), mostly intrafolial folds	Tight to isoclinal folds: mesoscopic and macroscopic	Tight to isoclinal folds: microscopic, mesoscopic, macroscopic axial planes steep, plunge moderate to steep.	Tight to isoclinal folds: mesoscopic (mostly intrafolial) macroscopic.
	Faults	?	possible low angle thrusting	low angle thrusts	?
Post-D_1				local crenulation, steep axial planes	
Second (D_2)	Planar Fabric (S_2)	Crenulation cleavage, Fracture cleavage: less penetrative than S_1 moderately steep to shallow	Crenulation cleavage: penetrative, shallow to horizontal (more penetrative and stronger developed than in Area I)	Crenulation cleavage, Fracture cleavage } penetrative in schistose rocks, steep to moderate	Schistosity, Crenulation-cleavage: very penetrative, in many places major plane of anisotropy, shallow to horizontal

	Linear Fabric (L_2)	Axes of crenulations, normally observed on S_1, intersection of S_1 and S_2	Axes of crenulations, intersections of S_2 and S_1 and S_2 and S_0	Axes of crenulations, intersections of S_2 and S_1, S_2 and S_0	Axes of crenulations (mostly obliterated by D_3) intersections S_2 and S_1
	Folds (F_2)	Mostly asymmetric tight to open crenulations, some chevron folds: microscopic, mesoscopic, locally macroscopic. Axes moderate to shallow	Crenulations: microscopic mesoscopic recumbent, shallow to horizontal axes	Crenulations: tight to open, mesoscopic	Crenulations: isoclinal to open, microscopic, mesoscopic recumbent
	Faults	?	?	small lateral offsets along S_2	?
Third (D_3)	Planar Fabric (S_3)	No penetrative cleavage, local joints and tension gashes	Crenulation cleavage, Fracture cleavage } locally developed, vertical	No penetrative cleavage	Crenulation cleavage: penetrative in schistose rocks, steep to vertical
	Linear Fabric (L_3)	Axes of kink folds	Axes of fine crenulations mainly on S_2 but also on S_1	Axes of kink bands (shallow and steep	Axes of crenulations: very penetrative (on S_2)
	Folds (F_3)	Local kink folds, asymmetric and conjugate sets. Large regional fold (Tetagouche antiform), steep axis	Kinks, chevron folds, open folds, microscopic mesoscopic, macroscopic shallow axes	Kink bands (shallow and steep sets) age relationships not known, mesoscopic; regional folding, steep axes	Crenulations: tight to open microscopic mesoscopic, macroscopic, upright, horizontal axes. A-C joints connected with mesoscopic folds.
	Faults	?	faults associated with upwarping	? faulting with relatively large horizontal slip components	?
Post-D_3*		Faults and various joint sets, may in part be caused by D_3	Faulting (?)	Faulting (i.e. lateral offsets of late dykes)	
Fourth (D_4)	Planar Fabric (S_4)				Fracture and crenulation cleavage, steep, very local
	Linear Fabric (L_4)				Local crenulation, intersection of S_4 and older S-planes
	Folds				Local open folds upright, mesoscopic
	Faults				?East-West faults (Tomogonops fault)
Post-D_4					Faulting (could be related to D_4), or later

* Post-D_3 in Areas I, II and III may be later than D_4 of Area IV.

thickest in the center of the district and thins towards the margins (Fig. 2). In the northeastern part the abundance of rhyolitic rocks decreases and the main volume of volcanics consists of basic rocks interlayered with greywackes and slates. The massive sulphide deposits are related to the early rhyolitic volcanism and are concentrated in the porphyries near the upper boundary of the basal sediments (Fig. 2). Oxide, silica, and carbonate facies of iron formation as well as hematitic slates occur at a similar stratigraphic level as the sulphide deposits. The upper sedimentary sequence is characterized by lithic greywackes and dark grey to black slates. Most of these sediments are typical first cycle weathering products of volcanic rocks. Towards the margins of the district, where the volcanic rocks pinch out, there appears to be a gradational transition from lower to upper sediments. Although the Tetagouche Group as a whole was generally considered to be of Middle Ordovician age, it is now clear that the two fossil occurrences on which this age assignment is based are in the upper part of the sequence (Fig. 2). A bituminous limestone occurring between basic volcanics of Camel Back Mountain in the northwestern part of the area yielded trilobite and conodont faunules that are of Early Porterfield age (approx. zone 11 of Berry, 1962) (W. T. Dean, personal communication, 1971). Black slates of the upper sedimentary sequence near Bathurst contain graptolites which were described by Ami (1905) and Alcock (1941). An examination of this fauna by W. T. Dean of the Geological Survey of Canada (oral communication, 1971) indicated that these graptolites are clearly younger (zone 12 to 13 of Berry, 1962) than the trilobite and conodont fauna from the limestone lens at Camel Back Mountain.

Rocks of the Tetagouche Group are intruded by small stocks of gabbro and granites that were deformed and regionally metamorphosed together with their country rocks. Large bodies of granitic rocks including only minor amounts of gabbros post-date most of the deformation and regional metamorphism of the Tetagouche Group.

REGIONAL METAMORPHISM

Regional metamorphism increases from the northeast to the southwest along the axis of the Miramichi geanticline. In the northeast subgreenschist assemblages containing prehnite and pumpellyite are locally preserved within the area characterized by the occurrence of relic igneous clinopyroxene in the basic volcanic rocks (Fig. 1). The rocks north of a line connecting Brunswick Mines and Portage Lakes and in the southeastern part

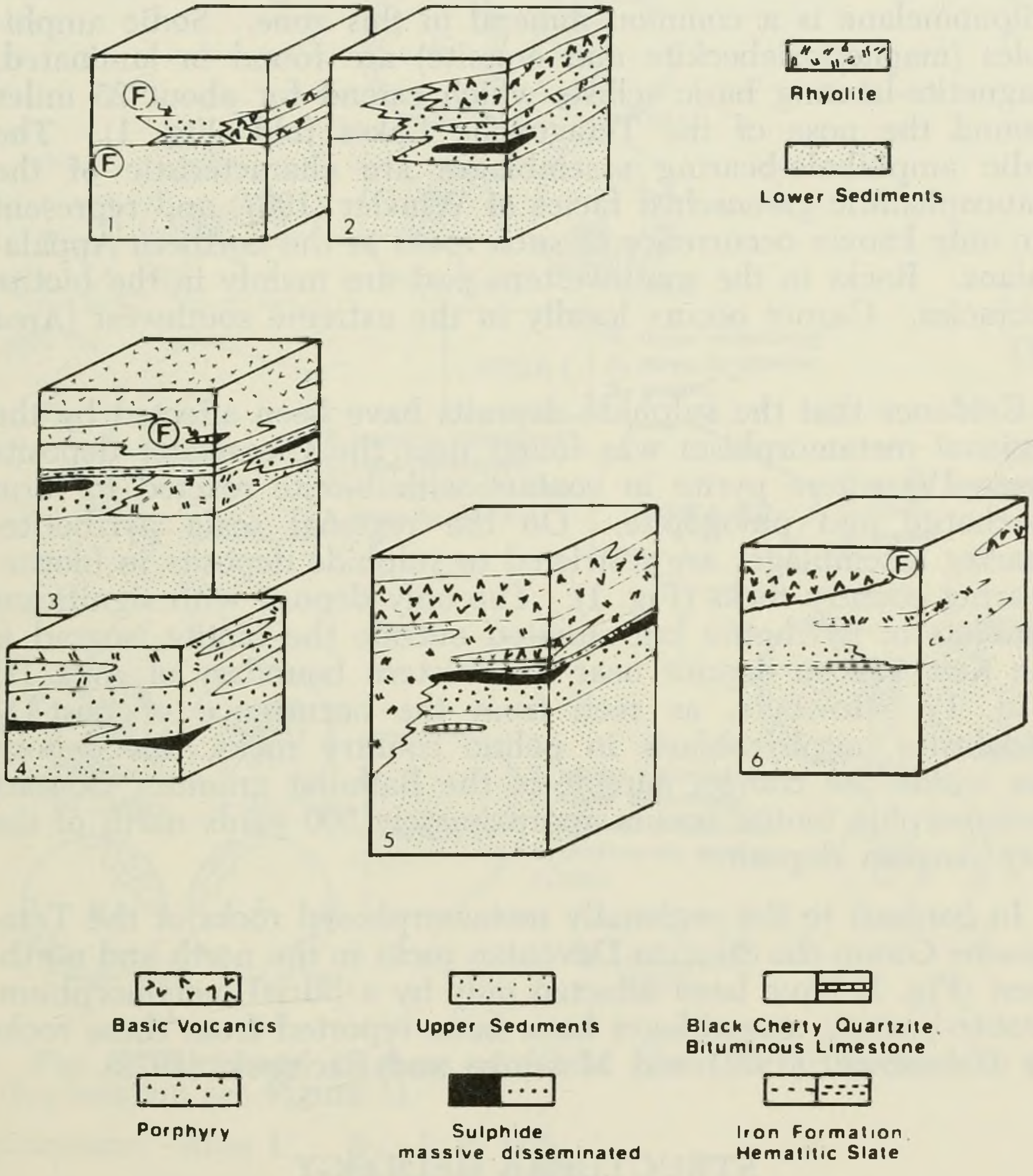

Fig. 2 Diagram illustrating stratigraphic relationships of Tetagouche Group to Ordovician rocks of Central New Brunswick.

1. Hayesville Area, Central New Brunswick (Poole, 1963).
2. Clearwater area (Area IV), (Helmstaedt, in press).
3. Portage Lakes area (Area II), Helmstaedt (1971).
4. Heath Steele area, modified after McMillan (1969).
5. Brunswick Mines area (Area III), (Helmstaedt, in press: modified after Boyle and Davies, 1964, and Stockwell and Tupper, 1966.)
6. Lower parts of Tetagouche and Middle Rivers (Helmstaedt and Skinner, in preparation).

(Fig. 1) are in the chlorite subfacies of the greenschist facies. Stilpnomelane is a common mineral in this zone. Sodic amphiboles (magnesioriebeckite and crossite) are found in laminated, magnetite-bearing basic schists which extend for about 25 miles around the nose of the Tetagouche Lakes fold (Fig. 1). The sodic amphibole-bearing assemblages are characteristic of the glaucophanitic greenschist facies of Winkler (1967) and represent the only known occurrence of such rocks in the northern Appalachians. Rocks in the southwestern part are mainly in the biotite subfacies. Garnet occurs locally in the extreme southwest (Area IV).

Evidence that the sulphide deposits have been affected by the regional metamorphism was found near the Clearwater deposits (Area IV) where pyrite in contact with biotite reacted to form pyrrhotite and phlogopite. On the regional scale pyrrhotite-bearing assemblages are restricted to sulphide deposits in biotite-bearing country rocks (Fig. 1). The only deposit with significant amounts of pyrrhotite but situated outside the biotite isograd is the Key Anacon deposit near the western boundary of Area III (Fig. 1). However, as seen from the occurrence of post-D_2 andalusite porphyroblasts in pelitic country rocks, this deposit lies within the contact aureole of the Bathurst granite. Contact metamorphic biotite occurs approximately 500 yards north of the Key Anacon deposit.

In contrast to the regionally metamorphosed rocks of the Tetagouche Group the Silurian-Devonian rocks in the north and northwest (Fig. 1) have been affected only by a burial metamorphism. Zeolite-bearing assemblages have been reported from these rocks by Helmstaedt (1971) and Mossman and Bachinski (1972).

STRUCTURAL GEOLOGY

Three regionally developed sets of structures are developed in all four areas (Figs. 1, 3). The observed fabric elements are summarized on Table I. Additional fabric elements are found locally (for instance, the local post D_1 crenulation cleavage in Area III, and D_4 structures in Area IV), but they do not appear to influence the overall geometry.

D_1 was accompanied by regional metamorphism throughout the region. The continuation of metamorphic conditions beyond D_1 is indicated by porphyroblasts of stilpnomelane (Areas I and II), stilpnomelane, muscovite, and biotite (Area III), and albite, muscovite and biotite (Area IV), that cut across the S_1 foliation. Progressive metamorphism had essentially subsided during D_2

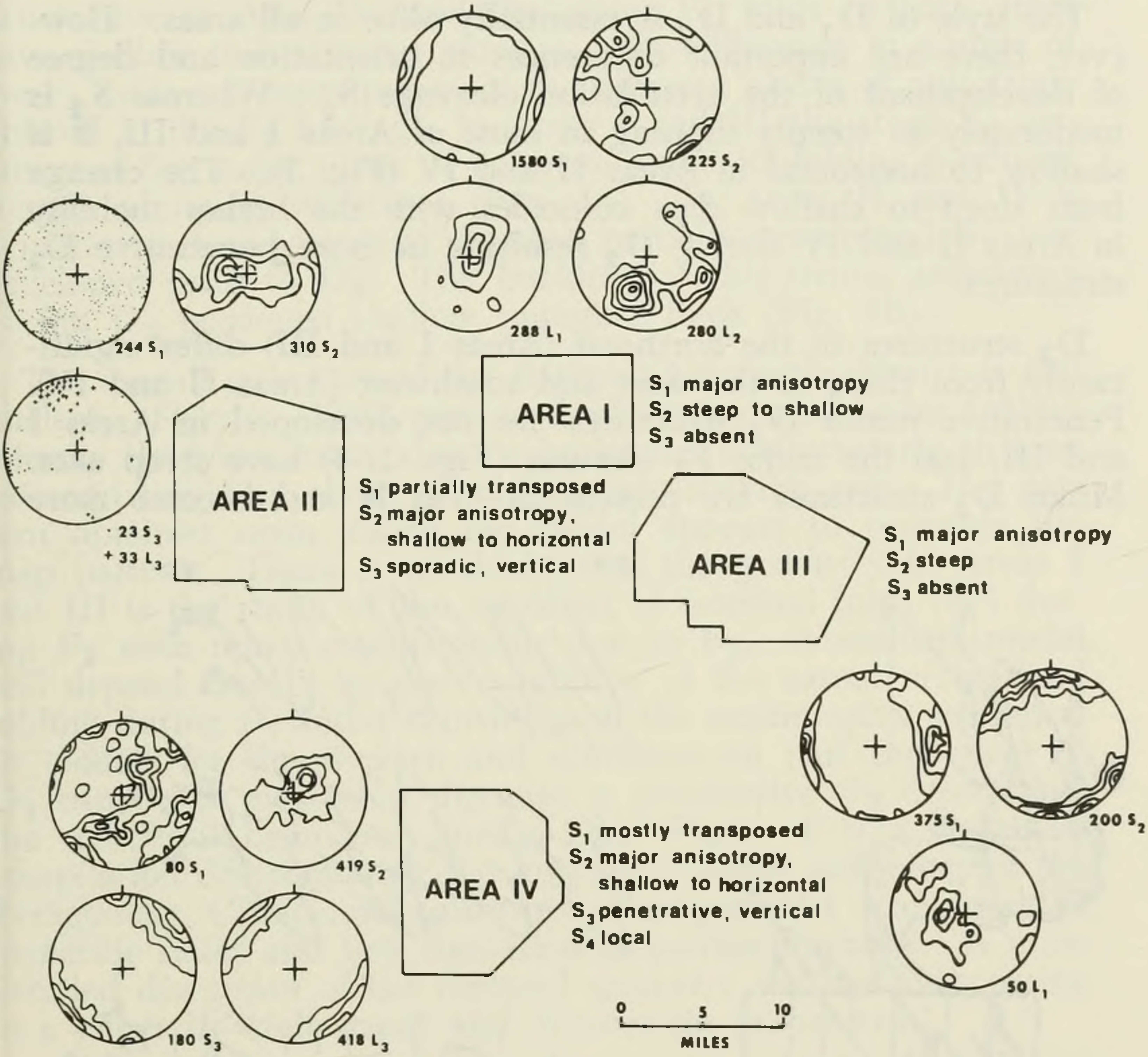

Fig. 3 Summary diagram of fabric elements in Areas I to IV (for location see Figure 1).

Contours:	Area I	S_1	1, 3, 12%
		S_2	1, 2, 4, 6%
		L_1	1, 5, 10%
		L_2	1, 2, 3, 6, 9%
	Area II	S_2	1, 2, 4, 7%
	Area III	S_1 and S_2	1, 3, 6, 12%
		L_1	1, 10, 15%
	Area IV	S_1	1, 2, 4%
		S_2	1, 3, 6, 12%
		S_3	1, 3, 6, 9%
		L_3	1, 4, 10%

in areas I, II, and III, where F_2 crenulations deformed the S_1 metamorphic fabric as well as the porphyroblasts, and little or no neocrystallization was observed along S_2. Biotite continued to be stable during D_2 in the central part of Area IV, but it was retrogressively metamorphosed to chlorite during D_3.

The style of D_1 and D_2 is essentially alike in all areas. However, there are important differences in orientation and degree of development of the crenulation cleavage S_2. Whereas S_2 is moderately to steeply dipping in most of Areas I and III, it is shallow to horizontal in Areas II and IV (Fig. 3). The change from steep to shallow dips coincides with the higher mobility in Areas II and IV during D_2 resulting in more penetrative D_2 structures.

D_3 structures in the northeast (Areas I and III) differ significantly from those in the west and southwest (Areas II and IV). Penetrative minor D_3 structures are not developed in Areas I and III, and the major F_3 closures (Figs. 1, 4) have steep axes. Minor D_3 structures are present in Area II and become more

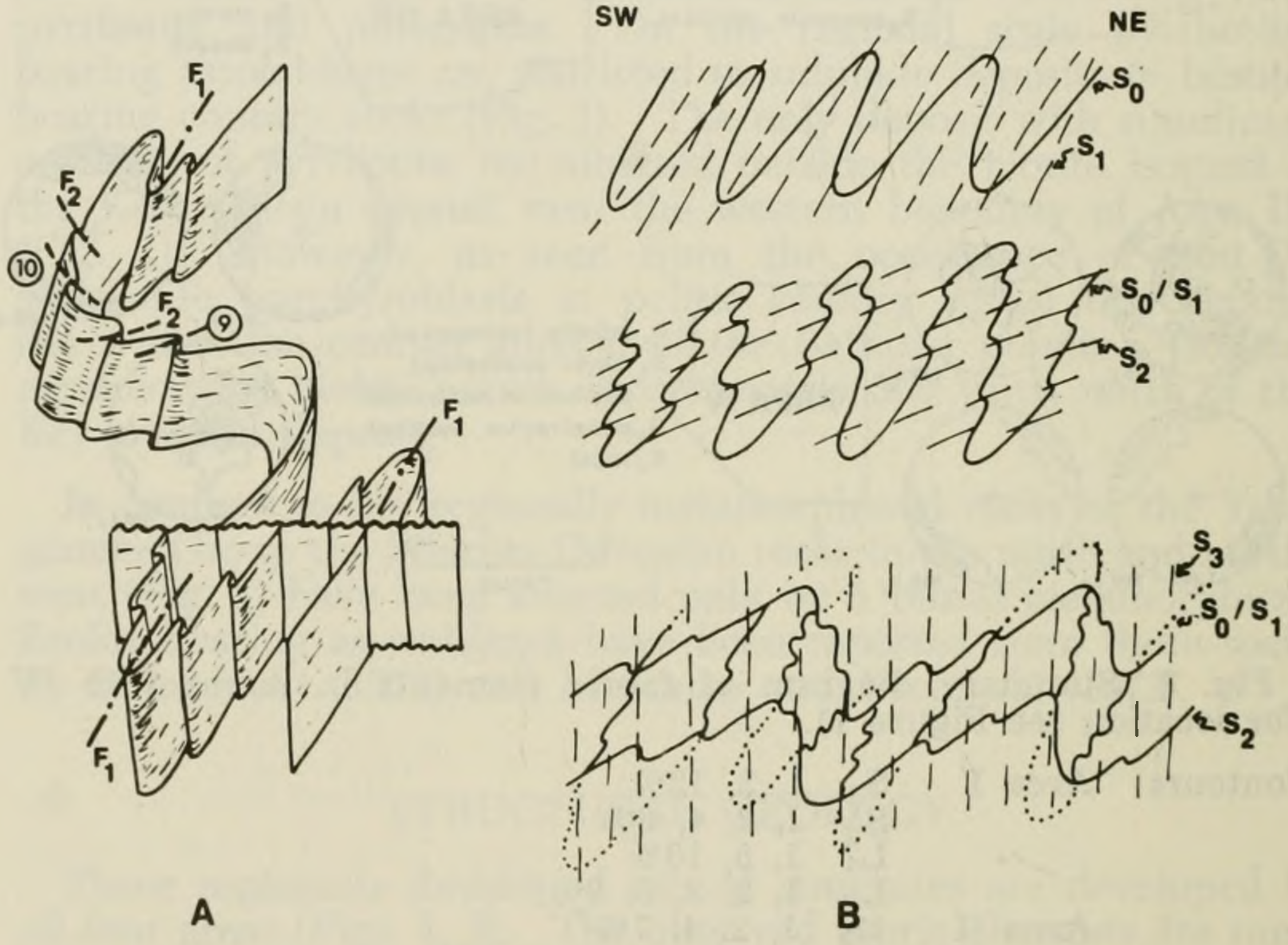

Fig. 4 Sketches illustrating difference in structural style between northeastern and southwestern parts of Bathurst-Newcastle district.

A. Diagram illustrating folding of S_0 in Area III (see Figure 1). Not to scale.
Note the consistent z-sense of asymmetry of F_2 in folds around steeply plunging F_3 closure.
Numbers correspond to field trip stops in road log.

B. Hypothetical sections showing the structural evolution in Area IV. Interference patterns as illustrated in the lower diagram have been observed on the mesoscopic scale. F_3 folds have horizontal axes and a penetrative S_3 as axial plane cleavage.

penetrative in Area IV, and the major F_3 folds in both areas have shallow to horizontal plunges. The difference in plunge of the F_3 folds is a consequence of the different planes of anisotropy utilized in the F_3 folding. In Areas I and III the steep S_1 surface was the major plane of anisotropy and its folding produced steeply plunging structures (Fig. 4A). In Areas II and IV a penetrative near-horizontal S_2 that partially transposed S_1 was developed prior to D_3. The buckling of this strong anisotropy during D_3 produced shallow plunging folds (Fig. 4B).

The overall geometry of the Bathurst-Newcastle district is still unclear. Skinner (1956) produced plasticine models by folding initially flat-lying strata about a horizontal northwesterly striking axis and refolding about a northeasterly striking axis. The pattern obtained upon slicing the model appears to resemble the map pattern. There is no doubt that the geometry in Areas I and III is the result of the refolding of isoclinal folds (F_1) during F_3 with minor modifications due to F_2. A realistic model will depend largely on the recognition of the extent of isoclinal folding during F_1 and a knowledge of the stratigraphic sequence. In models for the western and southwestern part the effect of D_2 cannot be neglected, because a penetrative S_2 determined the structural behaviour during D_3. Figure 1 is a structural compilation differentiating the lower and upper sediments of the Tetagouche Group and showing the potential usefulness of hematitic slates and iron formation as marker horizons. A more detailed discussion of the regional geometry will be forthcoming in a paper by Helmstaedt and Skinner (in preparation).

The Ordovician Folded Belt is generally regarded as a Taconic folded zone that has been refolded during the Acadian orogeny (Smith and Skinner, 1958; Neale et al., 1961; Poole, 1967; Davis, 1972). Evidence that D_1 and D_2 fabrics in Area II are pre-Upper Silurian was presented by Helmstaedt (1971). Although there is uncertainty as to the age of D_3, the lack of a geometric correlation of structures in the Silurian-Devonian with those of the Tetagouche Group in Area II (Helmstaedt, 1971; Helmstaedt and Skinner, in preparation), and the direct correlation of penetrative D_3 structures to areas that reached higher grades of regional metamorphism during the Taconian orogeny appear to be stronger arguments in favour of a late Taconian age of D_3. A K-Ar age of 424 $\pm$ 17 m.y. of muscovite from a gneiss in Area IV in which D_3 was most penetrative suggests that at least in this area the D_3 event was pre-Devonian. If D_3 was indeed part of the Taconian Orogeny, the penetrative effect of Acadian movements on the Tetagouche basement, apart from faulting, cannot have been profound.

THE POSITION OF THE MASSIVE SULPHIDE DEPOSITS WITHIN THE STRUCTURAL SEQUENCE

Structural studies strongly support a volcanogenic origin of the massive sulphide deposits in the Tetagouche Group. The major control of the orebodies is not structural, but stratigraphic; the sulphides are confined mainly to the upper contact of the lower sedimentary sequence and the porphyries immediately over-lying the sediments (Fig. 2). The location of an orebody is the consequence of the relationship between volcanic centers (Fig. 1) and the basin configuration as originally suggested by Holyk (1957), Stanton (1959), and McAllister (1960). The ore formation predates penetrative deformation and regional metamorphism (Helmstaedt, 1971) and the geometry of the ore bodies varies with the structural style of the host rocks.

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LOG AND STOPS

MILEAGE

0	START – Bathurst, City Motel
	Highway 11 to West Bathurst
1.9	Turn south on road to Tetagouche Falls.
9.4	STOP 1 – Tetagouche Falls outcrops near Falls and on road showing crystal tuff, red manganiferous slates and upper sediments.
	Continue past Imhoff onto new road to St. Quentin (under construction)
18.7	STOP 2 – Road cut, deformed pillow lava
24.2	STOP 3 – Metavolcanic rocks on N-S limb on Tetagouche fold. Steep S_1, L_1, shallow southerly plunging L_2 occasional S_2.

24.7 Turn north on lumber road, proceed 0.6 mile to north.

STOP 4 – Just south of South Tetagouche River. "Augenschist" with feldspars and quartz elongated along near-vertical L_1. Return to St. Quentin road, proceed to west.

25.9-26.3 STOP 5 – Stilpnomelane-bearing metarhyolite on E-W limb of Tetagouche fold. L_2 shallow plunging to SE and E.

Following stop 5 there are two options to be decided depending on road conditions, weather, and preference of participants on field trip.

Option I Continue westwards past Caribou Mines into 18 Mile Brook area on lumber roads, approximately 15 miles.

STOP 6 – SE Depot on Upsalquitch River containing pebbles of Tetagouche Group. Upper Silurian conglomerate.

STOP 7 – 19 Mile Brook. Unconformity of Upper Silurian conglomerate on Tetagouche Group basic metavolcanics.

STOP 8 – Upsalquitch Lake. Southwest of old Lumber Camp near north end of Lake. Structures in lower sedimentary unit.

Additional stops if time permits. Return via Dalhousie.

Option II Return from stop 5 to Bathurst and take Bathurst Mines Road.

0 Bank of Montreal, center of Bathurst.

16.9 Junction to Brunswick No. 12 Mine.

Continue towards Brunswick No. 12.

19.9 STOP 9 – Papineau River
"Augenschist" on E-W limb of F_3-fold
NE striking S_2 (See fig. 4A).

21.1 STOP 10 – Just before Brunswick No. 12 Mine turn SW across Hauling Road. Walk towards Papineau River, N-S limb of F_3-fold, SE striking S_2 (See Fig. 4A).

24.3 Return to junction to Brunswick No. 6, go south towards Brunswick No. 6.

25.4 Turn left (east) towards Grand Falls.

26.3 STOP 11 – Road bends to south.

Outcrop of Lower sediments.

27.9 STOP 12 – Nepisiguit Falls. Quartz-feldspar augenschist ("porphyry").

Contact to Lower sediments below falls.

Continue east along Nepisiguit River.

STOP 13 – Austin Brook Iron Mine. Minor structures in oxide and sulphide facies of iron formation and their country rocks.

Return to Bathurst.