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A STUDY OF THE MEGUMA TERRANE IN LUNENBURG COUNTY, NOVA SCOTIA

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ABSTRACT

Cambro-Ordovician clastic metasediments , Devono-Carboniferous granitoids and hypabyssal rocks , Lower Carboniferous carbonates and evaporites , and a Triassic-Jurassic dolerite dyke comprise the Meguma Terrane in south-central Lunenburg County , Nova Scotia .

The flyschoid Cambro-Ordovician Meguma Group is separated into three formations and seven members in the study area , most of which vary considerably in thickness . From oldest to youngest , these units are the Goldenville Formation (New Harbour member) , the Green Bay formation (Rissers Beach , West Dublin , Tancook and Moshers Island members) and the Halifax Formation (Cunard and Feltzen members) . The concretionary green beds of the Green Bay formation are regionally correlatable with the Goldenville-Halifax transition (GHT) zone of the Meguma Group . The 1-2 km thickness of the GHT in south-central Lunenburg County is , however , three orders of magnitude larger than GHT thicknesses in nearby counties . Some members of the Green Bay formation are lateral facies equivalents of each other ; only the metalliferous Moshers Island member is present throughout the study area . The Lunenburg GHT was deposited in local , tectonically unstable basins , which continued to subside after they had been blanketed by the regionally extensive Cunard member of the Halifax Formation .

Strata belonging to the Meguma Group were paratectonically shortened in the Devonian Acadian Orogeny . Deformation produced upright periclinal folds and steep foliations typical of the slate belt association . The alteration of Meguma clastics to chlorite-grade metasediments began during diagenesis and continued with regional dynamothermal metamorphism . High temperature-low pressure contact metamorphism associated with intrusion of Devono-Carboniferous granitoids postdated the regional folding event . Deformation persisted , however ,in the innermost part of the contact aureole of the South Mountain batholith , where schistose hornfelses record relatively large strains and are locally refolded . The Lower Carboniferous Windsor Group unconformably overlies metasediments , hornfels and granitoids . It is folded , faulted and regionally fractured along with the basement rocks . Brittle-ductile deformation of Mesozoic dolerite and Cambro-Ordovician metasediments occurred during and after the emplacement of the Shelburne dyke .

The map boundaries of the Cunard member of the Halifax Formation are identifiable on total field and vertical gradient aeromagnetic maps of south-central Lunenburg County . An independent analysis of the outcrop and shallow-level subcrop of the Cunard member is provided by the geophysical data , which can be

used in interpreting the regional structure of the Meguma Group .

Precious metal , base metal and granophile element mineralization occur in the Meguma Group , the Windsor Group and the South Mountain batholith . Epigenetic gold mineralization is present in quartz-carbonate lodes hosted by altered metasediments . Auriferous vein arrays comprising several diagnostic sets originated during the folding and faulting of the Meguma Group . U-W-Mo-Ag-Cu greisens in granitoids of the South Mountain batholith are located near intrusive contacts with manganiferous strata of the GHT , themselves a potential source of syngenetic base metals .

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INTRODUCTION

Rocks within the study area record , in large part , the Paleozoic and Mesozoic evolution of the Canadian Appalachian Meguma Terrane , particularly the economically important , gold-bearing , sedimentary strata of the Meguma Group . Since the local succession of Meguma Group rocks is notably thick , lithologically heterogeneous , simply folded and weakly metamorphosed , it provides an ideal opportunity to study one of the most extensive , distinctly non-volcanic , Lower Paleozoic flysch basins in the Appalachian orogenic belt .

Location

The area mapped for this report is located in Nova Scotia 75 km southwest of the capital city of Halifax in the South Shore district of the province (Figure 1) . Protected coves , bays and islands offer an abundance of magnificent coastal sections . In contrast , low-relief , heavily-forested , inland regions are dominated by broad river valleys and poorly-incised dendritic streams and yield relatively few natural exposures .

The map area is situated between $44^{\circ}09'$ and $44^{\circ}40'$ north latitude and $63^{\circ}30'$ and $64^{\circ}00'$ east longitude and comprises parts of NTS map sheets 21 A/1 , 21 A/8 and 21 A/9 . An area of approximately 1700 km was systematically mapped during the 1984 and 1985 field seasons (O'Brien et al. ,1985 ; O'Brien et al. , 1987) . Five geological maps of the LaHave River and Mahone Bay areas were prepared on 1:25 000 scale and are with this report (Figure 2) .

Access

Access within and to the map area is easily achieved through an extensive network of public and private roads . Most of the islands can be reached with a small open boat ; a regularly scheduled ferry service operates between Chester Town and the Tancook islands . Several past-producing gold mines , including the Blockhouse , Indian Path , Spondo , Ovens and Gold River mines , are located in the study area but only surface exposures are accessible . They , along with numerous prospects and showings , are indicated on the accompanying maps .

Methodology

Field mapping was carried out on 1:10 000 scale , colour aerial photographs . The information collected was transferred to 1:25 000 scale topographical base maps . During each field season , a team of four mapping-geologists traversed the entire coastline , all roads and trails , most of the rivers and streams and the majority of the lakes and ponds . Forested areas devoid of these features were crossed on traverse lines spaced 0.5 km apart . All the exposures encountered during 1984 and 1985 are shown on GSC Open File Maps 1156 and 1373 . Each locality is numbered individually and described on separate field data sheets . References to exposure numbers in the figure captions relate to sample and outcrop location maps , which are presently stored in the Ottawa archives of the Geological Survey of Canada .

Scope

The objectives of this study were (1) to provide updated geological maps which could overlay the 1:25 000 scale , vertical gradient aeromagnetic maps of the region , (2) to attempt stratigraphical subdivision of the monotonous shaley flysch in the Meguma Group and to represent these strata in cross-sections of south-central Lunenburg County and (3) to comment on economic mineralization in the area mapped for this report .

The purpose of this paper is (1) to describe a revised stratigraphical succession of the Meguma Group in south-central Lunenburg County and comment on the local architecture of the Meguma flysch basin , (2) to illustrate as accurately as possible the large-scale structures affecting the study area and comment on the applicability of aeromagnetic maps in achieving this purpose , (3) to describe the geological setting and possible origin of turbidite-hosted gold deposits in the area mapped , (4) to report on a pilot study of the lithogeochemistry of an anomalously metalliferous part of the Meguma succession , and (5) to document the relationships of the Meguma Group to younger sedimentary and intrusive rocks , and report on associated geochronological studies .

Previous work

A history of greater than 60 years of geological mapping has been recorded in south-central Lunenburg County . Over this period , parts or all of the study area have been mapped at various scales , although some of these maps have emphasized one group of rocks at the expense of others (Figure 3 ; Table 1) .

The first systematic mapping of the study area was carried out by E.R. Faribault of the Geological Survey of Canada . Faribault (1924 , 1929a , 1929b) produced several 1 inch = 1 mile map sheets on which he distinguished three fundamental units . Faribault referred to his oldest unit as the 'gold-bearing series' and tentatively assigned it a Cambrian or Precambrian age . He established the gross structure of the region by separating and mapping two sedimentary formations within this series . Faribault also recognized Devonian plutonic rocks in the study area , which he demonstrated as intrusive into the 'gold-bearing series'. He mapped two major phases of plutonic rocks and referred to them as biotite granite and muscovite granite , respectively . Faribault's third and youngest unit contained limestone and gypsum , which he grouped in his Lower Carboniferous Windsor series .

Sage (1954) corraborated and redefined Faribault's maps of the Lower Carboniferous rocks in the study area and formally referred to them as the Windsor Group . He mapped the distribution of these rocks in the coastal regions of Mahone Bay and , using paleontological , sedimentological and stratigraphical parameters , correlated individual outliers in the area and compared them to Windsor Group strata in a Carboniferous basin near Antigonish , Nova Scotia .

In 1969 , F.C. Taylor of the Geological Survey of Canada produced a 1 inch = 2 mile compilation map of a large part of southwestern Nova Scotia . His map confirmed Faribault's essential tripartite division of the rocks in the study area into lower and upper Paleozoic sediments , and middle Paleozoic intrusions . More specifically , he used the term Meguma Group to describe Faribault's 'gold-bearing series' and referred to the two constituent formations as the older Goldenville Formation and the younger Halifax Formation . The Meguma Group was assigned a Late Cambrian to Early Ordovician age based mainly on fossil occurrences found outside the study area . Taylor's (1969) map outlines the same major structures seen on Faribault's maps of the Chester Basin , Mahone Bay and Bridgewater sheets . In the northern part of the study area where Faribault mapped muscovite granite and biotite granite phases , Taylor (1969) recognized one map unit of Devono-Carboniferous age . In this unit of intrusive granitoids , he grouped four types of plutonic rocks regionally developed in the South Mountain batholith . Taylor's map also shows the local outcrop of a Mesozoic mafic intrusion called the Shelburne dyke .

Hall (1981) constructed a 1:50 000 scale geological map of the area around Lunenburg as part of a thesis on the local Meguma Group (Figure 3) . In some well-exposed coastal sections , she separated the Halifax and Goldenville formations of the Meguma Group into several members , which she logged in great detail . Unfortunately , most of the members defined by Hall (1981) are not regionally mappable ; their suggested outcrop distributions having being extrapolated using the locations of major folds mapped by Faribault and Taylor . Highly altered, posttectonic sills of intermediate composition were interpreted as original calc-alkaline intrusions of possible Carboniferous age (Hall , 1981) .

Allied to this study , Rowley (1985) made a 1:25 000 scale photogeological map of the LaHave River area utilizing remote sensing techniques . Rowley found that the lithological units of the Meguma Group , mapped on the ground at scales as small as 1:250 000 , do not illustrate enough contrast in reflected light energy to permit their recognition or characterization by remote sensing . In contrast , major structures such as faults are obvious in multispectral satellite photographs of coastal regions and Rowley (1985) traced many of them inland through areas of poor exposure .

Most recently , the Geological Survey of Canada has released colour-contoured and line-contoured , total field and vertical gradient , aeromagnetic maps for parts of the study area (Aeromagnetic maps , 1984) . They are available on 1:25 000 and 1:50 000 scale .

Additional geological information about heavily populated areas is found in hydrogeological reports located in Chester Town Hall and in water-well drilling records published by the Nova Scotia Department of Environment . Maps of claim blocks and reports of exploration activity , filed at the Nova Scotia Department of Mines and Energy , are numerous in the study area and date back to the early part of this century .

Recently published geological studies dealing with rocks outcropping in south-central Lunenburg County include work on the sedimentology of the Meguma Group (Schenk and Adams , 1986 ; Waldron and Graves , 1987) , work on the economic geology and lithogeochemistry of the Meguma Group (Zentilli et al. , 1986 ; Graves and Zentilli , 1988) , work on the structure of the Meguma Group (Fyson , 1966) , work on the geochronology of the Meguma Group (Reynolds et al., 1973 ; Reynolds et al. , 1978 ; Reynolds et al., 1981) , work on the petrology and mineral potential of the Devono-Carboniferous granitoids (MacDonald et al., 1987) , work on the sedimentology of the Windsor Group and the Carboniferous paleogeography of the Mahone Bay area (Giles , 1981) , and work on the geochemistry and tectonics of the Mesozoic Shelburne dyke (Papezik and Barr , 1981) .

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GENERAL GEOLOGY

Geology of the study area

The area mapped is underlain by rocks which are readily divisible into four fundamental geological units . These are : (1) the Cambro-Ordovician metasedimentary rocks of the Meguma Group , (2) the Devono-Carboniferous granitoid rocks of the South Mountain batholith and unnamed hypabyssal rocks , (3) the Lower Carboniferous clastic , carbonaceous , and evaporitic rocks of the Windsor Group , and (4) the Triassic-Jurassic doleritic rocks of the Shelburne dyke . As such , the fundamental geological units of south-central Lunenburg County are representative of the Meguma Terrane of mainland Nova Scotia (Keppie , 1985) .

In the study area , the Meguma Group comprises a minimum of 6 km and a maximum of 11 km of shaley and less common sandy flysch . It is locally composed of three formations and seven members (Figure 4) . From oldest to youngest , these are : the Goldenville Formation (New Harbour member) , the Green Bay formation (Rissers Beach , West Dublin , Tancook and Moshers Island members) and the Halifax Formation (Cunard and Feltzen members) . Of these units , the Halifax Formation has the widest areal distribution . Erosion of regional anticlines makes for complete outcropping of the underlying Green Bay formation but for limited exposure of the Goldenville Formation . The quartz wackes of the New Harbour member represent only the uppermost 1 km of the Goldenville Formation .

The Green Bay formation ranges in thickness from 1-2.5 km and contains concretionary green beds that are in sharp conformable contact with Goldenville and Halifax formations . The basal Rissers Beach member of the Green Bay formation is restricted to the LaHave River area . The overlying West Dublin member of the Green Bay formation is laterally equivalent to the Tancook member of that formation , wheras the distinctive Moshers Island member of the Green Bay formation overlies both the West Dublin and Tancook members .

In the Mahone Bay and LaHave River areas , the total exposed thickness of the Halifax Formation probably varies from about 2-7 km . The lowest unit of the Halifax Formation is represented by black slate and sandstone of the Cunard member , which varies considerably from as little as 0.5 km to as much as 5 km in thickness . The overlying grey slate and sandstone of the Feltzen member of the Halifax Formation is probably 2 km thick ; however , its top is not exposed in south-central Lunenburg County .

The clastic sedimentary rocks of the Meguma Group were diagenetically altered to form nodular beds . Concretionary and nodular strata near the top of the Green Bay formation were relatively enriched in metals . During the Devonian Acadian Orogeny , strata belonging to the Meguma Group were dynamo-thermally metamorphosed at chlorite grade conditions and folded by generally upright , periclinal folds fanned by a regionally developed slaty cleavage . The earliest group of syntectonic gold-quartz veins originated at this time and were hosted by the Goldenville , Green Bay and Halifax formations .

Undeformed , variably altered , Devono-Carboniferous granitoids of the South Mountain batholith intrude regionally folded and metamorphosed rocks of the Meguma Group . They produce kilometric-scale zones of variably-altered spotted hornfels that outcrop along the intrusive contact of the granitoids . In the innermost parts of the hornfelsed aureole , cordierite and andalusite porphyroblasts developed during high T-low P contact metamorphism and have overgrown the regional slaty cleavage . These porphyroblasts are distorted and their host beds attenuated in narrow zones of large total strain that are partly concordant with the margin of the intrusion . Within such zones , pre-existing M-shaped anticlines and axial planar slaty cleavage were locally refolded near the margin of the South Mountain batholith .

Conglomerate , limestone and gypsum of the Windsor Group unconformably overlie metasediments and hornfelses of the Meguma Group and granitoids of the South Mountain batholith . The Windsor Group is folded , faulted and regionally fractured along with Carboniferous sills and basement rocks . The latest group of syntectonic gold-quartz veins hosted by the Meguma Group were generated near northwest-trending faults of unknown age . This period of gold mineralization could have formed concomittantly with fracture-controlled U-W-Mo-Ag-Cu greisens near the granitoid aureole or with fracture-filled Pb veins in the Windsor Group cover . Alternatively , the latest introduction of gold may have occurred as the Meguma Group was sericitized during intrusion , kinking and transcurrent faulting of the Mesozoic Shelburne dyke .

Geology of the Meguma Terrane

Of the five Appalachian tectonostratigraphic zones mappable throughout eastern North America , only the Avalon Zone and the Meguma Zone are present in the onshore portion of Nova Scotia (Williams , 1979 ; Figure 5) . However , on Late Paleozoic reconstructions of the North Atlantic and Western Mediterranean regions (Lefort and Haworth , 1978 ; Haworth and Lefort , 1979) , the Meguma Zone occupies an extensive offshore belt of crustal rocks characterized by a unique geophysical signature (Figure 3) . Williams and Hatcher (1982) and Keppie (1985) referred to

Appalachian terranes instead of tectonostratigraphic zones to emphasize (1) the sequential accretion of major tectonic units in the orogenic belt , (2) the large transcurrent movements involved in orogenic displacement and (3) the presence of suspect terranes , particularly in the southeastern or most outboard part of the orogenic belt . The Minas Geofracture (Figure 5) or , alternatively , the Cobequid Fault (Figure 6) is a deep crustal fault zone in Nova Scotia that separates the Avalon Terrane in Cape Breton Island and the northern mainland from the Meguma Terrane in the southern part of the province (Keppie , 1982).

The Meguma Terrane comprises four fundamental geological units ranging from Cambrian to Cretaceous in age . The oldest unit is a shallowing-upward , Lower Paleozoic sedimentary sequence which contains Cambro-Ordovician turbiditic sandstone and shale , Silurian orthoquartzite and subaerial volcanic rocks , and Devonian terrestrial conglomerate and sandstone (Taylor , 1969 ; Smitheringale , 1960) . A second unit of granitoid rocks is composed of batholiths and plutons that range in composition from granodiorite to granite , that vary in age from Devonian to Carboniferous and that intrude the Lower Paleozoic sedimentary sequence and each other at various stages of the regional deformation (Reynolds et al., 1987 ; Dallmeyer and Keppie, 1987 ; Rogers , 1985) . A variably thick , locally deformed , Upper Paleozoic sedimentary sequence comprises the third unit in the Meguma Terrane . It is represented by alternating marine and nonmarine strata of Mississippian age and less voluminous , terrestrial strata of Pennsylvanian age . The youngest unit is made up of Triassic , Jurassic and Cretaceous mafic volcanic rocks and continentally-derived sedimentary rocks , which rest unconformably above a basement represented by all three of the Paleozoic units .

Lower Paleozoic sediments

The Cambro-Ordovician Meguma Group is the oldest and most extensive rock unit in the Meguma Terrane (Figure 7) . The most likely site of Meguma deposition was the edge of a passive continental margin ; the ultimate source of detrital material was either the South American or Northwest African Precambrian shield (cf. Schenk , 1970 , 1971 , 1981) . Schenk and Lane (1982) have estimated the volume of the Meguma Group to be 5 x 10 km . They have suggested that high-volume detrital sedimentation led to the build-up of an embankment near the continental rise between the abyssal plain and the shelf slope . Two main depositional modes are recognizable on various scales : (a) sandy channelized turbidites (Waldron and Jenson , 1985) deposited near the toe of the embankment and (b) muds deposited by overflow turbidites and bottom currents on an advancing frontal slope of the embankment (Schenk and Lane , 1982) . Sub-polar conditions may have prevailed during accumulation for some period of time (Schenk , 1972) .

Regional fold structures in Cambro-Ordovician , Silurian and Devonian sedimentary rocks outline an oroflex in the Meguma Terrane south of the boundary fault with the Avalon Terrane to the north (Figure 8) . Throughout most of the southern mainland of Nova Scotia , the Appalachian tectonic grain is typically northeast . However , as the terrane boundary fault is approached , fold axial traces swing to an east-trending regional orientation and lie parallel to the fault zone . The Meguma oroflex was produced by ductile , syn-Acadian , dextral transpression (Keppie , 1982) .

Regional metamorphism of the Meguma Group varies from lower greenschist to upper amphibolite facies (Taylor and Schiller , 1966 ; Muecke , 1984 ; Figure 6). Mineral assemblages indicate high temperature-low pressure (Pyrennean) conditions . Regional metamorphic zones are highly discordant to the major fold structures (Keppie and Muecke , 1979) ; however , they are themselves crossed by contact metamorphic zones surrounding the granitoid intrusions (Muecke , 1984) . In some aureoles , hornfelses show a more protracted structural and metamorphic history than Meguma Group rocks unaffected by syntectonic intrusion (Mawer and Williams , 1986) . The highest grade rocks are centered in two distinct regions of the province , where they are associated with several small plutonic bodies (Figure 9) .

Paleozoic granitoids

The largest peraluminous granitoid complex in the Appalachian orogenic belt occurs in the Meguma Terrane of Nova Scotia (Clarke et al., 1982 ; Clarke et al , 1985) . Granitoids highly saturated in alumina are , however , absent in the Avalon Terrane (Barr et al , 1982) . The South Mountain batholith of the Meguma Terrane intrudes country rocks as young as Emsian (Lower Devonian) and is unconformably overlain by strata as old as Tournaisian (Lower Carboniferous). Major phases of the batholith range in age from 372 2 Ma to 361 1 Ma with a mean age of 367 4 Ma (Reynolds et al , 1981) , although minor `specialized´ phases may be much younger (MacDonald et.al., 1987) .

Most of the granitoids shown in Figure 9 are emplaced post-tectonically into their metasedimentary envelopes . Clarke et al. (1985) report that the largest of these bodies (the South Mountain batholith) shows no tectonic foliation and no disturbance of regional structural trends . Stoping is stated to be associated with brittle rather than ductile processes . Geophysical models of the South Mountain batholith favour a three-dimensional mushroom shape with the cap varying from 10-20 km in thickness (O´Reilly in Clarke et al , 1985) . Other Meguma Terrane granitoids , especially those in the vicinity of the boundary fault with the Avalon Terrane , are strongly foliated and sheared along with their high-grade country rocks (Keppie , 1983 ; Mawer and White , 1986) .

Petrologically distinct units are present in most of the granitoid complexes in the Meguma Terrane . In the South Mountain batholith ,one-mica granodiorite is intruded by variably textured , two-mica monzogranite . Accessory minerals in the peraluminous bodies include andalusite , garnet , cordierite , tourmaline and topaz . Smith (1979) suggested that the granitoid magmas were derived solely by melting Meguma Terrane rocks . Clarke et al. (1985) favoured a deeper primitive crustal source , although the contribution of Meguma melting was not entirely discounted .

Upper Paleozoic sediments

In the Canadian Appalachians , Carboniferous rocks developed in successor basins upon the eroded Acadian Orogen (Bell , 1960 ; Webb , 1969). Sedimentary infill began in many areas in the early Mississippian and continued , in some places , into the uppermost Pennyslvanian . Some basins , especially those along the northern margin of the Meguma Terrane , received substantial volumes of sediment (e.g. Boehner and Ryan , 1985 ; Yeo and Ruixing , 1986) . A mobile belt containing highly deformed Mississippian rocks occurs for up to 50 kms on both sides of the Meguma Terrane-Avalon Terrane boundary in northern Nova Scotia , southern New Brunswick and southern Prince Edward Island (Poole , 1970 ; Rast and Grant , 1973) . Deformation wanes to the north and south into areas of platformal Carboniferous cover (Figure 10).

In the Meguma Terrane , a thick Mississippian sequence (the Horton , Windsor and Canso groups) is succeeded by a relatively thin Pennsylvanian succession (the Pictou Group). Although earliest Horton beds are mostly found along the terrane boundary fault , younger Carboniferous strata occur in northeast-trending , regional fold structures that coincide with original depositional basins (Giles , 1985) . Limestones and evaporites of the Windsor Group are located in four areas of the Meguma Terrane , namely , the Shubenacadie Basin , the Musquodoboit Basin , the Windsor Basin and the Mahone Bay-St. Margaret's Bay area (Figure 11) .

In general , the thinnest and least deformed Carboniferous rocks are present in the south of the terrane , where pre-Windsor land masses are most common (Keppie , 1982 ; Giles , 1981) . Farther north , approaching the mobile belt and the terrane boundary , Mississippian deposits are thicker and strongly deformed by a variable combination of halokinesis and tectonic compression (cf. Giles , 1977 ; Boehner and Giles , 1977; Boehner , 1984) . A major northeast-trending zone of post-Visean sinistral shear , the Tobiatic Fault Zone of Giles (1985) , extends from the Shubenacadie Basin southwestwards into granitoids and Lower Paleozoic metasediments . Based on reconstructions of the Meguma Terrane prior to left-lateral offset of 110 kms, Giles (1985) suggested that Carboniferous strata accumulated in linear belts which reflect the sites of early Mississippian cauldron subsidence and/or ancestral Lower Paleozoic faults.

Mesozoic sediments and volcanics

Sedimentary, volcanic and hypabyssal rocks of Late Triassic, Jurassic and Early Cretaceous age are present in the onshore and offshore of Nova Scotia. On the Scotian shelf (Figure 6), the Meguma Group and other Paleozoic rocks of the Meguma Terrane comprise the local basement to the Mesozoic coastal plain deposits (Figure 5). Onshore, Mesozoic rocks occur in fault-bounded basins within the Meguma Terrane, where they rest unconformably upon a variety of rock units ranging in age from Cambrian to Carboniferous. Mixed volcanic and sedimentary rocks of Triassic and Jurassic age are located in the Annapolis Valley, poorly lithified sediments of Cretaceous age are present in the Musquodoboit Valley and a large Triassic-Jurassic dyke occurs along the South Shore district (Figure 12). Keppie (1977) interpreted most of these deposits and intrusions to have formed in small incipient rifts in the Meguma Terrane on the extended margin of the North Atlantic Ocean.

LITHOSTRATIGRAPHY

MEGUMA GROUP

Regional framework

The Lower Paleozoic Meguma Group comprises one of the most extensive belts of non-volcanic , unfossiliferous , eugeosynclinal flysch in the Canadian Appalachians (Schenk , 1983 ; Williams , 1978a, 1978b) . This flysch basin or marine trough may have received from 10-15 km of turbiditic sediment . The flysch basin is capped by fossiliferous , shallow water , Siluro-Devonian deposits (Taylor , 1969 ; Smitheringale , 1960) ; however , underlying basement is not exposed .

At least two formations are mappable in the Meguma Group in all counties on the southern mainland of Nova Scotia (Keppie , 1979) . They are a sandy , silicious flysch termed the Goldenville Formation (Woodman , 1904a , 1904b) and a shaley , sulphurous flysch named the Halifax Formation (Ami , 1900) . In most places , the older Goldenville Formation is stated to be in gradational contact with the younger Halifax Formation (e.g. Schenk , 1970) . The boundary between the two formations has been defined in a variety of ways by different workers (see Zentilli et al, 1986) and , therefore , it is mapped at different stratigraphical positions in the Meguma Group from one place to another . Nevertheless , the Goldenville-Halifax boundary has been generally regarded as the only regional marker horizon in the Meguma Group (Schenk , 1970) . In certain regions , however , strata occurring in the 'gradational' or 'transitional' zone between Goldenville and Halifax formations form a thick , lithologically distinctive , mappable unit in the Meguma Group (e.g. Bailey , 1898) . Thick 'transitional' zones commonly contain excellent marker horizons . Where such zones are well developed , the Goldenville and Halifax formations do not share a mutual map boundary .

On the southern Nova Scotian mainland , the Goldenville Formation is the most widespread unit of the Meguma Group . In the east and north of the Meguma Terrane , the Halifax Formation is restricted to narrow synclinal keels , where it is infolded with a relatively thick Goldenville succession (Figure 13) . In Lunenburg and Queens counties , however , the shaley flysch is uncharacteristically widespread and is disposed about anticlines and synclines alike (Figure 13). This is because the Halifax Formation is much thicker in Kings , Queens and Lunenburg counties than it is in counties to the northeast and southwest (Taylor , 1969) .

Fossil localities in the Meguma Group are rare and widely dispersed. Fragmentary trilobites, microscopic acritarchs and several types of trace fossils have been reported (Pickerill and Keppie, 1981; Taylor, 1969; Jenkins, W.A.M. in Keppie, 1977; Crosby, 1962) . Goldenville and Halifax formations contain poorly preserved fossils that indicate a probable Cambro-Ordovician age . In Kings County , beds in the lower part of the Halifax Formation , however , are definitely Tremadocian . In the study area , undiagnostic trilobite remains obtained from the Cunard member of the Halifax Formation have been found in the coastal section at The Ovens (W.H. Poole , 1985 , pers. comm.) .

Cambro-Ordovician rocks in the Mahone Bay and LaHave River areas are assigned to three regionally mappable formations belonging to the Meguma Group (O'Brien et al., 1985 ; O'Brien et al. , 1987 ; Figure 4) . In the following section , these formations and their constituent members are described in detail ; however , they are not formally defined in this report .

GOLDENVILLE FORMATION

The Goldenville Formation outcrops in three distinct localities around the periphery of the study area but it is presumed to also underlie the centre of the region (Figure 14) . The best exposures and most complete stratigraphical sections occur on the tip of the Aspotogan Peninsula . Relatively incomplete or poorly exposed sections are found in the Green Bay and Gold River areas , respectively (Figure 14) . The Goldenville Formation is generally composed of massive or thickly stratified wackes interbedded with variable but commonly lesser amounts of green slate . Its contact with the overlying Green Bay formation is sharp and conformable.

New Harbour member

In the study area , all strata belonging to the Goldenville Formation are grouped together in one distinctive map-unit . Recently named the New Harbour member , it includes rocks in the LaHave River area originally called the Long Point Sandstone (see O'Brien , 1986a , Table 52.1) . The distribution of the New Harbour member is controlled by the fold plunge of three major structures (the Gold River , Indian Path and Ovens anticlines of Figure 14) . Using a combination of outcrop width and local structure to estimate stratigraphical thickness , the New Harbour member is calculated to be about 1 km thick on the Aspotogan Peninsula . Since the minimum or total exposed thickness of the Goldenville Formation has been reported to be approximately 6 km (Schenk , 1970) , the New Harbour member presumably represents one of the highest units in the formation .

In most places , the uppermost part of the New Harbour succession is composed solely of 2-3 m thick , buff-weathered wacke . Green slate is rare throughout the upper 500 m of the unit . These features permit the recognition of a sharp contact at the upper boundary of the member that can be accurately located and precisely mapped throughout the study area . The New Harbour sequence is atypical of the upper Goldenville Formation in other parts of the Meguma Terrane , where the green slate: wacke ratio generally increases with height in the Goldenville succession .

The lower 500 m of the New Harbour member is made up of dominant , 1-3 m thick wacke with subordinate , 1-10 cm thick green slate . In general , its field appearance is regionally typical of the Goldenville Formation . The lower part of the member contains uncommon , laterally discontinuous , 5-30 m thick sequences displaying green laminated sediments characteristic of the Green Bay formation . The thickest of these intervals is located in map sheet C in the Herring Cove-Broad Cove area . Fortunately for mapping purposes , their abundance increases stratigraphically downwards away from the contact of the Green Bay formation .

The stratification of quartz wacke in the uppermost part of the New Harbour member is quite variable . Where the New Harbour beds are succeeded by the Rissers Beach or Tancook members of the Green Bay formation (Figure 4) , wacke thickness is generally 2-3 m . Where the New Harbour beds are overlain by the West Dublin member of the Green Bay formation , 2-3 m thick wackes pass vertically into 25-50 cm thick wackes some 200 m below the upper contact .

Original sedimentary structures are observable in strata of the New Harbour member . Some slates show parallel lamination where cleavage does not obscure delicate bedforms . Wackes are only rarely graded from the bottom to the top of individual beds and , instead , grading and cross-stratification are confined to small parts of a single bed . Bouma cycles are either poorly or incompletely developed . Amalgamation surfaces are recognizable in some of the thicker wackes , and fluid escape structures such as sand pipes and sand volcanoes are also present . Original depositional bedforms may have been largely destroyed by dewatering triggered by the weight of overlying strata (following Waldron and Jenson , 1985 ; personal communication , 1985) .

Although the original matrix of New Harbour wacke is recrystallized , sand-sized clasts are still recognizable in many localities . Detrital clasts of quartz predominate over feldspar and many sand grains appear sub-rounded . They are , however , strained to the point where some grain boundaries are sutured .

Minerals and textures of metamorphic origin are present in rocks of the New Harbour member . Regional metamorphism formed microscopic white micas and chlorites that are much finer-grained than the detrital phyllosilicates and that show a preferred orientation at angles to bedding . Mesoscopic silicate and sulphide porphyroblasts are mostly observed in the contact aureole of the granitoids but also occur in concretionary strata or in alteration haloes near veins .

The New Harbour member is in stratigraphical contact with three members of the Green Bay formation . The top of the unit is drawn at the highest bed of a succession of massive , amalgamated and thick-bedded wacke . With the exception of a narrow tongue of quartz wacke at Broad Cove , this boundary is also coincident with the first appearance of extensive packages of rhythmically--interbedded green beds . Sharp conformable contacts are seen with the Rissers Beach member in the LaHave River area and with the Tancook member in the Mahone Bay area . The contact with the West Dublin member is not exposed but , if gradational , it must be so over a maximum of 75 m . The base of the unit is not defined and its age is unknown .

GREEN BAY FORMATION

The recently named Green Bay formation (O'Brien , 1986a) is widely distributed throughout the study area (Figure 15) . It is , however , best and most completely exposed on the Tancook and LaHave islands . Lithologies typical of the formation are rhythmically-interbedded , green and grey-green siltstones and less common beds of quartz wacke . It is regionally correlatable with strata occupying the Goldenville-Halifax transition zone (GHT) of the Meguma Group . The Green Bay formation is distinguished from other GHT zones by (1) its sharp rather than gradational boundaries with the Goldenville and Halifax formations , (2) its considerable thickness and lateral extent , (3) its mapability on scales ranging from 1:25 000 to 1:250 000 , and (4) its distinctive internal stratigraphy .

The Green Bay formation comprises four members , namely , the Rissers Beach member , the West Dublin member , the Tancook member and the Moshers Island member . These members are distributed throughout south-central Lunenburg County (Figure 4) . The basal Rissers Beach member is restricted to the southwestern part of the study area . The overlying West Dublin member is found throughout most of the western part of the region but it is replaced in the north and east of the area by the Tancook member . In this regard , it is noteworthy that West Dublin strata resemble certain Tancook beds in the southeasternmost LaHave Islands . The stratigraphically highest Moshers Island member is present in all parts of the Mahone Bay and LaHave River map areas , where it overlies both the Tancook and West Dublin members .

The total thickness of the Green Bay formation varies between 1 km and 2.5 km approximately . In any one locality , this variation is normally due to thickness changes in one or perhaps two of the constituent members . Generally , a one-to-one relationship does not exist between facies changes and thickness changes . Nevertheless , the Tancook member is considerably thicker than the West Dublin member where both directly overlie the New Harbour member .

The contacts of the Green Bay formation with the overlying Halifax Formation and underlying Goldenville Formation are conformable and are the sharpest of any map-unit in the Meguma Group of south-central Lunenburg County (see descriptions of the Moshers Island and New Harbour members) . In this report , the boundaries of the Green Bay formation are not located in logged sections , although Waldron and Graves (1987) have indicated the position of the upper contact of the Moshers Island member in detailed maps and stratigraphical sections of Big Tancook Island .

Rissers Beach member

The basal Rissers Beach member of the Green Bay formation is confined to the LaHave River area , where it is disposed about two northeast-plunging anticlines (Figure 4) . The unit was originally mapped as the Rissers Beach Sandstone by O'Brien et al. (1985) and subsequently referred to as Unit 2A in a preliminary report on the area (O'Brien , 1985a) . In the vicinity of Green Bay , the Rissers Beach member is approximately 300 m thick .

The unit is typified by green siltstones rhythmically interbedded with buff-weathered , fine-grained, grey-green sandstones (Figure 16a) . These two lithologies occur in approximately equal abundance in a member that is , as a whole , thinly stratified relative to the rocks which bound it . Beds generally range from 5-10 cm in thickness .

The buff-weathered sandstones in the Rissers Beach member characteristically show spectacular cross-stratification , especially where several sets are developed in each bed (Figure 16a) . The interbedded green siltstones are either featureless or parallel-laminated . In thin section , laminations are recognized as primary bands of detrital phyllosilicates that are alternately rich in white micas and in chlorites . A conspicuous feature of these green beds is the presence of pyrite cubes surrounded by aggregates of fibrous chlorite and quartz . Such crystals are commonly recessed in or completely weathered-out of rock exposures . Where present , they measure from a fraction of a millimetre to several centimetres in grain size . Silicate pressure shadows developed around probable diagenetic or metamorphic sulphides , however , replacement of sulphide by silicate is also observed .

Schenk and Adams (1986) noted that , although the Rissers Beach deposits contained substantial amounts of mica-rich silts or muds , a high-energy depositional environment was indicated by trough cross-stratification and intrastratal truncation of bedforms . They concluded that the Rissers Beach member accumulated as a turbiditic overbank or levee deposit situated near a major channel-fill system (the New Harbour member) .

Chlorites and white micas of regional metamorphic origin occur in rocks of the Rissers Beach member in addition to the detrital varieties . Preferentially-oriented grains define the regional rock cleavage . Coarse detrital clasts are generally contained within microscopic bedding layers , although the basal cleavage of some grains is not parallel with the compositional laminations . Detrital chlorites are not observed to be replaced by metamorphic chlorites nor are they pseudomorphs after other minerals . The colour of the green beds may , therefore , reflect primary compositional or diagenetic features enhanced by secondary recrystallization and oxidation .

Rarely , biotite is present in the Rissers Beach member south of Green Bay . A regional metamorphic origin is most likely (see Figure 9) ; however , Rissers Beach strata hornfelsed by the Mesozoic Shelburne dyke also contain biotite . Because of its regional distribution , the Rissers Beach member is the only unit in the Green Bay formation not affected by contact metamorphism associated with granitoid intrusion .

Whereas the basal contact of the Rissers Beach member is sharp and conformable , its upper contact with the West Dublin member is gradational . The upper boundary is marked by the first appearance of graded , decimetre-thick wackes lithologically similar to those in the Goldenville Formation . A narrow , sharply-bounded tongue of quartz wackes of New Harbour affiliation is present at Broad Cove near the base of the Rissers Beach member . Adams and others (pers. comm. 1985) have traced this horizon along strike for several kilometres to the southwest ; however , it is not regionally mappable in the study area . The age of the Rissers Beach member is presently unknown , although some poorly preserved acritarchs have been located (Schenk , pers. comm. , 1986) .

West Dublin member

The West Dublin member of the Green Bay formation was named by O'Brien (1986a) as a replacement for the term West Dublin Sandstone . The unit is best and most completely exposed in the LaHave River area on the Green Bay coast near the village of West Dublin and on some of the LaHave islands . On the western side of Mahone Bay , it outcrops in several fold structures as far north as Chester Basin , although West Dublin exposures in the two periclinal folds east of Bridgewater are poor (Figure 4) . In the section near the village of West Dublin , the member may be 200 m thick ; however , the stratigraphical thickness may exceed 300 m on the offshore islands .

The West Dublin member is typically composed of 1-2 m thick

, buff-weathered , quartz wacke interstratified with rhythmically-interbedded green siltstone and grey-green , fine-grained sandstone . The buff wackes are like those seen in the Goldenville Formation except they are generally thinner (25 cm-1 m) and contain abundant internal sedimentary structures . Comparison of West Dublin and New Harbour wackes in thin section shows the West Dublin strata to have finer-grained clasts of quartz and feldspar , and to generally contain a higher proportion of matrix .

The green rhythmites in the West Dublin member are probably best considered as background sediments (e.g. Walker and Pettijohn , 1971) . The 5-15 cm thick , green beds at the base of the unit are similar to green siltstone and grey-green sandstone of the Rissers Beach member . Rhythmically-laminated green beds near the top of the West Dublin succession are comparable to laminated siltstone in the overlying Moshers Island member . Buff-weathered , quartz-rich wackes of the West Dublin member commonly have scoured bases , which cut deeply into the background rhythmites . Where West Dublin strata are bounded by rocks of the Rissers Beach and Moshers Island members , the ratio of wacke:rhythmite increases away from its external contacts to a maximum in the centre of the unit . Where the beds of the West Dublin member occupy a position between the New Harbour and Moshers Island members , the ratio of wacke:rhythmite decreases vertically upwards . It seems that New Harbour-type channels changed position on the seafloor or tried to re-assert themselves by cutting into the Rissers Beach overbank deposits . Processes related to the wedging-out of the Rissers Beach member beneath the West Dublin succession presumably also account for the thin stratification locally observed in the uppermost New Harbour member .

Over most of the study area , the West Dublin member maintains an approximately constant thickness and has the same lithological appearance . However , in the ground between Green Bay and the LaHave Islands , lateral facies variations are apparent as the unit is mapped southeastwards across a well exposed , M-shaped anticline (Figure 4) . The buff wacke beds representing the majority of strata in the middle part of the member on the Green Bay coast split to form two discrete subunits near the Bell Channel (see GSC Open File Map 1156) . A wedge of rocks dominated by decimetre-thick green beds separates the wacke subunits and forms part of a conformable succession that faces consistently northwards . Complete Bouma cycles are observable within the green-bed-wedge on Bell Island , Middle Island and Round Island . Large-scale thixatropic deformation and slump folding are particularly well displayed along the southeast shore of Cape LaHave Island . The green-bed-wedge is included in the West Dublin member because the bounding , wacke-dominated subunits are underlain by the Rissers Beach member and overlain by the Moshers Island member . Therefore , the increased map width of the Green Bay formation around the M-shaped anticline is due largely to stratigraphical wedging and splitting affecting only the West Dublin member of that formation .

Chlorites and white micas of regional metamorphic and detrital origin are common in the West Dublin member . Their occurrence is similar to that described for the Rissers Beach member . Strata that have been contact metamorphosed by granitoids are rust-weathered , hard and massive . West Dublin hornfelses displaying relict bedforms also contain abundant porphyroblasts and calcsilicates . They are found in two localities in the Mahone Bay area , one near Squid Cove in map sheet C and the other near Wake-up-Hill in map sheet A .

The stratigraphical contacts of the West Dublin member are conformable and gradational . The lower boundary is drawn at the base of the lowest decimetre-thick wacke in a succession of quartz wackes and interbedded rhythmites . The upper boundary is drawn at the top of the highest decimetre-thick wacke in a succession of quartz wackes and interbedded laminites . These boundaries are well exposed and are traceable along strike throughout the LaHave Islands . The age of the West Dublin member is unknown .

Tancook member

The Tancook member is the most recently recognized unit in the Green Bay Formation (O'Brien , 1986a) . It is well displayed in virtually continuous coastal exposures on Big Tancook and Little Tancook islands . The Tancook member is regionally disposed about several southwest-plunging folds to the east and north of Mahone Bay (Figure 4) . Estimated thicknesses are in the order of 600 m on the Aspotogan Peninsula and Tancook islands , and perhaps 800 m north of Chester Basin .

The Tancook member is generally made up of 25 cm-3 m thick , buff-weathered , quartz wackes interlayered with rhythmically-bedded green siltstones and grey-green , fine-grained sandstones . Metre-thick , buff-weathered wackes interbedded with less common , decimetre-thick green rhythmites occur near the base of the member . Ascending the stratigraphical succession , the wacke:rhythmite ratio appears to be highly variable . Generally , however , the thickest amalgamated wacke beds (3 m) are found with the thickest rhythmite intervals (15 m) . Stratigraphical packets composed solely of rhythmite may be useful for correlation purposes , at least in the vicinity of The Chops . Thixatropic deformation of thick-bedded wackes is common in the lower part of the unit . The uppermost part of the Tancook member contains green rhythmite at the expense of increasingly isolated occurrences of buff-weathered wacke .

Microscopically , Tancook wacke contains relict , sand-size quartz clasts set in a totally recrystallized metamorphic matrix . Some siltstones have also preserved angular , matrix-supported , quartz clasts . In places , however , the siltstone matrix is composed entirely of micritic calcite .

In the uppermost part of the Tancook member, carbonate alteration is notably strong. Green beds displaying BCE Bouma cycles contain discrete, fibrous rosettes of carbonate (Figure 16b). The rosettes are reversely graded from the E to the C horizon, suggesting a diagenetic or regional metamorphic origin. Cross-stratified beds in the upper Tancook member display excellent mud-drapes over foresets in sandstone (Figure 16c). The material defining the mud-drapes weathers a distinctive reddish-brown colour, a feature indicative of significant Fe/Mn concentrations in other parts of the study area.

Contact metamorphism alters the appearance of the Tancook member by producing rust-weathered, massive, spotted hornfelses. Because the wacke:rhythmite ratio is difficult to decipher in hornfelsed rocks, the outcrop of the Tancook member is hard to assess in the granitoid aureole. This is particularly so in areas north and west of Chester Basin. Occurrences of regional metamorphic and detrital phyllosilicates are similar to those in the Rissers Beach and West Dublin members.

The Tancook member is in sharp conformable contact with the underlying New Harbour member; however, it is stratigraphically gradational with the overlying Moshers Island member. The upper contact of the Tancook member is drawn at the top of the highest bed of decimetre-thick wacke in a succession of quartz wacke and interbedded laminite.

From Figure 4, it is evident that the Tancook member replaces the West Dublin member on the northwest limb of the Gold River Anticline. Furthermore, the Tancook succession is up to 3-4 times as thick as the West Dublin sequence on the southeast limb of the fold. They may be, therefore, lateral facies equivalents beneath the Moshers Island member. Prior to regional folding, the Tancook and West Dublin members may have had a continuous, wedge-shaped, cross-sectional geometry. Alternatively, they may have been in abrupt contact across a synsedimentary fault located near what was to become the axis of the Gold River Anticline.

Moshers Island member

The uppermost unit of the Green Bay formation is called the Moshers Island member. Originally mapped in the LaHave River area, it was first referred to as the Snug Harbour Sandstone (O'Brien, 1986a, Table 52.1). The Moshers Island member is the most widely distributed unit in the formation, occurring everywhere the Green Bay succession crops out in the study area (compare Figures 4 and 15). Some of the best exposures of the member are found on Moshers Island and Cape LaHave Island. The most complete stratigraphical sections, however, are located on Big Tancook Island. The Moshers Island member is probably 200-

300 m thick .

Rhythmically laminated and rarer crosslaminated, green and grey-green siltstones comprise the Moshers Island member (Figure 16d) . The unit is stratified only on the millimetric and centimetric scale of the rhythmic layering . In thin section , the laminites are seen to contain minute crystals of garnet , clinozoisite and Fe-oxides scattered evenly throughout the rock (Figure 17a) . Certain horizons , however , display coarser , porphyroblastic clinozoisites with radial inclusions of carbon-rich material . Typically , laminae that weather a reddish-brown colour are notably rich in manganese (see Zentilli et al. , 1986 ; Graves and Zentilli , 1988) . Mineralogically zoned concretions , commonly 1-3 cm in diameter , are seeded in the Mn-rich laminae and in pink coticule horizons (Figure 17b) . In thin section , these concretions are observed to overgrow primary bedding laminations (Figure 17c) . They are distinct relative to concretions and nodules in other members of the Meguma Group and define excellent marker horizons in the Moshers Island member .

The Moshers Island laminites presumably accumulated in a more quiescent , lower-energy environment than the underlying West Dublin and Tancook deposits . Rare ripple marks and crosslamination , however , attest to current action and some sediment traction . Chemical sediments were not observed , although the laminites are relatively enriched in Mn, Ba, Pb, Cu and Zn (Graves and Zentilli , 1988) .

Diagenetic alteration and regional metamorphism of the Moshers Island member has produced garnet , ankerite and epidote group minerals in addition to the common chlorites and white micas . In Moshers Island strata , garnet is stable in the regional chlorite zone presumably because it is the Mn-rich variety (following Zentilli and MacInnis , 1983) . Contact metamorphism associated with the granitoids makes the hornfelses of this unit rusty and hard , although the distinctive rhythmic laminations are well preserved and the calcsilicates are zoned like their concretionary protoliths . As a result of metamorphic recrystallization , coticule horizons become more apparent features of the Moshers Island member and make it the most readily recognized unit of the Meguma hornfelses .

The basal contact of the Moshers Island member with underlying units is gradational and mapped at the first appearance of buff-weathered , quartz wacke . The upper contact with the Cunard member is conformable , notably sharp and drawn at the first appearance of black slate . In contrast with overlying and underlying units , the Moshers Island member has approximately the same thickness and lithological appearance everywhere in the study area . The age of the unit is unknown .

HALIFAX FORMATION

The Halifax Formation underlies most of the ground in the study area (Figure 4) and is , by far , the thickest formation of the Meguma Group in south-central Lunenburg County . It is best exposed in spectacular coastal sections north and south of Lunenburg Bay . The Halifax Formation is generally composed of black and grey shale interbedded with fine grained sandstone . In the study area , it is separated into two units , namely , the Cunard member and the Feltzen member (Figure 4) . The younger Feltzen member is restricted to the coastal region of Mahone Bay . In contrast , the older Cunard member regionally encircles the Feltzen member and is widespread in inland regions , particularly north of Bridgewater and near the lower reaches of the LaHave River (Figure 4) .

Minimum thickness values of the Halifax Formation have been estimated in several places in the Mahone Bay and LaHave River areas . The onland thickness of the Feltzen member is approximately 1 km ; however , the plunge of Feltzen strata on offshore islands and 'depth-to-Cunard' information from vertical gradient aeromagnetic maps suggest that the upper member is probably 1.5-2 km thick in the study area . The thickness of the Cunard member was estimated near regional anticlines that expose all or most of the lower member . Assumed minimum thicknesses of the Halifax Formation are calculated by summing local values from the Cunard and Feltzen members . The considerable thickness variation of the Halifax Formation from about 2 to 7 kms is due to abrupt thickness changes in the lower member . Although the base of the Halifax Formation is conformable and sharp , the top of the formation is not exposed in the LaHave River and Mahone Bay areas .

Cunard member

The term Cunard member was first introduced by Hall (1981) to describe a succession within the Halifax Formation dominated by black slate . She logged the coastal section in the type area near Cunard Cove (The Ovens) in great detail . In many localities , however , her maps of the Cunard member also include strata that are here assigned to the overlying Feltzen member or to underlying members of the Green Bay formation . In contrast , the Ovens Slate member defined in her logged section is not regionally mappable and has been included in the upper Cunard member of this report . Similar isolated bodies of Feltzen-type lithofacies locally occur well down the Cunard succession on the Kingsburg Peninsula .

The distribution of the Cunard member in the study area is shown in Figure 18 . Because of its thickness and lateral extent

, the Cunard member is the only unit in the Meguma Group disposed about all major fold structures at present erosional level .

The Cunard member of the Halifax Formation contains black slate and siltstone interbedded with pyritiferous , cross-stratified , ripple-marked sandstone . In some parts of the succession , fining upward cycles are present (Figure 19a) . In other parts of the sequence , however , cycles coarsen upwards . Near the top of the Cunard member , the bed thickness generally decreases but the ratio of slate:sandstone remains highly variable . Fine grained , grey sandstones are 20-50 cm thick and commonly display giant concretions made up of chlorite , carbonate and sulphide (Figure 19b) . Some of the thicker sandstones are graded , display BCE Bouma cycles and have scoured bases . In thin section , the finely laminated shales are composed of primary phyllosilicate-rich bands alternating with black , sulphide- and carbon-rich layers . These muds presumably accumulated in a reducing , organic-rich environment that periodically received sandy turbidite flows , although muddy turbidites may also be present (Schenk , pers. comm., 1985) . Strata of the Halifax Formation similar to the black slate and sandstone succession of the Cunard member have been previously interpreted as continental rise deposits (Schenk , 1970) .

Penninitic chlorites and less common white micas define the regional cleavage in Cunard slate . Detrital chlorites are generally much coarser-grained and are preferentially concentrated in particular shale horizons . Contact metamorphism of the black slate in the Cunard member produces excellent examples of pelitic spotted hornfels . Outside the granitoid aureole , the softer slate is recessed relative to the interbedded sandstone . However , in the hornfels , pelite is harder and locally more resistant than psammite . Stratification is generally difficult to discern , although porphyroblast-rich beds are reversely graded in some localities . Regionally , Cunard strata are generally distinguished by their rust-weathered appearance . However , the Cunard member loses some of its distinctiveness in the hornfels , where contact metamorphic sulphides are developed in most units of the Meguma Group .

The basal contact of the Cunard member is exposed in several localities and is everywhere observed to be notably sharp and conformable . The upper contact with the Feltzen member is gradational over approximately 150 m . The boundary is , however , most conveniently drawn at the top of the stratigraphically highest black slate . Most of the Meguma Group trilobite localities are located in black slate of the Halifax Formation and , therefore , the Cunard member is probably Tremadocian .

In Figure 18 , it is evident that the outcrop width of the Cunard member is highly variable (e.g. compare rocks along the hinge zones of the Rhodes Corner and Ovens anticlines) . To best interpret this pattern , the following facts should be realized : (1) the lower and upper contacts of the Cunard member are invariably stratigraphical where exposed ; (2) the Cunard succession is in stratigraphical order along fold axial traces ; (3) the direction and amount of plunge remain constant between lower and upper contacts of the Cunard member in any given anticline , although the regional plunge of the Cunard member varies from fold to fold and (4) the bulk strain in anticlinal hinge zones unaffected by syntectonic veins is low . The latter point is evidenced by delicate bedforms crossed at a high angle by cleavage and by a lack of structural thickening or thinning in second and third order folds .

In the writer's opinion , the outcrop pattern in Figure 18 is best explained by abrupt changes in the stratigraphical thickness of the Cunard member . For example , although the Ovens Anticline tightens slightly to the northeast , the plunge remains gentle at about 30° . If regional dip isogons are drawn on the Cunard contacts near the core of the Ovens fold , t_x is assumed to be approximately equal to t_o and corrections are made for the 30 tilt of the Cunard succession in the hinge zone , a thickness estimate of about 5 kms is obtained . In contrast , where the Cunard member plunges vertically off the northeastern end of the Rhodes Corner dome only 9 kms away across the tectonic strike , thicknesses of about 500 m are calculated . It appears that Cunard strata are (1) thinnest along parts of the Rhodes Corner Anticline , (2) thickest in the Ovens Anticline , (3) thin near the depression of the Indian Path Anticline but thick up-plunge to the SW and (4) are of intermediate thickness along the northeast-plunging part of the Blockhouse Anticline (Figure 18) .

In more general terms , the Cunard member is thinnest near Mahone Bay in a linear zone that has a substratum represented by the Moshers Island member and yet separates two regional basins of the Feltzen member . The Cunard member thickens inland away from the Mahone Bay linear zone across strike to the northwest and southeast , and also up-plunge to the southwest in the southern part of the region . Local thickness variations have not been reported elsewhere in the lower Halifax Formation where it is directly underlain by the Goldenville Formation or where GHT deposits are thin . Regional folds may , therefore , reflect the original shapes of second-order basins in the Meguma Group . As such , anticlines cored by Green Bay strata with an anomalously thin Cunard carapace may have been situated near the margins of upfaulted blocks active during deposition of the Cunard member .

Feltzen member

The name Feltzen member was first used by Hall (1981) to identify a grey slate division in the upper part of the Halifax Formation . Unfortunately , her maps showing the extension of the Feltzen member away from the complexly folded type area of South Feltz are inaccurate . The distribution of the Feltzen member as discussed in this report is illustrated in Figure 20 . Two distinct outcrop areas are located on the coast and islands of Mahone Bay . Separated by the Indian Path Anticline , they are informally referred to as the northern Feltzen basin and the southern Feltzen basin (Figure 20) . The boundary of the northern outcrop area is traced undersea and , therefore , is largely inferred . Its structure is that of a complex doubly-plunging synclinorium . The southern outcrop area is better defined and has the structure of a W-shaped synclinorium . The fold plunges recorded on the most offshore islands indicate that this structure may close northeast of the study area . Onshore exposures of the Feltzen member are at least 1 km thick in the southern basin . An estimate of the total exposed thickness might be in order of 2 kms .

The Feltzen member of the Halifax Formation is composed of light grey , dark grey and blue-grey slate rhythmically interbedded with laminated to thin-bedded , fine-grained , buff-weathered , grey sandstone . At the base of the member , sandstone beds are 5-10 cm thick ; higher in the stratigraphical succession , laminated and 1-2 cm thick beds prevail . Characteristic features of the Feltzen member include abundant worm burrows (Figure 19c) and patchy replacement of quartz-rich sandstones by secondary carbonate (Figure 17d) . The Feltzen slates contain white micas at the expense of chlorites and , as a result , are grey in colour . Thin microscopic laminae are made up of detrital white micas that are augened , rotated and distorted by the phyllosilicates outlining the regional slaty cleavage (Figure 19d) . Fine grained sandstones of the Feltzen member are generally poorer in sulphides than those from the Cunard member .

Because of its limited distribution , the Feltzen member is found only in the chlorite zone of regional metamorphism and is not observed to be contact metamorphosed by the granitoids at present erosion level . Cleavage-forming minerals are fine-grained white micas and rare chlorites .

The stratigraphical top of the Feltzen member is not exposed in the LaHave River and Mahone Bay areas . The youngest beds in the unit are , however , located in the vicinity of Green Island . Its lower boundary with the Cunard member is gradational and drawn at the first appearance of black slate . Common occurrences of the trace fossil Arenicolites indicate a probable Ordovician age (Pickerill and Keppie , 1981) for the Feltzen member .

The two major areas of Feltzen outcrop are structural basins and it is simplest to assume that contiguous Feltzen beds once extended over relatively thin Cunard strata in the hinge zone of the Indian Path Anticline (Figures 4 , 18 and 20) . Fault blocks controlling Cunard sedimentation may have become inactive and blanketed by consistently thick Feltzen deposits . Alternatively , two distinct Feltzen basins may have formed during continued emergence of the Mahone Bay linear zone .

WINDSOR GROUP

In the study area , the outcrop of the Lower Carboniferous Windsor Group is restricted to the coastal region of the northern part of Mahone Bay (Figure 4) . Giles (1981) correlated strata in the Mahone Bay area with the Gays River Formation of the Musquodoboit and Shubenacadie basins (Figure 11) . The Lower Carboniferous rocks are locally preserved as a thin veneer on the coast (Giles , 1981) and in submarine areas (Barnes and Piper , 1978) . They probably do not exceed 100 metres in thickness .

The Windsor Group is locally composed of limestone , dolostone , gypsum , sandstone , shale and conglomerate . Exposure is , however , too poor to map lithological subunits . The basal beds are decimetre-thick conglomerate and sandstone sharply overlain by laminated dolostone . The basal conglomerate contains angular to sub-rounded clasts of foliated Meguma metasediments . Overlying limestones are variably textured and are commonly fossiliferous . Gypsum occurrences are recorded in waterwell drilling records and are assumed in regions of karst topography . Stratigraphically , they probably occur above the fossiliferous limestone sequence (following Giles , 1981) .

The boundaries of the Windsor Group are largely assumed and drawn where there are abrupt changes in physiography or where the surficial deposits show a substantial number of Windsor clasts . Faribault (1924 , 1929a) locally distinguished gypsum and shale within the outcrop belt of the Windsor Group . Exposures of evaporites on Mahone Bay islands shown on previous maps were not relocated , although large blocks occur within drumlins . Fauna of the Windsor Group are Visean in age (Sage , 1954) .

Folded and faulted strata of the Windsor Group rest with angular unconformity on Goldenville , Green Bay and Halifax formations , and on contact hornfels . In places , the Windsor Group lies nonconformably on Devono-Carboniferous granitoids . The present distribution of the Windsor cover on the local pre-Visean basement (Figure 4) has been interpreted in several ways . Cameron (1956) reasoned that a pre-Carboniferous depression , the ancestral Mahone Bay , was bounded by northwest-trending faults . He concluded that the thin Carboniferous cover sequence was only deposited in this depression . Barnes and Piper (1978) stated that the present topography in the Mahone Bay area might be largely controlled by the exhumed basal Carboniferous unconformity . Giles (1981) postulated that the Gays River Formation once extended over much of Lunenburg and Halifax counties . He presumed that Carboniferous strata were preserved in the Mahone Bay area on the downthrown side of faults that were sited on pre-existing structures in the pre-Visean basement .

In the study area, the most deeply weathered hornfelses and the most exfoliated granitoids occur beneath or near the Windsor Group outliers. In situ tropical erosion preceded deposition of Visean carbonate and probably resulted in negligible mass wasting or landscape modification. It may be simply coincidence that the local Windsor basin is approximately the same size and shape as the northern Feltzen basin. Pre-Visean topography and post-Visean folds may, however, have been controlled by the regional plunge depression of Feltzen rocks under Mahone Bay.

IGNEOUS INTRUSIONS

In the LaHave River and Mahone Bay areas , igneous rocks are restricted to major and minor intrusions hosted by the Meguma Group . They fall conveniently into two groups : (1) Devono-Carboniferous granitoids and associated pegmatites and aplites that form part of the southern margin of the South Mountain batholith and (2) intermediate sills and mafic dykes of probable Carboniferous and Triassic-Jurassic age , respectively .

Granitoids of the South Mountain batholith

Granitoid rocks in the study area comprise a small part of the Devono-Carboniferous South Mountain batholith (Reynolds et al. , 1981) . A great variety of rock types and rock textures are present in the granitoids at the batholith margin . In the Mahone Bay area , granitoid phases have not been separated on map sheets A and C .

The most common intrusive phases are a biotite granodiorite and a biotite-muscovite quartz monzonite . The granodiorite is relatively coarse-grained and porphyritic in places . It contains slightly sericitized , zoned plagioclase and zircon-rich , brown biotite in addition to some quartz and alkali feldspar . The finer-grained quartz monzonite is variably textured but equigranular rocks dominate over other types . Unexsolved alkali feldspar and plagioclase containing sericitized cores are intergrown with fresh grains of muscovite and biotite as well as quartz (Figure 21a) . Accessory minerals in these phases include tourmaline and cordierite .

Many of the granitoids are altered , particularly so in the vicinity of Cu-Mo and Cu-Mo-W showings near Chester Grant and Chester Basin . Replacement textures are common in the variably altered granitoids . The transformation of microcline to albite occurred during the exsolution of perthite and , in some thin sections , plagioclase has broken down to give alkali feldspar and muscovite . Brown biotite grains are partially altered to green chlorite and alkali feldspar in rocks which also show the replacement of chlorite by muscovite (Figure 21b) . Where these reactions go to completion , the granitoids are greisenized and composed of coarse , unaltered grains of albite , muscovite and quartz (Figure 21c) . Thin sections of the contact between granitoid and hornfels show both rock types to be sericitized to the extent that it becomes difficult to microscopically distinguish between intrusion and country rock .

The intrusive relationship between granitoid rocks and the Meguma Group is indicated by the presence of abundant xenoliths and large enclaves of host strata near the batholith margin (Figure 21d) . Unfoliated , marginal-phase granitoids contain inclusions of contact metamorphosed schist . The Meguma xenoliths are assimilated to varying degrees .

The steeply dipping intrusive contact is exposed in several localities in map sheet C between Aspotogan Harbour and Deep Cove . Subvertical screens of unfoliated granite separate septae of schist and migmatite . Subvertical bedding-parallel fabrics in strongly attenuated schist are parallel to the intrusive contact at the margin of the batholith . Regionally , however , the granitoid contact is highly discordant to the trend of major folds in the Meguma Group .

Pegmatite and aplite intrude the main phases of the batholith , the hornfelsed rocks near the granitoids and the low-grade rocks outside the contact aureole .

Hypabyssal intrusions in the Meguma Group

Northeast-trending minor intrusions of intermediate and mafic composition are present in the Meguma Group in the southern part of the study area . Two types of intrusion are separated on the basis of lithology , structural setting and age . Both types were probably emplaced after the Acadian folding episode but before all or some of the faulting that affected the Meguma Group in the LaHave River and Mahone Bay areas .

Paleozoic sills

Leucocratic intrusions approximately 1-2 metres wide occur in the Cunard member near Ovens Point on the northern headland of Rose Bay and in the Feltzen member near Western Harbour on Cross Island . In both localities , they are concordant with host strata and are traceable for up to 40 metres along strike . They are , however , too small to be shown on the 1:25 000 scale maps of the study area .

In the field , hypabyssal sills are fine-grained and equigranular to slightly porphyritic in texture . In thin section , they are strongly sericitized and contain pseudomorphs of originally euhedral phenocrysts . Plagioclase is mostly altered to white mica , and ferromagnesian minerals are replaced by chlorite and rarer actinolite . This low-grade metabasite assemblage may have been produced during the regional dynamo-thermal metamorphism of the Meguma Group , although the intrusions are unfoliated . However , it is equally likely that the alteration occurred during the cooling of sill and host-rock slate , or perhaps simultaneously with the sericitic alteration of South Mountain granitoid and hornfels . Barr et al. (1983) considered that there were two groups of mafic sills in south-western Nova Scotia , an Ordovician synvolcanic group and a Devonian posttectonic group . Hall (1981) concluded that the hypabyssal intrusions at Ovens Point probably crystallized in the Carboniferous as calc-alkaline granodiorites and were best correlated with plutonic rocks in the Shelburne area rather than with rocks of the South Mountain batholith .

In the Cunard member , beds and minor intrusions dip vertically ; whereas , in the Feltzen member , they both dip northwesterly at 35° . These observations can be interpreted in two ways . In one interpretation , the intrusions were originally emplaced as bedding-parallel horizontal sills that were subsequently folded with the host sediments . If this is so , it is difficult to explain why the unfoliated sills should chill against country rocks already containing a bedding-cleavage intersection compatible with the regional fold structure . An alternate interpretation is that the minor intrusions were emplaced preferentially along bedding planes within existing fold structures . It seems fortuitous , however , that dykes are not observed in places .

Mesozoic dykes

A subvertical , northeast-trending , brown-weathered , doleritic dyke approximately 30 metres wide and associated decimetre-scale dykelets are mappable for approximately 20 kms from Cherry Hill to Cape LaHave Island to West Ironbound Island (see GSC Open File Map 1156) . Traceable along the entire length of the province's South Shore district (Figure 12) , the intrusion is regionally referred to as the Shelburne dyke (e.g. Papezik and Barr , 1981) . The host rocks to the Shelburne dyke are either Cambro-Ordovician metasediments or Devono-Carboniferous granitoids . In Shelburne County , the dyke and the metasediment-granitoid contact are sinistrally displaced about 5 kms (Keppie , 1979) . Wanless et al. (1968) reported a 199 ± 32 Ma , whole-rock , K/Ar age for the intrusion .

In the study area , the Shelburne dyke intrudes a folded and cleaved succession of rocks belonging to the Goldenville , Green Bay and Halifax formations . Fresh specimens of the unfoliated , kink-banded dyke are unaltered . Microscopically , the intrusion is chiefly composed of clinopyroxene and plagioclase , although interstitial granophyre is rarely present . In the centre of the body , the rock is equigranular , medium grained and ranges in composition from quartz diorite to granodiorite . Textures most commonly observed in thin section are ophitic or sub-ophitic .

At the intrusive contact of the Shelburne dyke , porphyritic plagioclase phenocrysts occur in the glassy matrix of the chilled margins . A zone of spotted hornfels of undetermined width is developed in the contact aureole of the dyke . The glassy margin of the intrusion yielded a K/Ar whole-rock age of 182 ± 8 Ma , which presumably dates the age of crystallization (Table 3) . A sericite concentrate was made from hornfelsed

Cunard metasediment in the aureole of the Shelburne dyke and a K/Ar mineral age of 209 ± 8 Ma was obtained (Table 4). Since the sericite population analysed included detrital, regional and contact metamorphic grains, the date probably indicates an incomplete isotopic re-setting of Meguma Group country rocks during the latest Triassic or earliest Jurassic (see Reynolds et al., 1987).

CONTACT METAMORPHISM

Porphyroblastic , partly magnetic hornfelses occur in the Meguma Group on map sheets A, B and C of the Mahone Bay area . They are located in a zone up to 2 km wide in the aureole of the South Mountain batholith (Clarke et al., 1985) . The hornfelsed zone generally follows the contact of the granitoids and , despite changes in contact orientation , is approximately the same width throughout the study area . Because the contact aureole trends across the regional tectonic grain , most members of the Meguma Group are locally hornfelsed (see section on lithostratigraphy) .

Field Appearance

Most of the Meguma hornfelses are distinctly spotted rocks in which primary bedforms and stratification are still recognizable . The spots are small crystals or mineral aggregates that formed during contact metamorphism and are increasingly well developed approaching the margin of the batholith . Unlike the alteration products of diagenesis or early gold mineralization , spotted porphyroblasts are observed to overgrow the regional slaty cleavage and are areally restricted features of certain members of the Meguma Group .

Contact metamorphism enhances delicate bedforms and compositional layering , although the overall field appearance of the altered unit changes considerably . For example , porphyroblasts are reversely graded in Cunard beds that elsewhere demonstrate only faint evidence of grading . Likewise , hornfelses of the Moshers Island member are still recognizable as being original rhythmites , although now much harder and massive in appearance . Primary concretionary strata such as green laminite and grey siltstone are presently dark-grey , spotted pelite and pink-coloured , coarse-grained semipsammite , respectively (Figure 22a) . The light pink hue of coticule-bearing semipsammitic layers is partly due to abundant visible garnets .

Hornfelses of the innermost part of the contact aureole are composed of highly recrystallized , porphyroblastic schist . Here , sharp boundaries separating layers of pelite and psammite attest to an original stratification , although the layers are not necessarily in depositional order . Pelitic horizons , in particular , show evidence of partial melting and the development of migmatitic texture (Figure 22b) . Zoned calc-silicates are found in units that are nodular outside the metamorphic aureole .

Microscopic relations

In the outermost part of the aureole , hornfelsed slate contains phyllosilicates of detrital and regional metamorphic origin , and just perceptible porphyroblasts of cordierite . Rocks obviously spotted in hand specimen illustrate well-defined cordierite and small euhedral andalusite in thin section (Figure 22c) . Farther into the aureole and closer to the batholith , hornfelsed rocks are recrystallized to the extent that (1) detrital minerals are no longer recognizable in the matrix and (2) porphyroblasts , particularly chiastolite , become coarser-grained and more euhedral . Narrow reaction rims on andalusite porphyroblasts indicate an incipient hydration of the spotted hornfels .

In the inner part of the aureole , Meguma Group rocks take on a schistose appearance . The recrystallized matrix of the schist is relatively coarse grained and some of the phyllosilicates are crudely aligned . Porphyroblast species of the outer aureole are present in the contact metamorphosed schist except that they are retrogressed and partially replaced . Shimmer aggregates of white micas commonly surround twinned chiastolites (Figure 22d) . Near the margin of the granitoids , euhedral pseudomorphs after andalusite porphyroblasts are completely composed of coarse blades of muscovite (Figure 23a) . Where this late stage hydration of the hornfels is complete , the schist displays new porphyroblasts of muscovite intergrown with chloritized biotite and highly sericitized feldspar . The texture and mineralogy of the schist in the innermost aureole is similar to the hydrothermally altered parts of the adjacent granitoids .

STRUCTURAL GEOLOGY

All rocks in the LaHave River and Mahone Bay areas are deformed in one way or another . Tectonic structures are observed in the Meguma Group , the contact hornfels , the Windsor Group and the minor intrusions . Most of these rocks have been deformed in a brittle-ductile manner . Generally , the younger the rock , the more brittlely it behaves , although many examples of overlapping brittle and ductile deformation exist in the study area .

Structure of the Meguma Group: ductile deformation

Ductile deformation of the Meguma Group occurred on all scales during the Acadian Orogeny . Three orders of generally upright folds and axial planar slaty cleavage were produced during the main phase of regional deformation and are widely developed throughout the study area . Vertical shear zones are restricted to certain fold structures and rock units , and formed during the development of the regional slaty cleavage . Cross-folds and fracture cleavage were produced after the regional folding and foliation-forming event during a late phase of Meguma Group deformation (Fyson , 1966) .

Folds

Northeast-trending folds of the main phase of deformation are quite large and are essentially responsible for producing the map pattern seen in Figure 4 . Fold wavelengths vary from 0.5 km to 6 km ; however , fold amplitudes remain constant at approximately 0.5 km to 1.5 km (Figure 24) . The width:length ratios of hinge zones are as small as 1:1000 for many of the major folds . For example , the axial trace of the Indian Path Anticline extends for at least 50 kms across the study area but the exposed hinge zone is less than 50 m wide in places .

Cuspate major folds are tight in the thinly stratified , shale-dominated Cunard member (sections AB and NO) . In contrast , open major folds occur in the thickly stratified , sandstone-dominated New Harbour member (sections AB and GH) . Bedding thickness and viscosity contrast are , however , not the only parameters controlling fold shapes in the Meguma Group . As evidence of this point , some folds tighten along their axial trace within units of the same lithology (compare the Cunard synclines in sections EF and AB) . Furthermore , open synclines occur in shale-dominated successions at high structural and stratigraphical levels (see section LM) .

The fold between the Indian Path and Ovens anticlines in section KLM is a good illustration of the open W-shaped synclines present in the Meguma Group . The box-like fold in section NO is representative of the open M-shaped anticlines . As a regional W-shaped fold tightens to a V-shaped fold , two of the constituent folds simply die out . This is one reason why the Meguma Group is not regionally repeated between major anticlines and synclines . Care must be taken not to confuse these structures with en echelon folds or the 'transform' folds of Faribault (1924 , 1929a , 1929b) .

The axial surfaces of most major folds dip subvertically (Figure 24) and , as a result , the Meguma succession is generally right-way-up . Notable exceptions are located near the Rhodes Corner Anticline where the Feltzen member is regionally inverted (section CD) . In this area , an upward-facing , gently dipping slaty cleavage occurs in strata that are upside-down and moderately to steeply inclined .

The direction and amount of plunge varies systematically for minor and major folds of the main phase of deformation (Figure 25a) . Changes in local and regional plunge direction confirm that most of the elliptical outcrop patterns in the study area are produced by periclinal folds . The plunge of minor folds along the axial trace of major folds is commonly gentle , although vertical plunges are locally recorded . Where the major fold is open and the minor folds are reclined , strata strike northwesterly and dip subvertically . Examples of this type of structure are seen in the Cunard member near Pleasantville , Schnare's Crossing and Indian Path . Northwest-striking beds in the open hinge zones of vertically plunging , regional folds presumably flatten upwards and downwards in such a way that the Meguma succession is nowhere seen to be upside-down in gently plunging , periclinal hinge zones .

Minor folds of the late phase of regional deformation generally trend northwest (e.g., the crossfolds of Fyson , 1966) , although a conjugate set of eastnortheast-trending folds are also poorly developed (Figure 25b) . Commonly , they are steeply-plunging kink folds or chevron folds that deform the regional slaty cleavage (Figure 23b) . Although late phase crossfolds are present throughout the study area , they are concentrated (1) where northwest-trending transcurrent faults are present or (2) where the axial surfaces of the major folds are flexured or megakinked (see GSC Open File Map 1156) . Near the Ritchie Cove-Lower South Cove fault system , late phase folds are abundant and are commonly associated with syntectonic quartz veins . Locally , several orders of tight crossfolds display penetrative , axial planar , fracture cleavage .

Shear zones

Numerous , small-scale , ductile shear zones affect rocks of the Meguma Group and indicate the inhomogeneous nature of the regional Acadian deformation . Second- and third-order parallel folds displaying vertical , axial planar , slaty cleavage tighten in directions perpendicular and parallel to the fold axes until they cease to be recognizable in vertical zones of platey or straightened rocks (Figure 23c) . Platey rocks are developed parallel to slaty cleavage on the vertical limbs of asymmetrical folds . On the gently dipping limbs of such folds , slaty cleavage forms a large angle with beds that show primary sedimentary features . However , bedforms become highly attenuated and the rocks highly strained as they pass from the hinge zone onto the vertical limb of mesoscopic folds .

As minor folds of the main phase of deformation tighten near the margins of ductile shear zones , their axes become highly curvilinear . Fold axes pitch at various angles on vertical slaty cleavage from 0°-90° in northeast and southwest directions . Where the curvilinear fold axes pass from the horizontal through the vertical and back towards the horizontal (i.e. rotations of greater than 180°) , the strata become inverted in the fold hinge zones . As a result , the slaty cleavage and fold axial surfaces locally face downwards on the bedding . Sheath folding associated with shear zone development produces outcrop-scale domes and basins containing antiformal synclines and synformal anticlines . Regional periclinal folds are , however , not affected by this type of deformation .

Ductile shear zones are most commonly developed in open Feltzen-cored synclines . Excellent exposures of such structures are located at South Feltz , Flat Island , Cross Island , East Point Island and the Hell Rackets . They are , however , also locally observed in the Green Bay formation , particularly on Cape LaHave Island . As certain regional folds tightened , it appears that vertical shear zones developed to accomodate anomalous amounts of shortening in fold cusps . Displacements across shear zones did not cause regionally significant breaks in the succession of Meguma Group members .

Foliations

Mineral foliations are widespread in rocks of the Meguma Group ; whereas , strong XY-shape fabrics are restricted to the ductile shear zones . Northeast-trending slaty cleavage of the main phase of deformation (Figure 26a) is the most common and widely developed mineral foliation and forms a slightly divergent fan about the upright major folds . It is defined by zones of preferentially-oriented phyllosilicates and intervening microlithons (Figure 27a) , in which the domain spacing is less than 0.1 mm . In selective sandstone beds , a solution cleavage with domain spacing greater than 1 cm is rarely developed and displays a strongly convergent fan . Spaced solution cleavage is , however , generally uncommon in Meguma Group rocks in Lunenburg County in comparison with exposures of the group in Halifax and Guysborough counties (O'Brien , 1983 ; Henderson , 1983 ; Henderson et al., 1986) .

In some localities , especially in the Cunard member , a northeast-trending crenulation cleavage is locally well developed in certain shale beds . In thin section , this upright foliation crenulates a bedding-parallel fabric defined by micas (Figure 33a) . The micas have a strong preferred orientation ; however , the early fabric is nowhere seen to transgress the bedding laminations . Where the bedding-parallel micas are coarse-grained , they display much less of a dimensional orientation and are most simply interpreted as compacted detrital grains . Basal cleavages of detrital micas are variably rotated in the microlithons separating the crenulation cleavage planes (Figure 27b) . This foliation is the temporal and geometrical equivalent of the regional slaty cleavage .

In rare exposures of the Cunard member , a northeast-trending foliation of tectonic origin is overprinted by a coaxial foliation which is axial planar to the major folds . At such localities , both foliations cross depositional layering at a discernible angle (Figure 28) . The earlier foliation is observed to dip gentler than bedding , whereas the later foliation is steeper than bedding . Therefore , the early tectonic foliation and the main-phase foliation illustrate contrasting structural facing relationships in the same beds (Figure 28) . Similar foliation relationships have been described in the Goldenville Formation near Gegogan Harbour , Guysborough County (O'Brien , 1983) . Folds related to the early-formed foliation are not evident in the study area . The earlier foliation may have originally formed as an upward-facing structure , which either predated most of the folding or was entirely unrelated to folding (following Powell and Rickard , 1985) . Most likely , it was subsequently rotated about the main-phase fold axes into its present downward-facing orientation .

Steeply dipping fracture cleavage trending northwest and less commonly northeast is associated with minor folds of the late phase of regional deformation (Figure 26b) . Locally , especially near faults , fracture cleavage is closely spaced and forms the predominant foliation in some exposures . In most localities , however , overprinted slaty cleavage is still readily discernible (Figure 23d) . Small displacements of bedding laminations occur across fracture cleavage planes , along which foliation-forming chlorites have crystallized .

<u>Lineations</u>

Intersection lineations (location fabrics) and extension lineations (shape fabrics) are present in the Meguma Group in the study area . Intersection lineations are separated into two groups on the basis of relative age . The oldest group formed from the intersection of bedding and slaty cleavage , whereas the youngest group resulted from the intersection of fracture cleavage with bedding and slaty cleavage . For the most part , bedding-slaty cleavage intersection lineations plunge gently to the northeast and southwest , although subvertical plunges are locally recorded (Figure 29) . They confirm the plunge culminations and plunge depressions of the regional periclinal folds . Bedding-fracture cleavage and cleavage-cleavage intersection lineations display variable but generally steep plunges to the northwest and southeast . Orientations of the younger group of structures reflect lineation development within steeply dipping rocks on the northwest and southeast limbs of major folds .

Extension lineations (X-directional shape fabrics) are well displayed in the ductile shear zones , although regionally they are poorly represented . In minor and major folds throughout the study area , concretions and sand volcanoes are flattened by the regional slaty cleavage . Visual inspections of the aspect ratios of concretions and sand volcanoes were made on slaty cleavage planes and in naturally-exposed longitudinal sections of folds . They suggest that Meguma Group rocks may have been slightly extended on foliation parallel to gently plunging , minor fold axes and bedding-slaty cleavage intersection lineations . However , in the ductile shear zones , extension lineations plunge vertically down-dip .

Structure of the Meguma Group: brittle deformation

Brittle deformation produced Meguma Group structures on all scales from major faults , that are seen as lineaments on satellite photographs (Rowley , 1985) , to complex systematic joint patterns , which are present in most exposures .

Measurements on joints and small faults were made at approximately 500 stations throughout the LaHave River map-area . A contoured stereoplot of poles to these structures shows a distinct maximum related to northwest-trending , subvertical fractures . Two less abundant groups of steep fractures are also present . One set trends approximately east , whereas a less common , poorly defined set trends northeast (Figure 30a) . Northwest-trending joints are associated with vein-filled kink bands and fracture cleavage , all of which formed near the transcurrent sinistral faults that scar the seaboard of the Meguma Terrane (Figure 31) .

In places where the fracture sets are vein-filled or where normal drag folds of slaty cleavage are developed near the fractures , the relative age relationships and the types of displacement on each set are determinable (Figure 32) . The northwest-trending joints are branch or subsidiary fractures related to small northnorthwest-trending faults , both of which show sinistral displacement . The less common , northeast-trending joints display dextral offset . Overlapping age relationships between northwest- and northeast-trending joints probably implies that they originated as a conjugate pair with one set developed at the expense of the other . As indicated in Figure 32 , east-trending joints dextrally offset northeast-trending joints .

The geometrical relationship between northwest-trending and east-trending joints and northwest-trending , sinistral kink bands is illustrated in Figure 33b . East-trending joints cross both the kinked and unkinked segments of slaty cleavage and are the youngest of the three main fracture sets in the Meguma Group . Rowley (1985) thought that east-trending fractures were most visible in the Heckman's Island-Stonehurst region nearing the outcrop area of the Windsor Group . Contoured stereonets of poles to Meguma Group fractures on Heckman's Island show the northwest-trending and east-trending joints to be most abundant (Figure 30b) . Giles (1981) considered east-trending faults (e.g. the fault along the shore of Mahone Harbour) to offset the Carboniferous rocks and to form the local boundary between Windsor and Meguma groups .

Although most northwest-trending fractures and kink bands have sinistral offsets , many show evidence of dextral displacement (Figure 33c) . This may mean that the Meguma Group was affected by several distinct ages of northwest-trending transcurrent faults . Alternatively , local changes in the sense of fault displacement may be analogous to local changes in the sense of crossfold vergence . This may explain why northwest-trending chevron folds with axial planar fracture cleavage have Z- , M- and W-profiles in addition to the more common S-shapes (Figure 23b) .

Structure of the hornfels

The structure of the contact hornfels is well exposed on the Aspotogan Peninsula , where members of the Goldenville , Green Bay and Halifax formations are regionally folded about northeast-trending axes and strike discordantly into the outer zone of the aureole of the South Mountain batholith . In the outer aureole , slaty cleavage is still recognizable in the spotted hornfels and the intersection angle between cleavage and bedding is readily discernible . In some localities , cordierite porphyroblasts of contact metamorphic origin overgrow the slaty cleavage and display inclusion-free rims (Figure 33d) . Furthermore , microfolds of bedding laminae are included within some andalusite porphyroblasts . In the same exposures , however , strained cordierite porphyroblasts are flattened in the plane of the slaty cleavage (Figure 27c) . Therefore , in the outer aureole , growth of contact metamorphic porphyroblasts began late during dynamothermal metamorphism and partially overlapped the development of the regional slaty cleavage .

In the inner zone of the aureole , the three Meguma formations become highly strained and recrystallized approaching the granitoids . Porphyroblasts are distorted , bedforms are attenuated and bedding-parallel , vertical schistosity is developed (Figure 27d) . In places , the northeast-trending schistosity is axial planar to highly curvilinear, isoclinal folds of calcsilicate horizons (Figure 27d). However, in thin section, calcsilicate-bearing schist displays a polygonal texture indicating that recrystallization outlasted deformation in the inner aureole.

Pegmatites are common in the hornfels and presumably emanate from the South Mountain batholith. Undeformed bodies are highly discordant to host strata, whereas highly deformed bodies occur in rootless isoclinal folds that are concordant with bedding. Most pegmatites are generally shallow dipping sheets, which are locally folded and steepened. Their gentle dip may imply that a horizontal compressive stress acted on the contact hornfels at the time of pegmatite emplacement.

Partially migmatized, highly strained schist is reorientated some 50-100 m from the granitoids to lay concordant with the contact of the South Mountain batholith. In a section drawn parallel to the axial surface of the Indian Path Anticline on the Aspotogan Peninsula and perpendicular to the margin of the intrusion (section IJ in Figures 4 and 24), this reorientation is expressed by the downbending of the northeast-trending anticlinal axis. A locally abrupt culmination of the Indian Path Anticline during the main phase of folding could account for the change in regional plunge direction from gently southwest to vertical. However, it does not explain the following observations in the innermost aureole: (1) that bedding and foliation are parallel and both orientated northwest and (2) that rocks on the northwest limb of the anticline were reorientated along with rocks in the hinge zone.

The present disposition of hornfelses in the inner aureole at Aspotogan is controlled by a large-scale antiform, which plunges steeply northwest and refolds the Indian Path Anticline. This fold probably formed simultaneously with batholith emplacement as its axial surface is approximately parallel with the intrusive contact. Northwest-trending granitoid screens concordant with highly strained schist and the batholith margin comprise the relatively narrow, northeast limb of the antiform, whereas the southwest limb is composed of northeast-trending screens and variably deformed hornfelses. Faribault (1908) may have mapped similar types of folds in Halifax County. These folds were also localized in the Meguma Group near the margin of the South Mountain batholith and crossed regional folds that were discordant to the intrusion.

Brittle fractures are also present in hornfelsed rocks in the aureole of the South Mountain batholith. Northwest-trending joints and small faults illustrate sinistral and dextral offset. In places, they are filled with thin aplites and quartz veins that have leached and sericitized hornfelsed schist. If the aplites are pre-Visean like the main phases of the batholith, then these particular northwest-trending fractures represent one of the earliest sets with this orientation.

Structure of the granitoids

Granitoids of the South Mountain batholith are nowhere foliated ; however , they are notably sheeted immediately beneath the nonconformity with the Windsor Group . Although most of the steep joint sets in the granitoids are also present in the Windsor Group , a horizontal set of preferentially exfoliated joints does not occur in limestone above the unconformity . Mica grains in granitoids near vertical fractures are strained and kinked (Figure 34a) . Near flat-lying joints which offset vertical aplite dykes in strongly sheeted granitoids , hydrothermal sericitization of feldspar accompanied shear fracturing of quartz (Figure 34b) .

Structure of the Windsor Group

The regional structure of the Windsor Group is hard to decipher because of poor exposure . Although Carboniferous strata locally outcrop across the folded contacts of members of the Meguma Group , the trace of the unconformity defines folds that crudely mimic the shape of underlying structures in the basement rocks . For example , on map sheet B , northeast-trending , gently-plunging cover synclines are situated above similarly--oriented basement synclines . At Frail Cove , the basal strata of the Lower Carboniferous together with the unconformable surface separating Windsor and Meguma groups are folded by macroscopic folds that plunge gently southwest .

Large-scale , northwest-trending faults occur in Lower Carboniferous strata near East River and Chester Basin . Three steeply dipping sets of systematic joints are also present in Windsor Group strata and are presumably related to the Carboniferous system of folds and faults . A northwest-trending set of cross-strike joints is parallel to the faults , whereas a northeast-trending set of longitudinal joints is parallel to the fold axes . An east-trending set of possible master joints is particularly well developed .

Northwest-trending joints crosscut the angular unconformity between the Windsor and Meguma groups at Frail Cove and , along with the east-trending joints , are very common in the Meguma basement . Open longitudinal joints are more evident in Carboniferous than Cambro-Ordovician rocks , although northeast-trending fractures are widespread where granitoids form the local basement to the Windsor Group .

Approaching faults in Windsor limestone , fractures are very closely spaced and are filled with calcite veinlets that locally contain galena . The veinlets are en echelon , have branched or forked terminations and demonstrate linkage through ladder veinlets . These features are all characteristic of dilated shear fractures (following Escher et al , 1976 ; Nicholson and Pollard , 1985) .

Structure of the minor intrusions

Paleozoic sills

Sills of probable Carboniferous age display the same systematic joint pattern that is locally developed in Meguma Group host rocks . On Cross Island , a single intrusion is offset 15-20 metres by at least four , northwest-trending , vertical faults . As the spacing of the tectonic joints decreases near these faults , the fractures begin to show measureable dextral displacements (Figure 34c) . This is indicated by the offset of the intrusive contact and by normal drag folds of slaty cleavage in the adjacent host rocks . However , some northwest-trending fractures pass from the sill into sinistral kink bands in the Meguma Group (Figure 34d) . Regardless of whether offset along northwest-trending fractures was sinistral or dextral , the consistent subvertical plunge of associated kink folds suggests strike-slip displacement .

Mesozoic dykes

Although the vertical Shelburne dyke is mapped as a linear , northeast-trending intrusion on regional maps (Figure 12) , its outcrop pattern in the LaHave River area is very irregular (GSC Open File Map 1156) . The simplest explanation of this pattern is that the dyke is regionally kink banded and offset by northwest-trending , transcurrent faults . The positions and shapes of some kink folds are estimated on the open file map as the offshore trace is completely inferred . Where exposure is good , however , a reversal of the sense of shear given by map-scale kink folds and faults is demonstrable . The Shelburne dyke maintains its regional northeast trend because sinistral offset is more common than dextral offset . In the southern part of the study area , Mesozoic faulting shortens rocks of the Meguma Terrane , although regionally the deformation may have been extensional .

On West Ironbound Island , the main body of the Shelburne dolerite locally forms a sill in moderately dipping strata , although vertical offshoots are also present as metre-wide dykelets in the Cunard member . The chilled margin of a dykelet and an adjacent hornfels (described in Tables 3 and 4) are shown in Figure 35 . Fractures in the dykelet offset the contact with the hornfels and the bedding laminations in Cunard strata regardless of their orientation relative to the intrusive contact or each other . Therefore , dykelet fractures are unlikely to be tensile cooling joints and are interpretated as tectonic shear joints .

On Cape LaHave Island , the Shelburne dyke dips vertically and intrudes moderately dipping strata belonging to several members of the Green Bay formation . In several localities , the dyke is megascopically folded by vertically plunging , northwest--trending kink folds (Figure 36) .

Rowley (1985) recognized two major sets of lineaments on Cape LaHave Island ; one set generally parallel to the trace of the dyke and the other almost perpendicular to it . Ground truthing of lineaments south of Halibut Bay indicated the presence of northeast-trending , centimetric-scale bands of cohesive breccia and small , northwest-trending , sinistral kink bands . Exposures of the southern contact of the Shelburne dyke on the southwest coast of the island display a metre-wide zone of closely-spaced fracture cleavage in recrystallized wall rocks . The fracture cleavage is parallel to the margin of the intrusion and is deformed by northwest-trending ,sinistral kink bands . Thus , in the LaHave River area , it appears that (1) the Shelburne dyke was emplaced into a zone of northeast-trending lineaments locally marked by cohesive fault breccia and fracture cleavage , and (2) that at least some northwest-trending lineaments related to transcurrent faults and regionally developed kink bands were produced after the intrusion of the Shelburne dyke at 182 ± 8 Ma .

ECONOMIC GEOLOGY

In the Mahone Bay area , underground mining operations at the Blockhouse and Gold River mines produced in excess of 10,000 troy ounces of gold prior to 1940 (Gillespie-Wood , 1987) . In the LaHave River area , poor past-producers such as the gold--tungsten mine at Indian Path and the gold mine on the coastline of The Ovens have recently been examined as prospects for open pit and placer development , respectively (Assessment Report Index , 1979 , 1980) . Gold occurrences , mainly in the upper part of the Green Bay formation or the lower part of the Halifax Formation , are found near Centre , Clearland , Cross Island , Dares Lake , Dublin Shore , Farmville , Martin's River , Petite Riviere , Rhodes Corner , Spectacle Lake and Big Tancook Island (see accompanying maps) .

General Statement

In the study area , metallic mineralization occurs in a variety of map units of different age and composition . Proven mineralization in the Meguma Group is chiefly in the form of epigenetic , precious-metal lode deposits , although potential also exists for syngenetic , stratiform , base-metal targets . Granitoids near the margin of the South Mountain batholith contain greisens and veins rich in U , Mo and Be . Metals such as W , Cu , Zn , Mn , Au , As and Ag are common to the Meguma Group and the granitoids which intrude it (O'Reilly et al. 1982 ; O'Reilly , 1983 ; Bishop and Wright , 1974 ; Graves and Zentilli , 1988) . The Windsor Group is locally mineralized by Pb-bearing veins which fill fractures near faults . Limestones of the Windsor Group are also a source of industrial minerals .

The following discussion focuses on the general types of metallic mineral occurrences found in the Meguma Group in the study area . There is an extensive literature on the economic geology of the area and the reader is referred to the Assessment File Index at the Halifax offices of the Nova Scotia Department of Mines and Energy .

Mineralization in the Meguma Group

The extensive outcrop areas of the Halifax and Green Bay formations in the study area are coincident with some of the largest lake sediment geochemistry anomalies in the South Shore district of Nova Scotia . In south-central Lunenburg County , a strong W-Sb enrichment locally overshadows the regional Au-As association typical of regions underlain by the Meguma Group (Rogers et al., 1985 ; Rogers , 1987) . Despite the common association of these granophile elements with the South Mountain batholith , the distribution of geological units in the study area strongly suggests a local Meguma Group source for the geochemical anomalies (Rogers , 1987) .

All the past-producing mines and most of the prospects and mineral occurrences hosted by the Meguma Group are sited near structurally controlled , quartz-carbonate vein arrays containing Au , Au-W , Au-As , Au-Cu , Au-Zn , Au-Pb and Au-Mn mineralization . Gold-quartz veins are located in most members of the Goldenville , Green Bay and Halifax formations ; however , the Cunard member is the most common host due to its widespread distribution .

In the area mapped , two general types of vein arrays occur : 1) those produced during the development of cleavage and folds in the Meguma Group and 2) those produced during the development of brittle faults in the Meguma Group . Both are locally associated with gold mineralization and , in some localities , fold-related and fault-related veins occur together (e.g. the Gold River Mine) . As elsewhere in the Meguma Group (e.g. Kontak and Smith , 1987) , country rocks are commonly altered , although the extent and the nature of the alteration is quite variable . Macroscopic evidence of sericitization , pyritization and arsenopyritization are seen in host rocks on centimetric scales parallel to vein margins . Carbonitization and silicification are more restricted and typically occur within and along the outer portions of the veins . In the alteration zones , distorted sulphides and preferentially aligned sericites partly define the rock cleavage .

Fold-Related Vein Arrays

related Fig 37-41

Auriferous vein arrays , formed during the folding of the Meguma Group , are well displayed in coastal sections near the Ovens Mine and the Southeast Bay prospect on Cross Island . They are also poorly exposed in exploration trenches above the Indian Path Mine . Barren veins of this type are locally seen in a variety of lithologies near the axial traces of the Gold River , Rhodes Corner , Indian Path , Ovens and Hartling Bay anticlines .

Most of the synfolding veins are deformed in one way or another , yet still display systematic orientations and characteristic shapes that are used to classify the arrays in terms of constituent vein sets . Vein textures are fibrous , massive , vuggy and laminated (ribboned) , although neither of these features is peculiar to a particular type of vein . The arrays comprise a complex interconnected system of veins , which show overlapping relative ages based on crosscutting relationships . In past-producing mines , they have been informally described as 'lead', 'stockwork' and 'ladder' veins and have been interpreted as saddle reef deposits (Faribault, 1899 ; Malcolm , 1929) .

In the study area , the majority of the synfolding veins occur in steeply dipping beds near the hinge zones of regional anticlines . A notable feature of these folds (e.g. the Ovens Anticline) is that only a small proportion of the veins encountered on the limb hosting the largest array extends over the hinge zone of the fold . Rocks hosting synfolding veins commonly illustrate a structural complexity atypical of the region in general . Protracted deformation localized near hinge zones results in some veins forming while other veins were being folded or boudinaged .

In the study area , four main sets of veins comprise the synfolding arrays , although a greater number of individual morphological varieties are present (Figure 37) . These vein sets are fundamentally defined by their relationship to the slaty cleavage and the fold axial surface . However , they are also classified by their crosscutting relationships with bedding planes and other veins .

Vertical set 1 veins are the principal ribboned veins or 'leads' recently described from Eastern Shore deposits by O'Brien (1985b) , Henderson and Henderson (1986) and Mawer (1987) . They generally transgress bedding at a slight angle and , therefore , appear stratabound in local exposures (Figure 37) . In places , set 1 veins include enclaves of local country rock by bifurcating and recoalescing . They also form T- or Y- junctions with other veins in the array . A common feature of set 1 veins is the development of variably-sized offshoots called side veins or pinnate veins . On a local scale , offshoots from set 1 veins appear to be more transgressive than the principal veins from which they are fed (Figure 37). Principal veins and side veins both illustrate laminated , vuggy or massive textures ; however , only the laminated varieties have regularly orientated inclusion bands and inclusion trials (O'Brien , 1985b) . The principal veins generally lie subparallel to and include the regional slaty cleavage . Feeder veins and offshoot veins are , however , also deformed by folds with axial planar slaty cleavage . In the most complex arrays , they are folded and boudinaged along with the slaty cleavage (Figure 37). Set 1 veins are interpreted to occupy subvertical longitudinal fractures parallel to the AB-kinematic plane of anticlines and the axial planar foliation .

Vertical set 2 veins transect bedding planes perpendicular to their strike , display en echelon pinnate veins and are variably fibrous or massive (Figure 37) . Most commonly , set 2 veins form T-junctions with or crosscut set 1 veins , although the former locally transect minor folds of the latter . Set 2 veins are deformed by neutral folds with vertical axial planar cleavage , particularly within beds of slate . However , fibrous set 2 veins also occupy the necks of horizontally extended boudins of slaty cleavage and set 1 veins (Figure 37) . Set 2 veins are interpreted to occupy cross-strike fractures parallel to the AC-kinematic plane of anticlines and perpendicular to the axial planar foliation .

Horizontal set 3 veins transect bedding planes perpendicular to their strike , display en echelon pinnate veins and are variably fibrous or massive (Figure 37) . Like the set 2 veins , they either abutt or crosscut set 1 veins . Where they are deformed by subhorizontally plunging folds and vertical slaty cleavage , the internal fibres are distorted by the folding process . Elsewhere , veins with undistorted fibres occupy the necks of vertically extended boudins of slaty cleavage and set 1 veins (Figure 37) . Set 3 veins are interpreted to occupy cross-strike fractures parallel to the BC-kinematic plane of anticlines and perpendicular to the axial planar foliation .

Set 4 veins include a variety of folded veins that have a distinctive stepped-shape in vertical cross-section (Figure 37) . The steep parts of these step veins normally occur in strongly cleaved slates , whereas the flat portion and their spiked or feathered terminations are commonly located in more component sandstones . Folds defined by set 4 veins display vergence opposite to the parasitic folds of bedding on anticlinal limbs . However , they have shapes which are consistent with flexural slip along certain sandstone-shale boundaries and with differential flexural flow in slates (e.g. Henderson , 1983 ; Henderson and Henderson , 1986) . Set 4 veins crosscut set 1 veins , have inclusions of slaty country rock and are locally deformed by the regional slaty cleavage . They may represent a distinct class of veins in the array or they may be kinematically related to the set 3 veins .

Numerous assessment reports document 'crumpled and reveined leads' and 'barrel and roll' vein structure in gold workings near the Blockhouse , Gold River and Ovens anticlines . Folded set 1 laminated veins with preserved inclusion bands and inclusion trails yield important data relating to the origin of these features .

In the principal feeder veins , slaty cleavage in country rock inclusions is aligned parallel to the inclusion bands , which are parallel to the vein wall (Figure 38). Vein margins are coincident with bedding and slaty cleavage on the vertical limbs of anticlines . In the horizontal offshoots of set 1 veins , inclusion bands are governed by the local orientation of the wall of the side-vein but the inclusion trails remain parallel to the vertical slaty cleavage (Figure 38) .

The principal veins , side veins , slaty cleavage and bedding are locally folded to lie flat in zones of 'crumpled leads' (Figures 38 and 39a) . They are then buckled by gently plunging , northeast-trending folds that define a train of 'barrels and rolls' . An upright , axial planar , crenulation cleavage developed perpendicular to the principal veins and parallel to the side veins . It overprints the bedding-parallel , slaty cleavage on the horizontal limbs of probable bending folds (Figure 38) . A younger generation of set 1 veins are emplaced into the fold train along fractures aligned with locally developed crenulation cleavage (Figure 39b) . In the hinge zones of the secondary folds , new set 1 veins crosscut folds of older set 1 veins ; however , on the vertical limbs of such folds , all set 1 veins are parallel to the regional slaty cleavage (Figure 38) .

In summary , it appears that the synfolding vein arrays were emplaced into steeply dipping beds near the hinge zones of regional anticlines after the early stages of folding (Figure 40a) . Four sets of geometrically distinct veins were intruded along and across the developing slaty cleavage . Further deformation ,localized near subvertical arrays and aided by slip along cleavage-parallel veins , modified the shape of the early-formed folds and 'crumpled' the leads into 'barrels and rolls' (Figure 40b) . In anticlinal hinge zones , late-stage fold trains developed concomitantly with the renewed generation of set 1 veins . They are shown in Figure 40c in relation to brittle-ductile limb thrusts that are coaxial with and displace the hinge zones of early-formed folds . Upright folds , crenulation cleavage and related veins are restricted to such displacement zones , although they probably did not originate during thrusting . The localized flattening of originally steep features prior to late-stage folding may be due to differential displacement across the gently-dipping zone of limb thrusting or , alternatively , it may result from bending country rocks over buried granitoids that intruded along early-formed anticlines and are concealed beneath limb thrusts .

Fault-Related Veins

Quartz-cemented fault breccias and auriferous , sulphide-bearing quartz veins occupy northwest-trending , subvertical , transcurrent faults in various parts of the study area . Syn-faulting veins are widely distributed relative to synfolding veins , are rarely shortened and form as solitary bodies or in simple arrays . Textural varieties include massive , brecciated and fibrous veins . Several prospects of gold-quartz veins are located in highly faulted ground between the LaHave River and South Cove . There , and in most other occurrences , the host rocks belong to the Cunard member but fault-related veins are found in most members of the Meguma Group. The writer is uncertain if the synfaulting gold veins examined in the Meguma Group belong to the same family as the Pb-bearing veins in the Windsor Group .

Most of the synfaulting veins are associated with cross faults and brittle fractures that illustrate left-handed , lateral offset of bedding planes , fold axes and earlier cleavage-parallel veins . Principal veins occupy fault or kink planes and have regularly-oriented pinnate veins protruding into wall rocks (Figure 41) . Steep-sided , principal veins have horizontal quartz fibres oriented at large angles to their margins suggesting an origin by oblique extension on transcurrent fault planes . Syntectonic fibres in the pinnate veins are perpendicular to vein walls and parallel to those in the principal vein . Assuming that pinnate veins fill dilatant tensile fractures , their orientation gives the direction of maximum compressive stress acting on the principal vein (Figure 41) . Inferred orientations of the principal stress axes are commonly corroborated by bedding offsets along the trace of the northwest-trending veins . In places , fault-related pinnate veins are intruded along axial surfaces of steeply plunging drag folds defined by bedding and slaty cleavage (Figure 41) .

Thin sections of the principal veins show fibres growing antitaxially from a median suture . The fibres are inclined to the suture in the centre of the vein at a large angle . However , outwards and away from the median suture , strain-free fibres gradually curve towards the vein wall (Figure 41) . They may imply that the syndilational extension direction rotated in response to transcurrent movements along vein-filled fractures . This interpretation is supported by the observation of large unstrained grains of vein biotite that overgrow the sigmoidal shape of the fibres . Similar veins related to the Country Harbour fault system occur in the Isaacs Harbour and Seal Harbour gold districts of eastern Nova Scotia , where they have yielded bimodal , primary fluid inclusion , homogenization temperatures of 263°C and greater than 350°C (Yonover et al., 1984) .

From the perspective of timing and kinematics of deformation , the synfaulting veins are strongly contrasted with the synfolding veins . Although the fundamental structural control on the development of both vein types is the localized , brittle-ductile displacement of folded Meguma Group rocks , exploration strategy for locating fault-related veins contrasts strongly with that for fold-related veins . For example , northwest-trending vertical veins related to the Ritchie Cove fault system occur discontinuously for approximately 15 km along strike . They are commonly situated in kilometre-wide belts on the west side of the fault , where axial traces of the major folds map out broad , steeply-plunging kink folds or large-scale flexures in the Meguma Group . In contrast , the limb thrust associated with the synfolding veins in the Ovens Anticline developed parallel to the gently plunging fold axis for approximately a kilometre and only affected a small part of the hinge zone of an anticline that extends for at least 25 kms in the study area .

STRATIFORM BASE METAL TARGETS IN THE MEGUMA GROUP

Zentilli et al. (1984) considered transitional strata between the Goldenville and Halifax formations (GHT) to exert fundamental regional control on metallogenic mineralization in the Meguma Group . Although the GHT is host to many epigenetic gold deposits , it also contains stratiform Pb-Zn mineralization near Eastville (Zentilli and MacInnis , 1983 ; Binney et al., 1986) . The geochemical nature and stratigraphical framework of these green beds are important parameters in evaluating their potential for syngenetic base metals .

Field characteristics of concretionary strata

In the study area , concretions and nodules are found in all three formations of the Meguma Group . However , they vary considerably in appearance , size and abundance depending upon stratigraphical position and composition of host strata . The largest and most sulphurous nodules occur in the Cunard member , whereas concretions in the Moshers Island member are the smallest , most abundant and best zoned . Sandstone is favoured as a host bed over slate presumably because of its greater porosity . In the field , most concretions react positively to a HCl test , while the host sandstone generally does not .

In many localities , bedforms are observed within concretions and nodules . Original depositional features such as foresets are traced continuously from the host bed across the boundaries of concretions . In places , concretions and nodules appear to be periodically spaced along certain stratum . However , a preferred position between the top and bottom of a bed is not evident . In rare exposures , where nodules are nucleated on rip-up clasts in wacke , there is a complete gradation in a single bed from unaltered protolith through partially replaced clast to secondary nodule (Figures 39c and 39d) .

Mineralogically zoned concretions occur in all members of the Meguma Group but they are most spectacularly developed in the Moshers Island member (Figure 17b) . There , the spherical or elliptical concretions are 1-3 cm in diameter . Cross sections through the spheres or ellipses commonly show an outer , pink-coloured zone made up of carbonate and garnet , and a central , dark grey-coloured zone composed of chlorite and clinozoisite . In places , a hollow or mineral-filled tube is found in the centre of the dark-grey zone trending perpendicular to the external bedding planes and parallel to the short axis of the concretionary ellipse . The tubes may act as a conduit for fluids ; however , they do not pierce the contact between host sediment and the pink outer zone of the concretion . Laminations in strata directly overlying the nodular beds are draped over the top of the flat-lying elliptical bodies . This might imply that the concretions had some relief at the sediment-seawater interface . However , considering that these same concretions are observed to overgrow bedding laminations in thin section (Figure 17c) , differential compaction of sediment around the elliptical body is a more likely explanation .

In the chlorite zone of regional metamorphism , the timing of nodule development is constrained by the fact that (1) original depositional bedforms are replaced or overgrown by nodular material (Figure 39c) and (2) the nodules are distorted and augened by the regional slaty cleavage (Figure 19b) . Concretions and nodules must have formed during diagenesis or very early in the metamorphic history of the host strata .

Lithogeochemistry of concretionary strata

Concretions from most of the members of the Meguma Group in the LaHave River area were analysed for major and trace elements (Tables 5 and 6). The host strata and representative examples of the siltstone/slate and sandstone/wacke beds from each stratigraphical unit were also sampled. The major elements show significant chemical variations between concretion and host rock, and between concretions in the Moshers Island member and those from other units (Table 5). Concretions in all members are deficient in SiO_2 relative to their host rocks but show an increase in LOI (volatiles) and either CaO or Fe_2O_3. Whereas nodules in most of the Meguma succession are MnO-poor, CaO-rich, Fe_2O_3-poor and volatile-rich, concretions in the Moshers Island member are MnO-rich, CaO-poor, Fe_2O_3-rich and volatile-poor. These analyses are in general agreement with the observation that most Meguma nodules are calcite-rich and with reports of Mn-garnets and Fe/Mn carbonates in coticule horizons in the GHT (Zentilli and MacInnis, 1983).

The trace element analyses are more difficult to interpret (Table 6). It appears that Sr is mobile and that there is exchange between concretions and host rocks. Slate is slightly enriched in Rb and V relative to wacke and sandstone. The Moshers Island laminites are rich in Ba and, to a lesser extent, Zn and Cr.

These analyses are the results of a pilot study and the reader is referred to Zentilli et al. (1986) and Graves and Zentilli (1988) for a more complete report on the lithogeochemistry of the Meguma succession in the LaHave River area.

Tectonic setting of base metal targets

In the study area, the Green Bay formation represents a notably thick succession of transitional strata (GHT) characterized by abrupt sedimentological changes at the Halifax and Goldenville formation boundaries, by facies and thickness changes within the formation, and by a relative abundance of nodules and concretions, some of which are texturally unique.

The manganiferous green beds and zoned concretions of the uppermost Moshers Island member of the Green Bay formation are relatively enriched in metals (Graves and Zentilli, 1988). They were deposited in a quiescent, low-energy, marine environment where the sedimentation rate was relatively reduced but where oxygen was still supplied at the seawater/sediment interface (Waldron and Graves, 1987). These metalliferous muds overlie sand-dominated, high energy, well-oxygenated, channel-fill deposits and underlie silt-dominated, poorly-oxygenated or anoxic turbidites.

In the South Shore district , concretionary green beds defining the GHT are variably thick and locally present between black slate of the deep-sea fan facies and silicic wacke of the continental slope facies (Schenk , 1970 ; O'Brien and Charles , 1985 ; O'Brien , 1986b) . Relatively small depocentres formed during the accumulation of the Green Bay formation in eustatically unstable areas , which continued to subside during deposition of the Cunard member of the Halifax Formation . As the depocentres were filling with sediment , they were periodically starved of extrabasinal material and underwent gradual shifts in the amount of dissolved oxygen at the water/sediment interface (Waldron and Graves , 1987) . Using the Paleozoic Selwyn Basin of the Yukon Territories as an analogue (Goodfellow and Jonasson , 1984 ; Lydon et al. , 1985) , syndepositional faults , active during early diagenesis of basin substrata , may have channellized basinal fluids through Green Bay sediments , especially during the interval represented by the metalliferous Moshers Island member .

GEOPHYSICS

Aeromagnetic data are available for parts of the study area in the form of colour-contoured total field maps at 1:50 000 scale (GSC Map C21057G and C21058G), colour-contoured vertical gradient maps at 1:50 000 scale (GSC Maps C41057G and C41058G), line-contoured total field maps at 1:25 000 scale (GSC Maps 21052G-21056G) and line-contoured vertical gradient maps at 1:25 000 scale (GSC Maps 41052G-41056G). In the following section, discussion centres on the role of these geophysical maps as a geological mapping tool in the Meguma Terrane.

General Statement

The sulphide-rich black slate and sandstone of the Cunard member of the Halifax Formation are strongly magnetic in comparison to all other rock types in the study area. Since the Cunard member is the most widespread rock unit in the area surveyed, aeromagnetic maps can be used cautiously as a regional mapping tool.

In general, aeromagnetic maps do not indicate the presence of strongly magnetic horizons within the black slate succession (e.g. the magnetite-bearing and pyrrohotite-bearing beds) and, as a consequence, yield little information about the internal stratigraphy of the notably thick and monotonous Cunard member. However, they reliably show the regional distribution of the Cunard member and, therefore, outline the gross structure of the Meguma Group. More specifically, aeromagnetic maps illustrate the outcrop or shallow-level subcrop of Cunard contacts with underlying and overlying members of the Meguma Group and with intrusive granitoids.

Aeromagnetic data are much less useful in mapping the geological boundaries of relatively thin Carboniferous deposits and the borders of granitoid intrusions where host rocks are other than black slate. Pyrite- and pyrrohotite-bearing hornfelses are poorly outlined unless they are developed in the Cunard member. Aeromagnetic map coverage does not include the area underlain by the mafic Shelburne dyke.

Geological application of total field aeromagnetic maps

Total field aeromagnetic maps of parts of the LaHave River and Mahone Bay areas essentially illustrate the magnetic contrasts of the Moshers Island, Cunard and Feltzen members. The Moshers Island and Feltzen members have low values of magnetic intensity; the former typically in the range of 54600-54790 nannoteslas and the latter in the range of 54700-54790 nannoteslas. In contrast, the Cunard member is composed of rocks that lie in the 54950-55050 nannoteslas range . Steep gradients exist at the stratigraphical base (e.g. New Cumberland) and stratigraphical top (e.g. Heckmans Island) of the black slate . Irregularly shaped areas of low magnetic intensity material coincide with either (1) complex domes or periclinal anticlines exposing Moshers Island and older strata or (2) W- and V-shaped synclines cored by the Feltzen member . The inclination of the folded contacts of the Cunard member affects the pattern of total field anomalies . On the aeromagnetic maps , the Cunard boundaries are hardest to detect where open folds are shallowly plunging and the contact of the black slate dips gently . In contrast , the boundary of the Cunard member is most accurately located where the contact dip is subvertical around tight , steeply plunging folds .

When aeromagnetic and geological maps are overlain , it is evident that some regions characterized by low magnetic values occupy a larger area than the surface outcrop of the relatively non-magnetic Moshers Island or Feltzen members . For example , exposures of the magnetically high Cunard member near Mount Pleasant are located in the gently northeast-plunging hinge zone of the Indian Path Anticline but are coincident with a deep magnetic low . Near Mount Pleasant , the Cunard-Moshers Island contact presumably lies at shallow depth in the area below the magnetic low . Therefore , the shape of the anomaly probably reflects the shallow northeasterly plunge of the fold hinge zone in subsurface . This effect is also seen in the Cunard member in the hinge of the Ovens Anticline near Dublin Shore , the hinge of the Rhodes Corner Anticline near Upper LaHave and the hinge of the Gold River Anticline near Farmville . Thus , the total field maps of the area are not necessarily direct indicators of the type of rock outcropping at the surface . They are , however , useful in determining the shapes of folds at depth and placing independent controls on the construction of down-plunge profiles .

The boundaries of the Cunard member are most easily gleaned from the aeromagnetic maps where the black slates are thickest . In such areas , anticlines that expose the basal contact with the Moshers Island member are separated from adjacent synclines that expose the upper contact with the Feltzen member by up to 5 kms . In places where the Cunard member is thin and both contacts are folded around the hinge of the same regional fold , the weakly magnetic rocks of the Feltzen and Moshers Island members crop out in close proximity to each other . This situation exists in the hinge zone of the Rhodes Corner Anticline at Schnares Crossing , where Feltzen and Moshers Island members are separated by approximately 0.5 km . Here , the aeromagnetic map does not indicate the local presence of the black slate of the Cunard member .

Although the tectonic grain of the study area is northeast , many magnetic anomalies on the total field map have long axes trending northwest . These anomalies are explained by the northwest strike of the Cunard member in the hinge zones of large scale , gently to steeply plunging , M-shaped folds . For example , northwest-trending anomalies on the aeromagnetic map near The Shoughbac outline a M-shaped fold in poorly exposed parts of the Cunard member , which is the up-section equivalent of a regional anticlinorium well exposed on the LaHave Islands . The northwest-trending string of anomalies between Masons Beach and Dares Lake are coincident with subvertical beds of the Cunard member as they dip off the northeast side of a large anticlinal dome . The total field map suggests the presence of a similar structure in the Cunard member in poorly exposed ground between Pleasantville and Conquerall Bank .

Anomalies centred over the Carboniferous outliers do not correlate with the lithologies or local structure of the Carboniferous rocks . Again , the total field maps apparently reflect the structure of rocks at shallow depth rather than those at the surface . For example , the anomaly related to the Moshers Island-Cunard contact on the southeast limb of the Gold River Anticline is traceable beneath the basal Carboniferous unconformity and is seen through the Carboniferous strata at Chester Basin . Likewise , the Cunard-Feltzen boundary is probably folded about a southwest plunging syncline between Hirtle´s Cove and the Narrows Basin . This Meguma fold is presumably hidden by overlying Carboniferous rocks northeast of Mahone Harbour . An area characterized by a magnetic low on the Second Peninsula may be underlain by an unexposed , northeast-plunging , Feltzen-cored syncline or , alternatively , the assumed outcrop pattern of the Windsor Group is incorrect .

The total field maps also confirm the presence of some large faults that offset the major folds in the Meguma Group . For example , a northnorthwest-trending aeromagnetic linear coincident with the Ritchie Cove Fault offsets a northeast-trending anomaly in the Cunard member near Lower LaHave . The pattern of displaced anomalies agrees with the local sinistral offset of the Ovens Anticline .

A particularly noteworthy feature of the total field maps are anomalies centred on Meguma Group hornfels developed in the contact aureole of the Devono-Carboniferous granitoid intrusions . Although pyrite- and pyrrohotite-bearing hornfels are produced in all but the Rissers Beach and Feltzen members of the Meguma Group , intrusive contacts defined by steep gradients between magnetically low granitoids and magnetically high metasediments are noncontinuous . Contacts are magnetically well-defined where the host rocks belong to the Cunard member , are magnetically indicated but poorly defined where the host rocks belong to the Tancook member and are magnetically ill-defined elsewhere . Therefore , the borders of the intrusion do not have a characteristic magnetic signature which reflects either the granitoids or the hornfelsed metamorphic rocks . Rather , the first-order differences in magnetic intensity sporadically observed in the contact aureole are still those between members of the Meguma

Group . For example , the aeromagnetic anomaly near Chester Grant reflects the presence of the Cunard member in the cusp of a syncline which disposes the upper part of the Green Bay formation . Overlaying the geological and aeromagnetic maps of the Chester Grant area , it is evident that neither the distribution of the hornfelses nor the intrusive contacts of the granitoid are outlined by magnetic anomalies .

Taking the above information into account , the total field maps may provide additional data on the regional structure of the Meguma hornfelses . In critical unexposed areas , they may require that local revisions be made to the existing geological maps . A good example of this type of geological input from geophysical data may be seen in the aeromagnetic maps of the Spondo Lake area (Figure 42) . Here , the pattern of aeromagnetic anomalies suggests that the Cunard member may not be discordantly truncated by the granitoid intrusion as shown in Figure 42a . Rather , the Moshers Island and West Dublin members may possibly intervene between the black slate and the granitoid over a very narrow tract of ground (Figure 42b) . Since all units strike northwest in an open , southwest-plunging fold , the contact of the intrusion is locally concordant with the lithostratigraphical units .

Geological application of vertical gradient aeromagnetic maps

Vertical gradient maps reveal much of the same general geological information as the total field maps . However , they are much better indicators of the nature of the rocks outcropping at the surface and are thus a superior mapping tool . For example , near the lower reaches of the LaHave River northeast of Mount Pleasant , the vertical gradient maps illustrate an abundance of regularly spaced , northwest-oriented , steep gradient anomalies that reflect the strike and dip of the underlying Cunard member . This contrasts with the total field maps of the same area , which outline the folded Cunard-Moshers Island contact at shallow depth .

The vertical gradient maps partly resolve the detrimental effect that gently plunging folds of the weakly magnetic Moshers Island and Feltzen members have on accurately locating the upper and lower Cunard boundaries . Aeromagnetic anomaly patterns near the Dublin Shore section in the LaHave River area serve as a good illustration of this point . There , the basal contact of the Cunard member is coincident with a small discrete anomaly on the vertical gradient map ; whereas , on the total field map , the entire basal Cunard section at Dublin Shore underlies an uncharacteristic magnetic low .

Well defined , discrete , vertical gradient anomalies occur at the lower and upper contacts of the Cunard member , even in places where the black slate is relatively thin . Both contacts of a thin black slate succession occur on the southeast limb of the Gold River Anticline . An anomaly sited directly on the Cunard-Moshers Island boundary occurs near Gold River , wheras the anomaly over the Cunard-Feltzen boundary is located nearby at Western Shore .

The vertical gradient maps commonly confirm interpretations based on the total field maps or prompt more subtle explanations of the magnetic anomalies . Vertical gradient maps of the Spondo Lake area show anomalies with northeast-trending long axes passing into anomalies with northwest-trending long axes . This is most simply interpreted to be a result of folding Cunard strata and , near the lake , it means that the intrusion is locally concordant with the lithostratigraphical units . Gradiometer maps also illustrate displaced anomalies confirming the sinistral offset of the Ovens Anticline by a fault near Ritchie Cove . Whereas the total field map outlines the structural dome near Rhodes Corner by picking out the Cunard-Moshers Island boundary , the vertical gradient map depicts circular anomaly patterns relating to both the West Dublin-Moshers Island and the Moshers Island-Cunard contacts .

The regional distribution of the Feltzen member is gleaned much more easily from the vertical gradient than the total field maps . The large , northeast-plunging , Feltzen-cored syncline in Rose Bay is clear only on the vertical gradient map . Anomalies on the gradiometer maps also indicate that the Feltzen member underlies areas offshore Lunenburg Bay , Rose Bay and Mahone Bay . The lack of any uncharacteristically high magnetic anomalies in the Feltzen basins may indicate that the basal contact with the Cunard member is deeply buried .

Limitations to the geological use of vertical gradient maps are , however , also realized in the study area . The contact of the granitoid intrusion between Martins River and Chester Grant is not at all apparent , although the anomaly pattern near Millet Lake shows the trangression of the Cunard-Moshers Island boundary by the granitoids . It would appear that aeromagnetic maps cannot distinguish between enclaves and appendages of country rock in the intrusion .

The effect of shallowly inclined , magnetic units is much worse in interpreting vertical gradient than total field data . For example , the variation in the anomaly pattern over the Cunard-Moshers Island contact near New Cumberland is due to the asymmetrical shape of the Indian Path Anticline at this locality . The northwest limb dips much more gently than the southeast limb and , therefore , the shape of the anomaly defining the lithostratigraphical contact differs on either side of the fold hinge zone .

Severe limitations of both the vertical gradient and total field maps are that they cannot distinguish (1) the Goldenville

Formation and the Green Bay formation , (2) the Rissers Beach , West Dublin , Tancook and Moshers Island members of the Green Bay formation and (3) the Feltzen member of the Halifax Formation from the Moshers Island member of the Green Bay formation .

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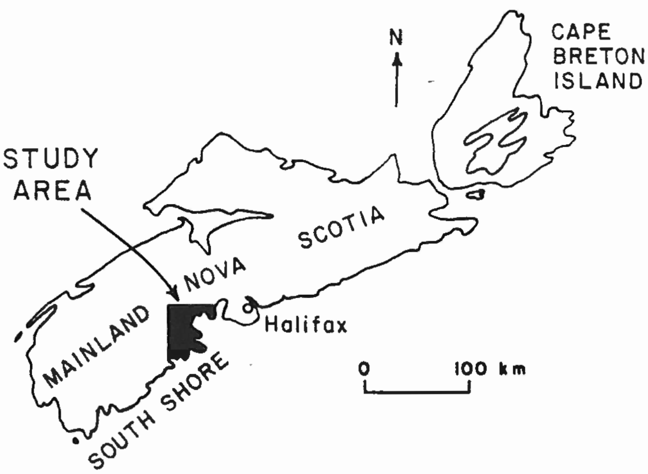
CAPE
BRETON
ISLAND
N
STUDY
AREA
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NOVA
MAINLAND
Halifax
0
100 km
SOUTH SHORE

Figure 1.

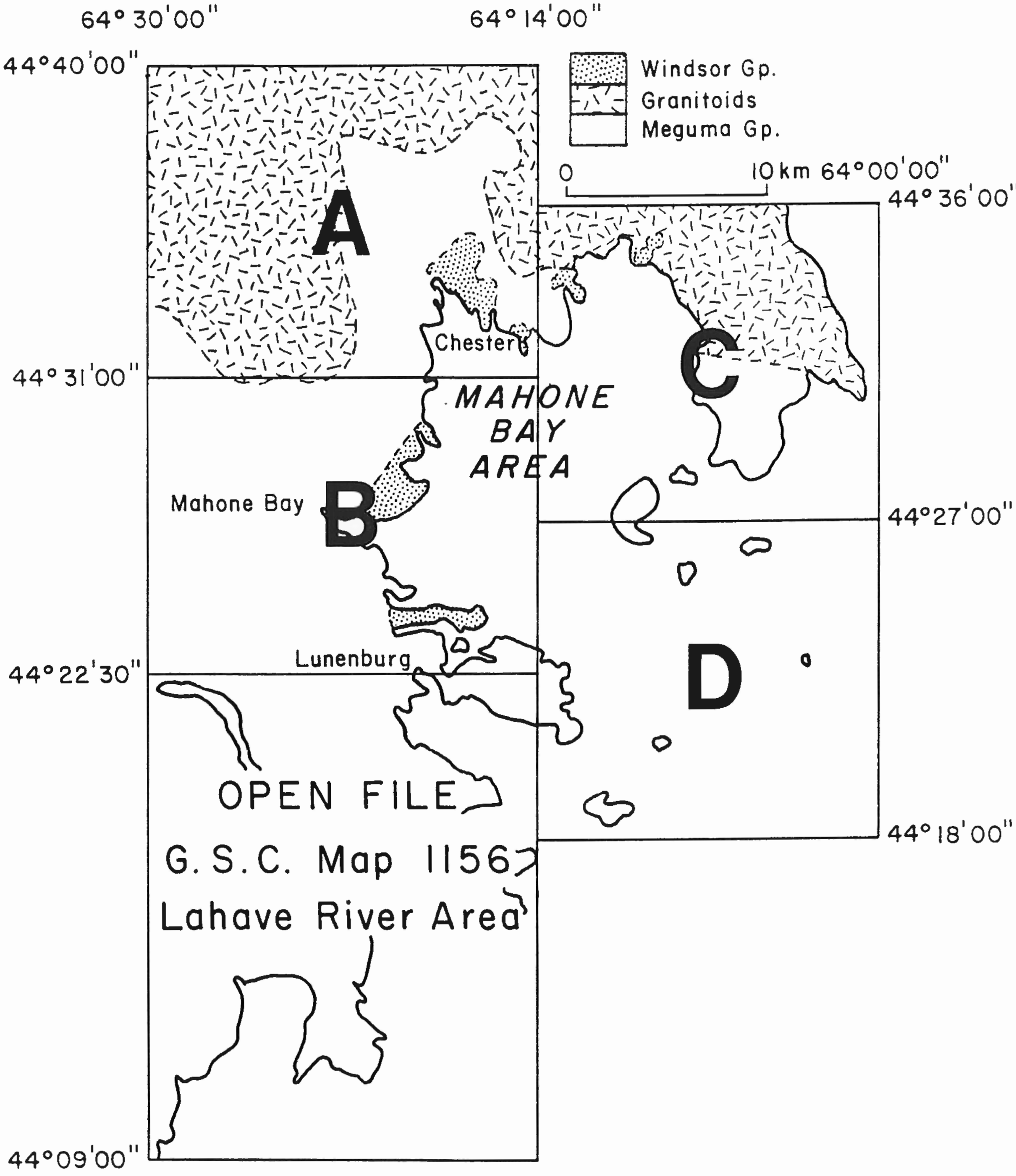

64° 30'00"
64° 14'00"
44°40'00"
Windsor Gp.
Granitoids
Meguma Gp.
0
10 km 64°00'00"
44° 36'00"
A
Chester
C
44° 31'00"
MAHONE
BAY
AREA
Mahone Bay
B
44°27'00"
Lunenburg
44°22'30"
D
OPEN FILE
G.S.C. Map 1156
Lahave River Area
44° 18'00"
44°09'00"

Figure 2.

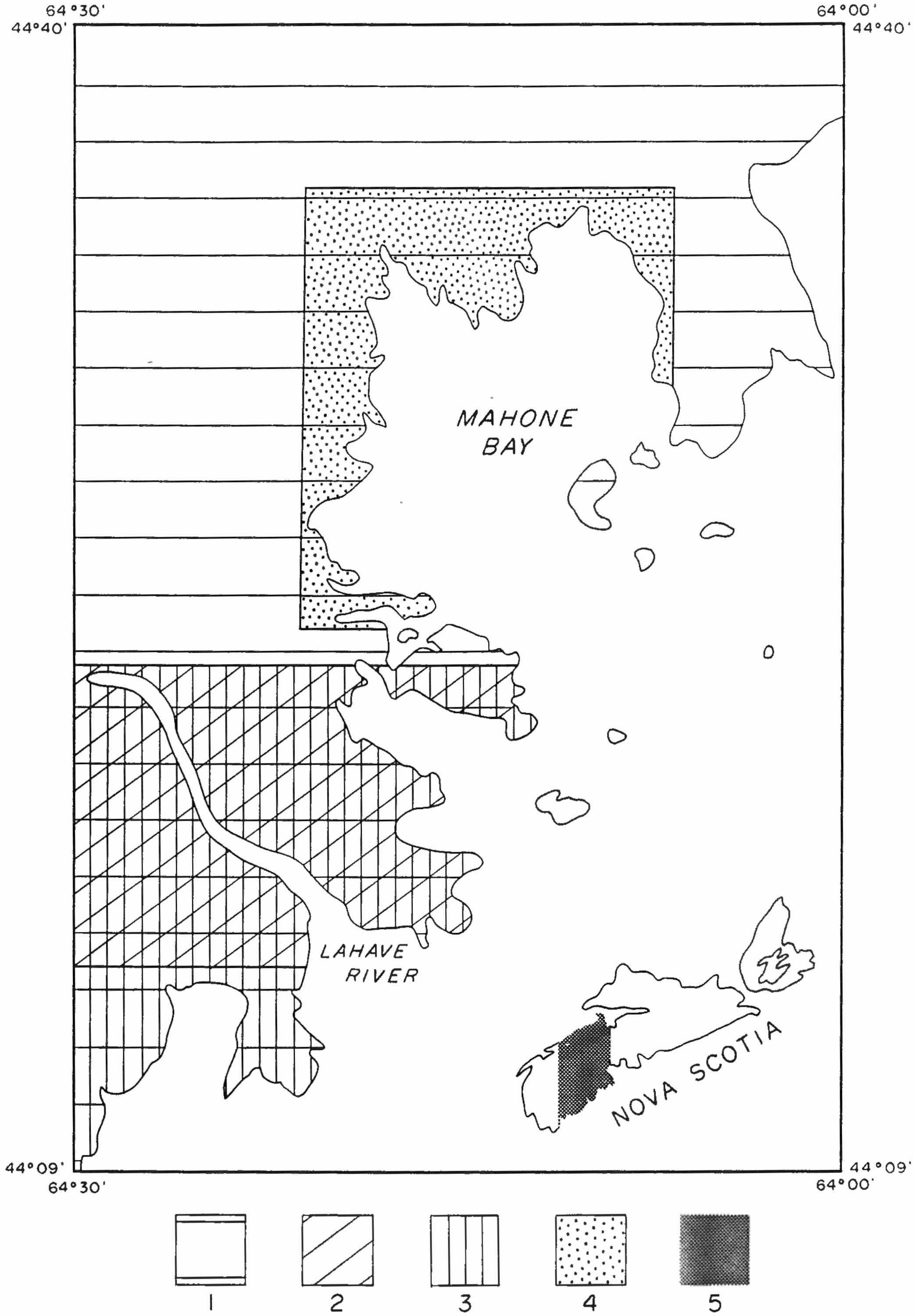
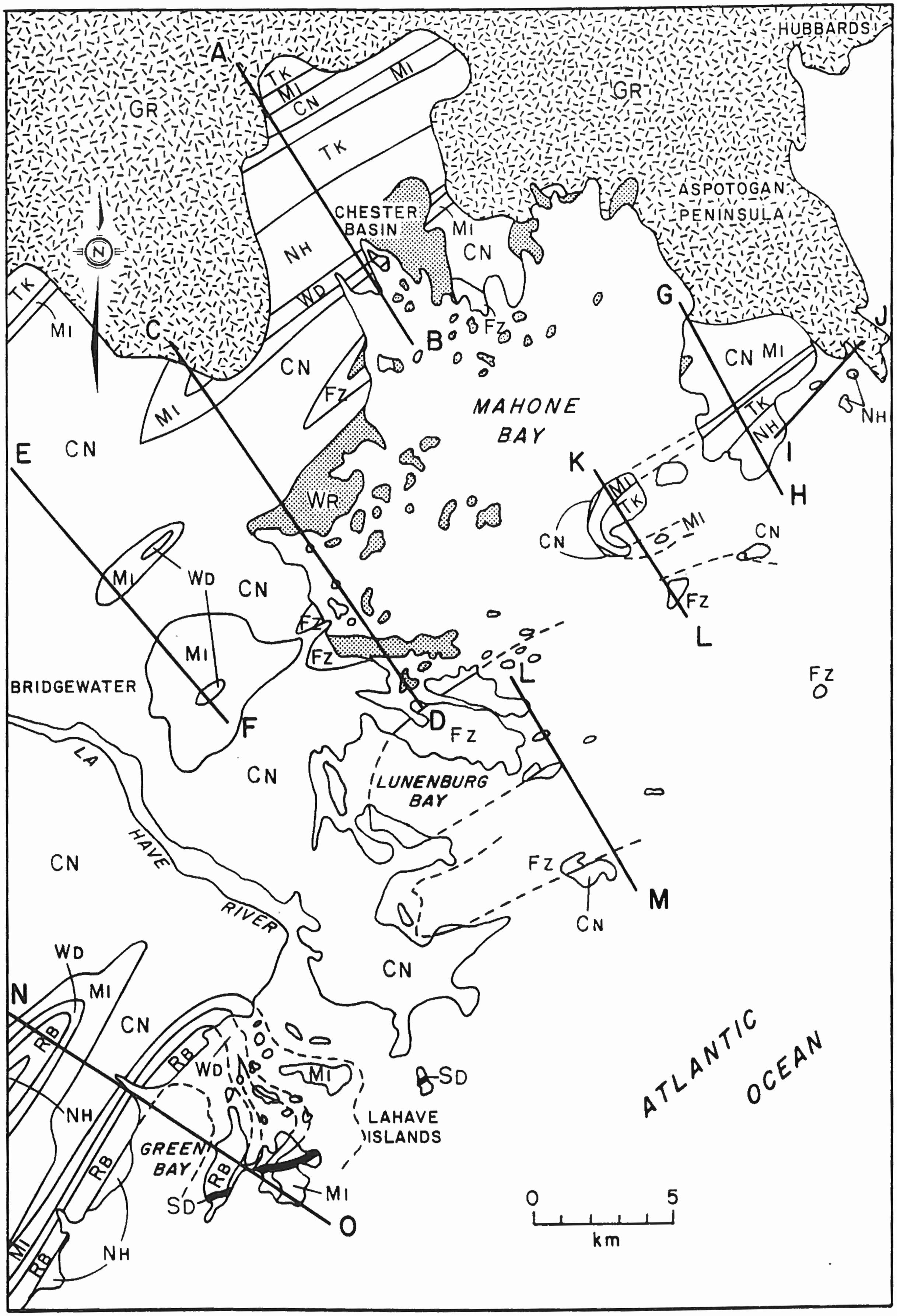

64°30'
44°40'
64°00'
44°40'
MAHONE
BAY
LAHAVE
RIVER
NOVA SCOTIA
44°09'
64°30'
44°09'
64°00'
1
2
3
4
5

Figure 3.


HUBBARDS
GR
ASPOTOGAN
PENINSULA
CHESTER
BASIN
MAHONE
BAY
BRIDGEWATER
LA
HAVE
RIVER
LUNENBURG
BAY
GREEN
BAY
LAHAVE
ISLANDS
ATLANTIC
OCEAN
TK
MI
CN
NH
WD
WR
FZ
RB
SD
A
B
C
D
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F
G
H
I
J
K
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M
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O
0
5
km

Figure 4

LEGEND

Triassic-Jurassic

SHELBURNE DYKE

SD *Dolerite dyke*

Carboniferous

WINDSOR GROUP

WR *Limestone, gypsum, conglomerate*

UNSEPARATED

Granodiorite sills

SOUTH MOUNTAIN BATHOLITH

Devonian

GR *Granodiorite, monzogranite plutons*

Cambro-Ordovician

MEGUMA GROUP

Halifax Formation

FZ Feltzen member: *grey slate; laminated to thin bedded, buff-weathered sandstone and siltstone.*

CN Cunard member: *black slate; thin- to thick-bedded, pyriferous sandstone and siltstone.*

Green Bay formation

MI Moshers Island member: *laminated, grey-green and green siltstone.*

WD West Dublin member: *thin- to thick-bedded, buff-weathered sandstone with green and grey-green siltstone.*

TK Tancook member: *thin-bedded, thick-bedded and massive buff-weathered sandstone with green and grey-green siltstone.*

RB Rissers Reach member: *thin-bedded, cross-stratified, buff-weathered sandstone and green siltstone.*

Goldenville Formation

NH New Harbour member: *mainly thick-bedded to massive, buff-weathered sandstone; subordinate green laminated siltstone and green slate.*

Legend for Figure 4

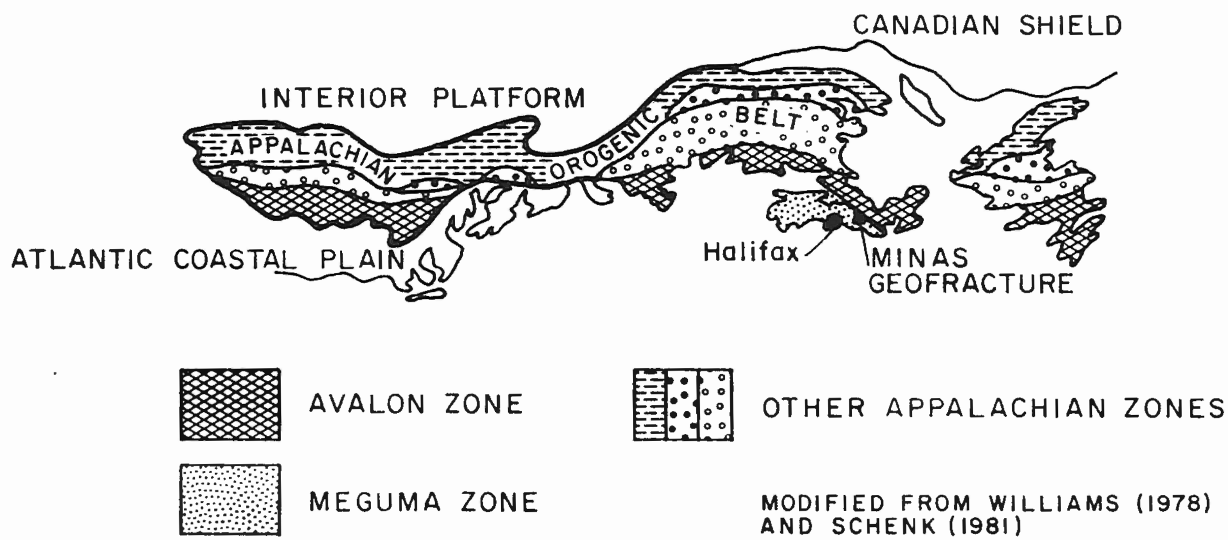

CANADIAN SHIELD
INTERIOR PLATFORM
APPALACHIAN
OROGENIC
BELT
ATLANTIC COASTAL PLAIN
Halifax
MINAS GEOFRACTURE
AVALON ZONE
MEGUMA ZONE
OTHER APPALACHIAN ZONES
MODIFIED FROM WILLIAMS (1978) AND SCHENK (1981)

Figure 5

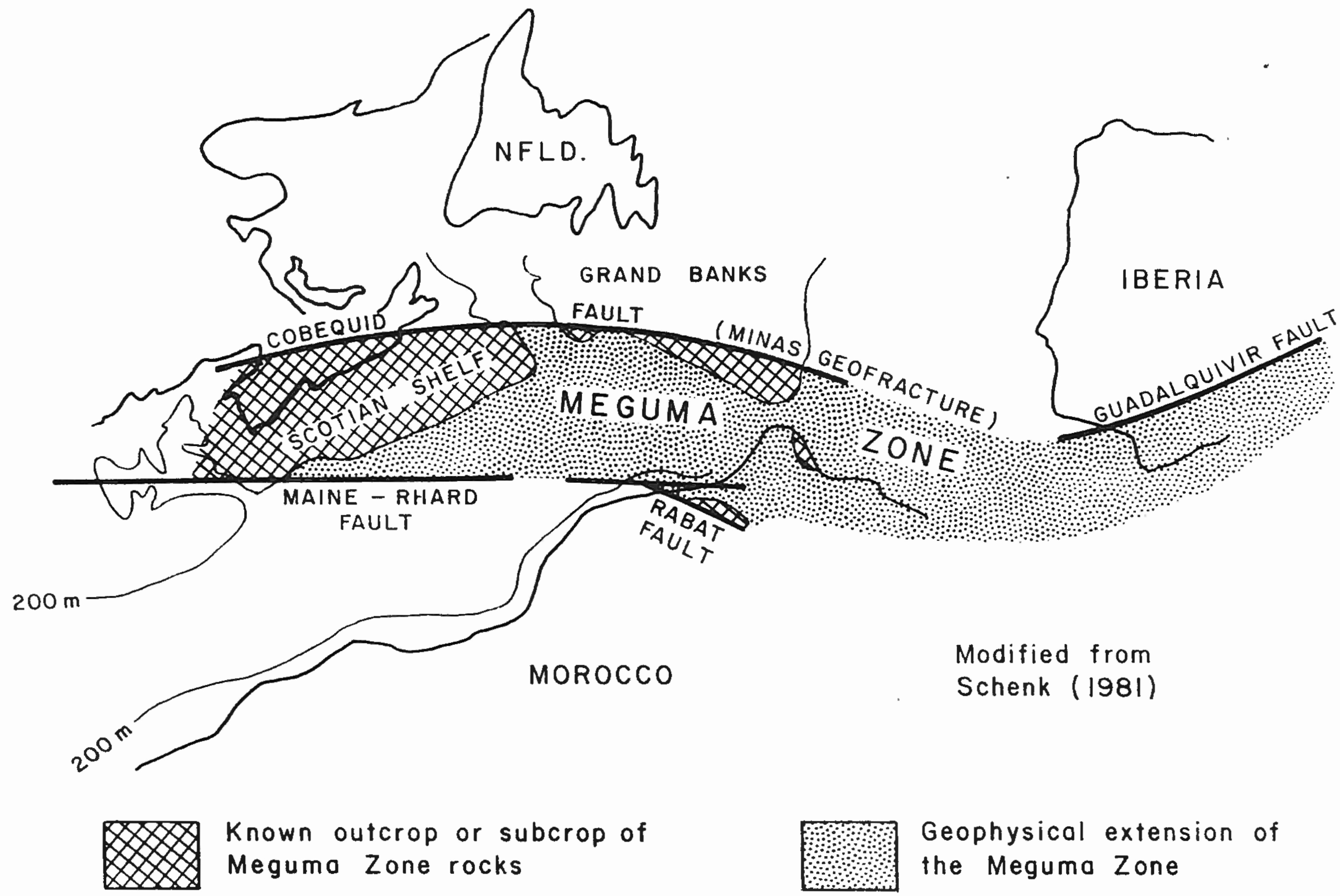

NFLD.
GRAND BANKS
IBERIA
COBEQUID
FAULT
(MINAS
GEOFRACTURE)
GUADALQUIVIR FAULT
SCOTIAN SHELF
MEGUMA
ZONE
MAINE - RHARD
FAULT
RABAT
FAULT
200 m
200 m
MOROCCO
Modified from
Schenk (1981)
Known outcrop or subcrop of
Meguma Zone rocks
Geophysical extension of
the Meguma Zone

Figure 6

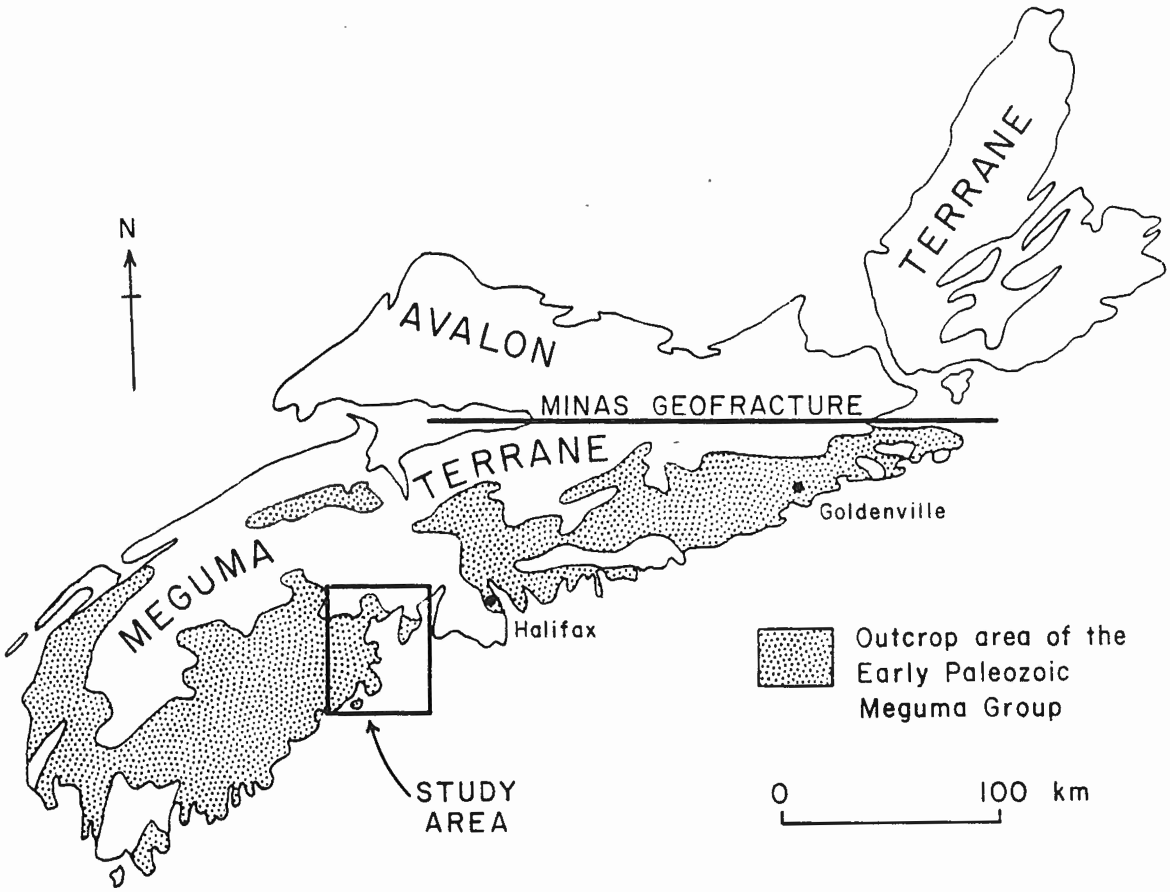
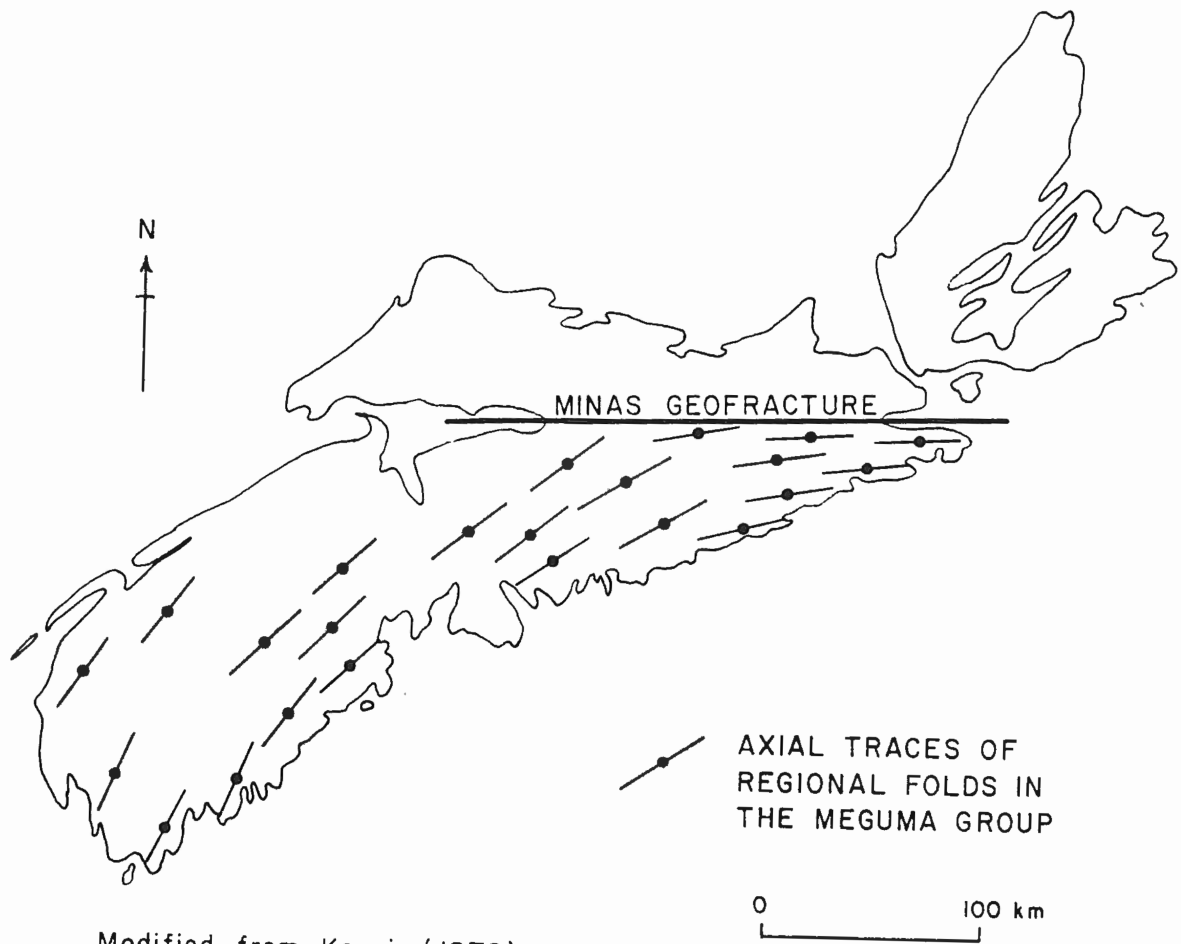
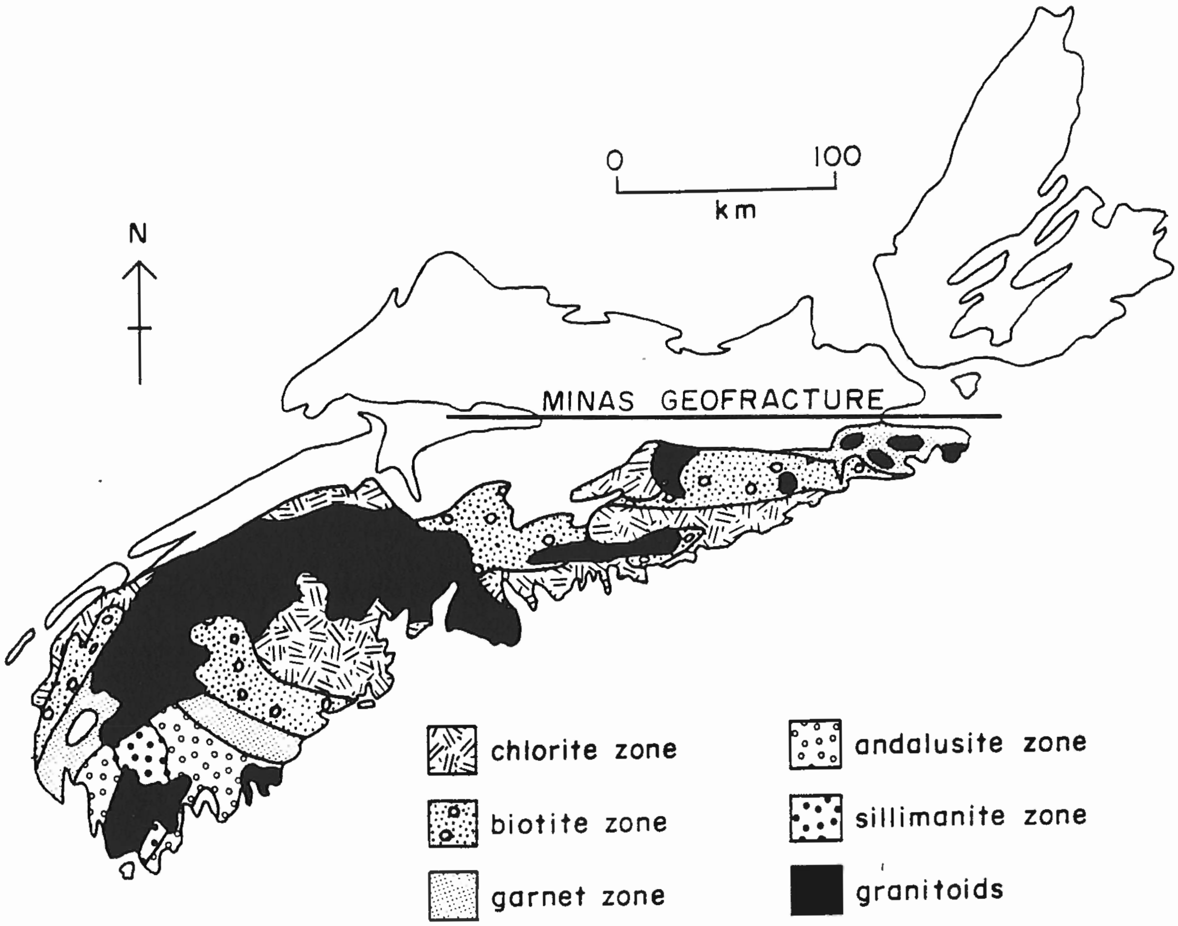

N
AVALON
TERRANE
MINAS GEOFRACTURE
TERRANE
MEGUMA
Goldenville
Halifax
STUDY AREA
Outcrop area of the Early Paleozoic Meguma Group
0
100 km

Figure 7



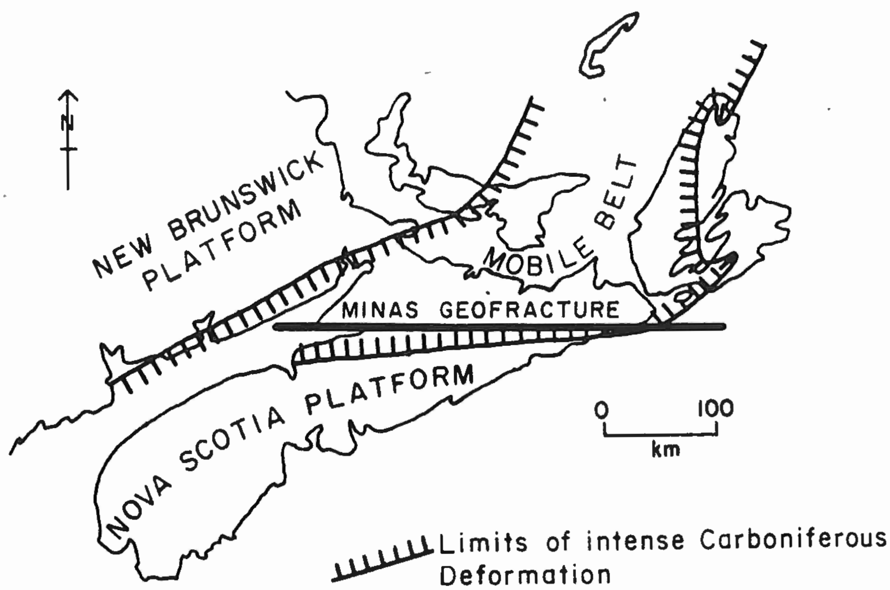
Modified from Keppie (1979)

Figure 8



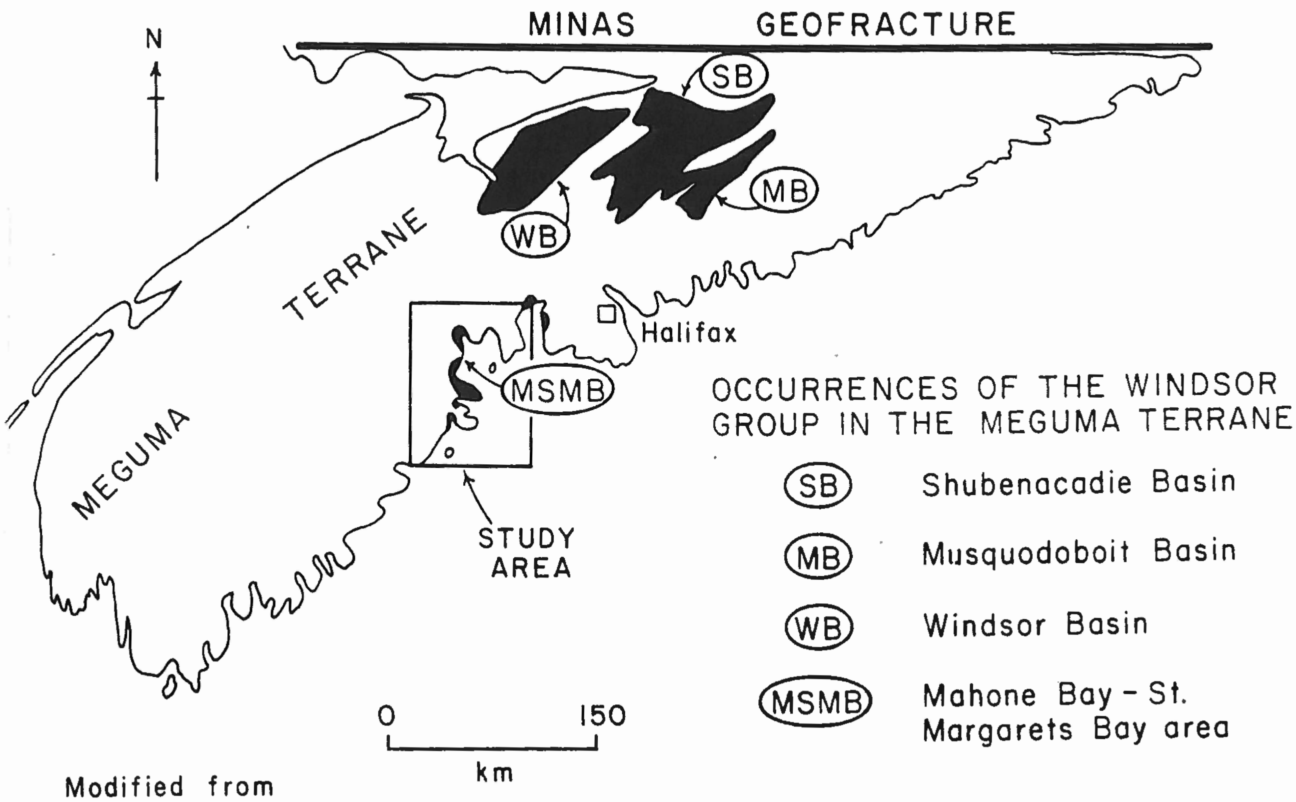
Modified from Keppie and Muecke (1979)

Figure 9



Modified from Keppie (1982)

Figure 10



Modified from Giles (1985)

Figure 11

C :URRENCES OF MESOZOIC ROCKS IN THE MEGUMA TERRANE

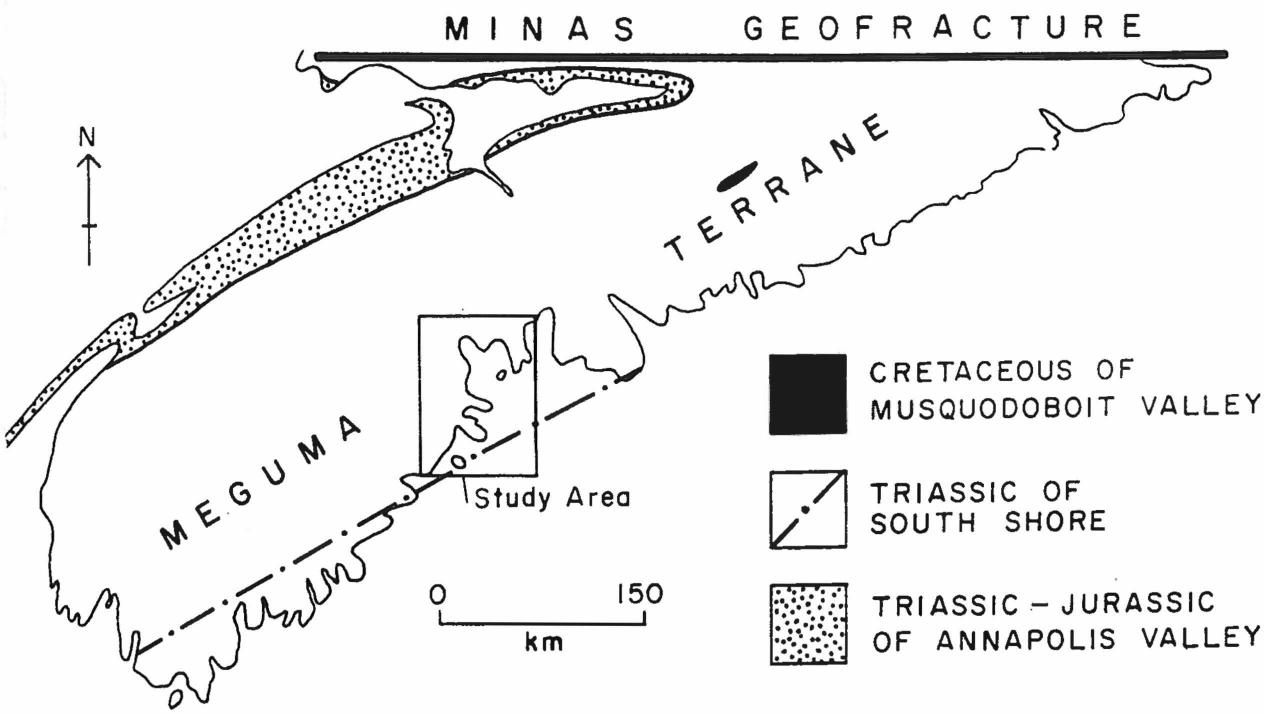
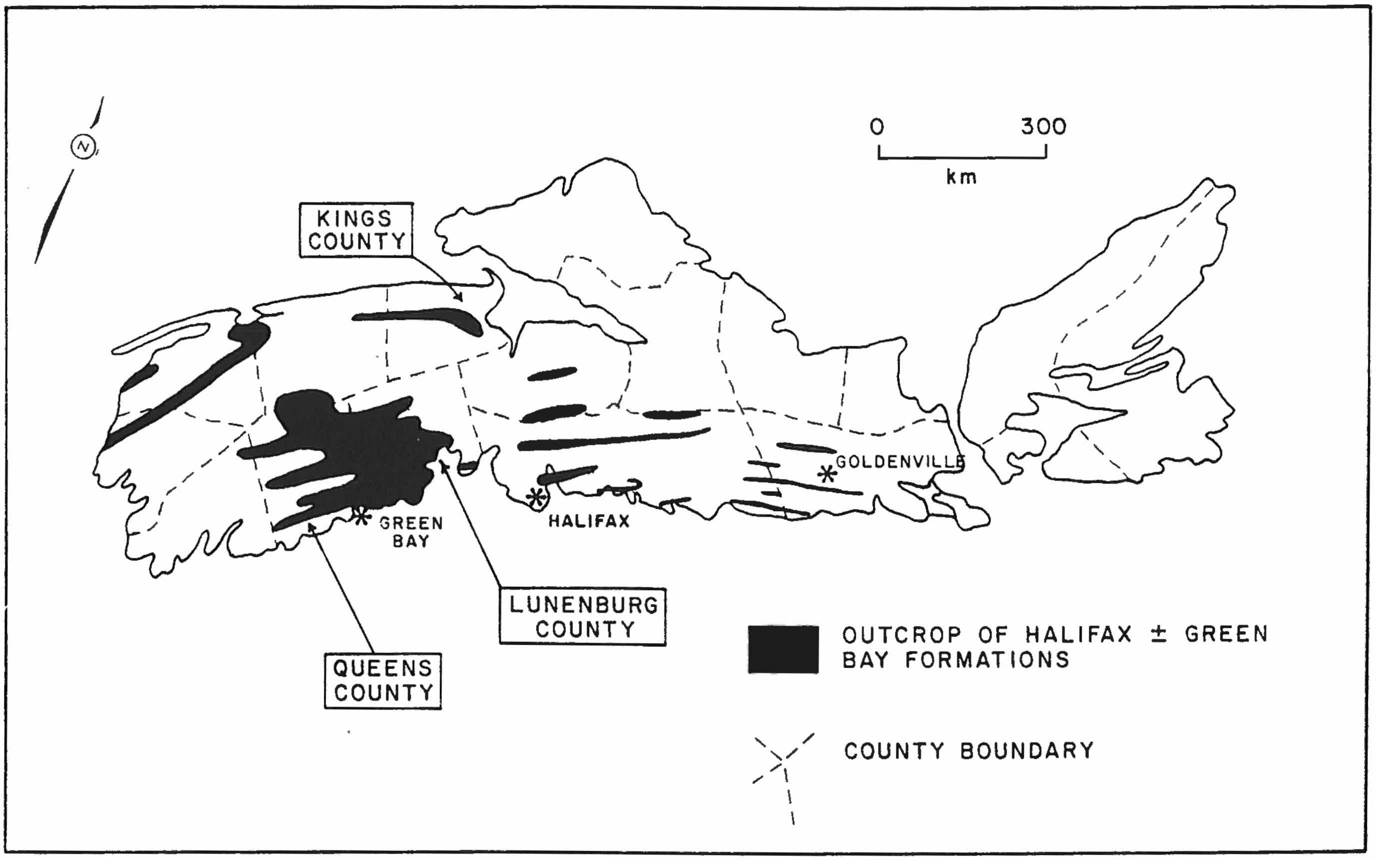


Figure 12



N
0
300
km
KINGS COUNTY
GREEN BAY
HALIFAX
GOLDENVILLE
LUNENBURG COUNTY
QUEENS COUNTY
OUTCROP OF HALIFAX ± GREEN BAY FORMATIONS
COUNTY BOUNDARY

Figure 13

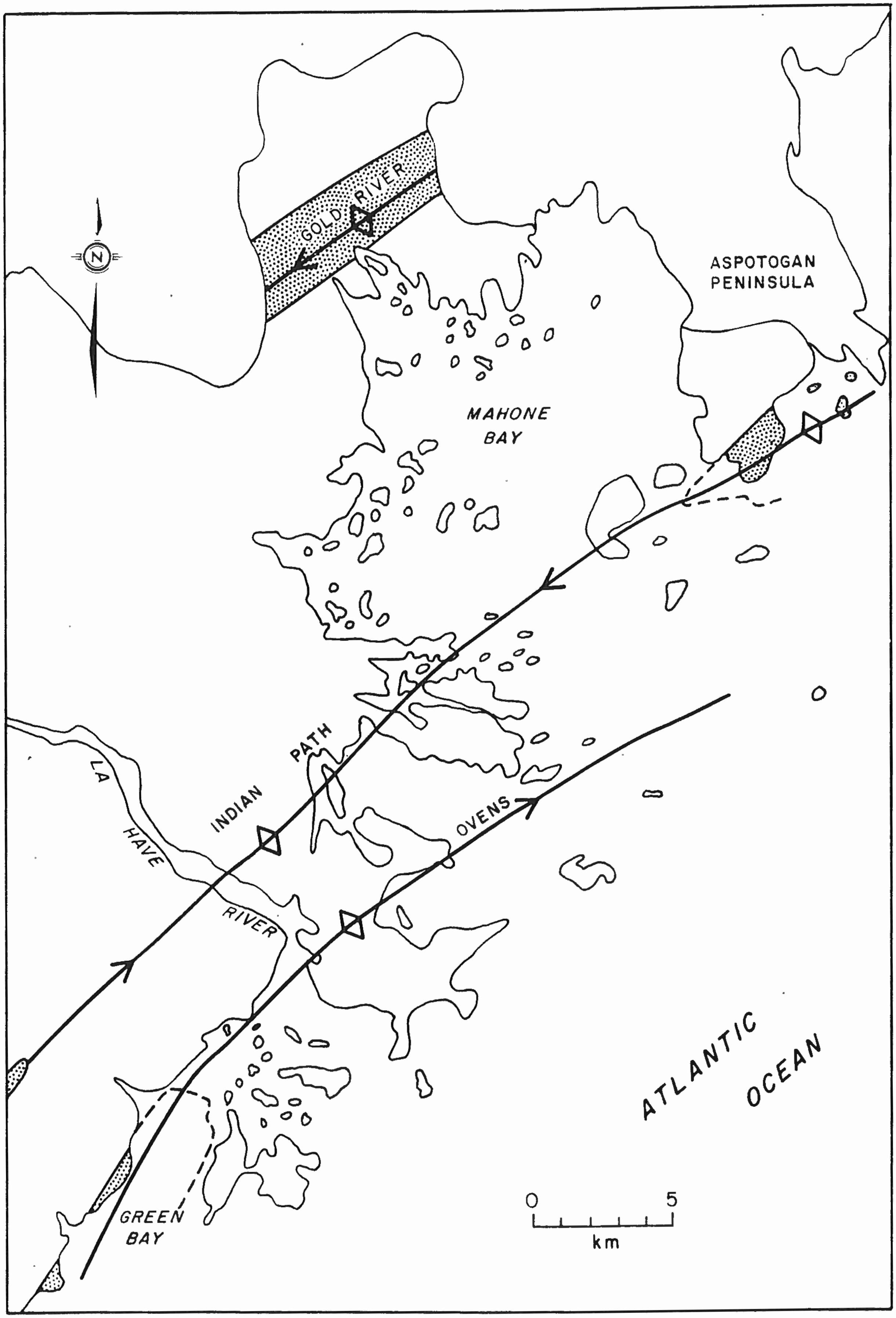

GOLD RIVER
N
ASPOTOGAN
PENINSULA
MAHONE
BAY
LA
HAVE
RIVER
INDIAN
PATH
OVENS
ATLANTIC
OCEAN
GREEN
BAY
0
5
km

Figure 14

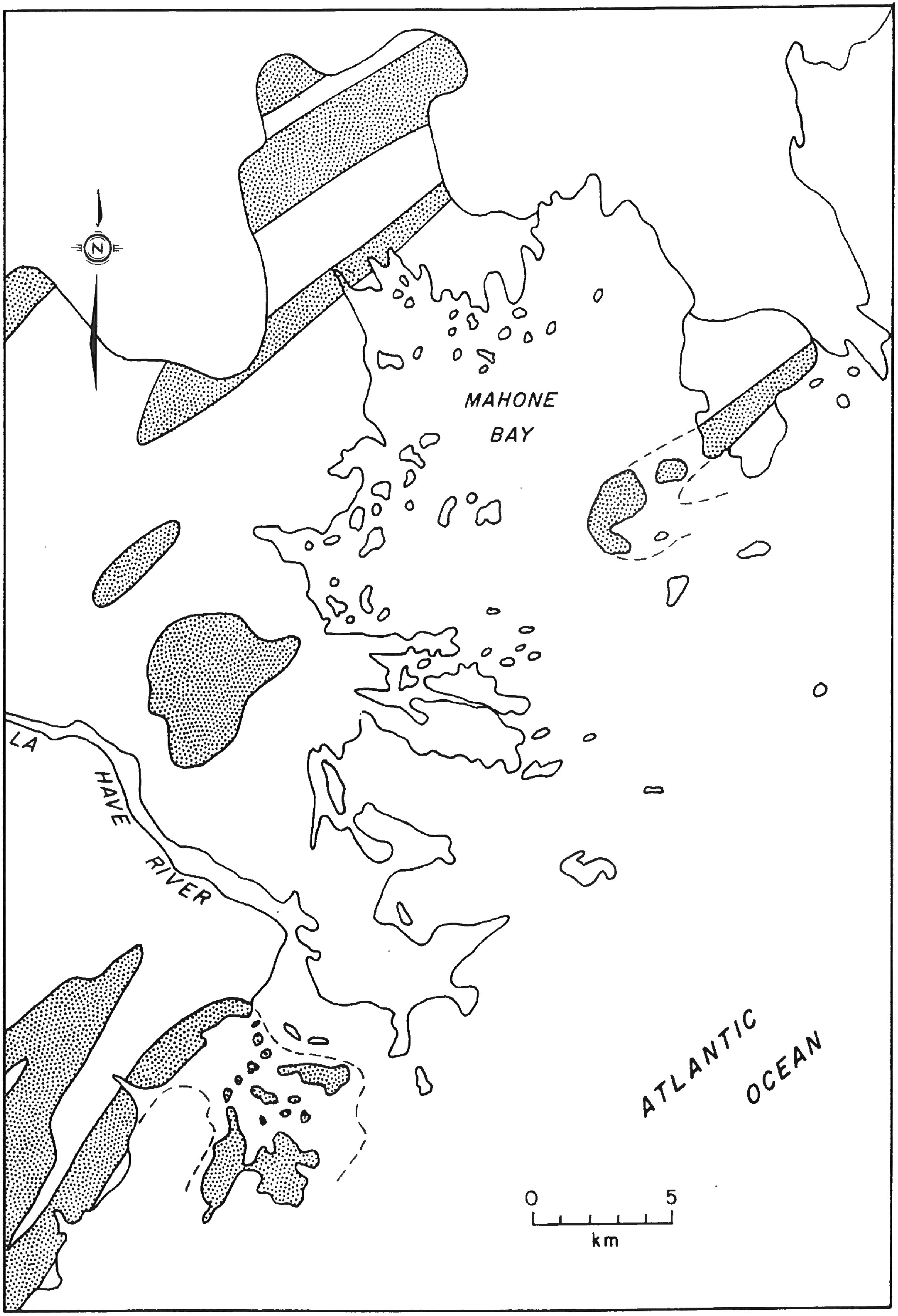


Figure 15

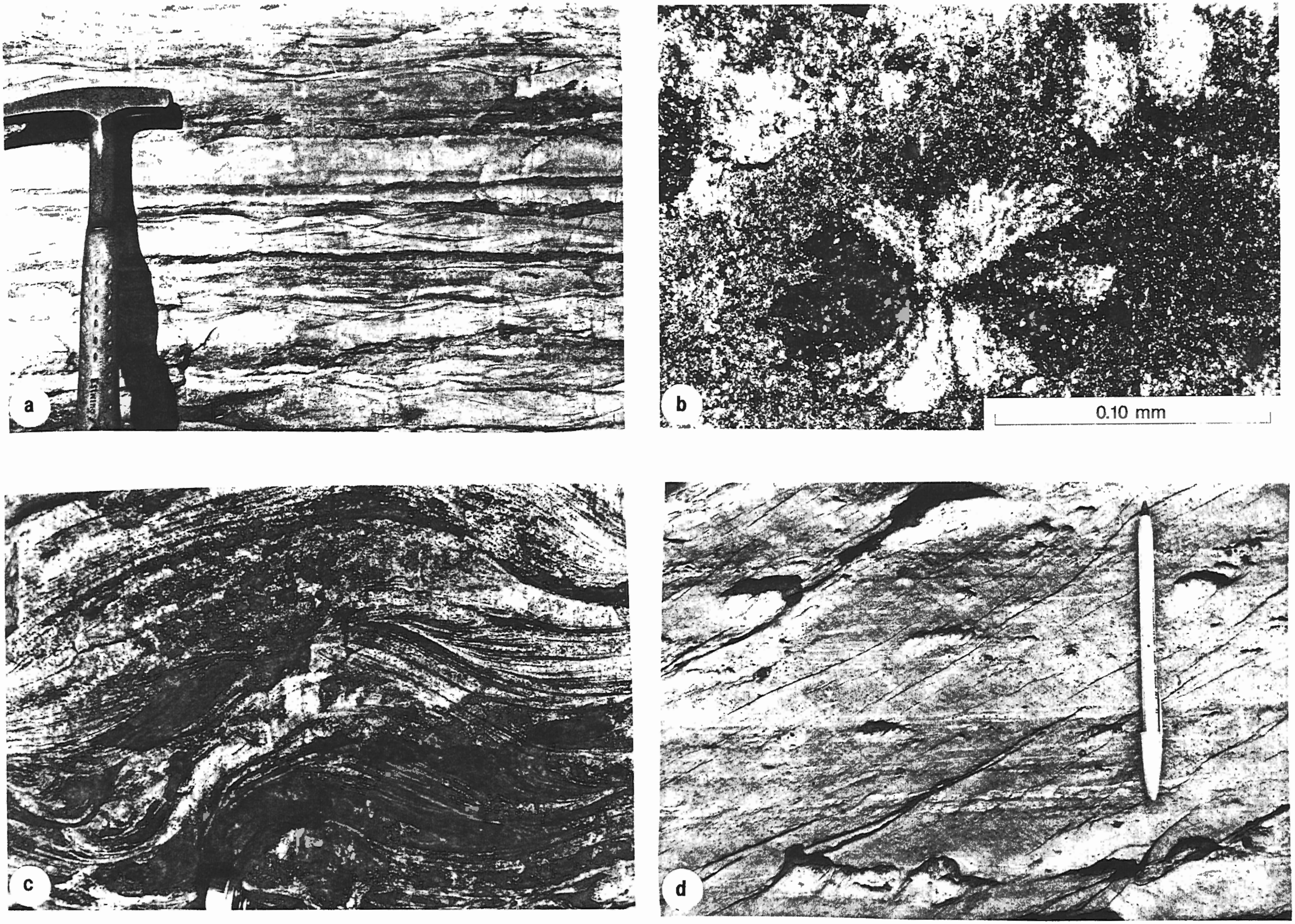


Figure 16.

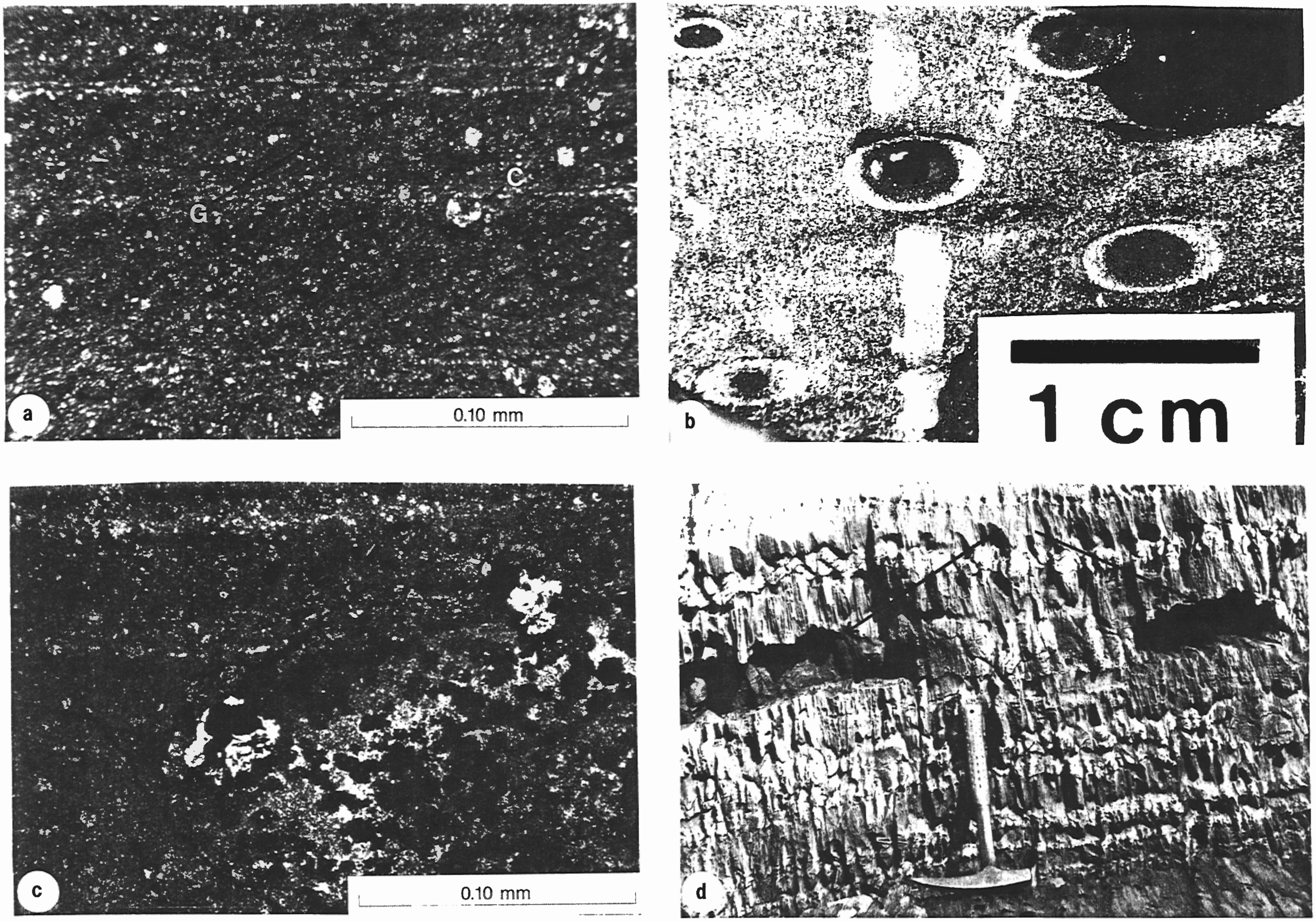


Figure 17.

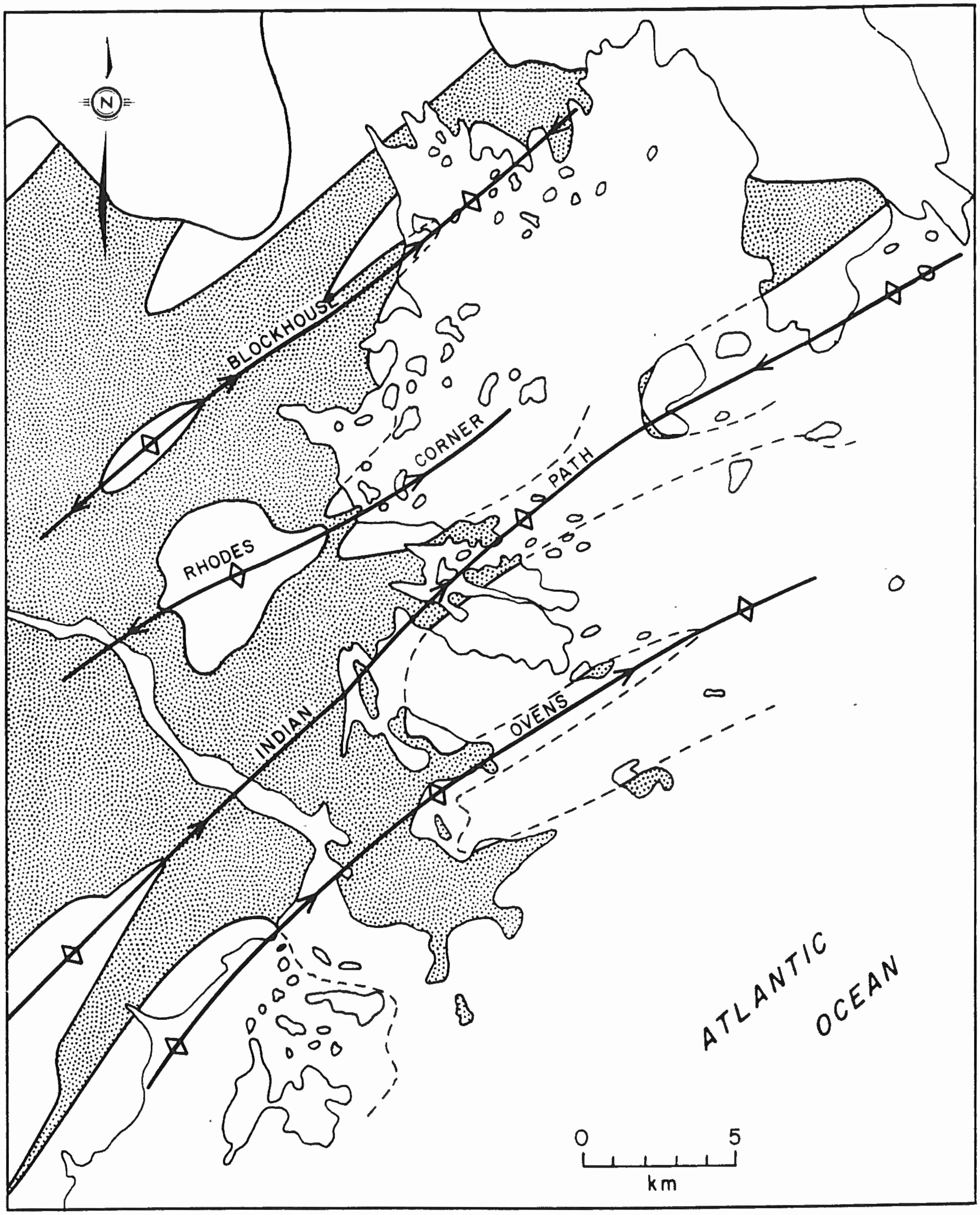

N
BLOCKHOUSE
CORNER
RHODES
PATH
INDIAN
OVENS
ATLANTIC
OCEAN
0
5
km

Figure 18

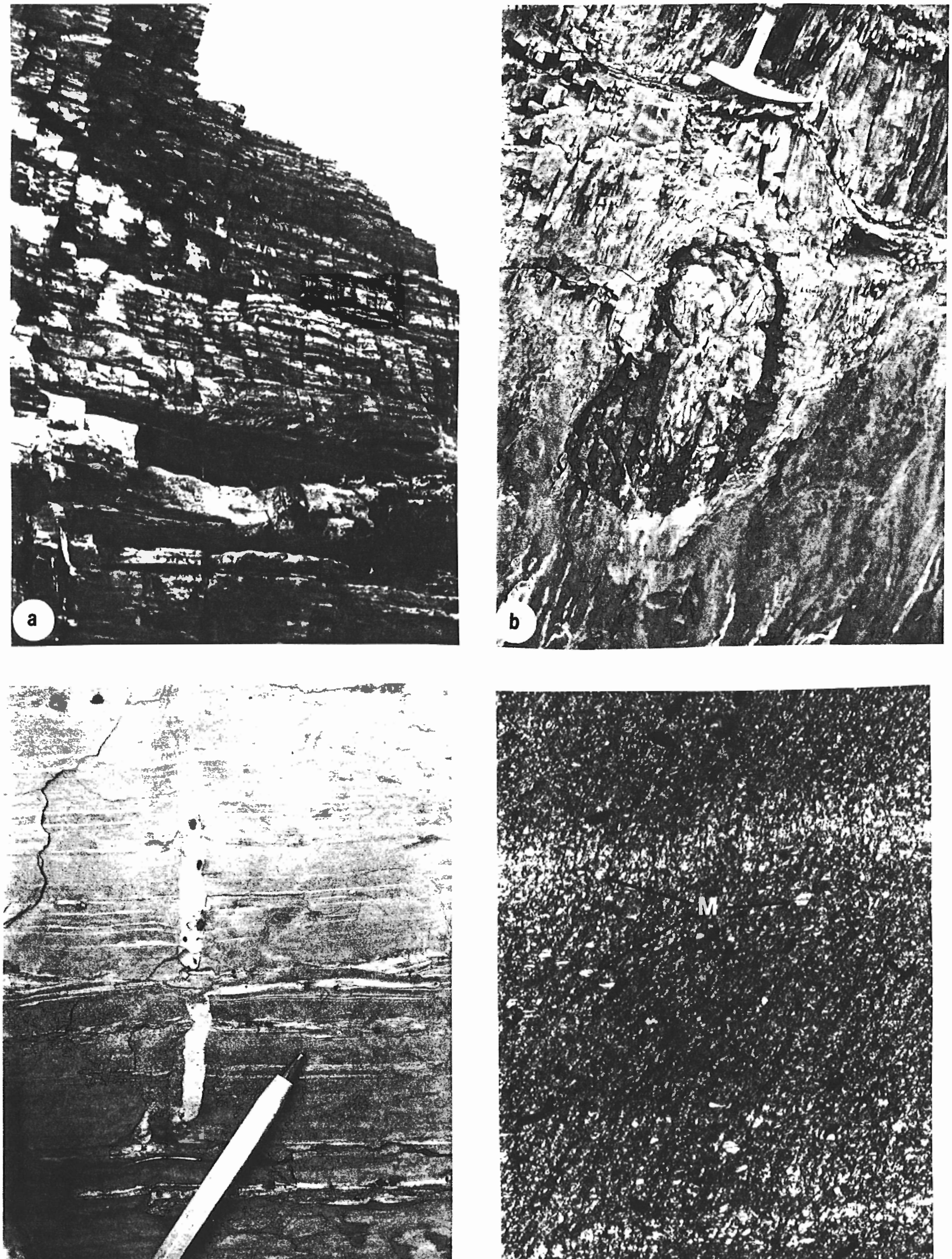


Figure 19.

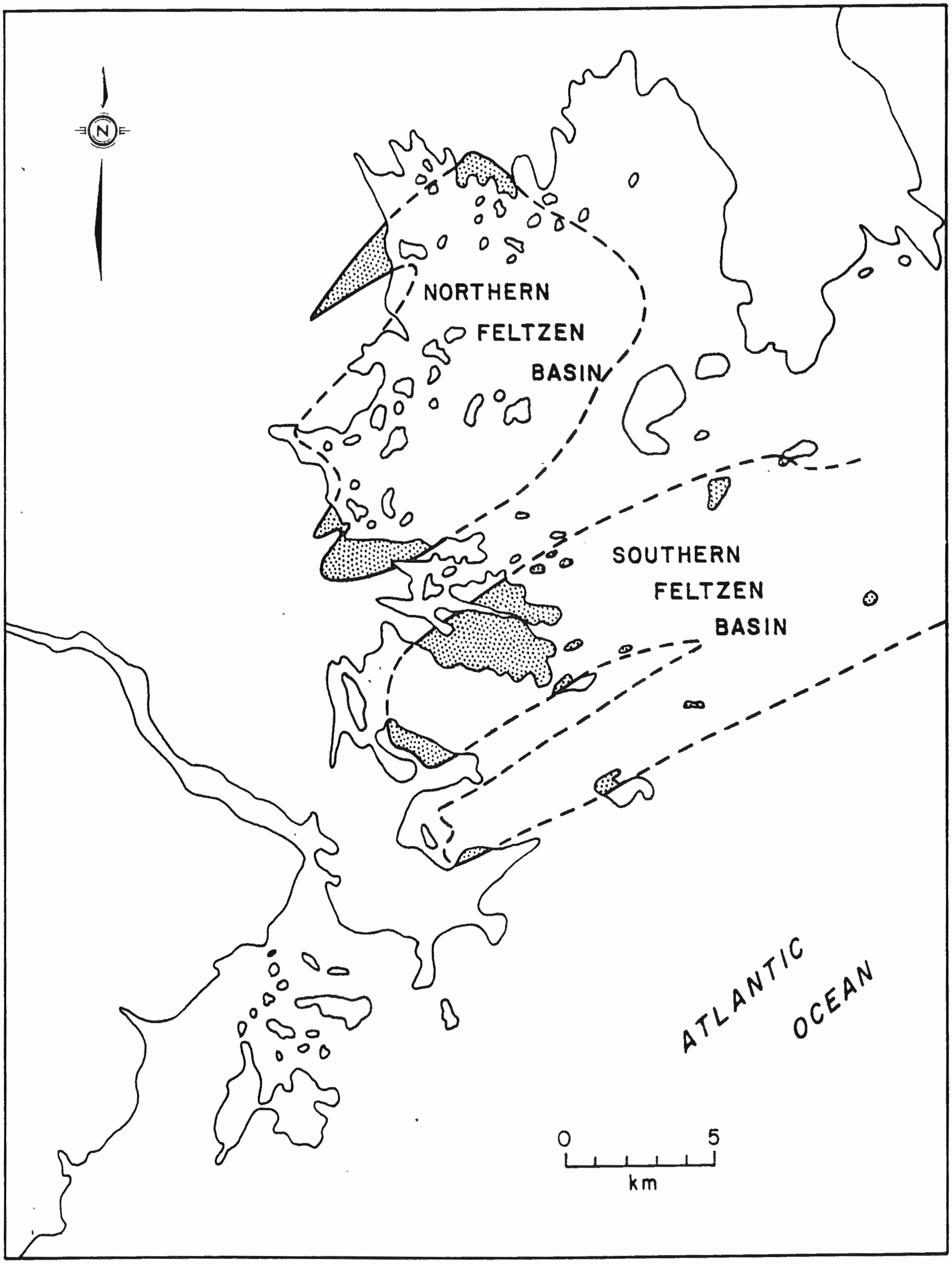

N
NORTHERN
FELTZEN
BASIN
SOUTHERN
FELTZEN
BASIN
ATLANTIC
OCEAN
0
5
km

Figure 20

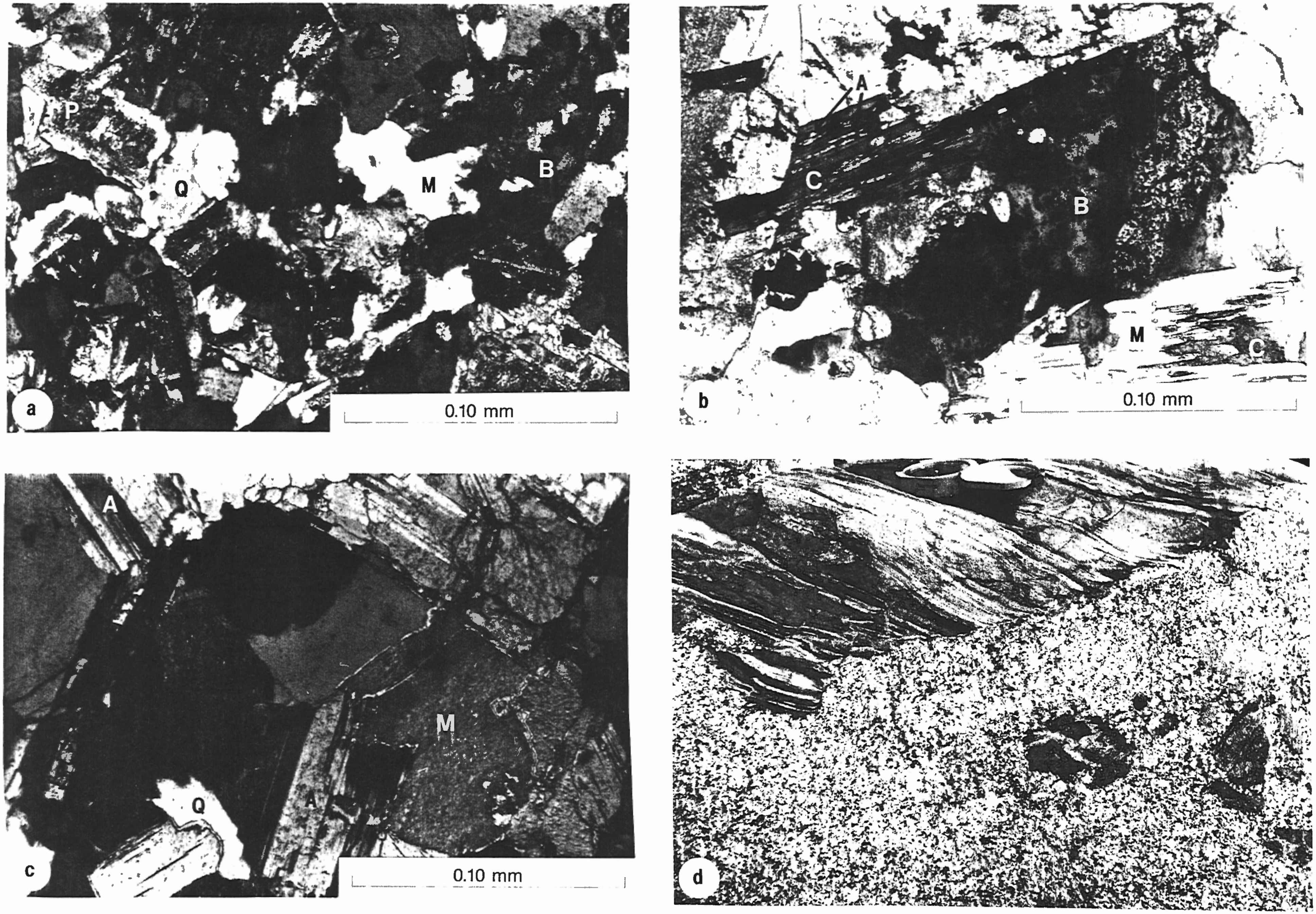


Figure 21.

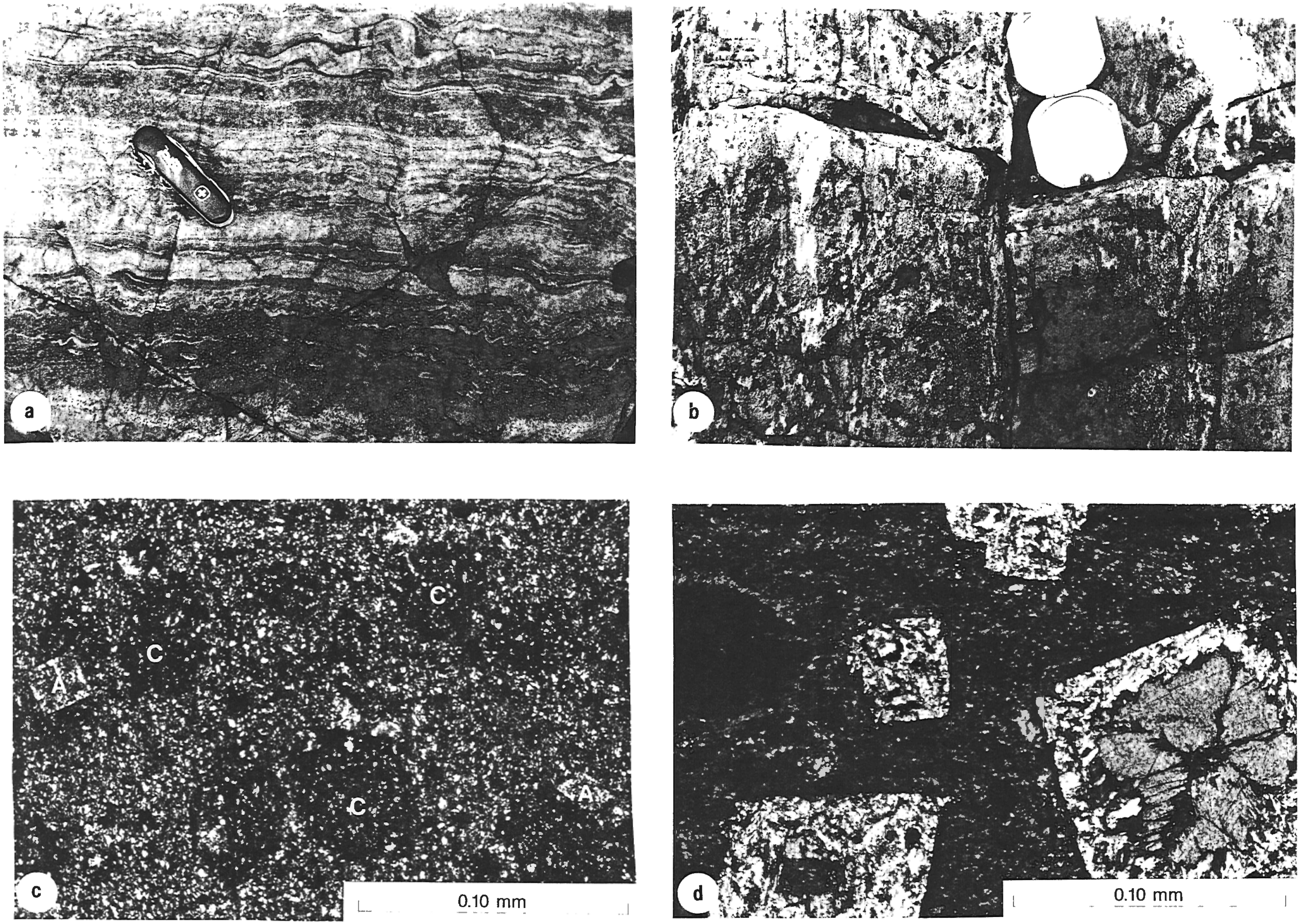


Figure 72.

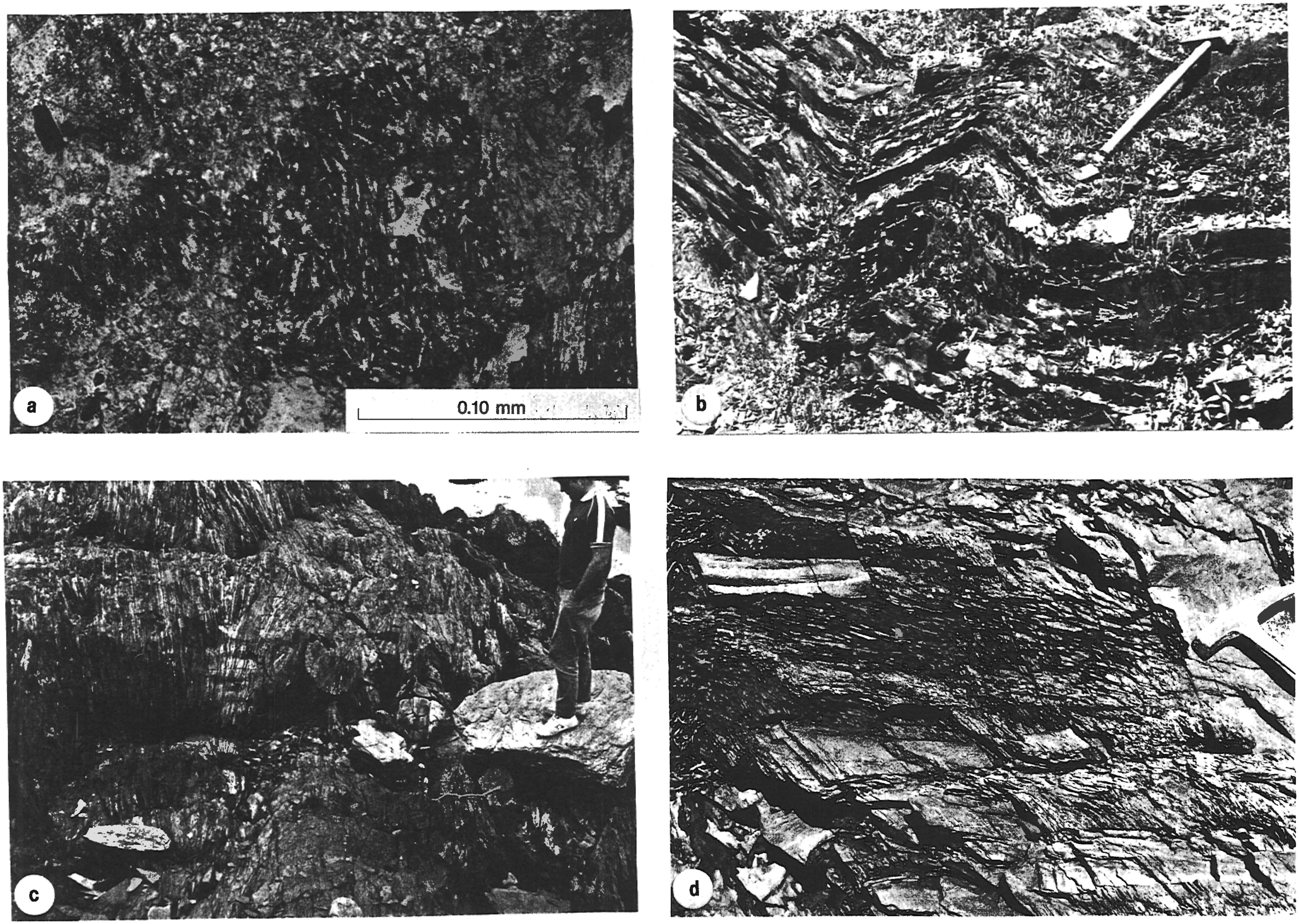


Figure 23.

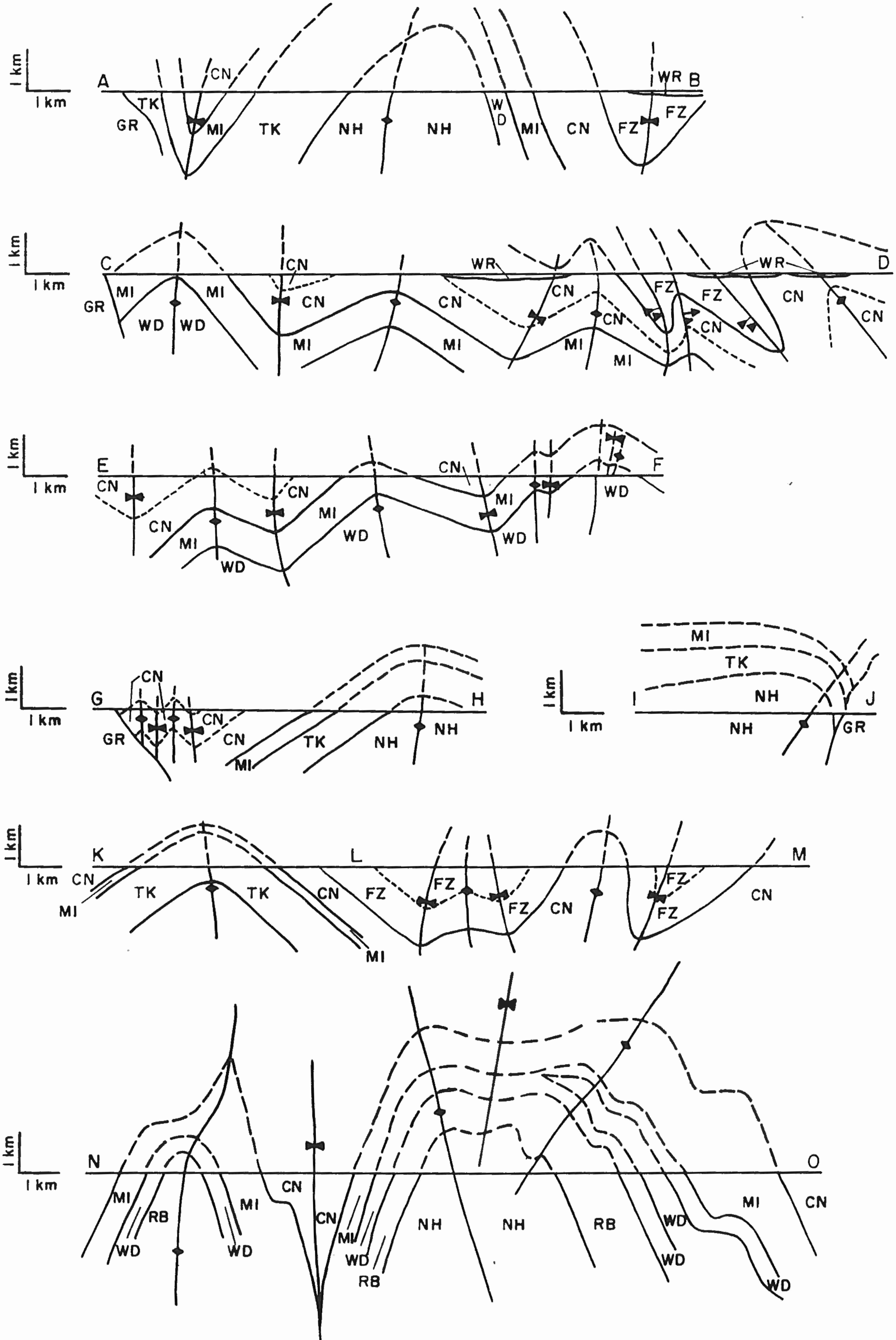
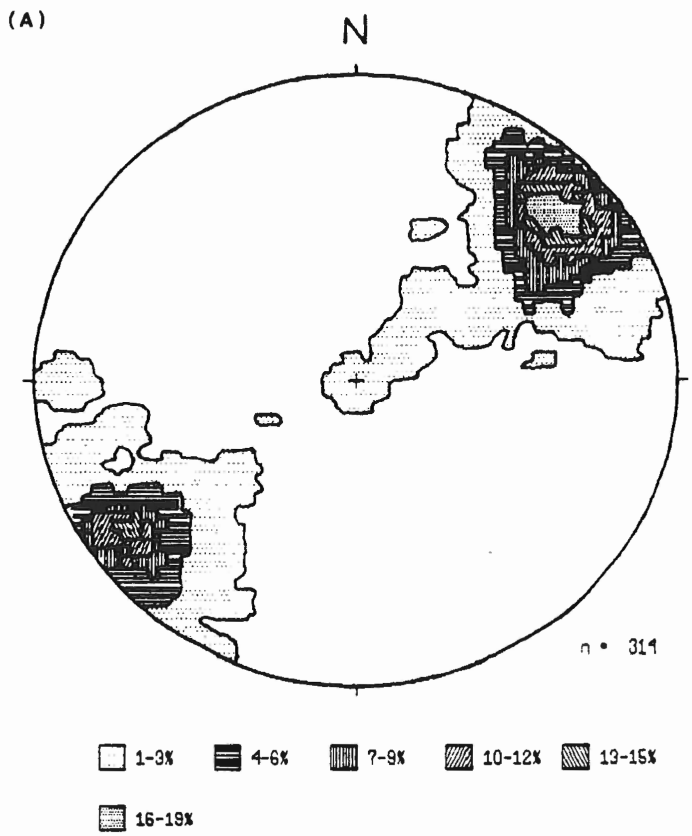

1 km
1 km
A
B
CN
TK
GR
MI
TK
NH
NH
W
D
MI
CN
FZ
FZ
WR
C
D
CN
WR
WR
MI
MI
GR
WD
WD
CN
CN
CN
FZ
FZ
CN
CN
CN
CN
MI
MI
MI
MI
E
F
CN
CN
CN
CN
MI
MI
MI
WD
WD
WD
WD
G
H
CN
CN
GR
CN
TK
NH
NH
MI
I
J
MI
TK
NH
NH
GR
K
L
M
CN
MI
TK
TK
CN
FZ
FZ
FZ
CN
FZ
FZ
CN
MI
N
O
MI
RB
MI
WD
WD
CN
CN
MI
WD
RB
NH
NH
RB
WD
WD
MI
CN
WD

Figure 24.


(A)
N
n = 314
1-3%
4-6%
7-9%
10-12%
13-15%
16-18%

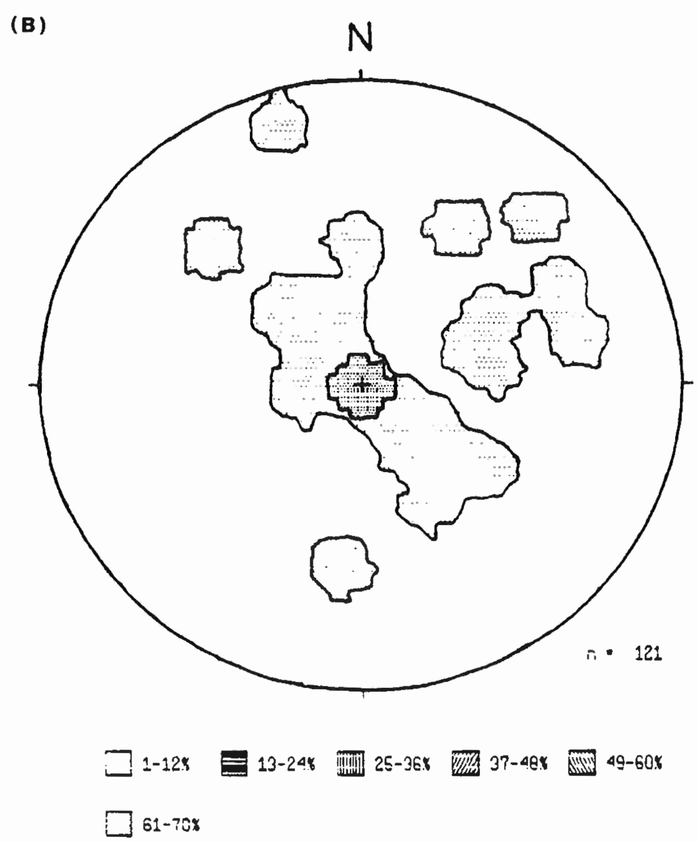

(B)
N
n = 121
1-12%
13-24%
25-36%
37-48%
49-60%
61-70%

Figure 25

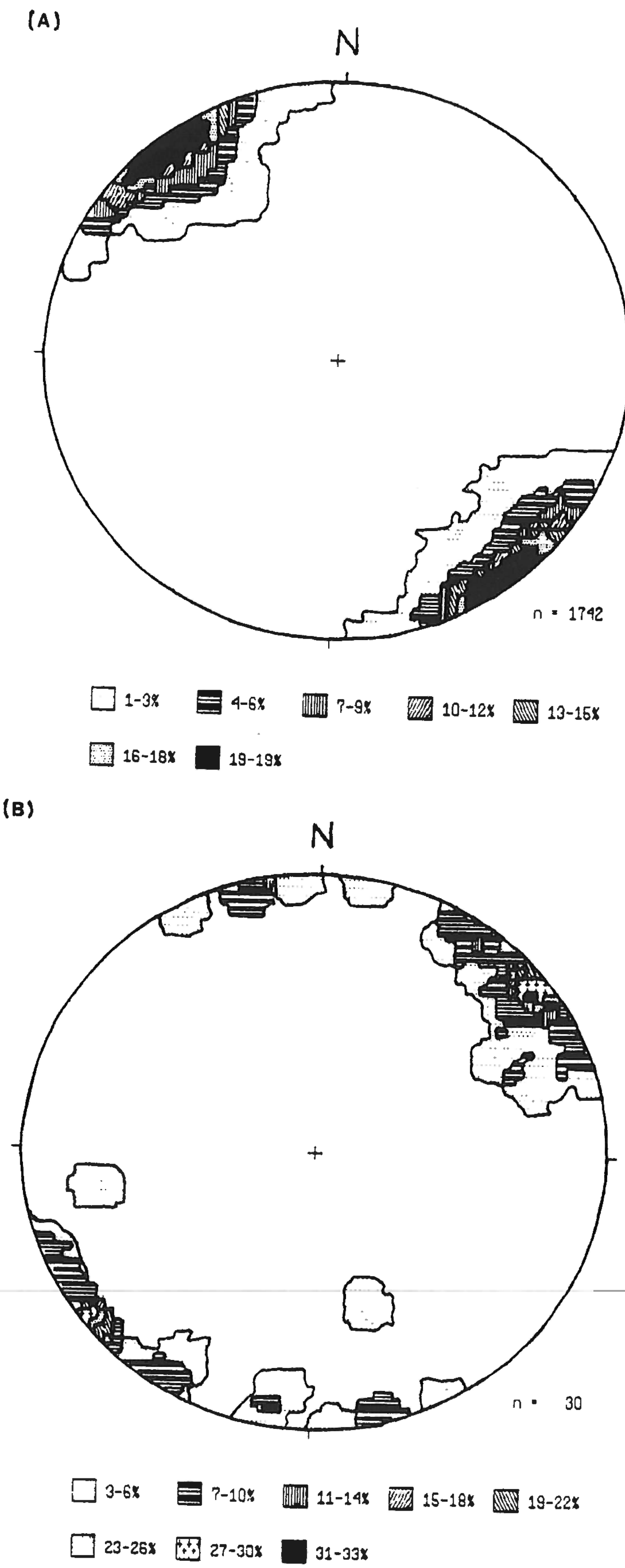

(A)
N
n = 1742
1-3%
4-6%
7-9%
10-12%
13-15%
16-18%
19-19%
(B)
N
n = 30
3-6%
7-10%
11-14%
15-18%
19-22%
23-26%
27-30%
31-33%

Figure 26

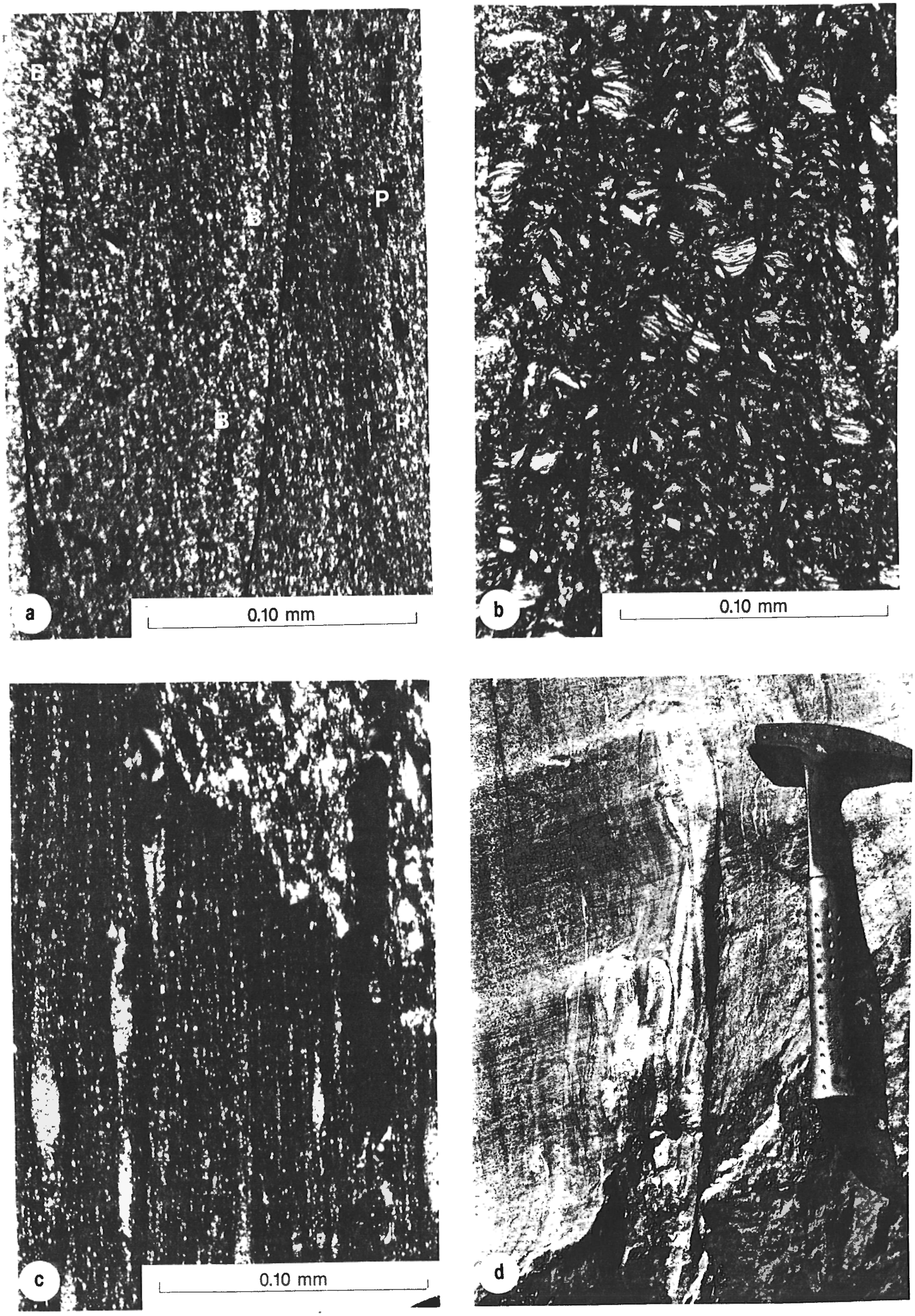
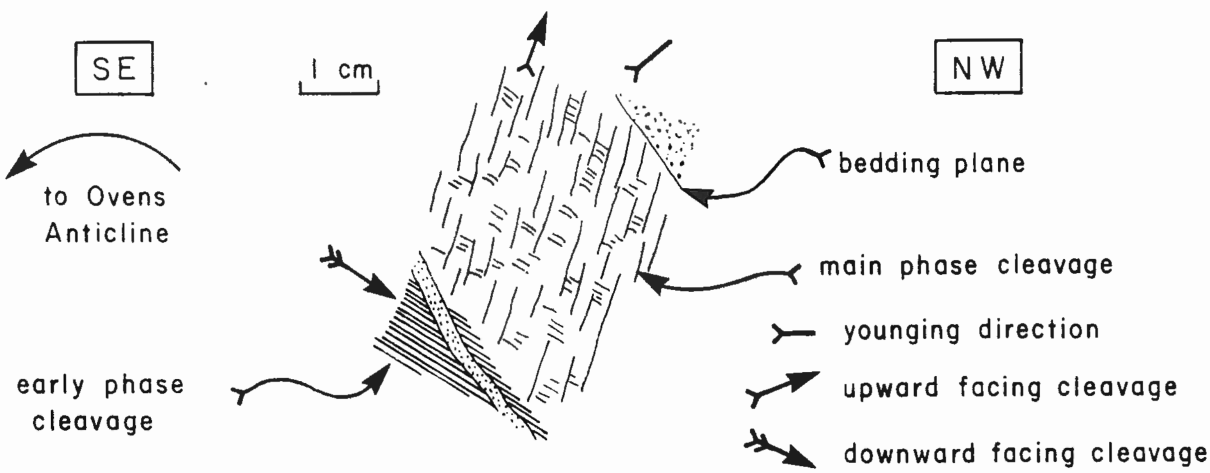


Figure 17.

CROSS SECTIONAL SKETCH OF ORIENTATED THIN SECTION (MEB-6-84B)
LOOKING S.W. ALONG MAIN PHASE CLEAVAGE DIPPING 80° S.E.



Beds dip 55° NW and are right way up. Main phase cleavage – bedding intersection confirms the presence of the Ovens Anticline to the SE.

Figure 28

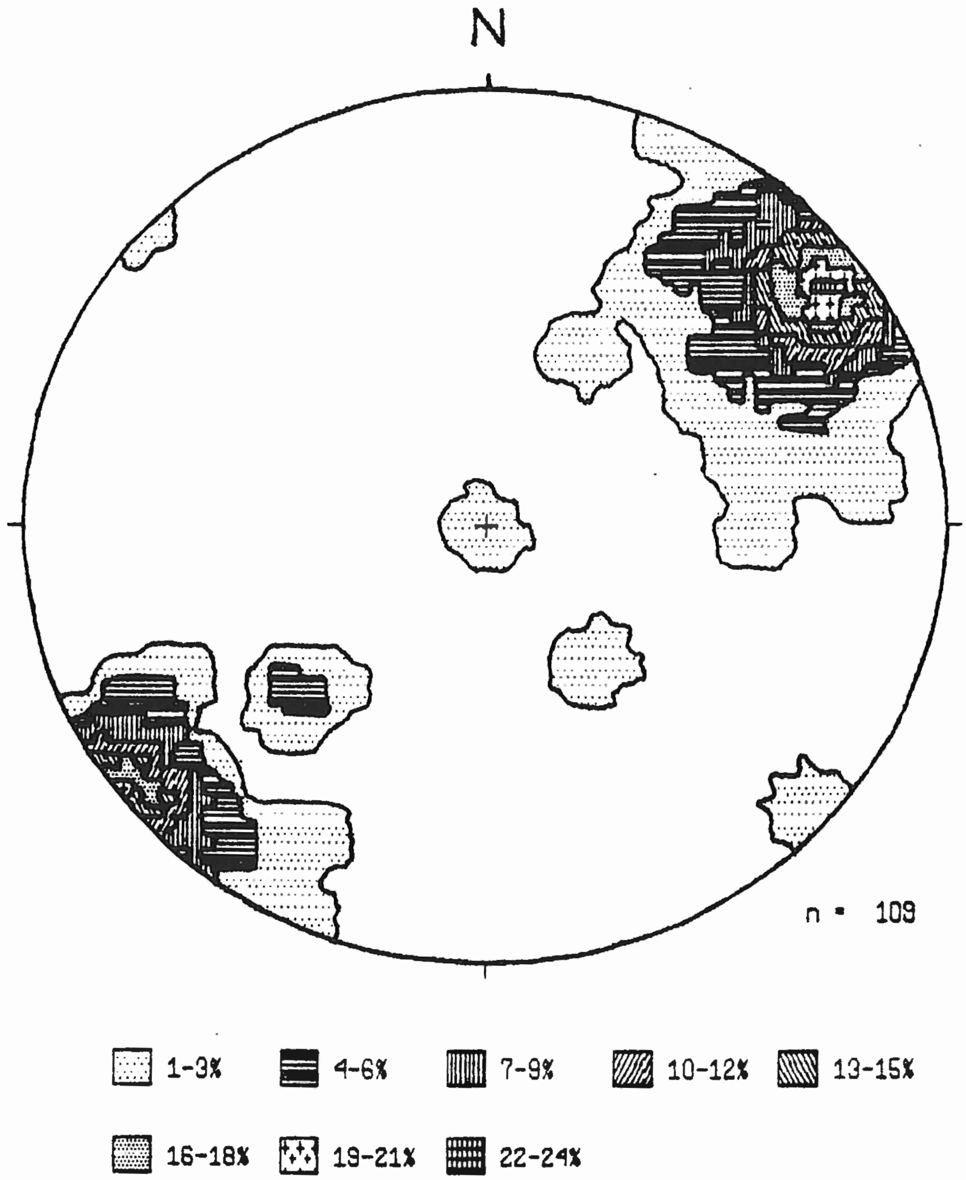
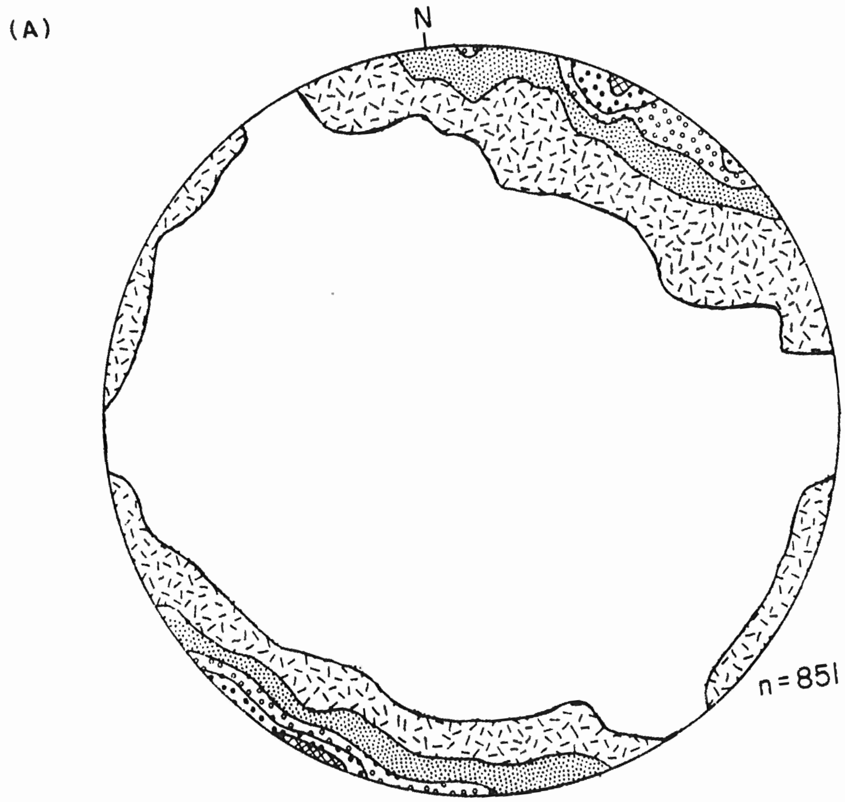


Figure 29



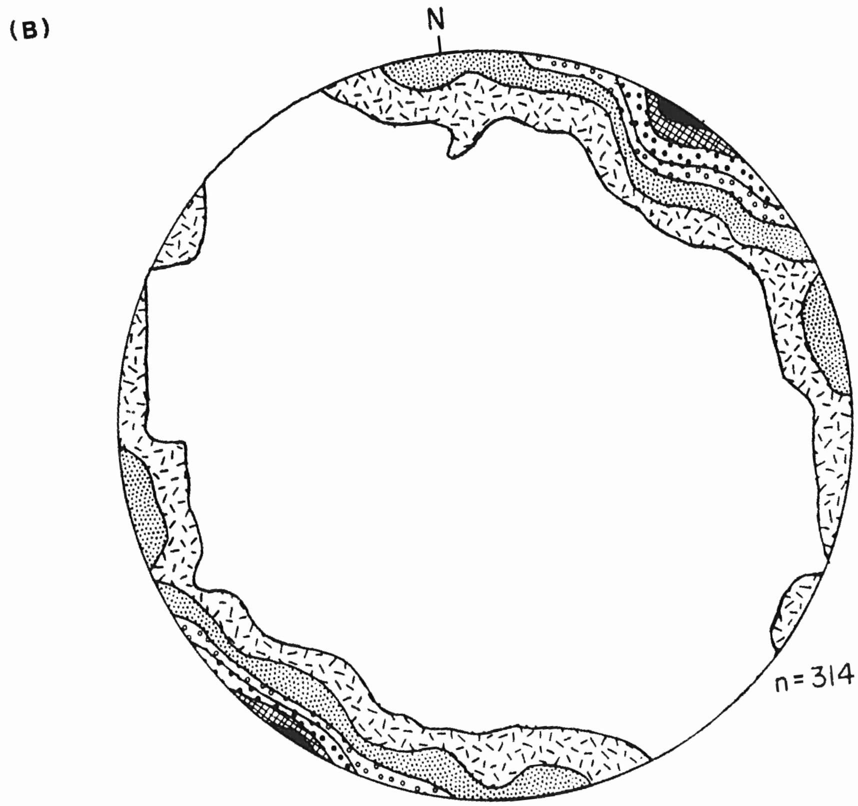


Figure 30

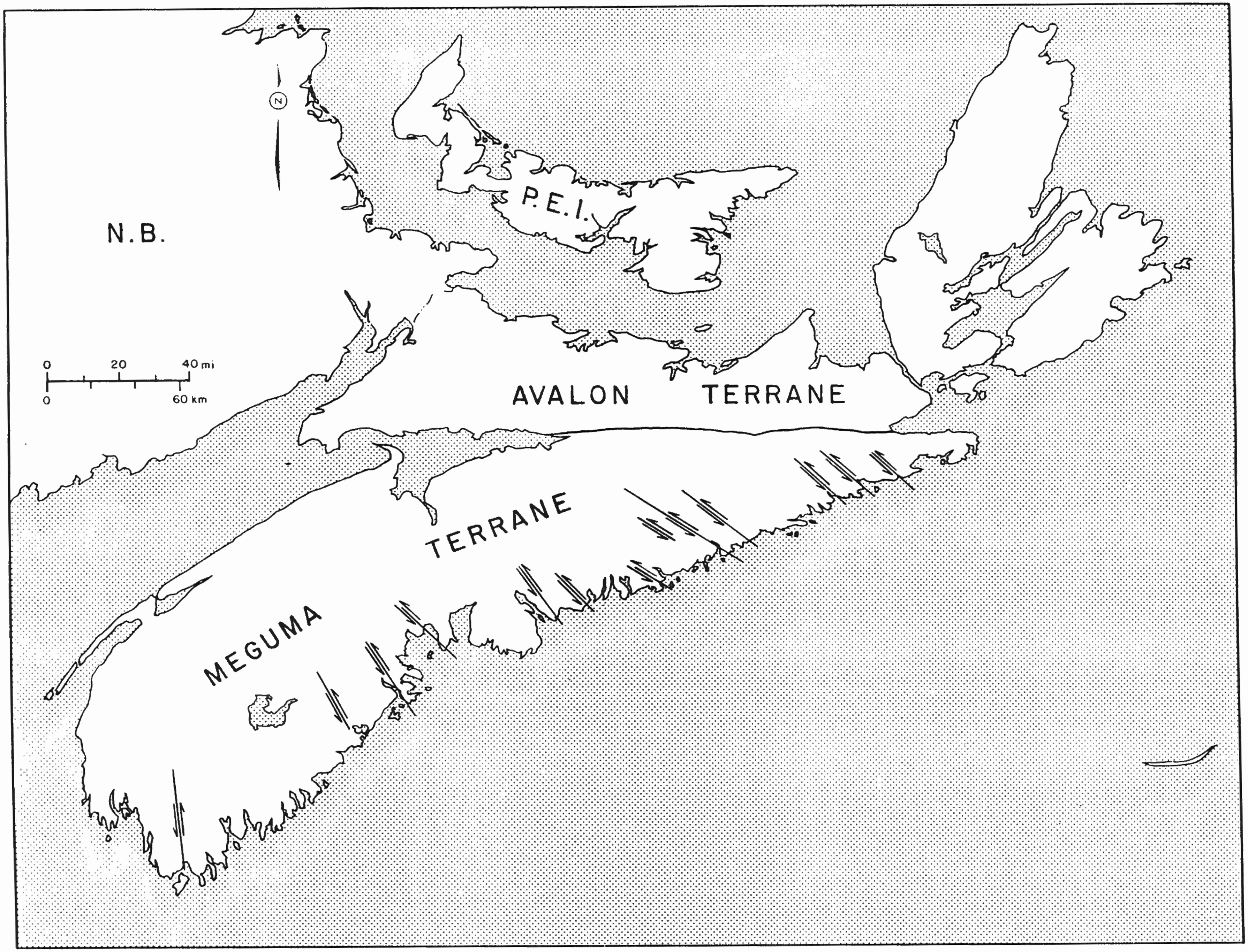


Figure 31

PLAN VIEW OF SUBVERTICAL BEDS, FRACTURES AND CLEAVAGE

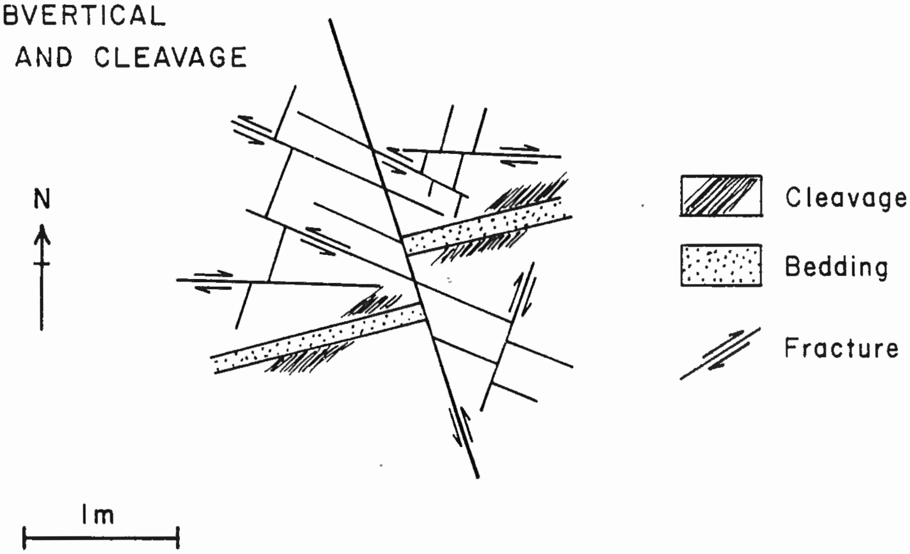


Figure 32.

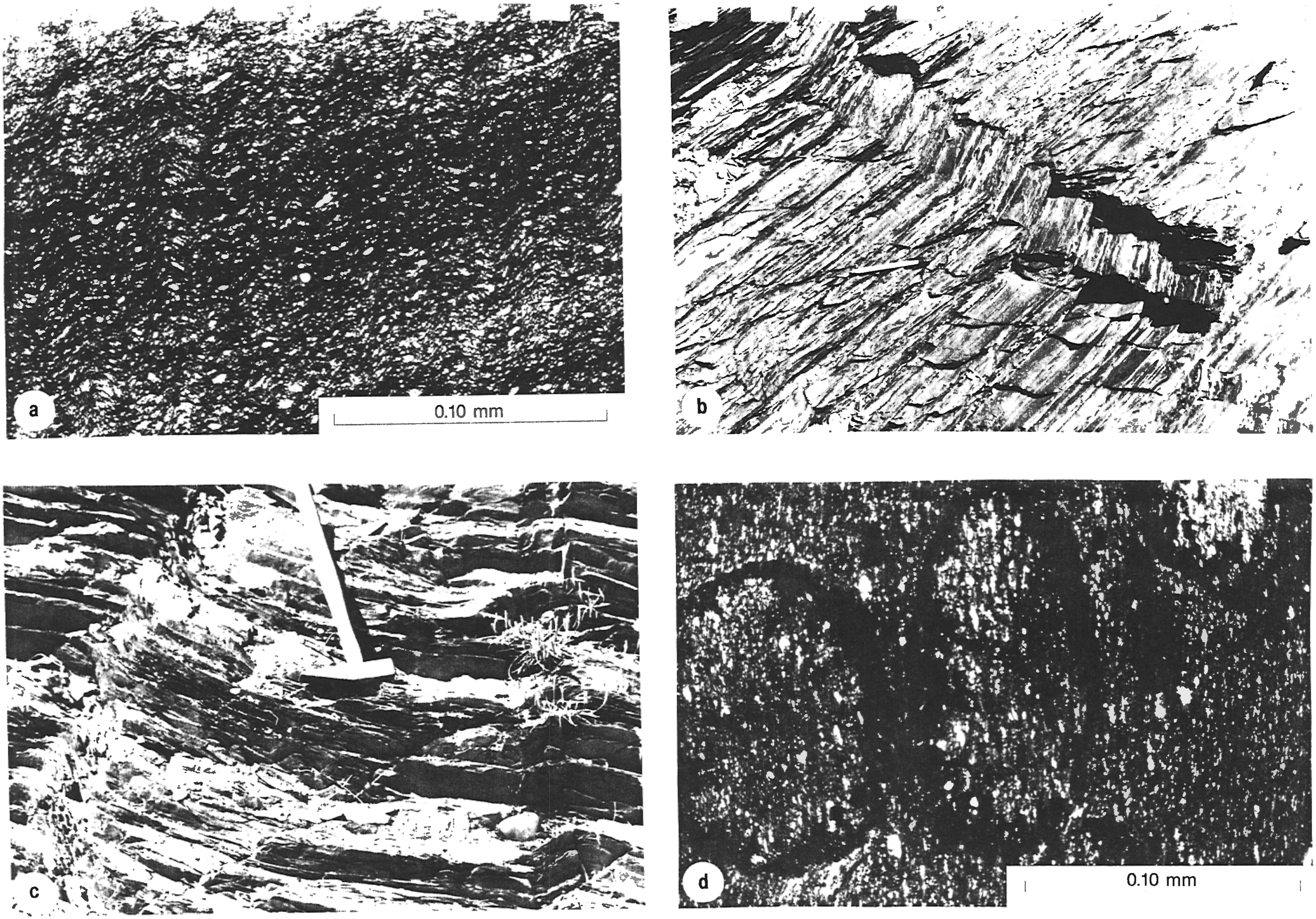


Figure 33.

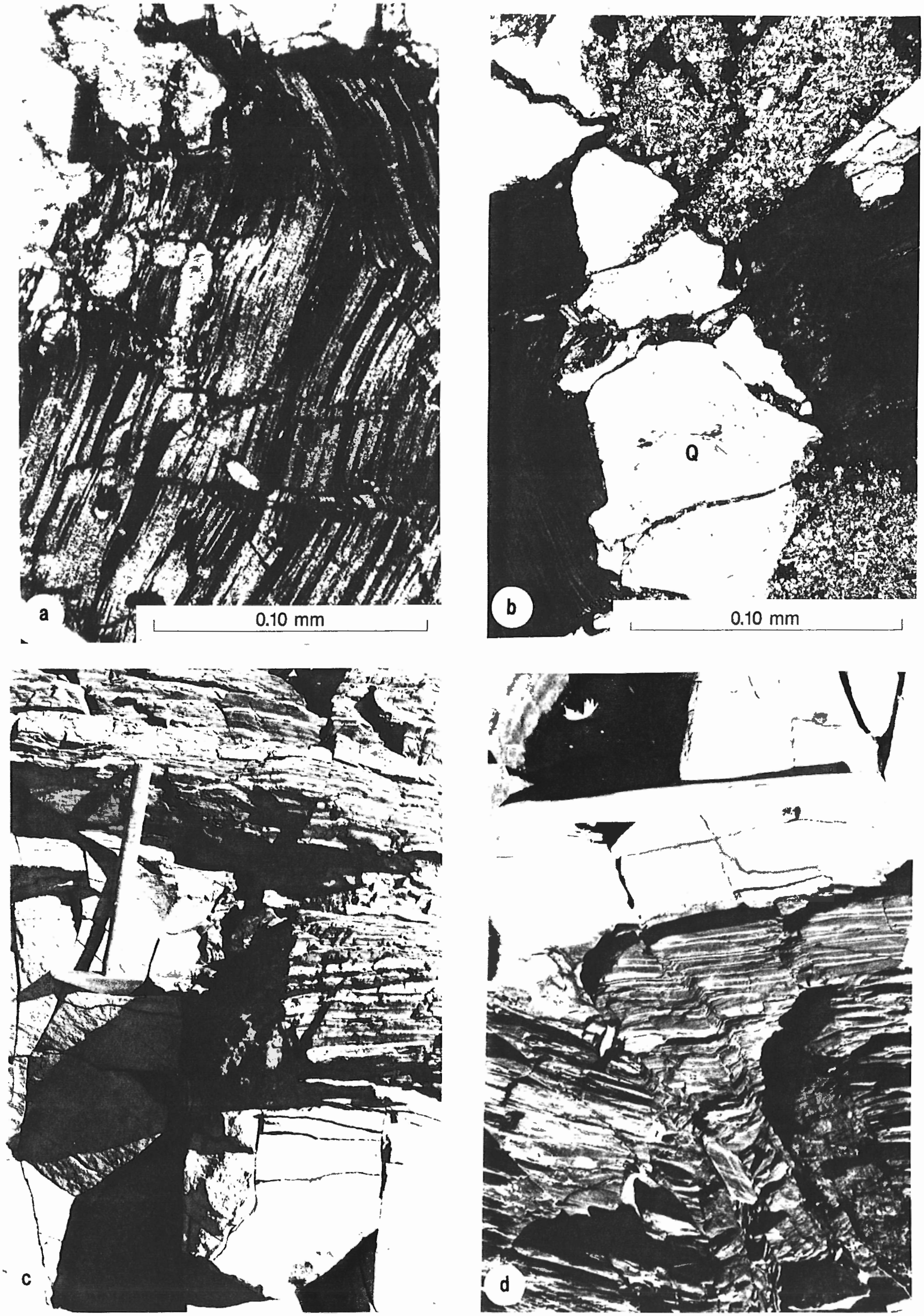


Figure 34.

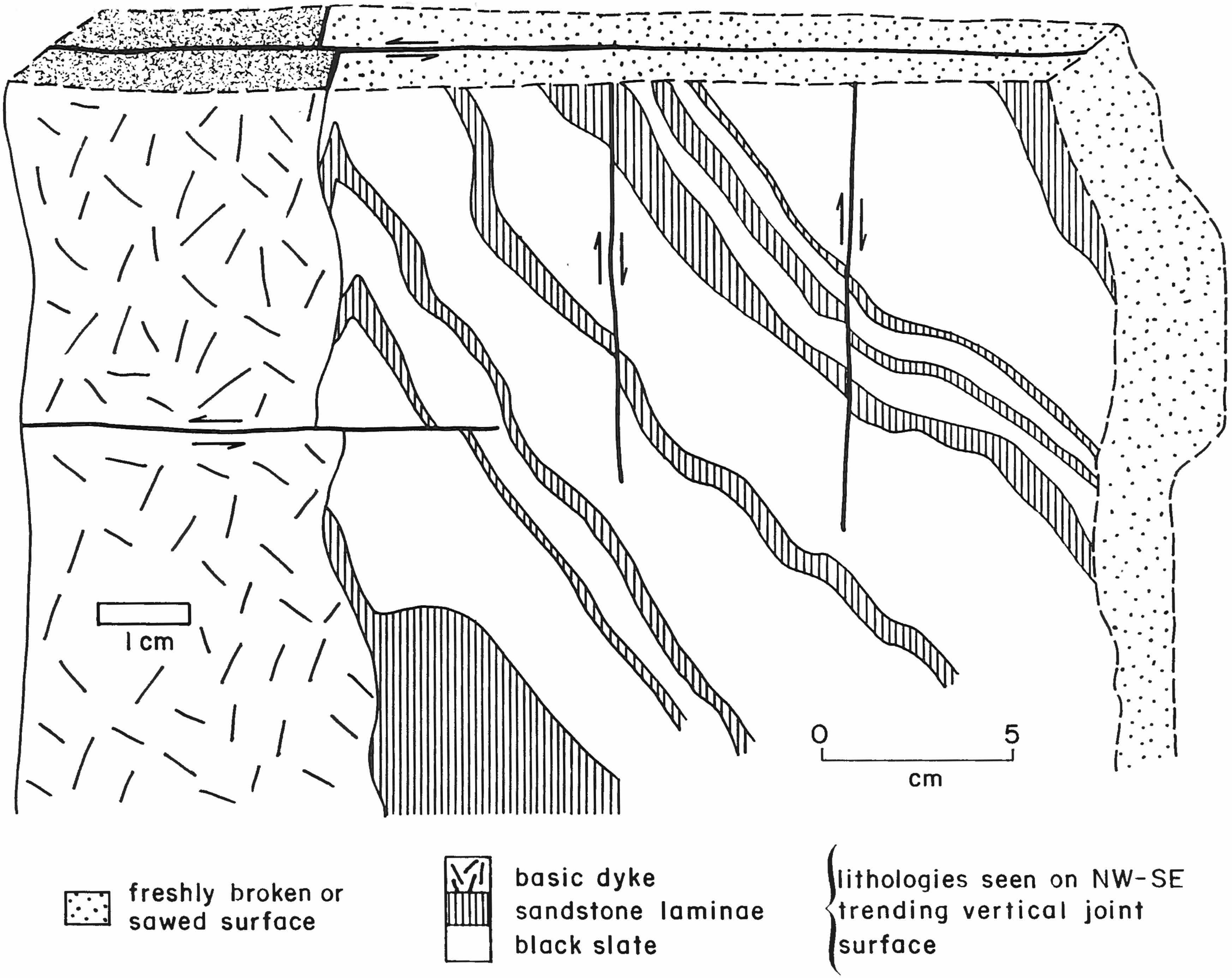

1 cm
0
5
cm
freshly broken or sawed surface
basic dyke
sandstone laminae
black slate
lithologies seen on NW-SE trending vertical joint surface

Figure 35

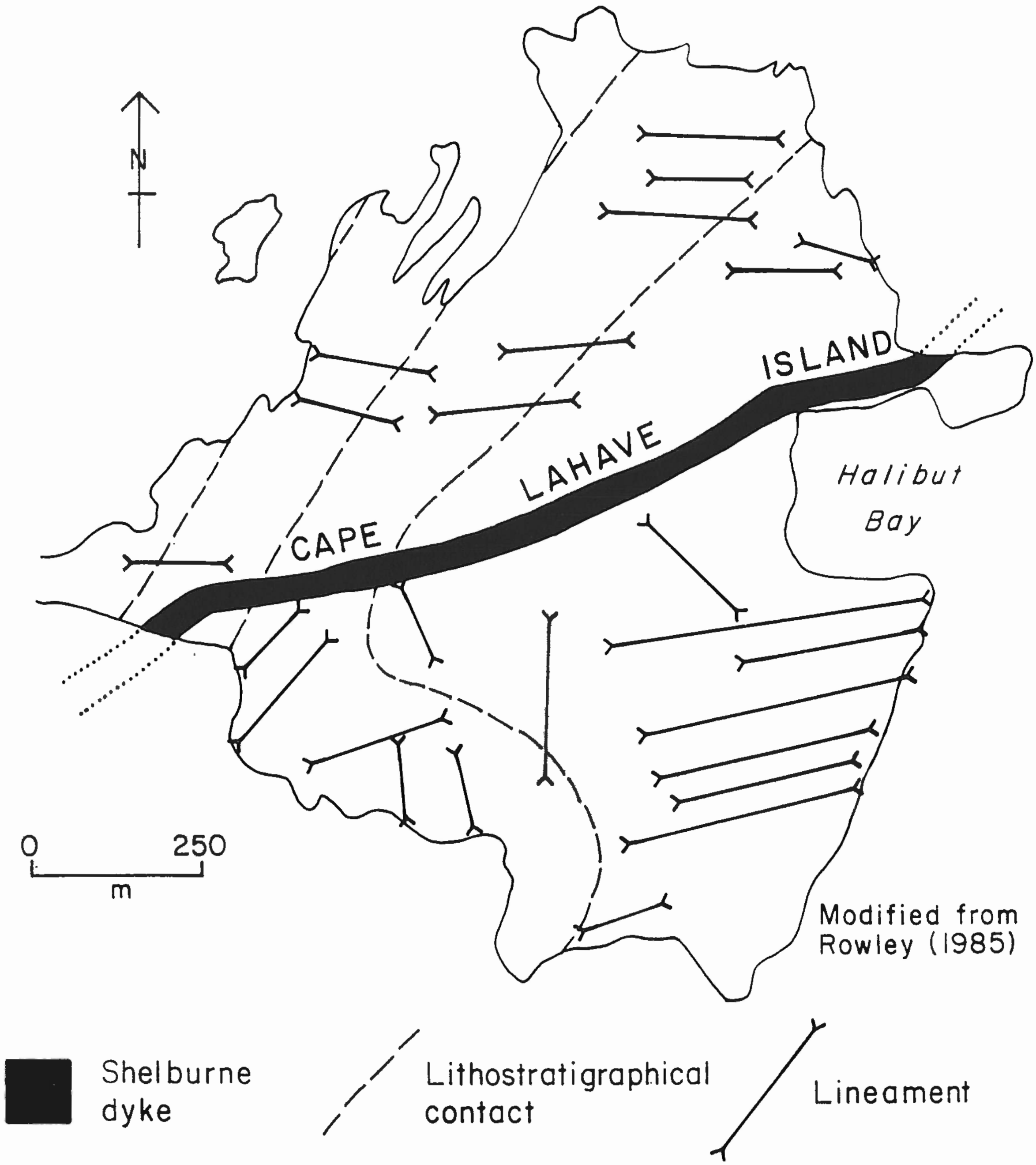

N
ISLAND
LAHAVE
CAPE
Halibut
Bay
0
250
m
Modified from
Rowley (1985)
Shelburne
dyke
Lithostratigraphical
contact
Lineament

Figure 36

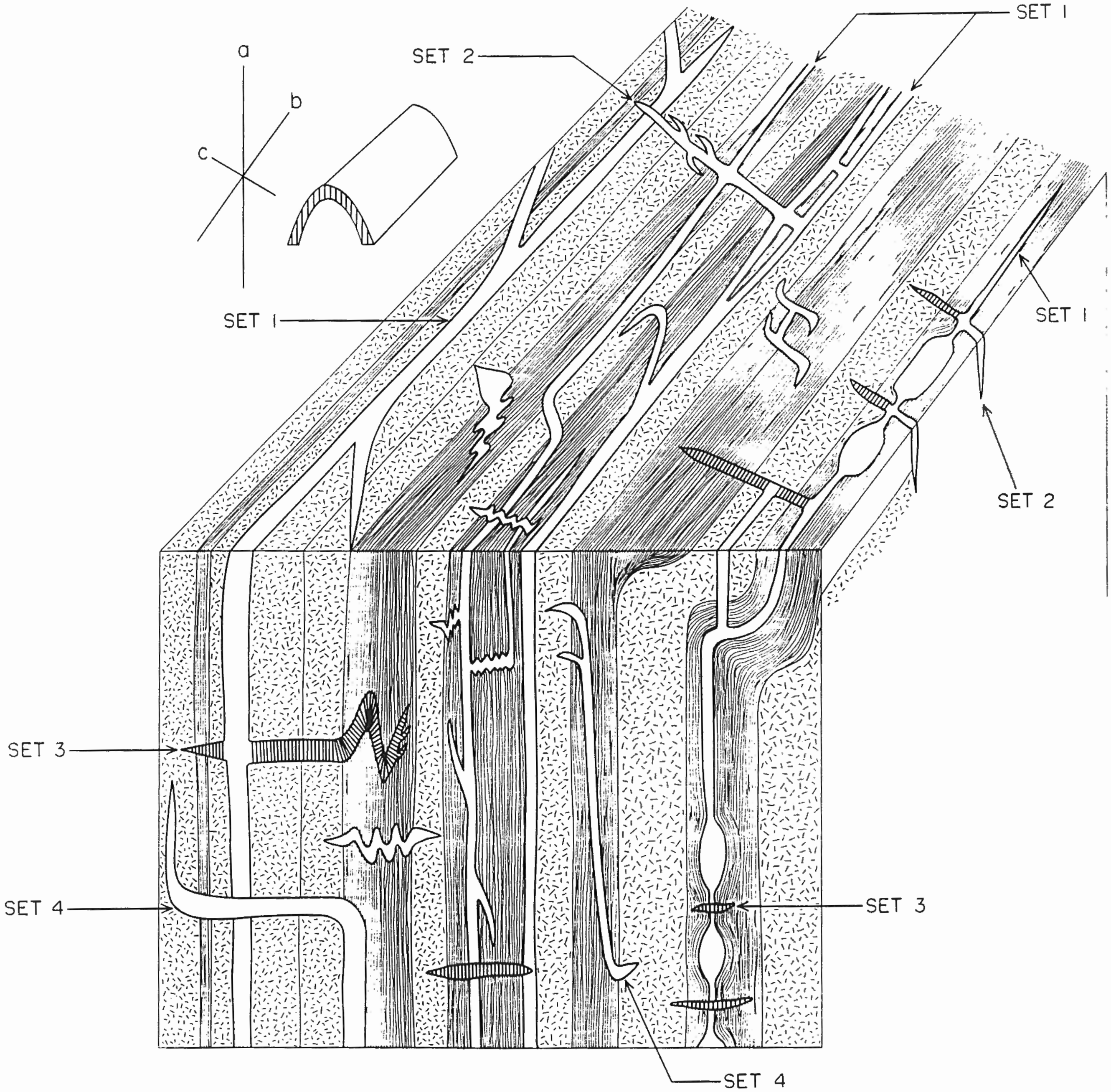


Figure 37

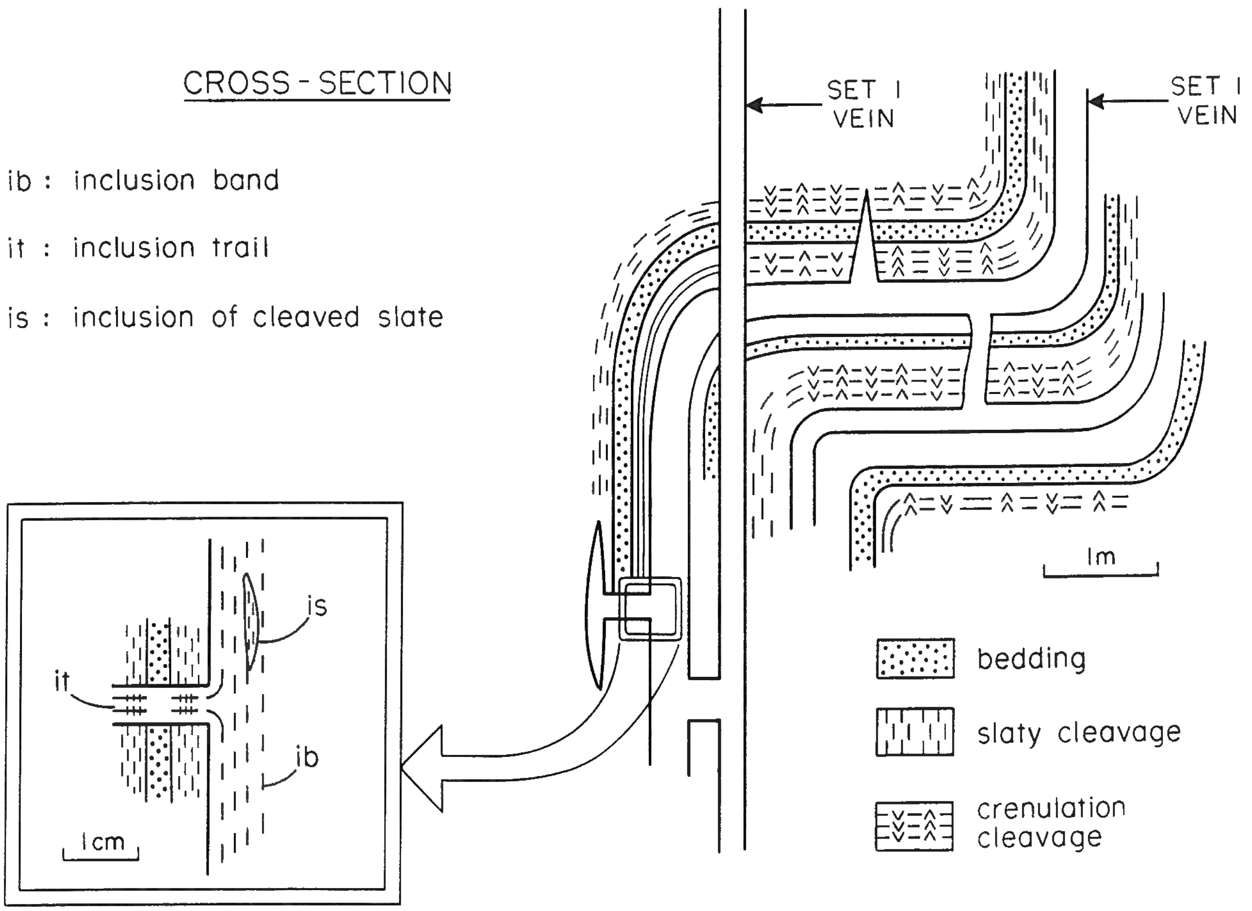

CROSS - SECTION
ib : inclusion band
it : inclusion trail
is : inclusion of cleaved slate
SET I VEIN
SET I VEIN
1m
bedding
slaty cleavage
crenulation cleavage
is
it
ib
1cm

Figure 38

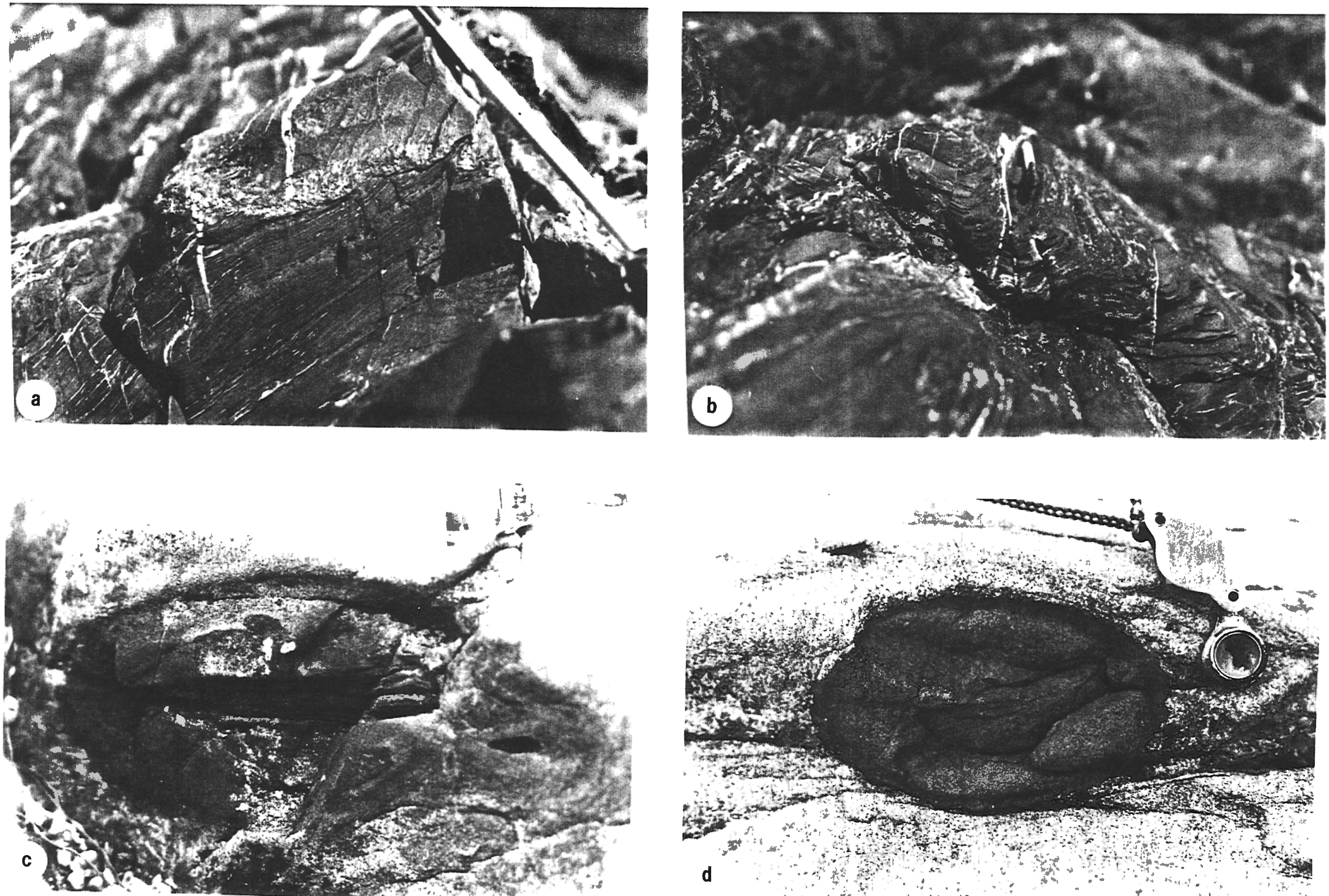


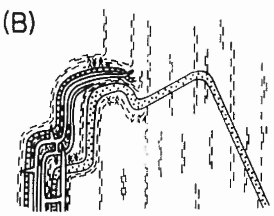
Figure 29

CROSS-SECTIONS

(A)

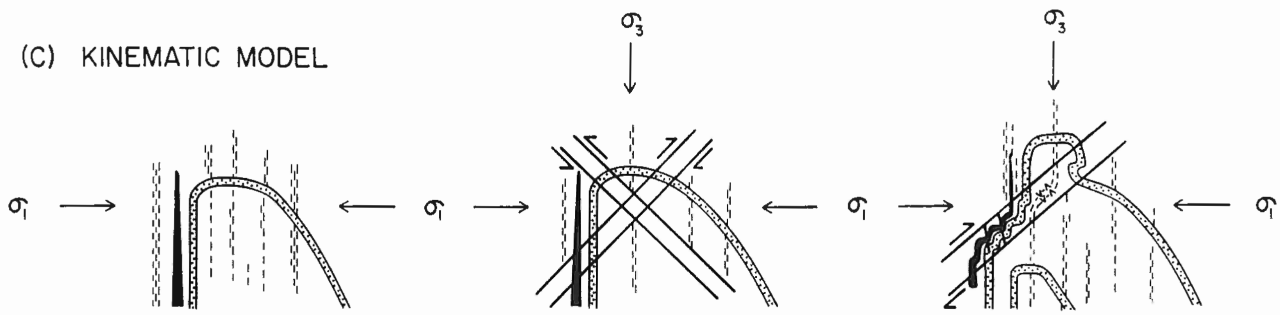
GEOMETRY OF VEIN ARRAYS DURING
EARLY STAGE OF FOLDING

(B)



GEOMETRY OF VEIN ARRAYS DURING
LATE STAGE OF FOLDING

(C) KINEMATIC MODEL



EARLY STAGE FOLDS
AND VEINS

HYPOTHETICAL DUCTILE-
BRITTLE LIMB THRUSTS

LATE STAGE FOLDS
AND VEINS

Figure 40

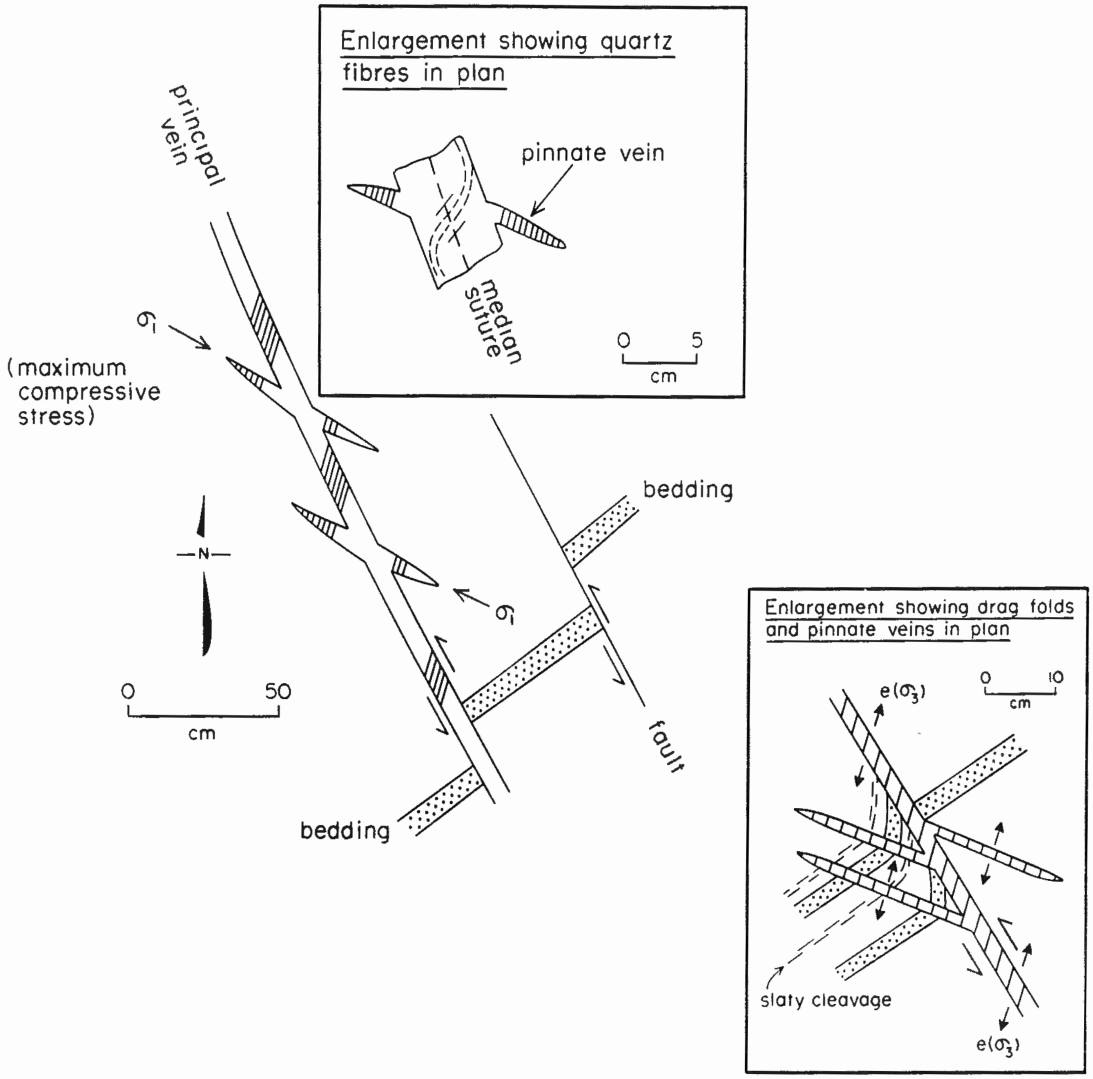

Enlargement showing quartz fibres in plan
pinnate vein
median suture
0 5
cm
principal vein
σ1
(maximum compressive stress)
N
0 50
cm
bedding
fault
bedding
σ1
Enlargement showing drag folds and pinnate veins in plan
0 10
cm
e(σ3)
slaty cleavage
e(σ3)

Figure 41

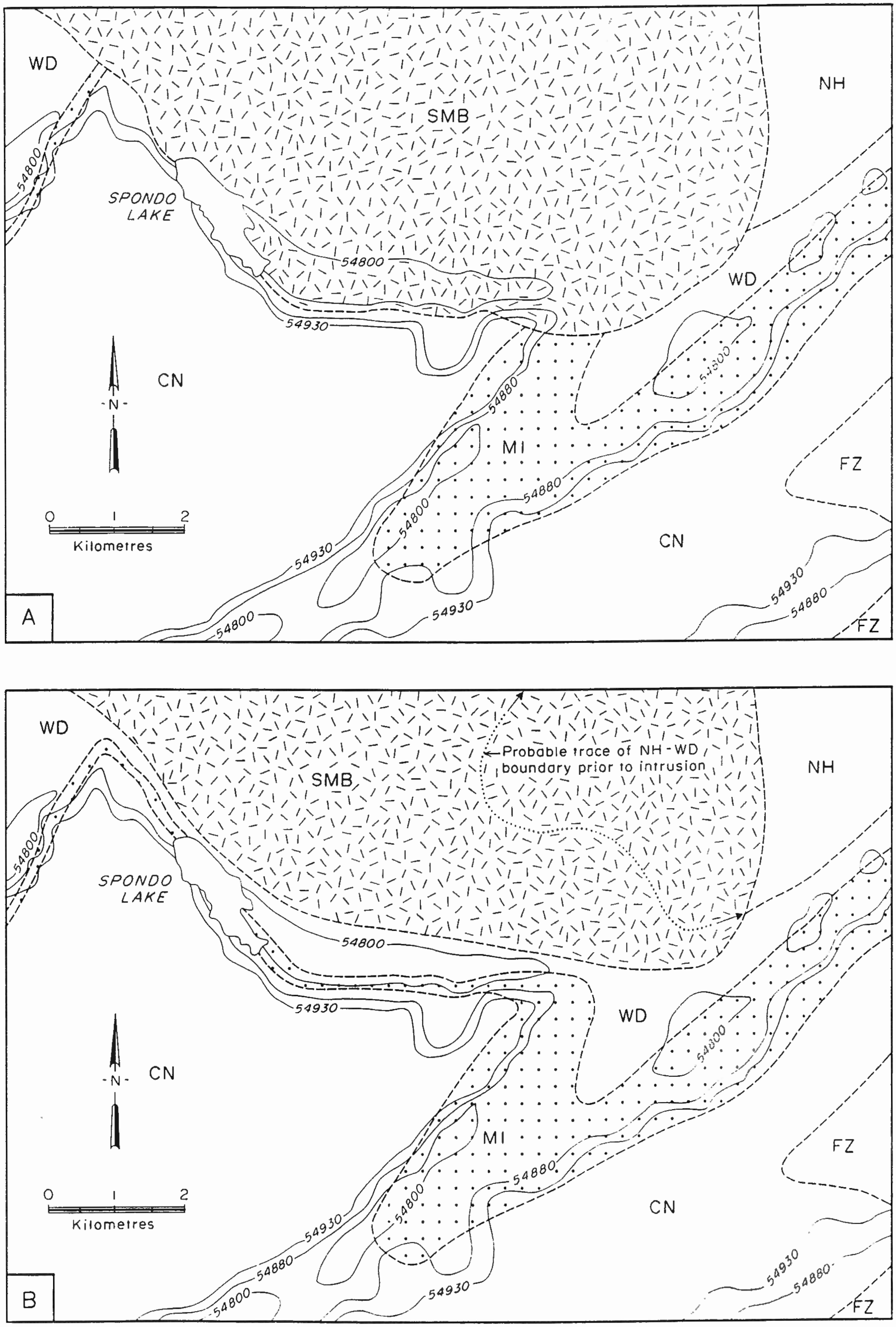

WD
SMB
NH
SPONDO LAKE
54800
54930
54880
CN
N
0 1 2
Kilometres
MI
FZ
A
WD
SMB
Probable trace of NH-WD boundary prior to intrusion
NH
SPONDO LAKE
54800
54930
54880
CN
N
0 1 2
Kilometres
MI
FZ
B

Figure 4.2

Table 1

No.	Reference	Map Emphasis and Area	Scale
1	Faribault, 1924	general geology; Chester Basin area	1 inch = 1 mile
	Faribault, 1929a	general geology; Mahone Bay area	1 inch = 1 mile
	Faribault, 1929b	general geology; Bridgewater area	1 inch = 1 mile
2	Hall, 1981	thesis map; Meguma Group; Lunenberg area	1:50,000
3	Rowley, 1985	thesis map; photo-geology and remote sensing; LaHave River area	1:25,000
4	Sage, 1954	thesis map; Windsor Group; Mahone Bay area	1 inch = 1 mile
5	Taylor, 1969	regional geology; southwestern Nova Scotia	1 inch = 2 miles

Table 2: TABLE OF BEDROCK FORMATIONS

ERATHEM	SYSTEM OR SERIES	NOMENCLATURE AND THICKNESS		LITHOLOGY	GEOLOGICAL EVENT
MESOZOIC	Upper Triassic or Lower Jurassic	Shelburne dyke (30 m)		dolerite, quartz diorite	faulting, kinking contact metamorphism
		INTRUSIVE		CONTACT	
PALEOZOIC	Lower Carboniferous	Windsor Group (100 m)		limestone, dolostone, gypsum; red sandstone, shale and conglomerate	folding, faulting (?) deposition
		ANGULAR		UNCONFORMITY	
	Devonian	South Mountain batholith		biotite granodiorite; biotite-muscovite, quartz monzonite	folding within contact hornfels contact metamorphism
			INTRUSIVE	CONTACT	
					faulting (?) regional metamorphism folding, local shearing
	Cambro-Ordovician	Meguma Group (6 km to 11 km)	Halifax Formation (2-7 km)	black and grey slate; pyritic sandstone and siltstone	deposition, faulting (?)
			CONFORMABLE	CONTACT	
			Green Bay formation (1-2.5 km)	green siltstone and quartz wacke	deposition, faulting (?)
			CONFORMABLE	CONTACT	
			Golden-ville Formation (1 km)	quartz wacke, minor green slate	deposition

Table 3: K/Ar Age Determination (Geochron Laboratories)

Specimen Locality: contact of the Shelburne dyke with the Cunard member of the Halifax Formation in coastal cliffs immediately north of Foggy Island Cove on West Ironbound Island. NTS Map 21 A/1. E 397900 N 4898200. See Figure 35.

Material Analysed: chilled margin of Shelburne dyke. Whole rock crushed to -80/+200 mesh. Treated with dilute HF and HNO_3.

Argon Analyses:

$^{40*}Ar$ (radiogenic ^{40}Ar in ppm)	$^{40*}Ar/Total^{40}Ar$	Average $^{40*}Ar$ (ppm)
0.005195	0.763	0.005268
0.005340	0.796	

Potassium Analyses:

% K	Average % K	^{40}K
0.402	0.396	0.473
0.379		
0.408		

$^{40*}Ar/^{40}K$ = 0.01114

Age = 182 ± 8 Ma =

$$\frac{1}{\lambda_\beta+(\lambda_e+\lambda_e')}\left[\ln \frac{\lambda_\beta+(\lambda_\beta+\lambda_e')}{(\lambda_e+\lambda_e')} \times \frac{^{40*}Ar}{^{40}K} + 1\right]$$

Constants Used:

= 4.962×10^{-10}/year

= 0.581×10^{-10}/year

$^{40}K/K$ = 1.193×10^{-4} g/g

Table 4: K/Ar Age Determination (Geochron Laboratories)

Specimen Locality: contact of the Shelburne dyke with the Cunard member of the Halifax Formation in coastal cliffs immediately north of Foggy Island Cove on West Ironbound Island. NTS Map 21 A/1. E 397900 N 4898200. See Figure 35.

Material Analysed: sericite mineral concentrate from hornfelsed Cunard metasediment. Crushed to -80/+200 mesh.

Argon Analyses:

$^{40*}Ar$ (radiogenic ^{40}Ar in ppm)	$^{40*}Ar$/Total^{40}Ar	Average $^{40*}Ar$ (ppm)
0.05367	0.728	0.05383
0.05400	0.649	

Potassium Analyses:

% K	Average % K	^{40}K
3.528	3.501	4.177
3.474		

$^{40*}Ar/^{40}K$ = 0.01289

Age = 209 ± 8 Ma = $$\frac{1}{\lambda_{\beta}+(\lambda_e+\lambda_e')}\left[\ln \frac{\lambda_{\beta}+(\lambda_{\beta}+\lambda_e')}{(\lambda_e+\lambda_e')} \times \frac{^{40*}Ar}{^{40}K} + 1\right]$$

Constants Used:

= 4.962 x 10^{-10}/year

= 0.581 x 10^{-10}/year

$^{40}K/K$ = 1.193 x 10^{-4} g/g

Table 5: Geochemical Analyses of Major Elements for Concretions and Host Strata in the Meguma Group (Bondar-Clegg Laboratories)

SAMPLE IDENTIFICATION	SAMPLE LOCATION	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3* %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	LOI %	Total %
NH nodule	#84-0128	41.50	0.35	8.61	02.33	00.55	00.72	24.30	02.23	01.37	00.21	18.90	101.08
Duplicate	#84-0128	42.10	0.35	8.28	02.34	00.58	00.75	23.80	02.20	01.37	00.16	18.70	100.64
NH wacke	#84-0128	72.06	0.51	11.95	03.80	00.06	01.20	00.47	03.22	02.13	00.30	01.30	097.00
WD wacke	#84-0005	68.70	0.99	14.01	04.44	00.14	01.18	00.57	01.92	03.32	00.37	01.90	097.54
WD nodule	#84-0046	40.80	0.41	8.34	02.43	01.48	00.68	23.50	01.64	01.40	00.17	18.65	099.51
RB rhythmite	#84-0009	66.30	0.82	14.50	06.16	00.15	01.76	00.79	02.59	02.15	00.22	02.45	097.88
MI nodule	#84-0028	37.20	0.86	14.40	14.30	18.90	02.48	01.74	00.33	00.64	00.38	06.70	097.94
MI coticule	#84-0028	45.90	0.88	14.00	13.30	18.80	02.19	01.54	00.14	00.22	00.23	02.90	100.10
MI laminite	#84-0028	53.50	1.12	16.90	11.80	03.15	02.24	00.54	01.59	02.84	00.29	03.20	097.17
CN sandstone	#84-0025	62.90	0.80	14.50	08.19	00.24	01.93	00.09	01.62	02.39	00.17	04.40	097.22
CN slate	#84-0025	67.30	1.14	17.80	04.31	00.11	01.20	00.12	01.34	03.47	<00.11	04.20	101.10
Duplicate	#84-0025	66.77	1.12	17.78	03.98	00.09	01.16	00.09	01.27	03.27	<00.11	04.65	100.29
CN nodule	#84-0391	31.90	0.27	7.36	03.52	00.60	00.74	30.20	00.31	01.33	00.01	22.45	098.67
FZ sandstone	#84-0819	67.57	0.54	12.74	09.57	00.18	01.98	00.47	01.70	01.42	00.01	02.30	098.47
FZ slate	#84-0819	61.80	1.05	19.60	05.15	00.09	01.16	00.17	01.37	04.43	00.03	03.40	098.25
altered FZ sandstone	#84-0819	61.59	0.55	12.85	08.45	00.29	01.76	03.96	01.59	01.59	00.03	04.60	097.26
MI laminite	#84-0698	58.20	1.09	19.01	07.26	04.22	01.25	00.51	01.02	03.73	00.10	02.90	097.29

Table 6: Geochemical Analyses of Trace Elements for Concretions and Host Strata in the Meguma Group (Bondar-Clegg Laboratories)

SAMPLE IDENTIFICATION	SAMPLE LOCATION	V PPM	Cr PPM	Ni PPM	Cu PPM	Zn PPM	Ga PPM	Rb PPM	Sr PPM	Y PPM	Nb PPM	Ba PPM	Au PPM	Pb PPM	Th PPM
NH nodule	#84-0128	024	2	008	004	014	014	045	801	025	<1	367	<5	020	<1
Duplicate	#84-0128			009	004	014								021	
NH wacke	#84-0128	065	077	015	016	033	032	094	236	017	004	508	<5	017	005
WD wacke	#84-0005	094	128	020	012	036	029	143	115	031	009	697	<5	025	015
WD nodule	#84-0046	026	<2	008	005	017	010	049	465	039	<1	278	<5	012	005
RB rhythmite	#84-0009	084	177	024	028	058	023	097	302	038	012	297	<5	017	010
MI nodule	#84-0028	090	273	058	079	124	010	019	057	024	007	485	<5	030	017
MI coticule	#84-0028	082	243	051	017	097	018	007	043	033	005	197	<5	026	013
MI laminite	#84-0028	137	191	104	040	098	023	094	100	041	013	1814	<5	037	008
CN sandstone	#84-0025	104	137	024	047	078	041	095	158	035	005	548	<5	068	010
CN slate	#84-0025	159	179	<2	008	025	036	150	312	027	015	733	<5	007	013
Duplicate	#84-0025	158	180	002	008	027		149	313		016	736	<5	007	012
CN nodule	#84-0391	022	<2	012	018	031	<10	047	147	036	<1	287	<5	043	010
FZ sandstone	#84-0819	051	100	032	037	090	013	069	071	036	008	177	<5	038	015
FZ slate	#84-0819	122	099	011	007	048	054	220	189	037	021	750	<5	018	024
altered FZ sandstone	#84-0819	052	081	031	049	089	014	074	118	032	010	233	<5	017	012
MI laminite	#84-0698	285	173	041	034	048	020	126	115	026	014	1940	<5	014	017