TECTONICS AND BASIN DEFORMATION IN THE CABOT STRAIT AREA AND IMPLICATIONS FOR THE LATE PALEOZOIC DEVELOPMENT OF THE APPALACHIANS IN THE ST. LAWRENCE PROMONTORY

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TECTONICS AND BASIN DEFORMATION IN THE CABOT STRAIT AREA AND IMPLICATIONS FOR THE LATE PALEOZOIC DEVELOPMENT OF THE APPALACHIANS IN THE ST. LAWRENCE PROMONTORY

by

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ABSTRACT

The Cabot Strait lies astride the Cabot Fault system at the eastern extent of the Magdalen Basin, a pull-apart structure which was the depocentre of the regional Maritimes successor basin during the late Devonian to early Permian development of the Canadian Appalachians. Under the Cabot Strait two linear grabens parallel the major fault trends and preserve up to 6 km of Devonian to Carboniferous sedimentary rocks.

In Part I of this study these strata have been mapped using conventional reflection seismic data, with support from potential field and onshore geological data. A series of major dextral strike-slip faults, including the Cape Ray Fault, the Hollow-St. George's Bay Fault, and the Red Island Fault parallel the regional trend, and define a wrench borderland geometry with the Cabot Fault as the master fault. The Cape Ray Fault is shown to have played a role in middle to late Devonian basin formation as well as Carboniferous deformation, while the others were active only in the Carboniferous. Four unconformities yield timing of movement along the faults and allow correlations to be made with regional deformation. Classic wrench-related features such as restraining bends, flower structures and inversion profiles are present in the Cabot Strait-Bay St. George area.

In Part II, the middle Devonian and later modification of the orogen at the St. Lawrence Promontory is examined through a series of crustal profiles, terrane configuration sketches, and paleogeographic reconstructions. Data pertaining to the Salinic and Acadian events are compiled, and evidence is presented for the development of the pre-Horton/Horton basins as extensional collapse features associated with the overthickening of the crust at the collision of two promontories. Overstepping, mainly post-Tournaisian basin development is seen primarily as a consequence of dextral strike-slip. Both of the above

processes were enhanced and overprinted in Newfoundland by tectonic ejection of crustal blocks away from the St. Lawrence Promontory. Localized terrestrial basins such as the Deer Lake Basin are related mainly to this latter process. The reconstructions further reveal that the distribution of pre-existing lower Paleozoic terranes can be explained by an evolving series of dextral strike-slip faults centered on the Cabot Fault system.

Part III consists of a series of paleogeographic reconstructions of lands bordering the North Atlantic, which allow conclusions of the foregoing chapters to be projected on a regional scale. The Silurian-early Devonian tectonic development of the St. Lawrence Promontory is visualized as a process of sinistral terrane accretion, featuring a continuum of terrane sizes, ranging from slivers to microplates. For the mid-Devonian and later, arguments are made for tectonic processes which have been accepted for some time in Europe, but which have not been fully evaluated in the Canadian Appalachians, such as tectonic indentation (wedging), tectonic escape and extensional collapse. The Maritimes Basin is interpreted to have evolved in two phases, the first related to Appalachian crustal overthickening and collapse, and the second related to Variscan foreland strike-slip. This latter transcurrent faulting is attributed to the action of the Iberian indentor and consequent escape of West Avalonia, and not to large scale rotation of the combined Laurentia + Baltica plate.

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List of Abbreviations: Maritimes Basin/St. Lawrence Promontory (Parts I and II)

Stratigraphic Units

AGG	Ackley granite, Gander
AGA	Ackley granite, Avalon
AMG	Andrews Mountain granite
B	top Barachois unconformity
B1,B2	Barachois seismically defined subsequences
BBS	Black Brook (intrusive) Suite
BCRG	Belle Cote Road gneiss
BdN	Bay du Nord Group
BG	Belleoram granite
BIS	Burgeo Intrusive Suite
CB	Clam Bank Group
CBD	Cameron Brook diorite
CBV	Cape Brule volcanics
CBS	Corney Brook Schist
CBG	Cameron Brook granodiorite
CFG	Cape Freels granite
CHG	Chetwynd granite
CHP	Cheticamp pluton
CL	Crabbe's limestone
CLG	Cheticamp Lake gneiss
CRIC	Cape Ray Igneous Complex
CS	Canso Group-Searston Formation
CSJ	Cape St. John volcanics
DBG	Dolland Brook granite
DBP	Deadman's Bay pluton
DRP	Devil's Room pluton
FBV	Fisset Brook volcanics
FG	Francois granite
FIG	Fogo Island granite
GBG	Gulch Brook granite
GBP	Grand Beach porphyry
GLG	Gander Lake granite

GLIS	Gull Lake intrusive suite
GMM	Gillanders Mtn. monzogranite
GMS	Gillanders Mtn. syenogranite
HA	top Horton-Anguille unconformity
HBG	Harbour Breton granite
HHP	Hodge's Hill pluton
HlC	Harbour le Cou Group
HNP	Hawk's Nest porphyry
IAMBG	Isle aux Morts Brook granite
IIIS	Iona Islands Intrusive Suite
IRT	Ingonish River tonalite
JBMS	Jumping Brook Metamorphic Suite
KRDS	Kathy Road dioritic suite
LASG	Lake Ainslie syenogranite
LBG	Locker's Bay granite
LPB	La Poile batholith
LPG	La Poile Group
LWIG	Little Woody Island granite
MBG	Middle Brook granite
MLG	Maccle's Lake granite
MMV	MacMillan Mtn. volcanics
MP	Margaree Pluton
MPgb	Mount Peyton gabbro
MPgr	Mount Peyton granite
MPG	Money Point Group
MRG	Middle Ridge granite
MRMS	Middle River metamorphic suite
NBG	North Bay granite
NPG	Newport granite
NHG	Neil's Harbour gneiss
NWU	Namurian-Westphalian Unconformity
OPG	Otter Pond granite
PBG	Pleasant Bay granite
PHB	Pre-Horton "basement"
PIG	Pass Island granite
PG	Petites granite

PPU	post-Pennsylvanian/post-Early Permian unconformity
PSG	Park Spur granite
RBG	Rose Blanche granite
RHP	Ragged Harbour pluton
RIG	Red Island granite
RIIS	Ragged Islands Intrusive Suite
RIS	Roti intrusive suite
OPG	Otter Pond granite
SBG	Strawberry granite
SBMS	Sarach Brook Metamorphic Suite
SG	Sugarloaf Granite
SLG	St. Lawrence granite
SMA	Steel Mountain Anorthosite
SPG	Salmon Pool granite
TBP	Taylor's Brook Pluton
TG	Topsails granite
TNG	Terra Nova granite
WC	Windsor-Codroy (Groups)
WCP	Wild Cove Pond granite
WHG	Windowglass Hill granite
WNG	West Branch North River Granite
WPG	Windsor Point Group
WSG	Wilkie Sugarloaf granite

Faults, Terrane Boundaries and Structural-tectonic Units

AA	Anguille Anticlinorium
ACSB	Anguille-Cabot Subbasin
AD	Ainslie detachment
AF	Aspy Fault
ANHL	Antigonish Highlands
AT	Aspy terrane
AZ	Avalon Zone
ATZ	Acadian triangle zone
BAT	Burgeo "arc terrane"
BdO	Bras d'Or terrane

BESZ	Bay d'Est shear zone
BIF	Belle Isle Fault
BLF	Birchy Lake Fault
BMSZ	Bay le Moine shear zone
BOI	Bay of Islands (ophiolite complex)
BPB	Big Pond Basin
BRC	Blair River Complex
BS	Barachois Synclinorium
BSG-CS-WNF	Bay St. George/Cabot Strait/Western Newfoundland
BT	Brookville terrane
CAF	Canso Fault
CB	Cumberland Basin
CBF	Clyburn Brook Fault
CBPB	Corner Brook Pond Block
CCFZ	Cinq Cerf fault zone
CF(Z)	Cabot Fault (zone)
CHM	Caledonia Highlands
COHL	Cobequid Highlands
CRF(Z)	Cape Ray Fault (zone)
DLB	Deer Lake Basin
DLLB	Deer Lake "lateral basin"
DSZ	Dashwoods Subzone
dbW	décollement at base Windsor
dbW/H	décollement at base Windsor or within Horton salt
EA	"East Aspy" terrane
EB-MB-GRF	East Bay-MacIntosh Brook- George's River Faults
EHSZ	Eastern Highlands Shear Zone
EWL	east-west lineament
FBA	Flat Bay Anticline (basement block)
GBC	Grand Bay Complex
GBF	Green Bay Fault
GBT	Grand Bay thrust
GHF/GHTF	Gunflap Hills Fault/tear fault
GSL/MB	Gulf of St. Lawrence/Magdalen Basin
HAF	Hampden Fault
HF	Hollow Fault

HLB	Howley "lateral basin"
IHC	Indian Head Complex
IMFZ	Isle aux Morts fault zone
KF	Kennebecasis Fault
KT	Kingston terrane
LBF	Lubec-Belle Isle Fault
LPT	La Poile "arc terrane"
LRI	Long Range Inlier
LRT	Long Range Thrust
MC	Mascarene Complex
MGF	Minas Geofracture
MGSB	Merigomish subbasin
MSB	Moncton Subbasin
MSZ	Margaree Shear Zone
MT	Mira terrane
NDSZ	Notre Dame Subzone
NWNB	northwestern New Brunswick
OTB	Orthotectonic block, Baie Verte Peninsula
PBC	Port aux Basques Complex
PPA	Port au Port allochthon
PTB	Paratectonic block, Baie Verte Peninsula
RHF	Ryan's Hill Fault
RIL	Red Indian Line
RRF	Red River Fault
SAB	"Sop's Arm block"
SAC	St. Anthony Complex
SAWB	St. Anthony-White Bay Basin
SB	Sydney Basin
SBF	Snake's Bight Fault
SCT	St. Croix terrane
SDS	St. David's Syncline
SGBF	St. George's Bay Fault
SLP	St. Lawrence Promontory
SSB	Sackville Subbasin
STSB	Stellarton Subbasin
TBF	Taylor's Brook Fault

TFZ	Tobeatic Fault Zone
TMLT	Ten Mile Lake thrust
THWR	"transverse hanging-wall ramp"
WA	"West Aspy" terrane
WBF	Wilkie Brook Fault

Additional Abbreviations: North Atlantic Maps (Part III)

ACT	Avalon Composite terrane
BAT	Burgeo Avalonian terrane
bt	blind thrust (Stockmal et al. (1990))
BT	Brookville terrane
c	extensional collapse (with normal fault)
(C)	reconstruction of Coward (1990; 1993)
CA	Collector Anomaly
CB	Cascumpec Basin
CAF	Caledonia Fault
CMB	Central Mobile Belt/Block
CT	Caledonia Terrane
DZ	Dunnage Zone
EA	"East Aspy" terrane
ESZ	Exploits Subzone
FF	Fredericton Fault
GFZ	Gibraltar Fault Zone
GGF	Great Glen Fault
GH	Grampian Highlands
GZ	Gander Zone
HB	unnamed Horton basin (Gulf of St. Lawrence)
HBF	Highland Boundary Fault
HNB	Hornelen Basin
HBF	Highland Boundary Fault
HZ	Humber Zone
KT	Kingston terrane (Complex)
(L)	compilation of Leeder (1982)

(LG)	compilation of Leggett et al. (1983)
L-BIF	Lubec-Belle Isle Fault
LC	Lewisian Complex
LPT	La Poile "terrane"
MB	Magdalen Basin
MC	Mascarene Complex
MGF	Minas Geofracture
MMT	Miramichi terrane
MSB	Moncton Subbasin
MT	Moines "terrane"
MV	Midland Valley
MVB	Midland Valley Basin
MVF	Midland Valley Fault
NF	Norumbega Fault
NPB	North Point Basin
ORB	Orcadian Basin
(S)	compilation of Soper et al. (1992); Soper and Hutton (1984)
SCT	St. Croix terrane
SL	Solway Line
SLP	St. Lawrence Promontory
SU	Southern Uplands
WA	"West Aspy" terrane
(Z)	compilation of Ziegler (1989)

Miscellaneous Abbreviations

mv	metavolcanics
vv	volcanics
bt	biotite (closure age)
hb	hornblende "
mu	muscovite "
amp	amphibolite facies
gs	greenschist facies
A	amalgamation time
IG	ignimbrites
M	mylonitization

SZ	Subzone

CHAPTER I: GENERAL INTRODUCTION

I.1 Purpose and Scope

The Cabot Strait, situated in the eastern Gulf of St. Lawrence, is 100 km wide and separates southwestern Newfoundland from Cape Breton Island (Figure I.1). The Cabot Strait is located at or near the southeastern corner of the St. Lawrence Promontory, a term referring to the irregular pre-Appalachian Laurentian continental margin, which is approximated today as the Humber tectonostratigraphic zone (Figure 1; Williams et al., 1988, Lin et al., 1994).

Recently, considerable interest has been shown in these areas and offshore western Newfoundland in general, both for their resource potential, and for their position at the forefront of several geological debates (*e.g.*, Cawood and Williams, 1988; Stockmal and Waldron, 1990; 1993). New tectonic interpretations have coincided with and stimulated a renewed search for petroleum in the Port au Port Peninsula area. Structural, petrologic/geochronologic, and deep seismic reflection studies in south-central and southwestern Newfoundland (Dunning et al., 1990a; Dubé et al., 1994), and similar studies in Cape Breton Island (Barr and Raeside, 1989; Dunning et al., 1990b); Lynch and Tremblay, 1994), have led to a discussion on the correlation of tectonostratigraphic zones between the two areas. Such issues have placed a focus squarely on the Cabot Strait as an area where further understanding is needed.

The Cabot Strait is underlain by part of the Maritimes Basin, and is situated at the boundary between two constituent subbasins, the Magdalen Basin to the west and the Sydney Basin to the east. The Maritimes Basin is considered to be a successor basin to the mountain building events of the Appalachians in eastern Canada, and appears to be spatially related to the St. Lawrence Promontory (Figure I.1). It has been the subject of several investigations, resulting in almost as many hypotheses to account for its origin. Arguments have been made principally in favour of rifting (Belt, 1968a), pull-apart (Bradley, 1983) and passive subsidence (McCutcheon and Robinson, 1987) interpretations. However, a completely satisfactory explanation of its origin has yet to be proposed as a number of issues appear to be unresolved. Foremost among these is the relative longevity of subsidence, from the middle Devonian (although these sediments are now mostly deeply buried and not directly observable) to the Lower Permian, representing some 110 million years. Subsidence rates during this time appear to have been episodic, suggesting a succession of tectonic processes over the basin's history.

This thesis proposes a hybrid origin for the basin, with middle-to-late Devonian extension overprinted by transtension in the Carboniferous.

Extensional basins have been broadly associated with oroclines in active mountain belts (*e.g.*, Pannonian Basin, Betic Cordillera, Altiplano: Dewey, 1988). For this reason a causal relationship between the Maritimes Basin and the St. Lawrence Promontory orocline merits consideration. The general question of orocline-basin relationships is potentially complicated by strike-slip modification of the orocline in the final stages of continent-continent collision. Lessons learned from the Maritimes Basin may therefore have global tectonic relevance.

Fortunately, nature has provided a passage where marine geophysical data could be collected along and across the strike of the orogen in the St. Lawrence Promontory. The acquisition of "industry-standard" reflection seismic data in the Cabot Strait by Petro-Canada in the early 1980's has presented a unique opportunity for the three-dimensional study of both the formational and deformational aspects of an entire Carboniferous section along one of the major fault trends. Most other Carboniferous sections in Atlantic Canada are partly eroded (New Brunswick), incompletely understood because of the lack of exposure of key unconformities (onshore Bay St. George), highly eroded because of late transpressive movement and exhumation of basement rocks (Cape Breton Highlands), buried too deeply for the whole section to be studied by conventional well-seismic ties (central Gulf of St. Lawrence), or cut by numerous salt diapirs (Magdalen Islands and eastern Magdalen Basin). The Cabot Strait, then, represents a rare situation where the progressive effects of ancient strike-slip tectonics on the sedimentary basin fill can be monitored.

Part I of this study describes the main structural features associated with the development of the Maritimes Basin along the major strike-slip Cabot Fault system, and attempts to tie the history of some onshore faults, such as the Cabot and Cape Ray Faults, to the development of the Devono-Carboniferous successor basins offshore. It also relates unconformities within the basin fill to strike-slip deformation along the major faults. A kinematic interpretation is then presented which describes the late deformation of the area in terms of both wrench borderland and stepover models.

Part II of this study arose out of the necessity to explain the kinematics and spatial implications arising from the mapping of the major strike-slip zone of Part I. In short, if the Cabot Fault system and associated faults were the focus of an intermittent but protracted period of strike-slip tectonics, then large geographical areas juxtaposed across the Cabot Fault system today must have originally been situated in very different positions along the strike of the fault system, a fact that has been largely ignored in discussions of the pre-Carboniferous history of the northeastern Appalachian mountain belt. It is the purpose of Part II to document the evolution of the fault zone, the history of displacement along it, and the progressive positions of large masses of the earth's crust on either side of it. The record of deformation of the Carboniferous sedimentary rocks in and adjacent to the Cabot Strait thus takes on additional significance in an interpretation of the late stage brittle strain experienced in "basement" rocks (to the Maritimes successor basin) at the St. Lawrence Promontory.

Part III of this thesis will bring processes from even further afield into the interpretation. Six reconstructions of the North Atlantic region, illustrating the effects of Silurian-Devonian terrane accretion and continent-continent collision, and subsequent Carboniferous transcurrent modification, will be presented. These time-slices illustrate the controls that the ongoing assembly of the Pangaean supercontinent had on the Maritimes Basin and St. Lawrence Promontory area, and allow a test of the assumption that the long history of basin evolution was a response to plate boundary forces, as well as localized body forces.

I.2 Previous terrane and zonal correlations between Newfoundland and Cape Breton Island

The island of Newfoundland has been divided into a series of tectonostratigraphic zones and subzones (Figure I.1) which were accreted to the Laurentian continent during lower to mid-Paleozoic orogenesis (Williams et al., 1988). These are, from west to east, the Humber Zone, the Notre Dame and Exploits Subzones of the Dunnage Zone, the Gander Zone, the Avalon Zone, and perhaps several small terranes of Avalonian affinity in southern Newfoundland (Barr et al., 1994; Dunning et al., 1990a; O'Brien et al., 1991).

The Humber Zone, which lies mainly to the west of the Cabot Fault, represents the ancient continental margin of eastern North America or Laurentia (Williams, 1979). It contains two tectonic assemblages in western Newfoundland: an allochthonous upper assemblage (*e.g.*, Stevens, 1970; Williams and Stevens, 1974), which includes both oceanic and continental slope rocks structurally superposed on the continental shelf rocks during the Ordovician Taconian orogeny, and a lower assemblage, which comprises a Cambro-Ordovician clastic to carbonate shelf succession resting unconformably on Precambrian basement rocks. This lower assemblage was formerly considered to be autochthonous and parauthochthonous, but recently has been reinterpreted by Cawood and Williams (1988), Stockmal and Waldron (1990) and Waldron and Stockmal (1991) to be allochthonous as a result of Acadian deformation. Part of the deformation and metamorphism may also have occurred in the Silurian Salinic Orogeny, which is now believed to have been widespread in Newfoundland (Dunning et al., 1990a; O'Brien et al., 1991; Cawood et al., 1994a, b). These interpretations imply that much, if not all, of the Humber Zone in western Newfoundland, and, in particular, the lower Paleozoic platformal rocks which probably form the substrate to the Carboniferous in the present study area, are allochthonous.

Similarly, Cape Breton Island has been divided into four tectonostratigraphic terranes on the basis of its pre-Carboniferous geology (Figures I.1; II.5). The Blair River

Complex contains rocks which are compositionally and geochronologically similar to Grenville basement rocks in western Newfoundland (Barr et al., 1987; 1992b; Barr and Raeside, 1989; Loncarevic et al., 1989). The Blair River Complex is considered the only correlative of the Humber Zone in Cape Breton Island, in fact in all of Nova Scotia. The Aspy Terrane contains Lower Paleozoic metamorphic rocks with sedimentary protoliths extensively intruded by middle Paleozoic granites and is correlated with the Gander Zone of Newfoundland (Dunning et al., 1988; O'Brien et al., 1991; Dunning et al., 1990a). The Bras d'Or terrane contains Late Proterozoic metasediments and Ordovician plutons, and is correlated with similar rocks of Avalonian affinity in the Hermitage Flexure of southern Newfoundland (Dunning and O'Brien, 1989; part or all of the "Bay du Nord subzone" of Currie and Piasecki, 1989). The Mira terrane contains a Late Precambrian volcaniclastic sequence intruded by mainly Late Precambrian granitoids, unconformably overlain by Late Precambrian to Cambrian sedimentary rocks, and is correlated with the type Avalon terrane on the Avalon Peninsula of Newfoundland.

In the Late Paleozoic the Cabot Fault in part reactivated and overprinted the Baie Verte Line, the inferred suture between the Laurentian continental margin (Humber Zone) and outboard terranes (Dunnage, Gander and Avalon Zones; Williams et al., 1988). In southwestern Newfoundland, the Cabot Fault lies west of a narrow belt of ophiolitic rocks within the Dashwoods Subzone (Piasecki et al., 1990) which may separate the Humber from the Dunnage Zone. In northern Cape Breton Island the Notre Dame Subzone of the Dunnage Zone appears to be entirely absent, and the Blair River Complex (Humber equivalent) is juxtaposed against the Aspy Terrane (equivalent to Exploits Subzone/Gander Zone) across the Wilkie Brook Fault (Barr and Raeside, 1989). This pattern of southwestward narrowing and possible pinching out of tectonstratigraphic zones implies that the boundaries between the outboard zones - *i.e.*, Notre Dame/Exploits boundary (the Cape Ray Fault - Red Indian Line), and possibly the Exploits/Gander boundary, join or are cut by the Cabot Fault under the Cabot Strait (Figure I.1).

I.3 Overview of the Maritimes Basin

I.3.1 General Description

Middle Devonian to Carboniferous rocks are widespread in Atlantic Canada and constitute the Maritimes Basin (Figure I.1; Roliff, 1962; Sheridan and Drake, 1968; Williams, 1974; Knight, 1983; McCutcheon and Robinson, 1987). The basin covers some 150,000 km^2, and extends from New Brunswick to Newfoundland, and from Nova Scotia to southeastern Québec. Strata are thickest in the 25,000 km^2 Magdalen Basin (Bradley, 1982; Howie and Barss, 1975) under the Gulf of St Lawrence, where at least 8 km of sediment accumulated between late Devonian and early Permian time. Bradley (1982) proposed that this depocentre developed as a pull-apart basin ("rhombochasm") between strike-slip faults in Newfoundland and New Brunswick. Specifically, he proposed that this occurred by dextral movement along a regional northeast-trending and right-stepping fault system (Cabot Fault - Belle Isle system). The right-stepping offset in this fault system is associated with the St. Lawrence Promontory (Williams, 1979; Stockmal et al., 1990; Lin et al., 1994).

In general, the lithostratigraphy of the Maritimes Basin can be subdivided into three gross intervals (Figure I.2, I.3; Belt, 1968a; Williams, 1974; Howie and Barss, 1975). Firstly, during Late Devonian through Tournaisian times, alluvial and fluvial clastics (Horton Group) were deposited in fault-bounded, rapidly-subsiding intermontane basins; secondly, during Viséan time, a marine transgression resulted in the deposition of carbonates, evaporites and fine-grained clastics (Windsor Group); thirdly, between Namurian and early Permian times, the basin as a whole was gradually filled by thick clastic successions prograding out from fault-controlled source terranes along the basin margins (Canso-Riversdale-Pictou Groups).

More recently, Ryan et al. (1987) and Ryan and Zentilli (1993) have subdivided the Late Devonian and Carboniferous stratigraphy into a series of three allocycles (also known as megacycles), each of which records a deceleration of the subsidence rate, from an initial rapid subsidence recorded by fanglomerate-lacustrine sequences, to fluvial-lacustrine and/or marine basin fill. These authors believed that such cycles represented a shift from local rapid subsidence associated with transtension along faults associated with the regional strike-slip system, to a broader, regional subsidence associated with flexure, itself induced by late stage terrane convergence. Although these allocycles were first clearly identified in the rocks of the Cumberland Basin (Figure I.1), Ryan and Zentilli (1993) suggested that they could be applied in correlating the stratigraphy across the Maritimes Basin, because they synthesize the relationship between regional and local tectonic activity.

Allocycle 1 was deposited between 365 and 325 Ma and includes rocks of the Fountain Lake to the Mabou (Canso) Group (Figure I.3). Allocycle 2 consists entirely of the lower part of the Cumberland Group (325-310 Ma), and allocycle 3 includes the upper part of the Cumberland Group and the Pictou Group, representing a span of 310 to 280 Ma. Ryan and Zentilli (1993) consider the Cumberland Group to extend down into the late Namurian, following the revisions proposed by Ryan et al. (1991). Although the validity of projecting this breakdown across the central part of the basin awaits the verdict of further research, using seismic and well control in these offshore areas, the present seismic-stratigraphic results from the Cabot Strait suggest that as one approaches the major basin controlling fault system, the Cabot Fault, the situation becomes very much more complex and regional generalizations are not as useful.

Bradley's (1982) model suggests that the subsidence of the Magdalen Basin occurred in two distinct phases: an early "rift" phase, which spanned late Devonian through Viséan time, and a thermal subsidence phase which began in the Namurian and continued into the early Permian. During the rift phase, sedimentation was restricted to fault-bounded, isolated depocentres located along the regional fault zones. During the subsidence phase, the pre-Carboniferous basement was onlapped by clastics to produce a classic "steer's head" basin profile.

The present topographic configuration of the Maritime Provinces and western Newfoundland is largely controlled by the regional fault system. Since late Paleozoic time, 1 to 3 km of Carboniferous sediment were removed from the Maritimes Basin (Ryan and Zentilli, 1993). Exposures of Carboniferous rocks now straddle and outline the traces of these old faults, often in the form of small, individual, linear, inverted, or partially inverted basins (Figures I.1 and I.3), such as the Moncton Subbasin (Webb, 1963; Nickerson, 1994), Cumberland Basin (Ryan et al., 1987, 1991; Fralick and Schenk, 1981), Stellarton graben (Martel, 1987; Yeo and Ruixiang, 1987), Bay St. George Subbasin (Belt, 1969; Knight, 1983) and Deer Lake Basin (Hyde, 1984; Hyde et al., 1988). Durling and Marillier (1993b) have mapped what they interpret to be equivalent, deeply buried Horton rift basins under the central Gulf of St. Lawrence. Other adjacent basins outside the main overstepping fault configuration, such as the Sydney

Basin (Gibling et al., 1987), also contain a thick Carboniferous succession.

I.3.2 Geology of the Onshore Carboniferous in the Cabot Strait Region

The stratigraphy of onshore subbasins in the vicinity of the Cabot Strait is summarized and illustrated in the chrono-stratigraphic chart of Figure I.3. Carboniferous rocks are preserved on both sides of the Strait but only the Bay St. George Subbasin has remained largely intact through late Paleozoic deformation. A detailed account of the stratigraphy within this subbasin is given by Belt (1969) and Knight (1983; Figure I.2). In northernmost Cape Breton Island, late Devonian to early Carboniferous rocks lay on both sides of the Aspy and Wilkie Brook Faults (Hamblin and Rust, 1989). Further south in the Aspy Terrane, extensive faulting occurs within both sediments and basement. In general, the presence of metamorphic rocks with both Humber and Gander Zone affinities along the Aspy Fault suggests that the basement has been significantly exhumed by late fault movements, leaving patches of remnant Carboniferous cover.

The better-preserved stratigraphic record (Figure I.2) of the southwestern Newfoundland Carboniferous, its position along strike from the Cabot Strait, and its relatively thorough documentation make it more useful than its Cape Breton Island counterpart as a guide in the interpretation of the offshore seismic data. The following is largely based on the more recent work of Knight (1983) in the onshore Bay St. George Subbasin.

I.3.2.1 Stratigraphy: southwestern Newfoundland

I.3.2.1.1 Anguille Group

The lowermost rocks in the Bay St. George Subbasin belong to the Anguille Group (Hayes and Johnson, 1938; Bell, 1948; Riley, 1962; Baird and Cote, 1964). This group is subdivided into the Kennel's Brook, Snake's Bight, Friar's Cove and Spout Falls Formations (Knight, 1983), which record development and progressive infill of a linear, fault-bounded lacustrine trough from Late Devonian through Tournaisian time. The Anguille Group is characterized by rapid changes of facies, controlled by proximity to major fault zones. The outline of this lacustrine basin measures approximately 30 by 100 kilometres, with its shape being largely controlled by northeast-trending faults. East-west splays from these main faults may control large variations in thickness, such as occur across the Shoal Point Fault at the northern edge of the Anguille Mountains. This thickness variation is manifested by the absence of the lower part of the Anguille Group just to the north in the Flat Bay Anticline (Figure I.4). The Friar's Cove and Spout Falls Formations contain detritus from western highlands, including rocks of the Cambro-Ordovician carbonate platform, and record a northeastern displacement of this source terrain. Knight (1983) considered this to be evidence for dextral strike-slip of this westerly provenance. Thicknesses in the Anguille Group range from 2000 to 4900+ metres, as measured from stratigraphic sections onshore (Knight, 1983).

I.3.2.1.2 Codroy Group

The overlying Codroy Group (Hayes and Johnson, 1938; Bell, 1948; Riley, 1962; Baird and Cote, 1964) is equivalent to the Windsor Group of Nova Scotia and New Brunswick, and records widespread marine transgression in the early Viséan, which resulted in the deposition of about 250 metres of marine-influenced strata (Ship Cove and Codroy Road Formations, Figure I.2). These rocks range from limestone-dominated sections, to limestones interbedded and coeval with evaporites and marine siliciclastics, over the lower half of the group. The marine facies were gradually overstepped by about 5500 metres of non-marine redbeds (Robinson's River and Woody Cape Formations) along the shallow margins of the Windsor Sea, as sediment supply outpaced subsidence. Short-lived marine incursions continued to influence depositional conditions throughout the period of upper Codroy deposition, suggesting that the depositional surface was never far above sea level.

I.3.2.1.3 Barachois Group

Rocks of the Barachois Group (Hayes and Johnson, 1938; Bell, 1948; Riley, 1962; Baird and Cote, 1964; Knight, 1983) occur in two outcrop areas and represent two distinct periods of deposition. In the south, the early Namurian Searston Formation (~2500 metres) is equivalent to Canso strata of the mainland, whereas deposits in the St. George's Bay lowlands in the north (1500-1600 metres) are probably of Westphalian age, although the age of neither the top nor base is well constrained.

Fluviatile rocks of the Barachois Group were laid down in low energy, swampy, floodplain conditions, and record both a lowering of the depositional slope, and a progressive change to a humid climate.

I.3.2.2. Structural geology: southwestern Newfoundland

Several types and orientations of structures have been mapped both within and bounding the Carboniferous succession in western Newfoundland, principally by Belt (1968a, b) and Knight (1983). These include high-angle faults, thrust faults/décollement zones, northeast-trending folds, and northwest-trending folds (Figure I.4).

Three principal orientations of high angle faults (dips of 60-90°) are present in the Bay St. George subbasin: northeasterly, northwesterly and easterly. The northeasterly-trending faults are of principal importance, and include the Cabot (Long Range Fault of Belt, 1969; Webb, 1969; Knight, 1983), Snake's Bight, and Crabbe's Brook Faults (Figure I.4). *En echelon* fold trends associated with several of these faults suggest right-lateral movement. The Cabot Fault is the most prominent of this family of faults, and although poorly exposed, is confirmed on land by a strong aeromagnetic signature and an exposed shear zone up to 180 metres wide in the north, and by a 800- to 1000 metre-wide zone of basement rock cataclasis in the south. Field observations (Knight, 1983) point to a complex history of movement, with oblique-slip occurring most recently. In the southern part of the subbasin the fault generally dips southeastward at high angles, but locally is vertical or dips at high angles into the basin. Sediments within the basin adjacent to the fault generally dip steeply away from it, or are deformed in an adjacent overturned syncline.

The Snake's Bight Fault lies close to the axial plane of the Anguille Anticlinorium; it parallels the Cabot Fault in the southwest but swings eastward and bears 025 at its northeast extent. Knight (1983) thought that this fault recorded downthrow to the southeast followed by about 10 kilometres of strike-slip, or an equivalent amount of oblique-slip. Similarly, the Crabbe's Brook and Ryan's Hill Faults trend subparallel to the Cabot Fault, and show downthrow to the southeast of several thousand metres, evidence of significant right-lateral movement, and compression in an associated array of *en echelon* faults (Figure I.4).

Thrust faults and décollement zones are developed locally in the Snake's Bight and Codroy Road Formations. In the Snake's Bight Formation the faults are northwest-directed, and form mostly where there is a competency contrast, *e.g.*, at the base of the Snake's Bight lacustrine shales. Another important detachment is visible in the northern Anguille Mountains, where evaporites and fine clastics at the base of the Codroy Road Formation overlie limestones of the Ship Cove Formation.

Northeast-trending folds (with axes trending 027-068) include the Anguille Anticlinorium (with the Snake's Bight Fault lying close to its axial plane), the Flat Bay Anticline, where harmonic folding of both the Anguille and Codroy Group strata occurs around a core of Grenville basement, and the Barachois synclinorium, a broader, more open feature than the others.

Northwest-trending folds include the St. David's syncline, which trends northwest, at right angles to the trends of the other regional structures.

PART I: CABOT STRAIT GEOLOGICAL AND GEOPHYSICAL INVESTIGATION

CHAPTER II: GEOPHYSICAL DATA BASE

II.1 Data Set for the Cabot Strait Offshore Area

II.1.1 Seismic Data

Approximately 1625 km of marine seismic data collected in the Cabot Strait by Petro-Canada (11xx and 40xx series) in the early 1980's, and 1300 km acquired by Mobil (MAQ and MBM series) and Golden Eagle (GE series) in Bay St. George in the 1970's, constitute the main seismic data set (Figure II.1). Other marine seismic data used in this study were drawn from various older datasets acquired in the Gulf of St. Lawrence between 1970 and 1973. These include lines AAJ031 (acquired by Amoco, 1971), FAB026 (acquired by Gulf, 1973), QAA009 (acquired by SOQUIP, 1971), and TAJ009, -010, -011 and TAN001 (acquired by Texaco, 1970). The quality of these data sets varies considerably, mainly because of variability in seabed geology (whether or not a "hard water bottom" is present). Nevertheless, this body of seismic data constitutes an important addition to the overall Carboniferous data set. Various aspects of these data are summarized in Table 1. In general, a major break in data quality occurs at the Cape Ray Fault: lines and portions of lines lying to the east in the Sydney Basin are invariably plagued by a severe multiple problem, and because the sedimentary strata are characterized by low dips, reflections over broad areas are indistinguishable from the trains of multiples, rendering the data all but unusable. To the west of the Cape Ray Fault, the common occurrence of less consolidated, Upper Carboniferous rocks at the sea floor results generally in less ringing in the water column. When coupled with the higher degree of structural differentiation in this area, the result is a much more usable dataset.

In the mid-1980's two long (20 sec) record profiles (86-4 and 86-5) were acquired in the Cabot Strait as part of the LITHOPROBE EAST marine program (Marillier et al., 1989). Because these were processed for deep objectives, they were not useful in interpreting the basin fill. Along with LITHOPROBE line 86-2 from west of Prince Edward Island (Marillier et al., 1989), these data were utilized in Part II of this study in the reconstructions and discussion of the pre-Carboniferous geology.

II.1.2 Potential Field Data

Gravimetric and aeromagnetic data were obtained from Open File 1504 of GSC Atlantic, Dartmouth, Nova Scotia (Geological Survey of Canada, 1990a and 1990b), and were gridded using the GEOSOFT mapping package at the Centre for Earth Resources Research, Memorial University, by W. Nickerson.

A gravity anomaly map (Bouguer on land, free air at sea) and a magnetic total field anomaly map were produced, both employing a grid spacing of 1 kilometre, and a Transverse Mercator projection. These maps are displayed in Figures II.2 and II.3.

Both the gravity and magnetic data have been used here as a supplementary dataset to the reflection seismic, and have proven useful in delineating certain trends and features of the basin fill. In particular, the gravimetric data were very useful in mapping areas of salt diapirism in the western Cabot Strait and Bay St. George areas. The magnetic data were more useful in mapping the trends of basement features in the eastern Cabot Strait/western Sydney Basin area, where the basin cover is thin. These data, then, were employed in basement terrane correlation and are displayed again in this respect in Chapter VI.

II.1.3 Well Data

One exploration well, St. Paul Island P-91, was drilled in 1983 in the Cabot Strait to a depth of 2883 m. It was abandoned without testing (Figure II.1). Other wells drilled further west and southwest during the 1980's in the Gulf of St. Lawrence have tested non-commercial quantities of gas.

In the present study, the synthetic seismogram from the St. Paul Island well was used to tie the borehole stratigraphy to the seismic line on which it was sited, Line 4093. The stratigraphy of the well was dominated by terrestrial, fine-grained siliciclastics from which no paleontological dates were obtained. However, a breakdown of the stratigraphy into a pre- and post-Windsor sequence was made possible by the presence of an 85 m thick salt layer which apparently represents the entire thickness of the Windsor Group in this well.

Analysis of Stratigraphic High Resolution Dipmeter Tool (SHDT) data enabled the identification of several possible thrust faults in the well, based on the interpretation of classic "red" (steepening upward) or "blue" (steepening downward) tadpole patterns (Schlumberger, 1985). One of these corresponds to the salt layer in the well and suggests that structurally-thinned Windsor sediments are related to thrust faulting, which corroborates the interpretations made from the seismic data. The post-Windsor section shows several faults which were an integral part of the interpretation of out-of-basin thrusting at the St. Paul restraining bend, as discussed in the following sections.

II.2 Description of Seismically-Defined Carboniferous Basin Fill

II.2.1 Cabot Strait

Four unconformities are recognized on seismic profiles and are assumed to be equivalent to similar features seen in the onshore stratigraphy (Figure I.3): the top Horton-Anguille (HA), Namurian-Westphalian (NWU), top Barachois (B) and post-Pennsylvanian (PPU) unconformities. The tectonic implications of these are discussed later; here they provide a framework for a description of the data and a subdivision for the seismically-defined sedimentary section. A summary of seismic reflection character as the basis for the subdivision into sequences is provided in Figure II.4.

The thickest accumulation of sediment under the Cabot Strait occurs in the Cape Ray and Searston Grabens, named herein and bounded by the Hollow-St. George's Bay, Cabot and Cape Ray Fault systems (Figures II.5, II.6, II.7 and II.8). Thick, typical sections of Maritimes Basin stratigraphy (Figures I.2 and I.3) are present in these troughs, with minor gaps related to local fault movements.

In the Cape Ray Graben, the shallow NWU dips westward into the Cabot Fault Zone, whereas younger reflectors such as the "B" in almost all cases continue straight across it (Figures II.9 and II.10: Lines 1105, 1107, 1109). Thus a wedge of sediment up to 0.75 sec (two-way time) thick is preserved at this location. This wedge is of remarkably consistent shape except for further south in the graben, where it is disrupted by complex late faulting. This "Barachois wedge" has a continuous, high frequency internal seismic character which distinguishes it from the virtually transparent section beneath the NWU. This difference may result from the usually highly reflective nature of the NWU itself, or from complex deformation patterns, such as high angle faults and fold axes, beneath the NWU that are not well-imaged by the seismic method.

The seismic data do not allow a clear interpretation of the deepest basin fill. Soling listric-shaped reflectors on lines 1103, 1111, and 1113, etc.

(Figure II.10), part of the Cape Ray fault trend, may represent the sediment-basement interface. On Cape Breton Island rocks of the Horton Group overlie Aspy terrane basement in a narrow graben immediately east of the Aspy fault (Belt, 1969; Webb, 1969; Hamblin and Rust, 1989). The onshore geology east of the Cabot Fault in southwestern Newfoundland consists mainly of Ordovician magmatic arc rocks of the Cape Ray Complex (van Staal et al., 1992). It is likely, therefore, that Horton-Anguille sediments overlie metamorphosed basic rocks on the floor of the Cape Ray graben. The absence of salt structures on the east side of the Cabot Fault suggests that the lower part of the Windsor-Codroy Group may be missing in this area.

The Searston Graben is characterized on seismic data by continuous, medium to high frequency parallel reflections that are consistently mappable from line to line. This is particularly true for the section underneath the NWU (Figure II.4), (with a few exceptions, *e.g.*, Line 1119, where reflectors are less clearly defined), and implies a period of continuous subsidence and deposition, at least in the axis of the graben, until mid-Carboniferous times. The strata within the graben display a synclinal aspect which on some lines (*e.g.*, Figure II.10: Lines 1105, 1115, 1119) is disrupted by faults and more complex fold patterns, especially in the northern half of the Searston Graben, near St. Paul Island. The Horton Group is recognisable at the bottom of the graben as a band of higher amplitude, lower frequency and less continuous reflectors (Figure II.4), above which salt flowage is often visible (*e.g.*, Lines 1105, 1111, 4075). This reflection character is similar to that seen from profiles in the Moncton Basin (Nickerson, 1994). The post-NWU section is thin and lies close to the present sea bottom, but is generally not well-imaged. Based on velocity estimates from the St. Paul and North Sydney wells (the latter in the Sydney basin) the maximum thickness of sediment in the Searston Graben is 5 to 6 km.

The HA unconformity at the top of the Horton-Anguille is localized along the Cabot Fault zone. On several seismic lines over the St. Paul block, the Windsor salt reflector is seen to onlap the top Horton reflector, which dips steeply westward away from the Cabot Fault zone (*e.g.*, Figure II.10: Lines 1111, 1113 and 1115). The presence of salt structures throughout the Searston Graben suggest that a thick Windsor-Codroy sequence is present.

II.2.2 Inner Bay St. George

The Carboniferous sedimentary succession in Bay St. George is interpreted to be Viséan to Westphalian in age, comprising rocks of the Codroy and Barachois Groups (Figure II.10b: Lines MAQ017, MAQ012). This is consistent with seabed mapping of strata equivalent to the Canso/Riversdale and Windsor Groups by Sanford and Grant (1990), and with results of potential field studies of Kilfoil (1988) and Miller et al. (1990). The half-graben along the eastern side of the bay was the locus of subsidence and accommodation of this infill. The existence of significant thicknesses of these rocks onshore implies that these sediments should be present in comparable thicknesses offshore. Knight (1983; his Figure 33) shows isopachs of 1000+ metres onshore in the St. George's Bay Lowlands for the lower part of the Robinson's River Formation (Codroy Group). The profusion of halokinetic structures indicates that the lower, evaporite-bearing formations of the Codroy Group attain thicknesses approaching those present in the Magdalen Basin, where salt rises from considerable depths to form shallow structures, some of which (*e.g.*, Magdalen Islands) have reached the present day sea floor. Several of these diapirs in the shallow subsurface (Line 81-1117; Figure II.10) are potentially of interest as petroleum prospects and have recently been the subject of seismic migration studies (Lines et al., 1995).

II.2.3 Outer Bay St. George/Eastern Magdalen Basin

In the outer Bay St. George, seismic lines TAJ009 and TAJ010 image the geometry of the St. George's Bay fault system (Figure II.10b). The lineament originally termed the Mid-Bay Fault in Langdon and Hall (1994) is now recognized as the hangingwall cutoff (Figure II.5) of a westerly-dipping displacement zone which passes beyond the seismic penetration at about 4 secs (*e.g.*, at SP 760 on Line TAJ009). This fault is here named the St. George's Bay Fault, and reaches the top of the Carboniferous section 10 km to the southeast at SP

680. At this position it is recognized as the southerly continuation of the major normal (transtensional) fault which bounds the eastern coast of Bay St. George.

A group of faults imaged at the eastern end of line TAJ010 appear to be continuous with the Hollow fault system seen in the Cabot Strait (Figure II.10a: Line 1103) and can be correlated southward to a group of similar faults (Hollow-Snake's Bight fault zone) on line TAJ009, south of the EW5 shear zone which transects the Anguille Mountain block (Figure II.5).

The northeastern edge of the Magdalen Basin depocentre can be identified on seismic data and approximately coincides with the boundary between the carbonate platform and Carboniferous section just south of the Port au Port Peninsula in Figure II.5. A series of older seismic lines in the western Cabot Strait and outer Bay St. George area are laden with sea bottom multiples, but are useful in delineating the extent of the very thick Carboniferous section in the Magdalen Basin. In the offshore Port au Port area, the unconformity separating Carboniferous rocks from Cambro-Ordovician carbonate platform rocks (and possible overlying Silurian foreland basin rocks) plunges south to southeastward under the Bay St. George (Figure II.10b). Farther southwest a continuous, high amplitude reflector is identified at 1.2 secs TWT at the northern end of line QAA009, and continues southward to its last recognizable position at 4.3 secs, SP 240 (Figure II.10c). Carboniferous rocks are identifiable above this bright reflector as reflective strata, within which there are suggestions of a series of broad open folds, with wavelengths of greater than 10 km. The southward truncation of this package of reflectors at SP 240 suggests the presence of a major lateral discontinuity at this point. South of here, any sign of a substrate to the Carboniferous disappears beneath a thick Carboniferous fill characterized by medium to high frequency reflection character, interrupted laterally and disrupted by character typical of intrusive salt bodies.

This position also has a strong expression on the gravity data (Figures II.2 and II.3). On Figure II.2, a small negative gravity anomaly of >-2 mGal is sharply truncated in an east-west direction along its southern edge. This is one of the strongest linear expressions in the area, and on Figure II.5 it is interpreted as an east-trending fault (EWL) west of the St. George's Bay Fault in the outer Bay St. George.

II.2.4 Pre-Carboniferous rocks

As mentioned above, rocks imaged as a group of subparallel, discontinuous, low frequency, moderate amplitude reflectors underlie the higher frequency, relatively continuous reflections beneath the Bay St. George and northeastern sector of the Magdalen Basin. In the inner bay these lower reflectors generally dip southeastward and show evidence of shortening and imbrication, and represent a continuation of the mainly Acadian structural disruption documented onshore (*e.g.*, Stockmal and Waldron, 1993). The top of this group of reflectors, then, is a major unconformity, likely equivalent to the Carboniferous/middle Ordovician unconformity seen in outcrop on the Port au Port Peninsula (Dix and James, 1989; Knight, 1983; Williams, 1985).

In the outer bay and Magdalen Basin area this unconformity is imaged only as a single bright reflector; the data are degraded due to the series of ringing multiples associated with a high impedance seismic event (*e.g.*, see line QAA009, Figure II.10c, where these multiples are most severe). However, the unconformity is relatively continuous and dips uniformly toward the south under the detached Carboniferous rocks, suggesting that the lower reflection package becomes less disturbed southward away from the Port au Port Peninsula.

CHAPTER III: STRUCTURAL INTERPRETATION OF THE STUDY AREA

III.1 Cabot Strait

III.1.1 Method

The structural analysis was based on an accompanying modified sequence-stratigraphic study. Seismic sequences and their boundaries (unconformities) were identified utilizing well data, published reports, and extrapolation offshore of data from the southwest Newfoundland onshore (*e.g.*, Knight, 1983; Belt, 1969; Gibling et al., 1987). These sequences were traced and tied around the seismic grid, which included some older data between the Cabot Strait and Bay St. George. Although "classic" sequence analysis related to fluctuations in marine base level is not possible in this predominantly terrestrial succession, important clues to the identity of the sequences comes from the seismic character observed at different stratigraphic levels. The late Devonian to Carboniferous succession in general is readily identifiable on the basis of the high frequency, high continuity and medium amplitude of its reflections, relative to older rocks. The important exception is the base of the Windsor-Codroy, where the presence of salt and interbedded marine carbonates and siliciclastics results in consistently high reflectivity and high amplitude/lower frequency reflections (Figure II.4).

The identification of unconformity-bounded sequences (particularly those bounded by the truncational Namurian-

Westphalian unconformity), and character recognition within these sequences (Figure II.4) provided a framework around which the following structural interpretation was constructed.

III.1.2 Fault systems

III.1.2.1 Northeast-trending regional faults

The Cabot Fault can be readily identified on seismic profiles and was mapped from the coast of Newfoundland to that of Cape Breton Island (Figures II.5 to II.10). The Cabot Fault is well-imaged just offshore from the northern tip of Cape Breton Island (Line 1121, Figure II.10a), where it is clearly expressed as a positive flower structure, and, just north of St. Paul Island (Line 1115, Figure II.10a), where the fault appears to branch and bound a "high block", likely an along-strike expression of the flower or piercement structure. On Line 1115 this "high block" appears to be an early Carboniferous structure which has been impinged upon by out-of-basin faulting on both sides.

The curvature in plan view of the Cabot Fault in this area is interpreted as a restraining bend, because small-scale, east-directed thrusting of strata out of the Searston Graben is visible on several lines (*e.g.*, Figure II.10: Lines 1117, 4075, 4077, 4083, 4093). Interpretations of thrusting are based upon several features and patterns which together are best explained as transpression-related contractional structures. These include (1) the occurrence of moderate to steep, west-dipping faults adjacent to synclinal structure in rocks of the Searston graben (Lines 1115, 1117, 4075, 1119), (2) the local occurrence of relief at the PPU/"B"/NWU levels, and in some cases, at the sea floor, which can be interpreted empirically as thrusting (Lines 4089, 1115, 4087, 1117, 4075, 1119), and (3) the presence of "rollover", apparently associated with fault drag, along the hanging walls near the Cabot Fault on Lines 1115, 4087, 4077 and 1119; these features are commonly associated with the relief noted above.

On Line 4093 (parallel to the fault) imbricated strata appear to be thrust northeastward toward the St. Paul Island "high block". This thrusting and structural stacking is probably localized in weak salt or shale layers of the lower Windsor or Horton Groups, respectively. This style of deformation is particularly intense at the fault zone on Line 4083. The Cabot Fault in the northern Strait is characterized by generally low relief and a narrow trace.

Two other fault systems have a strike subparallel to the Cabot Fault system: the Cape Ray Fault to the east, and the Hollow-Snake's Bight Fault to the west (Figures II.5 and II.10). The former fault trends offshore from Newfoundland (Brown, 1975; Chorlton, 1983; Dubé et al., 1992) to a point about 25 km east of St. Paul Island. Here it appears to terminate at or bend into an array of east-west faults, and to link westward with the Cabot Fault just south of St. Paul Island.

In southwestern Newfoundland the Cape Ray Fault is a kilometre-wide shear zone which extends for 50 km inland before swinging eastward for another 50 km (Figure II.5). Research on this part of the fault suggests that an earlier (pre-middle Devonian to syn- Late Devonian) period of reverse sinistral movement was followed by a post-late Devonian period of dextral transpressive shear (Chorlton, 1983; van Staal et al., 1992). Piasecki (1989) emphasized that these movements included important components of generally west-directed thrusting. Dubé et al. (1991, 1992) suggested that post-Late Devonian movement on the Cape Ray Fault is compatible with a transpressive, dextral deformation regime.

The Snake's Bight Fault (Knight, 1983) is here interpreted as a continuation of the regional Hollow Fault which outlines the western, northeast-trending coast of Cape Breton Island. The Hollow Fault system is complicated and perhaps partly controlled by the abundance of salt at the eastern margin of the Magdalen Basin. The orientation of salt along subsidiary east-west, as well as northeast-southwest faults, however, suggests that salt has migrated into zones of weakness along faults.

The trace of the Hollow Fault zone from the northern Cabot Strait to the Snake's Bight Fault is more difficult to map, because of the absence of good seismic data coverage in the northern Cabot Strait. The Hollow Fault may split into several strands north of the "deformed block" (Figure II.5 and II.6), and broaden northward into a zone which includes the high-standing Anguille Group in the Anguille Mountains. As there appears to be no throughgoing continuation of this fault at the eastern edge of the Anguille Group outcrop, displacement on the easternmost strand of the Hollow Fault may link northward across subsidiary strands to the Snake's Bight Fault. It is also possible that the easternmost strand of the Hollow Fault may be traced eastward across EW4, EW5 and associated faults (Figure II.5), to link with the Cabot Fault along the Stormy Point Fault on land (Knight, 1983). Despite the uncertainties, the general trends and continuity of the Hollow and Snake's Bight Faults strongly suggest that they are part of the same transpressive displacement system. The evolution of this kinematic system is illustrated in Figures V.2 and V.3.

The Cape Ray and Hollow-Snake's Bight Faults define the outside edges of two small linear grabens - the Cape Ray Graben and Searston Graben - which are more or less symmetrically disposed about the Cabot Fault as far south as St. Paul Island (Figures II.5 and II.8). The Cape Ray Graben is well defined by seismic reflection profiles over the northern two-thirds of the Strait. Onshore on the Newfoundland side metamorphosed Ordovician to Silurian mafic rocks of the Dinosaur Pond and Little Codroy Pond belts crop out between the Cabot and Cape Ray Faults (Chorlton, 1983). These likely form the basement to the Carboniferous under the Strait. Toward the Cape Breton Island side the Cape Ray

Graben is divided into northern and southern portions by a zone of east-west faulting (EW8 - the St. Paul fault zone).

The major faults and associated graben show varying degrees of linearity along their strike, and all are fragmented and offset by east-west faults (Figures II.5 and II.8).

III.1.2.2 East-west trending faults

East-west faults of varying offset are present, and these appear to cut, link and to be cut by northeast-trending faults. Nine of these faults or fault groups are named herein (EW1-EW9, Figure II.5). Between the Cabot and Cape Ray Faults, the St. Paul fault zone (EW8) is identified on seismic data by an array of mainly subvertical faults on Line 1106 near the intersection of Lines 1111 and 1113 (Figures II.8 and II.10). The southernmost of the faults within the St. Paul fault zone may be traced between the southern tip of St. Paul Island and an east-west bend in the Cabot Fault. The St. Paul fault zone appears to link the northeasterly-striking Cape Ray and Cabot Faults and may have transferred some of the late dextral motion on the Cabot Fault to the Cape Ray Fault.

The Hollow Fault system is interrupted by several east-west oriented, regularly- to irregularly-spaced shear zones (Figure II.5: EW1-EW5). These, with the exception of EW2, show small amounts of dextral displacement.

EW3 may present evidence for late displacement of the northeasterly-trending faults. Confirmation of this fault comes from seismic and potential field data. On Line 1108 (Figures II.9 and II.10c) the fault dips steeply to the north, separates the Magdalen Basin and "deformed block" domains, and is apparently intruded by a salt body with entrained sediments. It is visible on dip lines 1105 (Figures II.9 and II.10a) and 1107 (Figure II.10a) within the Searston Graben as a subvertical shear zone, possibly intruded by salt, and it appears to displace dextrally both the Hollow and Cabot Faults by 5-10 km. It may extend eastward to the Cape Ray Fault and the linear trend of the south coast of Newfoundland. This feature is strongly expressed on gravity data, where it forms the southern boundary to a deep low (<-40 mGal) which approximately coincides with the "deformed block" domain (Figure II.7). On the magnetic total field anomaly map it is also expressed as a group of relatively steep, east-west contours at the southern edge of a pronounced low (Figure II.3). In a similar manner, EW4 appears to indicate dextral displacement of the two strands of the St. George's Bay Fault.

III.1.2.3 Thrusts and décollements

Many lines show décollement and thrust faults, particularly at the margins of the Cape Ray and Searston Graben. This situation is particularly evident on short lines 4075, 4077, 4083, 4087, 4089 (dip-oriented, Figure II.10a) and 4093 (strike-oriented, Figure II.10c), with movement along bedding planes deep in the section in the salt layer being traceable updip where thrusting is expressed as relief at the seabed or at the Namurian-Westphalian unconformity. On several of these lines a small recessive area or "valley" of 1-2 km width is present underneath the hangingwall layers (Figure II.8; Figure II.10a: *e.g.*, Lines 4075 and 4077), and may represent a shear or mylonite zone with entrained fault gouge and salt. The extent of shortening along these faults, clearly seen on the high density seismic grid noted above, is related to the geometry of the Cabot Fault at this location (Figure II.8).

Faults which show décollement in their latest movement are generally seen in areas where significant compression has occurred, but because the whole system has experienced alternating transtensional and transpressive episodes, many of these faults may have experienced early phases of detachment (related to extension), such as is interpreted onshore in both western Newfoundland (Knight, 1983; Hall et al., 1992) and Cape Breton Island (Lynch and Tremblay, 1994).

III.1.3 Inversion structures

Inversion and ejection of sedimentary basin fill has occurred along the Cabot and Hollow Fault zones in particular. These features are clearly associated with the map patterns of thrusts and décollement faults discussed above. They occur primarily at both margins of the Searston

Graben, as observed on almost every transverse line along the trend of the faults. A good example is imaged on Line 1115 (Figure II.10a) in the thick sedimentary package lying northwest of the Hollow Fault zone. These features are associated with salt bodies, and the uniformity and consistency with which they occur lead one to speculate that salt (and to a lesser degree shale) acted as a lubricant in the ejection of the sedimentary fill from the graben. As noted in Section II.1.3 the presence of structurally-thinned Windsor Group comprising mainly salt in the St. Paul P-91 well supports this view. Some exhumation of basin strata may also have been driven by upward mobility of the salt itself. On the eastern, Cabot Fault side of the Searston graben, rollover, "drag" anticlines, with associated narrow, linear troughs (about 1 to 2 kilometres in width, termed "valleys" in Figure II.8) are mappable. These features occur both at the sea floor and within the unconformities where they are close to the sea floor (Figure II.10: Lines 4075, 4077, 4087, 4089).

On the western side of the Searston Graben, faults associated with the inversion of the graben appear to cut into the bounding rocks (probably Horton-Anguille) of the high block (Figure II.10: Lines 1103, 1107, 1111). These may be footwall "shortcut" thrusts which occur where pre-existing extensional faults are rotated too steeply to be reactivated as reverse faults (Hayward and Graham, 1989). Comparable structures are seen on seismic lines from the Devono-

Carboniferous of the Moncton subbasin, in the western onshore Maritimes Basin (Figure I.1; Nickerson, 1994).

III.1.4 Salt-related structures

Evaporite deposits in the lower part of the Windsor-Codroy Group affected the structural history of the basin in the Carboniferous, and to some extent, during post-Carboniferous time. Many of the low angle thrust faults under the Cabot Strait appear to be décollement faults, rooted at the base of the Windsor-Codroy section, and associated with the many salt structures that are seen to rise from this level. The top of the more competent and indurated Horton often behaved as a ramp upon which the Codroy-Windsor sediments, lubricated by salt layers, were thrust out of the basin. A similar interpretation was made for the eastern flank of the Flat Bay Anticline, in a position along strike from the Searston Graben, based on seismic reflection data (Hall et al., 1992). Décollement at the basal contact of the Codroy with the Anguille Group was also mapped by Knight (1983) at the northern edge of the Anguille Mountains (Figure II.4).

Salt is often seen to be associated with strike-slip fault movements. Along EW3 in the Searston Graben salt appears to have been entrained in, or to have invaded, the shear zone visible on Lines 1105 and 1107 (Figure II.5). Salt is variously present in the Cabot Fault zone (*e.g.*, Lines 1103, 1105, 1109) and may be responsible for a gravity low in the fault zone where it broadens northeast of St. Paul

Island (Figure II.2). Also, an elongate ridge of salt in the Hollow Fault zone just south of EW3 may have flowed into a zone of weakness along the fault zone (Figure II.5).

III.1.5 Structural domains

Identification of the major faults described above enables the area to be divided into several structural domains (Figures II.5 and II.6), which display varying styles of deformation. These are the Anguille Mountain Block, the "deformed block", the St. Paul Island domain and the remaining relatively undeformed basinal areas.

(1) The Anguille Mountain Block is a triangular shaped offshore extension of the Anguille Mountains (Figures II.5 and II.6). The southern boundary of this area is the EW4 fault, against which terminate several subparallel strands of the Hollow Fault. The domain is bounded by the St. George's Bay Fault on its northwestern side, and may reach to the Newfoundland coast in the east.

(2) The "deformed block" is a highly fragmented domain (Figures II.5 and II.6, and seismic line/line drawing 1108, Figures II.9 and II.10), which is seismically transparent, and is bounded on the northwest by the St. George's Bay Fault (defined in Section III.2.2.1), a major east-striking fault (EW3) in the south, fault EW4 in the north, and by the Hollow Fault in the east (Figure II.5). The Stormy Point Fault of Knight (1983) continues offshore into this group of faults, although they are for the most part poorly imaged

seismically. The rocks within this domain are bounded at their top by the NWU, and occasionally, a marked angular unconformity is imaged. The "deformed block" is interpreted to consist of Anguille Group rocks whose bedding has been rotated to vertical or near vertical position, similar to the disposition of these rocks in the present day onshore section. Alternatively, salt may be an important component of the "deformed block", and tight, upright structures may be partly halokinetic in origin. The latter interpretation is also favoured by the strong gravity and magnetic lows associated with this area (compare Figures II.2, II.3 and II.4).

(3) The St. Paul Island domain is mapped as a general area between Cape Breton Island and St. Paul Island, and from the Hollow Fault eastwards, where a complex zone of east-west steep faulting and out-of-basin thrusting is associated with the deformation along the Cabot Fault (Figure II.6). This domain includes a zone of thrusting and imbrication in the Searston Graben, as described earlier, and a complex zone of east-west faulting in the Cape Ray Graben, labelled as EW8, the St. Paul fault zone. This latter array of faults is principally identified on Line 1106 (Figures II.9 and II.10) and is a well-developed expression of the pattern of east-west faulting seen throughout the region. The nature of the displacement on these faults is difficult to determine on Lines 1111 and 1113 (Figure II.10a), but the complex pattern of faults and unconformity traces seen across the entire

fault zone (between the intersection of Lines 1111 and 1117) on Line 1106 suggests a net extension oriented approximately north-south. This is consistent with dextral movement on the Cabot and Cape Ray systems. Some of the faulting, particularly between the Line 1113 and 1115 intersections, appears to be contractional, and suggests a later reactivation of early transtensional faults.

The southward continuation of the Cape Ray fault zone undergoes a westward deflection adjacent to St. Paul Island and meets EW9 off the Cape Breton Island coast (Figure II.5). Furthermore, it widens and becomes northwest-vergent from Line 1115 to Line 1117 (south of EW8). The southernmost seismic data in this area (ends of Lines 1119 and 1121) show associations of upward-splaying and -shallowing faults ("flower structures"?) that are interpreted as an east-west transpressive zone (EW9), which may have reactivated earlier extensional or transtensional faults.

(4) A fourth domain includes several areas of relatively little deformation, including the Magdalen Basin, the northern half of the Searston Graben, and most of the Bay St. George area (Figures II.5 and II.6). These areas are characterized by thick, uniform accumulations of sedimentary rocks, with clearly defined salt bodies, and generally show only broad open folds, except at bounding faults where inversion of basinal sediments is present. Typical examples of this character are seen on the west end of Line 1117 in

the Magdalen Basin and in the Searston Graben on Line 1109 (Figure II.10a).

III.2 Bay St. George and Eastern Magdalen Basin Area

III.2.1 Method

The method employed in this section is that described in Section III.1.1 for the Cabot Strait.

III.2.2 Fault systems

III.2.2.1 Northeast-trending faults

As in the Cabot Strait several major, northeast-trending strike-slip faults are present, and control basin dimensions, the shape of the coastline south of Stephenville, and to some degree the structure of older rock units in the central and eastern areas of the Port au Port Peninsula (Figure II.5), where strike-slip faults with Carboniferous movement are mapped (Williams, 1985; Waldron and Stockmal, 1991). The St. George's Bay Fault of Belt (1969), controls the shape of the Anguille Mountain coastline and continues south into the Cabot Strait, where it is expressed as a pronounced gravity and magnetic gradient in the eastern Magdalen Basin, and is visible on seismic profiles as it enters the bay. This fault appears to mark the southeasterly limit of a band of bright continuous reflectors, which are interpreted to represent Cambro-Ordovician platform carbonates of the St. George and Table Head Formations, with or without the overlying post-Taconian Long Point/Clam Bank Groups. These rocks underly the

Codroy Group to the northeast of the St. George's Bay Fault. To the southeast (in the Cabot Strait), Anguille Group rocks in various states of deformation are interpreted to lie beneath the Windsor-Codroy transgressive deposits.

A spatially-associated fault, the Snake's Bight Fault, was mapped by Knight (1983) onshore in the Anguille Mountains and continues offshore to where it is cut by EW5 (Figure II.5, II.10b). This fault has the same trend and reverse-dextral character (as mapped by Knight, 1983, Figure I.4) as the Hollow Fault zone at the western edge of the Searston Graben, and as noted in Section III.1, it is likely also that these faults are part of the same displacement system.

The Round Head Thrust of Stockmal and Waldron (1993; their Figure 4b and Plate 1) emerges on the sea floor west of Red Island, and it is this low angle fault that is imaged on the older vintage seismic data interpreted in this study (Figure II.10b, Lines MAQ017 and -012). Foreland basin clastics of the Lower Silurian Clam Bank Group occur in the hanging wall of this thrust. There is also a possibility that minor Carboniferous dextral reactivation of this fault occurred, although the insufficient coverage of the older seismic data set do not allow an unequivocal determination of this. This matter may be resolved in the future, as new seismic data have recently been acquired on and offshore the Port au Port Peninsula by the petroleum industry; at the time of writing these data are not in the public domain.

III.2.2.2 East-west faults

East-trending faults offset the major trends in Bay St. George. Most evident is the offshore extension of the Shoal Point Fault (Knight, 1983), which along with EW6 appears to offset the St. George's Bay Fault. Other such faults offset salt anticlines in the middle of the bay, and possibly the coastline at the head of the bay, where it is indented eastward along EW7. These and other east-trending faults were delineated by Kilfoil (1988) and Miller et al. (1990) mainly on the basis of potential field data.

III.2.2.3 Salt-related structures

Salt has imposed a strong control on the development of structures in the area. Salt swells and ridges are common in Bay St. George, particularly in its middle and outer parts. These are disposed in several northeast-striking trends, parallel or sub-parallel to the major basin-controlling faults. They also appear to be variously cut and displaced by east-west faults, although the exact nature of this relationship is difficult to determine. In the inner and middle parts of Bay St. George, Carboniferous rocks appear to be detached and thrust westward. In the outer bay (and in areas where the platform is inclined more gently), the Carboniferous section shows detachment at its base along the relatively more competent carbonate platform sequence, and formation of disharmonic, upright anticline-syncline pairs, often cored by salt (Figure 10b, Lines TAJ-009 and TAJ-010).

Detachment and thrusting, then, is focussed in salt strata near the base of the Windsor Group, a phenomenon that has already been noted in the Cabot Strait.

III.2.2.4 Extent of Grenville basement and cover rocks of the Humber Zone

In Bay St. George, a relatively undeformed, banded reflection pattern signifies pre-Carboniferous strata, probably the Cambro-Ordovician platform with or without the late Ordovician-late Silurian Long Point and Clam Bank Groups overlying it. These strata dip homoclinally to the southeast under Bay St. George, and terminate abruptly against the St. George's Bay Fault (Figures II.5). As noted above, in most areas these strata behave as a competent ramp upon which Carboniferous rocks are detached.

Southwestward toward the Magdalen Basin the top of the carbonate platform is interpreted from the uniformly dipping bright reflector seen on Line QAA009 (Figure II.10c). The apparent southward dip of ~20° was imposed on the platform during Late Carboniferous subsidence in the Magdalen Basin, as the overlying Carboniferous section exhibits the same gross dip toward the axis of the Magdalen Basin. Again, as in the Bay St. George, the presence of disharmonic folding hints at salt detachment immediately above apparent carbonate platform-type character and suggests that Anguille sediments are absent, and that this area lies outside the regional trend of narrow Horton Basin development. It should be noted that Durling and Marillier (1993b) have interpreted a thin veneer (<1 km) of Horton rocks in the outer Bay St. George. It is the author's opinion that this is difficult to substantiate from the seismic data alone, and further arguments, based on tectonic models, for the absence of Horton sediments in this area are presented in Chapter V.

The strong east-west lineament (EWL) mapped west of the St. George's Bay Fault is interpreted as the northern boundary of the Magdalen Basin pull-apart, and may be sited along deep extensional faults in Grenville basement, which parallel the southern (east-west) margin of the St. Lawrence Promontory. This lineament lies considerably north of the projected edge of the Grenville basement and its cover sequence, which is reasonably constrained by the removal of Carboniferous dextral strike-slip, as discussed and depicted later in the mid-Devonian reconstruction of Figure VII.1. This can also be taken as the southernmost position of the Humber tectonostratigraphic zone in this area. It is anticipated that substantial areas of stretched Laurentian crust and lower Paleozoic cover sequence lie deeply buried beneath Carboniferous sediments south of this east-west lineament.

III.3 Structure Map on the pre-Viséan Substrate

The present day geometry of the Maritimes Basin in the study area is best illustrated by a map on the pre-Viséan substrate or unconformity. The Viséan represents the period of first expansion of the basin, when rift-bounded clastics of the Horton and Anguille Groups were overstepped by transgressive marine deposits of the Windsor and Codroy Groups. The true base of the Maritimes Basin in most areas - the Horton Group, cannot be mapped offshore, because this stratigraphic boundary is too deep to be consistently identified on the seismic data set.

The map presented here in Figure III.1 is an isochron map of Viséan and younger sediments. The map configures the "depth" (in seismic two-way travel time) to the unconformity at the base of the Windsor-Codroy Groups, and is best described as depicting structure on the pre-Viséan substrate. The outlines of the major faults and salt bodies are included in this figure, but it is instructive to compare this map with the complete structural elements maps of Figures II.5 and II.8.

Over the map area, three separate substrates to the Viséan section are recognized on seismic profiles, as discussed in the preceding sections. In the Cape Ray Graben, the Horton Group is probably present but thin, and is often difficult to identify on seismic profiles. For this reason, the "pre-Horton basement", or PHB, which may represent on most Cape Ray Graben profiles a Devonian listric extensional fault, is the mapped reflector; it may have controlled Horton deposition but was partially reactivated in the Carboniferous. In the Searston Graben and Anguille Mountain Block, and probably in the eastern Magdalen Basin as well (that is, the area lying between the St. George's Bay and Cabot Faults), Horton rocks are interpreted to underlie the younger Carboniferous section, in an area now encompassing the tract of Horton basin development.

A third substrate occurs northwest of the St. George's Bay Fault. Here, lower to middle Ordovician carbonate rocks are interpreted beneath the Codroy Group, as documented earlier and shown in Figure II.10b. Locally, late Ordovician carbonates of the Long Point Group, as mapped on the northern Port au Port Peninsula, may also be present.

This map illustrates the association of sedimentary thicknesses with (1) faults, which imposed syn- and post-depositional control on the isopachs, and (2) salt, which is responsible for deforming the sedimentary pile and hence controlling isopachs after most of the Carboniferous section had been deposited.

CHAPTER IV: DISCUSSION AND SYNTHESIS OF RESULTS OF OFFSHORE GEOPHYSICAL INVESTIGATIONS

IV.1 Unconformities and Timing of Carboniferous Deformation

Four Carboniferous unconformities are interpreted from seismic profiles in the Cabot Strait and Bay St. George area. These unconformities are associated in time and space with periods of activity on the Cabot master fault and the associated fault splays. Variations in deformation and sedimentation between the different graben, and between the graben and high blocks, can be attributed to differential movement on the fault splays, and resulted in minor local unconformities only. The unconformities vary in the duration of hiatus they represent and in their lateral extent, and are plotted in linear time on both regional and local scales, in Figures I.3 and IV.1, respectively.

IV.1.1 Top Horton-Anguille (HA) Unconformity

This unconformity at the top of the Horton-Anguille Group resulted from the deformation of strata near the Cabot Fault in the late Tournaisian to early Viséan. This unconformity is interpreted from several seismic lines across the Searston Graben north of St. Paul Island. Here, reflections of lower Codroy Group (Codroy Road Formation, CR) salt layers, progressively onlap the Horton-Anguille reflector in the direction of the Cabot Fault (*e.g.*, Figure

II.10: Lines 4075, 4077, 4013). South of St. Paul Island this onlap pattern is deformed by thrusting and décollement in the salt layer. Further evidence for this unconformity is provided by the apparent lack of Codroy Road sediments in the Cape Ray Graben (Figure IV.1). Knight (1983) did not interpret an unconformity in equivalent strata of western Newfoundland, but noted other work on the Lower Carboniferous in the Maritimes, in particular Geldsetzer (1978), who speculated that Horton sedimentation was confined to the lower part of the Tournaisian. This implies that a depositional hiatus, or continuing sedimentation followed by rapid, selective erosion, representing several million years of sedimentation and lasting until about middle Viséan time, may succeed deposition of the Horton. Such a break is documented only locally at other localities in the Maritimes (*e.g.*, Moncton Subbasin, Nickerson, 1994; Antigonish Highlands, Yeo and Ruixiang, 1987).

The uplift and relief which controlled Windsor-Codroy deposition resulted from movement along the Cabot Fault zone at the end of Horton times. The creation of some relief, however, may be partly due to volcanic activity at the end of Horton times or at least up to the end of deposition of the Codroy Road sediments (mid-Viséan). Volcanic rocks of a similar age are recognized by Barr et al. (1985) on the Magdalen Islands. The material at depth in the core of the Cabot Fault zone is assumed to be Horton, and not pre-Horton basement (except at St. Paul Island), because of the low gravity signature associated with the fault along much of its trace between Cape Breton and St. Paul Islands.

IV.1.2 Namurian-Westphalian Unconformity (NWU)

This unconformity displays strong angularity across the study area, and appears to be widespread across the central and eastern parts of the Maritimes Basin, including the Sydney Basin. In the basins of western Nova Scotia and New Brunswick, however, this unconformity is restricted to the Westphalian, although stratigraphic hiatuses appear to be localized along fault zones and associated tilted blocks during the Namurian (Figure I.3). The localization and later overstepping of the Namurian span of the unconformity by a later, broader Westphalian hiatus no doubt reflects the structural and tectonic style at the southwest margin of the "rhombochasm", where even the later Carboniferous sedimentation continued to be affected by individual fault block and graben geometries inherited from the earlier development of the basin. The smaller degree of the hiatus in New Brunswick is possibly influenced by a proximity to the exposed, eroding Appalachian landmass in the west, and the influx of Boss Point and Cumberland clastics into this area in early Westphalian time (Figure I.3).

The lateral persistence of the NWU, along with its extent and high degree of truncation on seismic profiles, suggest that it represents a protracted phase of deformation over much of the Maritimes Basin. This phase of regional compression, uplift, and associated faulting represents a primary level of deformation. This event likely activated and was further intensified and overprinted by secondary movement of large masses of lower Viséan salt. Large-scale inversion and exhumation of graben sediments are associated with this unconformity. The uppermost section of the Searston Graben in particular shows a high degree of angularity and bevelling.

IV.1.3 "Top Barachois" ("B"; Late Westphalian to Early Stephanian) Unconformity

This truncational boundary presently intersects the surface atop the Barachois Group in western Newfoundland, but in the Sydney Basin, and perhaps the Cabot Strait, it separates Morien Group rocks from overlying "unnamed redbeds" of Gibling et al. (1987). Again, such an unconformity may not be present basin-wide. However, the break between the Riversdale and Pictou in the Cobequid Highlands (Yeo, 1985; Yeo and Ruixiang, 1987) appears to be similar in duration (3 - 6 m.y.) yet slightly offset in time (Figure I.3). Fralick and Schenk (1981) recognize a lacuna in the Westphalian D in the Stellarton structural subbasin. Such an unconformity does not represent a basin-wide event, but may indicate a period of deformation where adjacent areas (*i.e.*, linked fault blocks and grabens) underwent similar styles of deformation, slightly offset in time, in a fault system with a common sense of movement.

This characterization is supported by the description of the unconformity on seismic lines. Truncation of seismic reflectors, indicative of the most intense erosion and levelling, are seen in the Searston Graben. Here the early Stephanian unconformity (B) merges with the angular Namurian-Westphalian unconformity, and the Barachois sequence is not preserved. West of the Hollow-St. George's Bay Fault, the B unconformity shows less truncation, and a wedge of Barachois Group rocks is preserved. A similar situation exists to the east between the Cabot and Cape Ray Faults, where a wedge of Barachois/Morien rocks thickens into the Cabot Fault, and the topmost reflections show parallel relationships with the B unconformity. East of the Cape Ray Fault, into the Sydney Basin, erosional relief on the early Stephanian unconformity (B) diminishes below seismic resolution. This sequence boundary is still traceable, however, and probably is reduced to the status of a diastem.

IV.1.4 Post-Pennsylvanian or Post-Early Permian Unconformity (PPU)

This unconformity cuts older ones, mainly the B and NWU, particularly near the major fault zones (Figure II.10: Lines 1103, 1105, 1113, 1115, 1117, 4083, 4089). In areas more removed from the fault zone, and where the faults show smaller offset, such as can be observed on Line 1111, a thin sequence is preserved between the PPU and the B or NWU, or both. In some areas the PPU reaches the sea floor, and rocks beneath this unconformity form a seacrop, or are covered only by a thin veneer of unconsolidated glacial sediment. In any case, the sequence of rocks bounded by the PPU and the B are interpreted as latest Stephanian at the oldest, and locally may be as young as mid-Permian or even Triassic. It is likely that they represent the youngest part of the late Carboniferous-Permian Pictou Group in this area (Figures I.3 and IV.1).

IV.2 Fault displacements

IV.2.1 Cabot Fault system

In western Newfoundland, the Cabot Fault is well defined in mylonite zones and forms the eastern limit of Carboniferous rocks in the Bay St. George Subbasin (Knight, 1983). This fault system extends to the Caledonides, and in eastern North America has been considered to have accommodated some 200 km of cumulative post-Acadian dextral offset across a broad displacement zone (Bradley, 1982; Belt, 1968b). Both the Maritimes Disturbance (Poole, 1967; Dewey and Kidd, 1974) and the Carboniferous Variscan and Hercynian orogenies have been attributed to this large-scale motion (Dewey, 1982; Lefort, 1989). Knight (1983) interpreted the onland Bay St. George Subbasin structural patterns as being consistent with such a stress regime. The timing of these orogenic events on the broad Atlantic scale fits well with the local style and apparent timing of deformation. The regional role of the Cabot Fault will be further examined in Part III of this thesis.

IV.2.2 Hollow-Snake's Bight Fault/Round Head Thrust Systems

These major faults west of the Cabot Fault appear to be strands of a regional cumulative displacement system. Several anticlinoria, such as the Anguille Mountains, "deformed block", and salt anticlines of both the western Cabot Strait and Bay St. George, may have been folded within stepover zones such as occur in a discontinuous fault system (Aydin and Nur, 1982), where compressive structures typically form in the overstepped areas between ends of the adjacent faults. Similar explanations have been proposed for such features within the Los Angeles Basin by Christie-Blick and Biddle (1985).

Rather than the total slip or offset being taken up or accommodated along one linear feature, it seems that the displacement in this area has been distributed along several linked splay faults. In the northwest, a minor amount of dextral offset may have occurred on the Round Head Thrust and associated Acadian faults, and indeed by Carboniferous faults exposed on the Port au Port Peninsula (Stockmal and Waldron, 1993; Williams, 1985). Southeastward, much greater offsets are associated with the St. George's Bay Fault and the Hollow-Snake's Bight Faults. Among the northeast-trending major faults, the Cabot Fault likely has the greatest and most recent displacement, as suggested by its continuous and brittle nature through western Newfoundland (see Section X.2), and it may lie closest to the deeper crustal suture along which Laurentian continental crust slid past, or rotated against, the crust of outboard terranes situated to the east.

IV.2.3 Cape Ray Fault Zone

In southwestern Newfoundland the Cape Ray Fault is a kilometre-wide shear zone which extends for 50 km inland before swinging eastward for another 50 km. Dubé et al. (1991, 1992) suggested that post-late Devonian movement on the Cape Ray Fault is compatible with a transpressive, dextral deformation regime.

Two branches of the Cape Ray Fault were mapped by Chorlton (1983) and have been further studied by Dubé et al. (1991, 1992). The western strand (Fault #1 of Chorlton) meets the eastern strand (Fault #2 of Chorlton) about 40 km inland, just south of where the fault zone swings to the east (Figure II.5). Fault #1 may be related to a westward-directed thrust imaged, albeit rather poorly, on Line 1101 (not reproduced). Thus the divergence of the two strands onshore continues and widens offshore into the Cape Ray Graben. The Windsor Point Group (Brown, 1975; 1976; 1977; Figures I.3 and II.5) which outcrops between the two strands of the fault, comprises bimodal volcanic, volcaniclastic and sedimentary rocks and is, at least in part, mid- to late Devonian in age (Chorlton, 1983; Wilton 1983), suggesting that there was an episode of basin development during this time.

The Cape Ray Fault is a regional, continuous displacement system that exhibits alternating northeast- and east-striking segments, exhibited by the St. Paul fault zone, and a similar bend exposed 50 km inland in Newfoundland (Figure II.5). Areas of extension are situated along the east-west segments, as seen across the St. Paul fault zone on Line 1106 (Figure II.10c).

IV.2.4 Importance of east-west faults at the St. Lawrence Promontory

Other significant east-trending faults in the northern Strait (*e.g.*, "EW3") appear to displace both the Cabot and Cape Ray Faults, and the east-west orientation of the south coast of Newfoundland, which persists for hundreds of kilometres to the east is notable. Faults of like orientation are recognized in Cape Breton Island, and further south in the Cobequid Highlands of Nova Scotia, where they run parallel to the regional east-west fault system known as the Minas Geofracture (Keppie, 1982; Yeo and Ruixiang, 1987) or the Cobequid-Chedabucto Fault system (Fralick and Schenk, 1981; Bradley, 1982; McCutcheon and Robinson, 1987). The importance of these faults in processes in and around the St. Lawrence Promontory will be discussed in the reconstructions of Part III.

IV.3 Fault reactivation

Many of the structural patterns in the onshore Bay St. George Subbasin can be explained in terms of dextral strike-slip (Knight, 1983; Christie-Blick and Biddle, 1985): for example, the Flat Bay anticline at bearing 037 and the Barachois synclinorium at 027-030 are considered *en echelon* folds relative to the Cabot Fault (Knight, 1983). Offshore, the grid spacing of seismic lines is not close enough to resolve smaller scale structural trends, although some of the larger salt anticlines and ridges display a general *en echelon* arrangement. The combination of northeast- and east-trending dextral faults, however, are not easily attributed to a single stress regime, as discussed in detail in Section VIII.4.3. It is likely that the primary controls on fault orientation were provided by pre-existing zones of weakness and the structural grain inherited from the Taconian and Acadian orogenic belts. The Devono-Carboniferous reactivation of the Cape Ray Fault and its genetic relationship to Lower and Middle Paleozoic orogenic events, as discussed by Chorlton (1983), supports this contention.

Late Paleozoic east-west faulting in the Cabot Strait may also reactivate earlier east-west trends, which may have been smaller scale expressions of the type of movement seen on the Midas Geofracture (Figure I.1; *e.g.*, Keppie, 1982; Webb, 1969). This fault system is believed to have been initiated during the Acadian orogeny, but was strongly reactivated with up to 165 km of dextral displacement in the late Carboniferous to Permian (Keppie, 1982). It also represents a much older trend - the southern boundary of the St. Lawrence Promontory, perhaps inherited from a pre-Iapetan rifting episode (Williams, 1979).

Stockmal and Waldron (1990) and Waldron and Stockmal (1991) have reinterpreted the structure of the Port au Port Peninsula as dominated by Acadian thrust tectonics. Early Acadian east-vergent thrusts on the northwestern part of the peninsula represent the development of a triangle zone, which was succeeded by the formation of west-vergent structures associated with a shear zone-thrust zone couple (Round Head Shear Zone, RHSZ, and the thrust at Tea Cove; Figure II.5). Such patterns are reminiscent of those seen in other areas of western Newfoundland and the Cabot Strait, as documented herein. Carboniferous strike-slip faulting occurs in the central and eastern areas of the Port au Port Peninsula (Williams, 1985, Waldron and Stockmal, 1991), and in conjunction with the major faults now recognized in the Bay St. George and further south, one suspects that Carboniferous faulting and reactivation of Acadian structures, especially as dextral shear - orthogonal thrust couples, may be much more common than previously recognized.

IV.4 Salt tectonics

It is difficult to assess exactly how much halokinetic deformation has affected the structural style. Over the southern portion of Line 1108 (Figures II.9 and II.10) ridge and swell structures resembling salt-rich zones from the Gulf of Mexico and other areas (West, 1989) are present. The relatively shallow bathymetry of this area may also be due to salt bodies in the shallow section. Some of the geometries ascribed to inverted basin development as discussed above in the Searston Graben (*e.g.*, Line 1115) may be due in part to salt movement. However, this movement was probably initiated by, and associated with, gentle compression and shortening in a wrench borderland. In other words, the salt may have been mobilized in the first post-Viséan tectonic event, perhaps in the Namurian.

CHAPTER V: REGIONAL IMPLICATIONS

V.1 Kinematic model for late stage deformation in the Cabot Strait

What kinematic model best accounts for the diverse collection of structures described above? Recently, the role of wrench tectonics in explaining kinematic behaviour in strike-slip zones has been reassessed. The San Andreas Fault has long been considered an example of wrench tectonics (Wilcox et al., 1973; Harding, 1976; Howell et al., 1980), where deformation is attributed to frictional drag along a transpressional fault zone. Deformation style is characterized by the development of a zone of distributed shear, or a wrench borderland (Jamison, 1991), adjacent to the master fault, and characterized by *en echelon* folds surrounding a throughgoing wrench fault (Figure V.1a). Recently, several authors have proposed an alternative explanation where there is decoupling or partitioning of strain between a strike-slip fault and its wrench borderland (Figure V.1b: Mount and Suppe, 1987; Figure V.1c: Namson and Davis, 1988; Holdsworth and Strachan, 1991). Deformation is resolved into two components: strike-slip faulting along an "almost-free surface" parallel to the master fault, and thrust faulting and folding, *i.e.*, the development of a compressional fold-and-thrust belt, oriented normal to the fault. The deformation style predicted by this model is one of low fault drag, strain decoupling and little distributed shear (Figure V.1b, c). In either of the above scenarios, complexities arise when the master strike-slip or wrench fault becomes a fault *system* and shows a splayed, braided or anastomosing configuration along a regional trend. Such splays commonly dip toward and join the master fault at depth to form a crustal scale "flower" geometry (Gibbs, 1987) with "mixed-mode" strike-slip and extensional basin formation. The individual strands of such a system tend to be discontinuous, and to experience deformation between the overstepping ends of the strands (Aydin and Nur, 1982; 1985), with formation of graben and horsts (pressure ridges, with common compressional structures including thrust faults) between overlapping strands.

The system under discussion in western Newfoundland is best explained by a strain partitioning model, as orientations of major compressional structures attest to principal stresses oriented normal to the Cabot Fault zone. In the Cabot Strait, opposite-verging, out-of-graben thrusting occurs along the Hollow and Cape Ray Faults. On land, the southern portion of the Snake's Bight Fault shows thrusting with the same vergence and orientation as the offshore structures, and the axes of the Flat Bay Anticline and Barachois Synclinorium are oriented at low angles to the Cabot Fault. These latter may indeed be compressional, decoupled structures, even though they have been described as *en echelon* by Knight (1983).

Subscribing to the Mount and Suppe (1987) strain partitioning model, the Cabot Fault would have behaved as an "almost free surface" with little frictional drag, but the existence of a sharp restraining bend at St. Paul Island produced a local pattern of thrusting out of the Searson Graben eastward and northeastward into this bend. Figure V.2 illustrates the development of the present structure in latest Carboniferous time using the strain partitioning model outlined above (compare Figures V.2b and V.1c).

V.2 Genesis of the Bay St. George half-graben

As noted earlier, the St. George's Bay Fault shows a net normal displacement and is the hinge fault along which the eastern Bay St. George has subsided to form a half-graben. Interpretations of the structure and stratigraphy in the Bay St. George enable the following interpretations to be made regarding the genesis of the Bay St. George half graben, and these are illustrated schematically in Figure V.3:

(i) Late Devonian-Tournaisian (Figure V.3a): Horton-Anguille sediments were deposited in a narrow pull-apart, fault-bounded basin, the width of which is approximately outlined by the present trace of the Anguille outcrop, between the St. George's Bay Fault and the Cabot Fault. Toward the end of the Tournaisian, this basin was partially inverted as transpressive strike-slip movement commenced. As discussed in Part III, this basin was probably originally situated west of the east Aspy terrane in Cape Breton Island, and in Part II is termed the Anguille-Cabot Subbasin (Knight, 1983; Hamblin, 1992).

(ii) Viséan (Figure V.3b): transtensional strike-slip resulted in the development of an oblique-normal fault system which bisected the partially-inverted Horton basin; this system remained mainly transtensional throughout the Viséan, resulting in the development of a half-graben and deposition of Codroy and Searston strata.

(iii) Namurian to early Westphalian (Figure V.3c): transpression and further inversion of Horton rocks, now with a transgressive Codroy cover, occurred, most spectacularly to form the Anguille Mountains. Deposition of middle Carboniferous rocks continued on a "Bay St. George floodplain" to the west. Detachment of Codroy rocks in the basal salt layers and gravitational sliding and deformation ensued, the evidence for which is seen along the northern periphery of the Anguille Mountains (Knight, 1983)(see also Figure VIII.1).

(iv) Early-middle Westphalian (Figure V.3d): the St. George's Bay Fault was initiated as a moderately west-dipping, normal fault system, with ongoing deposition in a flood plain environment in the onshore-offshore Bay St. George area. A "Port au Port highland", related to late Acadian basin inversion, may by this time have arrived in the west by dextral motion, and may have supplied sediment to the half graben.

(v) Stephanian to early Permian (Figure V.3e): transpressive deformation of thick Carboniferous sediments in the Bay St. George by detachment above a rigid pre-Carboniferous substrate took place, which resulted in the generation of disharmonic, open folds, accompanied by westward thrusting and further inversion of the Horton-Anguille basin fill along the oblique-reverse Hollow-Snake's Bight Fault system (Lines TAJ009 and TAJ010). Strike-slip and minor(?) thrusting also occurred along the Cabot Fault.

In summary, the history of development of the Bay St. George half-graben can be discussed in terms of the activation and reactivation of a zone of weakness sited between the present coastline and Cabot Fault. If the scheme presented in Figure V.3 is accurate, this was also an area where localized extensional collapse of Acadian thrust slices, mostly involving stacked rigid carbonate platform, occurred. A zone of upper to middle crustal weakness can also be inferred if extensional basins were able to develop by asymmetric simple shear, as in the model of Wernicke (1985). These weaknesses and/or inhomogeneities likely served to focus the placement of high angle strike-slip faults when rotational or oblique motions succeeded orthogonal interactions in the early Carboniferous. During the strike-slip phase, which persisted through the Carboniferous, alternating transtensive and transpressive episodes resulted in deposition and inversion of basin fill along an increasingly complex array of faults and fault splays.

V.3 Implications for the development of the Maritimes Basin

Bradley's (1982) model proposes that the Magdalen Basin depocentre developed in mid-Devonian times as a "rhombochasm" - a pull-apart at a large overstep in the regional dextral strike-slip system. While the two-stage Mackenzie (1978) model of rifting and thermal subsidence was originally proposed for passive margins and situations of pure shear, it was applied by Bradley (1982) in a context of transcurrent or wrench tectonics. There is no doubt that *later* (Viséan and younger) deformation focussed along major strike slip zones is widespread, and further transtensional basin development was localized along these faults, as in the case of St. George's Bay. However, evidence is accumulating for an alternative explanation for the early development of the depocentre, one in which post-orogenic (post-Acadian) extension resulted in the development of fault-bounded basins. Hamblin and Rust (1989) and Hamblin (1992) concluded that the late Devonian to Tournaisian Horton basins of Cape Breton Island were asymmetric half-graben segments of an overall distensive rift system. These considerations, and others such as the present argument for moderately-dipping faults (the ancestral St. George's Bay Fault discussed above, and the Cape Ray Fault) as possible Horton rift basin-bounding faults, imply that the Maritimes Basin experienced an early, Hortonian extensional phase associated with regional scale, map-view pure shear. This was followed by a

Viséan and younger strike-slip, simple shear phase which concentrated activity - either transtensional basin enhancement or transpressional basin inversion - along the major fault trends.

PART II: RECONSTRUCTIONS IN THE ST. LAWRENCE PROMONTORY AREA

CHAPTER VI: GEOLOGY OF SUCCESSOR BASINS AND BASEMENT ROCKS IN THE AREAS SURROUNDING THE CABOT STRAIT

VI.1 Introduction to Parts II and III: Terrane and Plate Reconstructions

The discovery and recognition of displaced or "suspect" tectonostratigraphic terranes (*e.g.*, Monger and Ross, 1971; Jones et al., 1972; other references compiled in the review of Wilson et al., 1989) led to the reinterpretation of much geology around the world, and by 1980 terrane analysis was firmly established as an important sub-discipline in the earth sciences.

One of the important advantages of this approach is that it encourages researchers to focus on local details of stratigraphy and structure. This places it at odds with the more traditional global paleogeographical approach (*e.g.*, Smith and Briden, 1977; Norton and Sclater, 1979; Ziegler et al., 1983), where entire and generally major continental blocks are considered. This latter approach can lead to considerable oversimplification and difficulty in placing local geological features in a regional or global context.

Wilson et al. (1989, p. 1), working in terranes of the west coast of North America, presented a progress report of their efforts "to 'marry' Mesozoic global plate reconstructions and terrane analysis to produce examples of a 'third generation' of global plate tectonic maps". In my opinion, this way of thinking can bring a fresh approach to geological problems by addressing them simultaneously on a number of scales, the endpoints of which might be defined by the largest lithospheric plates and the smallest slivers or flakes of terranes. Finally, the attraction of this approach is that it can be visualized and tested on any modern tectonic or relief map of the world, and such examples will be given later in this part of the study.

The terrane studies approach has been applied to the Canadian Appalachians since the work of Williams and Hatcher (1982), Keppie (1982) and Williams (1983, 1984), although the earlier subdivision of Newfoundland (and indeed the entire Appalachian belt) into a number of genetically consistent zones by Williams (1979) is clearly an early expression of the terrane concept. Since then a variety of studies have addressed the local details, in Newfoundland (O'Brien et al., 1983; van der Pluijm, 1986; Dunning et al., 1990a), mainland Nova Scotia (Keppie, 1985, 1989; Keppie and Dallmeyer, 1987), Cape Breton Island (Barr and Raeside, 1989; Keppie, 1990; Raeside and Barr, 1990; Barr and Jamieson, 1991; Keppie et al., 1992; Barr et al., 1994; Lynch and Tremblay, 1994) and New Brunswick (Fyffe and Fricker, 1987; Barr and White, 1991; White and Barr, 1991; Nance and Dallmeyer, 1993).

Up until now, however, the marriage of global tectonics and terrane studies/accretion tectonics in the Canadian Appalachians has yet to come about. Many data exist at both ends of the spectrum: the major works in terrane studies are cited above, and other workers have addressed the global scale, employing a variety of techniques. These include paleomagnetics (Deutsch and Rao, 1977; Kent and Opdyke, 1978; Irving and Strong, 1984, 1985; van der Pluijm and van Staal, 1988; Trench and Torvik, 1992), isotopic studies (Murphy et al., 1992) and general tectonic studies (Pickering and Smith, 1994), techniques which often do not provide the resolution to be useful in terrane analysis. With reference to the goal of the present study, it might be said that the absence of reconstructions has been partly a consequence of the lack of understanding of the late, strike-slip controlled repositioning of terranes which took place mainly in the Carboniferous.

The main objective of the second part of this study is to review the data available from terrane studies in the St. Lawrence Promontory, and to use this information to construct reasonable representations of the spatial positions of terranes, and identifiable fragments of terranes, through the late stages of assembly of the Canadian Applachians.

Reconstruction of terranes is of neccessity concerned with a specific portion of an orogen, where a particular style of accretion is thought to have been dominant, and where that style of accretion can be taken as a paradigm or model. In the present case, the oblique collision of an oceanic plate with Laurentia, and its already accreted Dunnage zone elements, is proposed as such a working model. As a first order approximation, terrane accretion during and after the late Silurian is viewed as a consequence of ongoing oblique subduction and convergence. The spatial relationship between these terranes, as a function of time, is reconstructed based on interactive inference from a range of geological observations. The result is a model of terrane positioning through time. As with all models, its value must by judged by its consistency with available data, and by the extent to which it provides useful insight into these data.

Parts II and III will portray time slices of terrane accretion and modification at the St. Lawrence Promontory at the regional and North Atlantic scales, respectively. These maps will attempt to bring about a marriage of terrane and lithospheric plate analysis in the sense of Wilson et al. (1989). Loosely, the two sets of maps may be taken to depict the endpoints of this approach, but tectonic processes illustrated will remain consistent, even if for clarity all the geological details cannot be shown on both sets.

VI.2: Geology of Rocks Considered "Basement" to the Maritimes Successor Basin: Southwest Newfoundland

VI.2.1 Statement of Intent

The following section will describe the relationship of middle and late Paleozoic faults to terrane boundaries at the St. Lawrence Promontory; these faults and boundaries are illustrated in Figure VI.1. Major faults which trend obliquely offshore along the south coast of Newfoundland and in northern Cape Breton are described; of these, the ones with primarily pre-Devonian histories are treated only cursorily, while those with documented or suspected Devonian and later histories are discussed in detail. These faults have been described by a number of workers in the area in the past 20 years or so, many in the context of terrane studies (*e.g.*, Brown, 1976, 1977; Chorlton, 1983; Wilton, 1983; Piasecki, 1989; Currie and Piasecki, 1989; Dubé et al., 1991, 1992, 1994; Burgess et al., 1992, 1993; Lin et al., 1994). Understanding the history of these faults is vital to an understanding of how they contribute to late Paleozoic basin development.

The south coast of Newfoundland is characterized by a number of major fault zones which generally trend in a southwesterly direction across the Cabot Strait and thus can be expected to have had kinematic linkages with faults now exposed in Cape Breton Island. These faults form the main boundaries between geological domains in the area, as illustrated in Figures VI.1 and VI.2, and are described from west to east, along with the domains they bound, in the following sections. A graphical representation of these features is presented in a time-space diagram in Figure VI.3.

VI.2.2 Cape Ray Igneous Complex

The area between the Cabot Fault and Cape Ray Fault contains the Cape Ray Igneous Complex (Figure VI.1), which comprises tonalitic and granodioritic orthogneisses, generally considered to be a deep remnant of the Taconian magmatic arc (van Staal et al., 1992), and ultramafic - mafic plutonic rocks which represent either early Ordovician oceanic crust associated with the arc complex (Dunning and O'Brien, 1989) or the remnants of an ophiolitic klippe (Brown, 1977). The Cape Ray Igneous Complex occupies the southern extension of the Dunnage Zone, renamed the Dashwoods Subzone by Piasecki et al.(1990).

VI.2.3 Port aux Basques "gneiss": Grand Bay and Port aux Basques Complexes, and Harbour le Cou Group

A body of rocks originally loosely termed the Port aux Basques gneiss (Brown, 1977) crops out between the Cape Ray Fault zone and Rose Blanche granite (Figure VI.1). These psammitic gneisses and pelitic schists have been subdivided into three major lithological units bounded by mainly Silurian shear zones. In the west, abutting against the Cape Ray Fault Zone, the Grand Bay Complex consists of garnet-bearing biotite gneisses that have evolved by amphibolite facies metamorphism from feldspathic sandstones (van Staal et al., 1992).

The Port aux Basques Complex lies east of the Grand Bay Complex (Burgess et al., 1993) and comprises mainly psammitic to pelitic gneisses and schists, interlayered with the Port aux Basques (gneissic) granite, and amphibolite sheets (Burgess et al., 1993), all intruded by several generations of pegmatitic and granitoid dykes. Its western boundary with the Grand Bay Complex is the Grand Bay Thrust, interpreted by van Staal et al.(1992) as a major shear, with NNW overthrusting of the Port aux Basques Complex over the Grand Bay Complex.

Lying east of the Port aux Basques Complex, and separated from it by the Isle aux Morts fault zone, the Harbour le Cou Group (Brown, 1976) consists of pelitic to semi-pelitic schists and minor psammites, metamorphosed to amphibolite facies conditions. Based on lithological and structural criteria, Lin et al. (1993) expanded the Harbour le Cou Group of Brown (1976) to include the "Otter Bay Division" of van Staal et al. (1992). Although not specifically discussed by these authors, the meta-sediments and -volcanics are presumed to have Paleozoic protoliths, likely associated with Iapetan oceanic island complexes (as discussed in Sections VI.1 and illustrated in Figures VII.1 and X.2).

According to Burgess et al. (1993) the Grand Bay Complex, Port aux Basques Complex and Harbour le Cou Group have each experienced three episodes of penetrative deformation. The Grand Bay Complex is distinguished by the presence throughout of kyanite-bearing metamorphic mineral assemblages (indicative of high-P conditions of metamorphism), as opposed to dominantly sillimanite-bearing assemblages in the other two units (Burgess et al., 1993). However, the fact that kyanite exists in the western part of the Port aux Basques Complex suggests that the Grand Bay Thrust may not represent a large metamorphic discontinuity. Migmatites are also present within the Port aux Basques

Complex, representing partial melting perhaps associated with deep crustal (gneissic) granite emplacement (Port aux Basques granite).

Burgess et al. (1993) inferred a clockwise trajectory in P-T space, with peak pressures of 6-9 kbar and peak temperature of 650° +/- 50°C. They suggested that a partial Barrovian metamorphic sequence typical of overthickened terranes is displayed at the present erosional surface, and that this was the result of a Silurian crustal thickening event, as proposed for the region by Dunning et al. (1990a).

VI.2.4 The Cape Ray Fault Zone and Windsor Point Group

Recent economic and structural studies along the Cape Ray Fault zone have led to a better understanding of its role in local and regional tectonic development. As reviewed by Dubé et al. (1994), the Cape Ray Fault (Gillis, 1972; Brown, 1972, 1977) is a high strain zone of some several hundred metres width that has been the subject of various interpretations. Brown (1972; 1976; 1977) viewed it as a Taconic suture representing the trace of the Iapetus Ocean, on which the Windsor Point Group (described below in this section) was deposited and deformed by later reactivation. Chorlton (1983) and Wilton (1983, 1984) identified pre- to syn-late Devonian sinistral wrench faulting accompanied or followed by deposition of the Windsor Point Group, and Chorlton (1983) further interpreted post-late Devonian (likely Carboniferous) reverse faulting accompanied by dextral shearing in the east-west splay of the fault.

Based on new mapping and geochronological data, Dubé et al. (1994) attempted to better define the timing of deformation in the Cape Ray Fault zone, and its implications for the broader Appalachian orogen. One of the keys to unravelling this story is the relationship of the rocks lying east of the fault zone (the Port aux Basques "gneiss", now known as the Grand Bay Complex of Burgess et al., 1993), to rocks within the fault zone, the Windsor Point Group. Along the coastal exposures, near the contact with the Windsor Point Group, amphibolite facies metamorphism in the Grand Bay Complex (westernmost subdivision of the Port aux Basques gneiss) is retrograded to greenschist facies. At the boundary, a mylonitic zone is well developed, with stretching lineations now plunging toward the SSE. Good kinematic indicators such as shear bands also indicate reverse dextral motion. Furthermore, van Staal et al. (1992) noted a progressive increase in strain in surrounding rocks as the Cape Ray Fault Zone is approached.

Further inland along the trace of the fault (Isle aux Morts River area) an important variation in the style of deformation along the fault is noted. The Port aux Basques gneiss (Grand Bay Complex) is again retrograded along the main fault zone, and a reverse sense of motion is indicated. However, a significant difference from the southern coastal exposure was noted: close to the boundary between the Cape

Ray Igneous Complex and the Windsor Point Group an additional mylonite zone is developed, with both dextral and later sinistral motion indicated. This latter sinistral mylonite zone is partly stitched by the 384 Ma Strawberry Granite, but a 100m mylonite zone with sinistral indicators persists inside the Strawberry Granite (Figures VI.1 and VI.3).

In the vicinity of the Cape Ray Fault zone an age of peak (amphibolite facies) metamorphism of 412 Ma based on titanite is indicated for the Port aux Basques gneiss (Grand Bay Complex), with a cooling age from syn-kinematic hornblende and biotite set at 406-403 Ma (Figure VI.3). The waning of the period of deformation is also set by the 386 Ma intrusive age of the Isle aux Morts Brook Granite (Dubé et al., 1994), which cuts across the Cape Ray Fault zone inland. Van Staal et al.'s (1992) observations of two generations of folding, with Z-shaped folds consistently overprinting S-shaped folds, led them to interpret a change from a sinistral to a dextral transpressive regime along the Cape Ray Fault, *i.e.*, that the sinistral and reverse shears predate the dextral shearing. Piasecki (1989) emphasized that these movements included important components of generally west-directed thrusting. In addition, Dubé et al. (1991, 1992) suggested that post-late Devonian movement on the Cape Ray Fault is compatible with a transpressive, dextral deformation regime.

Recognition of late shearing has a bearing on the present study, because the Cape Ray Fault can be traced offshore, at least as far south as St. Paul Island (Figure II.5).

The Windsor Point Group (Brown, 1975; 1976; 1977; Figure I.3) which crops out between the two strands of the Cape Ray Fault, comprises bimodal volcanic, volcaniclastic and sedimentary rocks and was considered to be Emsian to Eifelian in age by Chorlton (1983). However, the rocks are highly strained and variably mylonitized, and are now thought to have had a complex structural history (Wilton, 1983; Dubé et al., 1991; 1992). Dubé et al. (1994) noted that the Windsor Point Group contains Ordovician rocks (rhyolites ranging in age from 492 to 450 Ma) which are intruded by Silurian igneous rocks. Significant late Devonian-Carboniferous strike-slip fault movement is interpreted along the Cape Ray Fault (Part I of this study). For this reason, it seems likely that units of very different ages and affinities have been tectonically juxtaposed within the Cape Ray Fault zone, and are represented by the high strain zones within the Windsor Point Group (van Staal et al., 1992).

The Windsor Point Group can now be considered to consist of rocks of at least two ages: an older Ordovician component, and a younger, probably late Devonian component (Chorlton, 1983; Wilton, 1983; Dubé et al., 1994). The Lower Paleozoic history of the Windsor Point Group will not be further discussed here. With respect to the younger rocks, Wilton (1983) gives ages of 377-369 Ma for Windsor Point ignimbrite and the associated Windowglass Hill granite, respectively.

This would make the younger rocks late Devonian in age and equivalent to similar rocks in Cape Breton Island and other parts of the Maritimes (*e.g.*, McAras Brook and Fountain Lake Groups, Ryan et. al., 1987; Yeo and Ruixiang, 1987; Fralick and Schenk, 1981) which are in part coeval with Horton and Anguille rocks. The distribution of the Windsor Point Group within a southerly-opening fault splay suggests that it represents infilling of the northern extent of the Cape Ray graben as mapped offshore.

If the Windsor Point Group and equivalent rocks in the Maritimes Basin represent the earliest development of the post-Acadian fault-bounded alluvial basin system, then these rocks in a broad sense are equivalent to the Horton Group. Chorlton (1983, p. 10) states that "it is possible that the Anguille Group was deposited before the cessation of plutonism and ... Stage 3 [Windsor Point related] tectonic activity". In this scenario, the Cape Ray Fault under the Cabot Strait may locally represent an eastern limit of Horton sedimentation in this area, and the "high block" under the Strait represents an offshore extension of the western part of the Bay du Nord Group of Chorlton (1983), now termed the Grand Bay Complex (Burgess et al., 1993)(Figure VI.1).

The position of the Windsor Point Group along strike from possibly Horton-age Devonian-Carboniferous clastics along the Red Indian line (*e.g.*, Belt, 1969; Colman-Sadd et al., 1990), further suggests that the younger rocks belong to a stage of Devonian and early Carboniferous basin development.

Chorlton (1983) considered that the development of the Cape Ray Fault was the culmination of a series of processes that were initiated upon final collision of the North American continental margin: ophiolite imbrication, thrusting in the southeastern island arc terrane, tectonic burial and regional metamorphism, plutonism, and finally, the beginning of a compressive simple shear system. According to her, the Windsor Point Group was deposited in an intracratonic wrench basin controlled by the early Cape Ray Fault - this is the Cape Ray graben of the present study (Figure II.5). Although deposition of the Windsor Point Group was halted by oblique, high angle, northwest-directed thrusting, the Cape Ray graben offshore appears to have been reactivated as a normally-faulted basin sometime in the middle Carboniferous. Although Lower Viséan rocks are absent, Upper Viséan rocks may be present, as in the Deer Lake Basin (Hyde, 1979). This activity was focussed along the western strand of the onshore fault, *i.e.*, the western boundary fault of the graben offshore which merges with the Cabot Fault zone, underwent dip-slip during Westphalian time, witnessed by the westward thickening Barachois wedge on seismic profiles, as discussed earlier (*e.g.*, Figure II.10: Lines 1121, 1119, 1107).

In summary, the two data sets in the area - the onshore geology and the offshore seismic data - can be combined to suggest that the mid- to late Devonian Horton basins, associated with post-orogenic extension, were inverted and largely destroyed in post-late Devonian times along the Cape Ray Fault zone. Only scattered erosional remnants of these basins remain.

VI.2.5 Bay du Nord Group and Bay le Moine Shear Zone

The Bay du Nord Group includes phyllitic, fine-grained clastics, volcanoclastics, sandstones and conglomerates, and outcrops to the east of the Bay le Moine shear zone, where it is intruded by the La Poile batholith and the Petites Granite to the south. Lin et al. (1993) correlated the Bay du Nord Group with the Harbour le Cou Group, based on virtually identical deformation histories. They pointed out that the only significant difference between them was one of metamorphic grade, with the Harbour le Cou Group containing amphibolite facies and the Bay du Nord Group containing greenschist facies mineral assemblages. Sedimentary structures are commonly preserved in the latter.

Although the Bay du Nord Group experienced a complex early deformation history, much of the later deformation is associated with dextral movement along the Bay le Moine shear zone, which records a complex history of both ductile and brittle deformation (Lin et al., 1993; Figures VI.1 and VI.3). The zone contains a concentrated band of strong dextral shear, about 1 km wide, along which displacement was oblique-dextral. The F3 generation of folds, associated with D3 dextral shear, with strong "Z" asymmetry, become tighter near this shear zone. An apparently later generation of kink bands (F4) also appears to be related to movement along the Bay le Moine shear zone - like F3, the F4 folds may be related to the D3 dextral shear (Lin et al., 1993).

Other major lithological units in the area are affected by the Bay le Moine shear zone. The Harbour le Cou Group and Rose Blanche Granite are strongly sheared, with mylonite zones displaying a subvertical, northeasterly-striking foliation. Various kinematic indicators show dextral oblique shear with an apparently extensional, east-side down vertical component.

Some constraints on the timing of movement in the Bay le Moine shear zone exist. The older, ductile deformation structures are intruded by the 397 Ma Petites Granite (G. Dunning, pers. comm., 1995, Figure VI.3), but the granite body itself is dextrally offset by about 2.8 km along the shear zone (Lin et al., 1993). Quartz veins within a 300 m wide breccia zone are inclined at a low angle to the shear zone, and indicate significant normal extension during the brittle and dextral movement. These authors suggested that this extension caused down-to-the-east movement on the Bay le Moine shear zone, perhaps explaining the change in metamorphic grade across the shear zone between the amphibolite-grade Harbour le Cou and greenschist-grade Bay du Nord Group.

These data show that ductile development of the Bay le Moine shear zone occurred prior to the early Devonian, possibly associated with the widespread late Silurian thermal event in the area (Burgess et al., 1993). Some brittle movement, however, affected the early Devonian Petites Granite, and since this later phase of movement is dextral transtensional, the Bay le Moine shear zone may have been a locus of middle Devonian ("pre-Horton?") basin development. Alternatively, the Bay le Moine shear zone may be an easterly kinematic equivalent of the Cape Ray fault zone, because the late dextral motion matches that in the flexure (E-W tear fault continuous with the Gunflap Hills Fault; Lin et al., 1994) of the Cape Ray fault zone (Dubé et al., 1994).

VI.2.6 Bay d'Est Fault Zone, La Poile Group, and Cinq Cerf Fault Zone

The Bay d'Est Fault zone forms the western boundary to the La Poile Group and is a composite zone of basement-cover imbrication by which the La Poile Group was thrust westward over the Bay du Nord Group. The La Poile Group (O'Brien and O'Brien, 1990; O'Brien et al., 1991) consists of a thick succession of Silurian felsic, subaerial volcanic and fluvial clastic rocks and outcrops to the east of the Bay d'Est Shear Zone. These rocks were deposited in two separate subbasins between 431 and 417 Ma, and are recognized as a Silurian cover sequence deposited on an Avalonian (late Precambrian-Ordovician) basement. Both basement and cover rocks underwent ductile deformation, metamorphism and plutonism in the late Silurian tectonothermal event documented elsewhere on the southwest coast (Dunning et al., 1990a), and post-dated by the intrusion of the Chetwynd granite at 390 +/-3 Ma. During the Devonian, magma was emplaced at high crustal levels, while the area was affected by either pure extensional or transtensional brittle deformation, and cooling of the basement and cover occurred. O'Brien et al. (1991) considered the relationship between Silurian and Precambrian rocks in the Hermitage Flexure to indicate its affinity with the Avalon Composite Terrane (Keppie, 1985; 1989) as recognized in other parts of Maritime Canada.

The Cinq Cerf Fault Zone is a northwest-directed thrust complex which bounds the La Poile Group to the east and is cut by late Silurian post-thrusting granites (O'Brien et al., 1991). This zone is comparable to the Eastern Highlands Shear Zone in Cape Breton Island (Raeside and Barr, 1990), based on aeromagnetic and gravity data (Loncarevic et al., 1989), and on the fact that both are stitched by Devonian plutons. These considerations also suggest a correlation of rocks to the east of the fault zone, the Bras d'Or terrane in Cape Breton Island, and the Cinq Cerf Complex and Grey River Enclave in the Hermitage Flexure (*e.g.*, Barr and Raeside, 1989; Loncarevic et al., 1989; Colman-Sadd, pers. comm., 1996).

VI.3 Geology of Rocks Considered "Basement" to the Maritimes Successor Basin: Northern Cape Breton Island

VI.3.1 Blair River Complex

This terrane (Figures VI.1, VI.4) comprises an assemblage of quartzofeldspathic, amphibolitic and feldspathic gneisses which are intruded by igneous rocks displaying a wide compositional variation (Barr and Raeside, 1986; 1989). The intrusive rocks give late Grenvillian metamorphic ages but most of these rocks were retrograded, especially along shear zones, probably in Devonian and Carboniferous time (Barr et al., 1987). This terrane is correlated with the Humber Zone in western Newfoundland (Barr and Raeside, 1989; Loncarevic et al., 1989).

VI.3.2 Wilkie Brook and Red River Faults

These faults are the remnant strands of a displacement system separating the Grenvillian Blair River Complex from the Aspy Terrane, and along which these two elements were brought into juxtaposition between late Silurian and late Carboniferous time (Barr et al., 1994; Raeside and Barr, 1992; Figures VI.3 and VI.4). The Wilkie Brook Fault zone is 50 to 1300 m wide, while the Red River Fault zone is 200 to 500 m wide. The Red River fault is a splay of the Wilkie Brook fault which forms the southern boundary of the Blair River Complex against the northwest Aspy Terrane. These faults generally contain strongly cataclased mica schists, some with blastomylonitic textures. Observations from the fault zones suggest a period of movement between the time of amphibolite-granulite facies metamorphism of Helikian (and older) sedimentary and igneous protoliths (Raeside and Barr, 1992), probably the same late Grenvillian event that affected the Blair River Complex, and a second greenschist facies retrograde metamorphism which affected the Blair River Complex, Aspy Terrane and mylonites in the fault zones (Raeside and Barr, 1992), and probably was related to Silurian-Devonian terrane accretion. Open kink-band structures indicating late brittle movement also occur, and were attributed by Raeside and Barr (1992) to Carboniferous or younger movement.

VI.3.3 Aspy Fault

For about 40 km southwestward of Cape North the Wilkie Brook Fault is paralleled by the Aspy Fault, which branches into a number of splays in the vicinity of the Park Spur granite (Figure VI.4); south of this point, displacement on the fault system was likely partitioned along various combinations of these splay faults. The latest strand of the fault to move is shown as a branching "late steep fault" by Lynch and Tremblay (1994). It extends across most of the highlands (Raeside and Barr, 1992), to where it trends offshore along the southern boundary of the Mabou Highlands (Lynch and Tremblay, 1994; Figure VI.4). The earlier manifestations of this fault, however, are present throughout the southern part of the Aspy terrane, and these represent the development of this part of the Aspy terrane as a shear zone during the Carboniferous. Although no directional indicators have been observed onland, the fault is here interpreted to record dextral displacement, because of its continuation offshore to the north into the Cabot Fault system, which has been interpreted as dextral in Part I of this study (Figures II.5 and II.8).

The Aspy Fault, where mapped in the north, represents conditions of brittle deformation, which developed a very narrow, mostly covered, yet discrete, fault zone. Where exposed, it displays common brittle fracturing, accompanied by quartz and calcite veining (Raeside and Barr, 1992). Some age constraints are discernible from rocks cut by the fault. Both the Windsor Group and the 352 +/-13 Ma Margaree Pluton (O'Beirne-Ryan et al., 1986) have been affected by the Aspy Fault, indicating post-Viséan movement.

Mapping from seismic data offshore (Part I of this thesis) has revealed that the Wilkie Brook and Aspy Faults define the boundaries of a flower structure that has brought Aspy terrane rocks up through and possibly radially over Carboniferous rocks (Currie, 1977). From this mapping it is clear that these faults are part of the regional Cabot Fault displacement system.

The northern, discrete portion of the Aspy fault system appears to have been a major focus of lateral displacement, and subdivides the Aspy terrane into two parts: an eastern part consisting of the mainly metamorphic rocks to the north and east of the Park Spur granite, and a western part lying south and west of this point. Because of the significant amount of strain and dextral displacement inferred from the northern Aspy fault, and its splayed and branched fault system equivalent in the south, these two parts of the terrane are interpreted to have been separated by up to 25 km (Figure VII.1) at the onset of major strike-slip movement in the early Carboniferous. These two further breakdowns of the Aspy terrane will be central to arguments made for reconstructions in later chapters, and here are informally termed the "west Aspy terrane" and "east Aspy terrane".

The west Aspy terrane has experienced internal dextral movement, as the Margaree Shear Zone of Lynch and Tremblay (1994) is offset by about 15 km along the strands of the "late steep faults". It is likely also that significant amounts (tens of kilometers?) of dextral displacement are represented, but not directly measurable, across the array of splayed faults that traverse the entire western Aspy terrane. For the purposes of the present reconstructions however, the western Aspy terrane will be treated as a single entity.

This subdivision allows the point to be made during the reconstructions that the Aspy terrane includes the remnants of a major shear zone, and that the various pieces of the terrane now segmented by brittle faults were probably originally dispersed over considerable distances.

VI.3.4 Aspy Terrane

The Aspy terrane includes a range of low- to high-grade metamorphic rocks of volcanic and sedimentary clastic origin, and granitoid orthogneisses (Barr and Raeside, 1986; 1989). These are intruded by extensive suites of granitic rocks, some Silurian but mostly Devonian in age. Widespread Devonian plutonism is a diagnostic feature of the Aspy. The low grade rocks are in greenschist facies and include mafic and felsic pyroclastics interbedded with clastics; the felsic volcanic units have yielded U-Pb (zircon) igneous ages of 433 +7/-4 Ma (Dunning et al., 1990b). The higher grade rocks are mostly metamorphosed to amphibolite facies but, based on the presence of kyanite-K-feldspar assemblages, some of these rocks are interpreted to have experienced pressures over 850 MPa (Plint and Jamieson, 1989; Raeside and Barr, 1992; Jamieson et al,. 1987). Within the high-grade metamorphic rocks, an igneous age similar to that of the low-grade volcanic rocks was obtained for tonalitic orthogneiss (433-20/- [illegible], U/Pb, Jamieson et al., 1986; Figure VI.3), thereby establishing the age of these protoliths as Ordovician to Silurian.

The Fisset Brook Formation (Blanchard et al., 1984; Figure VI.4) comprises unmetamorphosed tholeiitic bimodal volcanic suites interbedded with alluvial fan, lacustrine and rare fluvial sediments, ranging in age from early Devonian to late Carboniferous. Blanchard et al. (1984) concluded that the volcanism started at MacMillan Mountain (in the southeastern Aspy Terrane near the boundary with the Bras d'Or) and migrated westwards toward the Magdalen Basin depocentre.

Barr et al. (1994) summarized aspects of Aspy terrane plutonic rocks in the following manner: (1) orthogneisses cogenetic with volcanic rocks within the ~430 Ma volcanic-sedimentary packages; deformation and metamorphism are clustered around 400 Ma, (2) S-type granites which as a group plot around 370 Ma and are probably related to crustal thickening and anatexis as the Bras d'Or terrane docked against the Aspy terrane, and (3) late Devonian plutons (the youngest around 365 Ma) which are cogenetic with the Fisset Brook Formation, and generally have a linear distribution controlled and modified by Devono-Carboniferous extensional and strike-slip faulting. These occur in both the Aspy and Bras d'Or and provide the first clear link between the two terranes.

The Aspy terrane is correlated in general with the Gander Zone in Newfoundland, mainly on the basis of ages of similar Silurian tectonothermal events (Dunning et al., 1988; 1990a; O'Brien et al., 1991). Specifically, middle Silurian to early Devonian high grade metamorphism in the Aspy terrane (Reynolds et al., 1989; Barr and Raeside, 1989) is similar in age to events concentrated along the Hermitage Flexure in southern Newfoundland. Furthermore, cooling ages for metamorphic minerals based on the Ar/Ar method are concentrated in the Lower to Middle Devonian for both areas

(Chorlton and Dallmeyer, 1986; Reynolds et al., 1989)(Figure VI.3).

VI.3.5 Eastern Highlands Shear Zone

This fault system separates the Aspy terrane from the Bras d'Or terrane, and shows both a complex geometry and history of movement (Raeside and Barr, 1992). Kinematic indicators show dextral transpressional movement, with a NW or N side up offset along the entire length of the shear zone (Lin and Williams, 1994), but this probably only represents its latest recorded stage of development. It is a zone of mylonites and chlorite schists, ranging from 200 to 1300m in width. It also appears to have undergone greenschist facies metamorphism after cessation of movement, similar to the case of the Wilkie Brook fault zone, with schistosities developed parallel to regional schistosities, oblique to the trend of the fault zone (Raeside and Barr, 1992). Currie (1977) and Raeside and Barr (1992) noted the presence of thrust geometries along some splays of the Eastern Highlands Shear Zone near Ingonish (Figure VI.4).

A varied and complicated history of movement is substantiated by several structural and intrusive relationships, illustrated by the following observations (Raeside and Barr, 1992): (1) an upper age limit is imposed by the Clyburn Brook Fault, which dextrally offsets the southern and perhaps major strand of the Eastern Highlands Shear Zone, and is itself cut off by the Cameron Brook granodiorite of 402 +/-3 Ma (Raeside and Barr, 1992; Dunning et al., 1990b), while (2) a splay of the fault has locally deformed the Horton Group, but contains clasts of the 373 +/-3 Black Brook Suite (Dunning et al., 1990b) in the shear zone. This suggests that such splays of the fault experienced their terminal movement in latest Devonian through early Carboniferous time (Figure VI.3), and indeed, that the northern area of the fault was active during intrusion of the Black Brook Suite.

The fact that the southern strand of the Eastern Highlands Shear Zone is stitched, albeit indirectly, by the Cameron Brook granodiorite, and the resemblance of this intrusive body to other plutons in the Aspy terrane, suggests that the Aspy and Bras d'Or terranes were juxtaposed, at least over this portion of the fault zone, by early Devonian time (Barr et al., 1994)(Figure VI.3).

VI.3.6 Bras d'Or Terrane

The Bras d'Or terrane is defined by a diagnostic association of low pressure pelitic and calcareous gneisses, mainly clastic, late Proterozoic metasedimentary units (555-565 Ma), and complex development of early Ordovician subduction-related granitic plutons (Raeside and Barr, 1990; 1992; Barr et al., 1990). Barr et al. (1994) pointed out that the map exposure of the Bras d'Or terrane preserves a thick profile of the crust: plutons in the western part of the terrane, *i.e.*, adjacent to the Eastern Highlands Shear Zone, were emplaced at levels of between 23-25 km (based on hornblende geobarometry), and these depths are seen to decrease eastward.

Recognition of this assemblage has enabled the Bras d'Or to be correlated with the Brookville Terrane in New Brunswick (Barr and White, 1989) and with similar rocks on the south coast of Newfoundland. Dunning and O'Brien (1989) reported the first documentation of Proterozoic units in the Hermitage Flexure with a protolith age of 686 +33/-15 and a metamorphic age of 579 +/-10 from the Grey River gneiss. Other late Proterozoic to early Ordovician intrusive ages from plutons in the area, which intrude stratified units, are thought to be correlative with metamorphic units from the northern part of the Bras d'Or terrane (Raeside and Barr, 1990). These units are tectonically bounded by a possible equivalent of the Eastern Highlands Shear Zone, the Cinq Cerf fault zone, which, like the Eastern Highlands Shear Zone, is stitched by Devonian plutons. Late Proterozoic plutons occur to the northwest of the Cinq Cerf fault zone (Evans et al., 1990) and may be analogous to the Cheticamp pluton, thought to represent allochthonous Bras d'Or within the Aspy terrane (Raeside and Barr, 1990).

Discussions of the relationship between the Bras d'Or and Aspy terranes have in fact centered around the interpretation of the 550 Ma Cheticamp Pluton of the Aspy terrane (Jamieson et al., 1986) which displays faulted contacts with the standard Aspy units but is relatively undeformed, with no thermal overprinting, and no resetting of muscovite ages (Barr et al., 1994). Raeside and Barr (1990) considered the Cheticamp Pluton as a klippe of Bras d'Or which at one time extended across the Aspy terrane, thereby indicating that the former was thrust westward over the latter.

Barr et al. (1994) used isotopic data to suggest that the basement to the Aspy and Bras d'Or terranes was identical, or at least had geochemical features in common. However, the results of U-Pb dating from twelve units in the Aspy and Bras d'Or terranes by Dunning et al.(1990b) supported the interpretation that the Aspy and Bras d'Or terranes were not adjacent to each other, and therefore did not share a common tectonic history, until the Devonian. This indirectly supports large amounts of oblique-sinistral motion in the Silurian (see Figure X.2, Part III). Lynch and Tremblay (1992) suggested that the Bras d'Or may actually be the basement to the Aspy volcanic arc, and that the two may be separated by a Taconic age unconformity.

VI.3.7 East Bay-McIntosh Brook-George's River Faults

The boundary between the Bras d'Or and Mira terranes is likely marked by a series of roughly colinear faults: the McIntosh Brook Fault in the Boisdale Hills (Raeside and Barr, 1990), and northward by the George River Fault which is characterized by considerable Carboniferous movement (Gibling et al., 1987). The southwestern extension of the boundary probably runs across the East Bay of Bras d'Or Lake where it is buried under Carboniferous cover in the extreme southwest of Cape Breton Island. Loncarevic et al. (1989) trace it offshore to the northeast on the basis of potential field data.

VI.3.8 Mira Terrane

The Mira terrane is characterized by a late Precambrian volcanoclastic succession, which is intruded by mainly late Precambrian granitic to dioritic plutons (Cormier, 1972). This package is separated by a major unconformity, or by faulting, from a sequence of sedimentary and volcanic rocks of late Precambrian to late Cambrian age. Clearly the Mira terrane had already undergone complex tectonic evolution by the middle of the Cambrian (Barr et al., 1990; Barr and Raeside, 1989; Barr et al., 1994). The Mira is correlative with Avalon *s.s.* rocks in both the Hermitage Flexure and Avalon Peninsula of Newfoundland (O'Brien et al., 1983).

The relationship between the Mira and the Bras d'Or terranes is unclear. Some workers (*e.g.*, Currie, 1986) have suggested that Bras d'Or-like rocks in New Brunswick underlie the Avalonian platform succession. Barr and Raeside (1989) rejected this idea of the Bras d'Or as the Avalonian basement, proposing instead that it is an adjacent terrane with its own unique Precambrian tectonic and stratigraphic history.

VI.3.9 Other Faults

An important contribution to the body of structural data on Cape Breton Island came from Currie (1977) who presented observational and circumstantial evidence for thrust faulting of pre-Carboniferous over Carboniferous rocks around the periphery of the Cape Breton Highlands. However, as Currie (1977) points out, these interpretations vary in their reliability, and are based upon (in order of decreasing reliability), observed thrust planes, geological relations apparently requiring thrusting, and geological anomalies resolved by the assumption of thrusting. The main examples of these thrust faults are indicated in the compilation of Figure VI.4; a number have been re-interpreted as extensional faults by later workers. (For a detailed description of the thrust faults, refer to Currie, 1977).

The thrust faults which fall into the "observed" category lie along lithological boundaries (identified on Figure VI.4). This type of contact was presumed by Currie (1977) to persist, and to represent a common mode of thrusting, for considerable distances northward and southward of the exposed features. He also pointed out that "additional indirect evidence for large-scale thrusting can be gleaned from the tendency of these contacts to follow topographic contours, even though the dips of the rocks are commonly steep" (Currie, 1977; p. 2939). Furthermore, the map pattern geometries exhibited in and around river and stream valleys (specifically, the tendency of the Carboniferous to be indented and exposed in the valleys) is strong evidence for the structural transposition of basement upon Carboniferous rocks. Similar examples of this were cited by Milligan (1970) and Fyson (1967). Probably the best example is present along the Grand Anse River, at the northern margin of the western Aspy terrane, where, as Currie (1977, p. 2939) describes it, a "narrow finger of Carboniferous rocks extends 10 km from the ocean in remarkably sinuous fashion, with large indentations in several creek valleys".

Currie (1977) concluded that thrusting was widespread and significant in northwestern Cape Breton Island, but was not able to determine the timing and scale of the thrusting. The fact that these thrusts place mid-Paleozoic metamorphic and plutonic rocks over virtually undeformed Tournaisian and Viséan sedimentary rocks has implications for the tectonic assembly of Cape Breton Island, as discussed in Section VIII.3.4.

VI.4 Correlation of "Basement" Zone and Terranes between SW Newfoundland and Northern Cape Breton Island

Correlation of zones and terranes between Cape Breton Island and Newfoundland now seems to be fairly well established, although there are minor differences of opinion among workers. For example, some authors place the whole of the Port aux Basques gneiss in the Gander Zone (*e.g.*, Chorlton, 1983) while others think that only the Port aux

Basques Complex (middle unit of the tripartite subdivision of the gneiss) belongs there (Lin et al., 1993), and that the Harbour le Cou Group and Grand Bay Complex should be placed within the Exploits subzone of the Dunnage Zone (Williams et al., 1988). Further east, Barr and Raeside (1990) thought that the Aspy Terrane and the La Poile Group were correlative within the Gander Zone, whereas O'Brien et al. (1991) have argued that the La Poile Group is broadly comparable to the Avalon Composite Terrane. Lin et al.(1994; their Figure 2), did not draw such distinctions, placing rocks between the Cape Ray Fault and the Bay d'Est shear zone within the undifferentiated "Exploits and Gander", and rocks east of the Bay d'Est shear zone within the Avalon Zone (Figure VI.1).

An interesting alternative view of the zonal partitioning in southern Newfoundland was presented by Currie and Piasecki (1989). These authors assigned all rocks south of the Cape Ray - Gunflap Hills Fault to their Bay du Nord Subzone, which they characterized as one of a series of small terranes bounded by subhorizontal faults and accreted at the St. Lawrence Promontory during Silurian sinistral shearing. This latter placement is particularly appealing, as it, in effect, considers rocks south of the Cap Ray-Gunflap Hills fault system to lie within the Cabot Promontory of Lin et al. (1994). This is the portion of the outboard terranes which is interpreted by Lin et al. (1994) to have collided with the St. Lawrence Promontory.

Possible correlations between tectonostratigraphic zones in southwest Newfoundland and terranes in northern Cape Breton Island are presented in Figure VI.1. These correlations are based on the present basin mapping, on magnetic anomaly data, and on the review of onshore basement geology of the preceding sections.

As suggested earlier, the Cinq Cerf fault zone may be the equivalent of the Eastern Highlands Shear Zone in Cape Breton Island, a correlation also implied by the potential field maps of Loncarevic et al.(1989; in particular their Figure 6: the horizontal gradient of the first vertical derivative of the total field magnetic anomaly). In the maps presented here, these two lineaments can be connected along the margins of a magnetically low area, as shown in Figures VI.1 and VI.2. This possible boundary between the Gander and Avalon Zones appears to be offset by a series of east-trending tear faults which step the Bras d'Or/Aspy boundary progressively westward in the direction of Cape Breton Island. Offshore, tear faults associated with the Eastern Highlands Shear Zone, which are inferred from magnetic data by analogy with those defined by seismic data further north ("EW9", Figure II.5) are straddled by a pronounced circular magnetic high which may represent a pile of Fisset Brook-equivalent volcanics (Section VI.3.4) extruded during Devonian extension (Lynch and Tremblay, 1994; Figure VI.3). Another smaller magnetic high, situated about 30 km offshore, may also represent volcanic accumulation. These two features in particular are notable because their northern boundaries appear to be controlled by east-west faulting. It is entirely consistent with the onshore geology to interpret these faults as tear faults (labelled "tf" on Figure VI.1), perhaps analogous to the Gunflap Hills tear fault (Lin et al., 1994). Such faulting would have allowed greater telescoping of Avalonian terranes against more westerly terranes closer to the focal point of the St. Lawrence Promontory.

The Bay le Moine shear zone can also be traced a considerable distance offshore, in this case parallel to the Cinq Cerf Fault and close to the northwest margin of the magnetically low trend. This is an interesting correlation because of the identification of mid- to possibly late Devonian dextral transtension on this fault (Lin et al., 1993). The area of low magnetic signature, then, may represent a small linear Horton or pre-Horton basin situated atop a collapsed Salinic-Acadian thrust. Caution must be taken with this interpretation because the magnetic low continues onshore in the Hermitage Flexure, and becomes even more pronounced under the Burgeo Intrusive Suite, where no Horton sediments are preserved.

The late Silurian Isle aux Morts fault zone may tentatively be traced for about 40 km southwestward along the eastern margin of the magnetic low.

The magnetic low itself is terminated by a trend of weak magnetic highs which bear approximately N20E, and appear to connect the large Eastern Highlands Shear Zone highs in the south with a similar trend under the Cape Ray graben. This trend may also represent an outpouring of Devonian volcanics within an area of intense east-west shearing. Alternatively, it may indicate the presence of Silurian (and older?) mafic rocks caught up in both the northeast- and east-trending shear zones.

The Grand Bay Thrust and Grand Bay Complex can also be traced about halfway across the Cabot Strait. The "high block" is the easternmost recognizable major structure on the seismic data set utilized in this study (because of strong water bottom multiples in the Sydney Basin), and its eastern boundary lines up well with the Grand Bay thrust. Seismic interpretation suggests that some extension on this fault has occurred along the eastern edge of the "high block".

The Grand Bay Thrust is also clearly traceable along the steep magnetic gradient which rises westward under the Cape Ray graben. The high magnetic anamolies under the graben may be due in part to Devonian mafic volcanics, and may represent offshore preservation of mafic components of the the Windsor Point Group. However, this magnetic anomaly continues onshore underneath the Cape Ray Igneous Complex, which is also rich in mafic rocks. The most conservative interpretation is that the magnetic signature is produced by a complex combination of Ordovician to Devonian rocks. Such rocks are now thought to be tectonically interleaved in the Cape Ray fault zone (van Staal et al., 1992).

As shown in the first part of this study, the Cape Ray fault zone appears to terminate southward against, or merge into, the St. Paul fault zone, which was active during the Carboniferous, but which is probably itself a late expression of a middle Paleozoic tear fault.

VI.5 Faults as terrane boundaries in the St. Lawrence Promontory

The nature and distribution of the major faults in areas peripheral to the Cabot Strait have been discussed in the preceding sections and in Part I of this study. Some of these faults have played a major individual role in the final late Paleozoic assembly of North America, whereas others have been involved primarily in earlier, middle Paleozoic episodes of accretion, and will not be treated further here. It is useful to group these faults and boundaries according to their age of activity and their role in this process of assembly. The timing and role of these faults, and the relationships between them, are illustrated graphically in Figure VI.3, to which the reader is referred for the course of this discussion.

(1) Faults involved mainly in late Silurian accretion and orogenesis. In southwestern Newfoundland, the Isle aux Morts fault zone and the Grand Bay Thrust were involved in the metamorphism of the Port aux Basques gneiss terrane during Salinic events. A similar history is invoked for the Cinq Cerf fault zone, forming the eastern boundary of the La Poile

Group (O'Brien et al., 1991). In Cape Breton Island, the initial development of the Eastern Highlands Shear Zone, presently represented by its southern trace (Lin, 1993), locally occurred within a zone of mainly orthogonal convergence (Lin and Williams, 1992) within a larger regime of oblique-sinistral displacement seen along the orogen (Figure X.2, Part III). The Cape Ray Fault undoubtedly had a significant Silurian history. Although early stages of movement cannot now be recognized, it is likely that the Aspy Fault and associated splays in Cape Breton Island also were active in the Silurian.

(2) Faults with late Silurian through mid-Devonian displacement. The Bay le Moine shear zone and the Cape Ray Fault represent this period of movement in the Promontory area. The former fault was transpressional during this period (Lin et al., 1993), but with no sense of offset interpreted. The Cape Ray fault zone shows clear evidence of a change from late Silurian sinistral to early Devonian dextral motion (Dubé et al., 1994 and references therein). Again, in Cape Breton Island, discrete periods of movement within this time frame are not identifiable on the major faults because of later overprinting.

(3) Faults with mid-Devonian extensional reactivation or activation. The main fault in this category is the Bay le Moine shear zone, which has dropped greenschist facies rocks in the Bay du Nord Group down against the higher grade Port aux Basques gneisses, as discussed in Section VI.2.6. The

Margaree Shear Zone of Lynch and Tremblay (1994) represents crustal extension that was probably not focussed along a discrete boundary.

(4) Late Devonian through Carboniferous strike-slip faults, with both transpressional and transtensional phases. The Red River Fault, Wilkie Brook Fault, Aspy Fault, Cabot Fault, Hollow Fault, and Cape Ray Fault fall into this category. These faults, and perhaps a few others initiated later in the Carboniferous (*e.g.*, St. George's Bay Fault) are the main controlling faults for the development of the Maritimes Basin in this area.

Of the above faults, the Red River Fault, Wilkie Brook Fault, Cape Ray Fault (including the Gunflap Hills tear fault) and the Cabot Fault, as well as the Eastern Highlands Shear Zone, can be considered terrane boundaries, at least in the sense of the middle Paleozoic accretion of the orogen, and some of them are indeed correlative with each other across the Cabot Strait. In Part I the Wilkie Brook Fault in Cape Breton Island has been shown to be part of the Cabot Fault System, continuing across the Cabot Strait to connect with the Cabot Fault in Newfoundland. However, southward in Cape Breton Island, most of the later strain on the Cabot Fault system becomes focussed on the Aspy rather than the Wilkie Brook Fault. This is an example of how a major tectonic boundary (separating the Humber and Dunnage Zones in Newfoundland) evolved into a new displacement system in the late stages of orogeny. The Cabot Fault probably juxtaposes

Humber Zone against Gander Zone rocks in the southern Cabot Strait, as is shown in Figure II.5 and discussed in Chapter IV. The Aspy Fault, and therefore the Cabot Fault system in the southern Cape Breton Highlands, separates Aspy terrane (Gander Zone) rocks on either side.

The array of faults which bound and subdivide the Port aux Basques gneiss (Cape Ray Fault zone, Grand Bay Thrust, Isle aux Morts fault zone and Bay le Moine shear zone) may represent northerly splays of the Aspy Fault, with their motion being progressively deflected and focussed westward into the Aspy Fault. For example, the Cape Ray Fault bends westward into the east-west St. Paul fault zone to meet the Aspy Fault at St. Paul Island (Figures II.5 and II.8).

Loncarevic et al. (1989) presented a version of the same argument by suggesting a correlation between the Aspy and the La Poile "terranes" on the basis of potential field data in the eastern Cabot Strait-Sydney Basin area, as well as surface geology.

If these correlations can be made, then the Aspy Fault has had at least a two-stage history. In the first stage, elements of the Hermitage Flexure (Bay du Nord Zone), representing the Cabot Promontory, were brought against the St. Lawrence Promontory (probably represented by earlier Humber Zone elements since eroded). In a later Carboniferous stage, motion was kinematically linked with that on the Cabot Fault as megashear systems were developed. These ideas are more fully explored and depicted in the map reconstructions and schematic cross sections of Chapter VII.

Consideration of the above factors has important implications for the paleogeographic reconstruction that will be presented in subsequent chapters. In such reconstructions, one caveat to bear in mind is that the present trace of faults at the surface represents only the latest period of movement along the fault system. This has been discussed above for the Aspy Fault, which in places coincides with a major terrane boundary, but which clearly cuts through and subdivides the Aspy terrane during the Carboniferous. Other examples of this "updating" of terrane boundaries comes from north-central Newfoundland, where the Baie Verte Peninsula has been preserved, probably as a laterally escaping wedge (see detailed discussion in Section VIII.3.1), within a Cabot Fault zone that has split into two separate but very active strands, the Hampden and Green Bay Faults, during its latest Carboniferous movement. An early suture and terrane boundary, the Baie Verte Line, is preserved within the wedge and was not significantly reactivated in the Carboniferous (Hibbard, 1983).

Since late Paleozoic strike-slip faults only partially overprint earlier terrane boundaries, the question arises whether or not these should in themselves be considered terrane boundaries, since, as the succeeding chapters will show, these faults are responsible for the displacement and final juxtaposition of the terranes. This may be largely a question of semantics, but some precedent has been set in western North America, where far-travelled tectonic blocks included in "Baja British Columbia" have reached their present positions by strike-slip processes and are indeed treated as terranes (*e.g.*, Umhoefer et al., 1989; Beck, 1980; Irving et al., 1985). By analogy, certain fragments presently located in the Humber Zone may qualify for terrane status during the Carboniferous, as will be demonstrated in Sections VIII.2 and VIII.3.3.

VI.6 Nomenclature and Nature of Middle Paleozoic Orogeny in the Canadian Appalachians

Traditionally, the Devonian had been considered to be the period of major middle Paleozoic tectonic activity in the northern Appalachians, and much of this activity had been correlated with the Lower to Middle Devonian Acadian Orogeny (*e.g.*, Williams, 1893; Boucot et al., 1964; Neale et al., 1961; Rodgers, 1967; Cawood, 1993; Williams, 1993). As noted by Hibbard (1994), the Acadian Orogeny is now interpreted by most workers to represent interactions in the mid-Paleozoic between Laurentia and a distinct Avalonian crustal block, and to be markedly heterogeneous in terms of the distribution, intensity and timing of tectonothermal events which constitute it.

The advent of more precise radiometric dating techiques in the last several years, using mainly the U/Pb and Ar/Ar systems (Dunning et al., 1990a; O'Brien et al., 1991; Cawood et al., 1994a) has led to the identification in Newfoundland of at least two distinct orogenic episodes. The first occurred near the end of the Silurian, generally around 430-410 Ma, and the second in the early Devonian, centered around 390 Ma and ranging between 400-360 Ma (Figure VI.3).

The earlier of these two orogenic episodes is taken to represent peak conditions of high-grade metamorphism and polyphase deformation in the late Silurian. It is recognized in several areas of western and central Newfoundland, in the internal domain of the Humber Zone (Corner Brook Pond area and western Baie Verte Peninsula). Cawood et al.(1994b) consider that regional deformation, metamorphic mineral growth and cooling took place between 435 and 425 Ma. These ages closely resemble others from the Newfoundland Gondwana margin, in the Hermitage Flexure area.

Whereas the earlier pulse represents peak thermal metamorphic ages, the later represents cooling of metamorphic minerals and whole rocks below their blocking temperatures. These events often involve the resetting of peak metamorphic ages.

The Aspy Terrane also bears the marks of a two-stage orogenic cycle. Events here appear to be slightly younger than in Newfoundland, although the dates fall within the broad ranges outlined above for Newfoundland. As summarized graphically in Figure VI.3, high-grade metamorphism persisted into the early Devonian (Dunning et al., 1990b; Barr and Jamieson, 1991), while the second-stage cooling and uplift, as constrained by Plint and Jamieson (1989), occurred mainly in the mid-Devonian.

Some authors (*e.g.*, Dunning et al., 1990a; Keppie, 1992) have proposed to limit the use of the Acadian rubric to early to middle Devonian events, and designate the late Silurian event as the Salinic disturbance, after the usage of Boucot (1962). The Salinic is equivalent to the Late Caledonian orogeny or orogenic episode in Britain (*e.g.*, Coward, 1990). Alternatively, based mainly on evidence from north-central Maine, Hibbard (1994) invoked a two-stage kinematic scheme to account for this complex orogenic pattern, and proposed that the Silurian event be termed "early" Acadian and the Devonian events be termed "classic" Acadian. In the present work, the terms "Salinic orogeny" and "Acadian orogeny" will be employed. Reconstructions of paleogeography at the St. Lawrence Promontory will begin in the middle Devonian, thereby combining on the map the effects of both these orogenies.

Evidence for a general two-stage orogenic subdivision has also been seen on the local scale in southwestern Newfoundland. Based on observation of the rotation of the lineation along the coast in the Cape Ray Fault Zone, from SSW at amphibolite grade to SSE in greenschist facies rocks, Dubé et al. (1994) postulated a two-phase Acadian kinematic cycle, similar to that proposed by Hibbard (1994) and Nance and Dallmeyer (1993). The first stage consisted of sinistral transpression (oblique collision) in late Silurian time, with intense deformation and metamorphism to amphibolite facies conditions. The second stage involved dextral NE-SW convergence in early to middle Devonian time, with reverse dextral deformation and retrograde metamorphism to greenschist facies conditions.

In Cape Breton Island, dates of final amalgamation clearly postdate the foregoing ages of orogenic climax and cooling (Barr et al., 1994). The Blair River Complex and the Aspy Terrane show no evidence of amalgamation until the late Devonian. The Aspy and Bras d'Or terranes were amalgamated at about 350 Ma (Figure VI.3). Barr et al.(1994) interpreted very little activity during the Paleozoic within the Bras d'Or terrane until it was amalgamated with the Aspy, which experienced a distinct and complex Siluro-Devonian history.

The Bras d'Or and Mira terranes were sutured at about 300 Ma, although they were probably juxtaposed from the earliest Carboniferous, since Bradley and Bradley (1986) interpreted the pull-apart Big Pond Basin, situated at the Bras d'Or-Mira boundary, as being Viséan in age. Boehner and Giles (1986) also cite vertical displacement on the East Bay Fault during Westphalian time, and it is likely that this motion was oblique rather than purely orthogonal. Much of the motion at this boundary in the intervening time period, then, was strike-slip (as it likely was for the other boundaries as well).

It appears from these data that final amalgamation of terranes in Cape Breton Island occurred much later than the pulses of the Salinic and Acadian orogenies. This comes as no surprise, given the interpretation presented herein of parts of Cape Breton Island as a Carboniferous shear zone. In the case of the Aspy Fault, movement into the post-Carboniferous has split the terrane into two parts, and it becomes a question of semantics whether or not the western and eastern Aspy can be considered separate terranes.

VI.7 Preamble to Map Reconstructions

Each of the following chapters presents a map reconstruction for a particular time "slice", and has been organized in a common format as follows:

1. The regional setting for each time map will be described. This will present an overview of the tectonic configuration of the St. Lawrence Promontory area for the time period under consideration. To provide an even broader plate tectonic framework, reference will be made to the North Atlantic reconstructions which will be presented in Part III of the thesis.

2. The map data for the time slice will then be presented in point form. This section will outline the important mapped geological relationships on which the reconstruction is based, and will include data from on land geological map and other research compilations. It will also rely heavily on the structural elements map for the Cabot Strait and Bay St. George (Figure II.5).

3. The remaining section will function as a discussion section, and will incorporate interpretation of the mapped data sets with the broader implications arising out of the reconstructions themselves. The discussion will cover the time period between that of the previous map and that represented in the current map slice, and will be broken down geographically into a number of subheadings, the bulk of which will be repeated from chapter to chapter.

The plutonic bodies of Newfoundland and Cape Breton Island have been plotted on the maps for several reasons. Firstly, they provide reference points by which, in some cases, an idea of regional lateral offset can be gained. For example, the Devil's Room granite and the Gull Lake Intrusive Suite around White Bay have been clearly offset by Carboniferous motion on the Taylor's Brook Fault.

Secondly, they can aid in the reconstructions by constraining crustal levels now exposed at the surface. For example, the calderas and associated volcanics of the Topsails Igneous Complex evidently represent processes within the upper crust. By contrast many plutons in the Hermitage Flexure are associated with migmatites and high grade metamorphic rocks, and were intruded at lower and middle crustal levels.

Thirdly, many of the igneous bodies have been geochronologically dated, with the precision of this dating improving markedly in recent years. Such dates are potentially very useful in reconstructing terrane positions.

In the maps presented here, all plutons in place by middle Paleozoic time (Silurian to middle Devonian in age) are compiled for reference on the 380 Ma reconstruction. The major plutonic bodies are plotted graphically as ovals, with their association indicated, on the time-space diagram of Figure VI.3.

Fourthly, the composition and crustal origin of the magmas can provide valuable information. Several plutonic associations have been recognized in Newfoundland (*e.g.*, Williams et al., 1989; Fryer et al., 1992) and I have taken the liberty of plotting Cape Breton Island plutons according to their interpreted affinities. Hence, the Black Brook Suite is grouped within the St. Lawrence Association (or possibly the Ackley Association) because of its age and general post-orogenic character. Such data combined with terrane reconstructions and deep seismic data could eventually lead to more accurate mapping of lower crustal blocks and their position during the orogenic cycle.

It was outside the scope of this study to discuss fully the role of plutons (particularly since there appears to be considerable disagreement amongst workers on the ages of many of these bodies in Newfoundland). However, plutons of mid-Devonian to Carboniferous age are named on the reconstructions along with ε_{Nd} data where available. This exercise may stimulate workers in these areas to make use of my reconstructions in understanding the composition and origin of the melts.

A compilation of the nature of the data and the constraints involved in the reconstructions of Part II is found in Table II.

CHAPTER VII. MIDDLE DEVONIAN (ca. 380 Ma) RECONSTRUCTION

VII.1 Regional Setting and Salinic Heritage

This section will describe and illustrate middle Paleozoic events in the St. Lawrence Promontory area up to the end of Acadian mountain building in the mid-Devonian. The 380 Ma map (Figure VII.1) presents my model for the configuration of the geological elements at the end of this time period.

During the Silurian, large scale oblique sinistral convergence between outboard oceanic terranes of Iapetus and composite Laurentia took place, and resulted in the arrival of mainly oceanic terranes or subterranes into the promontory area (Figure X.3).

Currie and Piasecki (1989) described southwest Newfoundland as a "mosaic of subzones or terranes recognized by distinctive lithostratigraphy, plutonism and metamorphism", with generally south-directed shortening related to the collision of the Cabot and St. Lawrence promontories (Lin et al., 1994). A number of small accreted fragments may occur within Currie and Piasecki's (1989) Bay du Nord subzone (the area south of the Gunflap Hills fault generally referred to as the Hermitage Flexure).

Remnants of these terranes are today preserved in diverse configurations. Some are represented by basinal sediments, volcanics and plutonic rocks, recording the generation and destruction of a small Silurian ocean basin

(La Poile Group; O'Brien et al., 1991). Others are represented almost entirely by deep-seated plutonic rocks (*e.g.*, Burgeo Intrusive Suite), where much of the shallow crustal section has been lost to erosion. It is impossible to tell how many of these small terranes may be represented in southwestern Newfoundland, but the presence of important faults with a range of ductile to brittle structures suggest that these rocks as a whole have experienced a complex accretionary history. Such faults include the Grand Bay thrust, Bay le Moine shear zone, the Bay d'Est shear zone, the Gunflap Hills fault and the Cinq Cerf fault zone, all reviewed in the previous chapter (Figure VI.1).

Rocks metamorphosed in the Salinic orogeny, notably the Fleur de Lys Supergroup around Corner Brook Pond (Cawood et al., 1994b) and on the western Baie Verte Peninsula (Hibbard, 1983) may have been partially exhumed by mid-Devonian extensional tectonics and gravity sliding. Eclogites are present along the Baie Verte Line (Hibbard, 1983) and may have been brought to the surface by compression accompanying lithospheric delamination in late Silurian time (G. Quinlan, pers. comm., 1995). The amphibolite facies rocks of the Fleur de Lys Supergroup were likely contiguous prior to their separation by Carboniferous strike-slip; thus in this reconstruction, the western part of the Baie Verte Peninsula (orthotectonic block of Hibbard, 1983) is juxtaposed against the Corner Brook Pond belt.

Similarly, during the early to mid-Silurian the Aspy terrane of the Cape Breton Highlands was the site of oblique convergence and subduction-related igneous activity. The volcanic protoliths of the metamorphic rocks in this terrane were formed at 433 +7/-4 Ma (Dunning et al., 1990b); tonalitic rocks now exposed as orthogneisses crystallized at about the same time. The outboard Bras d'Or terrane began docking with the Aspy during the Silurian (Barr and Raeside, 1989).

Prograde regional metamorphism led to peak metamorphic conditions in the Aspy terrane during the late Silurian to early Devonian (Figure VI.3); in the Bras d'Or terrane reheating of the lower Paleozoic metamorphic assemblage occurred up to about 420 Ma. This was accompanied by large amounts of lower crustal melting and renewed intrusion of plutonic rocks at shallow as well as deep crustal levels. These data witness a time of high-strain convergence, crustal shortening and tectonic stacking (Craw, 1984) at or near the St. Lawrence Promontory.

The recognition of a well-constrained tectono-thermal event in the late Silurian of south-central Newfoundland and Cape Breton Island has also enabled a better characterization of lower to middle Devonian orogenic events. Stockmal and Waldron (1993) and Waldron and Stockmal (1994) recognized and defined the Port au Port allochthon, within which most of the rocks of the external Humber Zone have been transported westward. This tectonic episode is singularly characterized by foreland shortening of the Laurentian margin and therefore is quite distinct in space and time from earlier high temperature events involving oceanic terranes. Furthermore, this event deformed the sediments of the Clam Bank Group, and is therefore post-Pridolian in age. Its younger limit is constrained by the overstepping of virtually undeformed Viséan Codroy Group sediments on and around the Port au Port Peninsula.

Stockmal and Waldron (1993) distinguish an Acadian (post-Pridolian) and "Late Acadian" orogeny; the former represents the major crustal shortening (of ca. 40-50 km) which resulted in the creation of Port au Port allochthon and triangle zone structure, while the latter represents late, minor modifications of this structure, the latest movements of which could be as young as Tournaisian. Their data and interpretations argue very strongly for an early to middle Devonian pulse of shortening between adjacent continental blocks, focussed at the St. Lawrence Promontory.

Lin et al. (1994) considered the Gunflap Hills fault to represent the northern boundary of the Cabot Promontory, which collided with the St. Lawrence Promontory in late Silurian time (Figure VII.1). Elsewhere, however, Dubé et al. (1994) note that transcurrent strike-slip motion continued behind (eastward of) the collision front until at least 386 Ma, as the Strawberry Granite of this age is sheared within the Cape Ray Fault Zone. This suggests that collision of the two promontories was ongoing and complex, and was not complete until the arrival of West Avalonia in early to middle Devonian time, as argued in Sections X.3 to X.5.

Gravity-driven extensional collapse has been recognized and documented in many orogens, and can be expected to occur when overthickening of continental crust is attained (Dewey, 1988). In the promontory area, evidence for extensional collapse during the mid-Devonian has accumulated and this is discussed under the appropriate geographical headings below.

VII.2 Map data: Positions of Geological Elements in the mid-Devonian

Figure VII.1 displays the arrangement of the different geological blocks and elements as reconstructed at 380 Ma. Map patterns and abbreviations are explained in the legend accompanying the caption. The main features of the reconstruction are as follows:

(i) The Long Range Inlier and Port au Port allochthon are placed approximately 100 km southwestward along strike relative to their present-day position. This places these elements at or near the St. Lawrence Promontory, where maximum shortening is concentrated.

(ii) Similarly, the Baie Verte Peninsula is positioned approximately 100 km southwest of its current position along the Green Bay Fault (GBF).

(iii) The Corner Brook Pond block (CBPB) is aligned with the western "orthotectonic block" (OTB) of the Baie Verte Peninsula (Hibbard, 1983), *i.e.*, the Fleur de Lys Supergroup is considered to be contiguous southward across these two blocks.

(iv) The Baie Verte Line (BVL) is aligned with its apparent continuation on Glover Island, as suggested by Hibbard (1983). (The small sliver of unnamed ultramafic rocks exposed on the eastern side of Deer Lake may have also been part of the Baie Verte Line; here for clarity it is included in the northern part of the Corner Brook Pond block).

(v) Over the eastern Baie Verte Peninsula (PTB: "paratectonic belt" of Hibbard, 1983) associations of Cambro-Ordovician with Silurian volcanic and sedimentary rocks are placed opposite to, and in continuity with, a similar association of rocks in the northern Notre Dame Subzone. The spatial arrangement of these patterns upon reconstruction is quite striking.

(vi) The Sop's Arm block (SAB, named herein) is a small sliver of Silurian volcanics and clastics and includes the 394 Ma Gull Lake Intrusive of the Mt. Peyton Association (Williams et al., 1989). On the present day map, this sliver is clearly out of place as it is bounded on all sides by Carboniferous faults. In this reconstruction it is superimposed upon the southern corner of the Baie Verte orthotectonic block and the northern Corner Brook Pond block. This places it in continuity along strike with similar rocks in the Notre Dame and Dashwoods subzones, specifically with Cambro-Ordovician granites, Silurian volcanics and sediments, and Siluro-Devonian bimodal plutonic rocks (Colman-Sadd et al., 1990). The unroofing of these mid-and upper crustal rocks, then, can be spatially and temporally linked with the early, Hortonian-stage creation of the Deer Lake Basin, fragments of which (*e.g.*, Birchy Ridge, Fisher's Hill anticline) are now exposed as slivers and pressure ridges (flower structures?) along the major late strike-slip faults (see Chapter IX).

(vii) The precise placement of a series of Grenville basement fragments now found along the eastern margin of the Humber Zone is difficult, but their general reconstructed position can be determined from their current relationship to other fragments and terranes, and by their relationship with each other. The Blair River Complex (BRC) probably represents the southeasternmost fragment of Grenvillian basement brought to shallow levels by thrusting, and perhaps extensional unroofing, at the promontory during the Devonian. Its exhumation may be related to the extensional collapse responsible for the late Devonian development of the Horton basins.

In this reconstruction the Blair River Complex is superimposed upon the trace of the Anguille-Cabot Subbasin (ACSB) in a manner similar to that of the Sops Arm Block-Deer Lake Basin relationship shown above. Other small basement fragments are placed in a similar position along strike; these include Grenvillian gneiss which forms the core of the Flat Bay anticline (FBA), and the Steel Mountain anorthosite (SMA), which currently marks the northern onshore boundary of the Bay St. George Subbasin. The latter of these is here shown attached to the southern part of the Corner Brook Pond block, where it occurs with Grenvillian granitoid intrusions and pre-Grenvillian gneisses. However, these Grenvillian rocks may have formed a separate block situated further southwest along the fault zone, close to the Blair River Complex, Flat Bay Anticline and Steel Mountain basement "blocks" or fragments, and together may represent the easternmost Grenvillian basement elements of the rifted Iapetan margin.

(viii) The east Aspy and Bras d'Or terranes were not completely sutured until the early Carboniferous, but little displacement occurred after partial stitching of the Eastern Highlands shear zone by the Cameron Brook diorite in early Devonian time (Figure VI.3, Barr et al., 1994). On the mid-Devonian reconstruction, these two terranes are shown as slightly separated across strike, while no separation is depicted along strike.

(ix) The western Aspy terrane and Blair River Complex were probably sutured by this time and are placed a few tens of kilometres southwestward along the Aspy Fault relative to their present position with respect to the rest of Cape Breton Island.

(x) The monoclinal structure at the southwestern edge of the Long Range Inlier has been attributed by Waldron and Stockmal (1994; their Figure 9) to the existence of a "transverse hanging wall ramp" above the basal detachment of the Port au

Port allochthon. These authors predicted the existence, in Grenville basement to the east, of a correlative "transverse footwall ramp" (below the basal detachment) which would have been offset by movement on the Cabot Fault. Interestingly enough, the reconstruction at 380 Ma depicted here shows some features which could mark this correlation. The general alignment of Silurian plutons in the Dashwoods Pond area of the Dashwoods subzone appears to have been controlled by a northwest-striking feature. Indeed, one of these bodies is bounded by a northwest-trending fault, which in this reconstruction, is roughly aligned with the transverse hanging wall ramp of the Port au Port allochthon.

VII.3 Crustal Profiles and Plate/terrane Configurations

Figure VII.1 includes conceptual profiles and maps which summarize the ideas presented in this chapter and illustrate possible relationships between plate collision, lithospheric delamination, lower crustal shear zones, the eventual position of the Cabot Fault, and basin development, for two locations: one at the site of promontory-promontory collision (Cape Breton Island), and the other in a position north of the promontory-promontory collision (Newfoundland north of the Gunflap Hills tear fault). As has been introduced in Section VI.1, the outboard, westward-moving promontory is considered to be a collage of small terranes, possibly arranged into two groups with common crustal characteristics

(La Poile-Aspy-St. Croix-Mascarene; Burgeo-Bras d'Or-Kingston-Brookville), and at least one large terrane/microplate (West Avalonia). This differs from the "Cabot Promontory" of Lin et al. (1994), which is shown as part of a large plate approaching the St. Lawrence Promontory prior to collision. Other elements of the two models, particularly the significance of the Gunflap Hills tear fault (GHF), are similar.

It is also noteworthy that the tectonic wedging as shown is consistent with the position of the Port au Port triangle zone of Stockmal and Waldron (1990; 1993), which in its pre-strike-slip position lies clearly in the foreland of the promontory-promontory collision (Figure VII.1: terrane configuration sketches and paleogeographic reconstruction).

An important aspect of the promontory model presented here is the suggestion that basin development in the St. Lawrence Promontory area may have been related to the existence of large scale shear zones, in the middle and lower crust in and around Newfoundland and Cape Breton Island, as interpreted on LITHOPROBE reflection seismic profiles by Quinlan et al. (1992) and Hall and Quinlan (1994). The profiles presented here in Figure VII.1 are broadly consistent with LITHOPROBE seismic fabrics where good data exist (mainly north of the Gunflap Hills Fault), and are conceptual south of this area where they rely on "shallow" seismic data (Cabot Strait) and field geology (Cape Breton Island). With respect to basin development, they illustrate that shear zones may have facilitated the development of basins by extensional collapse in the middle to late Devonian.

The profiles further suggest that shearing may have affected different types of crust for the two situations. South of the Gunflap Hills tear fault, where extensive delamination is assumed at the promontory-promontory collision, shearing affected mainly Grenvillian crust of the St. Lawrence Promontory (Figure VII.1: lower profiles), while north of the tear fault crust of the accreted terranes (presumably largely "Avalonian" in nature) is involved (Figure VI.1: upper profiles). In each case the main trend of Horton basins appears to be fundamentally situated at the eastern margin of Grenvillian crust (illustrated by the dense cross pattern in Figure VII.1), regardless of the intensity of crustal shearing (Figure VII.1: middle Devonian panel).

The plate/terrane configuration maps serve to place the detailed St. Lawrence Promontory paleogeography in perspective relative to the broad North Atlantic picture, which is presented in detail in Figures X.2 to X.7 of this study.

VII.4 Discussion and Interpretation

VII.4.1 Western and Southwestern Newfoundland

The dominant features of the Acadian Orogeny in western Newfoundland are the Port au Port allochthon (Stockmal and Waldron, 1993), which includes basement and cover rocks, and the Long Range Inlier, which is interpreted by Waldron and Stockmal (1994) to be part of the Port au Port allochthon.

Interpretation of considerable westward transport of the Long Range Inlier, then, suggests that it may have been close to the high-convergence zone of the St. Lawrence Promontory at this time. What are some of the arguments for and against large-scale transport?

Grenier (1990) and Grenier and Cawood (1988) interpreted the Long Range and Ten Mile Lake thrusts, which bound the northwest margin of the inlier (Figure VII.1), as high angle faults with reverse displacement. As such they were deemed to be the main faults by which Lower Cambrian Labrador Group and Precambrian basement rocks have been thrust over carbonate platform rocks, along the Ten Mile Lake and Long Range thrusts, respectively. Such an interpretation implies that only small amounts of horizontal transport have occurred in these allochthons, and therefore, only small amounts of carbonate platform have been buried beneath the Precambrian basement and Cambrian cover slices.

Other geological and geophysical data, some only recently in the public domain, suggest that these faults may have shallower dips and greater amounts of orthogonal transport than previously interpreted. These data include: (i) gravity data over the northern half of the Long Range "inlier" have a signature (unpublished data of G. Kilfoil, 1995) indistinguishable from the carbonate platform, suggesting that the Grenville basement outcrops as a thin, unrooted slice in this area.

(ii) in the southern Long Range Mountains, Owen (1991), on the basis of steep conjugate cataclasite zones above the Long Range frontal thrust, proposed that the foreland fringe of the massif was thin and underlain by cover. He also suggested from field evidence that the Long Range frontal thrust cut within 1 km of the sub-Cambrian unconformity.

(iii) recent industry reflection seismic data over the southern Long Range complement and support the field data of Owen (1991); they show overthrusting of basement above carbonate platform, with several tens of kilometres of movement implied.

(iv) studies of mineralization in and around the area of the Daniel's Harbour zinc mine, in the middle-western part of the allochthons (Figure VII.1), show that hydrothermal fluids responsible for the Daniel's Harbour Mississippi Valley-type Pb-Zn deposits originated in carbonate rocks buried eastward beneath the tectonic pile, presumably in the Acadian (Lane, 1990). Langdon (1991) suggested that maturation and migration of hydrocarbons from source rocks buried beneath the Acadian basement allochthons were part of the same fluid migration event that resulted in the mineralization.

(v) I. Knight (pers. comm., 1994-1995) considers that the Long Range Thrust and Ten Mile Lake Thrust are late Acadian normal faults formed to accommodate some of the extensional strain as the overthickened crust collapsed under gravitational forces. This implies that the Long Range Inlier once lay even further west of its present position.

(vi) Other features support the idea of late Acadian extensional collapse in and around the Long Range Inlier, related to the creation of high topography. Cawood (1989; 1990) proposed that the St. Anthony and Bay of Islands ophiolitic complexes were moved into their present foreland position in mid-Devonian times by a process of gravity sliding as a result of their elevation atop high topography along the Acadian mountain front in western Newfoundland (Figure VII.1). Waldron and Stockmal (1994) interpreted normal sense, northwest-dipping shear zones in the Old Man's Pond area, at the eastern edge of the external Humber Zone; these cut contractional structures (Silurian to early Devonian?) and are themselves cut by west-vergent kink and chevron folds, probably representing brittle Carboniferous deformation. Cawood et al. (1994b) discussed an episode of shallow delamination and extensional collapse which involved northwest and/or west-dipping normal faults at the eastern boundary of the external domain (Figure VII.1).

It is conceivable that the earliest manifestation of the Horton basins (equivalent to the "pre-Horton basins" of Durling and Marillier, 1990, in the Gulf of St. Lawrence and other mid-Devonian basins represented by volcanic and clastic successions in the Maritime Provinces) may have been formed in association with the extensional structures noted above. These may also have been partly responsible for the unroofing of the high-grade metamorphic rocks of the internal Humber Zone. The superposition of the Blair River Complex upon the Anguille-Cabot Subbasin in the paleogeographic reconstruction (Figure VII.1) illustrates the types of pre-extensional geometries that may have been associated with this mode of basin formation. It is suggested here that this basin was formed by activation of a low-angle mid-crustal detachment, above which the Blair River Complex moved eastward under conditions of extensional stress to create the basin "hole" (Figure VII.1: upper panel, crustal profiles).

Interpretations of large amounts of transport of the Long Range Inlier, and subsequent extensional collapse in the external domain of the Humber Zone fit with each other and argue for the placement of the Long Range Inlier and Port au Port allochthon at the promontory: in the first case because of the large amounts of strain involved, and in the second case because of spatial correlation with well-documented extensional features in Cape Breton Island. It seems reasonable to speculate that the creation of high topography (by crustal thickening through the westward transport of basement blocks), gravity sliding of the Humber Arm and related allochthons, and other manifestations of high strain are all symptoms of the final docking of West Avalonia against the St. Lawrence Promontory in early to middle Devonian times (Figure VII.1).

Since the Fleur de Lys Supergroup comprises continental slope facies rocks metamorphosed to amphibolite facies, the eventual separation and westward transposition of the less-deformed Sop's Arm block sliver may represent extensional unroofing of Fleur de Lys rocks in the late stages of the Acadian Orogeny. This process probably occurred in a manner similar to the late (Acadian) foreland-directed gravitational sliding of the western Newfoundland ophiolites (Cawood, 1989; 1990). A similar explanation is invoked by Lynch and Tremblay (1994) for the Margaree Shear Zone in Cape Breton Island.

The Sop's Arm block, then, can be interpreted as an allochthononous sliver of Dunnage Zone material which, in the mid-Devonian, formed part of an upper crustal carapace, and was subsequently transported westward by gravitational forces above a low angle detachment.

The middle Devonian in southwestern Newfoundland was a time of large amounts of structural transposition along the Cape Ray and related faults, with accompanying igneous activity. The range and style of the middle Devonian deformation is illustrated in Figure VI.3. The dominant structural control was provided by right lateral movement on the Gunflap Hills fault (Lin et al., 1994; Dubé et al, 1994), as the Cabot Promontory converged against the St. Lawrence Promontory (Lin et al., 1994; Figure VII.1). With regard to the regional paleogeography, the Avalonian (*sensu lato*) terranes which collided with southern Newfoundland in Silurian time, in a position to the east of their present position, were pushed westward along the Gunflap Hills fault in Devonian time. In fact, this westward transposition south of an east-west trending tear fault was the same strain episode responsible for the westward transport of the Port au Port allochthon across the continental margin, and the concomitant building of elevation.

As noted in Section VI.1.6, the Bay le Moine shear zone on the south coast of Newfoundland shows evidence of post-early Devonian dextral transtensional movement (Lin et al., 1993), and mid-Devonian basin development may be associated with this extensional phase. Alternatively, the Bay le Moine shear zone may be an easterly equivalent of the Cape Ray Fault Zone, which curved eastward to link kinematically with the Gunflap Hills Fault in middle and late Devonian time.

VII.4.2 Cape Breton Island

Plint and Jamieson (1989) carried out petrologically-constrained P-T-t modelling on metamorphosed supracrustal rocks of the Aspy terrane (Jumping Brook Metamorphic Suite, Figure VI.3), which suggested that rapid exhumation at ca. 405 Ma was followed at 390-380 Ma by isobaric cooling through the argon retention temperatures of hornblende (550°C) and biotite (350°C).

It is particularly significant that their model predicts that rapid cooling necessitated a rapid exhumation event by thrusting or extension, and could not have been accomplished solely by static erosion of the orogen. The absence of any clear structural evidence for early Devonian extension suggests that the early Devonian exhumation and cooling event in the Aspy terrane was a part of the same contractional episode that resulted in the westward transposition of the Port au Port allochthon.

At the end of Acadian shortening, then, the Aspy terrane was juxtaposed against the southern, presently submerged portion of the Port au Port allochthon, and had participated in the same episode of crustal thickening and westward transposition of structural elements. The Aspy terrane had not yet been completely assembled into its present configuration, and the eastern and western parts are depicted on Figure VII.1 as being separated by some 20 km along strike (Lynch and Tremblay, 1994, place dextral offset on the main "late steep fault" at about 14 km; Figure VI.4).

The Bras d'Or terrane was not yet totally amalgamated with the east Aspy terrane, but must have lain in a position very close to its present position with respect to the east Aspy terrane, as little disruption of the 402 Ma Cameron Brook diorite, which stitches the Eastern Highlands Shear Zone, is recorded (Dunning et al, 1990b).

The middle Devonian represents the time of arrival and docking of the Mira terrane at the St. Lawrence Promontory (Barr et al., 1994). However, like the Aspy terrane, the Mira terrane was probably only amalgamated with the larger mass of Cape Breton Island in Carboniferous time by dextral strike-slip movement along minor faults which are seen onshore and offshore in the Sydney Basin (Boehner and Giles, 1986; Gibling et al., 1987).

It is considered here that, given the large amount of late fracturing and faulting which marks the map of the western Cape Breton Highlands (Figure VI.4), and the magnitude of the Aspy-Cabot Fault system which clearly was active in the Cabot Strait and Newfoundland until early Permian time, a large degree of strike-slip offset has occurred along these faults. However, the evidence on the ground in western Cape Breton Island (Lynch and Tremblay, 1994) appears to argue against this, as the Margaree Shear Zone is only displaced by about 15 km. One solution to the apparent contradiction in such an interpretation is that the southern part of the Aspy Fault has splayed into a number of displacement zones which have resulted in the dispersion of the strain across a broad area in southern Cape Breton Island.

VII.4.3 Gulf of St. Lawrence/Maritimes Provinces

Evidence for significant early to middle Devonian basin development in the promontory area comes from the Gulf of St. Lawrence. Durling and Marillier (1990), utilizing an integrated data set, mapped "pre-Horton" basins (Figure VII.2) which appear to be precursors to the better-understood Horton basins observed on land (discussed in the next chapter). The largest and most significant of the pre-Horton basins are the North Point basin, which overlies an extension of the New Brunswick Gander Zone offshore, and the Cascumpec Basin, which occurs between the Fredericton and Belle Isle

Faults north of Prince Edward Island (Figures VII.2 and VII.3). The pre-Horton sediments in these basins were identified on the basis of high refraction seismic velocities (>6.1 km/s) and generally poor reflection character (Durling and Marillier, 1990).

In view of the present work, and the recognition of allochthon emplacement at the St. Lawrence Promontory during early to middle Devonian time, these basins are assumed to be synorogenic extensional basins probably developed as intermontane lakes in the high-standing Acadian topography. Stockmal and Waldron (1993) identified a 2.7 km thick sedimentary basin offshore to the west of the Port au Port Peninsula, which contains mostly post-late Silurian sediments. They concluded that this succession was deposited prior to the end of westward thrusting in the Devonian (with the possibility of some early Mississippian deposition) and that most of these rocks represent an Acadian foreland basin not exposed onshore. According to the large scale reconstruction presented in Figure X.4 of Part III, this offshore foreland basin would have lain directly along strike from the North Point/Cascumpec Basins. Their position south of the St. Lawrence Promontory, within the hinterland of the orogen, and their fault boundaries, suggest that they are intermontane rather than foreland basins.

Equivalents of the North Point and Cascumpec basins occur on land in Nova Scotia. The earliest development of the Fisset Brook, McAras Brook and Fountain Lake Groups date from the early to middle Devonian (Figure I.3). These units represent accumulations of sedimentary and volcanic material in extension-related depressions, partially overlapping in time with ongoing crustal thickening at the St. Lawrence Promontory. Such syntectonic basin formation is well known in active mountain belts and can form by: (1) the collapse of very high topography (generally above a 3 km buffering elevation) during ongoing crustal thickening associated with convergent plate processes at middle and lower crustal levels (Dewey, 1988; England and Houseman, 1988; Sonder et al., 1987), or (2) by the lateral escape or extrusion of crustal fragments or slivers to produce localized extensional areas into which sediments and volcanics are concentrated. Both of these processes of sedimentation are known to occur in the present day Alpine-Himalaya system. According to Dewey (1988) the Tibetan plateau and the Aegean Sea are examples of the former. Anatolia is probably the best known example of lateral escape tectonics, also known as tectonic extrusion. According to Dewey and Sengor (1979) and Sengor et al. (1985), the east-west oriented grabens of the western Anatolian Plate can be attributed to a locally dominant north-south extensional stress regime associated with the westward escape of Anatolia.

From the nature of the fault patterns interpreted from deep seismic in the Gulf of St. Lawrence (as discussed in the caption to Figure VII.3) Horton and pre-Horton basins can reasonably be interpreted as syn- to post-orogenic terrestrial basins formed by extensional collapse.

CHAPTER VIII. LATE NAMURIAN (ca. 320 Ma) RECONSTRUCTION

VIII.1 Regional Setting

This section will describe events occurring within the late Devonian to late Namurian time interval. The configuration of the geological elements at the end of this period is depicted in the 320 Ma reconstruction of Figure VIII.1.

Two major developments characterizing the period from 380 Ma to 320 Ma in eastern North America will be presented here. The first was the onset of major post-orogenic extensional processes associated with gravitational collapse. The second was the initiation of the Magdalen Basin pull-apart as a result of dextral displacement on the Cabot Fault and its continuation south of the promontory in New Brunswick, the Lubec-Belle Isle Fault system.

The rate of subsidence of Horton basins peaked in the late Tournaisian (Nickerson, 1994). For this reason, the strike-slip component along the major regional shear zones was likely playing a significant role in the ongoing, and accelerating, development of these basins by this time. Furthermore, the late Tournaisian unconformity and associated deformation, concentrated along the major strike-slip fault zones, as shown in Part I of this work, suggest that by the Lower Carboniferous, movement on these faults was responsible for localized basin inversion.

In their study of allocycles within the Maritimes Basin, Ryan and Zentilli (1993) described an early cycle of Fountain Lake to Mabou sediments (365-325 Ma), which crops out in northern Nova Scotia. They believed rapid subsidence was initiated in the early part of the cycle by strike-slip movement, and that the rate of subsidence decreased over the duration of the allocycle. This is generally consistent with a maximum subsidence rate represented by the Horton basins and indeed the subsequent early Viséan transgression.

The pattern studied by Ryan and Zentilli (1993) is not unlike that seen across the Maritimes Basin where the beginning of the Viséan marks the onset of a marine transgression that dominated the stratigraphy of the basin for the next 20 million years. This transgression resulted in the widespread deposition of carbonates, evaporites and marine shales (Figure I.2) which eventually were overstepped by clastic wedges prograding outward from the basin margins.

Data from different areas of the Maritimes Basin (this study; Nickerson, 1994; Durling and Marillier, 1990) show that the end of the Tournaisian was marked by a compressive, probably transpressional pulse, which resulted in the inversion of Horton basins and the erosion of strata within them. This unconformity (HA) is illustrated in Figure I.3 of Part I; in most basins it cuts out strata as old as late Tournaisian and as young as early Viséan, suggesting that the timing of tectonism responsible for the unconformity occurred exclusively within, or persisted into, the early Viséan.

Nickerson (1994) has suggested that for the Moncton Subbasin the Viséan transgression represents a continuation of rapid subsidence which had already commenced with the formation of the Albert tectonic lake in the Tournaisian. If this is so, then the early Viséan inversion event must have been restricted to fault zones now exposed on land around the margins of the Maritimes Basin. Indeed, deeply buried Horton basins imaged on seismic data in the central Gulf of St. Lawrence are, for the most part, not disturbed (Durling and Marillier, 1990).

The most suitable explanation for the post-Horton inversion event is that it signifies a transpressional pulse whose effects were felt only in the vicinity of the regional fault system. This is clearly seen from the Cabot Strait seismic data set, where the HA unconformity is shown to be restricted to areas bordering the various fault strands (Figures II.9 and IV.1).

VIII.2 Map Data: Positions of Geological Elements at the End Namurian

The accompanying map (Figure VIII.1) displays the arrangement of the different geological blocks and elements at 320 Ma. To the author's knowledge no kinematic data are available from strike-slip faults in western Newfoundland, so interpretations of offset are based entirely on the tectonic models contained herein. The cumulative development of the important features is outlined in the following:

(i) The earliest dextral strike-slip system, which likely developed in Tournaisian time as a broad (up to 25 km-wide?) transcurrent fault zone with branching and interconnected strands, as depicted in Figure VIII.1. By Viséan time the Baie Verte Peninsula has been initiated as a discrete terrane within this fault zone and begins to escape northeastward. Subsequently, the Baie Verte Peninsula and Central Mobile Belt move away as escaping blocks along strike from the St. Lawrence Promontory. The Long Range Inlier shows overall dextral displacement relative to the St. Lawrence Promontory (considered here for argument's sake to be "anchored" in Cape Breton Island), and a lesser amount relative to the escaping Central Mobile Belt. The rates of motion of these blocks (relative to each other, and to the St. Lawrence Promontory) dictate the sense of offset along the Green Bay and Hampden Faults, where these faults bound the Baie Verte Peninsula. This means that, during the time interval displayed, offset on the Hampden Fault was sinistral along the western margin of the Baie Verte Peninsula, and dextral along the southern continuation of this fault into the St. George's Bay Fault. When plotted on Figure VIII.1 the sense-of-motion arrows show opposing directions on the Hampden Fault, and illustrate the extensional concept for the origin of the Deer Lake Basin presented in the following section.

(ii) The Central Mobile Belt and other terranes to the east of the Cabot Fault by the end of the Namurian have been displaced approximately 120 km southwestward relative to the Long Range Inlier and Port au Port allochthon.

(iii) The Anguille-Cabot subbasin is situated just south of the Corner Brook Pond block at the St. Lawrence Promontory, between the Port au Port allochthon to the west and the Cabot Strait-southern Dashwoods subzone to the east. In the current interpretation, this subbasin is the Horton depocentre recognized by Hamblin (1992) and Hamblin and Rust (1989) from east-directed paleocurrent directions in northern Cape Breton Island, and has moved by dextral strike-slip to its present position.

(iv) In Tournaisian time, the west Aspy terrane represents the main provenance area for the Anguille-Cabot subbasin. The first dextral movement on the Aspy Fault is shown, and movement of the Mira toward the Bras d'Or terrane has also been initiated. The Big Pond Basin (BPB), documented by Bradley and Bradley (1986) was initiated by strike-slip and persisted through Viséan times.

(v) The Mira terrane is still placed a substantial distance to the east, based on known Carboniferous movement along the boundary with the Bras d'Or terrane (Bradley and Bradley, 1986), movement which occurred throughout the Carboniferous.

(vi) Late Devonian to Tournaisian extensional basins are plotted in several areas. In the promontory itself, the Anguille-Cabot depocentre has formed under distensive stress conditions (terminology of Hamblin and Rust, 1989). A second major Horton depocentre in central Cape Breton Island was termed the Ainslie Subbasin by these authors. This basin shows drainage polarities opposite to that of the Cabot Subbasin discussed above, *i.e.*, paleocurrents are primarily directed toward the southeast. North of the promontory, the Horton extensional phase is represented by the St. Anthony-White Bay and Deer Lake Basins.

(vii) Along the Green Bay Fault, a small degree of extension and basin development, which has moved the Baie Verte Peninsula orthogonally away from the Notre Dame subzone, is shown.

(viii) A small amount of extension is plotted along the Cape Ray Fault and Red Indian Line. Here Horton age rocks such as the Windsor Point Group lie adjacent to rocks formerly at mid-crustal levels (*e.g.*, Port aux Basques gneisses).

(ix) Pull-apart is shown in the Sydney Basin in a roughly north-south orientation, similar to that occurring in the Magdalen Basin (Figure X.6, Part III). In relative terms, this can be expressed as the Dunnage, Exploits and Gander Zones (Central Mobile Belt) escaping or being wedged northward away from the promontory. This activity was likely initiated in late Viséan or early Namurian times.

(x) East-west faults are also depicted in other areas of the Cabot Strait; these developed at this time in response to north-south extensional or transtensional stresses, associated with Sydney Basin extension, and some of these would eventually develop into minor strike-slip faults later in the Carboniferous. This family of faults is mapped from seismic and potential field data in Figure II.5.

(xii) In the southwest, the Magdalen Basin pull-apart is by this time widened to about 100 km along its north-south dimension.

VIII.3 Crustal Profiles and Plate/terrane Configurations

Figure VIII.1 includes conceptual profiles and a terrane configuration map which summarizes much of the discussion presented in this chapter and illustrates the relationship between strike-slip tectonics, crustal composition, and further basin development along the Cabot Fault system. The position of the Cabot Fault suggests that it may have been preferentially developed in transitional crust weakened by earlier shear zones associated with lithospheric delamination (cf. Figure VI.1).

VIII.4 Discussion and Interpretation

VIII.4.1 Baie Verte Peninsula and Deer Lake Basin

By the late Namurian, cumulative strike-slip along the Cabot fault zone had displaced east of the fault by about 120 km relative to the Laurentian Plate. This resulted in an approximate alignment of the Notre Dame Subzone with the Humber Arm Allochthon (as presently exposed). This motion overprinted Horton Basin development along the fault zone.

The Green Bay strand of the Cabot Fault system was the locus of extensional Horton basin development, as small, unnamed, isolated remnants of Horton-age strata are preserved on both sides of the fault (Figure VIII.1, Colman-Sadd et al., 1990). Based on the size of these remnants alone, these basins were probably small and may have been isolated from the main mass of Tournaisian sediments preserved in the Anguille Group of the Deer Lake Basin. The difference between this outcrop and Horton rocks of the Deer Lake Basin is that the latter are entirely fault-bounded and crop out in highstanding pressure ridges or flower structures such as the Fisher Hills anticline and Birchy Ridge (Hyde, 1982). Their unconformable relationship with underlying Silurian crystalline rocks suggest that they represent the margins of Horton basins whose depocentres are now inverted and exposed in the central Deer Lake Basin.

The Red Indian Line, which runs NE-SW through central Newfoundland, and separates the Notre Dame from the Exploits subzone (Williams et al., 1988), was also a locus of Horton basin development (Figure VIII.1). Exposures of Hortonian strata are found on the shores of Red Indian Lake, where they straddle the trace of the Red Indian Line (E. Belt, 1969: pers. comm. with H. Williams, 1969; Colman-Sadd et al., 1990). Again, the relatively small extent of this outcrop suggests that the basins of this trend were not as extensive or as deep as those along the Cabot Fault system. The Notre Dame and Exploits Subzones are interpreted to have been sutured across the Red Indian Line by late Silurian times, as this suture is straddled by a late Silurian overlap assemblage (Cawood et al., 1988), and displays no Carboniferous strike-slip movement. Late Devonian-early Carboniferous basin formation in this area may have been entirely caused by late upper crustal extension, perhaps associated with the collapse of Devonian topography in central and western Newfoundland.

Therefore, there appears to be a spatially-controlled cause and effect relationship between the location of Horton basins with respect to active strike-slip fault zones, and their ultimate size and depth. The position of the Anguille-Cabot and Deer Lake-White Bay Basins in the broad Cabot Fault zone allowed an early extensional phase in the late Devonian to be overprinted by a later transtensional phase in the Tournaisian and later, perhaps along irregular fault traces. Small patches of Horton-age sediments along the Cape Ray Fault and Red Indian Line suggest that Horton basins in these loci experienced only the early extensional phase, and their shallow fill has been all but eroded.

As in other parts of the promontory, east-trending faults are known in the area of the Baie Verte Peninsula. In fact the northern coast appears to be controlled by such a fault, because thick Carboniferous sediments are known immediately offshore in the St. Anthony/White Bay Basin (Haworth et al., 1976; public domain seismic data collected by Tenneco in 1970).

The second-stage expansion of the Deer Lake Basin in the early Viséan (see Hyde, 1984, and Hyde et al., 1988, and their explanation of "lateral basin" development) could represent a specialized case of the sedimentary overlapping (transgression) of the Maritimes Basin as a whole. The Deer Lake Basin appears to be the only Carboniferous subbasin in eastern Canada not to experience a marine transgression during the Viséan, as no evidence of marine sedimentation is present.

It is proposed that this second-stage expansion occurred as two complementary phases of large-scale activation of the regional fault system in Viséan time, as demonstrated in the 320 Ma reconstruction:

(1) the Baie Verte Peninsula has been extruded northwards relative to both the Central Mobile Belt and the Port au Port allochthon (Figure VIII.1). This mechanism could account for the subsidence of the portion of Deer Lake Basin lying south of the Baie Verte Peninsula, *i.e.*, the narrow wedge of Carboniferous strata partly defined and limited southward by the confluence of the Green Bay and Hampden Faults (termed the Howley "lateral basin" by Hyde, 1984, and Hyde et al., 1988). Westphalian-age Howley Formation rocks are exposed over the northern half of this basin and will be discussed in Chapter IX. However, Viséan-age Deer Lake Group outcrops to the south on and near Glover Island; these rocks are interpreted to underlie the Howley Formation in the north.

(2) To the west of the Hampden Fault (Figure VIII.1), "second-stage expansion" and its expression, the Deer Lake "lateral basin" (Hyde, 1984), appears to owe its development, at least in part, to a different mechanism. In the north, Viséan North Brook Formation sediments unconformably lap onto plutonic rocks of the Gull Lake Intrusive Suite (Glover, 1983), here included as part of the Sops Arm block in the reconstruction. (This contact has been partly faulted in later Carboniferous movement - see Chapter IX). The formation of the Deer Lake "lateral basin" can be explained by a change in the fault trace in the early Tournaisian and incorporation of the Sop's Arm block and the St. Anthony-White Bay basin into the internal Humber Zone plate: this would have created an irregular, right-stepping restraining bend geometry immediately to the south of the Gull Lake Intrusive Suite. Dextral motion on this newly-developed Hampden Fault, linked with the St. George's Bay Fault in the south, would have created a basin south of the Sops Arm block. This is witnessed by the onlap of Viséan strata both onto the Gull Lake Intrusive Suite and the Grenvillian basement of the Long Range Inlier to the west. The Viséan fault trace likely ran through the present Deer Lake area and curved northeastwards to join the Hampden Fault along Birchy Ridge, as there is no strike-slip faulting at the Deer Lake Group/Precambrian basement interface along the western margin of the basin (Hyde, 1982). A minor hinge fault may have been developed along the early Hampden Fault at this time, similar but

subsidiary to that developed along the eastern side of the Howley "lateral basin". These geometries and the location of Viséan depocentres is supported by magnetic data (unpub. map and pers. comm., G. Kilfoil, 1994). Thin accumulations of Deer Lake (and Howley?) Group strata probably originally onlapped considerable areas of Fleur de Lys Supergroup and other pre-Carboniferous rock units to the north and south of the Deer Lake Basin.

The development of the Rocky Brook tectonic lake, as outlined by the yellow stipple on Figure VIII.1, was spread over a broad area, but with a southwestern and a northeastern depocentre related to two separate but related, and perhaps even kinematically linked, processes of upper crustal thinning. These depocentres were separated by tens of kilometres along the Hampden Fault. A narrow zone of some relief may have been present along the fault zone. Hyde (1984) inferred from sedimentary provenance studies that narrow, Anguille-cored peninsulas protruded into the lake, from which Anguille Group sediments were eroded and deposited westward into the southwestern depocentre. The presence of exposed topography along the fault zone, perhaps associated with the development of a flower structure along the transpressive fault, is also supported by a recently acquired 12 km reflection seismic line (Wright et al., in press) which runs across the eastern margin of the Deer Lake "lateral basin". Here, lacustrine shale facies of the Rocky Brook

Formation are interpreted to onlap a "high block", which is the paleo-topographic expression of the flower structure.

With respect to the orientation of the principal stress field, as shown on Figure VIII.1, both the continued dextral strike-slip across the Cabot fault system, and tectonic extrusion of the Baie Verte Peninsula are consistent with a principal compressive stress field oriented roughly east-west, as illustrated by the stress ellipsoids of Figure VIII.1. Compressive stress in this orientation would have caused the Central Mobile Belt to slip dextrally on the Cabot Fault south of the Deer Lake Basin. North of this juncture, the Central Mobile Belt would have slipped at the same rate relative to rocks west of the Hampden Fault (*i.e.*, the Port au Port allochthon), but the displacement of the interposed Baie Verte Peninsula across the Hampden fault would have actually been sinistral, because of its northward extrusion. Following this line of reasoning, the Green Bay Fault would actually have experienced the highest rate of displacement of any of these faults, as both regional dextral slip and local extrusion contributed to the total displacement. This situation is illustrated by the relative sizes of the displacement arrows in Figure VIII.2: in effect, these arrows can in a general sense be taken to represent displacement rate vectors.

VIII.4.2 SW Newfoundland

The most significant development in southwestern Newfoundland during this period was the initiation of east-west normal faulting along or just offshore from the present south coast of Newfoundland; terranes within the Hermitage Flexure were finally sutured to the Central Mobile Belt prior to this normal faulting. Evidence for this east-west faulting is found in the substantial thickness of lower Carboniferous rocks laid down in the Sydney Basin (Gibling et al., 1987; Loncarevic et al., 1989).

This extensional faulting can be viewed in two ways with respect to the relative movement of blocks: (1) in a passive view, the Cape Breton terranes continued to be dextrally displaced past the promontory, while the Central Mobile Belt/Hermitage Flexure lagged behind, or (2) in a more active view, the area experienced squeezing and northward lateral extrusion as part of the Central Mobile Belt/Hermitage Flexure "megablock", which resulted in increasing separation from Cape Breton Island terranes.

The mechanism which allowed the Sydney Basin to develop, however, differed from that of the Magdalen Basin. Where the latter formed due to the thinning of continental crust in a strike-slip stepover configuration (*e.g.*, Aydin and Nur, 1982; 1985; Part I of the present work), the former resulted from compressive strain and, at least in part, from tectonic wedging, which caused the Central Mobile Belt to move relatively northeastward away from Cape Breton Island, *i.e.*, away from the high strain zone of the St. Lawrence Promontory (Figure VIII.2). This tectonic wedging or escape is consistent with an east-west orientation of the principal stress vector at this time, which would also account for dextral movement on the NE-SW trending regional displacement system.

VIII.4.3 Cabot Strait/Bay St. George

The development of Horton age basins under the Cabot Strait is interpreted from offshore seismic data and is documented in Part I of this study. Of particular interest here is the Cape Ray graben, situated between the Cabot and Cape Ray Faults. In the northern Cabot Strait, the Cape Ray Fault is imaged as a moderately west-dipping feature that probably marked the eastern limit of Horton deposition. In other words, it likely represents one of the major faults along which late orogenic normal movement was localized, and may control the northeasterly extent of this subbasin. In the kinematic model shown in Figure V.2, the Cape Ray graben is seen as a dismembered remnant of a larger Horton basin which was bisected by the later Cabot Fault.

The continuation of the Cape Ray Fault into the Red Indian Line appears to mark the position of the fault system controlling the extension: on land, at least, erosion has all but removed the trace of the Horton basins. At the south end of Red Indian Lake a small vestige of Horton age sediment represents the last remnants of this basinal tract on land.

East-west shear zones and fault structures were initiated at least as early as the late Devonian, as such structures control the distribution of Anguille sediments in the onshore Bay St. George (Knight, 1983). For example, the east-trending Shoal Point Fault at the northern margin of the Anguille Mountains marks the position north of which lower Anguille sediments are very thin or absent (the lowermost Kennel's Brook Formation is absent on the Flat Bay anticline).

The Viséan and Namurian epochs in the Cabot Strait represent a period of marine transgression followed by a major compressive episode, as illustrated on chronostratigraphic charts in Figures I.3 and IV.1. On these charts the NWU (Namurian-Westphalian Unconformity) represents the omission of rocks of middle Carboniferous age in the Cabot Strait but also throughout several small constituent subbasins of the Maritimes Basin, most of which are located along the major fault zones in western Newfoundland, northern Nova Scotia and eastern New Brunswick (Figure I.3). Nickerson (1994; his Figure 7-3) identified a change in the stress field, from roughly E-W maximum principal compression in the Viséan to SE-NW in the Namurian, as the major reason for Namurian thrust faulting in the Moncton subbasin.

The effects of the Namurian shortening event are equally as dramatic in the Cabot Strait area. The structural effects of this deformation have been described in Part I of the present study. Presumably, both the relief represented by the

NWU and the deformation of pre-Namurian strata by inversion of basin fill were caused by an increase in compressive (transpressive) stress.

In the Promontory area such a dramatic change in stress orientation may not have occurred, but the increase in compressive stress which resulted in the NWU can indeed be explained by a rotation of the strain ellipse by about 20° in a clockwise direction. Such a reorientation would result in an increase in the orthogonal component of an obliquely-convergent system. Strain ellipses for both the Viséan and the Namurian are plotted with the map reconstruction in Figure VIII.1.

It is tempting to generalize further and to regard the Namurian as a period of transition from a transtensional or mildly transpressional to a strongly transpressional stress regime across the regional fault system. Reasons for this change, from the perspective of regional terrane motions, are presented in the reconstructions of Figures X.6 and X.7, Part III.

East-west faults had begun to develop during this time in the Cabot Strait, and several major shear zones of this orientation cut the entire Carboniferous section. It is likely that they are related to east-west tear faults in the St. Lawrence Promontory, such as the Gunflap Hills Fault (Lin et al., 1994) and the east-west splay of the Cape Ray Fault (Dubé et al., 1994). These faults accommodated the east-west differentials of strain between geological domains that were in the process of being re-oriented by northeast-southwest brittle structures.

In an ideal system, *i.e.*, one having isotropic properties with no pre-existing weaknesses, angular relations between structures that tend to form in dextral simple-shear can be predicted (*e.g.*, Wilcox et al., 1973; Tchalenko and Ambraseys, 1970, who compiled data from clay models and geological examples). If an ideal strain ellipse is applied to the Late Namurian reconstruction, orientations of east-west faults may approximate those of minor shears which form between the angle of the main regional strike-slip faults (Cabot Fault system) and the direction of principal compressive stress (approximately azimuth 290° in this reconstruction). These faults have been termed synthetic shears by Wilcox et al. (1973) and Riedel 'R' shears by Tchalenko and Ambreseys (1970) and Bartlett et al. (1981), and are illustrated on the strain ellipse in Figure VIII.1.

In terms of pre-existing structural weaknesses, the relationship between the two main orientations of faults - northeast-southwest and east-west - may also be described in a less rigorous, more empirical manner. The east-west faults may be thought of as an array of minor tear faults which facilitated the final stage of collision by accommodating minor irregularities in the edges of the colliding plates, in the same way that the Acadian tear faults, mainly the Gunflap Hills and Canso Faults, are an expression of large amounts of differential strain across the promontory as a whole. This situation in plan view can be simply visualized by pushing (shearing) a deck of cards against an irregular buttress (Figure VIII.3): the displacement parallel to the card surfaces would be analogous to the strain accommodated along an array of tear faults. This pattern of faulting was recognized by Kilfoil (1988) and Miller et al.(1990) from combined potential field and seismic studies in Bay St. George. Such irregularities would also explain the small amounts of sinistral displacement on some of the east-west faults, as discussed earlier (Section III.1.2.2; Figure II.5). Therefore the interpretation of the east-west faults and a strongly transpressive episode as Namurian in age is consistent with the proposal that the strain ellipse was reoriented counterclockwise by some 20°, which realigned the direction of Riedel 'R' shears to approximately east-west (see strain ellipses, Figure VIII.1).

The western Cabot Strait in the Lower Carboniferous was thus the locus of several intersecting trends and a focal point for subsidence. The preservation of such a thick pile of Carboniferous sediments here cannot be explained by post-Carboniferous differential fault movement, because much thinner sections of equivalent Carboniferous strata are today present on the sea bed in and around the eastern Gulf of St. Lawrence. Such observations argue for the presence of a Cabot Strait-Sydney Basin pull-apart during this time, which developed along east-west faults such as control the trend of the south coast of Newfoundland, and which are mappable throughout the Cabot Strait. This part of the reconstruction is consistent with another aspect of the dextral simple-shear strain ellipse. Extension fractures are ideally oriented at very low angles to the principal compressive stress (strain ellipse, Figure VIII.1), and in this scenario the fault presumed to bound the south coast of Newfoundland would qualify as an extension fracture. This should not be oversimplified, however, as a more complex regional strain system involving the northeastward tectonic escape of the combined Central Mobile Belt and Avalon Zone has already been discussed above. It is likely that the actual situation lies somewhere between this regional control and a local manifestation of the strain ellipse, such that east-west faults in the Sydney Basin can be considered extension fractures (Figures VIII.1 and VIII.2).

Whatever the precise origin of these faults they appear to have affected the entire crustal profile, because by the end of the Namurian the Cabot Strait had increased in width to nearly its present width of 100 km, according to the series of reconstructions presented here.

The Viséan to Namurian was an important period of development for the Bay St. George half-graben as well. The stages of its development, as interpreted from seismic data, are illustrated schematically in Figure V.3.

The initiation of the Bay St. George half-graben at the beginning of the Viséan can be clearly viewed in the map reconstruction as a result of the southwestward transposition of the outboard terranes (Central Mobile Belt plus Avalon Zone) relative to the Humber Zone along the St. George's Bay fault system. Extensional stress dominated at this time because of the large-scale kinematic linkage with the Belle Isle Fault and the Magdalen Basin pull-apart system. It is further suggested that upper crustal elements in the external Humber Zone and Central Mobile Belt, *i.e.*, terranes lying to the east of this active fault system, were moved toward the internal Humber Zone by the end of the Namurian, within the east-west directed contractional strain field outlined above. This is consistent with the interpretation of the Namurian-Westphalian unconformity and widespread basin inversion in the Cabot Strait area at this time.

The inversion of the high-standing and topographically dominant portion of the Anguille Group known as the Anguille Anticlinorium (Knight, 1983) is interpreted to have occurred during the Namurian compressive event as a result of its position between two strands of a regional displacement system. This took place as the fault-bounded Anguille-Cabot subbasin was squeezed northward between the Hollow-St. George's Bay and Cabot fault strands (Figures II.5 and VIII.1), which gradually converged and became more kinematically linked as the outboard terranes slid southwestward past the St. Lawrence Promontory.

An associated feature is the presence of Codroy Group sediments which show detachment within the evaporitic horizons of the Ship Cove Formation, the lowermost stratal division of the Codroy Group (Knight, 1983). This phenomenon occurs above Anguille rocks around the northern periphery of the Anguille Mountains, and an equivalent structure was recognized in the shallow subsurface on reflection seismic data at Robinsons River, around 10 km to the northeast (Hall et al., 1992). Lynch and Tremblay (1994) have documented the same phenomenon in Cape Breton Island for this time period. The Codroy Group around the southern margin of the Anguille Mountains shows evidence of soft sediment deformation such as might be caused by gravitational sliding and detachment above an inverted and highly indurated Anguille surface (Knight, 1983; W. Jamison, pers. comm., 1991).

VIII.4.4 Cape Breton Island

Recent geological studies in Cape Breton Island by Lynch and Brisson (1994) and Lynch and Tremblay (1994) have led to more detailed interpretations of late extensional processes which have modified the orogen in the Cape Breton Highlands. These authors identified two episodes of low angle extensional faulting in the Cape Breton Highlands - the late Devonian-early Carboniferous Margaree Shear Zone, and the late Carboniferous Ainslie Detachment.

The Margaree Shear Zone is a thick retrogressive mylonite zone which carries Fisset Brook volcanics in its hanging wall, and has exhumed Acadian metamorphic assemblages in its footwall. From shear criteria, the upper plate demonstrates a general westerly direction of transport. The existence of the Margaree Shear Zone appears to be evidence for extension of the upper crust in and around the St. Lawrence Promontory in late Devonian to Carboniferous time. Although the early faults bounding the Horton Basins crosscut the Margaree Shear Zone, there is probably a direct kinematic connection between this episode of crustal extension and the almost immediate development of the Horton basins. One aspect of the distribution of the Horton basins should be borne in mind: the string of narrow Horton rift basins disposed along the regional strike-slip fault zones broadens in the Magdalen Basin west of Cape Breton Island (Durling and Marillier, 1993a). This geometry likely represents the overprint of extensional basin-forming processes by strike-slip processes. The Margaree Shear Zone appears to provide an on-land confirmation of this overprint.

Other, more indirect evidence for late Paleozoic orthogonal crustal extension is provided by the proliferation of plutonic rocks which mark the middle and late stages of the Devonian, especially within the Aspy Terrane (Figure VI.4). Although these rocks yield geochronological ages which in some cases range into the Carboniferous, most of these are likely minimum ages, due to the tendency of these systems to be reset by retrograde metamorphism. It appears, then, that most of these plutons are middle to late Devonian in age. These can also be correlated with plutonic rocks of similar age and composition in Newfoundland, particularly in eastern sectors of the Gander and Avalon Zones (Figures VI.1 and VI.2).

Hamblin (1992) and Hamblin and Rust (1989) studied the Horton Group in Cape Breton Island and, based on sedimentological evidence, identified two depocentres. The Ainslie subbasin is centred around Lake Ainslie and strikes roughly northeast with an asymmetric configuration, with the axis at the southeastern margin of the basin associated with a footwall fault scarp, and paleocurrent directions directed from the northwest toward this axial depocentre. The depocentre is exposed in and around the northern margin of Great Bras d'Or Lake. The Cabot subbasin in the north shows opposing polarity: the position of the depocentre and paleocurrent directions are reversed. Only the proximal edge of the basin is seen on land however. Paleocurrents directed offshore to the northwest indicate the presence of an adjacent depocentre, probably associated with a footwall fault scarp of opposite polarity, in this position. No such thick Horton depocentre is identifiable from geophysical data in a present-day adjacent position offshore.

It is proposed here that the Anguille Group now exposed in southwestern Newfoundland represents the missing "Cabot subbasin" depocentre of these authors, and is now part of Newfoundland due to northeastward, dextral transposition along the Aspy-Cabot fault zone. This supposition is further supported by examination of paleocurrent data within the Anguille Group, as collected by Knight (1983). The upper three formations of the Anguille Group (Figure I.2) yield paleoflow directions oriented toward the west, southwest or northwest, *i.e.*, they exhibit a dominant westward vector. For the lowermost formation, the Kennel's Brook, Knight (1983, p.19) notes that "although no paleocurrent data was obtained, the arkosic composition of the sandstones and the dominantly acid-plutonic and silicic-volcanic clast composition of the pebbles suggest the source of alluvium was from pre-Carboniferous crystalline and volcanic rocks of central Newfoundland". In keeping with the present reconstruction and bearing in mind the tectonic similarities drawn between Gander and Avalonian (*sensu lato*) rocks of southwestern Newfoundland and those of Cape Breton Island (Barr and Jamieson, 1991; Barr et al., 1994), it is proposed here that these sedimentary rocks within the Anguille Group were derived from the Aspy and Bras d'Or terranes in Cape Breton Island. This is best visualized paleogeographically by comparing the previous reconstruction for 380 Ma (Figure VII.1), which depicts the situation prior to the onset of Carboniferous strike-slip, and the current reconstruction for 320 Ma, which shows the Anguille-Cabot Subbasin as part of a terrane, now incorporated into the Humber Zone by strike-slip.

This point brings us back to the discussion of Section VI.1 on the semantics of terrane definitions. The Anguille-Cabot Subbasin and its underlying basement, the latter represented by the anorthositic rocks in the core of the Flat

Bay Anticline and possibly equivalent to those in the Steel Mountain Massif, qualify for terrane status when compared with similar fragments moved long distances by right-lateral slip along the west coast of North America (*e.g.*, Umhoefer et al., 1989; Section VI.5). Currie and Piasecki (1989) appear to have recognized the distinct nature of the basement rocks in this area, as they named it the Steel Mountain subzone (SMT on their Figure 1).

The exact positions of the various crystalline fragments of Cape Breton Island prior to the onset of Carboniferous strike-slip are impossible to determine. However, it is certain that a considerable amount of displacement must have occurred, as the Aspy Fault and many smaller faults, particularly those in the western Cape Breton Highlands, show Carboniferous motion (Lynch and Tremblay, 1994). Granite emplacement appears to have been focussed along the northern part of the Aspy fault (Figure VI.4). The degree of fragmentation of rocks in Cape Breton Island is striking, and much of this indicates Salinic and Acadian heritage. However, Carboniferous deformation likely utilized and reactivated faults already involved in multiple stages of Lower and middle Paleozoic shortening.

The Aspy-Cabot Fault is a discrete shear zone in the north of the island, which becomes more diffuse southward. Future mapping will no doubt fill in the details of Carboniferous-age structuring, but at the present time the nature and extent of kinematic linkage of the myriad of small faults that cut through the western Aspy terrane (Figure VI.4) is unknown. To first order, the displacement strain in Cape Breton Island, especially in the south, must have been distributed across a broad area, and much of the island itself must have been situated astride a shear zone in the Carboniferous. This is reflected in the current reconstruction where several fault strands are shown to converge northward into the Cabot Strait-Bay St. George area. These are perhaps the earliest manifestation of the strands now mappable under the Cabot Strait, and include early representations of the St. George's Bay, Hollow and Cabot Faults (compare Figure VIII.1 with Figure II.5).

Between the middle Devonian and the lower Carboniferous the various fragments of Cape Breton Island began to assemble into the familiar configuration of today. The western half of the Aspy terrane probably occupied a small sliver that was bounded by two strands of the fault zone and started to move northward relative to the eastern Aspy terrane. The Blair River Complex was likely incorporated into the same sliver as the west Aspy terrane by this time. The Mira terrane had probably been juxtaposed against the combined east Aspy and Bras d'Or terranes along an east and northeast-trending splay.

The tectonic assembly of Cape Breton Island continued during the Viséan and Namurian epochs. The east and west Aspy, Bras d'Or and Mira terranes may have moved westward along an east-west trending fault (possible westerly continuation of the Sydney Basin pull-apart) to abut against the Blair River Complex. These terranes together must have moved southwestward relative to both the east Aspy terrane and the Central Mobile Belt - this resulted in both strike-slip along the newly-formed Aspy Fault, and enlargement of the Sydney Basin by pull-apart (Figure VIII.1). By the end of the Namurian, the Blair River Complex may have docked against the west Aspy terrane across the Red River Fault.

The interpretation by Currie (1977) of widespread post-Viséan thrusting around the periphery of the Cape Breton Highlands (Section VI.3.9) implies some tectonic assembly of Cape Breton Island during the late Carboniferous.

Lynch and Brisson (1994) and Lynch and Tremblay (1994) have identified a major normal shear zone with a ramp-and-flat geometry in western Cape Breton Island which they have termed the Ainslie Detachment (Figures VI.2 and VI.3). This feature was first recognized by its omission of 2 - 3 km of Windsor Group stratigraphy: the top of the Macumber Formation (lowest, carbonate- and evaporite-bearing unit of the Windsor Group) passes upward across a calc-mylonite zone into rocks of the Namurian Mabou Group. Thus, the Ainslie Detachment is localized along the relatively incompetent carbonate and evaporite layers at the top of the Macumber Formation.

This structure has been responsible for the removal of much of the Windsor Group in western Cape Breton Island. Lynch and Tremblay (1994) proposed that the Ainslie Detachment acted as an upper crustal carapace fault, following the usage of Gibbs (1987). This may be the case, but here it is proposed that the Ainslie Detachment is equivalent to the detachment recognized near the base of the Codroy Group, in outcrop and on seismic data, in the onshore Bay St. George Subbasin, as discussed in Section VIII.3.3. On seismic data in the Cabot Strait, stratigraphically-equivalent décollement surfaces are identified on numerous profiles. As noted in Part I, these are interpreted as mainly contractional because of their relationhip to compressive tectonics in the Searston Graben; locally, however, they may have experienced tensional overprints and can be described as detachments.

The sliding of rocks above shallow-dipping detachments in the promontory area can be interpreted as a form of localized extensional collapse associated with the building of topographically high features during the Namurian transpressive event. In Cape Breton Island the detachment is related to elevation along the Aspy transpressive shear system: Windsor and possibly Horton sediments were likely inverted and rapidly eroded in the Namurian, but much of the sediment removal may have been mechanical, and effected by gravity sliding above a dramatically elevated topography. In the Anguille Anticlinorium a lesser degree of elevation and erosion may be postulated: the basin sediments are still preserved and the detached strata are clearly visible around the periphery of the elevated area.

VIII.4.5 Eastern Gulf of St. Lawrence/Magdalen Basin

The pull-apart fault geometry controlling the Magdalen Basin acted at this time to create an upper crustal hole by essentially north-south extensional strain. In this model, the southern boundary of the Magdalen pull-apart approximates the Canso tear fault, *i.e.*, the southernmost termination of the Cabot Fault and its splays. At this stage, the basin was in the process of being created by the northward movement of Grenvillian continental crust and its overlying sedimentary package which faced roughly southward along the bend in the old continental margin.

At this time, most of the Humber Zone geology exposed in western Newfoundland was being carried on the same plate as the northern edge of the Maritimes Basin. The gross geometry of the displacement system can be described as Humber Zone rocks moving dextrally past Dunnage and Gander Zone rocks, and this is generally accurate for the area north of the promontory-promontory collision zone (Figure VIII.1). However, from the Magdalen pull-apart eastward to the promontory area (ancestral Cabot Strait) the rhombic geometry of the area under extension dictates that the northeast corner of the pull-apart progressively necks and narrows, with the extensional component of the strain decreasing into the master Cabot Fault of the regional displacement system.

In the Viséan, stretching in the Magdalen Basin pull-apart may have reached a critical stage when crustal thinning and isostatic sagging started to affect the buoyancy of terranes peripheral to it. This for example may have been the reason for the general Viséan transgression across the Maritimes Basin, and the proposal of a classic "steer's head" profile by Bradley (1982) after Mckenzie (1978).

A further influence of sagging in the Magdalen Basin may have been the imposition of transtension along the regional strike-slip fault system, as elements to the west, such as the Long Range Inlier, were pulled southwestward by the crustal sagging and a resultant minor gravitational drive. This may have facilitated crustal subsidence along the regional fault system, contributing to Viséan broadening of the Deer Lake and St. Anthony Basins.

As shown on the map of Figure VIII.1, the Magdalen basin depocentre had widened to about 200 km along its north-south dimension by the end of the Namurian. The northern shelf/basin edge had slipped to a position west of the widened eastern Cabot Strait/Sydney Basin area. Sedimentary thicknesses at this time in the Magdalen Basin had reached about 8 km; this included Horton strata presumed to be preserved in linear, areally-restricted grabens underneath the Magdalen Basin depocentre (Durling and Marillier, 1990).

Evidence for the Namurian-Westphalian compressional and erosional event - the NWU - is also seen in all petroleum industry boreholes on Prince Edward Island and under the Gulf of St. Lawrence which pass through the middle Carboniferous section. SOQUIP (1987) identified an unconformity variously picked as a "chlorite break" or "base kaolinite", or on electric log character alone, but this unconformity always separates the Canso Group or older Carboniferous rocks from Pictou Group rocks (see correlation cross section, Enclosure 5.2.2 of SOQUIP report).

VIII.4.6 Western Gulf of St. Lawrence/Maritime Provinces

The post-tectonic Horton basins represent a second stage and style of Devonian basin development. The crustal extension which engendered the Horton basins is considered here to be principally due to extensional collapse, at least at the St. Lawrence Promontory, and secondarily due to the onset of dextral shear across old sutures with the final elimination of oceanic crust from northern Iapetus, and the final docking of Gondwanaland (and perhaps Iberia in part) against the outer edge of the Avalonian terranes now accreted to Laurentia (see Part III). In the early stages of Horton deposition these right-lateral shear stresses were incipient, and perhaps only contributed minimally to the overall extensional stress picture.

Under the Gulf of St. Lawrence other evidence for post-orogenic extension and Horton basin formation comes from deep reflection seismic data in the western Gulf of St. Lawrence. Line 86-2 (Figures VII.2 and VII.3) was acquired as part of the marine LITHOPROBE program. [For the original interpretation and discussion of this line see Marillier et al. (1989), Durling and Marillier (1990), and Stockmal et al. (1990)]. The interpretation shown follows that of Durling and Marillier (1990), who related basin development to crustal structure. The data reveal a continuous, south-dipping, shallow structure (beneath which reflectors A, B and C terminate), which is taken to represent a crustal scale detachment (here labelled CSD). Antithetic, moderately north-dipping structures which bound the upper crustal subdivisions of Durling and Marillier (1990: Laurent, Bradelle and Shediac domains of Figure VII.2, broadly equivalent to the Humber, Dunnage and Gander Zones), sole and terminate into the CSD. These domains appear to be allochthonous above southwest-thinning Grenvillian crust, and are uniformly separated from it by the CSD.

The scale of this crustal fabric, and its apparent association with crustal thinning under the Gulf of St. Lawrence (*e.g.*, Durling and Marillier, 1990) suggests that it is a reactivated, crustal scale detachment along which foreland-directed crustal shortening was accomplished in the Acadian Orogeny. The true direction of this motion is hard to determine from one line, but a significant vector along the trend of the line (roughly northeast) is clear.

Since the line is oriented roughly normal to the southern, east-west trending margin of the St. Lawrence Promontory, it may represent a component of north-directed imbrication and shortening particular to the Acadian Front in this area.

While the above explanation is plausible and partly necessary to explain the CSD entirely as a reactivated compressional structure, its southerly-directed extensional overprint is entirely consistent with the behaviour of the crust in collapsing orogens (in relation to the trend of the compressive orogen). Dewey (1988) pointed out the radial nature of gravitationally-driven spreading in the collapse of orogens, so that extension resulting from overthickened crust will tend to move along paths of least gravitational resistance, independent of the trend of the regional plate boundary mimicked by the main orogenic front (in this case, northeast-southwest). Extensional allochthons in this area, then, may have moved southward across the local, east-west tear fault-controlled bend in the orogen.

On Line LE-86-2 (Figure VII.2), Horton basins are developed above antithetic faults whose hanging walls appear to have rotated downward to sole into the Horton depocentres, and are thereby focussed along the boundaries between the Laurent, Bradelle and Shediac upper crustal blocks.

This particular seismic line may be unique amongst all LITHOPROBE lines in depicting the geometry of this crustal-basin relationship, because of (1) its orientation parallel to the regional strike of the orogen, but normal to the local strike, and (2) its position west of the Belle Isle Fault and, therefore, west of the area of major, strike-slip induced, crust-modifying processes. Strike-normal lines in the Cabot Strait and onshore Newfoundland (LE-86-4 and -86-5;

Burgeo and Maelpaeg lines) have been cut by the regional Cabot transcurrent system, and attempts to draw continuous Acadian and earlier structures across these faults may be spurious.

The strength of this argument is increased by the existence of a close analogue and interpretational precedent drawn from the Basin and Range area of the western United States. This geological province has long been studied as a model of crustal extension in an overthickened orogen (Davis and Coney, 1979; Coney and Harms, 1984; Hamilton, 1987; Sonder et al., 1987; Wernicke et al., 1987; Dewey, 1988), and in recent years deep reflection seismic data have contributed greatly to these investigations. On the COCORP 40°N transect through Nevada and Utah (Figure VII.3), seismic "fabric domains" are linked to position within the orogen, and the effects of superposition of extensional structures on the pre-existing contractional fabric of the orogen is evident (Allmendinger et al., 1987). The sub-horizontal reflection character of the lower crust is associated with magmatic underplating, processes which are considered to be symptomatic of extension in the lower crust.

The Sevier Desert Detachment is a low-angle, west (hinterland)-dipping detachment fault, visible at the surface in central Utah, that is seen on seismic data to penetrate most of the crust until its trace fades out in the lower crust near the Nevada-Utah border (Figure VII.3). Antithetic faults such as the Schell Creek Fault dip eastward and meet the SDD near the base of the crust. The Schell Creek Fault appears to be range-bounding at the surface, *i.e.*, it may control the downfaulting of crystalline rocks to form basins.

Its overall geometry and the presence of these representative geological features suggest that this seismic profile has sampled an extensional geometry analogous to that imaged on Line LE-86-2 in the western Gulf of St. Lawrence.

Finally, these cases may further be united by their adherence to the uniform-sense normal simple shear model of Wernicke (1985); in this model upper crustal rocks are situated on the upper plate, and mid-crustal rocks lie on the lower plate, of a low angle extensional fault. This model was suggested by Allmendinger et al.(1987) for the Basin and Range, and it presents a possible alternative, in terms of extensional geometry, to the uniform stretching model proposed by Bradley (1982), which is based on the pure shear model of Mckenzie (1978).

CHAPTER IX. EARLY PERMIAN (ca. 275 Ma) RECONSTRUCTION

IX.1 Regional Setting

This chapter will describe events occurring within the interval spanning the Westphalian to earliest Permian. The map at 275 Ma depicts the configuration of the major geological elements at this time. Thus, the final map reconstruction has restored the different elements to positions which together define the familiar geography of Newfoundland known today.

The late Carboniferous marked a change in tectonic style in the British Isles and northern Europe. Coward (1993) proposed that, after the major extrusion phase of the north European triangular wedge, the wedge was reinjected back along the same fault lines, as the Ural Sea closed in the east (Figure X.8, Section X.8, Part III).

Gibling et al. (1992), using an extensive paleocurrent database, studied the drainage patterns of the Maritimes Basin for the late Carboniferous to Permian time interval. They concluded that, for presently exposed areas, northeast-directed paleoflow was dominant between the late Westphalian "A" and early Permian, and confirmed van de Poll's (1973) hypothesis that drainage for this period was derived from the Appalachian Orogen to the southwest. During the late Carboniferous in particular, local uplands were found to significantly influence paleoflow patterns. On a broader scale, Gibling et al. (1992) suggested that the Maritimes

Basin probably drained eastward into then-adjacent areas of western Europe.

These authors noted that parts of the northern Appalachians (New England and northward) were characterized by considerable relief during the late Carboniferous to Permian, as a result of the pulse of mountain building known as the Alleghenian in the central and southern Appalachians. They proposed that this area might have been the source for the bulk of the sediment entering the Maritimes Basin at this time. The Mauritanides of western Africa (Figures X.7 and X.8) also experienced major thrusting and tectonothermal activity between the Namurian and early Permian (Lécorché, 1983; Villeneuve and Dallmeyer, 1987), and may have constituted another southerly source terrane for the Maritimes Basin.

The northeastward drainage followed major fault trends and associated paleovalleys across the New Brunswick platform and Naragansett/Fundy basins toward the Magdalen and Sydney Basin depocentres. In northern Nova Scotia and Cape Breton Island, where the intersection of the northeasterly and easterly fault trends are concentrated, the detailed picture is more complicated, as local small structural uplands deflected and controlled paleocurrents.

Gibling et al.(1992) compared the predominantly axial drainage of the late Paleozoic northern Appalachians to that of the late Cenozoic Himalayas, where some of the world's largest rivers originate behind the main thrust front and follow it eastward over long distances before disgorging their sediment loads into basins such as the Bay of Bengal and South China Sea.

The Permian in general was a period of slow exhumation of the Maritimes Basin and its uplands. Recent studies using apatite thermochronology and vitrinite reflectance data (Hendriks, 1991; Hendriks et al., 1993; Ryan and Zentilli, 1993) have built upon earlier studies which utilized coal rank as a guide to maturation levels of hydrocarbons (Hacquebard and Donaldson, 1970). All indicate that exhumation occurred in the interval between 280 and 200 Ma. According to Ryan and Zentilli (1993), this exhumation was effected by some combination of the following phenomena: (1) development of a pre-rift bulge related to the imminent (Mesozoic) opening of the Atlantic, and (2) continuing evolution of the Maritimes Basin in its late stages as an overfilled basin, with a base level up to 1 km above sea level. The overfilling of the basin continued as long as there was a steady supply of sediment entering it, consistent with Gibling et al.'s (1992) deduction of axial drainage from the northern Appalachians continuing into the early Permian. Peneplanation to sea level followed, as the sediment supply from the southwest waned, and consequent isostatic rebound kept the area buoyant, positive, and prone to erosion.

IX.2 Map Data: Position of Geological Elements in the Early Permian

The reconstruction shown in Figure IX.1 represents the paleogeography at 275 Ma. Events occurring between 320 and 275 Ma (late Namurian and early Permian) are outlined in the following:

(i) The last brittle deformation has become focussed along a single shear zone - the Cabot Fault in the south, and the Hampden Fault in the north.

(ii) During the Westphalian, extension occurs along the Cabot Fault zone, as evidenced by sedimentary wedges to the west of the fault in the Cabot Strait and with the ongoing development of the Bay St. George half-graben. Similar extension is known from this time period along the East Bay Fault (Boehner and Giles, 1986).

(iii) In the northwestern corner of the Deer Lake Basin, dextral movement is initiated on the left-stepping Taylor's Brook Fault; this results in reverse faulting of the Silurian Gull Lake Intrusive Suite over Viséan Deer Lake Group rocks.

(iv) The Howley "lateral basin" (Hyde, 1984) is depicted as forming during Westphalian time by the final pulse of extrusion of the Baie Verte Peninsula.

(v) The tightening and final assembly of Cape Breton Island is effected by the latest dextral movement of the Mira terrane towards the Bras d'Or; it probably is finally amalgamated in the late Westphalian.

(vi) The Cabot Strait-Sydney Basin has attained its present-day width of about 100 km at its narrowest point.

(vii) Cessation of regional strike-slip and lack of tectonic rejuvenation of source terranes and basin areas leads to infilling and overfilling of basins (Ryan and Zentilli, 1993) in the promontory area, probably by latest Carboniferous time.

IX.3 Discussion and Interpretation

IX.3.1 Western Newfoundland

The stress field set up in the Lower Carboniferous, involving dextral displacement along the Cabot Fault system, and a component of compression in the north, continued into Westphalian time. As a consequence, the Baie Verte Peninsula continued to be shunted northward, and subsidence was, therefore, focussed in the eastern, Howley "lateral basin" of the Deer Lake Basin area. The surrounding uplands were reduced by erosion and peneplaned, and feldspar-rich rocks exposed to the east, likely the Topsails Igneous Complex, became an important source of sediment (Belt, 1969; Hyde, 1984), for the arkose-dominated Westphalian "A" Howley Formation. The climate became more humid, and low energy, flood plain and meanderbelt sedimentary environments became widespread. The Taylor's Brook fault splay was initiated as the westernmost splay of the Cabot Fault system, which resulted in 10-20 kilometres offset of the Devil's Room granite from the Gull Lake Intrusive Suite (Colman-Sadd et al., 1990).

Measurements of maturation in coals and petroleum source rocks show that 1-3 km of sediment has been stripped from atop Carboniferous rocks throughout the entire region (Hacquebard, 1972; Hacquebard and Donaldson, 1970; Ryan and Zentilli, 1993; Hendriks et al., 1993). Presumably, over the more topographically positive areas of Newfoundland, Carboniferous thicknesses lay at the lower end of this range.

IX.3.2 Cabot Strait/Bay St. George

Under the Cabot Strait, deposition recommenced in mid-Westphalian time after the upheaval manifested by the NWU. The Westphalian appears to have been a time of active strike-slip faulting; along the southern trace of the Cabot Fault in the Cabot Strait a thick sedimentary wedge, identifiable in the shallow surface on seismic data, is placed within the Barachois Group (Figure II.9, Seismic lines 1121 and 1106). This sediment wedge appears to be fault scarp or proximal alluvial fan deposits, indicating significant periods of activity along these faults during the later half of the Westphalian. During this period, the Cabot Fault may have behaved as a relatively low strain zone. As a consequence, any topographic relief would have been localized to minor perturbations in fault zone geometry, resulting in deposition of localized sedimentary packages such as the fans or wedges noted above.

In the Cabot Strait, the latest part of the Westphalian is marked by a mild structural inversion ("B" unconformity: Figures II.10 and IV.1) localized along the Cabot Fault. It appears that by this time most of the late movement had been transferred from other splays in the system and was focussed along the main Cabot Fault. Evidence for concentration of movement along the Cabot Fault comes primarily from Lines 81-1103, -1105 and -1115 (Figure II.10), where the older NWU is progressively cut, and the subjacent sedimentary package increasingly truncated, as the Cabot Fault is approached. This is a convincing and clear example of the focussing along a single fault zone of brittle tectonics in the late stages of the orogen.

The Stephanian was probably a time of waning and intermittent movement along the fault zone. The peneplanation of high source terranes in the area, as well as the lack of major local basin-forming episodes (at least there is no evidence for such), precluded the accumulation of large thicknesses of sediment in the Cabot Strait. The Strait may have been mildly positive in relief relative to the central Gulf of St. Lawrence, where subsidence continued and Pictou Group sediments accumulated into early Permian times (Figure I.3). The Cabot Strait must have been eventually overstepped by the sedimentary blanket, however, in keeping with the interpreted burial of other areas of the region, as outlined above.

In the Bay St. George Subbasin the Barachois Group was deposited mainly during the Westphalian "A" and "C" (Hyde et al., 1991), but some upper undated sections may range into the Stephanian. According to Knight (1983) it accumulated in low energy fluvial plain environments, and was mainly derived from uplifted but now denuded source terranes along the fault zones in the east. This exemplifies a second-order control on provenance within a first-order regime of northeasterly paleoflow - here a proximal source terrane has provided sediment to a local basinal area (Gibling et al., 1992).

IX.3.3 Cape Breton Island

Very little Upper Carboniferous cover remains in the Cape Breton highlands to provide a gauge of late Carboniferous deformation. The Westphalian Cumberland Group crops out around the periphery of the highlands, but likely has been removed by erosion along the trace of the Aspy Fault zone, which resulted from elevation associated with late strike-slip movement.

In the lower-relief areas of southern and eastern Cape Breton, however, one of the classic sections of Upper Carboniferous strata is known from outcrop and coal mining, as these rocks are host to the economically important Cape Breton coalfield. Gibling et al. (1987; 1994) correlated these rocks with the offshore Sydney Basin, using well data from offshore drilling (Figure II.1). This composite stratigraphic section, reproduced in Figure I.3 of this study, depicts a continuous, fining-upward Westphalian "B" to (early?) Permian section ("upper megasequence"). These strata are dominantly fluvial and lacustrine in origin. However, the presence of foraminifera associated with Westphalian "D" coals indicate that, from time to time, transgression above a broad, low-lying coastal plain resulted in brackish, shallow marine conditions (Thibaudeau and Medioli, 1986; Gibling et al., 1987; White et al., 1992; Wightman et al., 1992).

Such results attest to the existence of a fluctuating and transitory marine shoreline located somewhere to the east of Cape Breton Island during the Upper Carboniferous. This sedimentologically defined boundary represents a change in relief and must approximate the eastern limit of the "overfilled" terrestrial basin, centred on the Magdalen Basin, of Ryan and Zentilli (1993) (Figure IX.1).

IX.3.4 Gulf of St. Lawrence

The central Gulf of St. Lawrence today represents the thickest relict accumulation of sediments in the Maritimes Basin, and has never been stripped of its thick Upper Carboniferous to Lower Permian alluvial succession. Wightman et al. (1994) and Rehill et al. (1994) combined seismic and well data to map a kilometre-thick Upper Paleozoic sedimentary sequence over this area. These strata have traditionally been considered to be fluvial and lacustrine in origin, but, as is the case for the Sydney Basin, discoveries of agglutinated foraminifera within or closely associated with sediments of the Westphalian Coal Measures indicate the intermittent presence of a marine environment.

The recognition of at least intermittent shallow marine conditions in both the Sydney Basin and central Gulf of St. Lawrence lends support to a number of ideas presented earlier in this chapter, as summarized and compiled from various researchers. Firstly, the deduction of an Upper Carboniferous peneplanation, or at least of a broad alluvial basin which even as early as the Westphalian was sustained at low relief, is consistent with the presence of shallow marine microfossils. Minor fluctuations in sea level would have pushed the shoreline westward across large expanses of the Gulf of St. Lawrence alluvial plain. Secondly, the interpretation of a shoreline (base level), which for most of the Upper Carboniferous lay somewhere to the east of Cape Breton Island, is consistent with the conclusions of Gibling et al. (1992) that a regional northeast-directed paleoflow was dominant for this period.

IX.4 Middle Permian to Mesozoic Overprint

Movement on the Cabot Fault system probably ceased in early Permian time, although a lack of sedimentary rocks of this age in the immediate study area preclude a full understanding of how late the fault system persisted. The fact that Upper Carboniferous rocks in western Newfoundland, such as the Howley Formation and Barachois Group, are known to have been buried to significant depths suggests that either regional subsidence continued well into the Permian, or that the effect of basin overfilling, as proposed by Ryan and Zentilli (1993) for the Magdalen depocentre, extended over much of Newfoundland. Since the geographical focus of this deposition was the central part of the Gulf of St. Lawrence, it is likely that the Cabot Fault and related faults did not play a major role in basin development and sedimentary accumulation, as they had in the early Carboniferous. Upland basin areas, such as covered most of the present geographical extent of Newfoundland, subsided only gently and passively by virtue of their proximity to the central Gulf of St. Lawrence depocentre. Early Permian subsidence in this area was probably the result of ongoing yet decreasing amounts of strike-slip on the Belle Isle and Cabot Fault systems.

An episode of late Triassic rifting and extension has been documented for the Bay of Fundy and onshore Moncton Subbasin area (*e.g.*, Nickerson, 1994; Brown and Grantham, 1992); this matter will be discussed in Part III in the context of the large scale plate tectonic reconstructions. This extension is not clearly recognized in the Cabot Strait and environs, and it appears to be largely limited to the area south of the Minas Geofracture. In the Moncton Subbasin, Nickerson (1994; his Figure 6-4)) recognized a major northwest-trending fault which acted as a tear fault for differential extension between the northern and southern sectors of the Bay of Fundy. There are no significant faults with such a trend mappable from seismic data in the Cabot Strait, although most of the lines of the regional seismic grid are oriented northwest-southeast, an arrangement not optimal for the imaging of Triassic extensional features.

One of the most convincing arguments for a Triassic overprint may be a straightforward one based on bathymetry: the Laurentian Channel is a strongly developed, southeast-trending feature that contains the main outflow of the St. Lawrence River. This young, post-glacial feature may follow an earlier structural weakness which could be the trace of an aulacogen - the failed arm of a triple point rift system which was responsible for the opening of the North Atlantic south of the Newfoundland Fracture Zone in the late Triassic, and which itself was sited upon an old transform fault system at the margin of the Laurentian Craton (Gibling et al., 1987).

PART III: NORTH ATLANTIC RECONSTRUCTIONS AND THEIR CONTRIBUTION TO AN UNDERSTANDING OF PROCESSES AT THE ST. LAWRENCE PROMONTORY

CHAPTER X: MIDDLE TO LATE PALEOZOIC TERRANES AND PALEOGEOGRAPHY ACROSS THE NORTH ATLANTIC

X.1 Objective

The origin of the late Paleozoic basins in the St. Lawrence Promontory is best understood within the framework of plate tectonic reconstructions for the northern Appalachian-Caledonide-Variscan system. Unfortunately the most recent reconstructions to be found in the literature (Ziegler, 1988; 1989) are suspect because Ziegler invokes large amounts of sinistral strike-slip through the Devonian to align western Newfoundland with the Central Mobile Belt + Avalon Peninsula (already sutured) by the early Carboniferous. Since large amounts (1500-2000 km) of sinistral displacement on the Great Glen Fault system (Van der Voo et al., 1980; Van der Voo and Scotese, 1981; Smith et al., 1980; Kent and Opdyke, 1978) were no longer considered reasonable by most workers (*e.g.*, Briden et al., 1984; Irving and Strong, 1985), Ziegler (1989) accommodated large amounts of sinistral shear by proposing a diffuse system of faults south of the Great Glen Fault in Britain, as illustrated in Figure X.1a.

The main difference between the work of Ziegler (1988; 1989) and the reconstructions presented herein is that mine treat the evolution of the northeastern Appalachians as a gradual buildup of accreted terranes (compare Figure X.1a with Figure X.3). This is accomplished by a process of sinistral shear which is completed by the earliest Devonian, thereby obviating large amounts of sinistral movement on the Great Glen Fault and related faults to the southwest during the Devonian. As will be seen, this is consistent with recent structural and geodynamic research in both the northeastern Appalachians (*e.g.*, Hibbard, 1994; Nance and Dallmeyer, 1993; Dubé et al., 1994; van Staal et al., 1992) and the British Caledonides (*e.g.*, Soper and Hutton, 1984).

This chapter presents a series of six map reconstructions based on ideas presented in Parts I and II of this thesis, and supplemented by literature sources. To my knowledge, these maps represent the only recent attempt to compile and summarize plate, microplate and terrane positions in the northeastern Appalachians, and to link them with similar recent work in Britain and northwestern Europe. In particular, my map reconstructions have been influenced by:

• the three-plate collisional model of Soper and Hutton (1984; Figure X.1b), and the importance of sinistral transpression emphasized by Leggett et al. (1983), Leeder (1982), and Soper et al. (1992);

• the recognition of continental escape tectonics as an important process in the assembly of northwestern Europe as articulated by Coward (1990; 1993);

• paleogeographic reconstructions of the circum-North Atlantic region by Ziegler (1988; 1989), as well as basement correlations across the same area by Lefort (1989);

• the reconstructions of Stockmal et al. (1990) based on deep seismic data, and including pre-Carboniferous restoration of western Newfoundland, and

• a model of promontory-promontory collision proposed by Lin et al. (1994).

My reconstructions expand on these earlier models by incorporating new data from conventional industry and deep crustal seismic profiling, and from new high-resolution geochronology.

The area covered by the reconstructions was limited to the North Atlantic borderlands because these areas now contain terranes which experienced late Paleozoic tectonic processes, such as tectonic indentation and escape, in common. Although the southern Appalachians underwent a similar development in the early Paleozoic, it will be suggested in the following pages that the processes which gave rise to late Paleozoic basins in the Northern Appalachians-Caledonides were associated with a combination of the irregular geometry of the Laurentian margin and the collision of European terranes (such as Iberia) with Laurentia + Baltica (sometimes referred to as Laurussia) and its accreted terranes.

A compilation showing the nature of the data and the constraints involved in the reconstructions of Part III is found in Table III.

Explanation of map patterns and other symbols is contained in the Legend and Key to North Atlantic reconstructions (accompanying the caption to Figure X.3).

X.2. Contribution of Terrane Analysis to an Understanding of Late Paleozoic Basin Development in the Study Area

The following general discussion on the broader tectonic aspects of terranes and their boundaries places the development of the late faults of the St. Lawrence Promontory in the context of larger scale processes. The reconstructions presented in this chapter will use the principles outlined below as guidelines. Perhaps the most important terrane studies have been carried out along the Cordillera of western North America, which is a tectonic collage comprising accreted crustal fragments or terranes (*e.g.*, Coney et al., 1980; Jones et al., 1983). The relatively well-documented history of recent strike-slip tectonics also has enabled an understanding of late modification of orogens by transform processes. Crowell (1985) emphasized that terrane analysis must include the effects of strike-slip in areas of large offset.

Accretion tectonics is a concept closely related to terrane analysis but providing a broader framework in which the origins of slivers now incorporated within orogenic belts are addressed (Nur and Ben-Avraham, 1983). These authors proposed that: (1) most allochthonous terranes are fragments of pre-existing continental blocks; (2) these fragments are physiographically represented by oceanic plateaus and carried on the world's oceanic plates; (3) their accretion to continents causes substantial orogenic deformation, whether or not large scale continent-continent collision ever transpires. In this view, collision and accretion of continental fragments, rather than continent-continent collision, are the main cause of orogeny.

Simply stated, then, subduction of oceanic crust beneath a continental or composite margin creates a magmatic arc, while arrival of an oceanic plateau (continental fragment or microcontinent) induces orogeny.

The relationships between the various terranes of Cape Breton Island and southern Newfoundland can be evaluated using this paradigm. As reviewed in Part II, some of these terranes have been correlated with the Gander Zone in Newfoundland, whereas others have been assigned either to the Avalon Zone *sensu stricto*, or to the Avalon Composite Terrane, a loose collection of terranes with Avalonian affinities (Keppie, 1985; Keppie et al., 1990; 1992; Nance and Dallmeyer, 1993). The Avalon-Mira terrane might reasonably have been a large Western Avalonian microcontinent, which was perhaps the sole passenger on a single oceanic plate.

By contrast, the Avalon Composite Terrane may represent a collage of oceanic plateaus. These individual continental fragments may have been carried on a single oceanic plate or on multiple plates. Any spreading ridges or transforms separating multiple plates would themselves have caused tectonic complications as they arrived at the subduction zone.

The convergence of the Australian Plate northward toward the Java Trench (Figure X.2, Pickering and Smith, 1994) is a modern analogue of a large microcontinent (or, in this case, a small continent) being carried by a single oceanic plate. At present oceanic crust of the Indian-Australian plate is being consumed, but eventually western Australia will arrive at the trench and initiate a continent-continent collisional event in eastern Indonesia. Such an episode of mountain building has already commenced in New Guinea (Figure X.2).

The area of the Philippine Sea provides a modern example of a complex system of trenches and transforms subdividing the Pacific Plate into multiple oceanic plates. The Philippine Islands at the western edge of this system has been formed by multiple collisional episodes which obviously do not involve continent-continent collision.

It is noteworthy that the model of Leggett et al.(1983) for the British Isles was based upon a composite analogue taken from studies of active plate boundaries in Japan, Sumatra and the Queen Charlotte Islands.

The Gander Zone together with all terranes of Avalonian affinity, including the Western Avalonian microcontinent, can be considered a "superterrane", following the usage of Nur and Ben-Avraham (1983). In such a scheme, Gander-type terranes represent cover sequences of continental slivers, whereas Avalonian terranes represent fragments in which basement can be more readily identified. Because of this, the latter may have been derived directly from the West Avalonian microcontinent, whereas the former may have been a part of West Avalonia or some equivalent body.

By this reasoning, then, the mass of the Central Mobile Belt of Newfoundland was created by ongoing oblique subduction, and the intermittent arrival at the subduction zone of dispersed continental components which now constitute the superterrane. The Avalon-Mira terrane combination (West Avalonia) can be viewed as the southernmost, and by far the largest continental fragment of this superterrane, and probably the only one large enough to be considered a microcontinent. These continental fragments were likely rifted or slivered from Gondwana during the late Precambrian breakup of that supercontinent.

Many of the small pulses of orogeny that are sometimes difficult to correlate on an orogen-wide scale (or even on the scale of a section of an orogen, such as the northern Appalachians), may be due to the arrival of such continental fragments into a subduction zone. The effects of such orogenic pulses would reasonably be expected be felt over an area comparable to the size of the fragments themselves.

The present day geographic expression of Newfoundland is an expression of accretionary tectonics. The Dunnage, Gander and Avalon zones were progressively joined to the growing mass of Newfoundland-Cape Breton Island precisely because the Iapetan oceanic plate(s) slipped obliquely northward relative to Laurentia (*e.g.*, Nance and Dallmeyer, 1993; Hibbard, 1994). This from time to time brought continental fragments, carried as oceanic plateaus, into collision with the promontory.

These events could reasonably have led to two styles of deformation and metamorphism. The first, associated with the destruction of oceanic crust at the oblique margin, involved island arc-type, convergent margin volcanism and plutonism, with high temperature metamorphism dominant. The second style, associated with the arrival of continental fragments in the collision zone, resulted in high strain, intermediate temperature metamorphism, and the formation of large nappes and allochthons, distributed in fold and thrust belt-type geometries. Such blocks were originally bounded by extensional faults in the early Paleozoic rifting event, and include the Long Range Inlier and affiliated smaller basement allochthons, with cover rocks. Locally, the high stresses associated with the second style would produce thick-skinned thrusting where basement blocks were caught up in the allochthons (*e.g.*, Cawood and Williams, 1988; Grenier and Cawood, 1988; Stockmal and Waldron, 1993; Waldron et al., 1993; Waldron and Stockmal, 1994).

The foregoing provides some insight into the tectonic processes which had combined to construct the northern Appalachian Orogen, and specifically the area in and around the St. Lawrence Promontory, up until the middle Devonian. The subsequent history of the area is one of equilibration and modification of the orogen, both by body forces such as gravitational collapse, and by plate boundary forces such as regional strike-slip. The proliferation of extensional processes of various types, and the consequent generation of sedimentary basins, is the signature of the late Paleozoic at the St. Lawrence Promontory. Given the fragmentary history and piecemeal assembly of Cape Breton Island and Newfoundland, it is no wonder that correlations of surface geology, deep crustal seismic fabric domains, and plutonic melt sources have been difficult to make (Quinlan et al., 1992; Hall and Quinlan, 1994; Fryer et al., 1992; Kerr et al., 1993, 1995). This realization applies equally to basin studies. For example, the Cabot Fault cannot be convincingly traced to the base of the crust on deep seismic profiles (Quinlan et al., 1992). It is probably unreasonable to expect that late transcurrent stresses between the most outboard of the accreted terranes (West Avalonia/Meguma) and the Humber Zone would be focussed along a single subvertical fault, except in the very latest, brittle stage of the orogen. In Part I we have seen this expressed in a wrench borderland model, where transcurrent shear is distributed among several subparallel, steep faults within the upper third or half of the crust (Figure V.2). Given the nature of the terrane collage fabric, it is likely that lateral displacement was accommodated at depth by at least as complex an array of interconnected subhorizontal boundaries throughout most of Carboniferous history.

In this respect, the "mixed mode" basin concept of Gibbs (1987) has some application. He sees such basins as surface, hanging-wall expressions of movement between subhorizontal "fault leaves" which combine to form an upper crustal carapace. Although Gibbs connects the bounding faults to a master subvertical fault at depth, the Promontory area under consideration here bears the inheritance of a tectonic collage fabric even in deeper levels of the crust (as evidenced by the outcrop of dismembered pieces of this crust in southwestern Newfoundland). This suggests that strain has been transferred through a series of stepped, interconnected, moderate to low angle faults, of which the Cape Ray-Gunflap Hills fault system may be an example (discussed further in Section X.5).

A distinction can be made between early and late stages of transcurrent faulting in the Promontory, perhaps separated by the NWU (Figures I.3 and IV.1). Early Carboniferous, more dispersed faulting was still an "Appalachian" process, as it represented a response to post-collisional tightening of accreted terranes against Laurentia. In contrast, late Carboniferous strike-slip faulting, which in the present study area is focussed almost entirely along the Cabot Fault system, is a response to the bulk shearing between newly-amalgamated rigid sialic plates. Arthaud and Matte (1977) proposed that the North American crust reached this state after "stress hardening" (sic) and cooling within a brittle Variscan foreland. Therefore, the Cabot Fault can be considered a Variscan rather than an Appalachian feature. To take this one step further, the inception of the Cabot Fault as a sharply-defined feature is our local expression of the final stage in the assembly of Pangaea, as collections of accreted terranes, on either side of the fault, are for the first time behaving as units in the context of large-scale plate motion.

X.3 Early Ludlow (ca. 420 Ma) Reconstruction

In northwestern Europe, this stage in the tectonic history (Figure X.3) is characterized by the impending collision of East Avalonia with the previously-assembled elements of the northern British Caledonides, which include the areas now known as the Southern Uplands, Midland Valley and Grampian Highlands (Leggett et al., 1983). The latter three of these were termed the early "metamorphic Caledonides" by Soper and Hutton (1984), and at this time lay at the southwest corner of Laurentia-Baltica continent-continent collision (Soper and Hutton, 1984). They are part of the "main Caledonian orogeny" of northwestern Scotland, which occurred between late Ordovician and mid-Silurian time, and are characterized by tectonic stacking, igneous intrusion, and metamorphism. The fact that these processes occurred at the same time here and in Scandinavia underlines their position as part of the Laurentia-Baltica collision, which involved a pairing of tectonic elements different from that of later Caledonide and related Appalachian events. As will be shown on subsequent maps, these collided terranes would eventually reach their final position in northern Britain by sinistral strike-slip.

In this reconstruction East and West Avalonia are configured as microcontinents situated on the same or adjacent plates, which are moving northward obliquely against an oceanic trench system as part of the ongoing closure of the remnants of the Iapetus Ocean, the Tornquist Sea in the east (Soper et al., 1992) and the Merrimack Ocean in the west (Bradley, 1983; Ziegler, 1989). The East Avalonian continental fragment is placed closer to the trench, and by the late Silurian is about to collide with the British Caledonide arc-trench system. A narrow remnant of the Tornquist Sea still exists in the east. In the west a collection of small oceanic island or arc terranes with Avalonian affinities are in the process of colliding with the Laurentian margin at the St. Lawrence Promontory, which causes the Salinic Orogeny. The accretion of the "non-metamorphic Caledonides" of southern Britain (Soper and Hutton, 1984), can be visualized as the time equivalent of these recently recognized Salinic events. Unlike their British counterparts, these events involve major crustal thickening and heating, as evidenced by plutonism and high-grade metamorphism (Dunning et al., 1990a and b; Barr and Jamieson, 1991; Burgess et al., 1993; Section VI.2.3).

Evidence for a Silurian sinistral accretionary event focussed along the Cape Ray Fault comes from van Staal et al.'s (1992) observation of a stage of s-folding which, by correlation with other well-documented events in the area, they interpret as belonging to a Silurian sinistrally transpressive regime.

The relatively high metamorphic grade of the Salinic event can be explained by the model of terrane accretion discussed in Section X.2, and the reconstruction of this section. Specifically, it is a collision between a protruding continental margin (St. Lawrence Promontory) and small, partially continentalized oceanic plateaus now recognized as the terranes and "subterrane" fragments of Cape Breton Island and southern Newfoundland. These outboard Avalonian terranes were likely carried within a complex mosaic of small platelets and approached the promontory by sinistral strike-slip (Figure X.3), as discussed in Chapter VI. Such collisions would be expected to involve much more crustal imbrication and thickening than that occurring in collisions between continental and oceanic blocks.

In the reconstructions presented here the different terranes are plotted and grouped according to similarities and differences drawn by workers in the area, as summarized most recently by Barr et al. (1994). For example, the Brookville (BT), Bras d'Or (BdO) and "Burgeo" (BAT), the most inboard Avalonian elements, were probably adjacent to each other before colliding with the Promontory. The Mascarene (MC), St. Croix (SCT; Fyffe and Fricker, 1987), Aspy (EA+WA) and "La Poile" (LPT) terranes include mid-Paleozoic arc complexes and can be viewed as products of convergence and subduction of the plate carrying the Avalonian terranes. The Notre Dame Subzone was accreted to the Humber Zone, and the Exploits Subzone accreted to the Gander Zone, during the Taconian Orogeny (Williams, 1978), but, based on sedimentological data, these two subzones of the Dunnage Zone were probably not finally sutured until early Silurian time (Nelson, 1981; Nelson and Casey, 1979; Knight and Cawood, 1991). The Gander Zone contains deformed, arenaceous sediments which may represent a shoreline-parallel prism at the eastern margin of Iapetus (Blackwood, 1982), or along one c the outboard Avalonian terranes. Nance and Dallmeyer (1993) suggested that emplacement of the Kingston Complex, which forms the northwestern boundary to the Carboniferous Moncton Subbasin in New Brunswick (Nickerson, 1994), took place at 435 Ma within a sinistral regime associated with the initial accretion of the Avalon Composite Terrane to North America.

The Clam Bank foreland basin began to receive clastic input from the east at the beginning of the Pridolian (ca. 411 Ma; Berry and Boucot, 1970). Knight and Cawood (1991; their Figure 43) related the Clam Bank Group to culmination formation, consistent with a buildup of topography across the Promontory.

Terrestrial basins in the hinterland of the Salinic orogen, represented by the Springdale, Botwood, and Sop's Arm

Groups, are accompanied both spatially and temporally by high level plutonism of the Topsails Association and comagmatic volcanism (Coyle and Strong, 1987; Taylor et al., 1980). Such extensional features in Newfoundland may originate in part by tectonic escape on a small scale of material away from the focus of convergence in the Cape Breton Highlands, although the exact amount of such movement is impossible to determine.

X.4 Earliest Devonian (ca. 400 Ma) Reconstruction

In this reconstruction (Figure X.4) East Avalonia has been largely accreted to the northern part of the British Caledonides along the Solway Line (Leggett et al., 1983). On the North American side, West Avalonia was about to dock with Laurentia and its inboard terranes, which were themselves still in the process of being completely amalgamated. The Bras d'Or, Aspy and associated terranes are shown as separated by hypothetical, still-active faults along which these terranes probably were further collapsed and imbricated during collision of the large West Avalonian microcontinent. The collision of East Avalonia with the British Caledonides probably marked the end of the large-scale oblique sinistral displacement system. Therefore, West Avalonia was unable to move further northeastward and began to move orthogonally, perhaps with a component of rotation, into the Promontory area. This change in the direction of principal compressive stress from north to northwest was reported by Hibbard (1994), and can be considered the beginning of orthogonal, "classic" Acadian as reviewed in Chapter VII. Nance and Dallmeyer (1993) documented a shift from dextral to sinistral shear within the Kingston Complex of New Brunswick, which they believed was due to the docking of the Meguma Terrane against the Avalon Composite Terrane around the early Devonian. This approximate geometry, displayed in Figure X.4, was also suggested by Soper et al. (1992, their Figure 6c).

These processes resulted in a splitting of larger terranes at the Promontory. As shown in the reconstruction, the Aspy and St. Croix terranes were possibly separated during this period, with the latter subsequently transposed toward New Brunswick along northwest-trending strike-slip faults parallel to the northern margin of the re-entrant and perhaps representing an early permutation of the Canso Fault. A similar process may have been operating to split the Bras d'Or and Brookville terranes.

The accumulation of buoyant fragments of continental and/or oceanic terranes with partially continentalized basements (*e.g.*, as produced by magmatic differentiation) would have led to crustal thickening and an increase in elevation across the mountain belt. In Newfoundland and Cape Breton Island, as well as in Britain, the widespread granitoid plutonism of this age would have further contributed to uplift and development of regional unconformities.

X.5 Middle Devonian (ca. 380 Ma) Reconstruction

As illustrated in Figure X.5, the mid-Devonian marked a change in the large-scale tectonic framework of northwestern Europe. The Aquitaine-Cantabrian terrane collided with the Ligerian-Moldan Cordillera, closing the Rheic Ocean (Ziegler, 1989; Leeder, 1982; Lefort, 1989). From this time onward Iberia continued to be driven northward, acting as an indentor into the Central Armorican "oldlands" (Leeder, 1982) and Rheno-Hercynian basinal areas. According to Coward (1993) such a northwest-directed compressive force in mid-Devonian time resulted in northeastward lateral extrusion of most of Britain along a reactivated sinistral Great Glen Fault and a conjugate dextral fault system. The latter is situated approximately along the southern English Channel, running eastward along the northern boundary of the East Silesian massif (Figure X.5; data combined from maps of Coward, 1993 and Ziegler, 1989). Leeder (1982) proposed the presence of a volcanic arc and molasse basin in Europe, and a back arc basin in the English Channel. The latter was gradually overstepped and destroyed by north-directed thrusting to form the Lizard Complex of Cornwall, conceivably as a result of continuing compression effected by the Iberian indentor (Figure X.4).

In northern Britain the abrupt northward bend of the Great Glen sinistral fault system became the focal point for large scale basin development. Some authors have attributed these terrestrial basins, which include the Orcadian-Midland

Valley system and the Hornelen and related basins of southwestern Norway, and contain the well-known Old Red Sandstone sequences, to the collapse of overthickened crust at the end of Caledonide continent-continent collision (Norton, 1987; Norton et al., 1987; McClay et al., 1986). In the two former basins in Scotland, up to 9 km of terrestrial sediments are present (McClay et al., 1986). Many smaller Old Red Sandstone basins are found within the northwest Scottish highlands, and offshore, where they have been identified by seismic profiling. McClay et al. (1986) argued for major crustal extension during the deposition of the Old Red Sandstone, with strike-slip motion on the Great Glen Fault and associated faults being subordinate to crustal-scale extension. This emphasis on gravity-driven crustal extension differs from Coward's (1993) model of lateral extrusion.

Hossack (1984) and Norton (1986) argued that extensional rather than strike-slip tectonics dominated in the Hornelen-type extensional basins in Norway. This is consistent with Coward's lateral extrusion model, because these basins are situated to the east of the bend in the Great Glen Fault, where the ejected block rapidly broadens (Figure X.5).

These three suggested processes of basin formation (transtension in a releasing-bend geometry, lateral extrusion, and gravitational spreading of an over-thickened crust) may all have operated in a complementary manner. The overall tectonic picture of the area is similar to the modern

Himalayan region, where syn-orogenic topographic basins are presently being formed by gravitational collapse (Tibetan Plateau; England and Houseman, 1989), and are accompanied by sideways ejection of crustal blocks along strike-slip faults subparallel to the orogenic front. Harrison et al. (1992) note that about one third of the accumulated strain resulting from the collision of India against Asia has been taken up along strike-slip fault systems which allow lateral extrusion of continental blocks (Tapponnier and Molnar, 1976; 1977).

Norton et al. (1987) also pointed out that the Midland Valley Basin formed at the southern margin of the thickened Caledonide crustal welt (*i.e.*, in the oceanic trench as opposed to the continent-continent domain). According to these authors, its association with "Cascade-type magmatism" suggests that its formation is closely related to extension caused by continued but waning subduction after collision. This viewpoint reiterates the classification of Leeder (1982) whose Group B basins are controlled temporally by Variscan tectonic forces but spatially by Caledonide inheritance. In any case, igneous activity is an important aspect of this phase of development.

Bimodal volcanics of the Fisset Brook and related extrusives represent similar and concurrent igneous processes in the Maritimes Basin (Blanchard et al., 1984), as discussed in Part II. A waning subduction zone may have persisted into the Devonian under the Maritimes Basin, and perhaps was related to, and had the same polarity as, the crustal scale detachment, imaged on LE-86-2 (CSD, Figure VII.3), which eventually would be the focus of asymmetrical, Wernicke-type extensional shear. This type of basin subsidence and igneous activity may be another ramification of the collision of terranes within the Promontory along a complex subduction system.

The middle Devonian also marks the time of collision of West Avalonia with Laurentia (Figure X.5). From this time on Laurentia likely was subjected to stresses applied to the Aquitaine/Cantabrian block and transmitted through the Iberian indentor. The immediate effect was to set up a dextral stress regime along long-lived faults such as the Cape Ray Fault, which records a dextral transpressive stress regime by post-late Devonian time (van Staal et al., 1992; Dubé et al., 1991; 1992).

The northwest stress vector implied by Coward (1993), and plotted by Leeder (1982) along the northern Aquitaine-Cantabrian terrane is identical to that proposed by Hibbard (1994) for the middle Devonian "classic Acadian" in the northeastern Appalachians. This allows a consistent orientation of tectonic stress to be plotted across the north Atlantic (Figure X.5). The St. Lawrence Promontory was the focus of orthogonal stress and crustal shortening, leading to the eastward escape of northwest Europe. West of the Promontory some dextral motion may likewise have been initiated, but mainly orthogonal convergence resulted in crustal thickening and considerable relief. Therefore, an extensional collapse origin for the late orogenic "pre-Horton" and Horton basins is consistent with the interpreted stress orientations. Not only do these basins have time equivalents in Britain (Old Red Sandstone), but they are located at, and just peripheral to, the apparent focal point of collision, *viz.*, the St. Lawrence Promontory. Basins such as the North Point, Cascumpec and unnamed Horton basins (Figure VII.2) are the best preserved examples of this category, and are preserved because they are peripheral to the main deformation of the Cape Breton Highlands. Similar basins in Cape Breton Island and perhaps on and offshore western Newfoundland were probably quickly destroyed once major strike-slip commenced along the Cabot Fault system in Carboniferous time.

The Caledonian and Mascarene terranes (Fyffe and Fricker, 1987) were presumably also displaced westward, relative to other parts of West Avalonia, along the dextral Canso tear fault, thereby resulting in the complete closure of the Merrimack Ocean of Ziegler (1989). At the same time the outboard Meguma terrane was displaced sinistrally westward, at the southern boundary of West Avalonia, along the Minas Geofracture, closing the Theic Ocean of Piqué and Skehan (1992).

An important feature of this period was the initiation of volcanism and associated post-tectonic plutonism in the Magdalen Basin and northern Nova Scotia. This resulted in the deposition of the Fisset Brook, Fountain Lake and other associated volcanic units, as compiled and illustrated earlier in Figures VI.3 and VI.4. The Ackley- and Mt. Peyton-type epizonal syenitic granitoids are symptomatic of melting of overthickened crust, perhaps as a result of detachment of a lower crustal "keel" and upwelling of hot asthenospheric mantle, as proposed by Dewey (1988) for orogens undergoing extensional collapse.

Escape tectonics or lateral extrusion may have played a minor role in the evolution of central Newfoundland from this period onward. The geometry of the Central Mobile Block suggests that it was squeezed and extruded northeastward away from the Cape Breton Island focus. Such motion would help explain the increasing grade of rocks southwestward across central Newfoundland. In fact an almost complete Silurian crustal profile is seen, from shallow epizonal granites, terrestrial basins, and volcanics in the north, to katazonal granites, migmatites and gneisses typical of the lower crust in the Hermitage Flexure (Kerr et al., 1993; Colman-Sadd et al., 1990). Such a pattern is consistent with upward and outward ejection of material away from the focus of collision. As shown in Figures VI.1 and VIII.2, the Baie Verte Peninsula may represent an even smaller-scale ejected sliver of this type.

X.6 Early Viséan (ca. 350 Ma) Reconstruction

This time slice (Figure X.6) is characterized by the collision of the Saharan Platform with the Iberian Block, continued compression of the Iberian indentor to form the Armorican arc, and ongoing lateral escape of northwestern Europe, all of which are aspects of the early stages of the Variscan Orogeny. The major effect in North America was the westward impingement of Iberia against the "Avalon high" to set up regional dextral displacement along the Cabot-Belle Isle fault system. The offset of this system along the Canso tear fault at the Promontory resulted in the development of a pull-apart geometry in the area of fault stepover. The result was accelerated subsidence in the late Tournaisian stage of Horton basin development, which continued into a widespread Viséan transgression centered in the Magdalen Basin. The Cabot Fault attained a complex wrench borderland geometry in the Cabot Strait area, and reactivated earlier sutures, as discussed in Parts I and II of this study.

The review of terrane accretion processes presented earlier now allows a visualization of the broader significance of the dispersed faulting which characterizes the Lower and Middle Carboniferous. At this time the orogen had apparently not cooled sufficiently to allow focussing of strain along straight and well-defined fault traces, and the various terrane fragments had not been sufficiently well sutured to act as single rheological entities. The wrench borderland geometry, with common reactivation of pre-existing zones of weakness, is an expression of this.

The Viséan stage marked the beginning of a long continuous period of subsidence and sedimentary accommodation in the Maritimes Basin which overlapped and buried the earlier fluvio-lacustrine basins, and eventually produced the classic "steer's head" profile as noted by Bradley (1982).

X.7 Early Westphalian (ca. 300 Ma) Reconstruction

By the Westphalian the escape of northwestern Europe toward the Ural Sea had ceased, perhaps because of the narrowing of the Ural Sea and juxtaposition of the Moscow Platform against the Kazakhstan plate. Figure X.7, illustrating this change, is compiled mainly from Ziegler (1989) and Coward (1993). The Variscan Orogen and the Iberian indentor had become a broad mountain belt reaching across most of Europe to southwestern England. The African plate, after its initial collision with Iberia in the Lower Carboniferous (Figure X.6), was displaced westward along a major east-west dextral megashear system to collide with North America, close the "proto-Atlantic" (Figure X.6) and form the Mauritanides of West Africa (Ziegler, 1989).

In the Canadian Appalachians the late Namurian to early Westphalian was a period of compression and basin inversion, accompanied by the development of the Namurian-Westphalian Unconformity, which was focussed along, but not restricted to, the controlling fault zones (Figures I.3 and IV.1; Part I). This event is known as the Maritimes Disturbance in the Canadian Appalachians (Poole, 1967; Schenk, 1978).

The reconstruction of Figure X.7 provides some insight into the cause of this structural reversal. It has already been suggested (Section VIII.3.3) that the Namurian-Westphalian Unconformity represents a clockwise rotation in the stress vector by about 20°, a situation similar to that noted by Nickerson (1994) in New Brunswick. This switch could be related to the sinistrally-transpressive arrival of the African Plate along the Midas Geofracture-Gibraltar Fracture Zone, as suggested in Figure X.7. Other manifestations of this tectonic upheaval were discussed in Part II and include the Ainslie Detachment and Anguille Anticlinorium.

After this period of disruption, subsidence was re-initiated across the whole of the Maritimes Basin, and terrestrial infilling continued in a broad, alluvial upland (Gibling et al., 1992; Ryan and Zentilli, 1993). Renewed dextral movement on the Cabot-Belle Isle fault system in the later Westphalian led to resumption of subsidence in the Maritimes and Sydney Basins, and, a shallow marine incursion into these areas (Wightman et al., 1992). The cause of this transgression is not fully understood. In his Westphalian reconstruction, Ziegler (1989; his Plate 9) depicts a small, restricted marine foredeep between the southern flank of the Iberian indentor and the northernmost Mauritanides, which reach as far west as the Scotian Shelf. Perhaps lithospheric loading of the Sydney Basin area in the Mauritanide foreland allowed westward expansion of the small Iberian foreland basin. In any case, intermittent marine incursion into the interior of the Maritimes Basin occurred, likely as a result of the renewal of transtensional subsidence.

X.8 Earliest Permian (ca. 275 Ma) Reconstruction

Figure X.8 presents the late brittle evolution of the Variscides and final configuration of tectonic elements in the northeastern Appalachians after the cessation of major strike-slip faulting north of the Minas Geofracture. North and west of Britain, the next ocean cycle had already begun with the development of continental rifts along the trace of the old collisional suture between Laurentia and Baltica. The brittle fracturing of the Variscan fold belt (Arthaud and Matte, 1977) was a consequence of decreased heat flow and reduced ductility in a waning and cooling orogen. In northern Europe, small pull-aparts and outpourings of flood basalts were induced by dextral displacement along these fractures (Ziegler, 1989). The cool, brittle state of the upper crust at this time suggests that these volcanics came from deep crustal or sub-crustal sources.

According to Coward's (1993) model, a major change in tectonic conditions comes about in the Stephanian-Autonian interval. (The Autonian is the general European term for the lowest stage of the Permian, spanning the period 280 to 260 Ma.) Kazakhstan collided with the Moscow Platform to create the Ural Orogen, and the northwestern European tectonic wedge began to be reinjected back between the Laurentian and Variscan plates. This resulted in a major inversion episode affecting basins of all orientations but particularly concentrated along the major conjugate fault systems by which the wedge was initially ejected and along which the basins formed (Coward, 1993, p. 1105).

In the west, the southern Appalachian-Mauritanide chain constituted a broad orogenic belt mainly focussed south of the Agadir Fault Zone in response to the westward drift of the African Plate. The Maritimes, Sydney and St. Anthony basins were eventually filled as tectonic activity came to a halt and subsidence ceased. This region of Atlantic Canada was gradually peneplaned and stripped of sedimentary cover during subsequent Paleozoic and Mesozoic time (Ryan and Zentilli, 1993; Hendricks et al., 1993). The latest stage of strike-slip faulting, which persisted into the early Permian, appears to have involved at least one transpressional episode. A late unconformity (Permo-Pennsylvanian Unconformity), representing the deformation of post-NWU Westphalian and Stephanian age sediments, is recognized on seismic profiles under the Cabot Strait (Figures II.9 and IV.1).

Nickerson (1994) calculated that the Bay of Fundy underwent 49% extension in the Triassic. This calclation was based on an application of a formula given by Wernicke and Burchfiel (1982) to seismic profiles of Brown and Grantham (1992). Furthermore, as these latter authors point out, if the basin-bounding faults are listric, then net extension is less than the above number, and is less than half the 40 km current width of the bay.

Nickerson (1994) drew an analogy between the Bay of Fundy and the Red Sea, comparing the details of the rift-splay faults which characterize the northern extremities of both rifts. The analogy can be extended to the equivalent roles played by the Minas Geofracture (in the Triassic) and the modern day Dead Sea transform. The latter is a sinistral fault accommodating differential strain between the Arabian and African plates as the Red Sea opens.

The palinspastic reconstruction of Nickerson (1994; his Figure 6-4) has been taken into account in the current North Atlantic reconstructions. The main ramification of this is to restore a maximum late Triassic and early Jurassic sinistral motion on the Minas Geofracture. This effectively reverses some of the Carboniferous displacement on the Geofracture and returns the area to its pre-Jurassic configuration, as depicted in Figure X.8.

CHAPTER XI. SYNTHESIS AND CONCLUSIONS: NEW INSIGHT INTO THE DEVELOPMENT OF THE MARITIMES BASIN

XI.1 Previous Interpretations of the Maritimes Basin

This study has enquired into the processes by which the Maritimes Basin developed, and has examined these processes at three different spatial scales. In Part I a geophysical data set was employed to examine local structural processes of basin development in the Cabot Strait and Bay St. George areas. In Part II the geological record from both sides of the Cabot Strait was used to generate a series of tectonic reconstructions illustrating local basin development, within the context of late- and post-orogenic development near a promontory-promontory collision. In Part III the scale was again broadened to include the entire North Atlantic region, and to incorporate several recent ideas about the late Caledonian to Variscan development of northern Europe. When plotted on the same map, these reconstructions from the eastern side of the present Atlantic complement and offer insights into processes I have studied in detail at the St. Lawrence Promontory.

This approach has allowed a synthesis of large amounts of information, both by contemporaneous lateral correlation along the orogen, and by analogy with other points in geologic time, notably the present day globe.

In order that the contributions made by this thesis can be brought into perspective, it is useful to summarize some outstanding questions regarding the origin of the Maritimes

Basin. The Magdalen Basin is the largest depocentre within this composite basin, containing up to an estimated 12 km of post-Acadian sediment (Howie and Barss, 1976). What controlled subsidence of this depocentre and accumulation of this great thickness of sediment?

Bradley (1982) interpreted the Magdalen Basin as a pull-apart basin, developed above a right-stepping offset in a regional-scale dextral strike-slip zone. He further suggested that McKenzie's (1978) pure shear model of lithospheric extension could explain observed subsidence history within the basin, although he made no attempt to demonstrate this quantitatively. This interpretation for the Magdalen Basin requires tens to hundreds of kilometres of dextral offset on the Belle Isle Fault within Maritime Canada and the New England states in order to produce sufficient crustal extension to allow the observed amount of subsidence.

McCutcheon and Robinson (1987) proposed an alternative to Bradley's (1982) model, in which orogenic extension within the Appalachian foreland led to subsidence within the Magdalen Basin. This mechanism does not require significant dextral offset along the Belle Isle Fault, motion which McCutcheon and Robinson (1987) feel is incompatible with the kinematic history of the Oak Bay Fault in southeastern New Brunswick.

Stockmal et al. (1990) present a plate-tectonic reconstruction of Atlantic Canada in which the Magdalen Basin is an element, but not the central focus, of the study. These authors do not accept the argument of McCutcheon and Robinson (1987) limiting motion on the Belle Isle Fault, and like Bradley (1982), explain the Magdalen Basin as a pull-apart formed by strike-slip motion. Similarly, Nickerson (1994) accepted significant dextral motion on the Belle Isle fault system in his study of the Moncton Subbasin.

Durling and Marillier (1990), using industry and Lithoprobe seismic reflection data from the Gulf of St. Lawrence, suggested that the Magdalen Basin is a half-graben with a deep depocentre near the Hollow Fault and a hinge line in east-dipping reactivated thrusts above the Fredericton Fault. These authors inferred little strike-slip motion along the Hollow Fault after early Carboniferous time, implying that middle Carboniferous to late Permian subsidence was caused solely by thermal equilibration of the extended crust. These authors identified widespread Horton Basin development under the Gulf of St. Lawrence, suggesting a large area of distributed extension, which they associated with evidence for magmatic underplating of the lower crust (by mafic and ultramafic rocks) as proposed by Marillier and Verhoef (1989).

McCutcheon and Robinson (1987) also proposed the existence of an east-west striking fault between Cape Breton Island and mainland Nova Scotia which they named the Canso Fault. This fault was hypothesized in order to explain the observed right-stepping offset of regional strike-slip faults and tectonostratigraphic zones from Newfoundland to mainland

Nova Scotia and New Brunswick. Stockmal et al. (1990) argued for the existence of the Canso Fault as a major Acadian "tear fault", and Lin et al. (1994) included the Canso Fault in their reconstruction of promontory-promontory collision. In this thesis, the terrane configuration sketches of Figure VII.1 and paleogeographic reconstructions of Figures X.3 - X.5 also infer the existence of the Canso Fault.

Despite the conclusions of these studies, there is little or no direct observational evidence for the Canso Fault. Durling and Marillier (1990), in their mapping of structure beneath the Gulf of St. Lawrence, found no evidence of right-lateral displacement of the offshore extension of the Fredericton Fault (Figure VII.2), such as would be expected from movement on the Canso Fault. Nor did these authors find any evidence of west or northwest-trending faults or shear zones which could be associated with the Canso Fault.

XI.2 Contribution of the Present Study to an Understanding of the Maritimes Basin

The present study, by considering the effect of broad-scale processes and of changing processes through time, substantiates the point of view that the Maritimes Basin experienced a complex and protracted development between Devonian and early Permian time. Several of the factors which contribute to this development can be isolated and identified: (1) localized, late orogenic extension associated with upper crustal collapse and/or lateral escape of basement blocks, represented by "pre-Horton" basins, (2) orthogonal, post-orogenic basins related strictly to gravitational relaxation and collapse, represented by the Horton family of continental rift basins, and (3) a regional sag phase of basin development which was driven by transtensional pull-apart under the Magdalen Basin. This latter event is manifested across the Maritimes Basin by regional marine transgressive conditions, which evolved though most of the subsequent Carboniferous into alluvial plain environments.

The latter is the most complex of the three. Although perhaps partially a consequence of thermal re-equilibration following Horton extension, the longevity of subsidence, which persisted for some 60-70 m.y. into the early Permian, brackets the same span of time as does strike-slip on the Cabot-Belle Isle fault system. Consequently, it is argued that the Magdalen Basin persisted in its development as a depocentre because dextral strike-slip continued throughout the Carboniferous.

This, in effect, amounts to a second, complementary phase of rifting, focussed in the Magdalen Basin depocentre, which can be invoked to explain the extraordinary persistence of the Maritimes Basin in space and time. Even though it was localized, the isostatic effect of thinning the upper crust in the promontory area was to create negative buoyancy in the lithosphere, thereby creating a longlasting sedimentary sink which became the locus of deposition throughout the Carboniferous.

The reconstructions of this thesis allow suggestions to be made regarding the nature of the Canso Fault. In Figures X.6 and X.7, the Canso Fault lies just north of, and subparallel to, the northern coast of Prince Edward Island. When superimposed on the structure map of Durling and Marillier (1990), such a lineament would trend approximately east-west, parallel to the Bradelle-Shediac boundary, approximately 50 km to the north (Figure VII.2). This structure could have been linked with the Grand Pabos Fault, as suggested by Durling and Marillier (1990), in the Lower Carboniferous, but would have been offset by later movement on the Lubec-Belle Isle Fault and possibly the Fredericton Fault. It is possible, then, that the portion of the Canso Fault lying in the Shediac Zone east of the Belle Isle Fault has been dismembered, which might explain why it is difficult to trace on seismic data.

XI.3 Synthesis and Conclusions

In Part I, interpretation of geophysical data reveals that up to 6 km of Devono-Carboniferous sedimentary rocks are preserved under the Cabot Strait, concentrated in two linear graben which parallel and are defined by major fault trends. These rocks are predominantly siliciclastics deposited in alluvial, fluvial or lacustrine environments, with the exception of Viséan strata, which include marine carbonates, evaporites and fine-grained clastics. In the western Bay St. George, rocks of the lower Carboniferous Codroy Group are interpreted to unconformably overlie lower Paleozoic carbonates, with clastics of the mid-Devonian to Tournaisian Horton Group absent.

Several major strike-slip faults can be mapped in the Cabot Strait-Bay St. George area. From east to west, these are the Cape Ray Fault, the Cabot Fault, the Hollow-St. George's Bay Fault and the Red Island Fault. The Cape Ray Fault was involved in the early (mid-late Devonian) *formation* of basinal areas by post-orogenic extensional processes, while the Cabot and other major strike-slip faults were important in the mid- to late Carboniferous *deformation* of the sedimentary basin fill. The Cabot Fault was a master fault along which most of the strike-slip displacement occurred. These faults, along with east-west trending faults, subdivide the area into structural domains, each showing internal consistency in its deformational style.

Four main unconformities are present within the basin fill. Three of these, the top Horton, top Barachois, and post-Pennsylvanian unconformities are localized events likely associated with longlasting movement along the Cabot Fault, whereas the Namurian-Westphalian unconformity probably represents a Maritimes Basin-wide deformational episode.

Carboniferous deformation shows patterns (doubly vergent thrust and décollement faults) consistent with kinematic partitioning within a wrench borderland. This is complicated by compressional structures associated with a restraining bend in the master Cabot Fault, and by the splaying or braiding of the Cabot Fault on a regional scale to produce a cumulative displacement system.

The preservation of thick late Paleozoic sediments has provided a superb opportunity for the study of the late stage modification of the northeastern Appalachians at the St. Lawrence Promontory. In Part II, these primary results are combined with a compilation of geological and geophysical data to create detailed reconstructions of this area for the middle Devonian, late Namurian and early Permian. This approach is interactive, as it also allows the older geology to be viewed with an appreciation of the late overprint.

The reconstructions have revealed that the different stages in basin evolution, as well as the distribution of pre-existing lower Paleozoic terranes, can be explained and illustrated by an evolving series of dextral strike-slip faults centered on the Cabot Fault system. This fault system was braided and diffuse in the early Carboniferous, but is discrete and sharply defined in its final (early Permian) manifestation. The deformation of basin fill in the Cabot Strait, inversion of the Horton Group in the Anguille Anticlinorium, development of the Bay St. George half-graben, and preservation of thick strata in the east-west oriented Sydney Basin can all be attributed to this process.

Integral to this approach was the consideration of exposed "basement" rocks bordering the Cabot Strait. Cape

Breton Island in particular is interpreted as a zone of Carboniferous transpression, which complements the recognition, from seismic data offshore, of strike-slip movement on the Aspy Fault. In southwestern Newfoundland, the Cape Ray Fault and the Bay le Moine shear zone exhibit normal faulting corresponding to the period of "pre-Horton" and Horton basin development.

East-west faults, mapped from offshore seismic data in the Carboniferous basin fill, likely are the late expressions or reactivations of pre-Carboniferous tear faults, such as the Gunflap Hills and Canso Faults, which in effect form the northern and southern boundaries, respectively, to the collision zone between the Cabot and St. Lawrence Promontories (see plate/terrane configuration diagram, Figures VII.1 and VIII.1; Lin et al., 1994).

The development of the Maritimes Basin is regarded as a protracted and complex process which involved up to three spatially and temporally overlapping basin-forming mechanisms. Firstly, depocentres associated with the Maritimes Basin, the synorogenic "pre-Horton" basins, were initiated as early as the early Devonian, and were probably associated with gravitational flow and/or tectonic extrusion. In the middle Devonian to early Carboniferous, late to post-orogenic basins developed above a thickened crustal welt by orthogonal extension, probably caused by gravitational spreading in the upper layers of the crust in topographically-dominant regions of the orogen, such as the St. Lawrence Promontory.

Secondly, from the early Carboniferous to early Permian, these basins were enhanced, modified and deformed in a strike-slip regime, with the intensity of deformation of basin fill dependent on position with respect to the geometry of the fault system. Restraining bends resulted in the local décollement, thrusting and inversion of basin fill, such as at St. Paul Island, whereas the convergence of the St. George's Bay and Hollow Faults, which marks the northern narrowing of the Magdalen Basin, produced extreme and dramatic inversion of Anguille Group sediments. In the Cabot Strait area, the bulk of this deformation occurred in the late Namurian to early Westphalian, as witnessed by the Namurian-Westphalian Unconformity. Minor deformational pulses occurred in the latest Carboniferous.

A third process involved the ejection of crustal blocks, such as the Baie Verte Peninsula and Central Mobile Belt, northeastward away from the Promontory area, after collision with an "Avalonian indentor" (Cabot Promontory of Lin et al.,1994, analogous to the Iberian indentor). This may have reflected a slight reorientation of the principal compressive stress. The Deer Lake and Sydney Basins may in large part owe their origin to this process.

In Part III, the position of the Cabot Strait/ St. Lawrence Promontory in the context of middle to late Paleozoic development of the orogen across the North Atlantic was examined. This provided a frame of reference to develop an understanding of the large-scale processes which controlled the "tectonic climate" of the northeastern Appalachians at the time. The recognition of Silurian to early Devonian sinistral accretionary buildup of the orogen on both the British and North American sides (*e.g.*, Soper et al., 1992; Barr et al., 1994; Nance and Dallmeyer, 1993), and the recognition by Coward (1993) of tectonic extrusion as an important factor in the middle Devonian and later development of Britain, has enabled the late evolution of the northeastern Appalachians to be studied in the same light. Finally, a series of reconstructions of the development of Europe in the Variscan Orogen (Ziegler, 1988; 1989) was brought to bear on the contemporaneous tectonic evolution of the Canadian Appalachians. Using this scheme, the generation and history of the Maritimes successor basin and affiliated subbasins has been elucidated.

These very broad, regional considerations shows that, simply stated, the Cabot Fault system developed in the cooling foreland of the Variscan orogen and became more focussed and discrete as the crust became more brittle, until the latest displacement of the Cabot Fault took place along a relatively linear fault configuration. The regional dextral shear, rather than acting in response to megaplate-scale torque across either the African or North American plates, likely was a result of northward encroachment of the Iberian indentor, which effected both easterly and westerly tectonic ejection. In North America this amounted to the westward pushing of West Avalonia and earlier-accreted Avalonian-type terranes against the Humber Zone along the reactivated Cabot fault suture. The intensity of the compressive strain was varied in the middle Carboniferous, as the stress vector rotated clockwise by about 20°, probably due to the transpressive impingement of the Gondwanan plate against the newly amalgamated mass of Laurentia (Ziegler, 1989).

The genesis of the Maritimes Basin had an earlier Appalachian phase, and a later Variscan phase. The former - orthogonal distension - was initiated as a response to Acadian crustal thickening and extensional collapse, while the latter - pull-apart - was caused by the large offset of strike-slip faults by tear faults in the St. Lawrence Promontory.

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TABLE I

Location and acquisition parameters for seismic lines

Operator	Year	Line ID	Orientation	Quality	Location
Petro-Canada	1981				
		81-1102	SW-NE	poor-fair	Sydney Basin
		81-1103	NW-SE	fair	Cabot Strait
		81-1104	SW-NE	poor-fair	Sydney Basin
		81-1105	NW-SE	good	Cabot Strait
		81-1106	SW-NE	fair-good	Cabot Strait
		81-1107	NW-SE	good	Cabot Strait
		81-1108	SW-NE	fair-good	Cabot Strait
		81-1109	NW-SE	good	Cabot Strait
		81-1111	NW-SE	good	Cabot Strait
		81-1113	NW-SE	good	Cabot Strait
		81-1115	NW-SE	good	Cabot Strait
		81-1117	NW-SE	good	Cabot Strait
		81-1119	NW-SE	good	Cabot Strait
		81-1121	NW-SE	good	Cabot Strait
	1982	4001-82	NW-SE	very good	Cabot Strait
		4003-82	NW-SE	very good	Cabot Strait
		4005-82	NW-SE	very good	Cabot Strait
		4007-82	NW-SE	very good	Cabot Strait
		4009-82	NW-SE	very good	Cabot Strait
		4011-82	NW-SE	very good	Cabot Strait
		4012-82	SW-NE	very good	Cabot Strait
	1983	4075-83	NW-SE	very good	Cabot Strait
		4076-83	E-W	very good	Cabot Strait
		4077-83	NW-SE	very good	Cabot Strait
		4079-83	NW-SE	very good	Cabot Strait
		4081-83	NW-SE	very good	Cabot Strait
		4083-83	NW-SE	very good	Cabot Strait
		4085-83	NW-SE	very good	Cabot Strait
		4089-83	NW-SE	very good	Cabot Strait
		4091-83	NW-SE	very good	Cabot Strait
		4093-83	NE-SW	very good	Cabot Strait
		4095-83	NE-SW	very good	Cabot Strait
Mobil	1971				
		MAQ-001	SW-NE	poor-fair	Bay St. George
		MAQ-002	NW-SE	poor-fair	Bay St. George
		MAQ-003	SW-NE	poor-fair	Bay St. George
		MAQ-004	NW-SE	poor-fair	Bay St. George
		MAQ-006	NW-SE	poor-fair	Bay St. George
		MAQ-007	SW-NE	poor-fair	Bay St. George
		MAQ-008	NW-SE	poor-fair	Bay St. George
		MAQ-009	SW-NE	poor-fair	Bay St. George
		MAQ-010	NW-SE	poor-fair	Bay St. George
		MAQ-011	SW-NE	poor-fair	Bay St. George

Table I, concluded.

		MAQ-012	NW-SE	poor-fair	Bay St. George
		MAQ-013	SW-NE	poor-fair	Bay St. George
		MAQ-014	NW-SE	poor-fair	Bay St. George
		MAQ-015	NW-SE	poor-fair	Bay St. George
		MAQ-016	NW-SE	poor-fair	Bay St. George
		MAQ-017	NW-SE	poor-fair	Bay St. George
		MAQ-018	NW-SE	pooı-fair	Bay St. George
		MAQ-019	NW-SE	poor-fair	Bay St. George
	1973	MBM-001	SE-NW	poor-fair	Bay St. George
		MBM-002	SE-NW	poor-fair	Bay St. George
		MBM-003	SE-NW	poor-fair	Bay St. George
		MBM-004	SE-NW	poor-fair	Bay St. George
		MBM-005	NW-SE	poor-fair	Bay St. George
		MBM-006	NW-SE	poor-fair	Bay St. George
		MBM-007	NW-SE	poor-fair	Bay St. George
Golden Eagle	1977				
	GE-77-1	SW-NE	fair-good	Inner Bay St. George	
	GE-77-2	NW-SE	fair-good	Inner Bay St. George	
	GE-77-3	NW-SE	fair-good	Inner Bay St. George	
	GE-77-4	NW-SE	fair-good	Inner Bay St. George	
Texaco	1970				
	TAJ-009	NW-SE	fair	Outer Bay St. George	
	TAJ-010	NW-SE	fair	Outer Bay St. George	
	TAJ-011	NW-SE	fair	Outer Bay St. George	
	1971				
	TAN-001	SW-NE	poor	Outer Bay St. George	
SOQUIP	1971				
	QAA-009	N-S	poor	East of Magdalen Is.	
	QAA-010	E-W	poor	Northeast of Magdalens	
	QAA-011	E-W	poor	Northeast of Magdalens	
Amoco	1971				
	AAJ031	N-S	fair	East of Magdalen Is.	

Table II

Summary of the Nature of Data used in Reconstructions: St. Lawrence Promontory Maps

Feature or Event	Source and Comments
<u>Mid-Devonian (380 Ma) Map</u>	
• alignment of the Port au Port Peninsula with southern coast of Newfoundland	constrained by closing the Magdalen Basin; in general aligns zones of E-W tear faulting in the St. Lawrence Promontory (SLP); maps of Stockmal et al. (1990)
• position of Baie Verte Peninsula	alignment of Baie Verte Line (BVL) suggested by Hibbard (1983); excellent correlation of other map units
• position of Corner Brook Pond block (CBPB)	alignment along strike with similar grade Fleur de Lys Supergroup rocks on the Baie Verte Peninsula
• position of the "Sop's Arm block" (SAB)	speculative, but based on correlation with Dunnage Zone units (Colman-Sadd et al. 1990)
• position of Bay of Islands (BOI) and St. Anthony Complex (SAC) ophiolites	adapted from Cawood (1989; 1990)
• Acadian foreland basin	inferred from position of Clam Bank Basin, and general orogenic profile
• Anguille-Cabot Subbasin (ACSB)	stratigraphic data for Cabot SB from Hamblin and Rust (1989), Hamblin (1992); paleocurrent data for Anguille SB from Knight (1983); position inferred from removal of dextral strike-slip
• distribution of Horton basins	interpreted from stratigraphic evidence and regional recognition of extensional collapse basins; correlation with northern Britain and Scandinavia
• Bay le Moine Shear Zone (BMSZ) as a major Devonian extensional fault	interpreted from potential field data and onshore mapping of Lin et al. (1993)

• edge of Grenville basement	inferred from projection of Humber Zone boundary from New Brunswick, and general geometry of St. Lawrence Promontory (e.g., Stockmal et al., 1990; Lin et al., 1994)

320 Ma (Late Namurian) Map

• structural geology of Cabot Strait area	mapped from marine geophysical data
• Namurian extensional detachment, Cape Breton Island and ACSB	after Lynch and Tremblay (1994); Knight (1983)
• Sydney Basin pull-apart	faulted basin margin implied by linearity of south coast of Newfoundland; analogy with Magdalen Basin pull-apart; inference of a tectonically-escaping Central Mobile Block (CMB)
• tectonic escape of Baie Verte Peninsula and CMB	implied by its general shape bounded by strike-slip faults; presence of the Deer Lake Basin (DLB)
• outline of the Deer Lake Basin	map of Hyde (1982); lateral basin concept of Hyde et al. (1988); hypothesis of BVP escape; removal of dextral displacement necessitates 10's of km of offset from modern map pattern
• subdivision of Aspy terrane into "East" and "West" fragments	significant strike-slip faulting on Aspy Fault seen on offshore seismic data; enhanced erosion of Carboniferous and exhumation of mid-Paleozoic rocks along fault zone; transpression implied by thrusting of Carboniferous over Aspy basement (Currie, 1977)

275 Ma (Early Permian) Map

• regional blanket of sediments	interpreted from regional burial and exhumation studies (Ryan and Zentilli, 1993; Hendriks et al., 1993); paleodrainage study of Gibling et al. (1992)
• Westphalian marine incursion	mapping of Wightman et al. (1994) and Rehill et al. (1994)
• late transtensional movement along Cabot Fault system	Westphalian depocentres in Deer Lake Basin, Bay St. George and Cabot Strait

Table III

Summary of the Nature of Data used in Reconstructions: North Atlantic Maps

Early Ludlow (420 Map)

• arrangement of small terranes at the Promontory (SLP)	speculative, but based on St. Lawrence amalgamation ages given by Barr et al. (1994) and regional studies from SW Nfld, Cape Breton Island, and New Brunswick (e.g., O'Brien et al., 1991; Dunning et al., 1990a, b; Nance and Dallmeyer, 1993; Nickerson, 1994). Small Avalonian terranes like the Burgeo, Bras d'Or originally part of a larger terrane, as are the Aspy, St. Croix (SCT) and Mascarene (MT) terranes.
• orogen-wide oblique-sinistral subduction	regional studies from the SLP, as above, and Britain (e.g., Soper and Hutton, 1984; Soper et al., 1992; Leeder, 1982; Leggett et al., 1983); analogy with western Pacific (Pickering and Smith, 1994)
• configuration of larger microplates	East Avalonia: 3-plate concept of Soper et al. (1992); Iberia-Armorica: after Ziegler (1989); West Avalonia: this study after Soper et al. (1992)
• paleogeography	compiled from present work and Ziegler (1989); Coward (1993); Soper and Hutton (1984); Soper et al. (1992)

Earliest Devonian (400 Ma)

• dissection of originally contiguous terranes	speculative separation into smaller terrane fragments by tear faulting upon convergence at the SLP
• formation of a blind thrust (bt) to accommodate crustal convergence and thickening at the SLP	interpreted from crustal seismic data by Stockmal et al. (1990)
• switch to NW compression in the Canadian Appalachians	documented by Hibbard (1994) and Nance and Dallmeyer (1993)
• accelerated crustal thickening and elevation	implied by exhumation and cooling studies in Cape Breton Island (Plint

	and Jamieson, 1989; Reynolds et al., 1989) and SW Nfld (Burgess et al., 1993)
• inversion of small marginal basins	evidence from the La Poile basin (O'Brien et al., 1991)
• initiation of Canso Fault between the SLP and "New Brunswick recess"	controversial, but here accepted in principal as earliest of a series of tear faults which must have existed to accommodate differential accretion of terranes
• amalgamation of East Avalonia with northern Britain	Soper et al., 1992, and references therein
• paleogeography of European elements	Ziegler (1989)

Mid-Devonian (380 Ma)

• collision of West Avalonia with Laurentia in Devonian	Acadian Orogeny of Boucot Early (1962); Cawood (1993), Stockmal and Waldron (1993), Waldron and Stockmal (1994), Williams et al. (1988), Bradley (1982). Corresponds to major W-directed thrusting and crustal thickening in SW Nfld and Cape Breton Island
• development of pre-Horton/early Horton basins by extensional collapse	correlation with Britain; identification on crustal seismic lines in Gulf of St. Lawrence; onshore candidates include Windsor Point Group, early Fisset Bk., etc., which contain volcanics. Analogue: Basin and Range Province; theory from Dewey (1988)
• oblique collision of Meguma terrane with accreted West Avalonia along Minas Geofracture	this study; Keppie, 1982
• ongoing Acadian orogeny driven by collision of Aquitaine-Cantabrian terrane with W. Avalonia, driving it into the SLP	Ziegler (1989); Leeder (1982)
• tectonic escape of Baie Verte Peninsula and Central Mobile Block, driven by the motion of W. Avalonia into the SLP	speculative, but reasonable by correlation with Britain (see below)

• tectonic escape of England and northern Europe toward the Ural Sea	Coward (1990; 1993); analogy with eastern Himalayas (Tapponnier and Molnar, 1977) and Anatolia (Sengor et al., 1985)
• extensional collapse basins in Britain and Scandinavia	McClay et al. (1986); Norton (1986)

Early Viséan (350 Ma)

• regional dextral strike-slip in SLP area	interpreted from structural and stratigraphic studies (e.g., this study; Knight, 1983; Nickerson, 1984)
• association of regional dextral strike-slip with westward push of W. Avalonia ("Avalon high")	possibly associated with development of the Iberian indentor (Ziegler, 1989) against the Cabot Fault system
• Iberian indentor formed by collision of the Aquitaine-Cantabrian terrane with Europe	Ziegler (1989)
• tectonic ejection of crustal material northward and westward from a focal point of strain located just west of Ireland	ongoing tectonic escape documented by Coward (1990, 1993); in North America speculative, but consistent with dextral movement along the Cabot-Belle Isle system. Southern boundary of ejected W. Avalonia-Meguma terrane is probably an oblique sinistral subduction system
• development of the Magdalen Basin as a (e.g., strike-slip related "rhombochasm" between overstepped Cabot and Belle Isle Faults.	geologic/geophysical studies Williams, 1974; Bradley, 1982; Durling and Marillier, 1993a, b; this study); information from offshore drilling (SOQUIP, 1987)
• regional transgression	deposits of marine siliciclastics and evaporites in Windsor Gp. and equivalents in Britain; Magdalen Basin depocentre is site of thick evaporite accumulation

Early Westphalian (300 Ma)

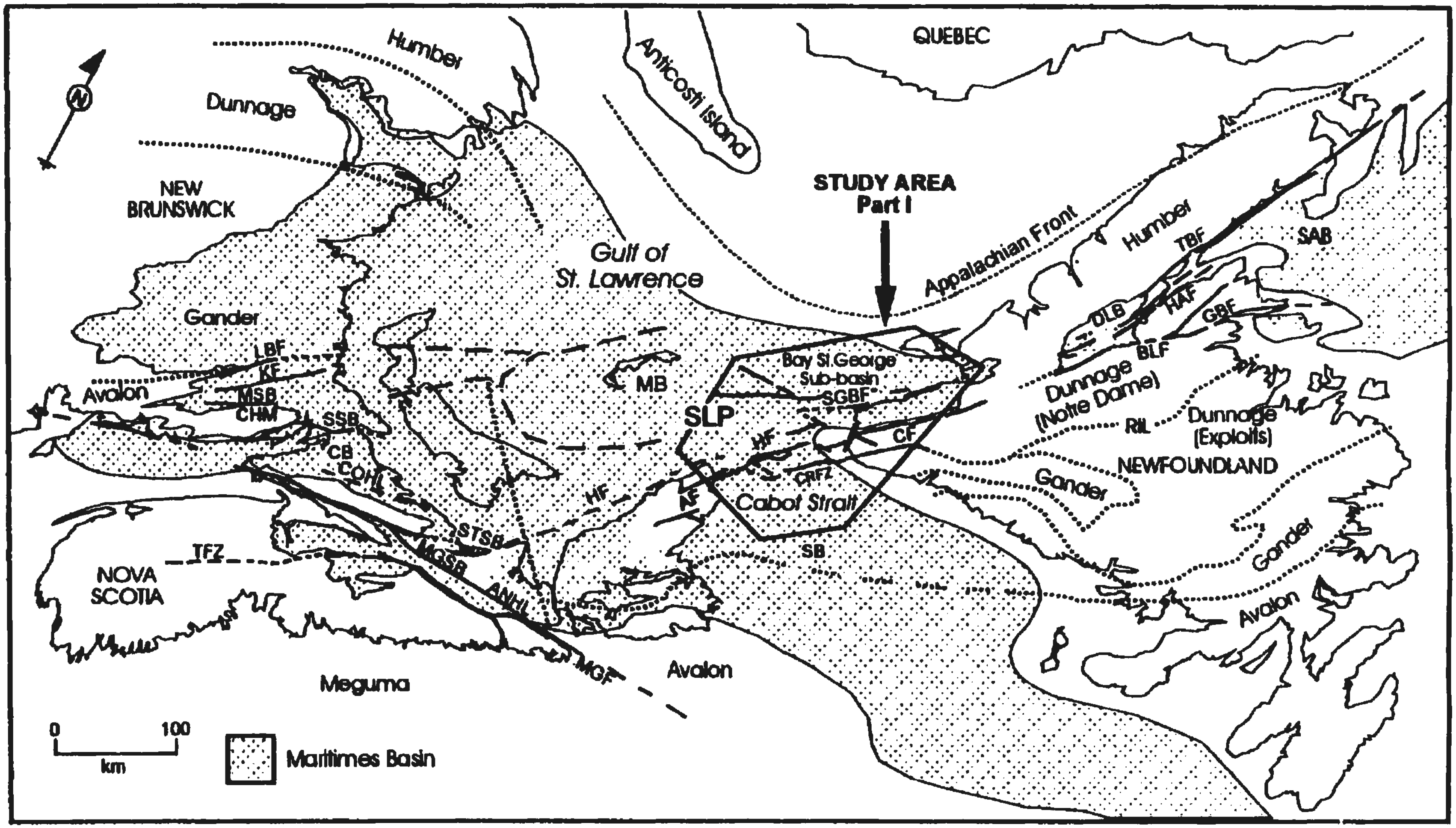
• development of broad Variscan Orogen in Europe	Ziegler (1989)

• ongoing but probably waning extension in the Magdalen and Sydney Basins	stratigraphy records Westphalian deposition controlled by faulting (Knight, 1983; this study)
• reorientation of principal stress at SLP clockwise by approx. 20°	development of transpressional NWU, effects are widespread across Maritimes Basin (this study). Also identified by Nickerson (1994) in Moncton Subbasin
• relationship drawn between NWU, reorientation of stress, and impingement of Africa along the Gibraltar Fracture Zone	speculative, but consistent with paleogeography of Ziegler (1989)
• cessation of tectonic escape in Britain	Coward (1993)
• reduction of topography, continuing accumulation within a regional flood plain-dominated basin, with minor marine incursions, in North America	Gibling et al. (1992); Wightman et al. (1994); Rehill et al. (1994)

<u>Earliest Permian (275 Ma)</u>

• fracturing across the Variscan orogen: response to cooling, increased brittleness, and formation of the S. Appalachians and Mauritanides	Ziegler (1989), after Arthaud and Matte (1977)
• tectonic wedging of northern Europe back towards Britain	Coward (1990; 1993)
• Maritimes Basin overfilled by terrestrial sediments; axial drainage	Gibling et al. (1992)
• dextral strike-slip along Minas Geofracture	Nickerson (1994); Keppie (1982)
• collision of Kazakhstan with Moscow Platform to form the Ural Mountains	Ziegler (1989)

Figure I.1: Location map of the study area, showing subbasins and major bounding faults of the Maritimes Basin (stippled), with tectonostratigraphic zone boundaries for the northeast Appalachians. **AF**: Aspy Fault; **AT**: Aspy terrane; **ANHL**: Antigonish Highlands (Yeo and Ruixiang, 1987); **BdO**: Bras d'Or terrane; **BLF**: Birchy Lake Fault (Webb, 1969); **CB**: Cumberland Basin; **CF**: Cabot Fault; **CHM**: Caledonia Highlands Massif; **COHL**: Cobequid Highlands (McCutcheon and Robinson, 1987; Yeo and Ruixiang, 1987; Martel, 1987; Nickerson, 1994); **CRFZ**: Cape Ray Fault Zone (Chorlton, 1983; Wilton, 1983); **DLB**: Deer Lake Basin (Hyde, 1984; Hyde et. al., 1988); **GBF**: Green Bay Fault (Bradley, 1982); **HAF**: Hampden Fault; **HF**: Hollow Fault; **KF**: Kennebecasis Fault; **LBF**: Lubec-Belle Isle Fault; **MB**: Magdalen Basin; **MGF**: Minas Geofracture; **MGSB**: Merigomish subbasin (Fralick and Schenk, 1981); **MSB**: Moncton Subbasin; **RIL**: Red Indian Line; **SAWB**: St. Anthony Basin; **SB**: Sydney Basin (Gibling et. al., 1987); **SGBF**: St. George's Bay Fault; **SLP**: St. Lawrence Promontory; **SSB**: Sackville subbasin; **STSB**: Stellarton subbasin; **TBF**: Taylor's Brook Fault; **TFZ**: Tobeatic Fault Zone.



QUEBEC
Humber
Anticosti Island
Dunnage
NEW BRUNSWICK
STUDY AREA
Part I
Gulf of St. Lawrence
Appalachian Front
Humber
TBF
SAB
Gander
HAF
DLB
GBF
LBF
KF
Avalon
MSB
CHM
MB
Bay St.George Sub-basin
SGBF
SLP
BLF
Dunnage (Notre Dame)
RIL
Dunnage (Exploits)
SSB
CB
COHL
HF
CF
CRFZ
NEWFOUNDLAND
AF
Cabot Strait
Gander
HF
STSB
MGSB
TFZ
NOVA SCOTIA
SB
Gander
ANHL
Avalon
MGF
Avalon
Meguma
0
100
km
Maritimes Basin

Figure I.2: Generalized Carboniferous lithostratigraphy for western Newfoundland and the Cabot Strait area (after Knight, 1983; Hall et al., 1992).

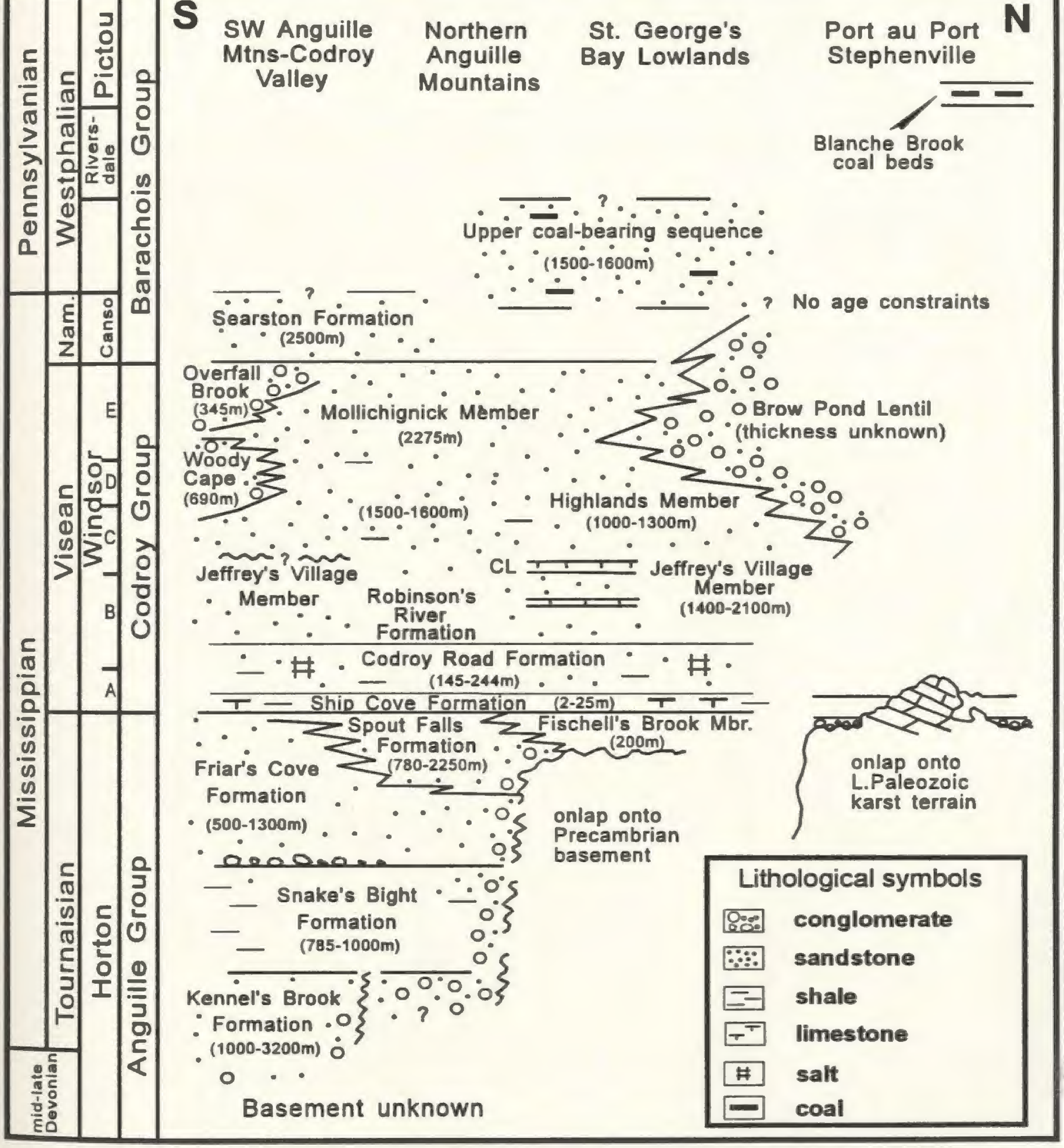

S
N
SW Anguille Mtns-Codroy Valley
Northern Anguille Mountains
St. George's Bay Lowlands
Port au Port Stephenville
Pennsylvanian
Mississippian
mid-late Devonian
Westphalian
Nam.
Visean
Tournaisian
Pictou
Rivers-dale
Canso
Windsor
Horton
A
B
C
D
E
Barachois Group
Codroy Group
Anguille Group
Blanche Brook coal beds
Upper coal-bearing sequence
(1500-1600m)
Searston Formation
(2500m)
No age constraints
Overfall Brook
(345m)
Mollichignick Member
(2275m)
Brow Pond Lentil
(thickness unknown)
Woody Cape
(690m)
(1500-1600m)
Highlands Member
(1000-1300m)
Jeffrey's Village Member
CL
Jeffrey's Village Member
(1400-2100m)
Robinson's River Formation
Codroy Road Formation
(145-244m)
Ship Cove Formation
(2-25m)
Spout Falls Formation
(780-2250m)
Fischell's Brook Mbr.
(200m)
Friar's Cove Formation
(500-1300m)
onlap onto Precambrian basement
onlap onto L.Paleozoic karst terrain
Snake's Bight Formation
(785-1000m)
Kennel's Brook Formation
(1000-3200m)
Basement unknown
Lithological symbols
conglomerate
sandstone
shale
limestone
salt
coal

Figure I.3: Chronostratigraphic summary chart for main fault-controlled subbasins of the Maritimes Basin. **NWNB**: northwestern New Brunswick; **MSB**: Moncton subbasin; **SSB**: Sackville subbasin; **CB**: Cumberland Basin; **CB***: revised Cumberland Basin stratigraphy of Ryan et al. (1991); **COHL**: Cobequid Highlands (McCutcheon and Robinson, 1987; Yeo and Ruixiang, 1987; Martel, 1987; Nickerson, 1994; **STSB**: Stellarton subbasin; **ANHL**: Antigonish Highlands (Yeo and Ruixiang, 1987); **MGSB**: Merigomish subbasin (Fralick and Schenk, 1981); **BSG-CS-WNF**: Bay St. George-Cabot Strait-western Newfoundland (Knight, 1983; this study); **SB**: Sydney Basin (Gibling et. al., 1987); **DLB**: Deer Lake Basin (Hyde, 1984; Hyde et. al., 1988); **CRFZ**: Cape Ray Fault Zone (Chorlton, 1983; Wilton, 1983); **IG**: ignimbrites used in dating the Windsor Point Group (Wilton, 1983). Abbreviations for unconformities: **HA**: top Horton-Anguille unconformity; **NWU**: Namurian-Westphalian unconformity; **B**: top-Barachois unconformity; **PPU**: post-Pennsylvanian or post-early Permian unconformity. Brackets **1**, **2** and **3** refer to allocycles of Ryan et al. (1991). Lithological symbols as in Figure I.2.

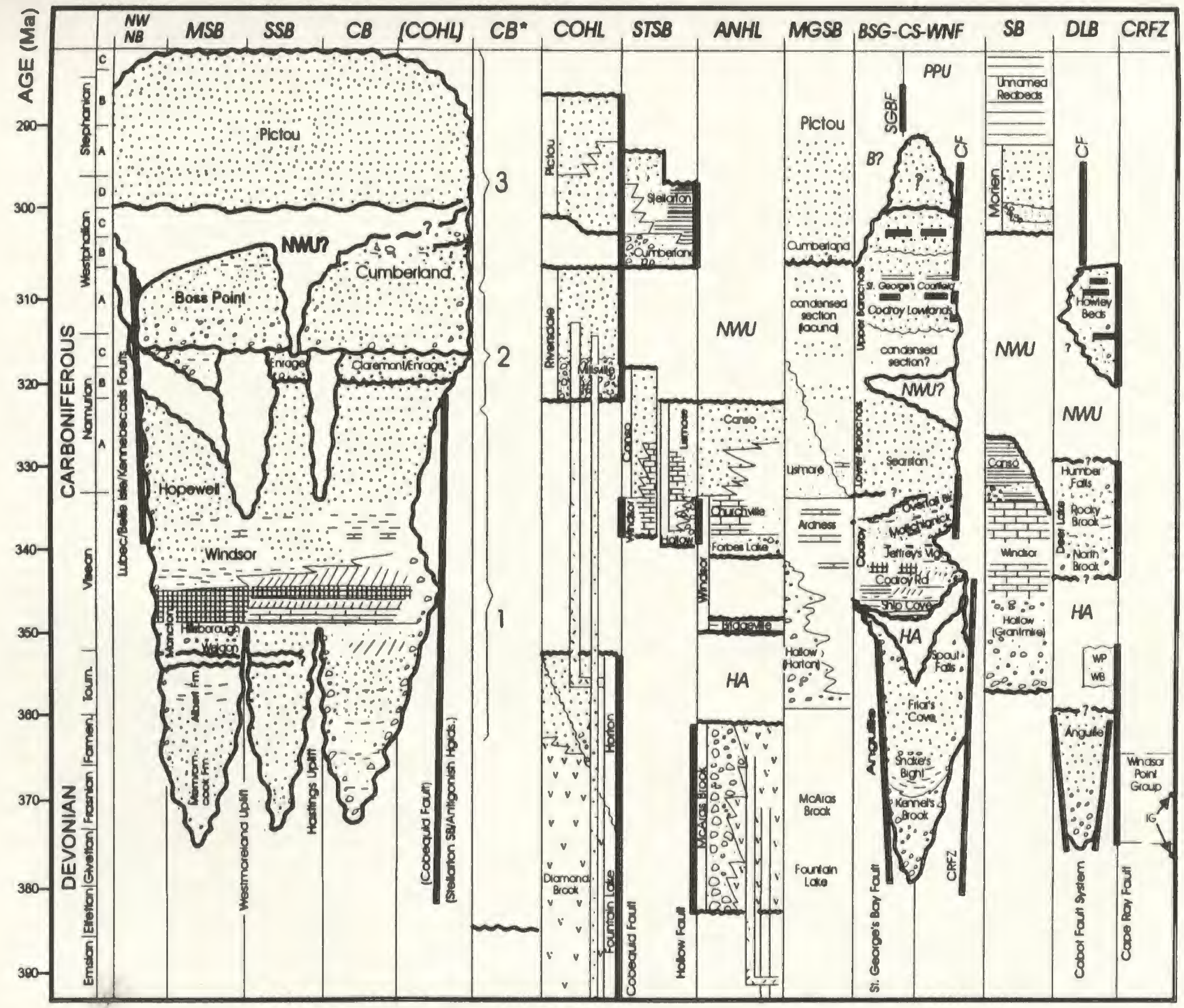

AGE (Ma)
NW NB
MSB
SSB
CB
(COHL)
CB*
COHL
STSB
ANHL
MGSB
BSG-CS-WNF
SB
DLB
CRFZ
CARBONIFEROUS
DEVONIAN
Stephanian
Westphalian
Namurian
Visean
Tourn.
Famen.
Frasnian
Givetian
Eifelian
Emsian
Pictou
NWU?
Cumberland
Boss Point
Claremont/Enrage
Hopewell
Windsor
Hillsborough
Westmoreland Uplift
Hastings Uplift
Albert Fm
Lubec/Belle Isle/Kennebecasis Faults
(Cobequid Fault)
(Stellarton SB/Antigonish Hglds.)
3
2
1
Riversdale
Horton
Diamond Brook
Fountain Lake
Cobequid Fault
Stellarton
Canso
Hollow Fault
NWU
HA
Churchville
Forbes Lake
McAras Brook
Lismore
Ardness
Hollow (Horton)
Fountain Lake
condensed section (lacuna)
PPU
SGBF
CF
Upper Barachois
St. George's Coalfield
Codroy Lowlands
condensed section?
Searston
Lower Barachois
Ship Cove
Spout Falls
Friar's Cove
Snake's Bight
Kennel's Brook
Anguille
St. George's Bay Fault
CRFZ
Unnamed Redbeds
Morien
Windsor
Hollow (Grantmire)
Howley Beds
Humber Falls
Rocky Brook
North Brook
Deer Lake
WP
WB
Anguille
Cabot Fault System
Windsor Point Group
IG
Cape Ray Fault

Figure I.4: Major structures of the onland portion of the Bay St. George Subbasin (after Knight, 1983: his Figure 42).

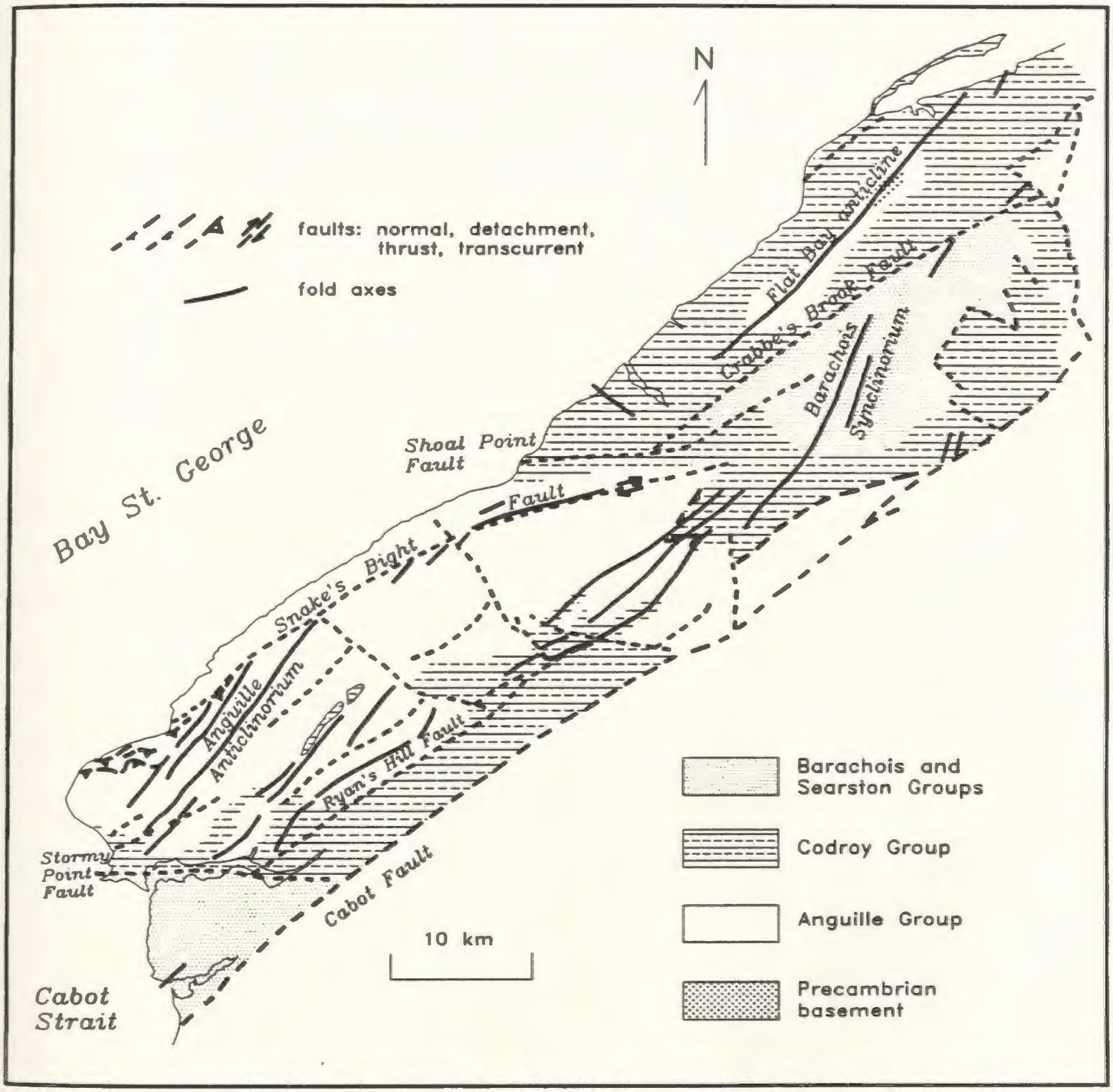

N
faults: normal, detachment, thrust, transcurrent
fold axes
Bay St. George
Shoal Point Fault
Fault
Snake's Bight
Flat Bay Anticline
Crabbe's Brook Fault
Barachois Synclinorium
Anguille Anticlinorium
Ryan's Hill Fault
Stormy Point Fault
Cabot Fault
Cabot Strait
10 km
Barachois and Searston Groups
Codroy Group
Anguille Group
Precambrian basement

Figure II.1: Map illustrating industry reflection seismic data set used in this study and petroleum industry well locations. Seismic profiles displayed as line drawings in Figure II.10 are highlighted as heavy lines.

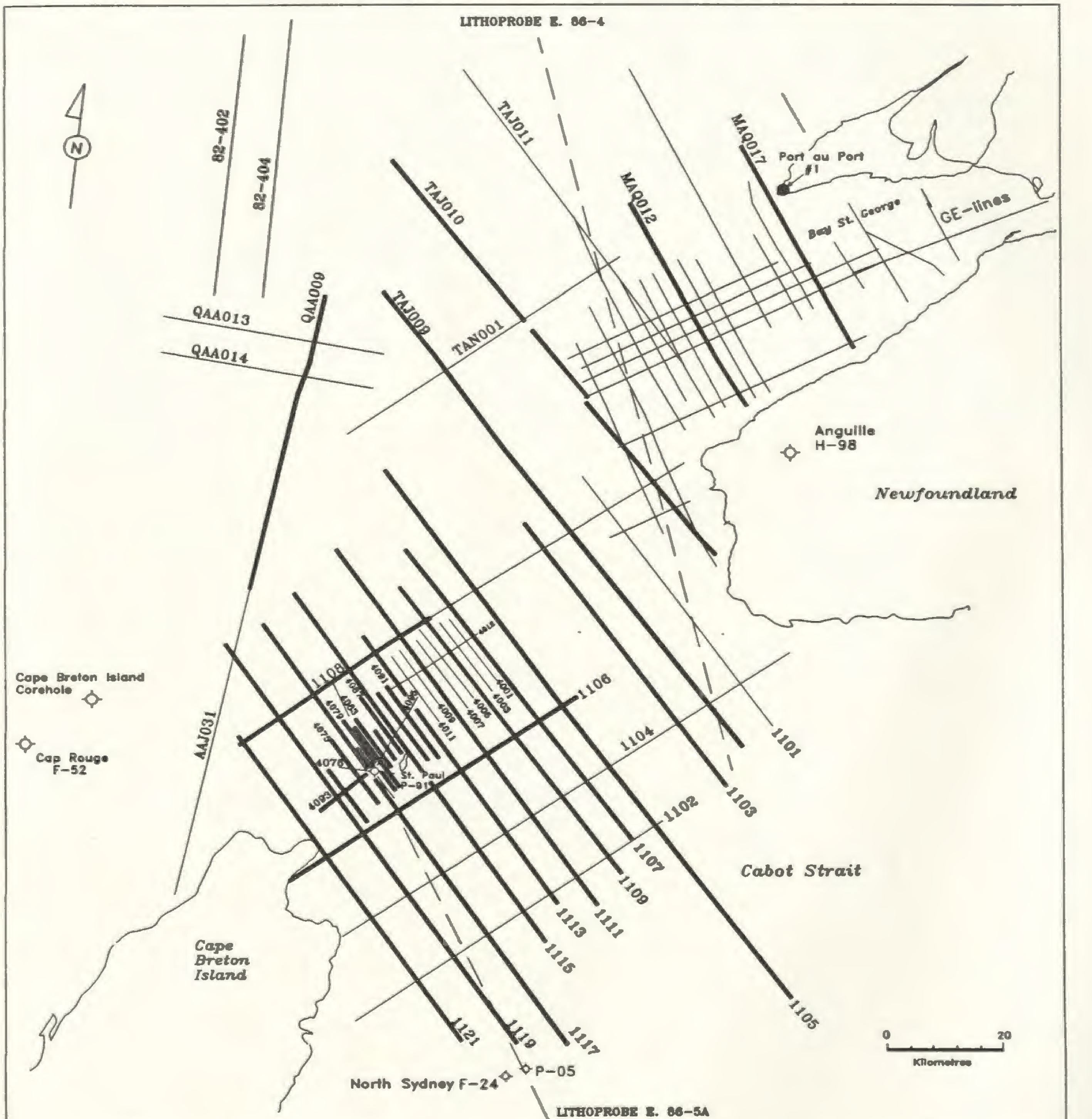
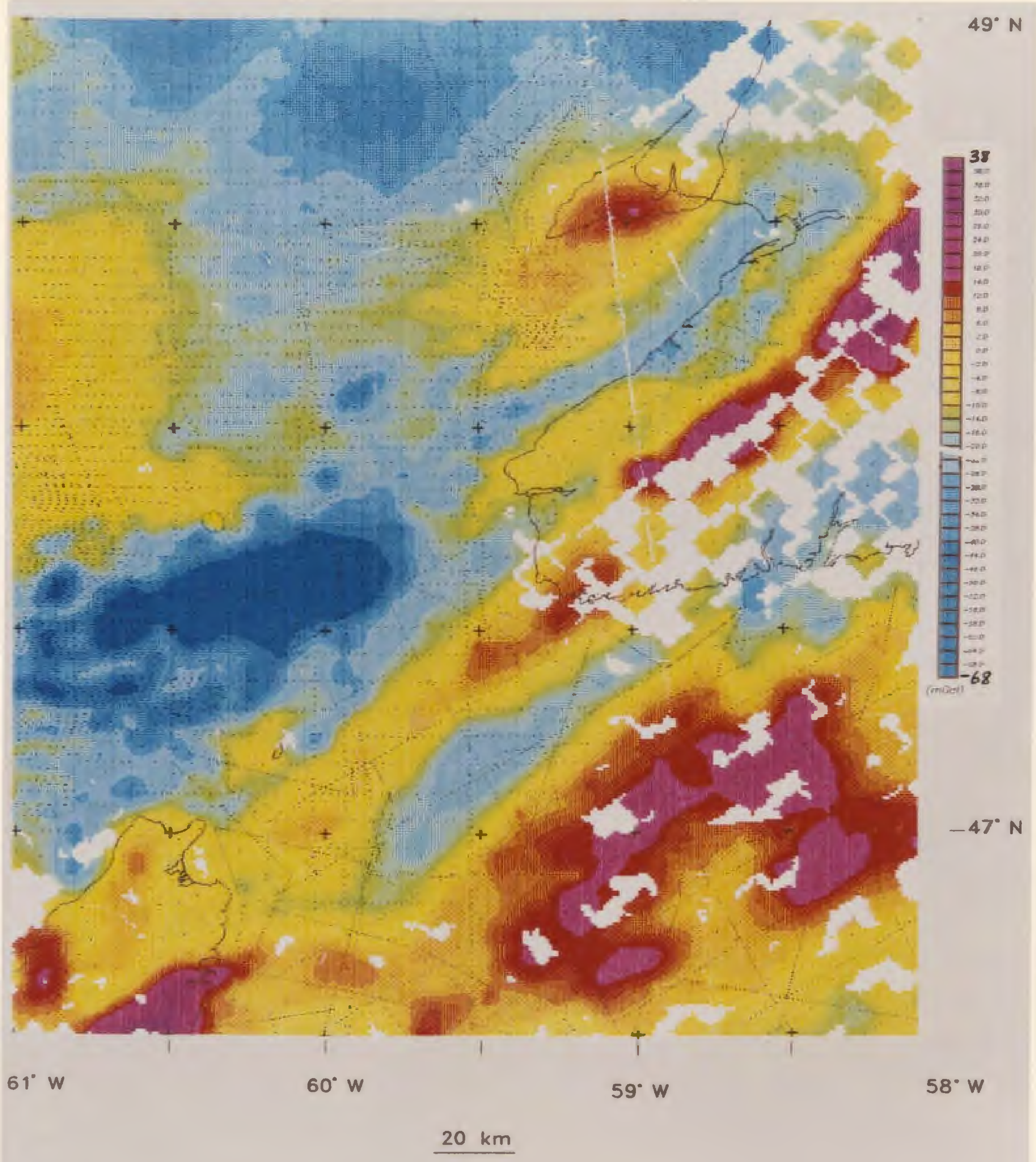
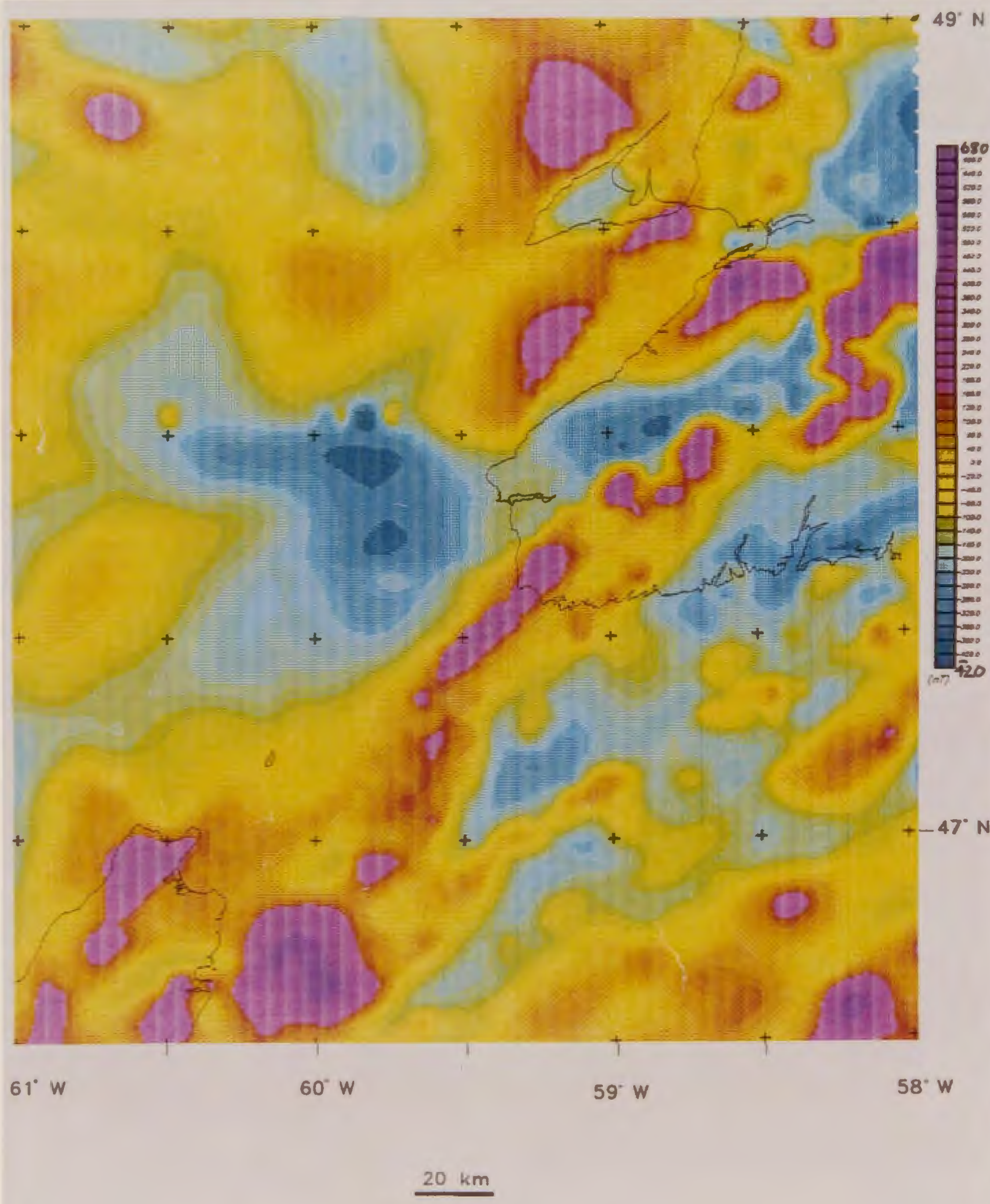

LITHOPROBE E. 86-4
82-402
82-404
TAJ011
TAJ010
TAJ009
MAQ017
MAQ012
Port au Port #1
Bay St. George
GE-lines
QAA013
QAA014
QAA009
TAN001
Anguille H-98
Newfoundland
Cape Breton Island Corehole
Cap Rouge F-52
AAJ031
St. Paul P-91
1101
1102
1103
1104
1105
1106
1107
1108
1109
1111
1113
1115
1117
1119
1121
Cabot Strait
Cape Breton Island
0
20
Kilometres
North Sydney F-24
P-05
LITHOPROBE E. 86-5A

Figure II.2: Gravity anomaly map, showing Bouguer gravity on land, and free air gravity at sea, of the Cabot Strait-Bay St. George area. Grid spacing = 1 km. Scale bar runs from -68 to 38 mGal. Map was gridded from public domain data (Geological Survey of Canada, 1990a and b) by W. Nickerson at the Centre for Earth Resources Research, Memorial University.



Gravity anomaly
(Bouguer on land, free air at sea)

Figure II.3: Magnetic total field anamoly map of the Cabot Strait-Bay St. George area. Grid spacing = 1 km. Scale bar runs from -420 to 680 nT. Map was gridded from public domain data (Geological Survey of Canada, 1990a and b) by W. Nickerson at the Centre for Earth Resources Research, Memorial University.



Magnetic total field anomaly

Figure II.4: Diagram illustrating reflection character and the basis for identification of unconformities as discussed in text.

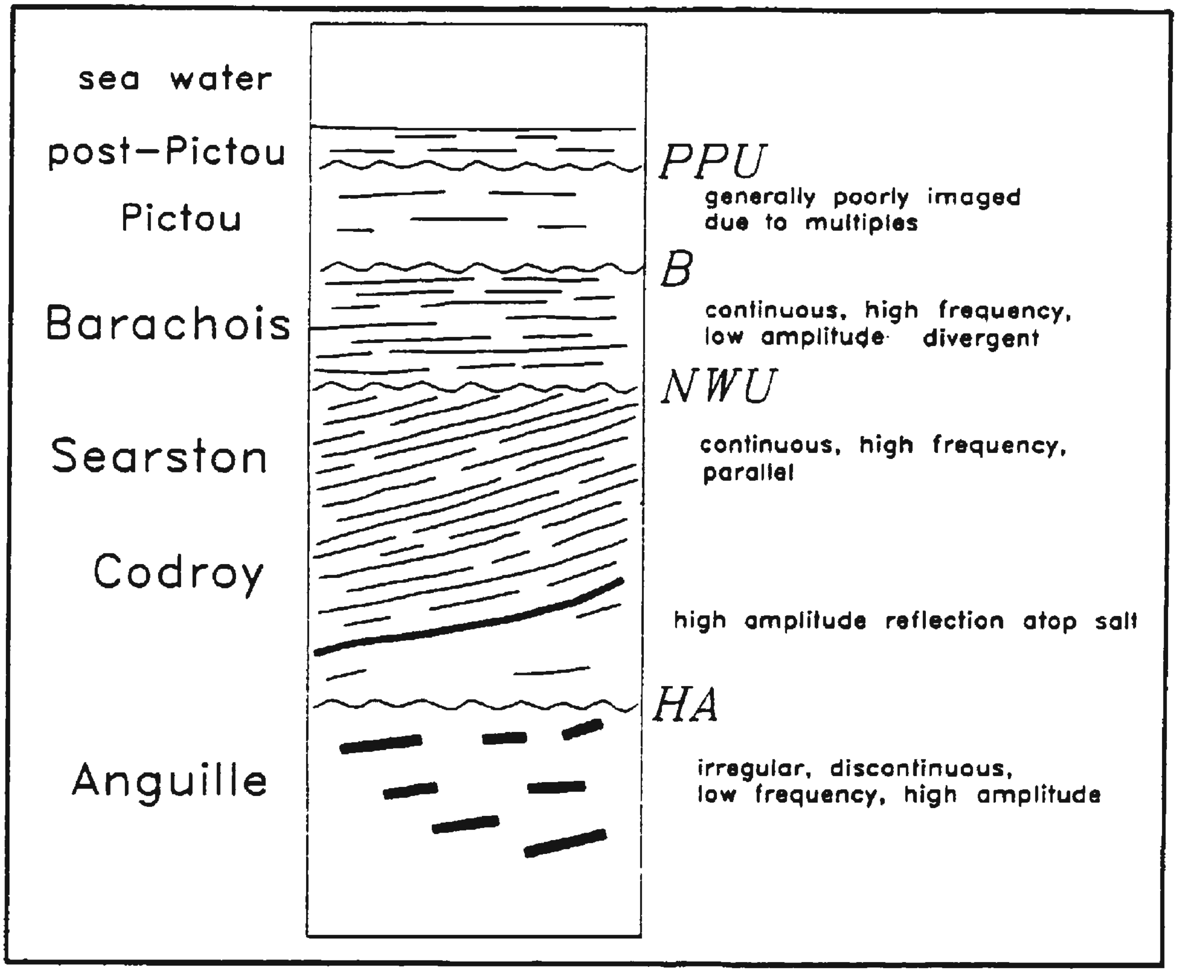
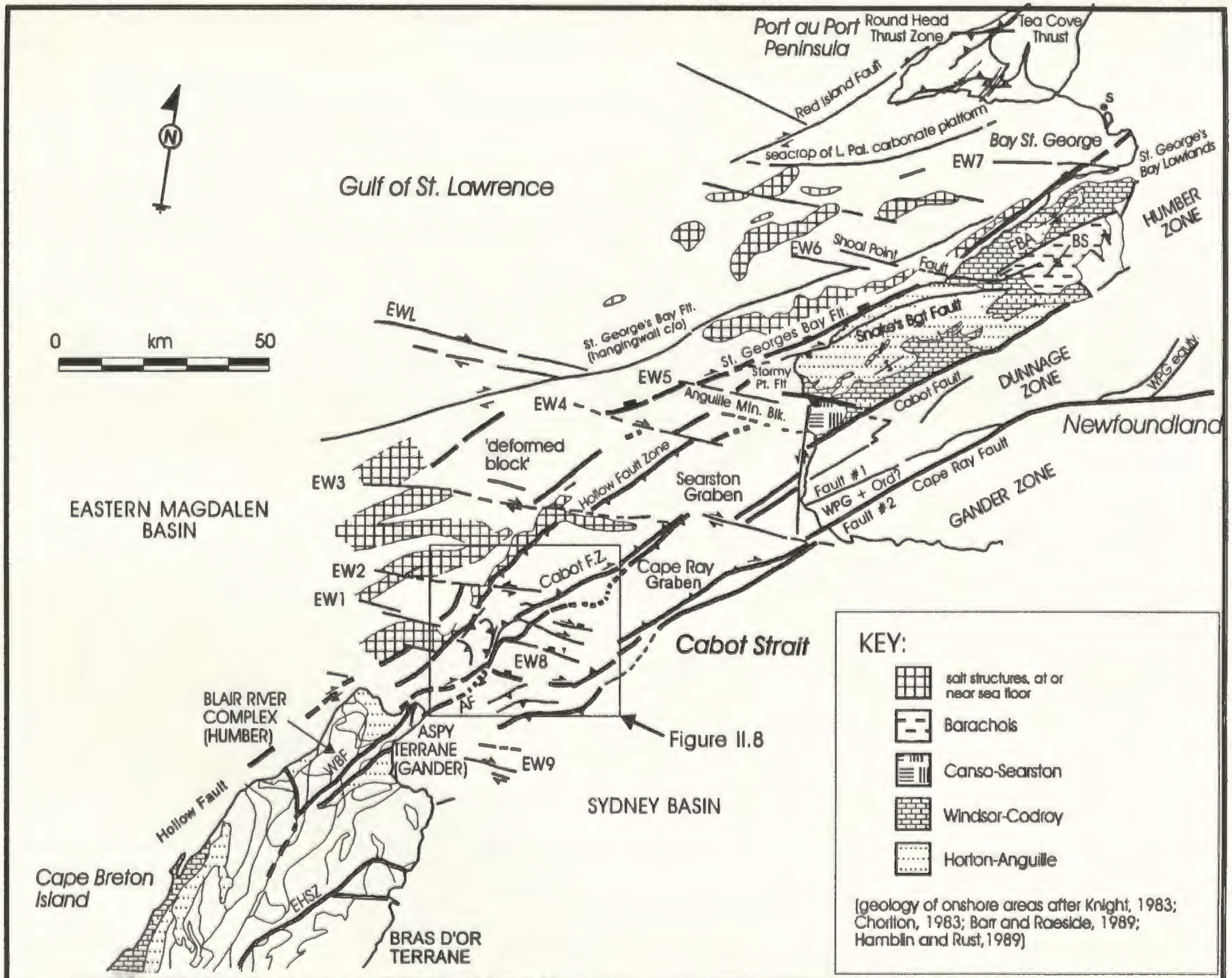

sea water
post–Pictou
Pictou
Barachois
Searston
Codroy
Anguille
PPU
generally poorly imaged
due to multiples
B
continuous, high frequency,
low amplitude divergent
NWU
continuous, high frequency,
parallel
high amplitude reflection atop salt
HA
irregular, discontinuous,
low frequency, high amplitude

Figure II.5: Structural elements of the Cabot Strait and surrounding area. **AF**: Aspy Fault; **BS**: Barachois Synclinorium (Knight, 1983); **C**: village of Codroy; **EHSZ**: Eastern Highlands Shear Zone (*e.g.*, Barr and Raeside, 1986; Barr et al, 1992a); **EWL**: east-west lineament; **FBA**: Flat Bay Anticline; **S**: town of Stephenville; **WBF**: Wilkie Brook Fault; **WPG**: Windsor Point Group (Wilton, 1983).



Port au Port Peninsula
Round Head Thrust Zone
Tea Cove Thrust
Red Island Fault
seacrop of L. Pal. carbonate platform
Bay St. George
St. George's Bay Lowlands
EW7
HUMBER ZONE
Gulf of St. Lawrence
EW6
Shoal Point Fault
FBA
BS
EWL
St. George's Bay Flt. (hangingwall c/o)
St. Georges Bay Flt.
Snake's Bgt Fault
0 km 50
EW5
Stormy Pt. Flt
Anguille Mtn. Blk.
Cabot Fault
DUNNAGE ZONE
WPG equiv.
EW4
Newfoundland
'deformed block'
Hollow Fault Zone
Searston Graben
Fault #1
WPG + Ord?
Fault #2
Cape Ray Fault
GANDER ZONE
EW3
EASTERN MAGDALEN BASIN
EW2
EW1
Cabot F.Z.
Cape Ray Graben
Cabot Strait
EW8
AF
BLAIR RIVER COMPLEX (HUMBER)
ASPY TERRANE (GANDER)
WBF
EW9
Figure II.8
Hollow Fault
SYDNEY BASIN
Cape Breton Island
EHSZ
BRAS D'OR TERRANE
KEY:
salt structures, at or near sea floor
Barachois
Canso-Searston
Windsor-Codroy
Horton-Anguille
(geology of onshore areas after Knight, 1983; Chorlton, 1983; Barr and Raeside, 1989; Hamblin and Rust, 1989)

Figure II.6: Structural domains identified from interpretation of geophysical data sets. Non-shaded areas offshore are relatively undeformed Carboniferous basinal areas.

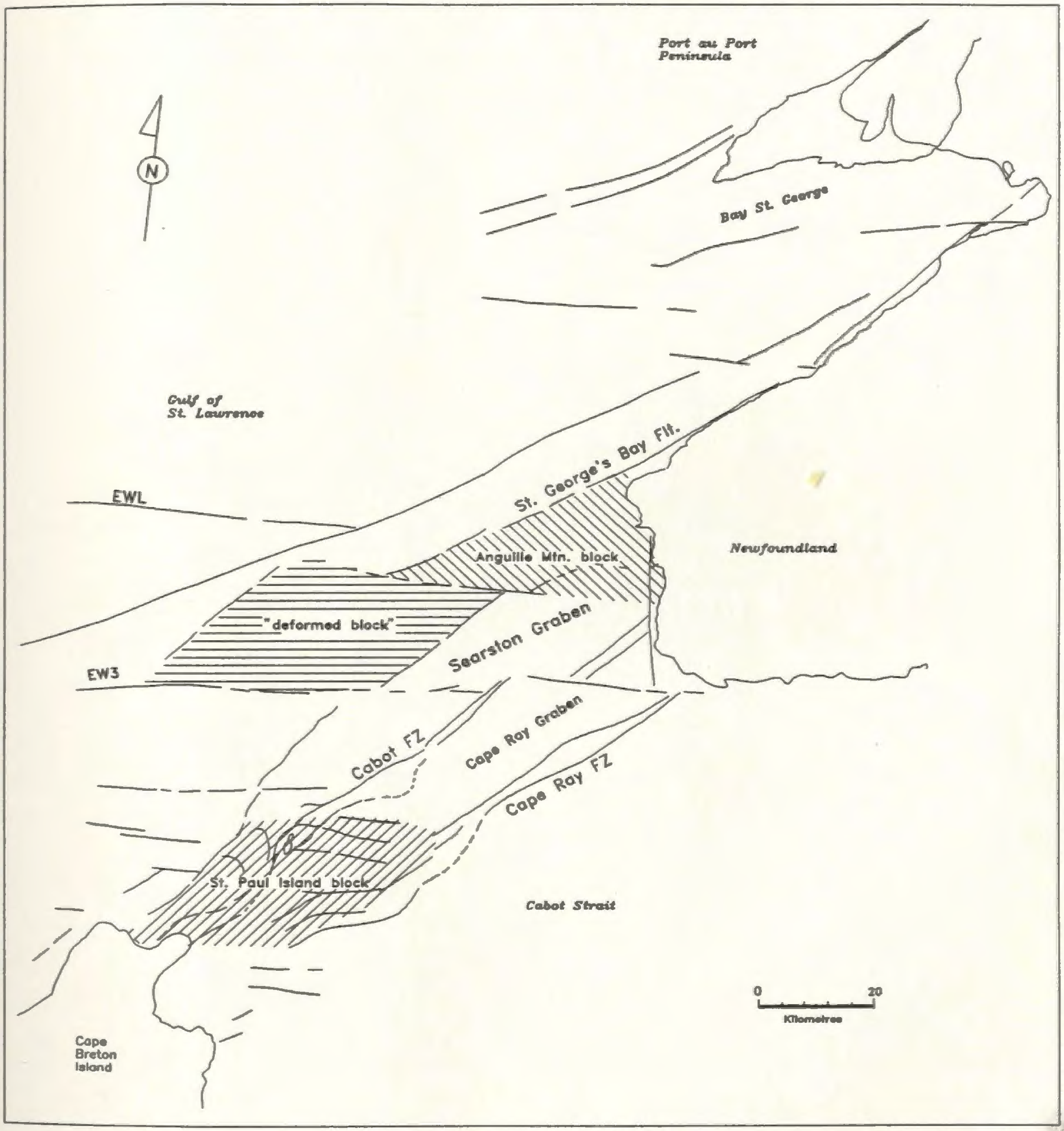

Port au Port
Peninsula
N
Bay St. George
Gulf of
St. Lawrence
EWL
St. George's Bay Flt.
Anguille Mtn. block
Newfoundland
"deformed block"
Searston Graben
EW3
Cabot FZ
Cape Ray Graben
Cape Ray FZ
St. Paul Island block
Cabot Strait
0
20
Kilometres
Cape
Breton
Island

Figure II.7: Comparison of major faults and potential field features.

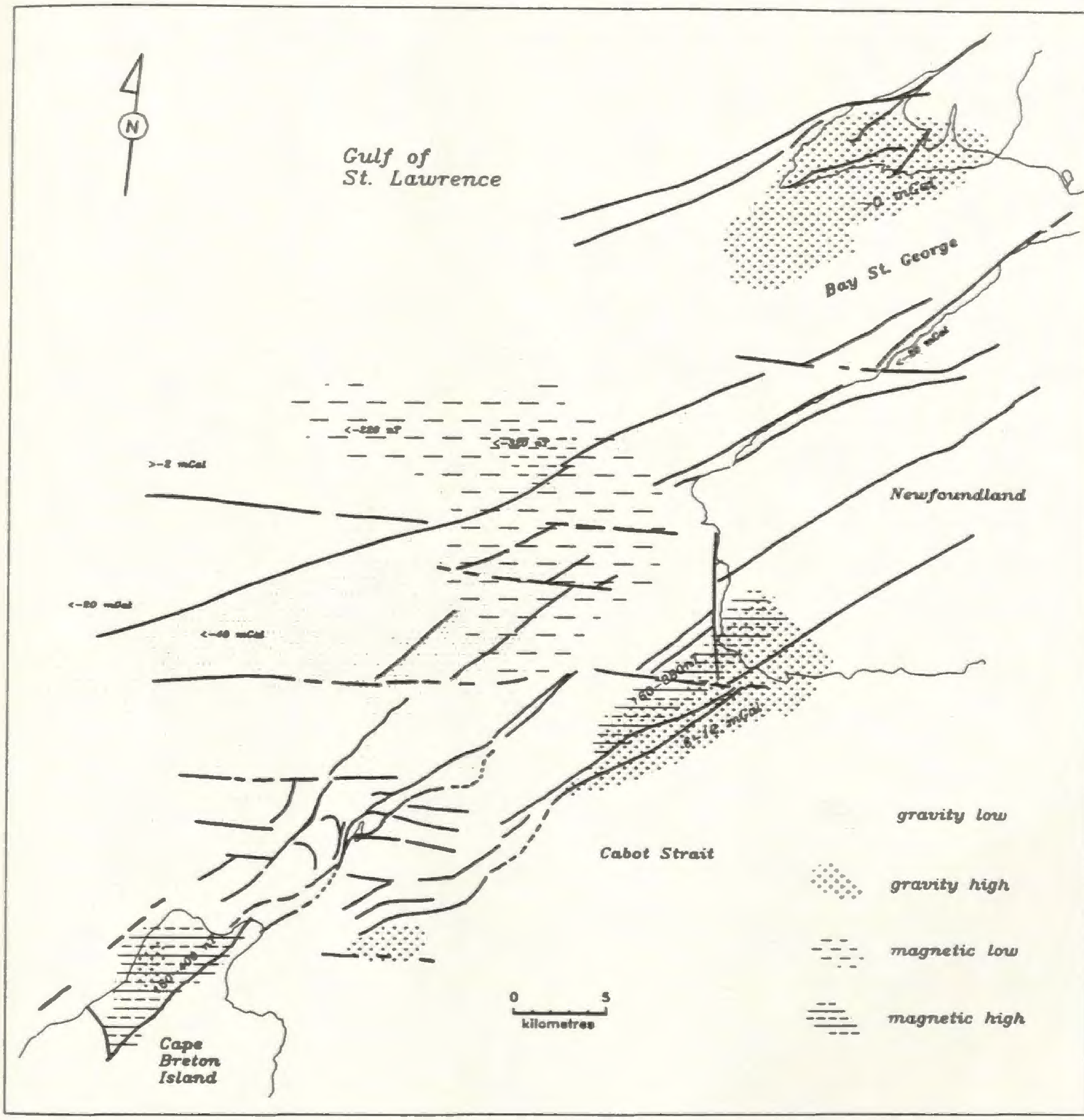
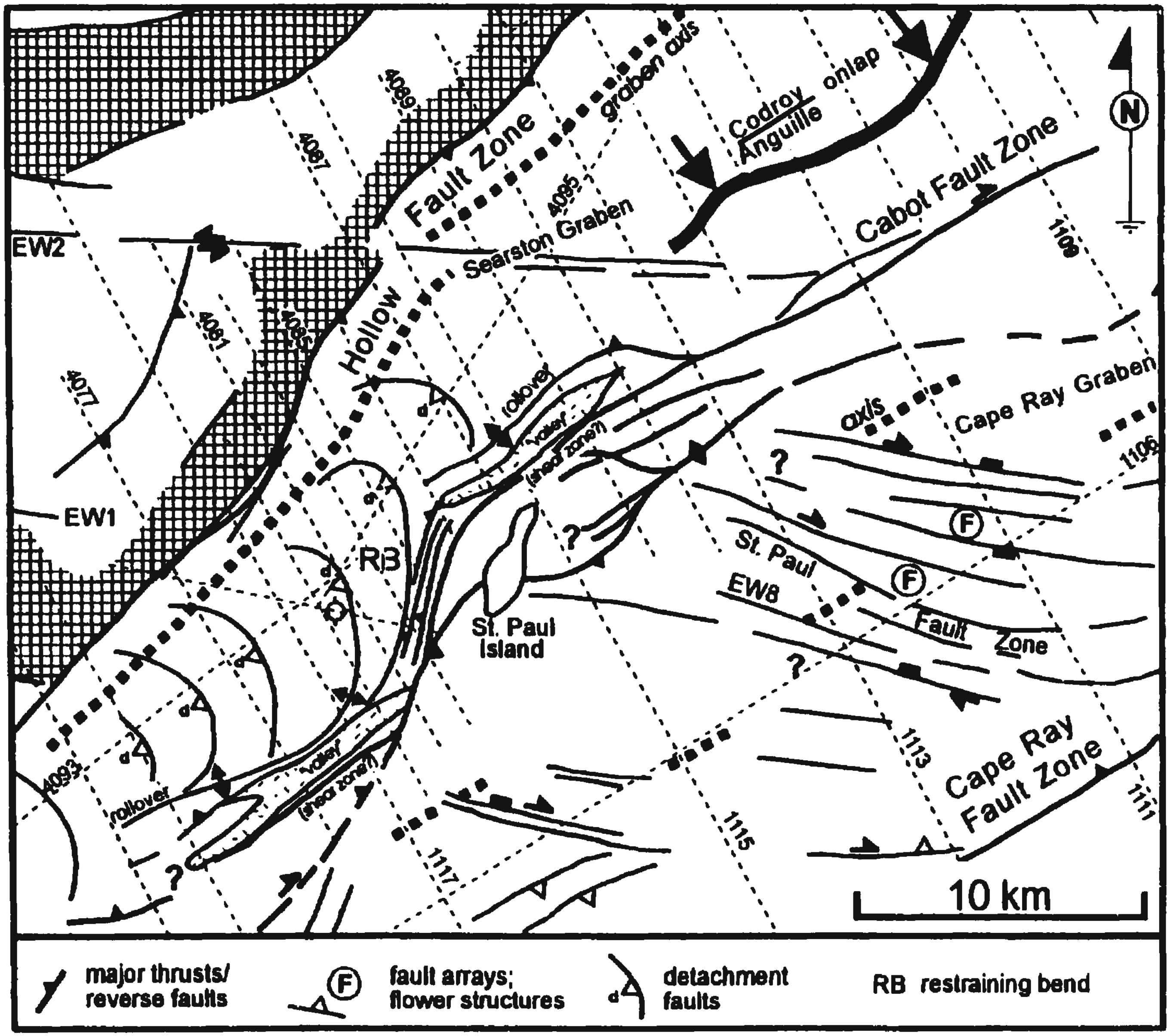
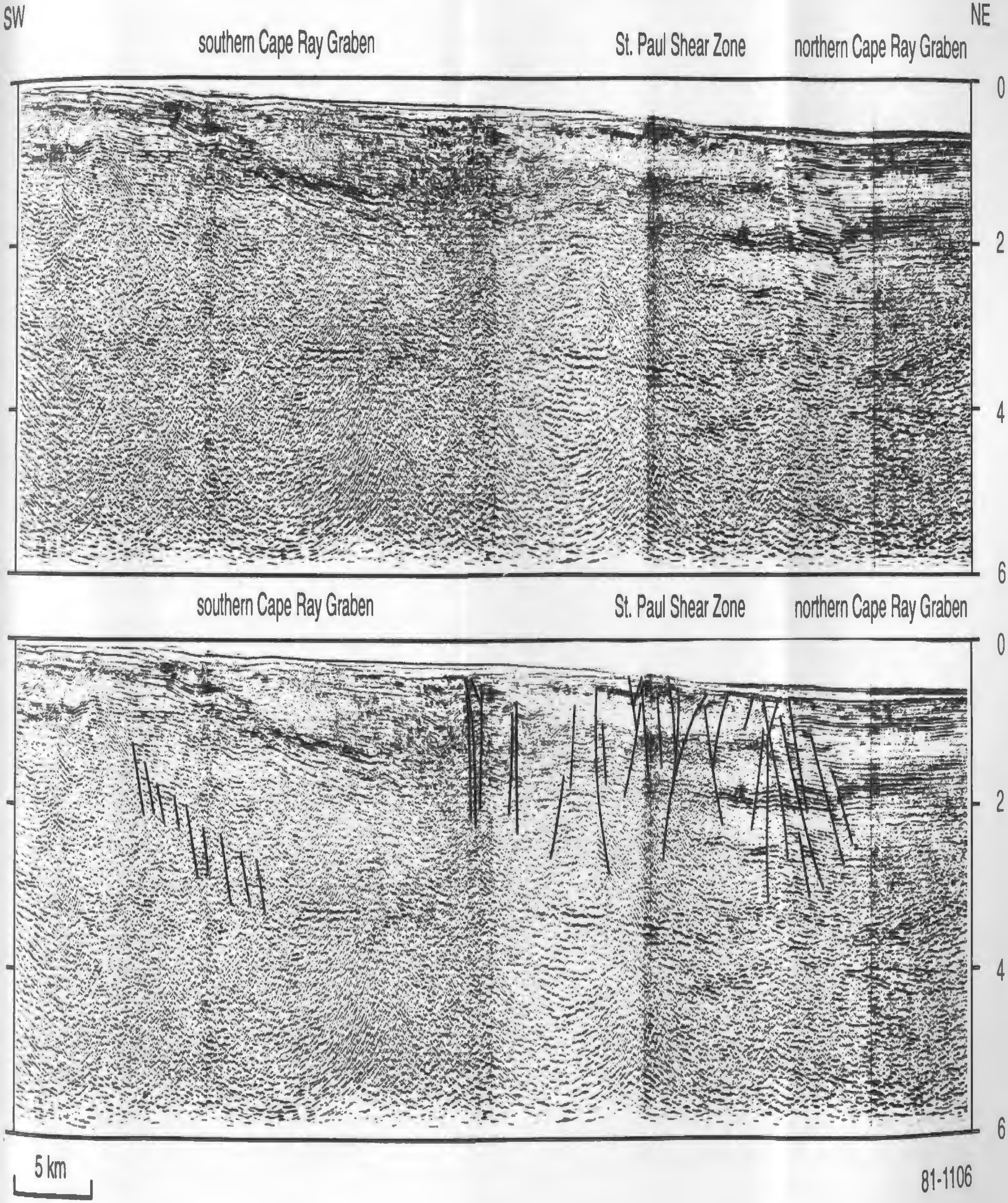

N
Gulf of
St. Lawrence
Bay St. George
Newfoundland
Cabot Strait
Cape
Breton
Island
0
5
kilometres
gravity low
gravity high
magnetic low
magnetic high

Figure II.8: Detail map of St. Paul Island area, showing the restraining bend along Cabot Fault, associated detachments in the Searston Graben, the St. Paul Shear Zone, and the positions of graben axes. Well symbol immediately west of St. Paul Island indicates location of St. Paul P-91 exploratory well. **RB**: restraining bend.

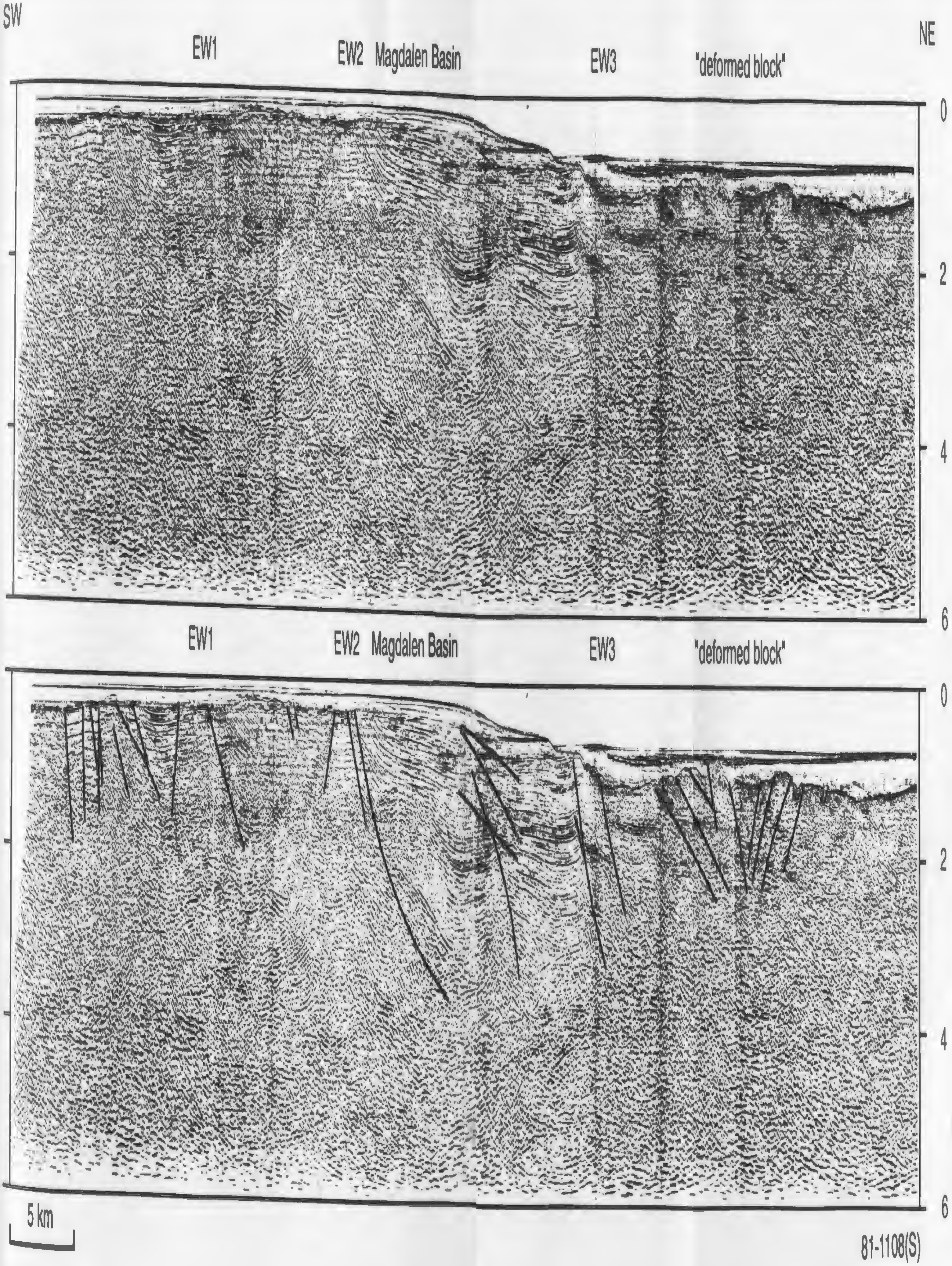


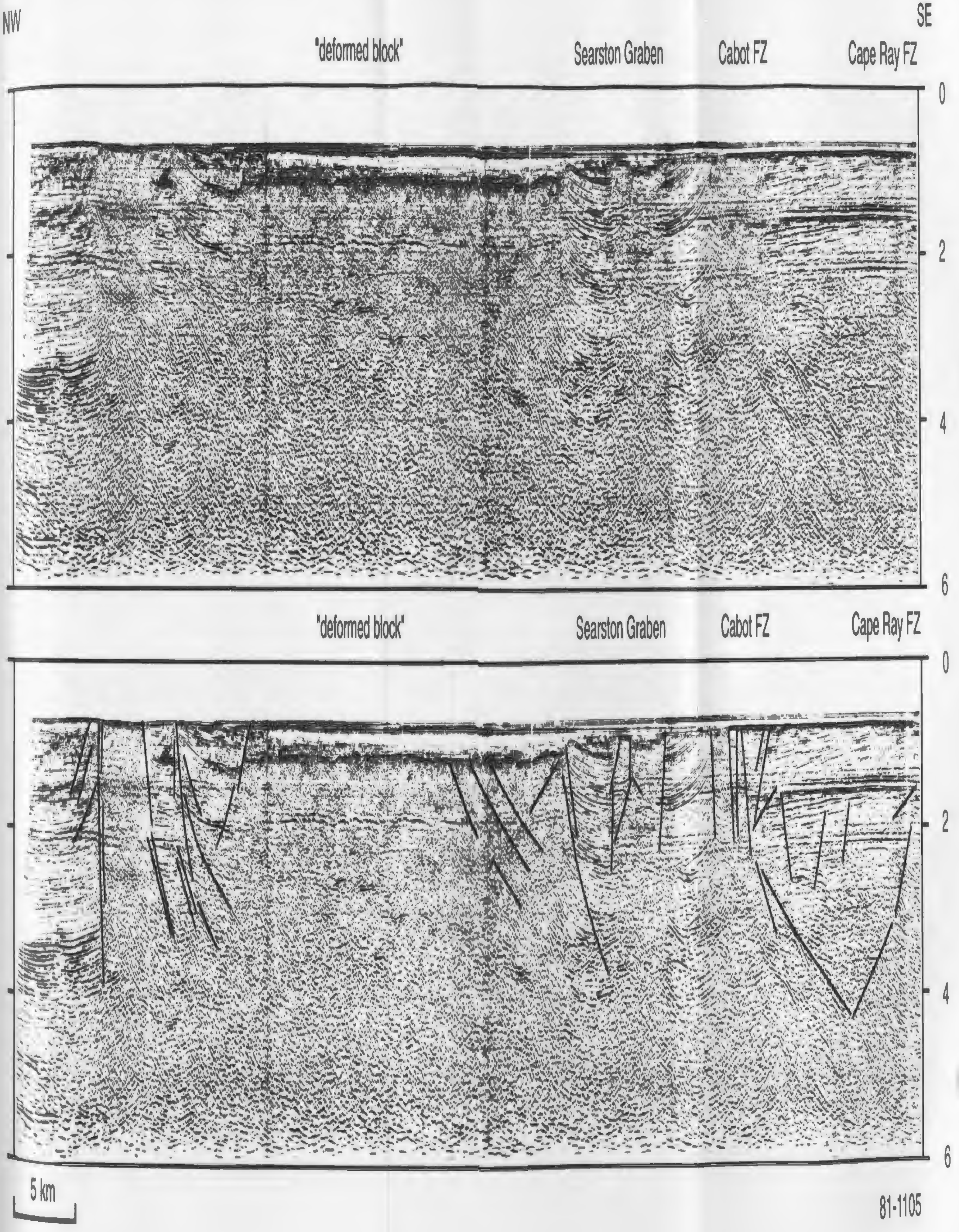
Hollow Fault Zone
graben axis
Codroy
Anguille
onlap
Cabot Fault Zone
Searston Graben
EW2
EW1
RB
rollover
valley
(shear zone?)
St. Paul Island
Cape Ray Graben
axis
St. Paul Fault Zone
EW8
Cape Ray Fault Zone
N
10 km
4077
4081
4083
4085
4087
4089
4093
1106
1108
1111
1113
1115
1117
major thrusts/ reverse faults
fault arrays; flower structures
detachment faults
RB restraining bend

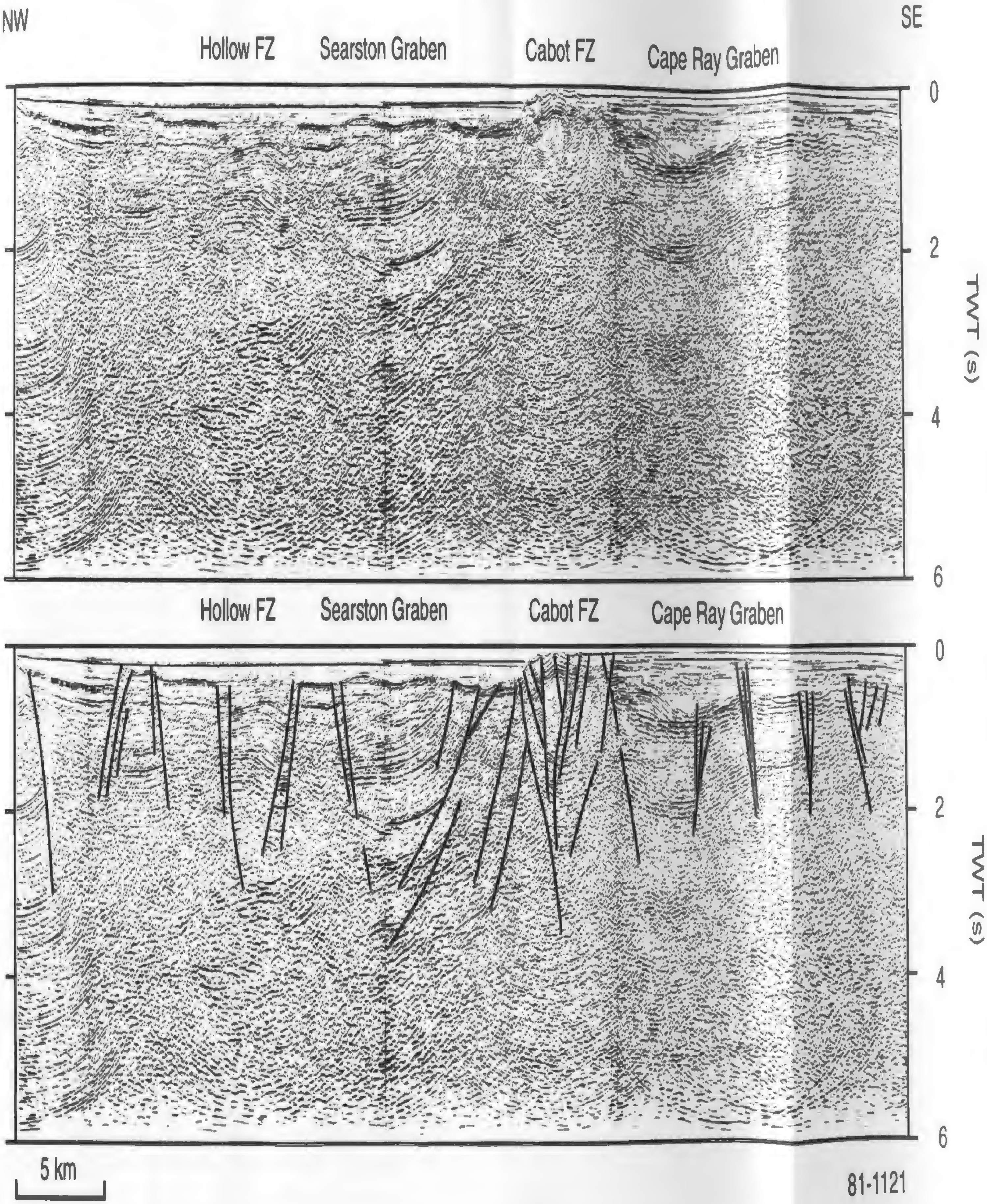
Figure II.9: Reproductions of four representative seismic profiles: Petro-Canada 82-1106, -1108, -1105 and -1121. V/H scale ~ 1 for assumed average velocity of 5 km/sec. Locations given in Figure II.1. Upper panels display unadorned seismic sections. Lower panels show locations of inferred faults. See Figure II.10 for stratigraphic interpretations of reflectors.



SW
NE
southern Cape Ray Graben
St. Paul Shear Zone
northern Cape Ray Graben
0
2
4
6
TWT (s)
southern Cape Ray Graben
St. Paul Shear Zone
northern Cape Ray Graben
0
2
4
6
TWT (s)
5 km
81-1106


SW
NE
EW1
EW2 Magdalen Basin
EW3
"deformed block"
0
2
4
6
TWT (s)
EW1
EW2 Magdalen Basin
EW3
"deformed block"
0
2
4
6
TWT (s)
5 km
81-1108(S)


NW
SE
"deformed block"
Searston Graben
Cabot FZ
Cape Ray FZ
0
2
4
6
TWT (s)
"deformed block"
Searston Graben
Cabot FZ
Cape Ray FZ
0
2
4
6
TWT (s)
5 km
81-1105



NW
SE
Hollow FZ
Searston Graben
Cabot FZ
Cape Ray Graben
0
2
4
6
TWT (s)
Hollow FZ
Searston Graben
Cabot FZ
Cape Ray Graben
0
2
4
6
TWT (s)
5 km
81-1121

Figure II.10 (a-c, in pocket): Line drawings from seismic profiles, displayed with vertical two-way time scale, V/H ~1. Part **a** shows regional NW-SE ("dip") lines, (from Petro-Canada, 1981 series): 1103, 1105, 1107, 1109, 1111, 1113, 1115, 1117, 1119, 1121, and infill grid Searston Graben lines (from Petro-Canada, 1983 series): 4075, 4077, 4083, 4087, 4089, 4093. These are aligned along intersecting strike lines 1106 and 1108, which roughly parallel the strike of the Cabot Fault system.

Part **b** shows Bay St. George dip profiles MAQ-017 and MAQ012 (from Mobil, 1971) and TAJ-009 and -010 (from Texaco, 1970). These are aligned along the St. George's Bay Fault.

Part **c** shows corresponding SW-NE ("strike") lines: 81-1106, -1108 (south), and QAA009 from the outer Bay St. George.

Stratigraphic symbols: **B**: top Barachois (unconformity), **B1**, **B2**: Barachois subsequences; **CB**: Clam Bank; **CL**: Crabbe's Limestone; **CR**: Codroy Road Fm.(top evaporite-rich zone); **CS**: Canso-Searston; **HA**: top Horton-Anguille (unconformity); **NWU**: Namurian-Westphalian unconformity; **OSC**: Ordovician-Silurian carbonates; **PHB**: Pre-Horton basement; **PPU**: post-Pennsylvanian unconformity (separates Permo-Carboniferous from possible scattered, thin Mesozoic/Tertiary deposits); **WC**: Windsor-Codroy. **dbW**: décollement at base Windsor, **dbW/H?**: décollement at base Windsor or within Horton salt. Although not everywhere indicated, most faults are contractional and represent reverse or thrust displacement in their latest movement. Asterisk (*) after line name indicates that corresponding seismic data are reproduced in Figure II.9. Shading: dark represents salt; light stipple represents pre-Horton basement.

Figure III.1: Isochron map on the pre-Viséan substrate. Three different substrates or unconformitities are mapped: **a**. NW of St. George's Bay Fault: = structure on Cambro-Ordovician platform. **b**. St. George's Bay to Cabot Faults: = structure on Horton (HA unconformity). **c**. SE of Cabot Fault: = structure on pre-Horton basement (PHB). Outlines of major faults and salt bodies are also given for comparison to Figure II.5. For further discussion, see text, Section III.3. Contour interval is 0.5 sec two-way time, which at an average velocity of 4 km sec^{-1} represents 1 km thickness.

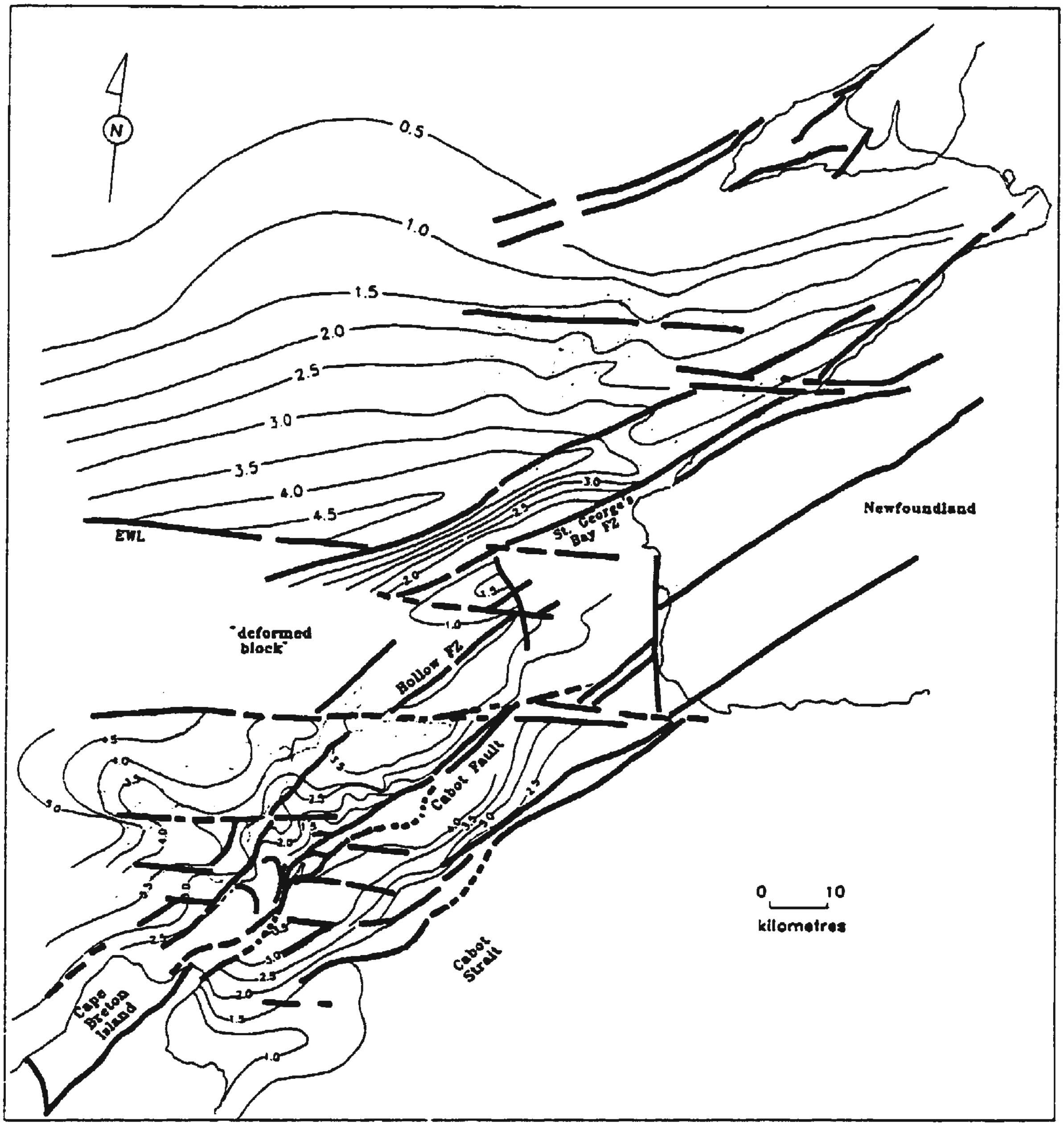
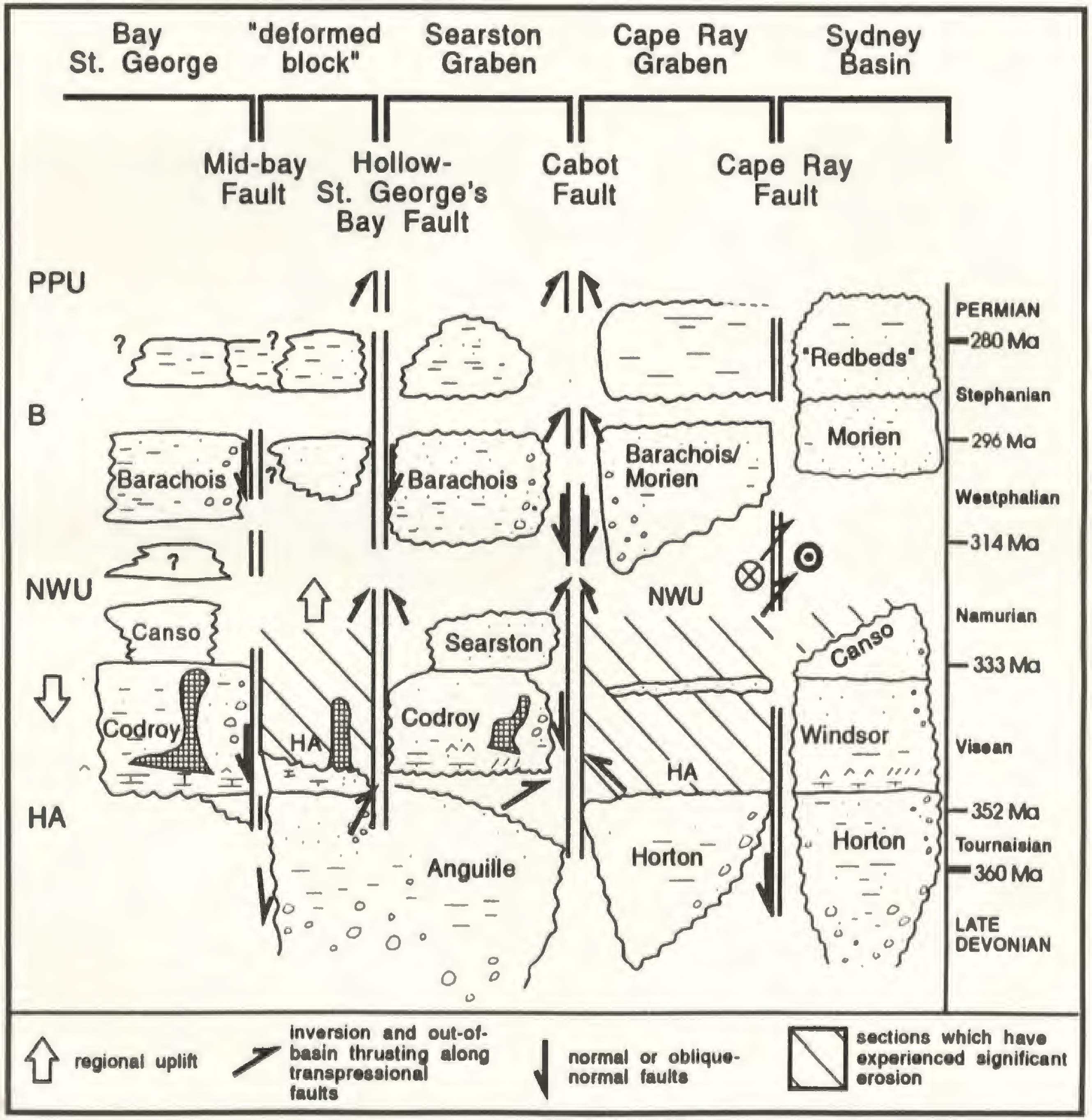

N
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
EWL
St. George's Bay FZ
Newfoundland
"deformed block"
Hollow FZ
Cabot Fault
0 10
kilometres
Cabot Strait
Cape Breton Island

Figure IV.1: Chronostratigraphic chart, Cabot Strait and Bay St. George. Vertical time scale is linear. Stratigraphic symbols: **PHB**: Pre-Horton basement; **HA**: top Horton-Anguille (unconformity); **WC**: Windsor-Codroy; **CS**: Canso-Searston; **NWU**: Namurian-Westphalian unconformity; **B**: top Barachois (unconformity), **B1**, **B2**: Barachois subsequences; **PPU**: post-Pennsylvanian. The sense of lateral displacement for all transpressive faults (solid, inclined up-arrows) is interpreted to be dextral. Salt patterns are schematic and indicate late diapiric motion.



Bay St. George
"deformed block"
Searston Graben
Cape Ray Graben
Sydney Basin
Mid-bay Fault
Hollow- St. George's Bay Fault
Cabot Fault
Cape Ray Fault
PPU
B
NWU
HA
Barachois
Barachois
Barachois/ Morien
"Redbeds"
Morien
Canso
Searston
NWU
Canso
Codroy
HA
Codroy
Windsor
HA
Anguille
Horton
Horton
PERMIAN
280 Ma
Stephanian
296 Ma
Westphalian
314 Ma
Namurian
333 Ma
Visean
352 Ma
Tournaisian
360 Ma
LATE DEVONIAN
regional uplift
inversion and out-of-basin thrusting along transpressional faults
normal or oblique-normal faults
sections which have experienced significant erosion

Figure V.1: Published kinematic models illustrating distributed shear and strain partitioning.

a and b. [Mount and Suppe (1987)]: in (a), zone of wrench deformation is confined to a zone of distributed shear adjacent to fault (wrench borderland model); (b) deformation style predicted for decoupled transcurrent and thrust deformation (strain partitioning) and manifested in western North America, as illustrated in **c** [Namson and Davis (1988)]: crustal scale profiles across the North American/Pacific Plate boundary. In this profile, points in the immediate vicinity of the San Andreas Fault remain at a fixed distance from the fault after compression, whereas further from the fault, shortening results in the development of a fold-and-thrust belt. See text Section V.1 for further discussion.

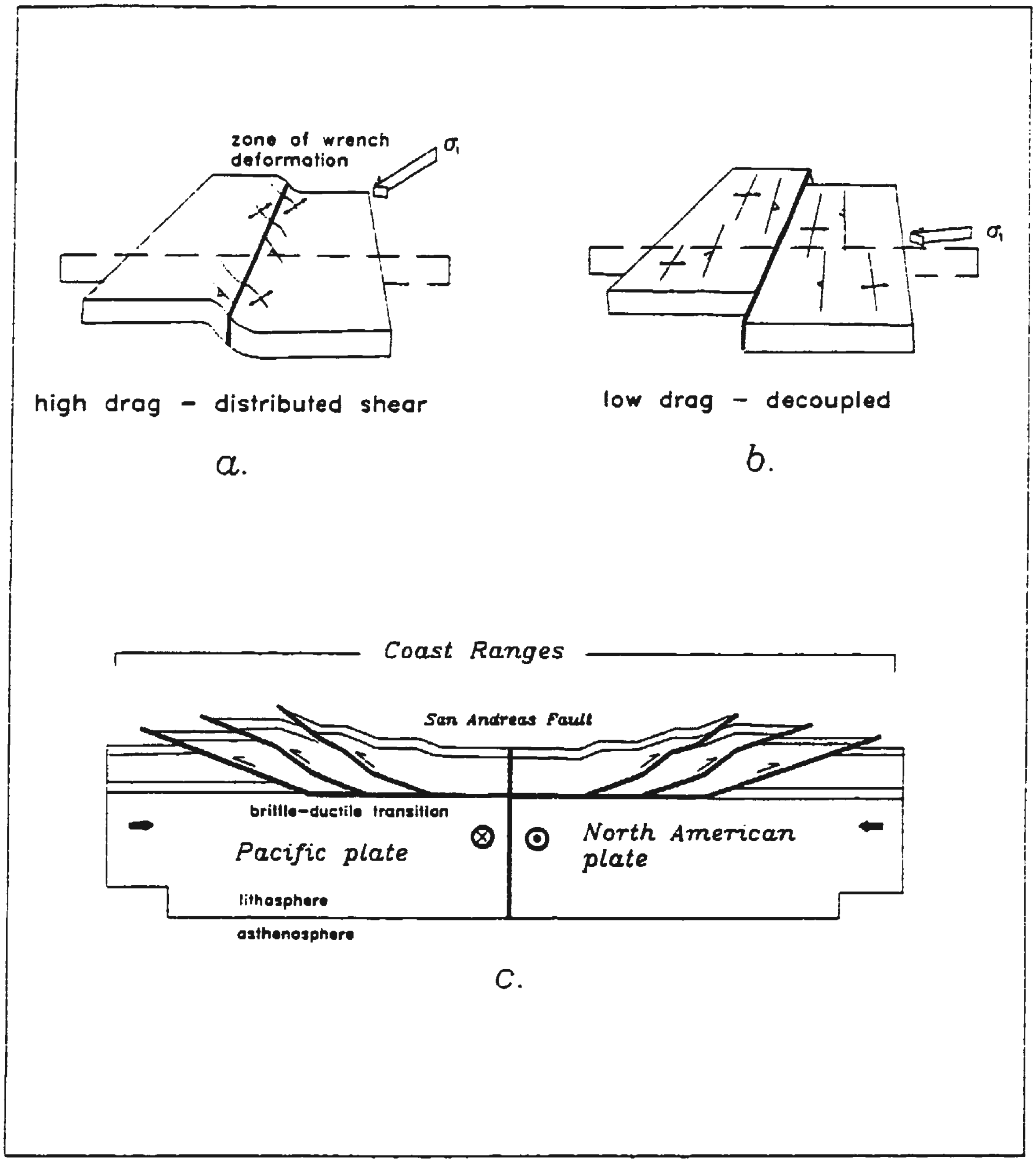

zone of wrench deformation
σ1
high drag - distributed shear
a.
σ1
low drag - decoupled
b.
Coast Ranges
San Andreas Fault
brittle-ductile transition
Pacific plate
North American plate
lithosphere
asthenosphere
c.

Figure V.2: Kinematic model of the formation and subsequent inversion of Late Paleozoic basins in the Cabot Strait area as part of the development of a strain-partitioned wrench borderland (see discussion in text). **a.** Middle Carboniferous: The Horton half-graben developed mainly by orthogonal shear or distension (*e.g.*, Hamblin and Rust, 1989) and was eventually overstepped by sediments from a rapidly-subsiding Magdalen Basin to the west. Major displacement along the Cabot Fault occurred at this time, and may have been responsible for the Namurian-Westpalian uncomformity (NWU) seen on seismic profiles. Numbers indicate sequence of faulting. **b.** Late Carboniferous: The shallow geometries on this cross section are based upon seismic profile 1105. Late Carboniferous dextral transpression affected the basin, creating compressional structures and inverting the basin fill. A simple wrench borderland geometry was made more complex, mostly in the latest Carboniferous, by braiding of the regional master fault system, resulting in small components of dextral movement on each of the strands. Compressional structures along the master fault are localized and related to irregularities in the trace of the fault, such as the restraining bend at St. Paul Island. The wrench borderland is about 50 km across.

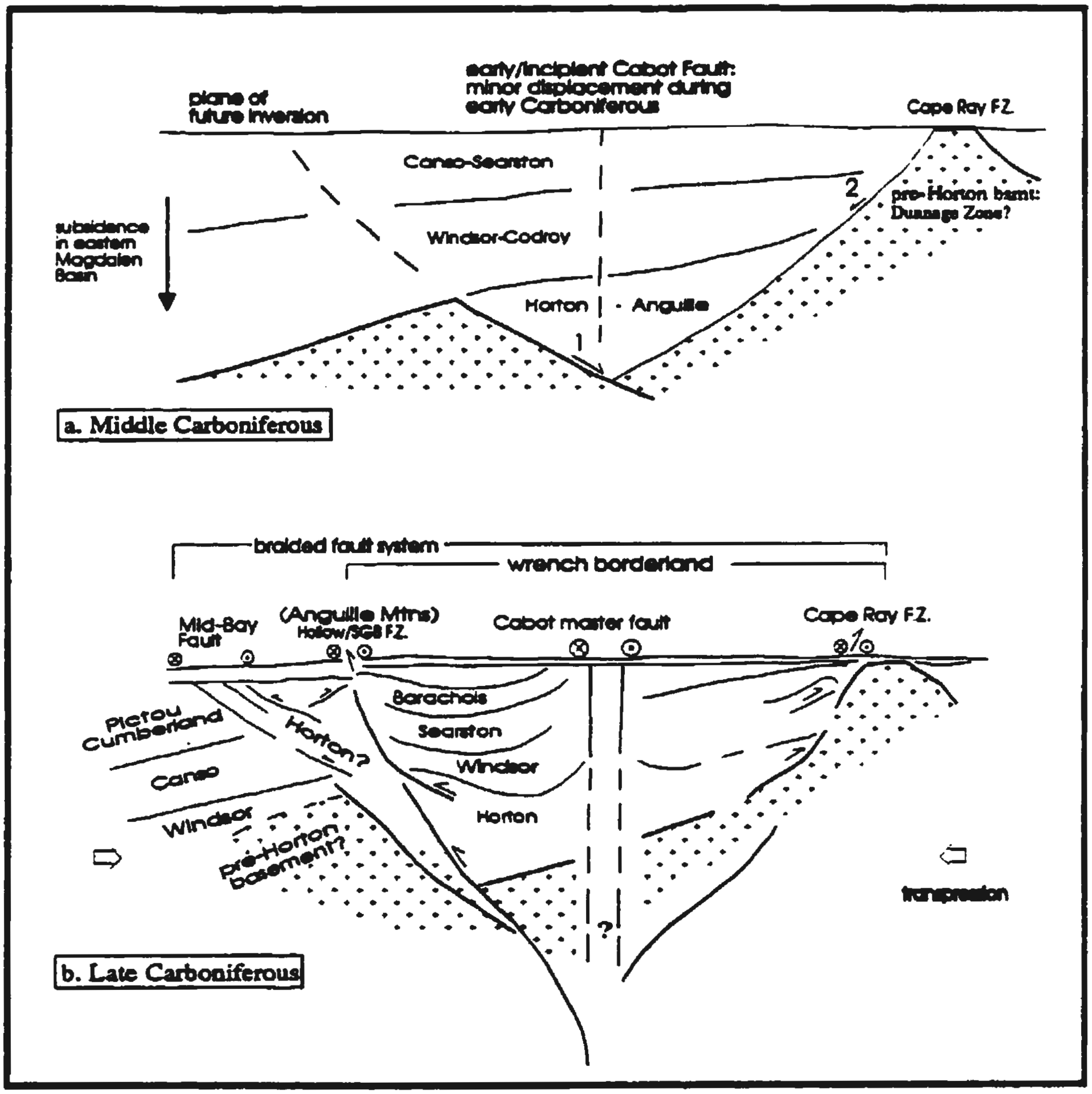
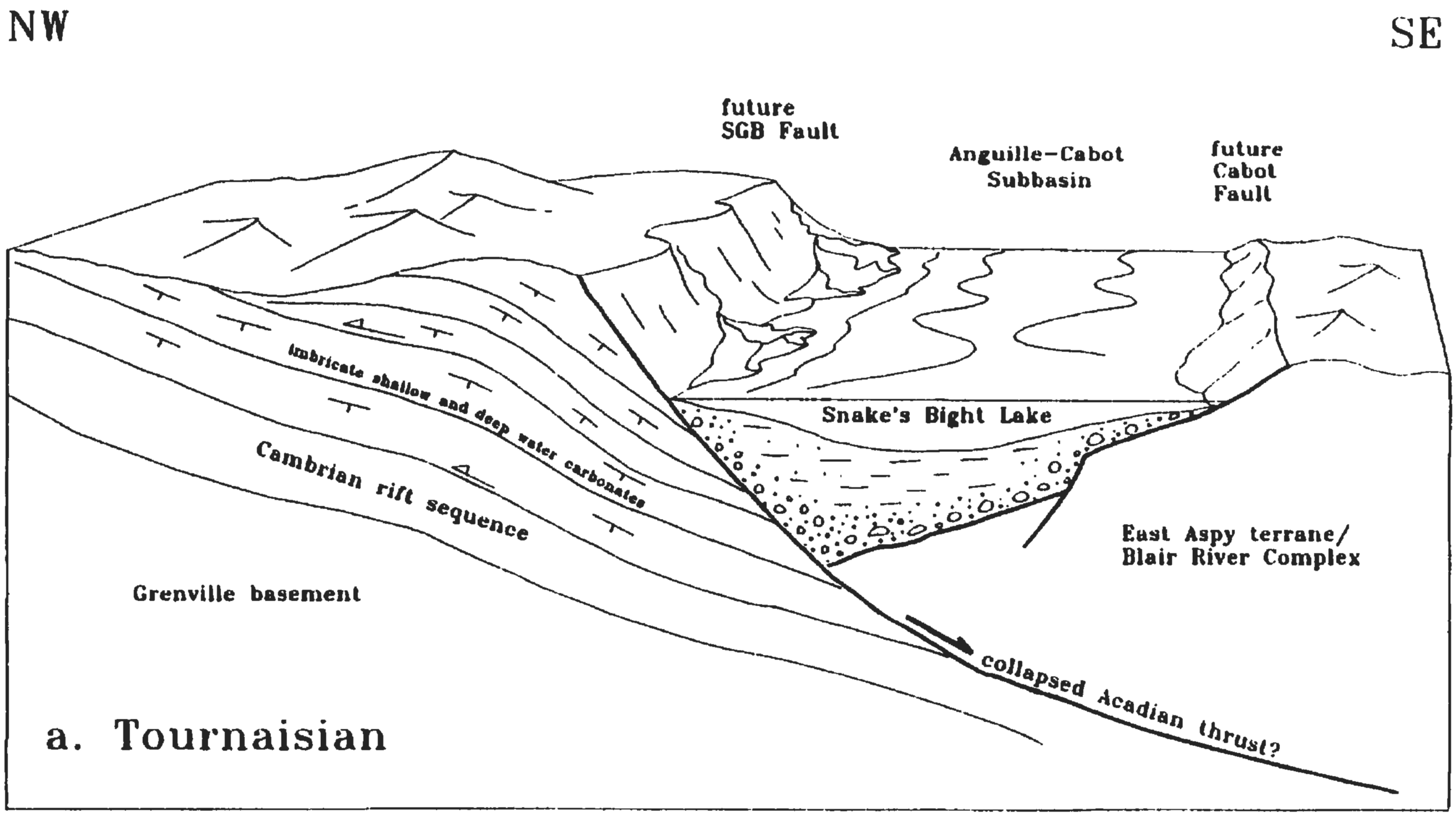
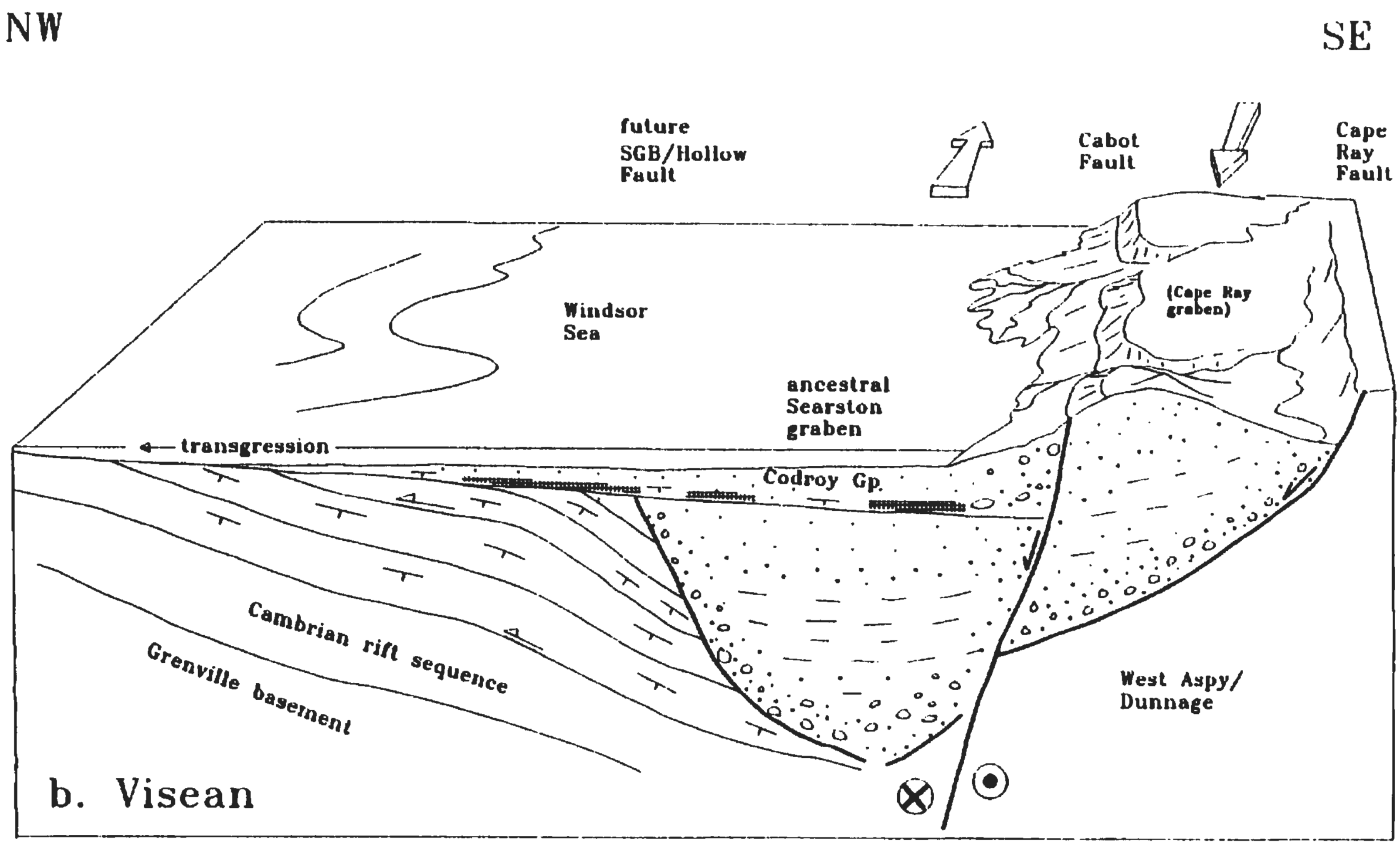
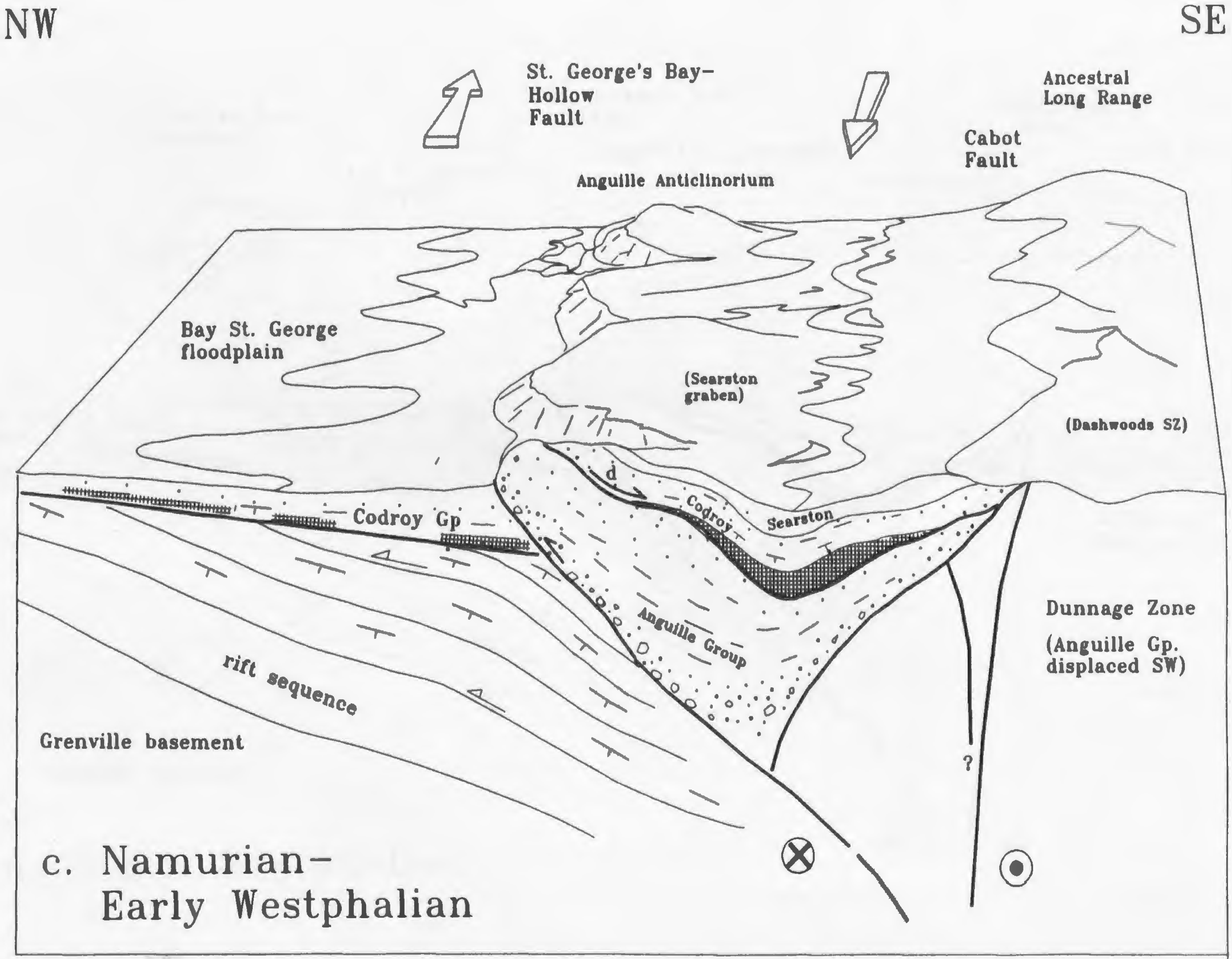

early/incipient Cabot Fault: minor displacement during early Carboniferous
plane of future inversion
Cape Ray F.Z.
Canso-Searston
subsidence in eastern Magdalen Basin
Windsor-Codroy
2
pre-Horton bsmt: Dunnage Zone?
Horton
Anguille
1
a. Middle Carboniferous
braided fault system
wrench borderland
Mid-Bay Fault
(Anguille Mtns)
Hollow/SGB F.Z.
Cabot master fault
Cape Ray F.Z.
Barachois
Searston
Pictou Cumberland
Horton?
Windsor
Canso
Horton
Windsor
pre-Horton basement?
transpression
?
b. Late Carboniferous

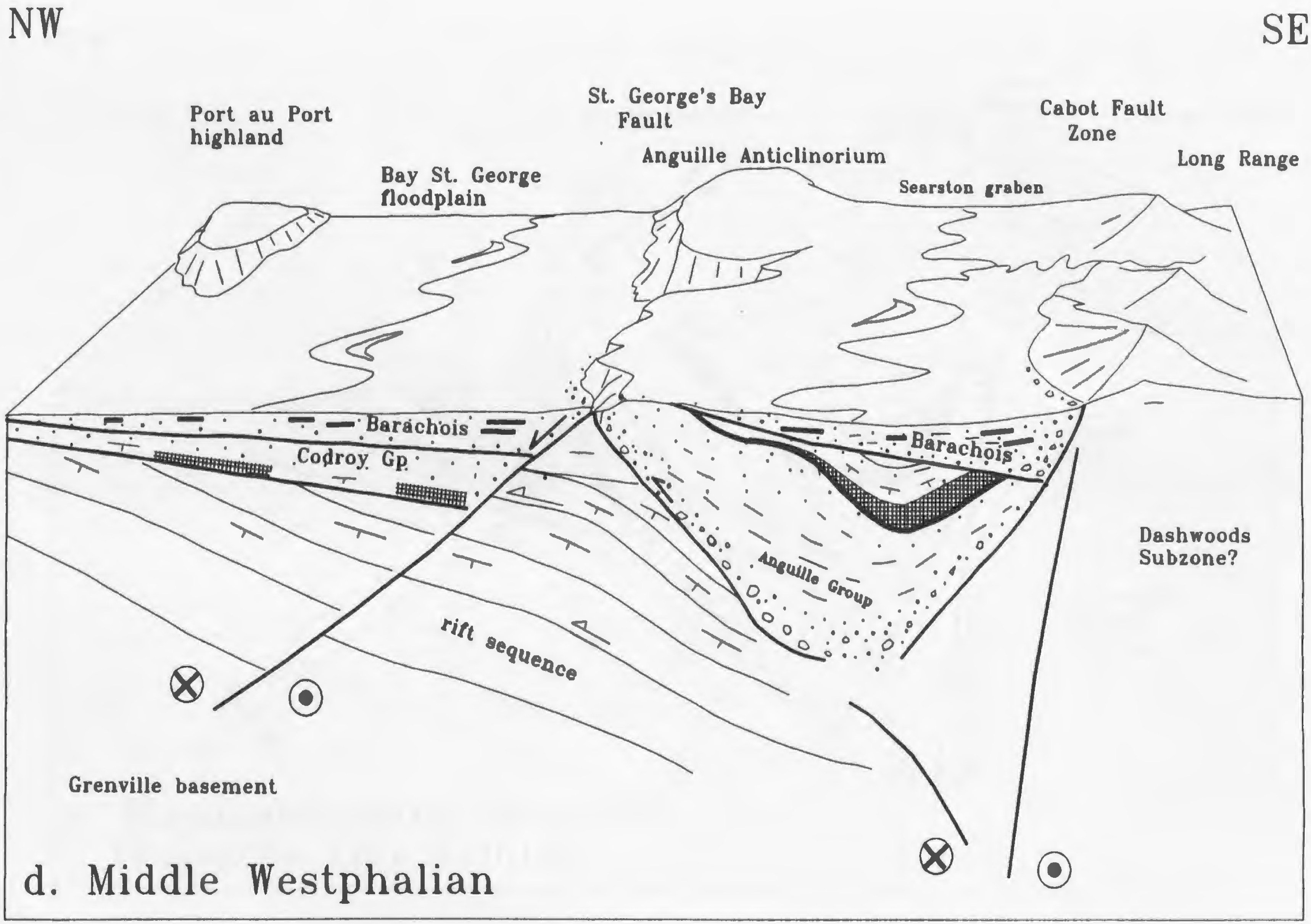
Figure V.3: Three-dimensional sketches depicting the evolution of the Bay St. George half-graben. The stages of development are discussed in Section V.2 of the text. Open thrust arrows indicate Acadian thrusting in carbonate platform, imbricated carbonates may include thin slices of Grenville basement; solid arrowheads indicate Carboniferous thrust and normal faulting. Arrowhead and arrowtail symbols indicate sense of strike-slip. Changes in terranes juxtaposed in the plane of the section occur because of substantive movement by strike-slip normal to the plane of the section. Terms in brackets indicate geographical locations which change across major strike-slip faults. Final stage (**e**) is based largely on seismic line TAJ010 from the outer Bay St. George (cf. Figure II.10b).


NW
SE
future
SGB Fault
Anguille-Cabot
Subbasin
future
Cabot
Fault
imbricate shallow and deep water carbonates
Snake's Bight Lake
Cambrian rift sequence
East Aspy terrane/
Blair River Complex
Grenville basement
collapsed Acadian thrust?
a. Tournaisian

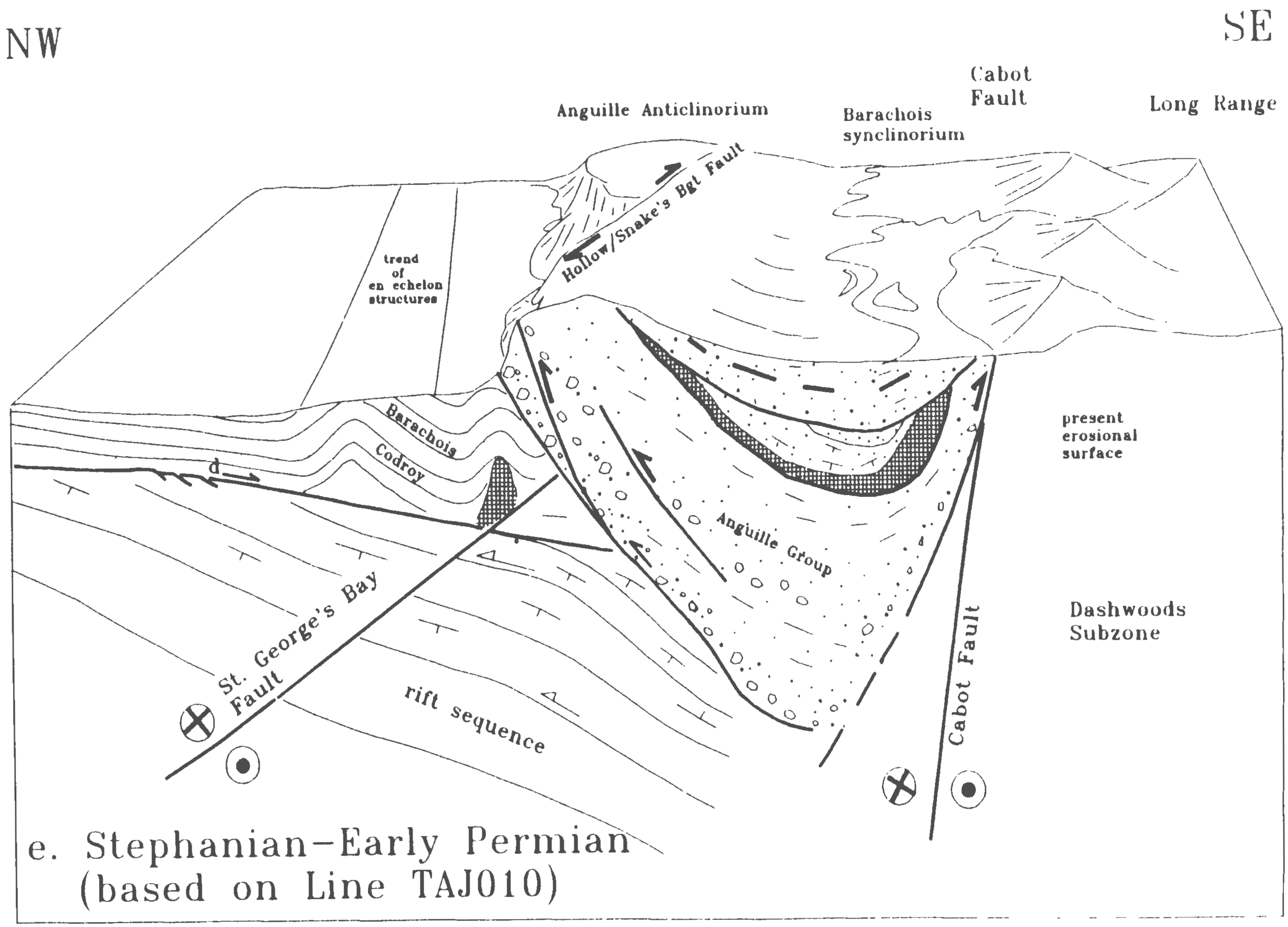

NW
SE
future
SGB/Hollow
Fault
Cabot
Fault
Cape
Ray
Fault
Windsor
Sea
(Cape Ray
graben)
ancestral
Searston
graben
transgression
Codroy Gp.
Cambrian rift sequence
Grenville basement
West Aspy/
Dunnage

b. Visean


NW
SE
St. George's Bay-
Hollow
Fault
Ancestral
Long Range
Cabot
Fault
Anguille Anticlinorium
Bay St. George
floodplain
(Searston
graben)
(Dashwoods SZ)
Codroy Gp
d
Codroy
Searston
Anguille Group
Dunnage Zone
(Anguille Gp.
displaced SW)
rift sequence
Grenville basement
?
c. Namurian-
Early Westphalian



d. Middle Westphalian



e. Stephanian–Early Permian (based on Line TAJ010)

Figure VI.1: Present day positions of basement terranes of southwestern Newfoundland, and possible correlations with Cape Breton Island, based upon geology of onshore areas, potential field (mainly magnetic anomaly, see Figure VI.2) data, and industry reflection seismic data north of the Cape Ray fault zone. Periods of fault movement are associated with particular styles of faulting and are identified by lower case letters: s=Silurian, d=Devonian, c=Carboniferous, tf=tear fault. Abbreviations and symbols for rock units are found in Tables II and III.

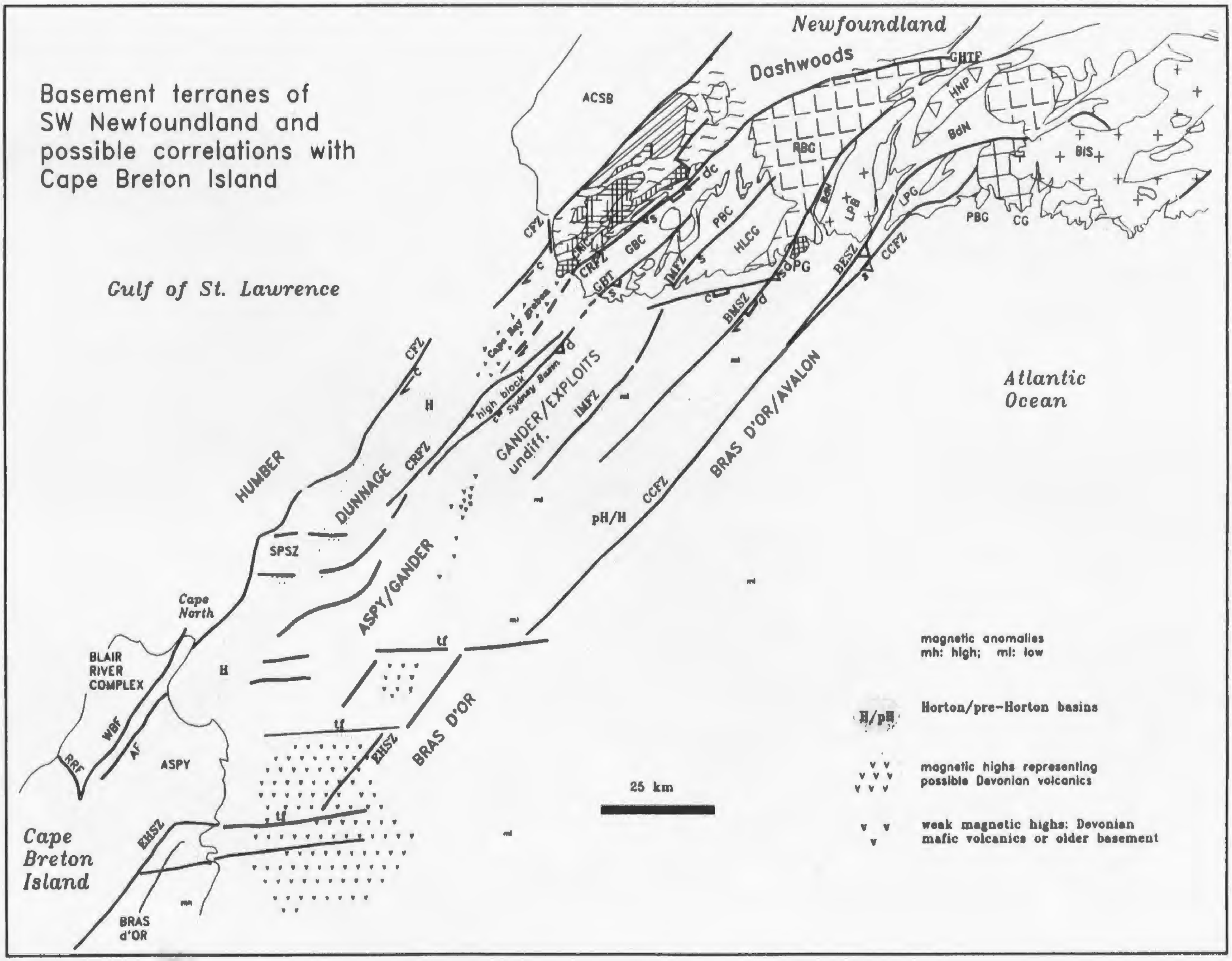

Basement terranes of SW Newfoundland and possible correlations with Cape Breton Island
Newfoundland
Dashwoods
Gulf of St. Lawrence
Atlantic Ocean
Cape Breton Island
ACSB
RBG
HNP
GHTF
BdN
BIS
PBG
CG
LPG
LPB
PBC
HLCG
GBC
CRFZ
CFZ
GBT
IMFZ
BMSZ
BESZ
CCFZ
PG
dc
Cape Ray Graben
high block
SW Sydney Basin
HUMBER
DUNNAGE
GANDER/EXPLOITS undiff.
BRAS D'OR/AVALON
ASPY/GANDER
BRAS D'OR
SPSZ
pH/H
H
tf
Cape North
BLAIR RIVER COMPLEX
WBF
RRF
AF
ASPY
EHSZ
BRAS d'OR
25 km
magnetic anomalies
mh: high; ml: low
H/pH
Horton/pre-Horton basins
magnetic highs representing possible Devonian volcanics
weak magnetic highs: Devonian mafic volcanics or older basement

Figure VI.2: Magnetic total field anomaly map (unmarked version in Figure II.3), showing fault interpretations in eastern Cabot Strait used in terrane correlations of Figure VI.1.

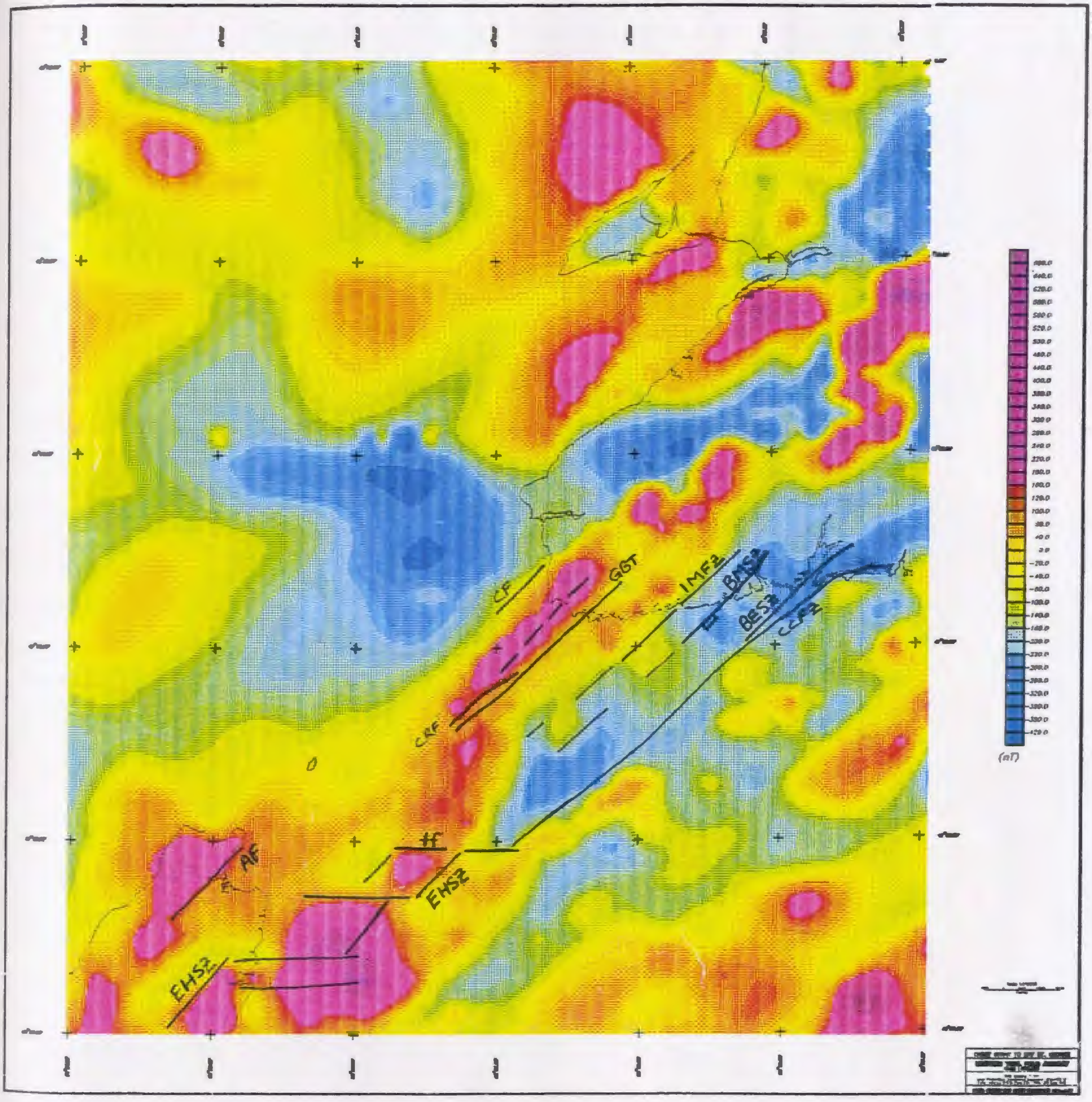

CF
GGT
IMFZ
BMSZ
BESZ
CCFZ
CRF
FF
AF
EHSZ
EHSZ
(nT)

Figure VI.3 (in pocket): Time-space diagram of mid-late Paleozoic events in the St. Lawrence Promontory. Diagram is divided into two panels, with areas associated with the Cabot (Aspy) Fault system on the left, and areas principally situated to the east of the Cabot Fault on the right. Within each panel, geological features are arranged from northwest to southeast. Plutons are plotted as ovals and their associations are shown where known or interpreted; a vertical bar joining two ovals indicates an age range.

Symbols for Time–Space Chart

blocking ages of minerals in post–metamorphic cooling

period of cooling of pluton

plutons with associations indicated

porphyroblastic growth: peak metamorphic conditions

strike–slip, dextral

reverse or thrust fault

transpression

transtension

low angle detachment

block faulting

late brittle structures: kink bands, crenulation cleavage, chevron folds

mylonitization

amalgamation

uplift and denudation

marine transgression

continental rift basin

Legend for Maps and Time-Space Chart

Cambro-Ordovician volcanics and
and granites (Notre Dame Subzone)

Fleur de Lys rift facies, and Cambro-
Ordovician intrusions (Dashwoods subzone)

Silurian volcanics and sediments

Cambro-Ordovician mafic/ultramafic rocks

Topsail Intrusive Suite

Humber Arm Allochthon

Fleur de Lys rift facies clastics, amphib grade
(Humber Zone)

Grenville mafic intrusions

Granitoid Associations

St. Lawrence Association Granitoids

Ackley Association (negatives)

Ackley Association (positives)

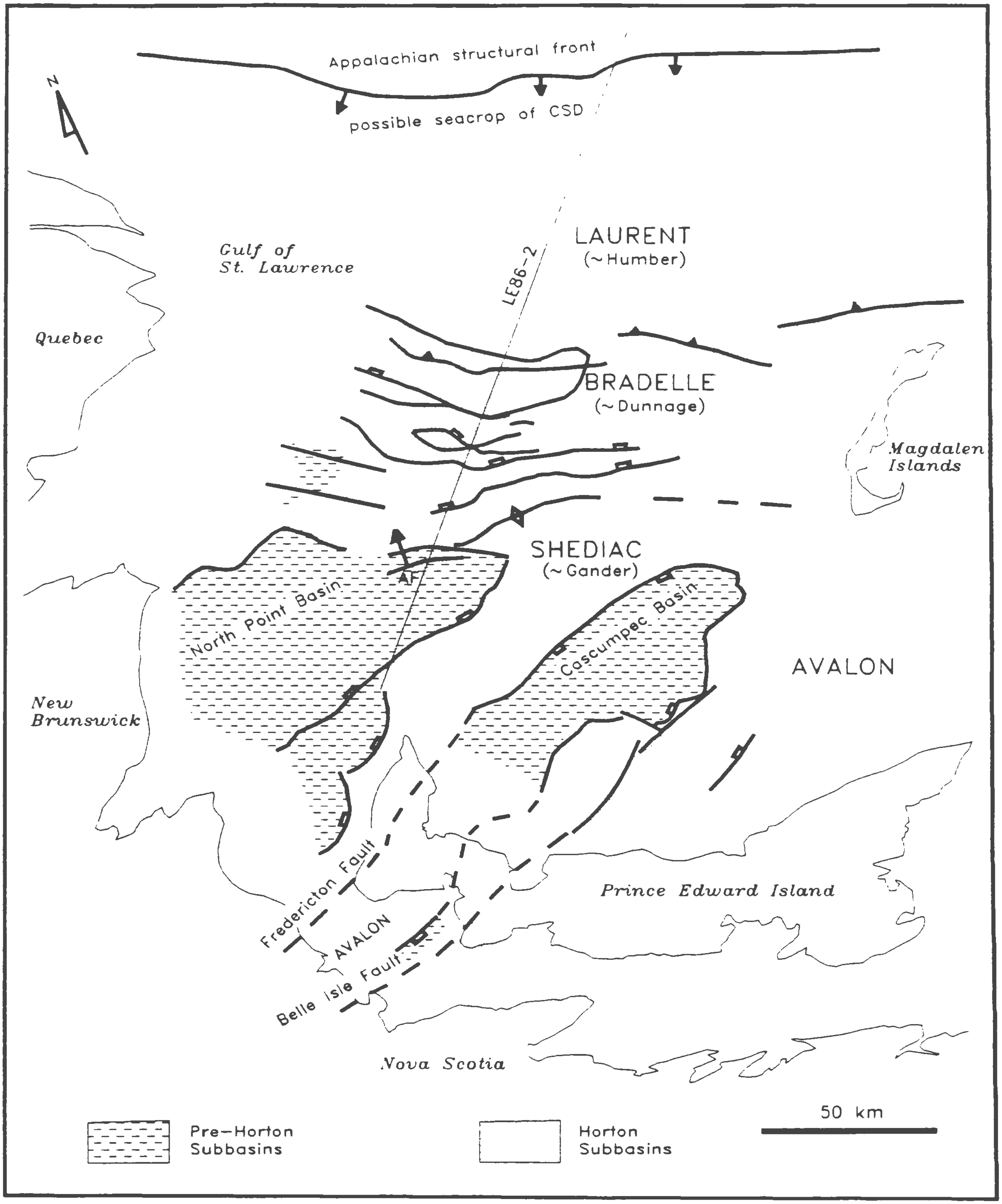
Mt. Peyton Association (transitional)

Middle Ridge Association (SPAMB, S-type)

Figure VI.4 (in pocket): Compilation map of Cape Breton Island geology, principally after Barr et al.(1990), Lynch et al. (1994), Kelley (1967) and Currie (1977).

VII.1 (in pocket): Conceptual crustal profiles, plate/terrane configurations, and paleogeography of the St. Lawrence Promontory at 380 Ma (Mid-Devonian). This map portrays late orogenic and post-orogenic events of the early to middle Devonian, and the configuration of terranes prior to the onset of strike-slip in the early Carboniferous, but also shows the incipient development of events that persist into the late Devonian, such as the formation of Horton basins, which are shown in yellow. Numbers associated with plutons indicate epsilon-Nd values. See Chapter VII for detailed discussion. The legend for this series of maps is contained on page 313. Commentary on sources and nature of information is contained in Table II.

VII.2 Mid-Devonian (Pre-Horton and Horton) basin development in the western and central Gulf of St. Lawrence, as mapped by Durling and Marillier (1990), with interpretation of a crustal scale detachment (CSD) and antithetic fault (AF), seen on LITHOPROBE EAST line 86-2, which controlled the basin development.


Appalachian structural front
possible seacrop of CSD
N
Gulf of St. Lawrence
Quebec
LE86-2
LAURENT
(~Humber)
BRADELLE
(~Dunnage)
Magdalen Islands
SHEDIAC
(~Gander)
AF
North Point Basin
Cascumpec Basin
AVALON
New Brunswick
Fredericton Fault
AVALON
Belle Isle Fault
Prince Edward Island
Nova Scotia
Pre-Horton Subbasins
Horton Subbasins
50 km

VII.3 Comparison of similar crustal structure on deep seismic lines from the Gulf of St. Lawrence and the Basin and Range Province. **Below**: Variation on Durling and Marillier's (1990) Interpretation of LE86-2 to show a crustal scale detachment (CSD) with associated antithetic faulting (AF), above which pre-Horton and Horton basins were localized.
Above: Sketch of major features of COCORP 40°N transect between 112° and 115°W in the Basin and Range of Nevada and Utah, after Allmendinger et al., 1987 and Hauser et al., 1987. The Sevier Desert Detachment (SDD) is interpreted as a crust-penetrating Tertiary extensional structure which reactivated an earlier Laramide contractional thrust plane. A deep antithetic fault, the Schell Creek fault (SCF), also appears to be an important control in the placement of the basins. At the modern surface, basins with sediments and volcanics are separated by extensional faults from ridges, often formed by metamorphic core complexes, which have been exhumed as extensional allochthons from mid-crustal levels (e.g., Wernicke, 1985).

The two areas are remarkably similar in terms of their position along major sutures within the orogen, scales, and location of basins in reference to deep crustal structure, suggesting that Horton and pre-Horton basins are syn-to post-orogenic terrestrial basins formed by extensional collapse.

Basin patterns as in Figure VII.2.

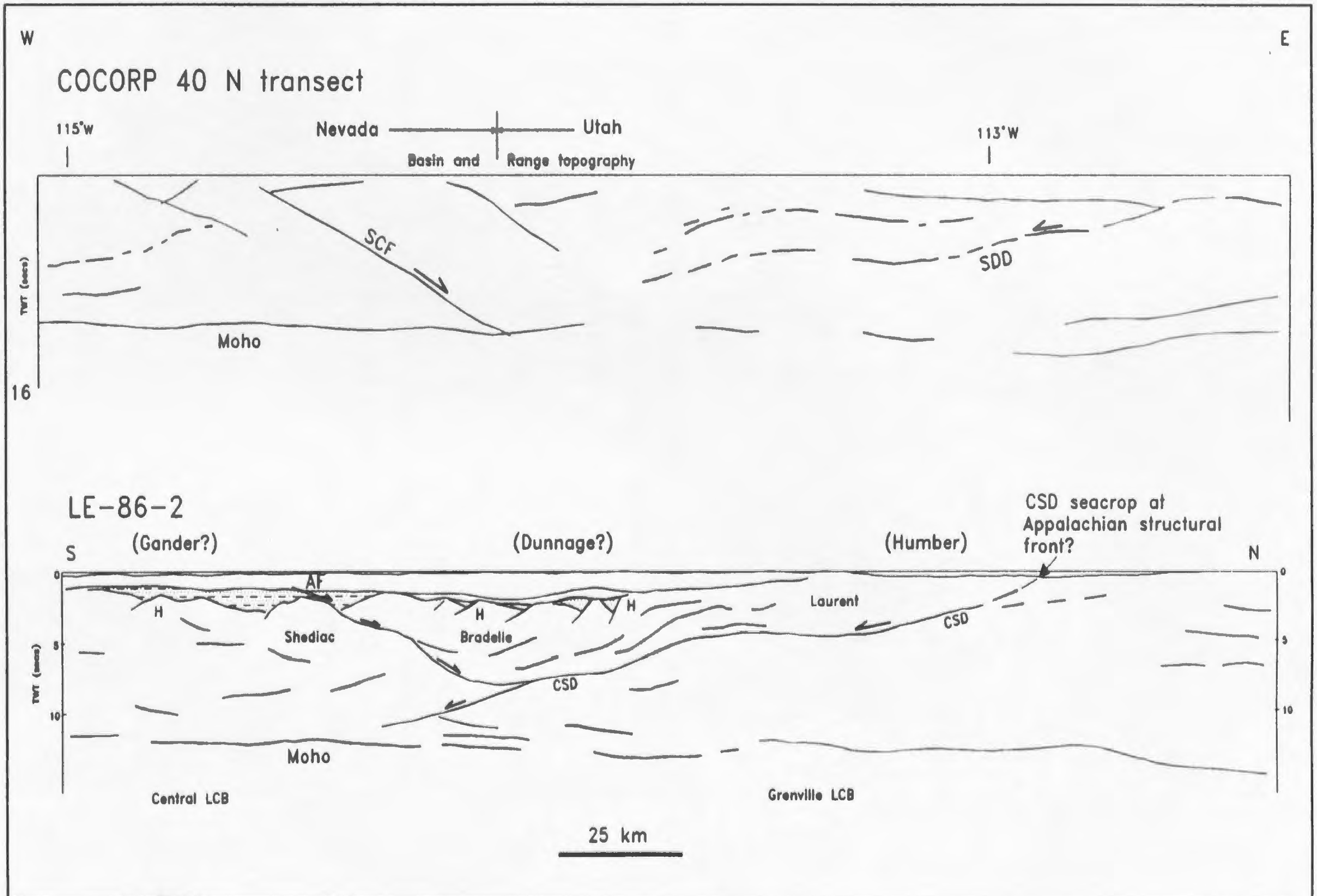

W
E
COCORP 40 N transect
115°W
Nevada
Utah
113°W
Basin and
Range topography
SCF
SDD
TWT (secs)
Moho
16
LE-86-2
(Gander?)
(Dunnage?)
(Humber)
CSD seacrop at Appalachian structural front?
S
N
AF
H
Shediac
Bradelle
Laurent
CSD
Moho
Central LCB
Grenville LCB
25 km

Figure VIII.1 (in pocket): Conceptual crustal profiles, plate/terrane configurations, and paleogeography of the St. Lawrence Promontory at 320 Ma (End Namurian). This map portrays the results of major lateral offset in the early Carboniferous, and relates both transtensional events of the Tournaisian and Viséan and transpressional events of the Namurian to this strike-slip motion. The former group of events include the formation of the Bay St. George half-graben and Deer Lake Basin, as well as the regional Viséan marine transgression, while the latter events include compression at restraining bends (St. Paul Island), basin inversion (Anguille Mountains), and detachment in base Windsor carbonates and evaporites (Ainslie Detachment). See Chapter VIII for detailed discussion. The legend is found on page 313, and commentary on sources and nature of information is contained in Table II.

Figure VIII.2: Diagram illustrating the relationship between the shift to a higher degree of convergence in Namurian time, consequent tectonic extrusion, and ongoing development of the Deer Lake and Sydney Basins.

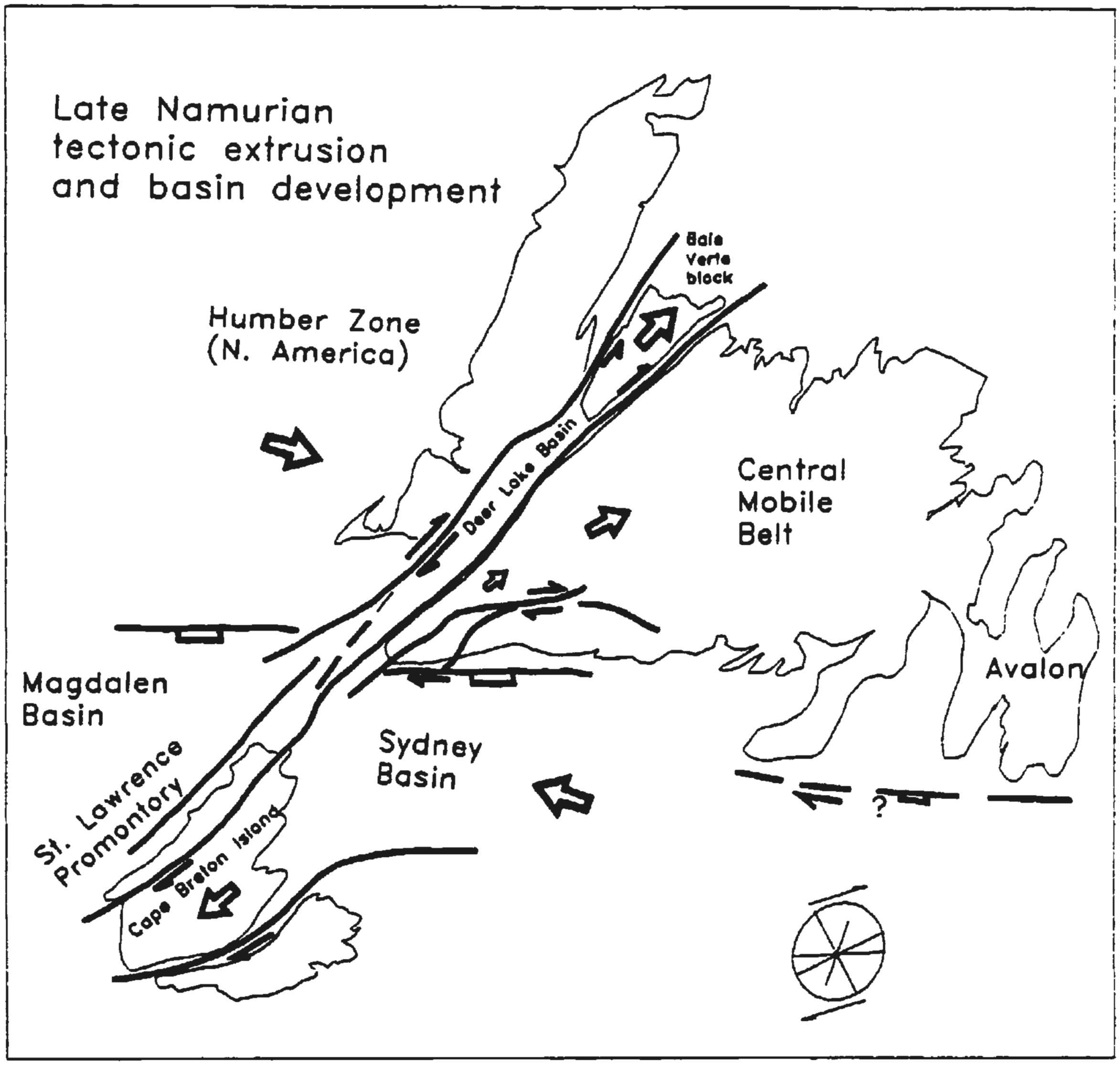

Late Namurian
tectonic extrusion
and basin development
Humber Zone
(N. America)
Baie
Verte
block
Deer Lake Basin
Central
Mobile
Belt
Magdalen
Basin
Avalon
Sydney
Basin
St. Lawrence
Promontory
Cape Breton Island
?

Figure VIII.3: Sketch illustrating possible generation of east-west faults as a result of collision of St. Lawrence Promontory with irregular Cabot Promontory. Regularly-spaced east-west fracture patterns were recognized from detailed potential field modelling of Carboniferous strata by Kilfoil (1988) and Miller et al.(1990).

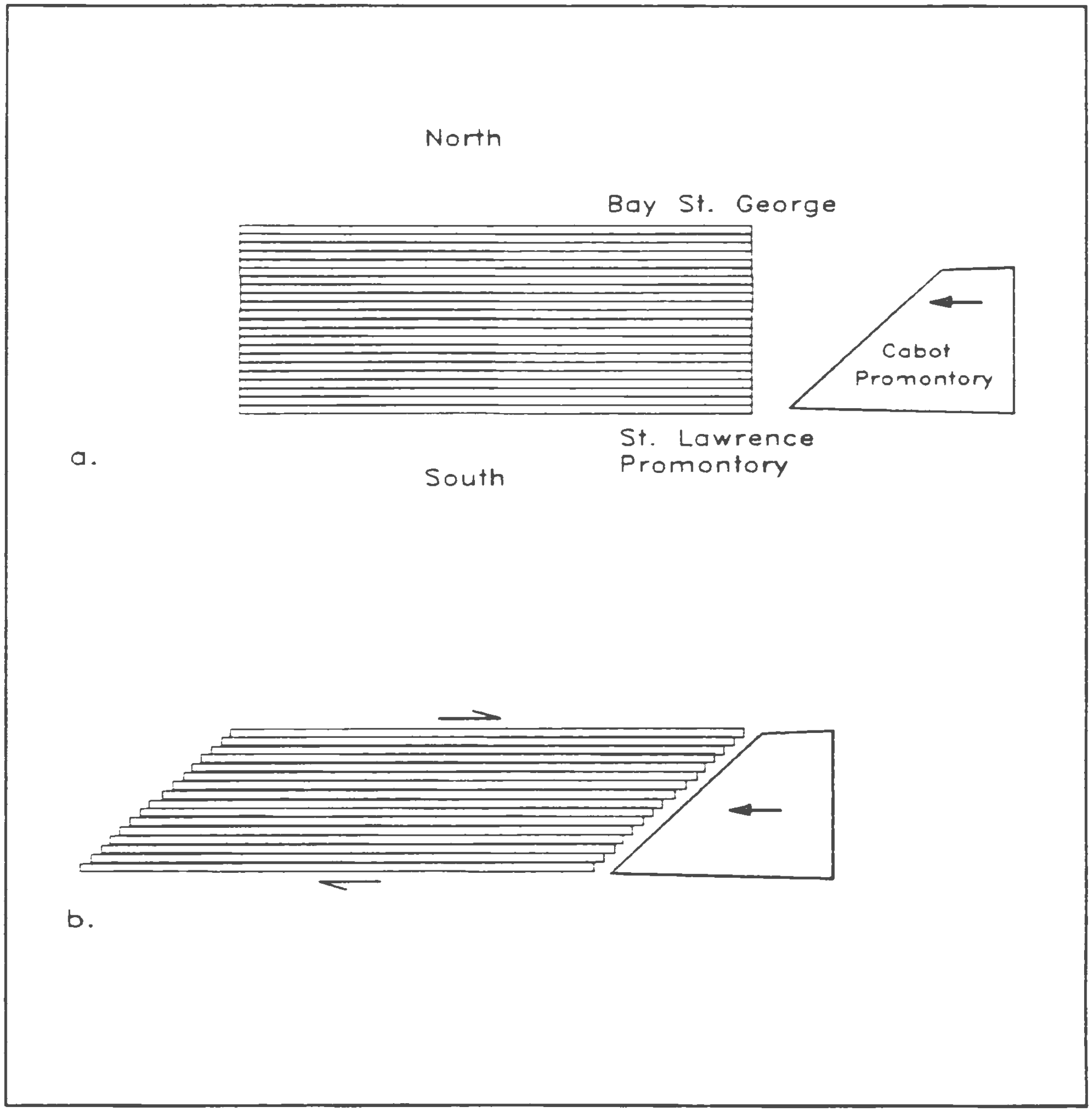

North
Bay St. George
Cabot
Promontory
St. Lawrence
Promontory
a.
South
b.

Figure IX.1 (in pocket): Paleogeographic reconstruction of the St. Lawrence Promontory at 275 Ma (Early Permian). This map shows the final position of the terranes after major Carboniferous strike-slip; most sedimentation during the late Carboniferous and early Permian occurred in alluvial basins which gradually became overfilled and then eroded. A transgressive episode in the Westphalian resulted in the flooding of low-lying coastal plain areas and coal swamps by shallow marine waters. See Chapter IX for detailed discussion.

Figure X.1: Outlines of Silurian paleogeographic reconstructions of Ziegler (1989) and Soper and Hutton (1984), illustrating main differences with reconstructions of this thesis. Ziegler's reconstruction for the Pridoli assumes large amounts of Devonian sinistral strike-slip along the Great Glen Fault (GGF) and associated faults, to displace Newfoundland from northern Britain, which is already assembled. Soper and Hutton's reconstruction is considered more accurate as it treats Avalonia and Cadomia (equivalent to West and East Avalonia in this work) as large terranes emplaced by oblique-sinistral motion. This thesis treats the late Silurian to early Devonian development of the northeastern Appalachians as a gradual buildup of accreted terranes by sinistral shear.

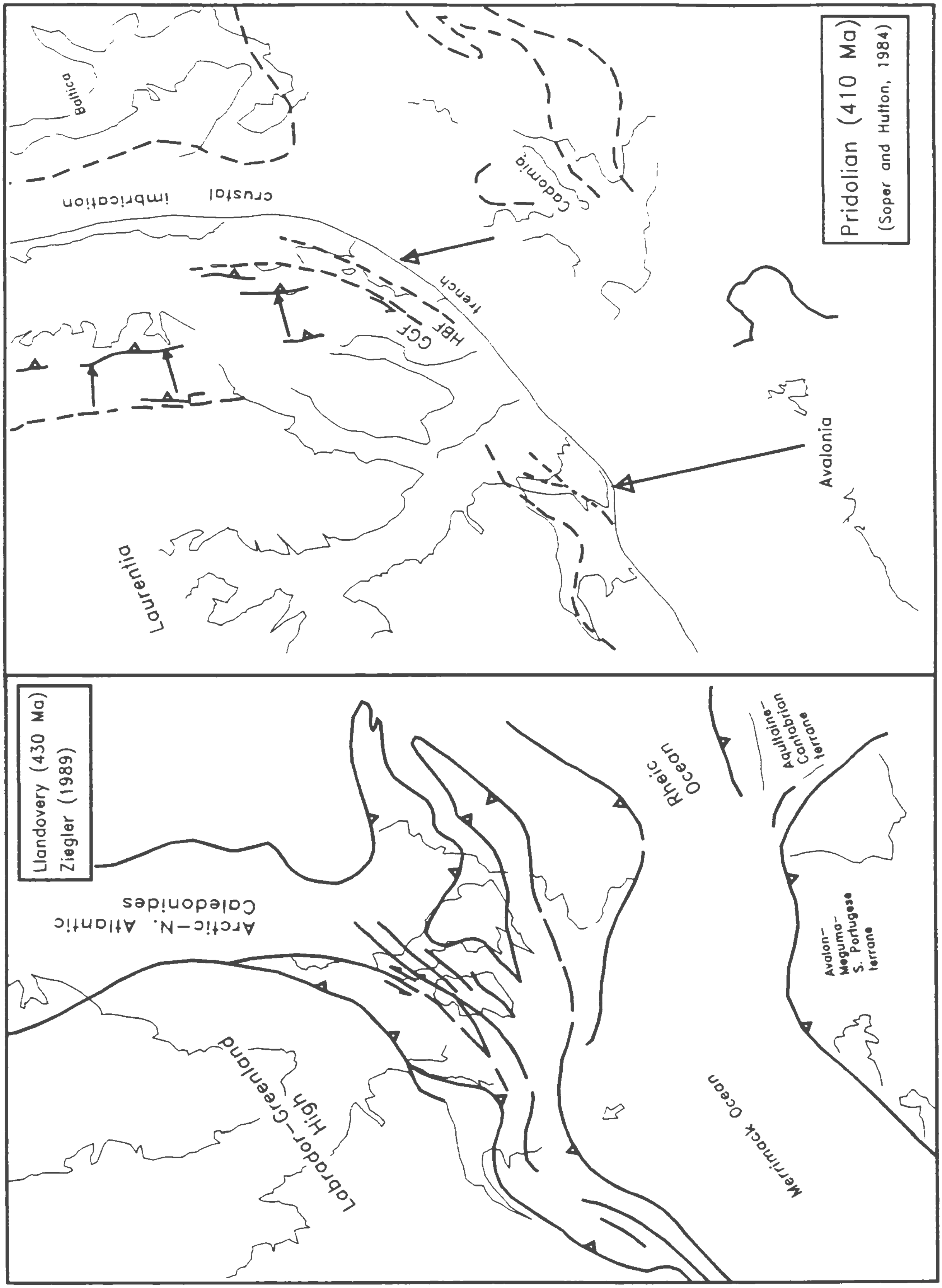
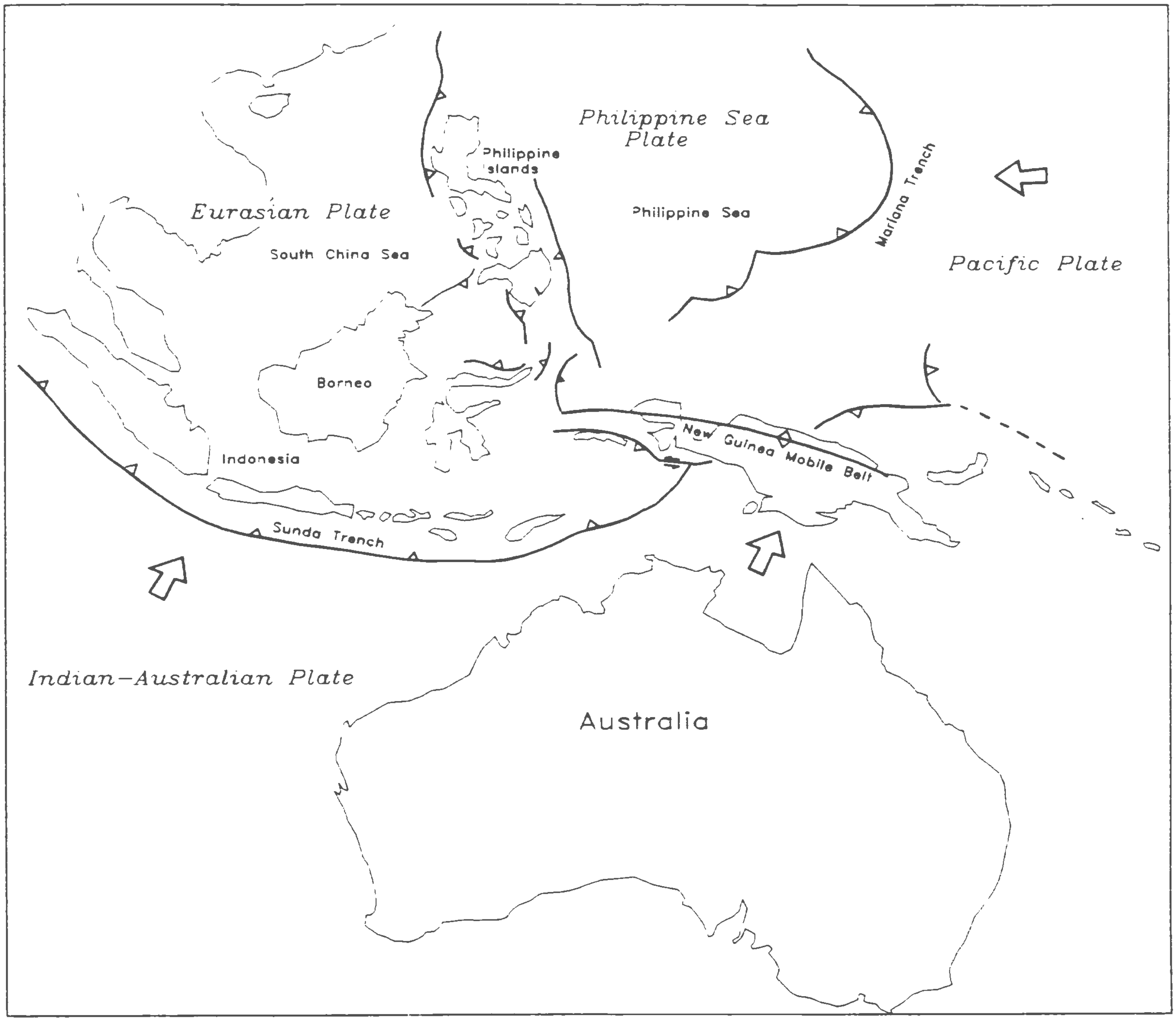
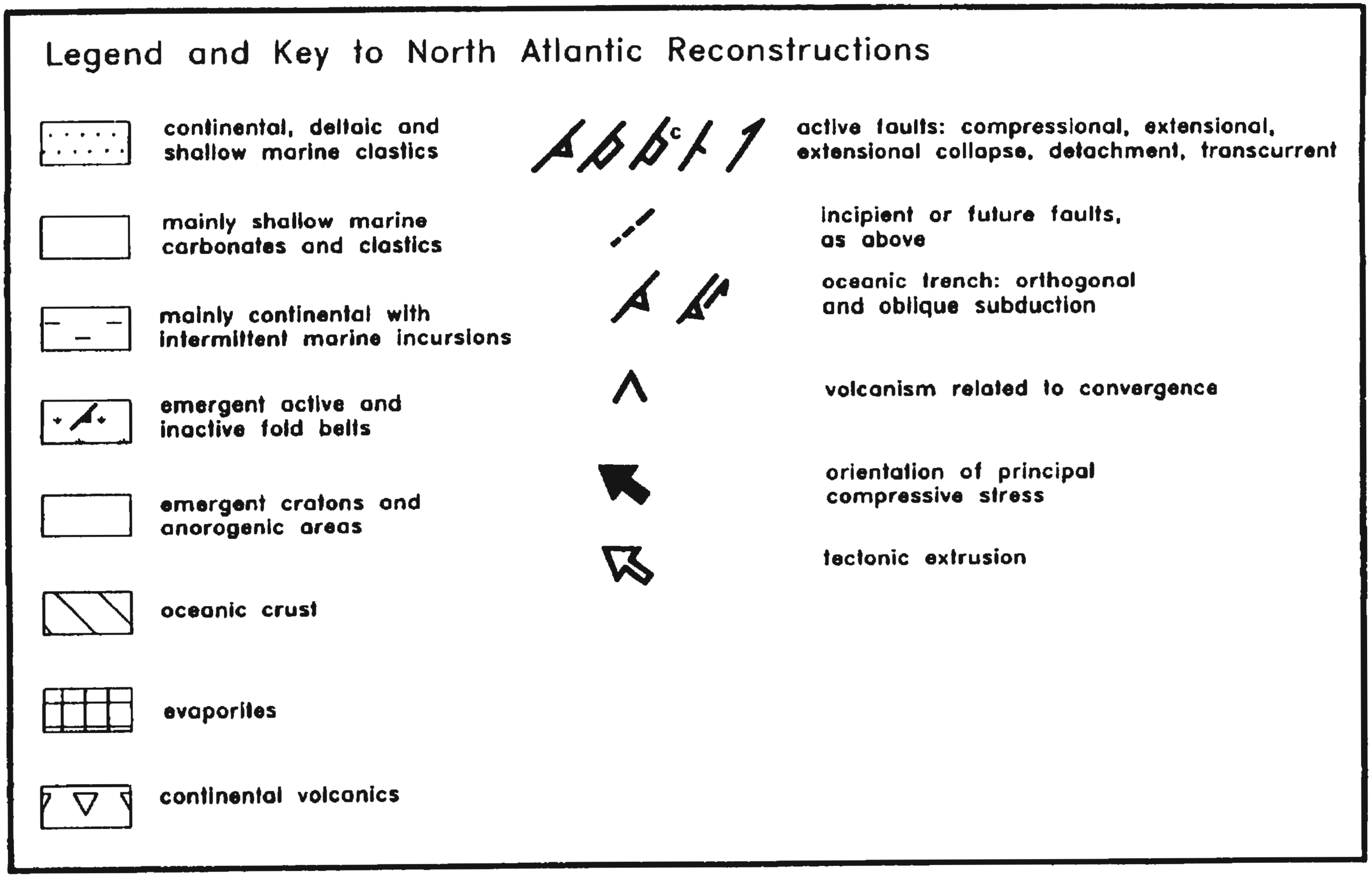

Pridolian (410 Ma)
(Soper and Hutton, 1984)
Baltica
crustal imbrication
Cadomia
trench
HBF
GGF
Avalonia
Laurentia
Llandovery (430 Ma)
Ziegler (1989)
Arctic–N. Atlantic
Caledonides
Labrador–Greenland
High
Rheic
Ocean
Aquitaine–
Cantabrian
terrane
Avalon–
Meguma–
S. Portugese
terrane
Merrimack Ocean

Figure X.2: Collision zone between the Indian-Australian, Eurasian and Pacific plates, illustrating the contrasting effects of subduction (Sunda Trench and Indonesian archipelago) and collision (New Guinea Mobile Belt). After Nishiwaki and Uyeda (1983), Uyeda and McCabe (1983) and Stauffer (1985). See discussion in Section X.2.


Philippine Sea
Plate
Philippine
Islands
Eurasian Plate
Philippine Sea
Mariana Trench
South China Sea
Pacific Plate
Borneo
Indonesia
New Guinea Mobile Belt
Sunda Trench
Indian–Australian Plate
Australia

Figures X.3 - X.8 (in pocket): Reconstructions of the North Atlantic borderlands for the Early Ludlow, Earliest Devonian, Middle Devonian, Early Viséan, Late Westphalian and Early Permian. Britain and Scandinavia were reconstructed primarily by combining Soper et al.'s (1992) three plate model for sinistral accretion of the Caledonides, Coward's (1993) tectonic extrusion model for Devonian-Permian modification of northwest Europe, and Ziegler's (1988, 1989) maps depicting the evolution of "Laurussia", which were mainly used to illustrate the position and effects of the Variscan Orogeny.
The northeastern Appalachians are reconstructed from interpretation of available geological and geophysical data, and emphasize terrane accretion as the main mechanism for the Middle Palezoic assembly of Laurentia, and extensional collapse, minor extrusion and Variscan-imposed strike-slip as the main causes of Late Paleozoic overprinting and basin formation. Commentary on sources and nature of information is contained in Table III, and the Legend and Key to North Atlantic Reconstructions is found on page 331.


Legend and Key to North Atlantic Reconstructions
continental, deltaic and shallow marine clastics
mainly shallow marine carbonates and clastics
mainly continental with intermittent marine incursions
emergent active and inactive fold belts
emergent cratons and anorogenic areas
oceanic crust
evaporites
continental volcanics
c
active faults: compressional, extensional, extensional collapse, detachment, transcurrent
incipient or future faults, as above
oceanic trench: orthogonal and oblique subduction
volcanism related to convergence
orientation of principal compressive stress
tectonic extrusion

NOTE TO USERS

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LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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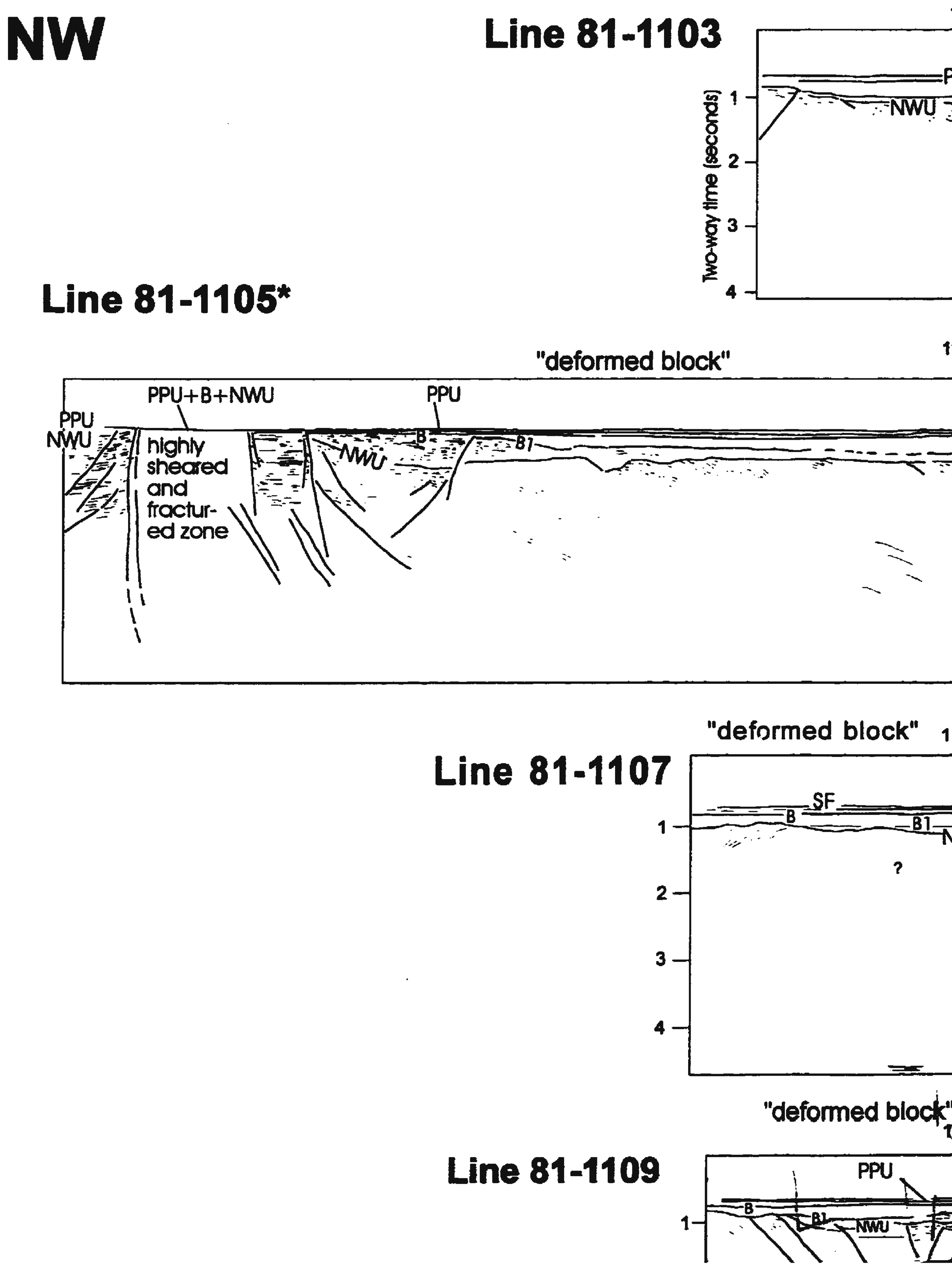
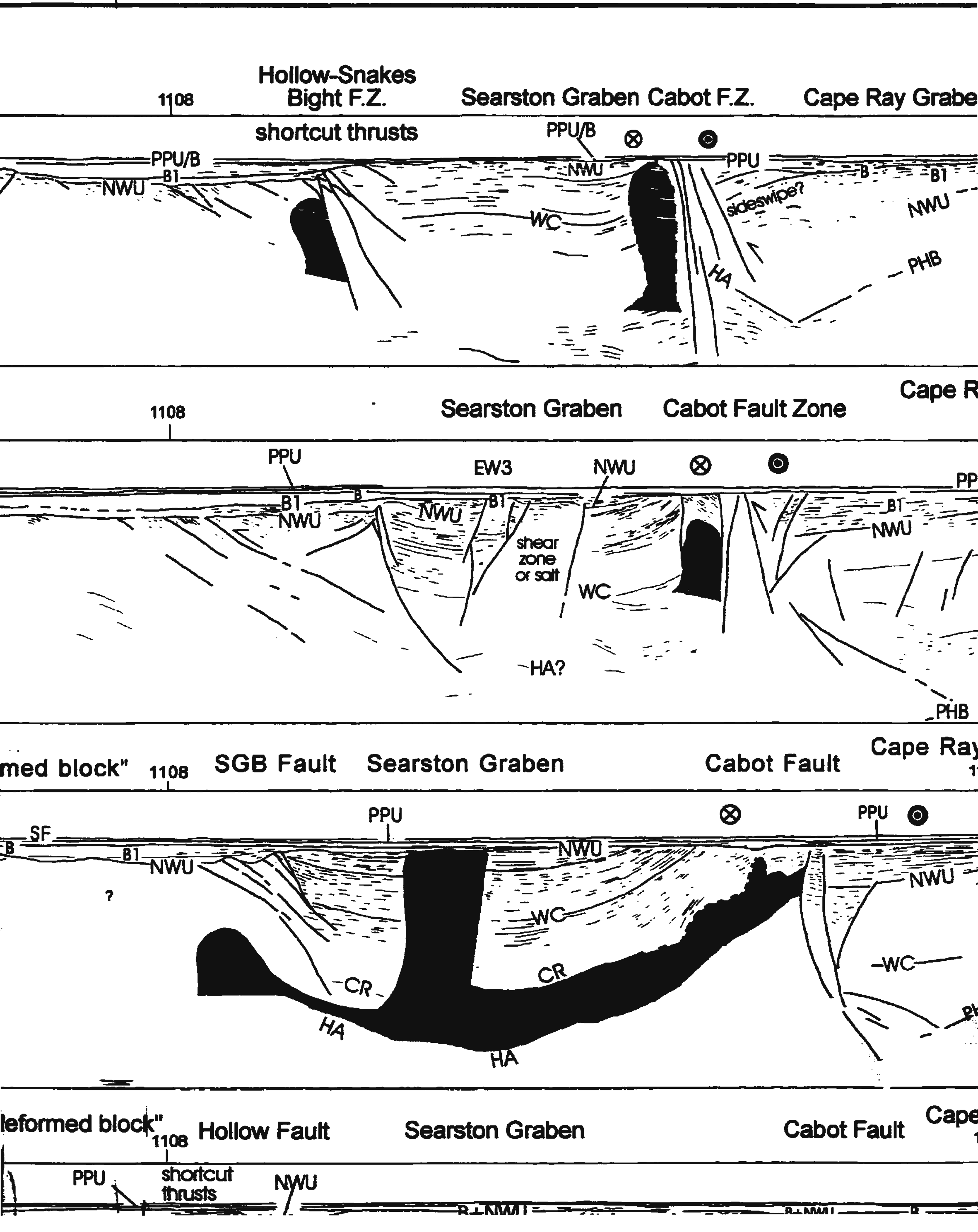
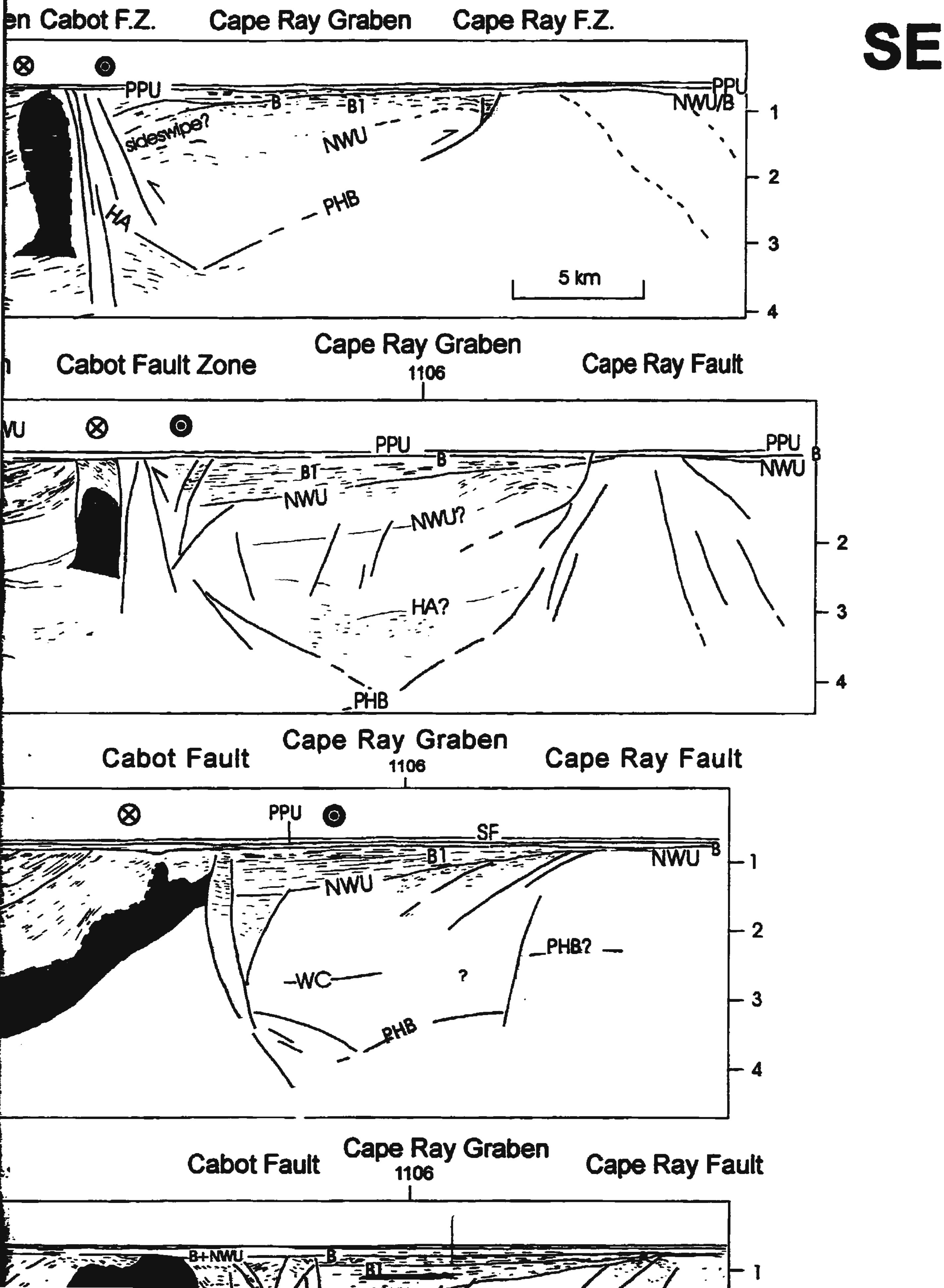
UMI

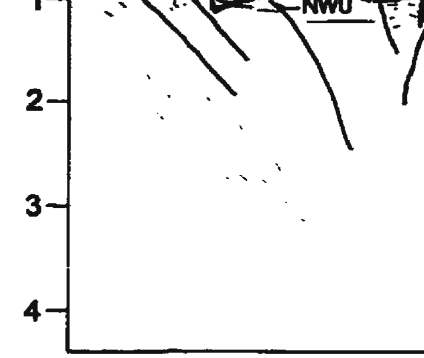

NW
Line 81-1103
Two-way time (seconds)
1
2
3
4
NWU
Line 81-1105*
"deformed block"
PPU+B+NWU
PPU
PPU
NWU
highly sheared and fractur-ed zone
B
NWU
B1
"deformed block"
Line 81-1107
SF
B
B1
1
2
3
4
?
"deformed block"
Line 81-1109
PPU
B
B1
NWU
1



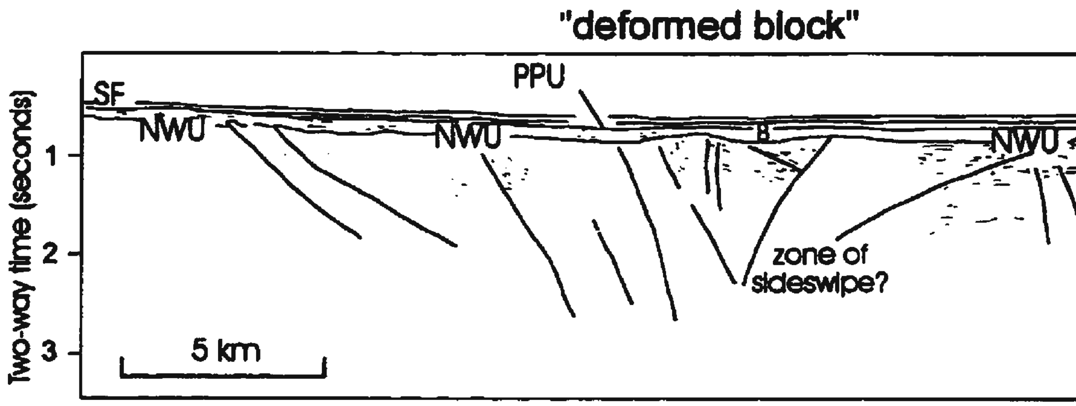
Hollow-Snakes Bight F.Z.
1108
Searston Graben
Cabot F.Z.
Cape Ray Grabe
shortcut thrusts
PPU/B
PPU/B
PPU
B1
NWU
NWU
B
B1
NWU
WC
sideswipe?
HA
PHB
Cape R
1108
Searston Graben
Cabot Fault Zone
PPU
EW3
NWU
PP
B1
B
NWU
NWU
B1
B1
NWU
shear zone or salt
WC
HA?
PHB
med block"
1108
SGB Fault
Searston Graben
Cabot Fault
Cape Ray
PPU
PPU
SF
B
B1
NWU
NWU
NWU
?
WC
WC
CR
CR
HA
HA
leformed block"
1108
Hollow Fault
Searston Graben
Cabot Fault
Cape
PPU
shortcut thrusts
NWU



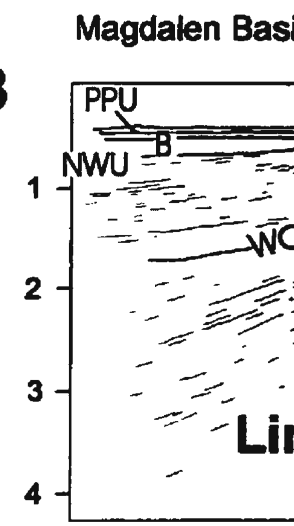
en Cabot F.Z.
Cape Ray Graben
Cape Ray F.Z.
SE
PPU
B
B1
NWU/B
sideswipe?
NWU
PHB
HA
5 km
1
2
3
4
Cabot Fault Zone
Cape Ray Graben
1106
Cape Ray Fault
PPU
B
BT
NWU
NWU?
HA?
PHB
2
3
4
Cabot Fault
Cape Ray Graben
1106
Cape Ray Fault
PPU
SF
B1
NWU
B
PHB?
WC
?
PHB
1
2
3
4
Cabot Fault
Cape Ray Graben
1106
Cape Ray Fault
B+NWU
B
B1
1



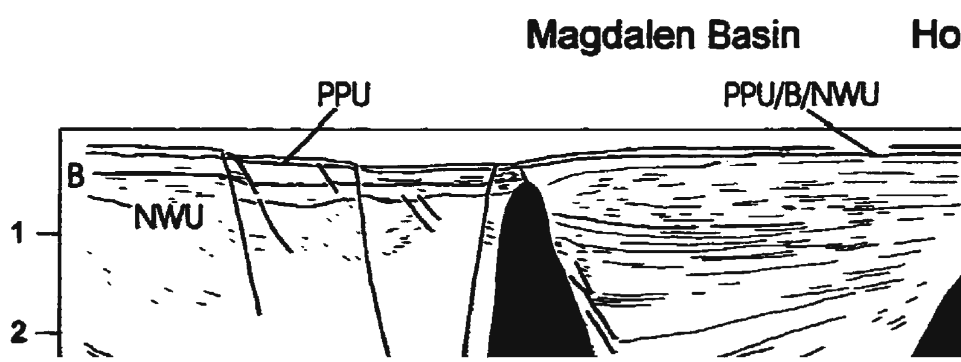
Line 81-1111

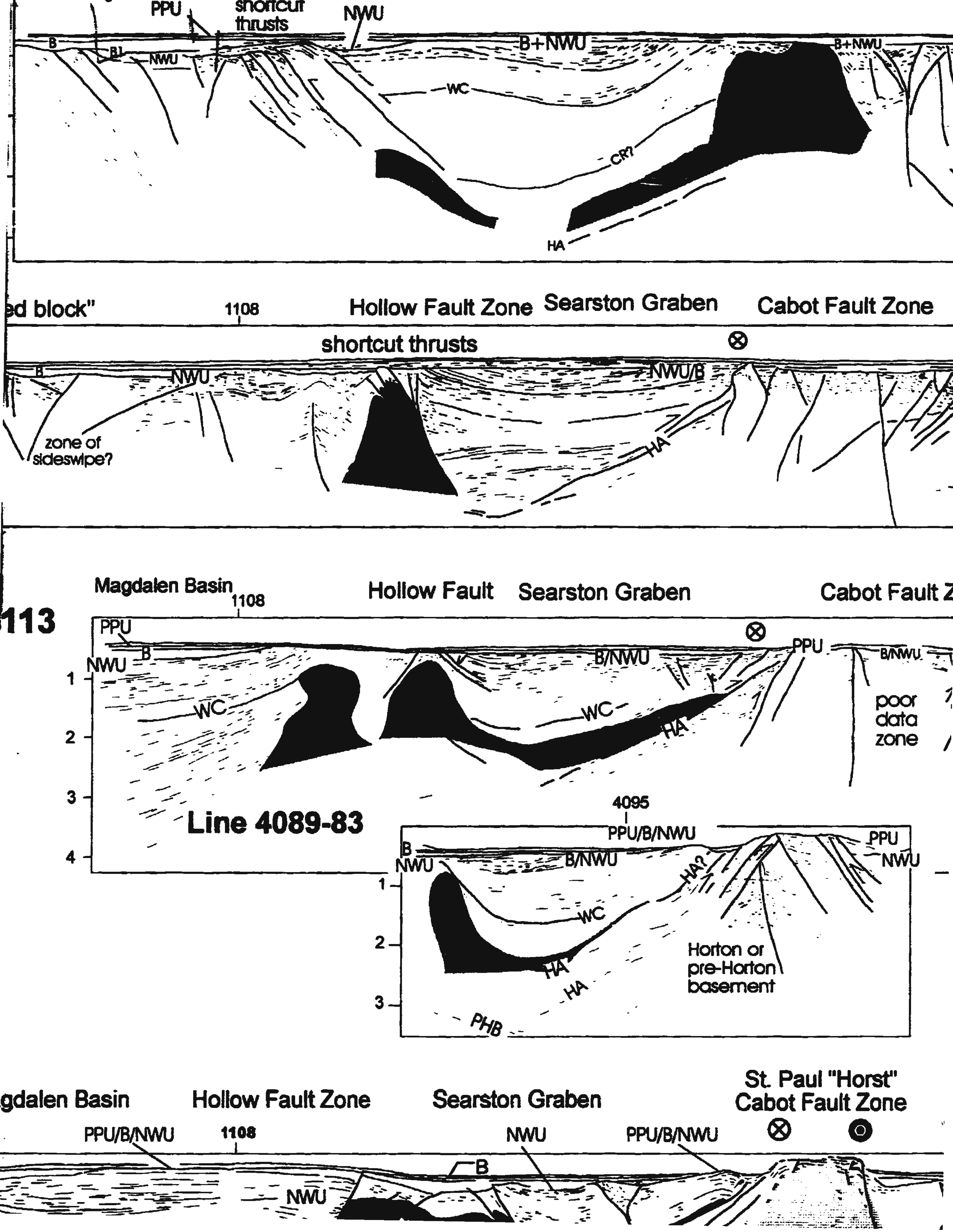


Line 81-1113

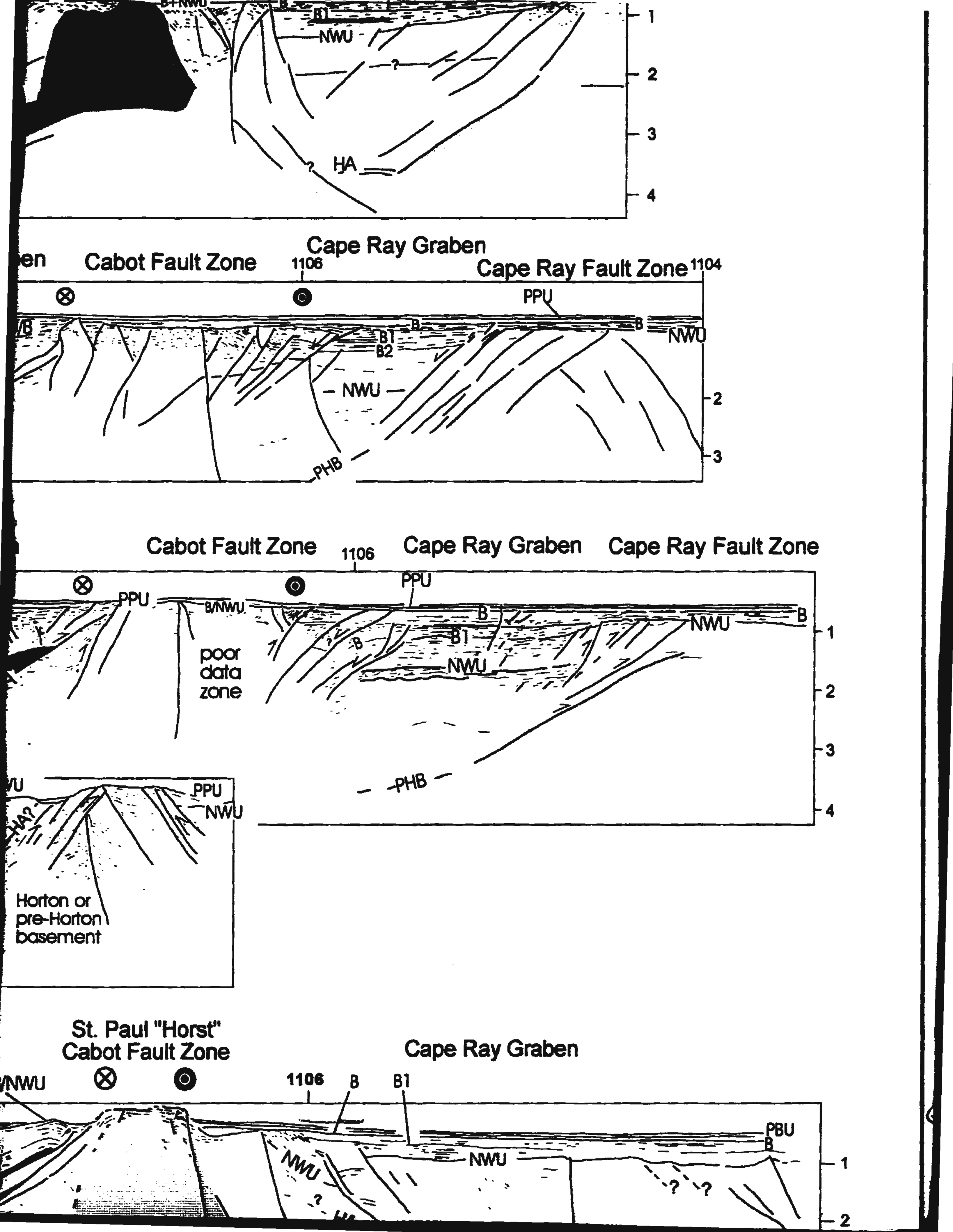


Line 81-1115



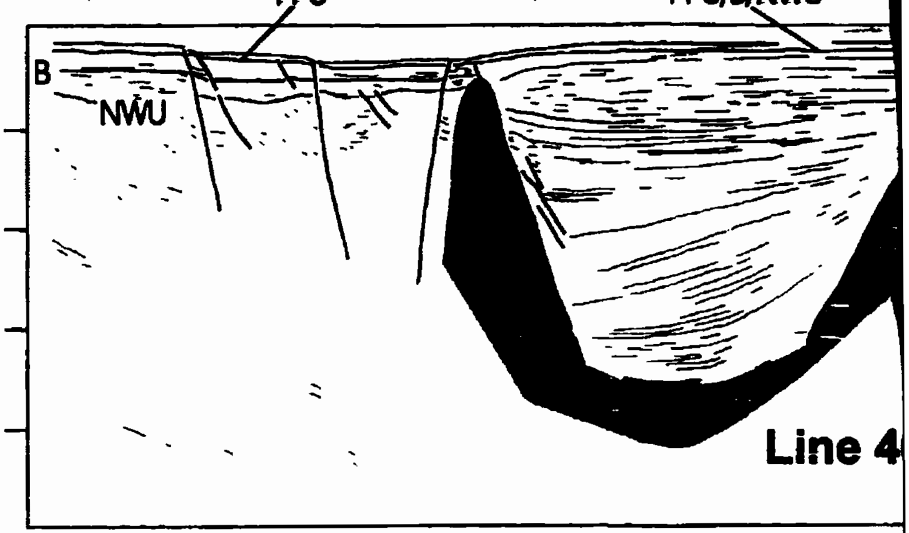


PPU
shortcut thrusts
NWU
B
B1
NWU
B+NWU
B+NWU
WC
CR?
HA
ed block"
1108
Hollow Fault Zone
Searston Graben
Cabot Fault Zone
shortcut thrusts
B
NWU
NWU/B
zone of sideswipe?
HA
Magdalen Basin
1108
Hollow Fault
Searston Graben
Cabot Fault Z
113
PPU
B
NWU
B/NWU
PPU
B/NWU
WC
WC
HA
poor data zone
1
2
3
4
Line 4089-83
4095
PPU/B/NWU
B
NWU
B/NWU
HA?
PPU
NWU
WC
HA
HA
PHB
Horton or pre-Horton basement
1
2
3
gdalen Basin
Hollow Fault Zone
Searston Graben
St. Paul "Horst"
Cabot Fault Zone
PPU/B/NWU
1108
NWU
PPU/B/NWU
B
NWU

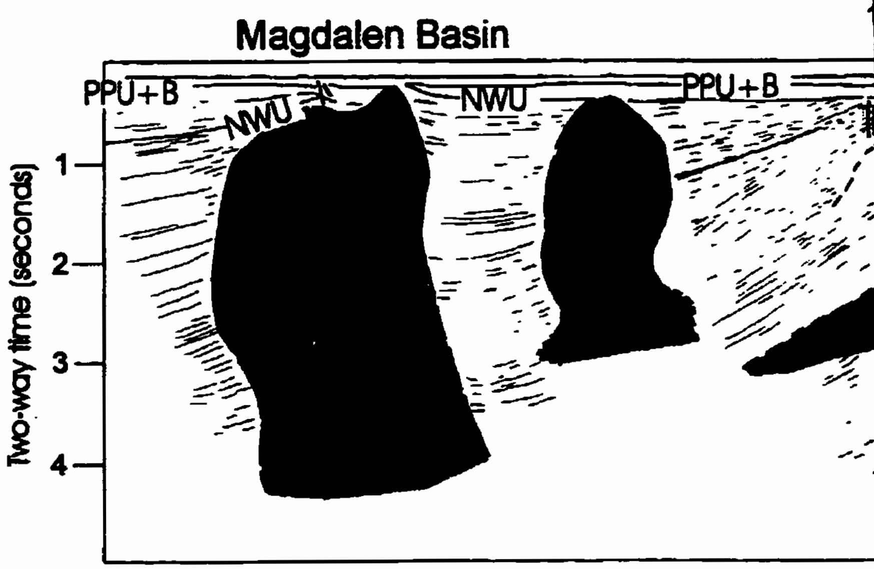


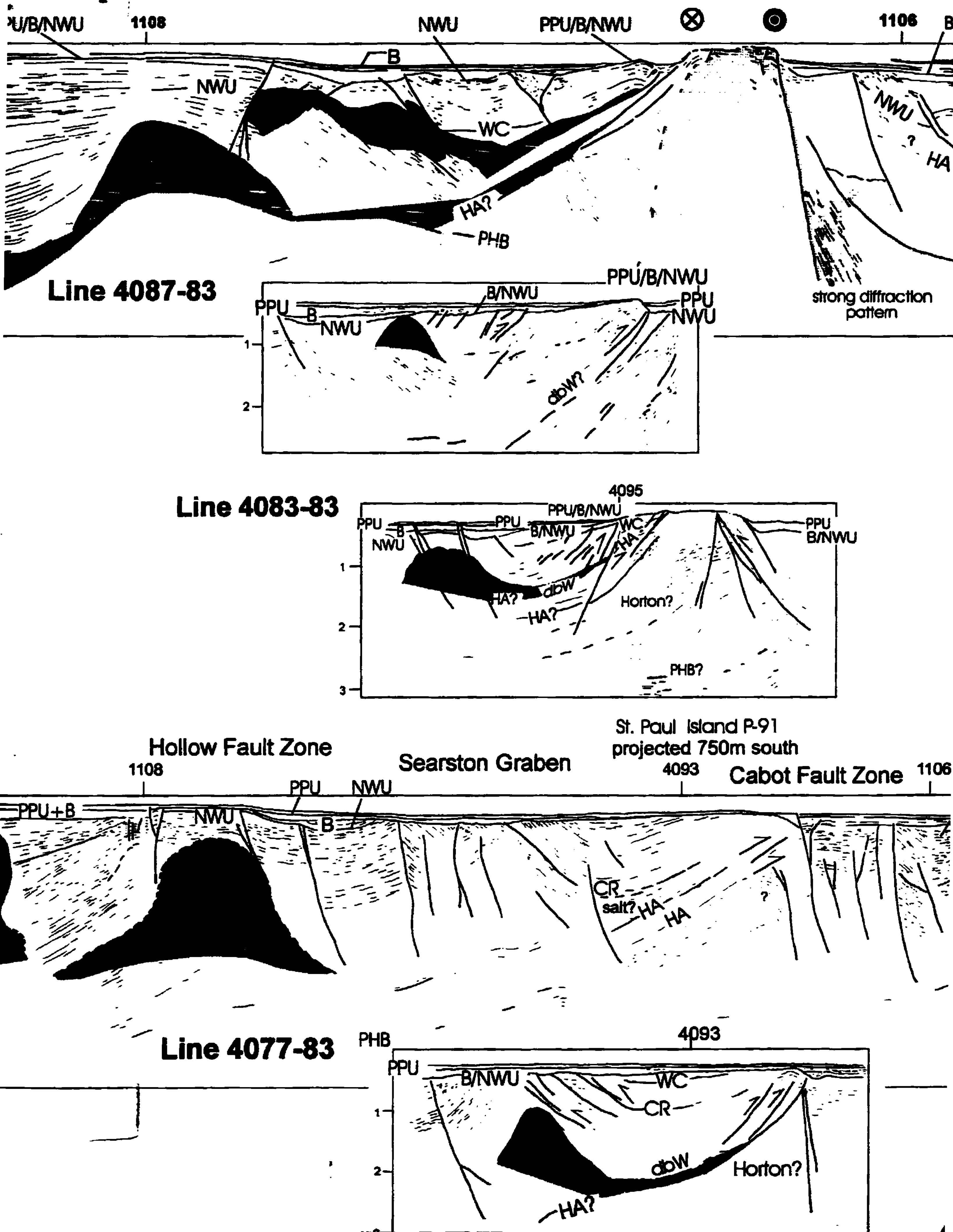
B1
NWU
HA
Cape Ray Graben
Cabot Fault Zone
1106
Cape Ray Fault Zone
1104
PPU
B
B1
B2
NWU
PHB
Cabot Fault Zone
1106
Cape Ray Graben
Cape Ray Fault Zone
PPU
B/NWU
poor data zone
PHB
HA?
Horton or pre-Horton basement
St. Paul "Horst"
Cabot Fault Zone
Cape Ray Graben
1106
PBU

Line 81-1115

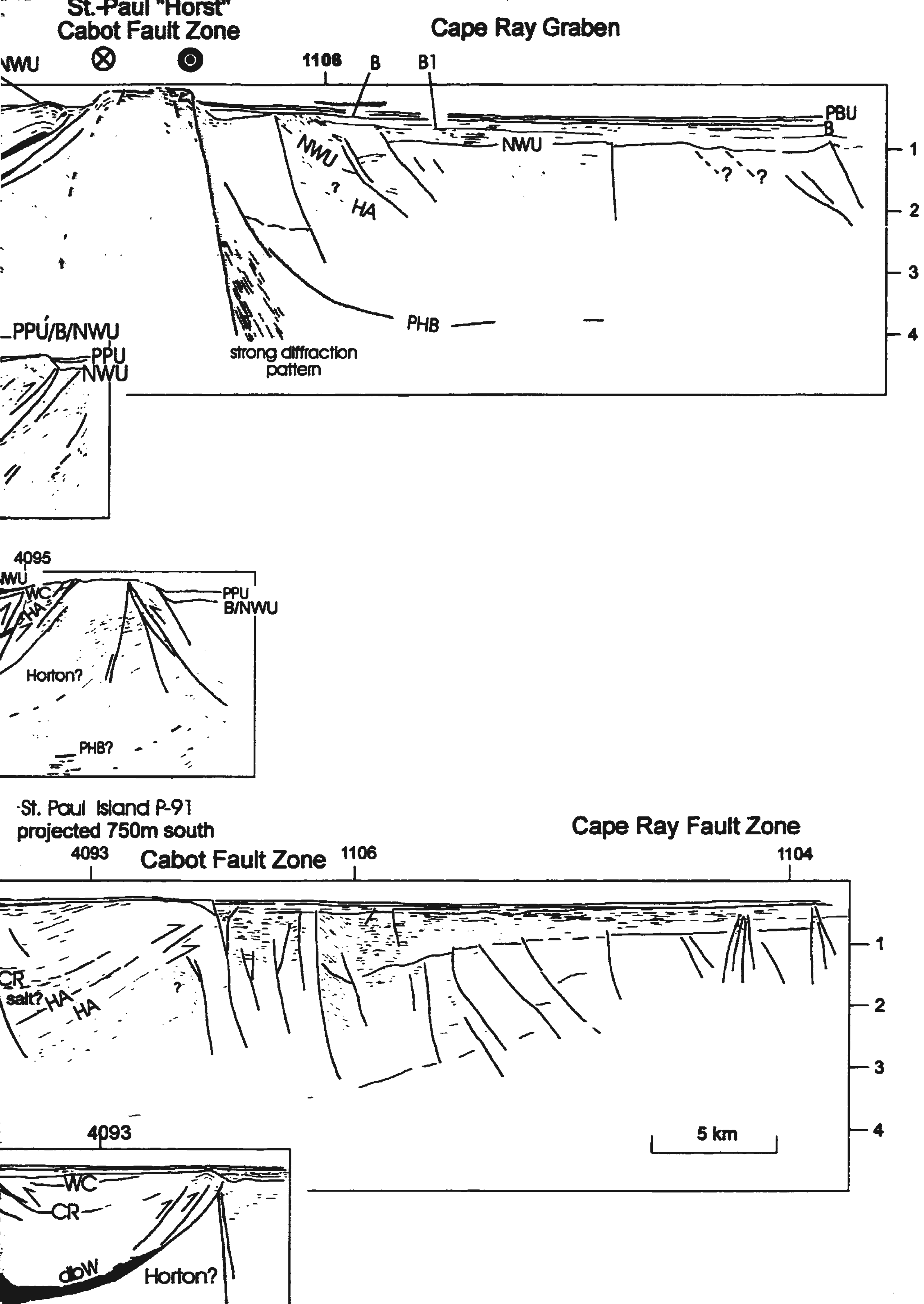


Line 81-1117

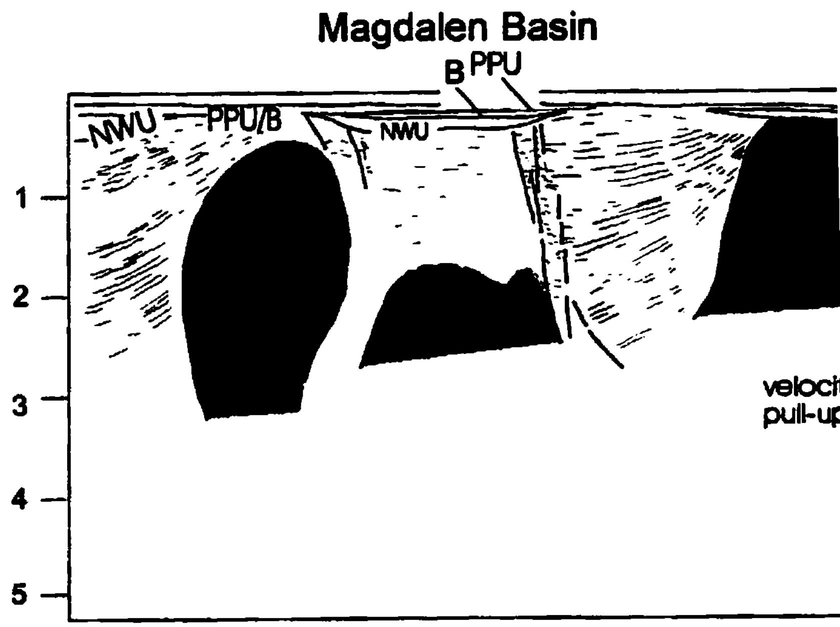




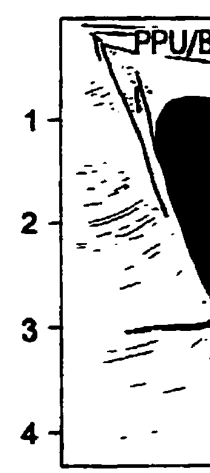
PPU/B/NWU
1108
NWU
PPU/B/NWU
1106
B
NWU
WC
NWU
?
HA
HA?
PHB
Line 4087-83
PPU/B/NWU
B/NWU
PPU
B
NWU
PPU
NWU
dbW?
1
2
strong diffraction pattern
Line 4083-83
4095
PPU/B/NWU
PPU
PPU
B
NWU
B/NWU
WC
HA
PPU
B/NWU
dbW
HA?
HA?
Horton?
PHB?
1
2
3
Hollow Fault Zone
1108
Searston Graben
St. Paul Island P-91
projected 750m south
4093
Cabot Fault Zone
1106
PPU+B
NWU
PPU
NWU
B
CR
salt?
HA
HA
?
Line 4077-83
PHB
4093
PPU
B/NWU
WC
CR
dbW
Horton?
HA?
1
2

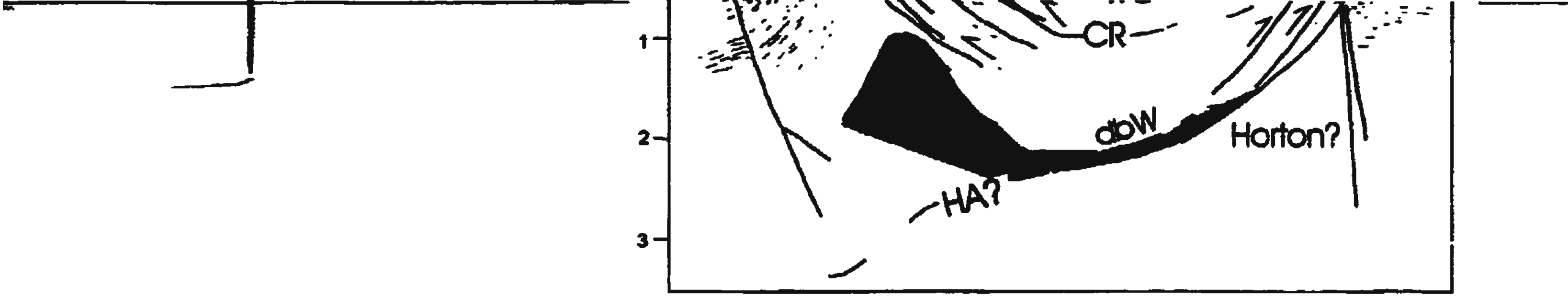

St.-Paul "Horst"
Cabot Fault Zone
Cape Ray Graben
NWU
1106
B
B1
PBU
B
NWU
NWU
?
HA
?
?
1
2
3
4
PHB
strong diffraction
pattern
PPU/B/NWU
PPU
NWU
4095
NWU
WC
HA
PPU
B/NWU
Horton?
PHB?
St. Paul Island P-91
projected 750m south
Cape Ray Fault Zone
4093
Cabot Fault Zone
1106
1104
CR
salt?
HA
HA
?
1
2
3
4
5 km
4093
WC
CR
dbW
Horton?

Line 81-1119



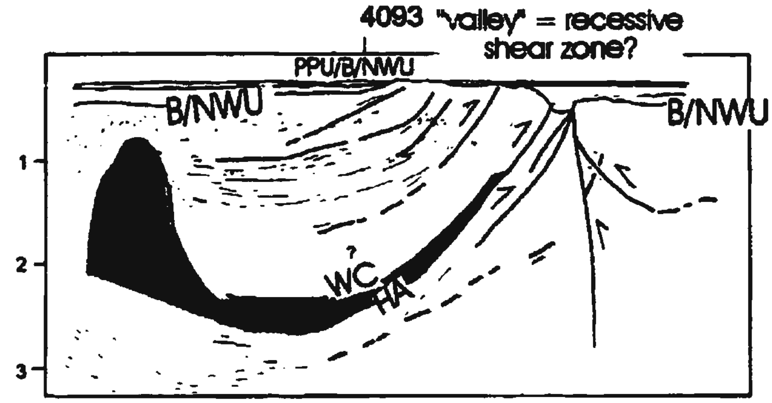
Line 81-1121*



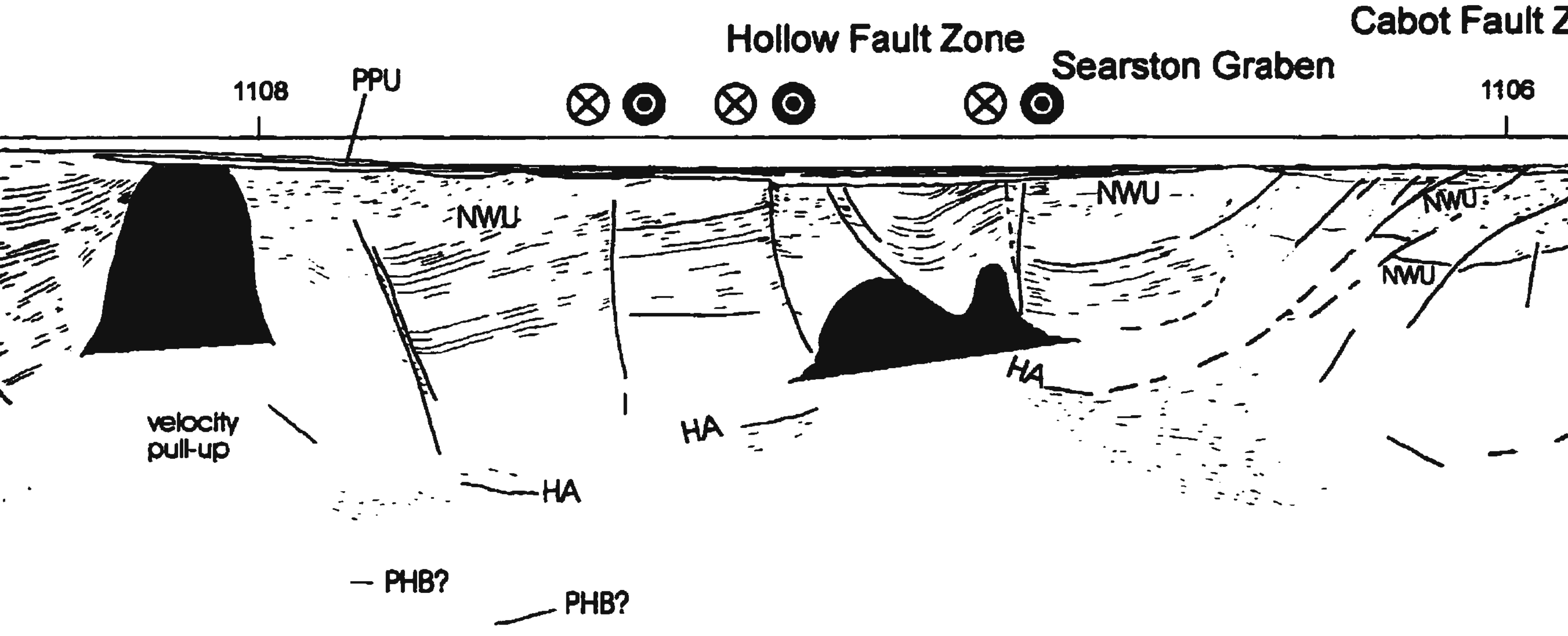


CR
dbW
Horton?
HA?
1
2
3

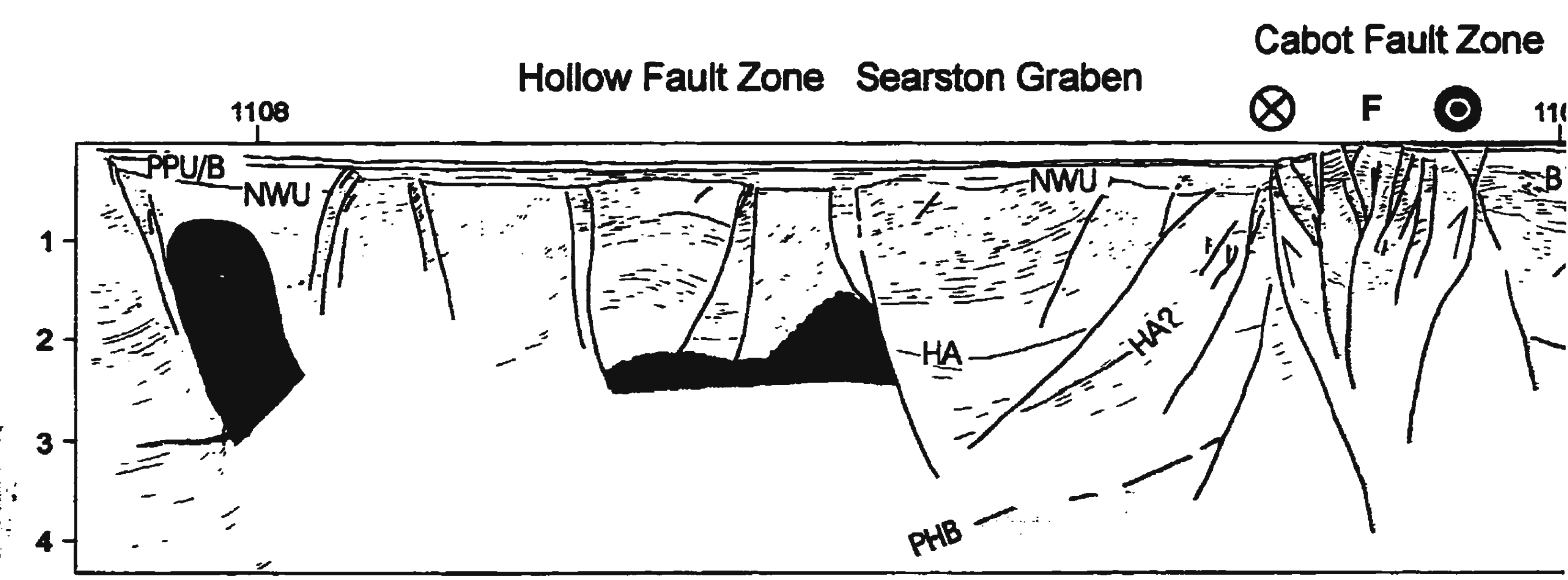
Line 4075-83



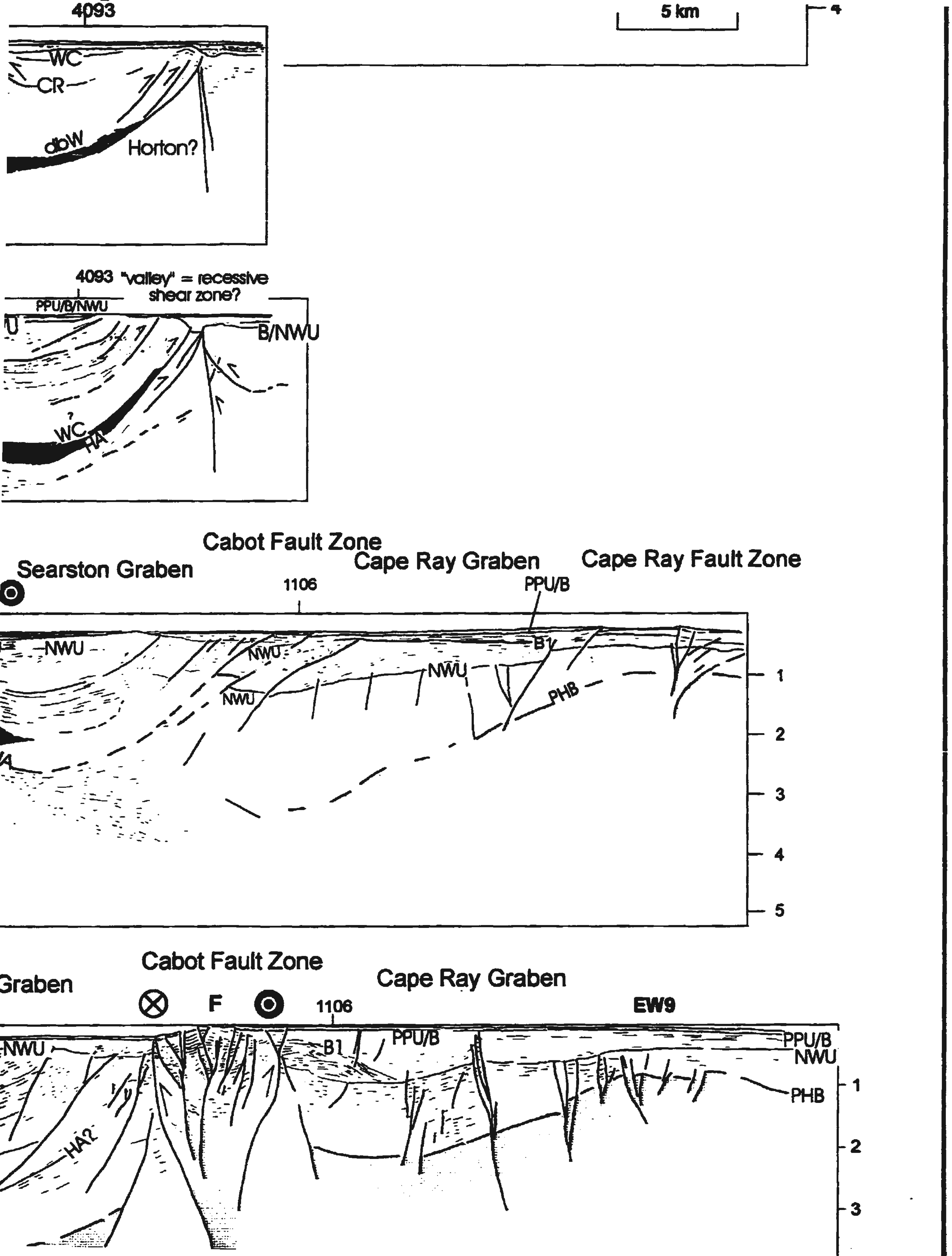
4093 "valley" = recessive shear zone?
PPU/B/NWU
B/NWU
B/NWU
WC
HA
1
2
3



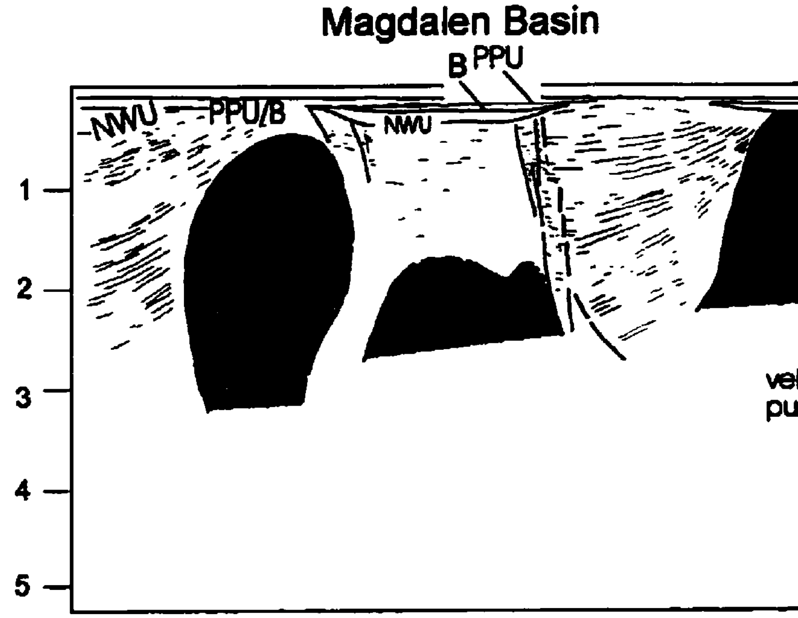
Hollow Fault Zone
Cabot Fault Z
Searston Graben
1108
PPU
1106
NWU
NWU
NWU
NWU
HA
HA
HA
velocity pull-up
PHB?
PHB?



Cabot Fault Zone
Hollow Fault Zone
Searston Graben
F
1108
PPU/B
NWU
NWU
HA
HA?
PHB
1
2
3
4


4093
5 km
WC
CR
dloW
Horton?
4093 "valley" = recessive shear zone?
PPU/B/NWU
B/NWU
WC
HA
Cabot Fault Zone
Searston Graben
Cape Ray Graben
Cape Ray Fault Zone
1106
PPU/B
NWU
B1
PHB
1
2
3
4
5
Cabot Fault Zone
Graben
F
Cape Ray Graben
1106
EW9
PPU/B
NWU
PHB
HA?
B1

Line 81-1119



Line 81-1121*

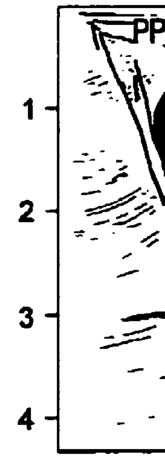
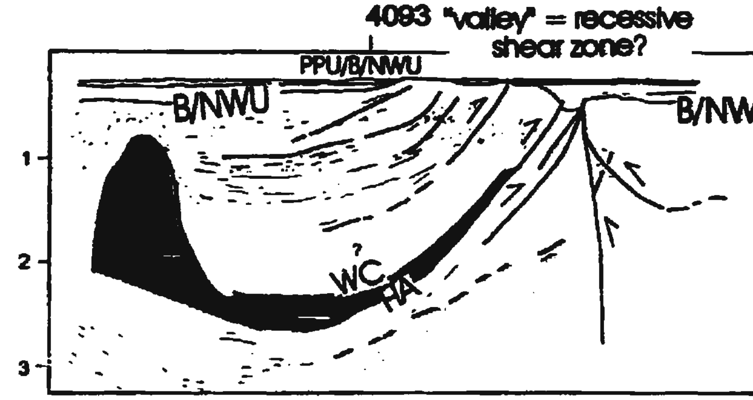
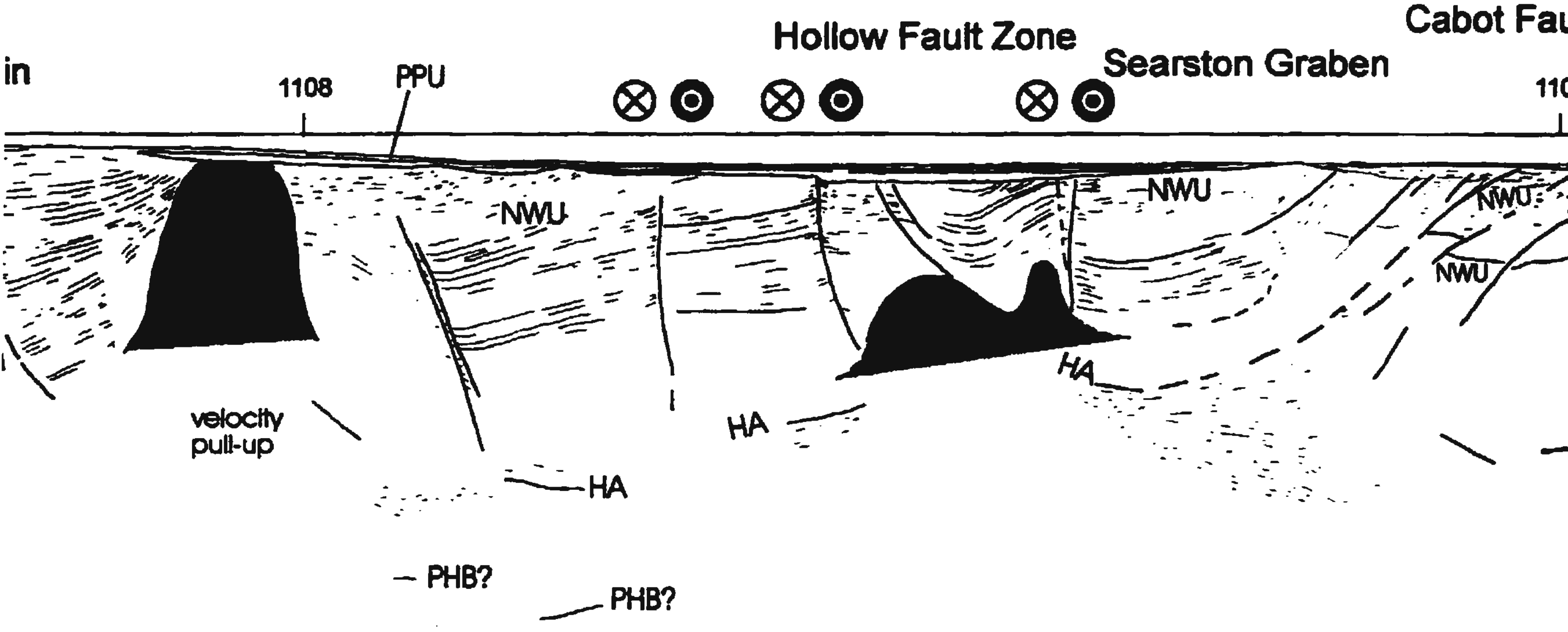
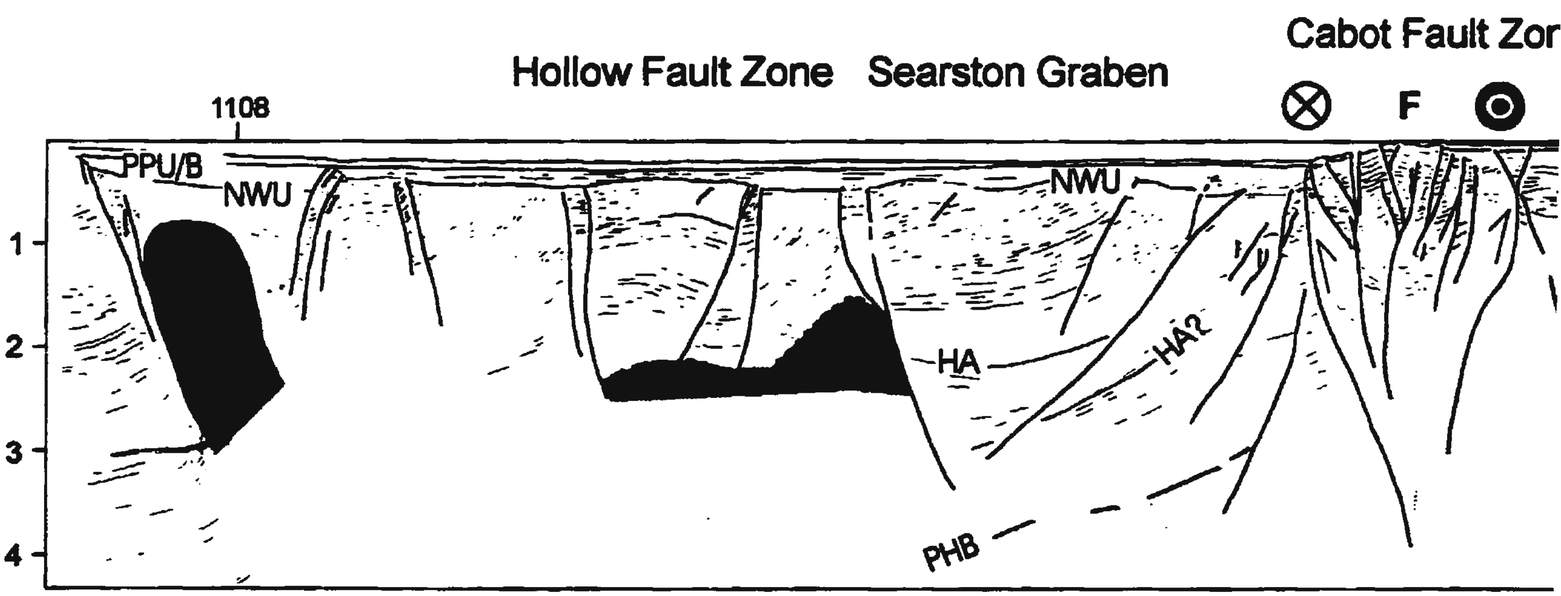


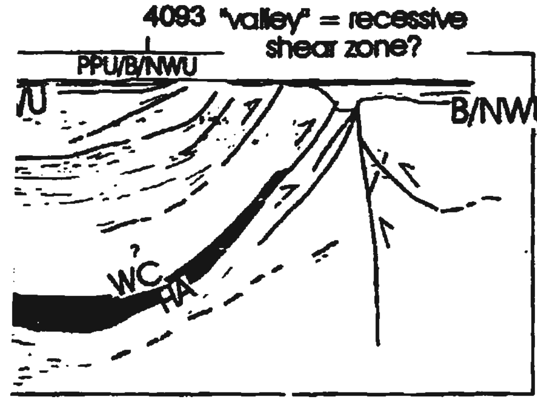
FIGURE II.10a

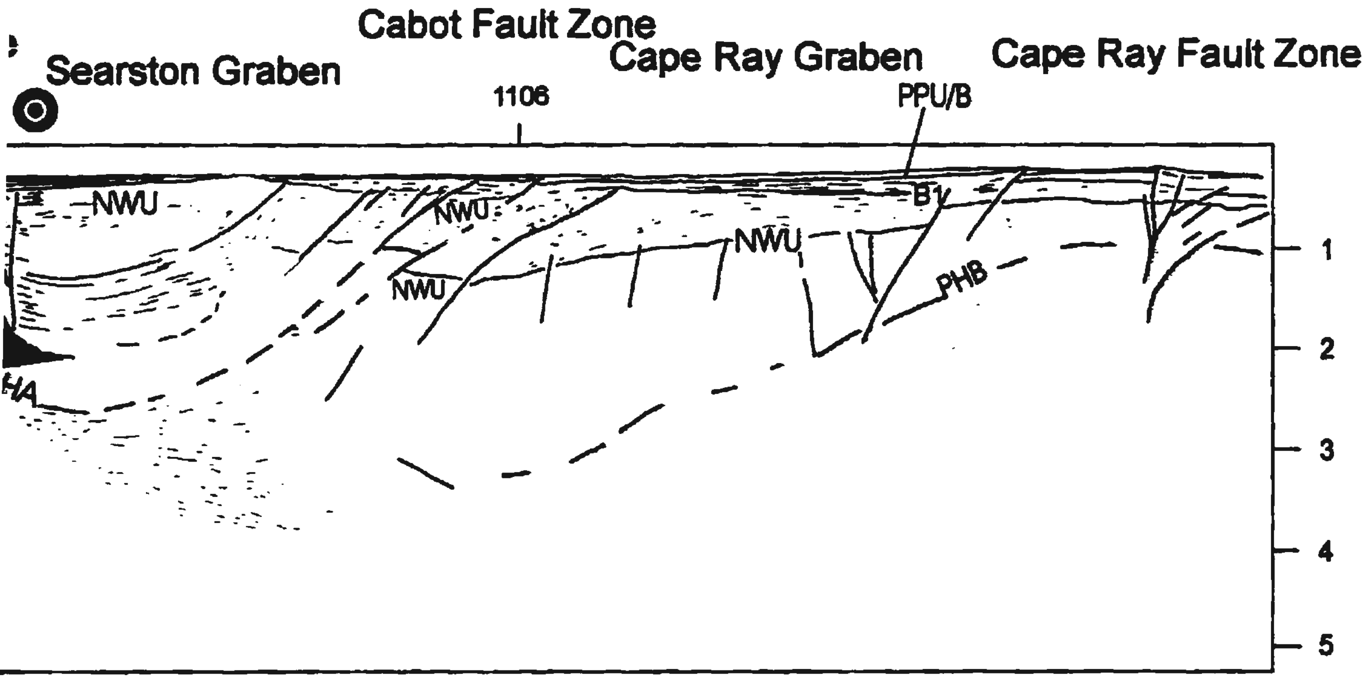
Line 4075-83


4093 "valley" = recessive shear zone?
PPU/B/NWU
B/NWU
B/NW
WC
?
HA
1
2
3


Hollow Fault Zone
Searston Graben
Cabot Fau
in
1108
PPU
110
NWU
NWU
NWU
NWU
HA
HA
HA
velocity pull-up
PHB?
PHB?


Hollow Fault Zone
Searston Graben
Cabot Fault Zor
F
1108
PPU/B
NWU
NWU
HA
HA?
PHB
1
2
3
4


4093 "valley" = recessive shear zone?
PPU/B/NWU
B/NWU
WC
HA


Cabot Fault Zone
Searston Graben
Cape Ray Graben
Cape Ray Fault Zone
1106
PPU/B
NWU
B1
PHB
HA
1
2
3
4
5

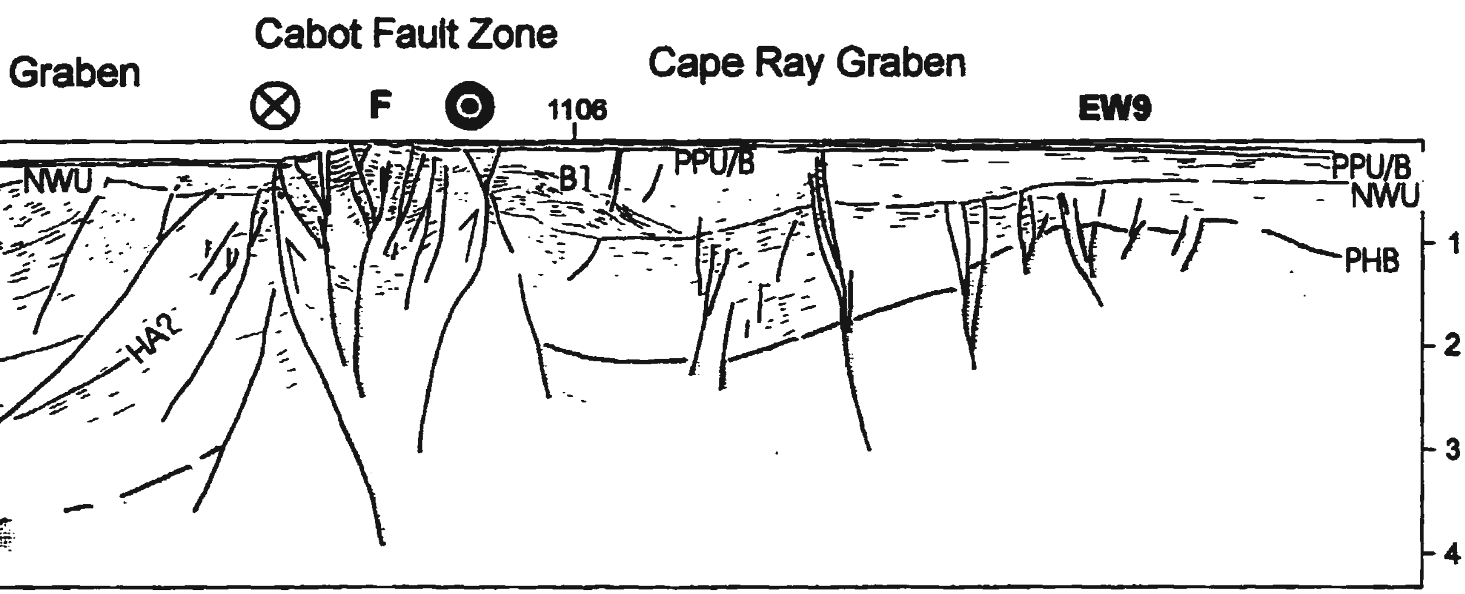
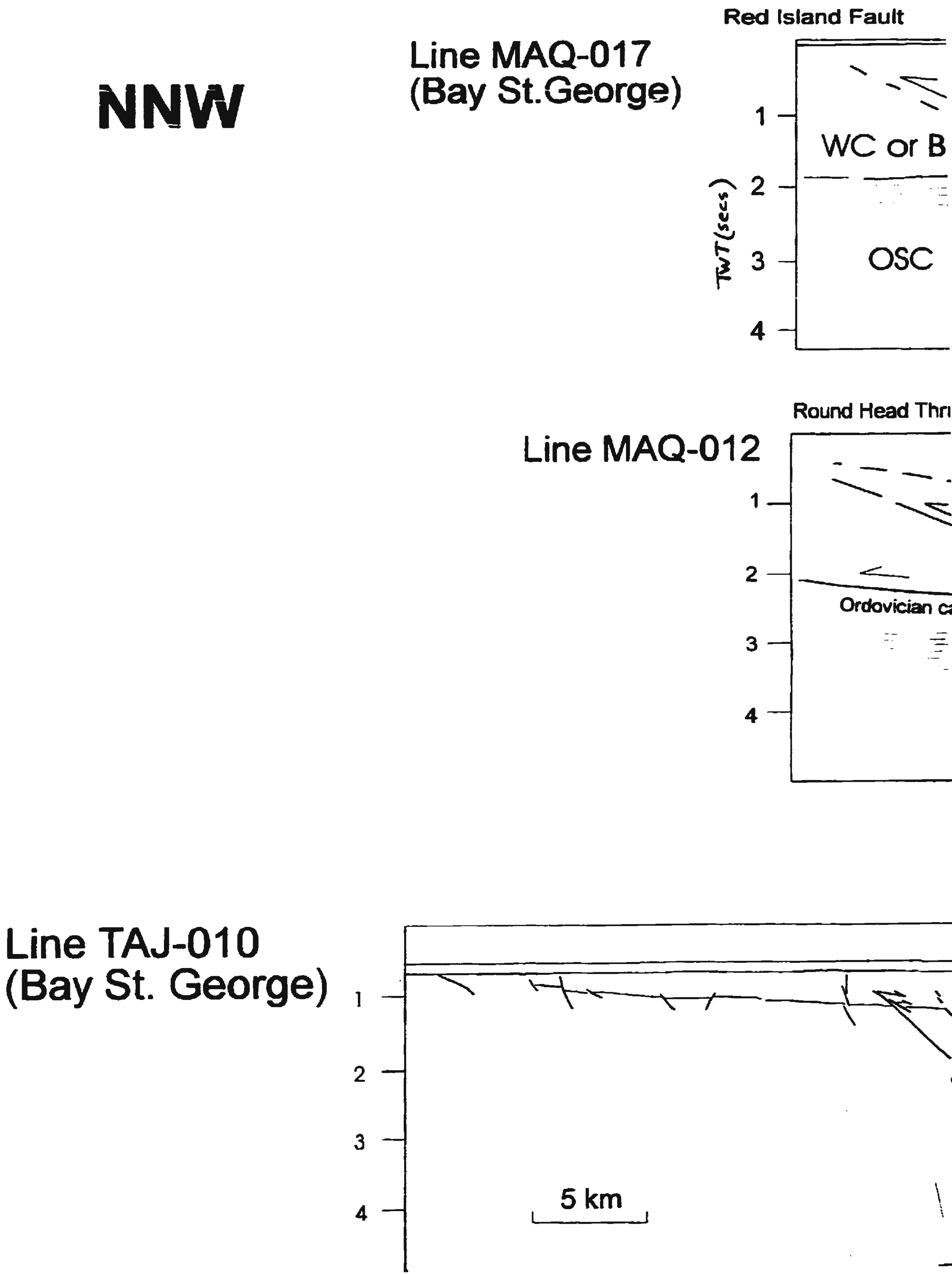
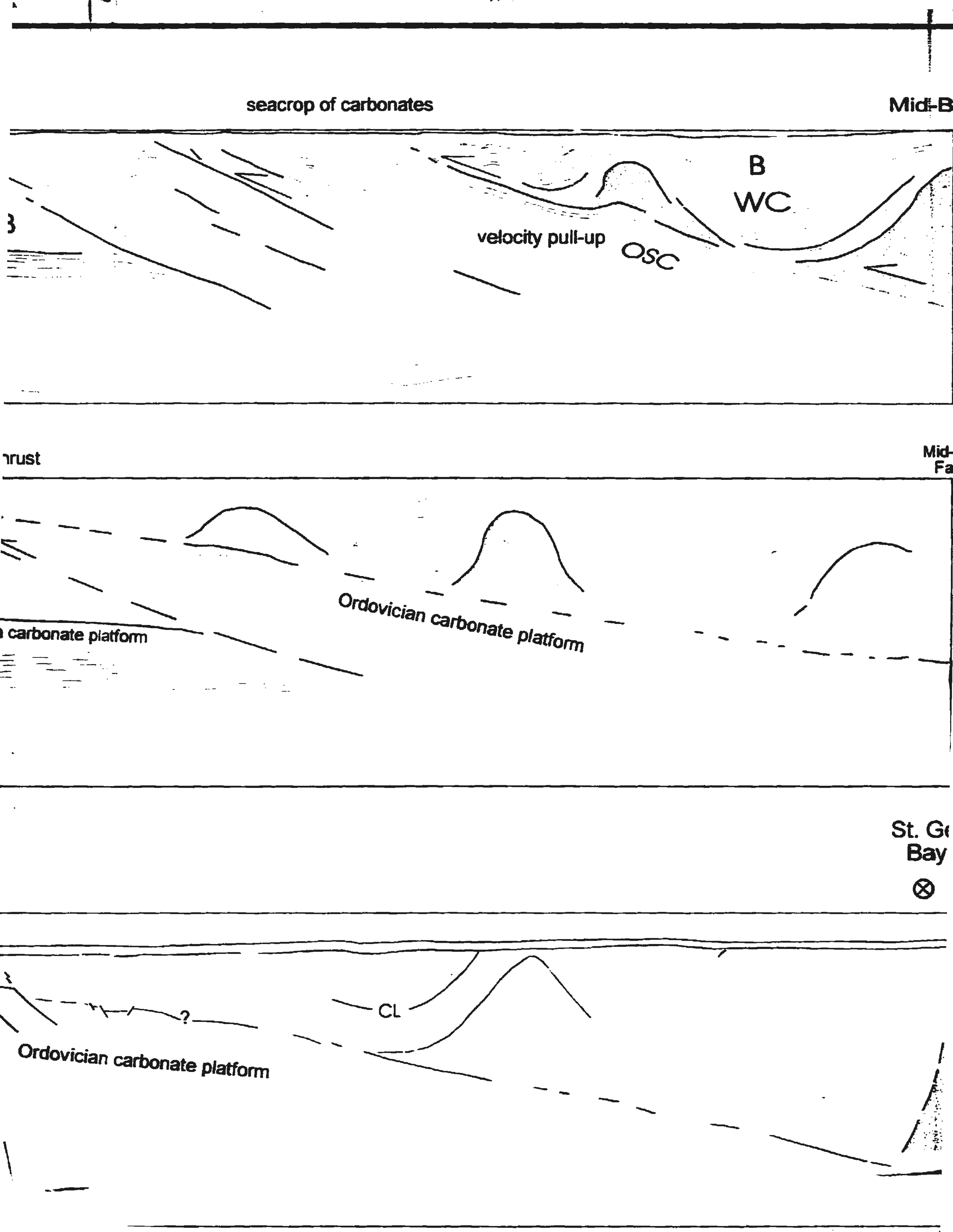
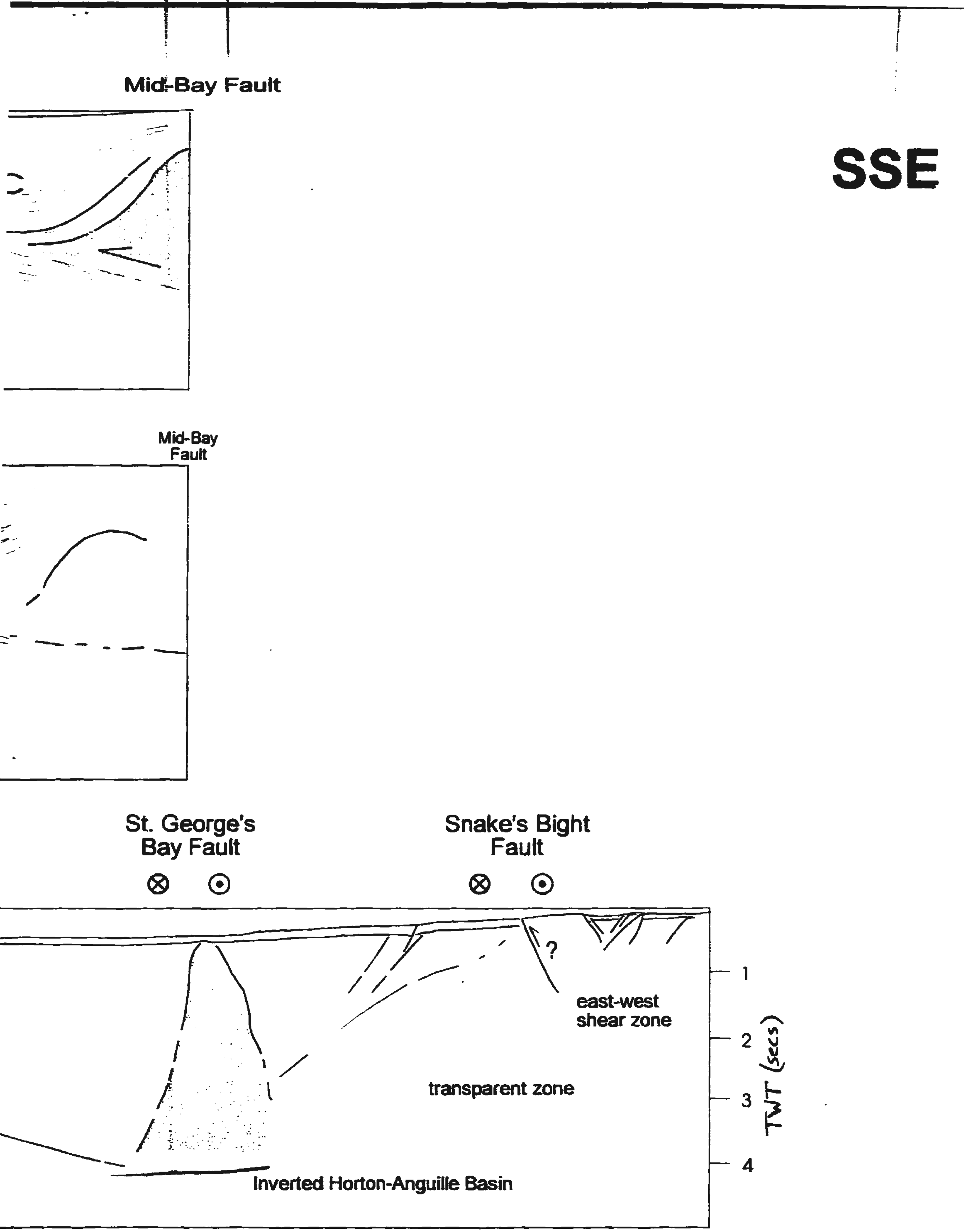

Cabot Fault Zone
Graben
F
Cape Ray Graben
1106
EW9
NWU
B1
PPU/B
PHB
HA?
1
2
3
4

FIGURE II.10b

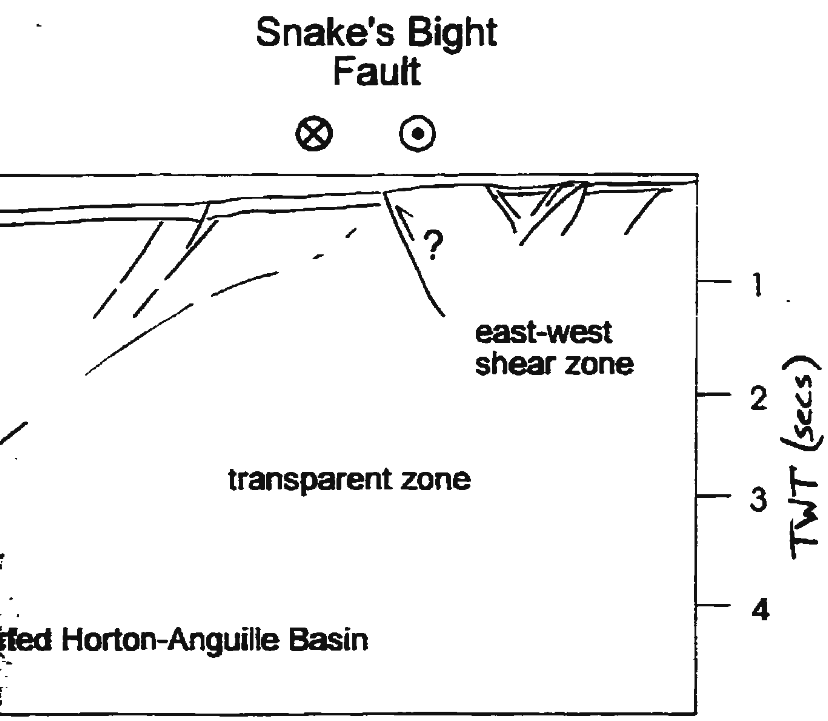



seacrop of carbonates
B
WC
velocity pull-up
OSC
carbonate platform
Ordovician carbonate platform
Bay
CL
?
Ordovician carbonate platform

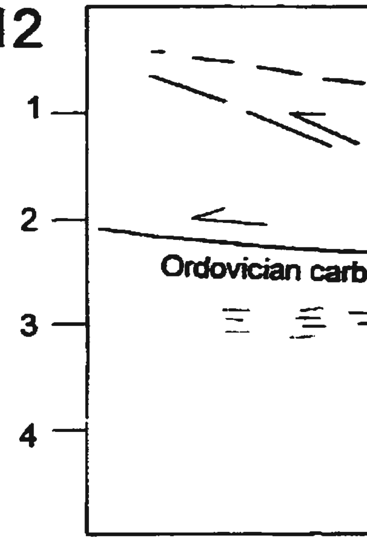


Mid-Bay Fault
SSE
Mid-Bay Fault
St. George's Bay Fault
Snake's Bight Fault
?
east-west shear zone
transparent zone
Inverted Horton-Anguille Basin
1
2
3
4
TWT (secs)

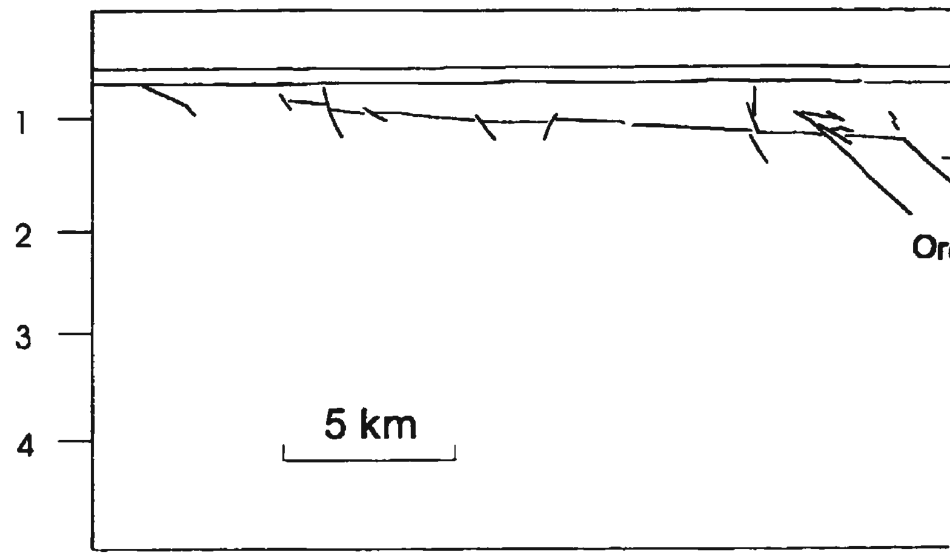
SSE


Snake's Bight
Fault
?
east-west
shear zone
transparent zone
tted Horton-Anguille Basin
1
2
3
4
TWT (secs)

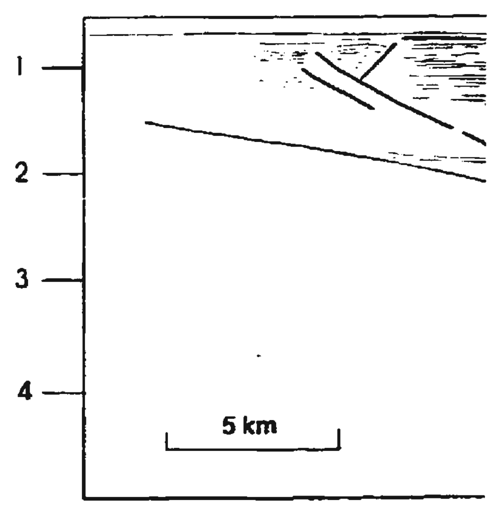
Line MAQ-012

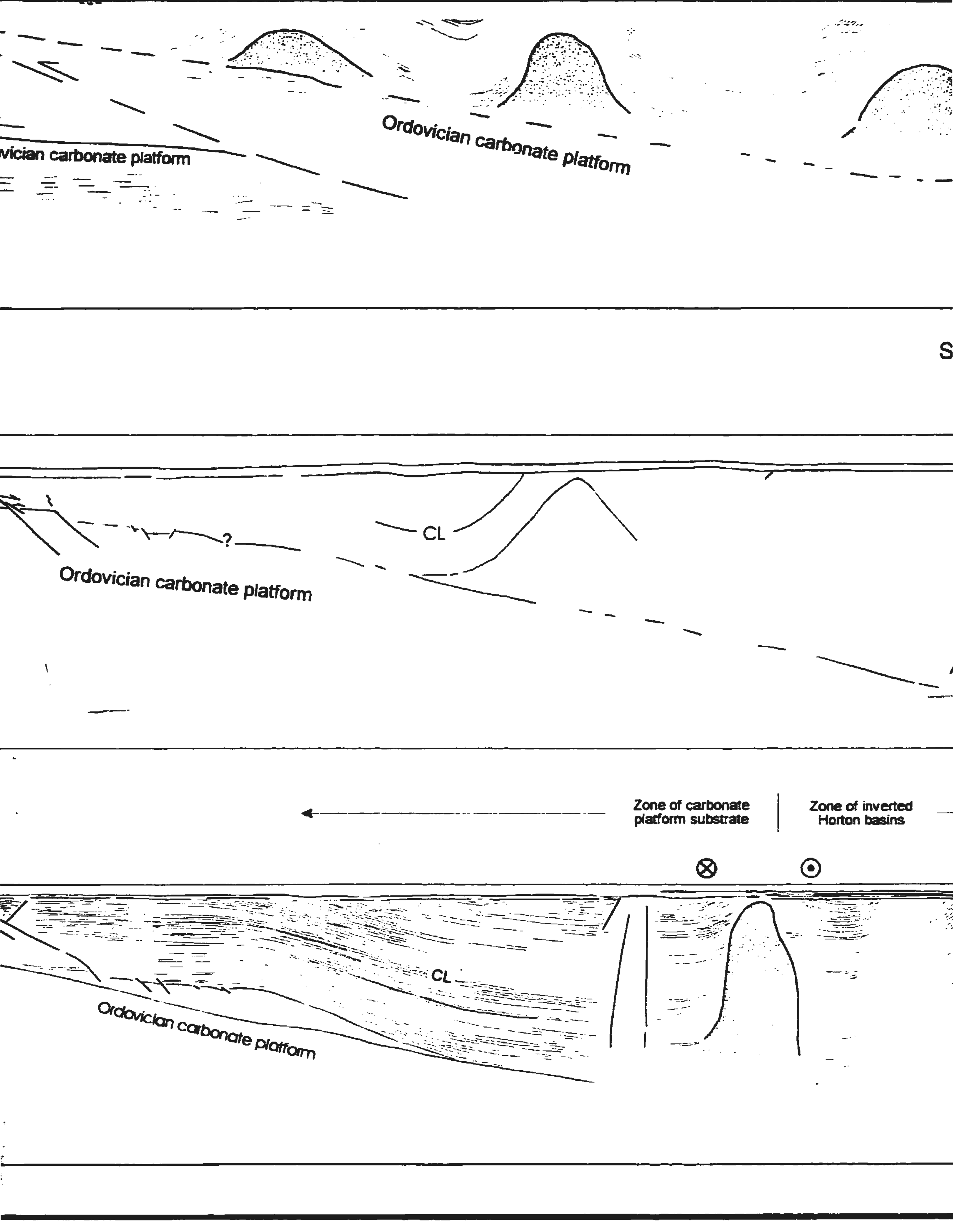


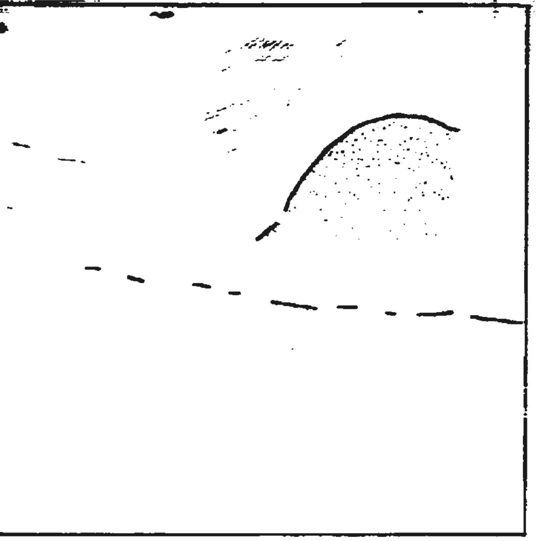
Line TAJ-010
(Bay St. George)

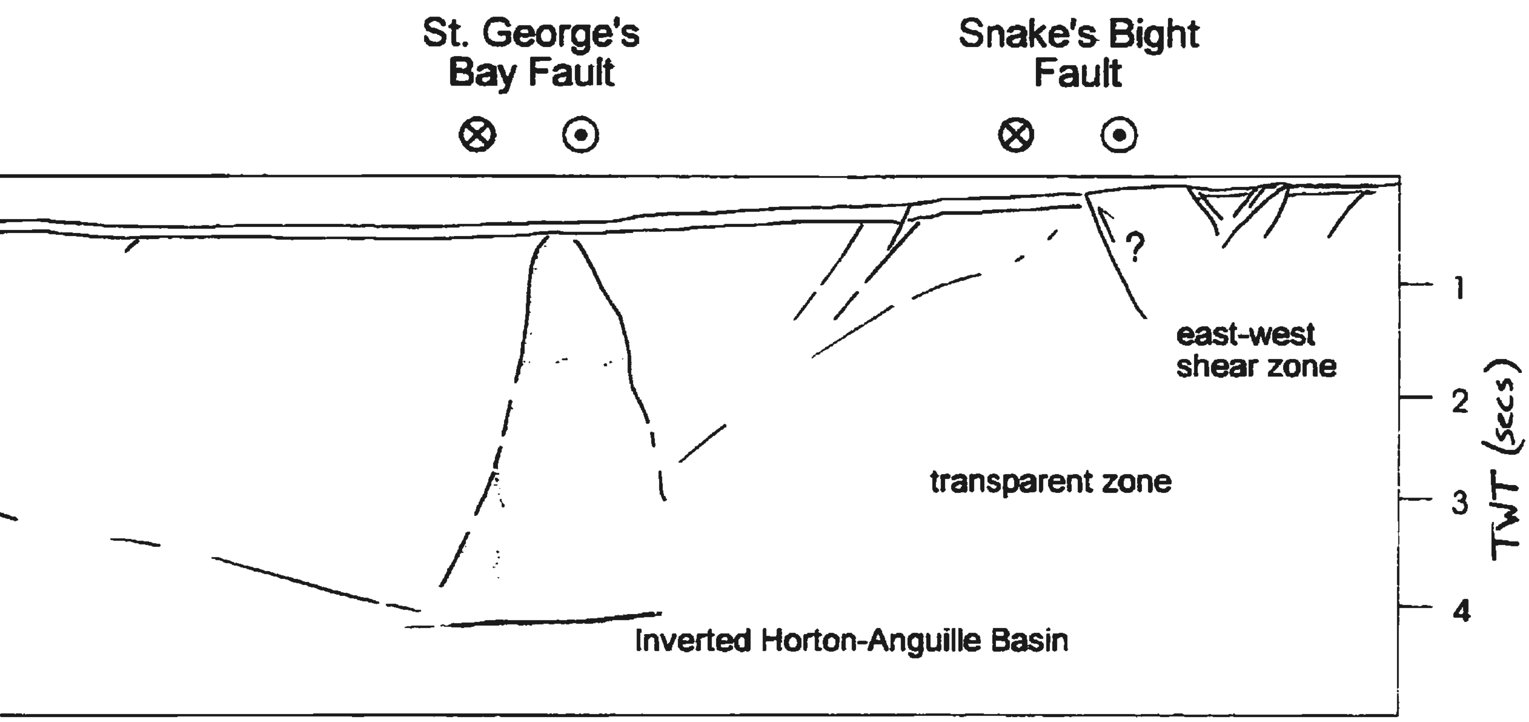


Line TAJ-009
(Bay St. George)

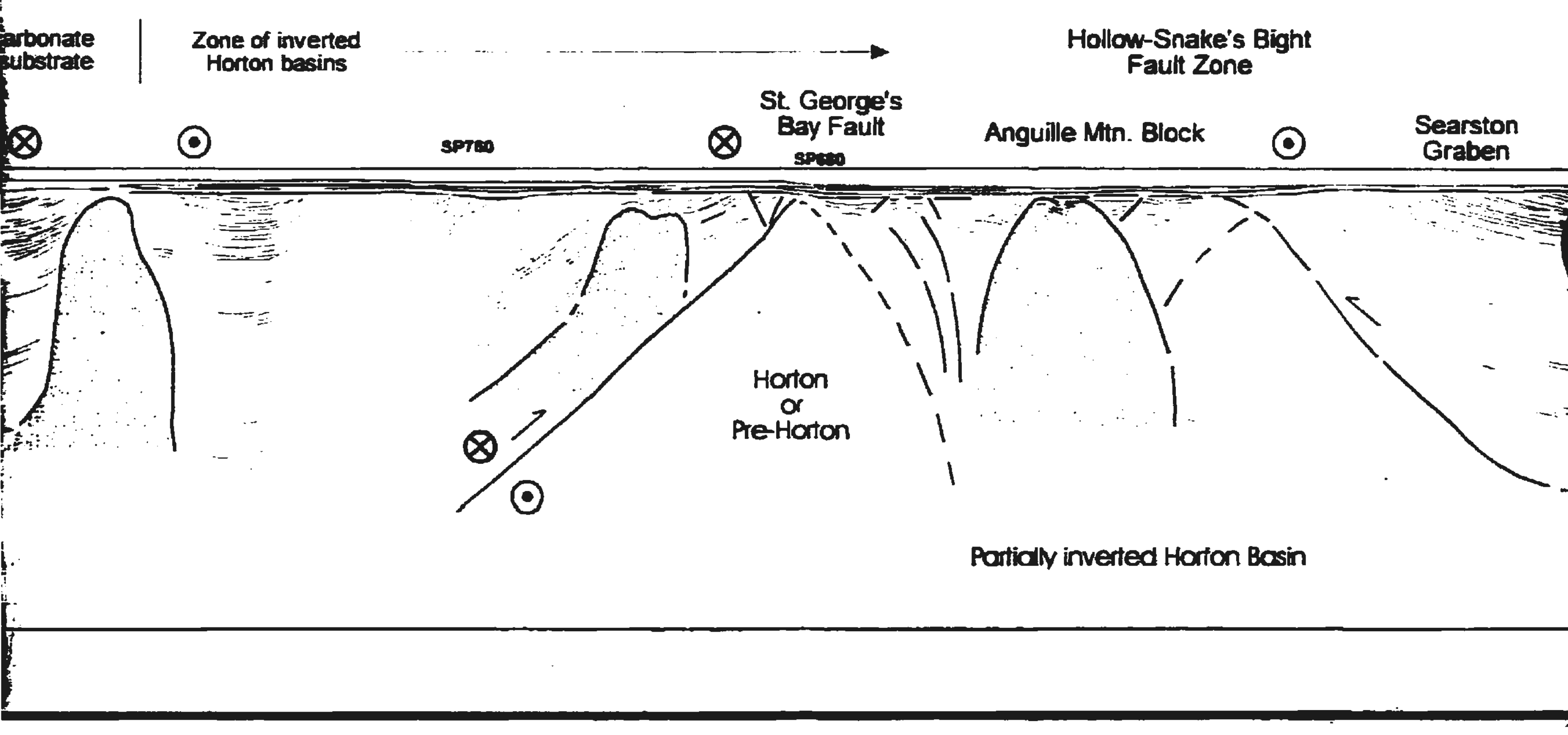



vician carbonate platform
Ordovician carbonate platform
S
CL
?
Ordovician carbonate platform
Zone of carbonate platform substrate
Zone of inverted Horton basins
CL
Ordovician carbonate platform

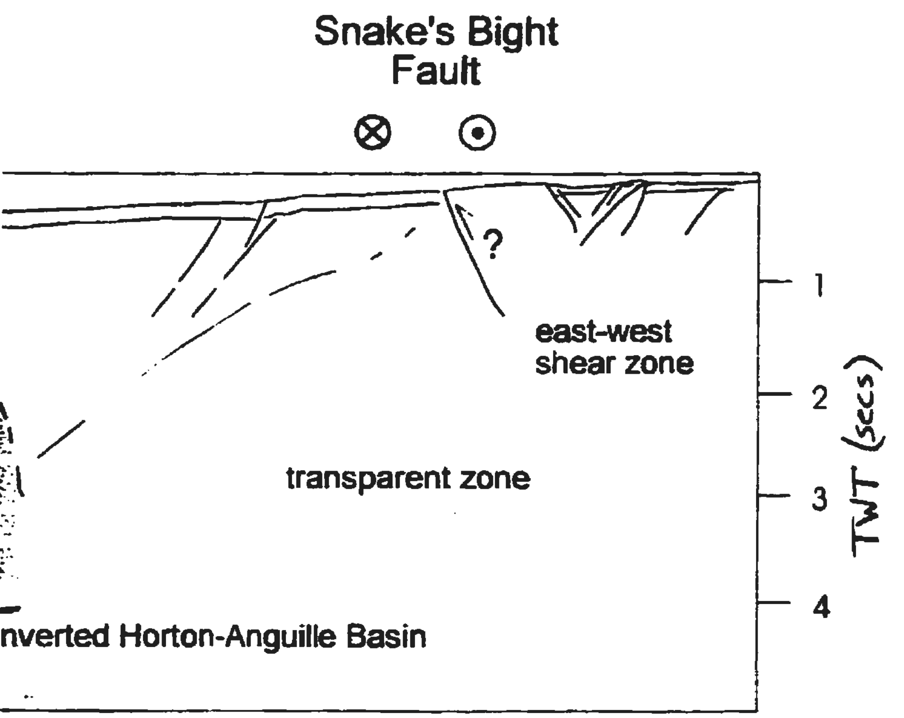




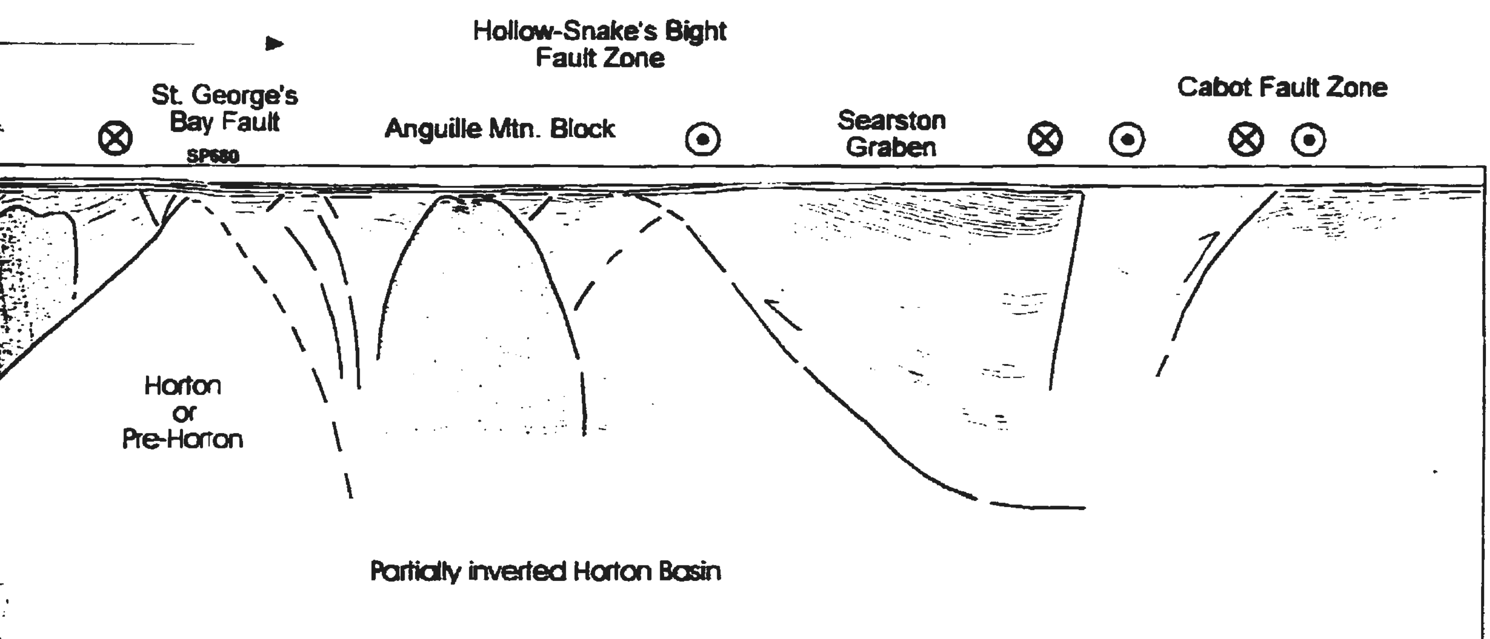
St. George's Bay Fault
Snake's Bight Fault
?
1
2
3
4
TWT (secs)
east-west shear zone
transparent zone
Inverted Horton-Anguille Basin



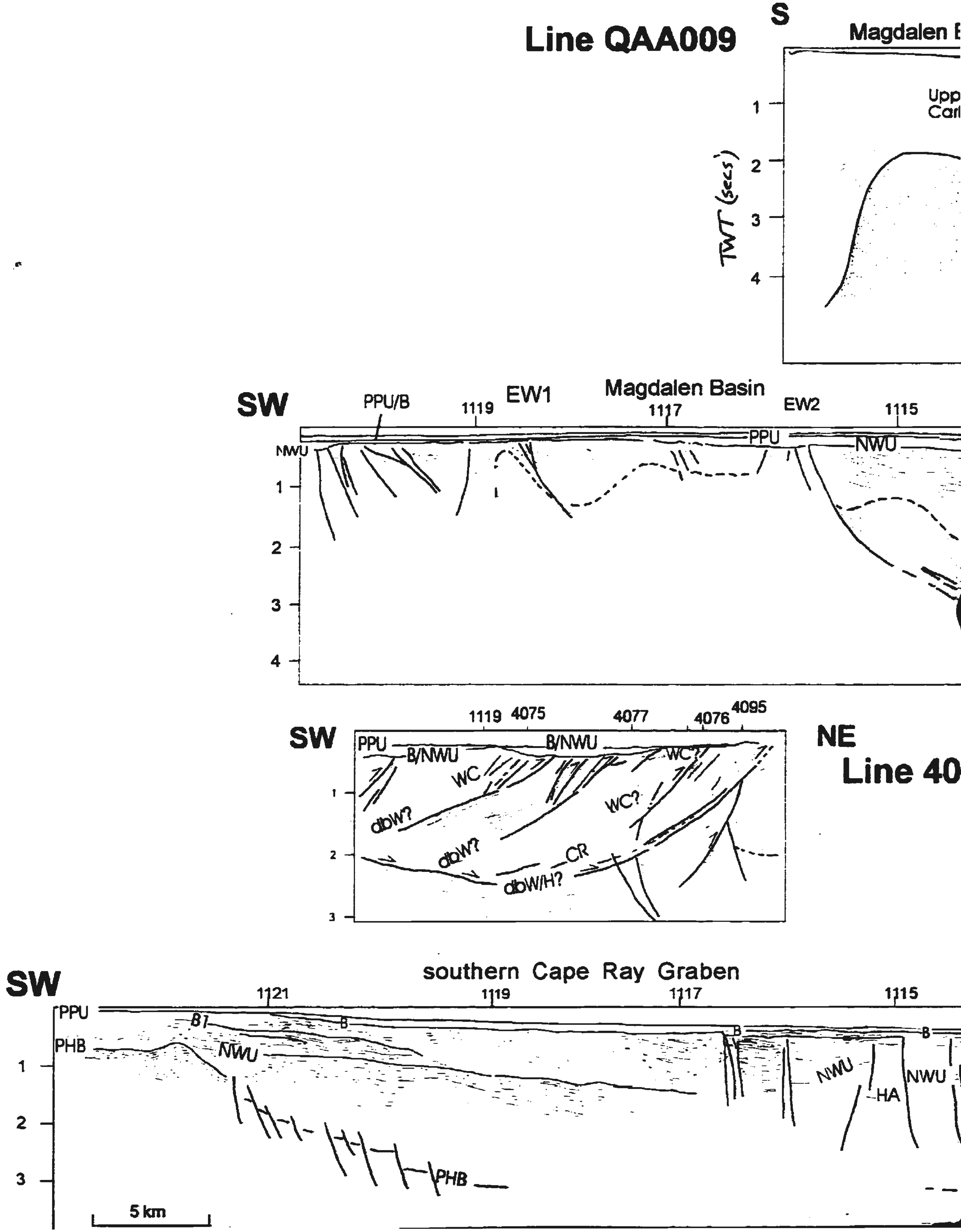
arbonate substrate
Zone of inverted Horton basins
Hollow-Snake's Bight Fault Zone
St. George's Bay Fault
Anguille Mtn. Block
Searston Graben
SP760
Horton or Pre-Horton
Partially inverted Horton Basin

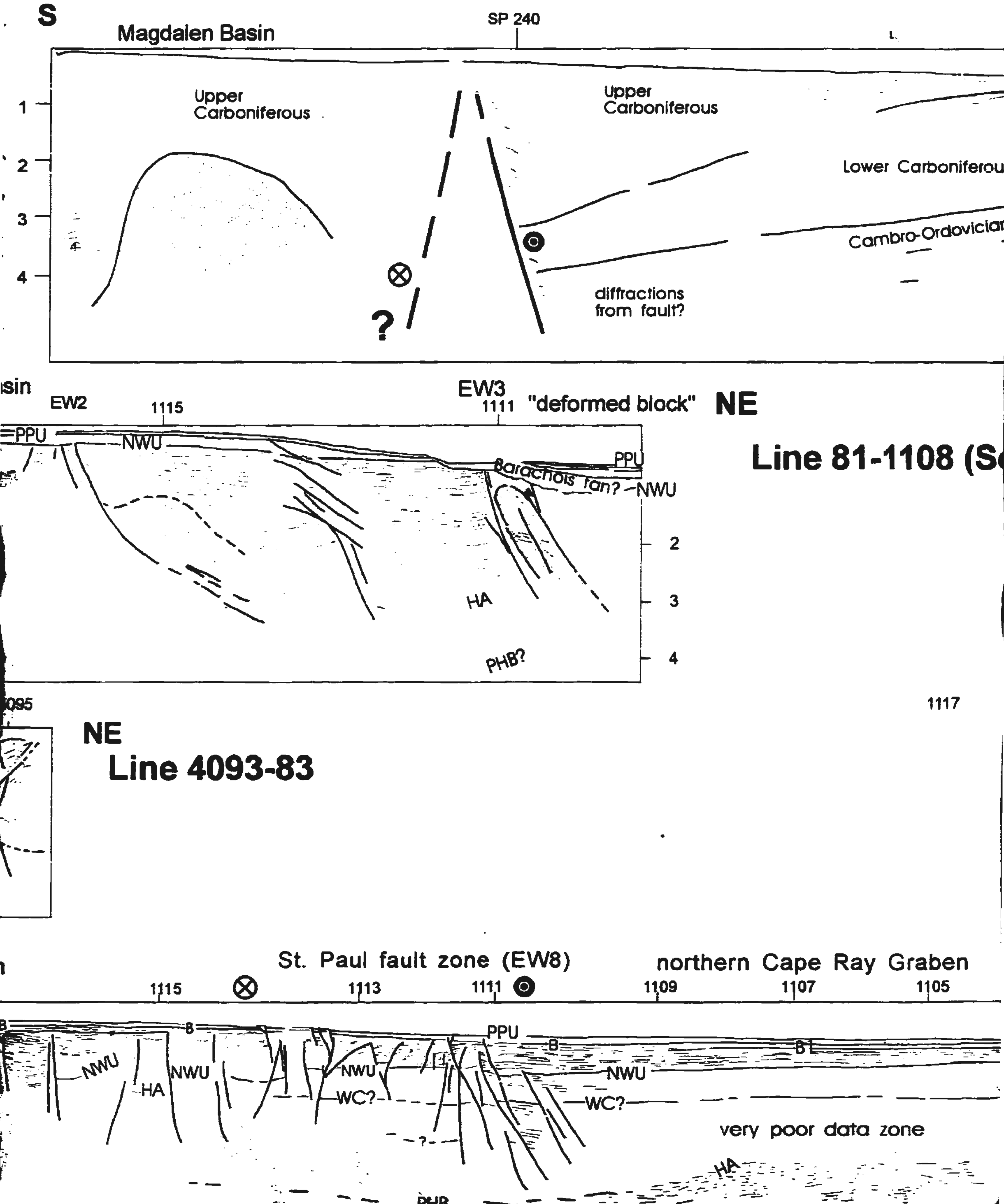


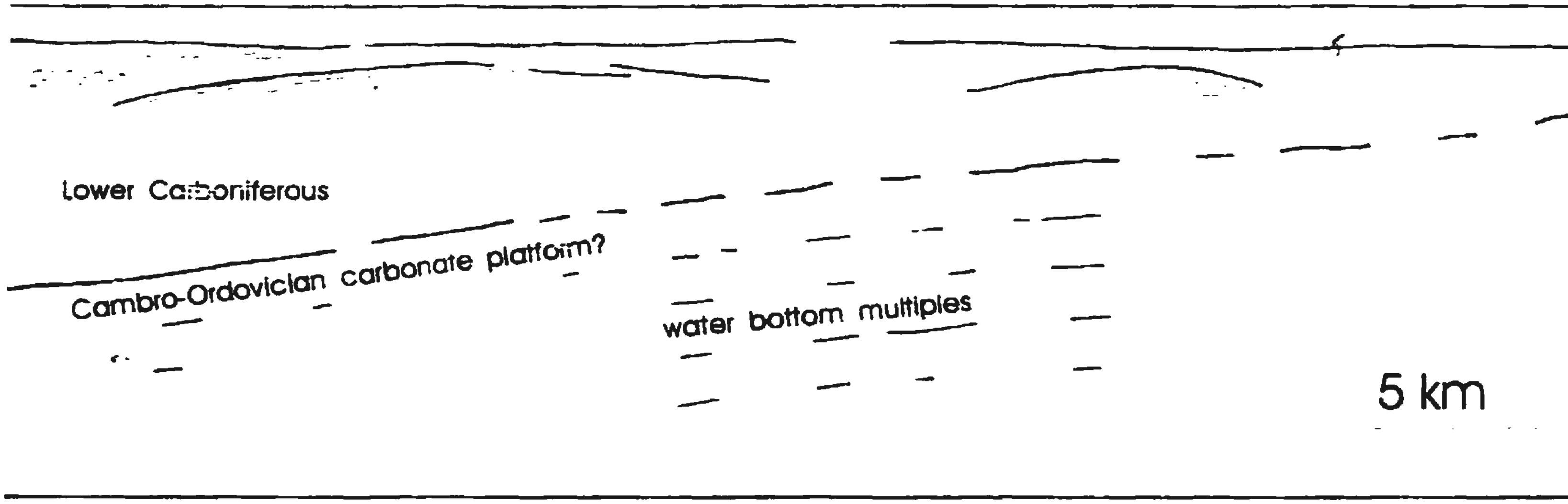
Snake's Bight
Fault
?
east-west
shear zone
transparent zone
nverted Horton-Anguille Basin
1
2
3
4
TWT (secs)



Hollow-Snake's Bight
Fault Zone
St. George's
Bay Fault
SP680
Anguille Mtn. Block
Searston
Graben
Cabot Fault Zone
Horton
or
Pre-Horton
Partially inverted Horton Basin

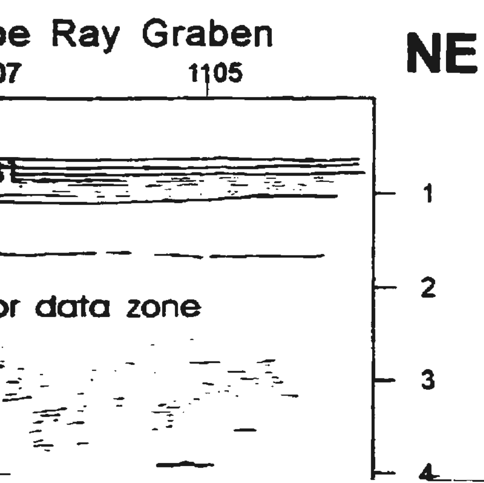

Line QAA009
S
Magdalen B
Upp
Carl
TWT (secs)
1
2
3
4
SW
PPU/B
1119
EW1
Magdalen Basin
1117
EW2
1115
NWU
PPU
NWU
1
2
3
4
SW
1119
4075
4077
4076
4095
PPU
B/NWU
B/NWU
WC
WC?
WC?
dbW?
dbW?
CR
dbW/H?
1
2
3
NE
Line 40
SW
southern Cape Ray Graben
1121
1119
1117
1115
PPU
B1
B
B
B
PHB
NWU
NWU
NWU
HA
PHB
1
2
3
5 km


S
Magdalen Basin
SP 240
Upper Carboniferous
Upper Carboniferous
Lower Carboniferou
Cambro-Ordovicia
diffractions from fault?
?
1
2
3
4
sin
EW2
1115
EW3
1111
"deformed block"
NE
PPU
NWU
PPU
Barachois fan?
NWU
HA
PHB?
2
3
4
Line 81-1108 (S
095
1117
NE
Line 4093-83
St. Paul fault zone (EW8)
northern Cape Ray Graben
1115
1113
1111
1109
1107
1105
B
B
PPU
B
B
NWU
HA
NWU
NWU
NWU
WC?
WC?
?
very poor data zone
HA



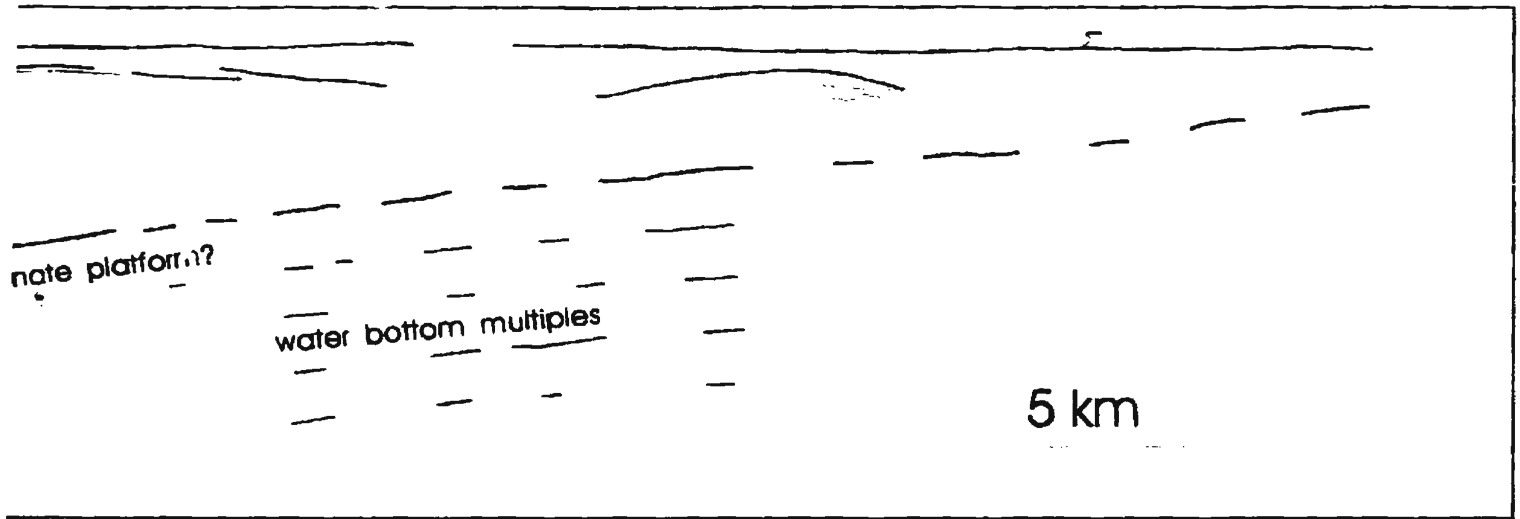
e 81-1108 (Southern half)*

1117



Line 81-1106*

N



ıern half)*

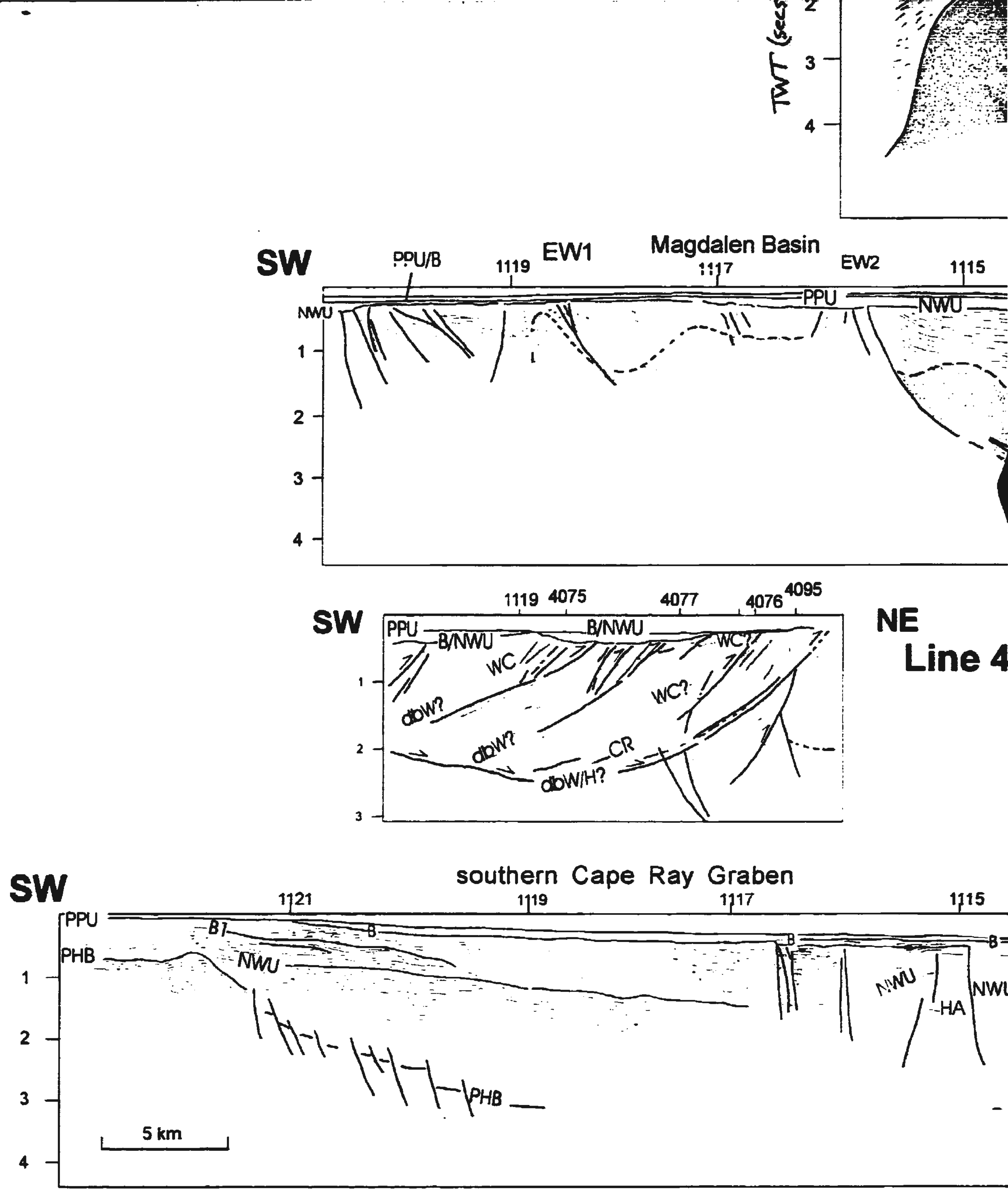
NE

Line 81-1106*

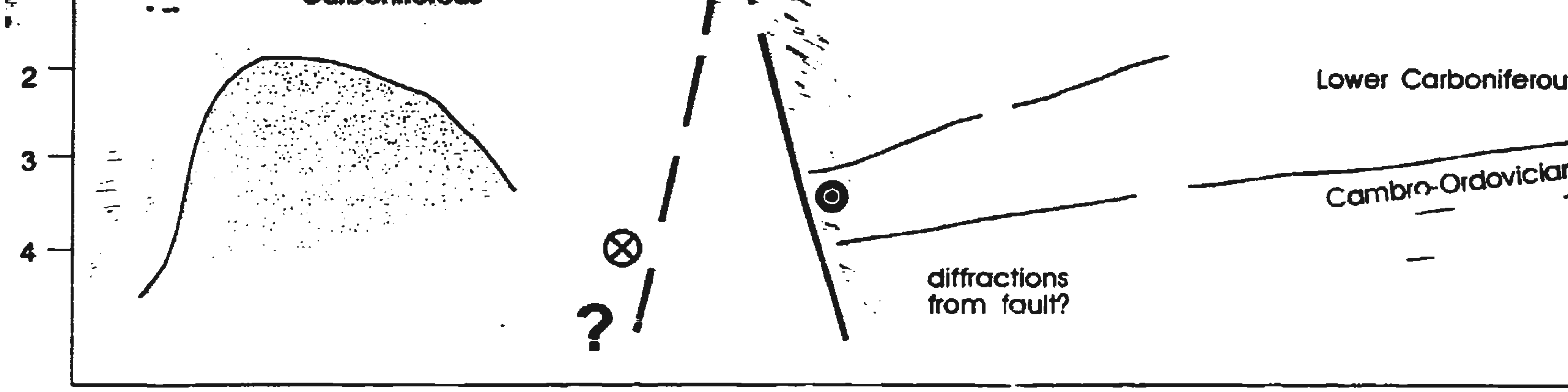
1

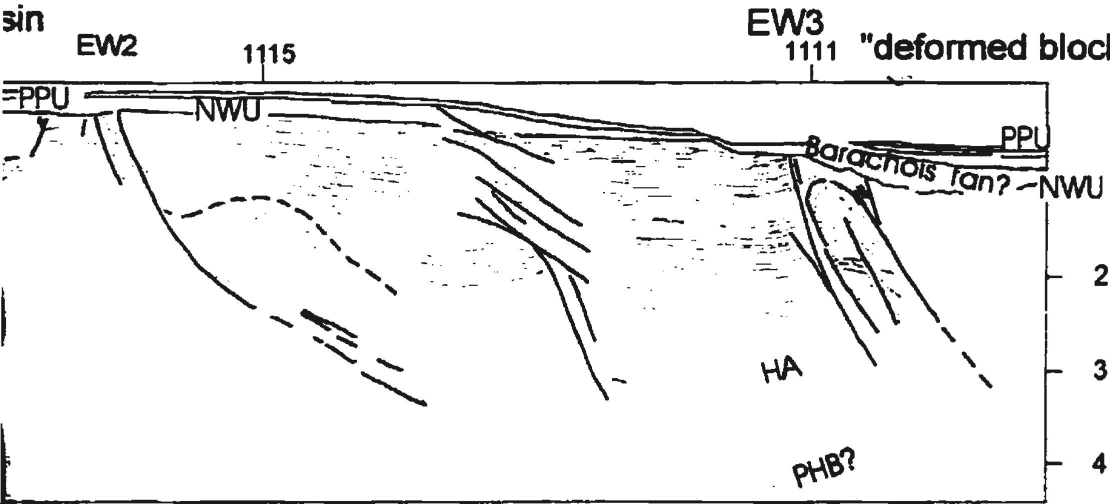
2

3



TWT (secs)
SW
Magdalen Basin
EW1
EW2
PPU/B
1119
1117
1115
PPU
NWU
SW
NE
Line 4
1119 4075
4077
4076 4095
PPU
B/NWU
WC
WC?
dbW?
CR
dbW/H?
SW
southern Cape Ray Graben
1121
1119
1117
1115
PPU
B1
B
PHB
NWU
HA
5 km





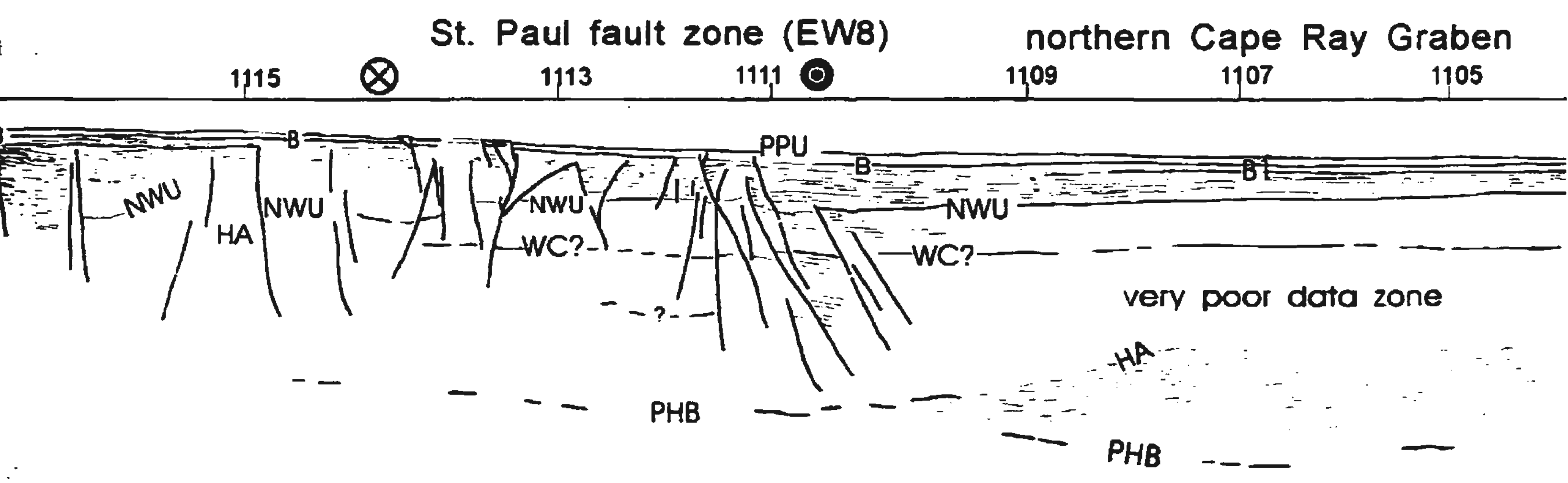
NE

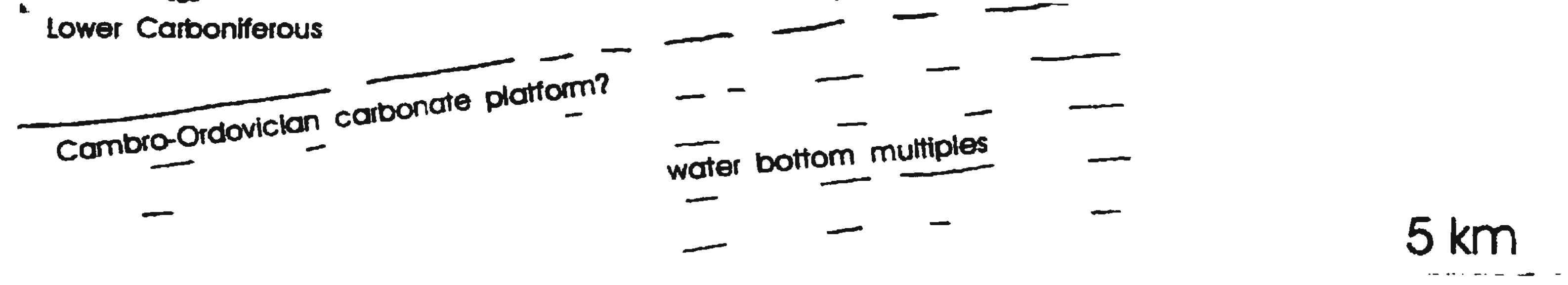
Line 81-1108 (Se

1117

NE

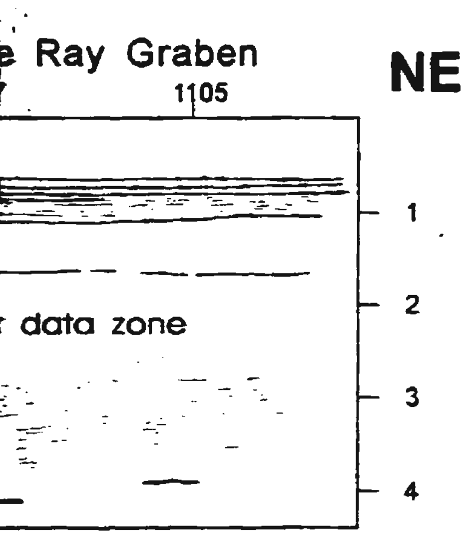
Line 4093-83



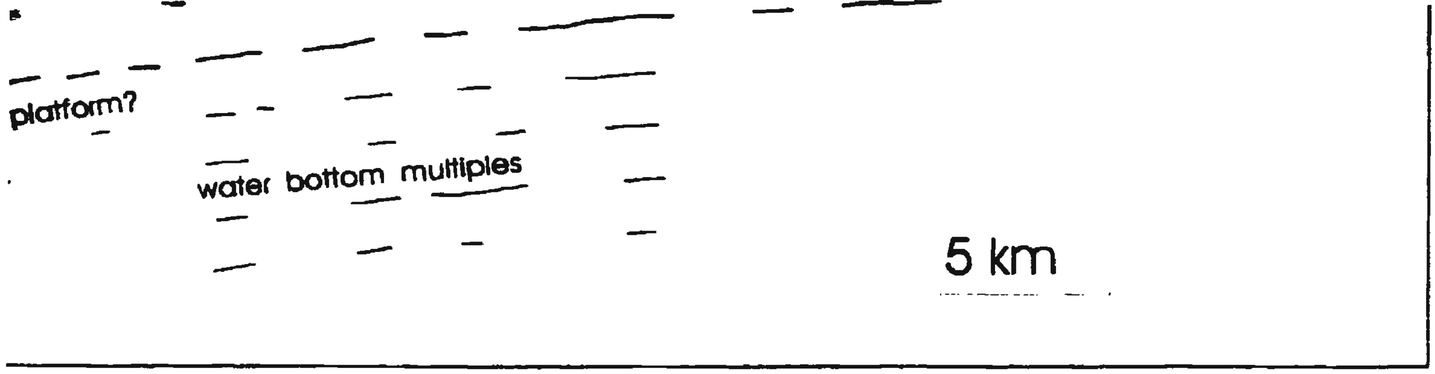


81-1108 (Southern half)*

1117



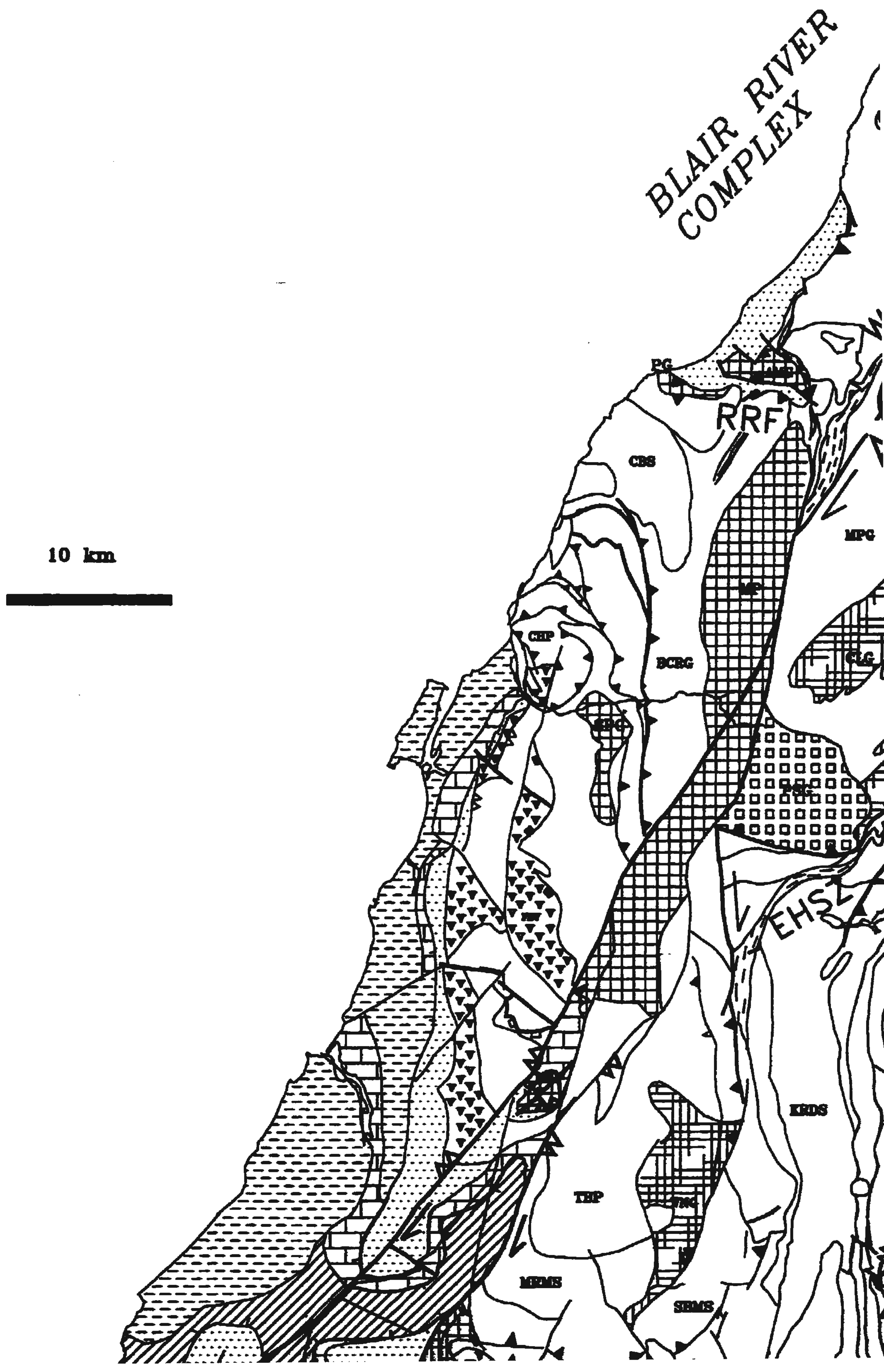
Line 81-1106*



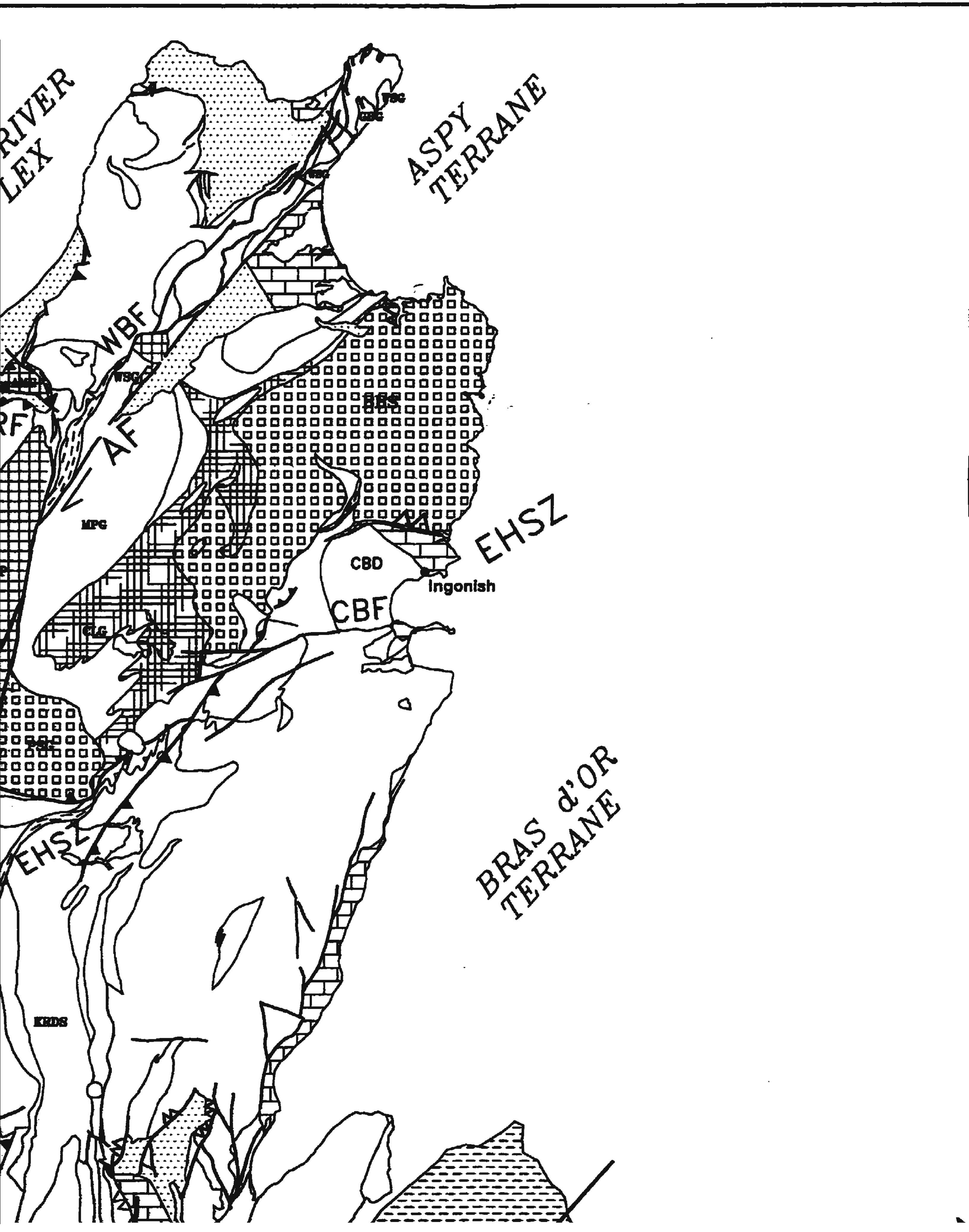
n half)*

Line 81-1106*

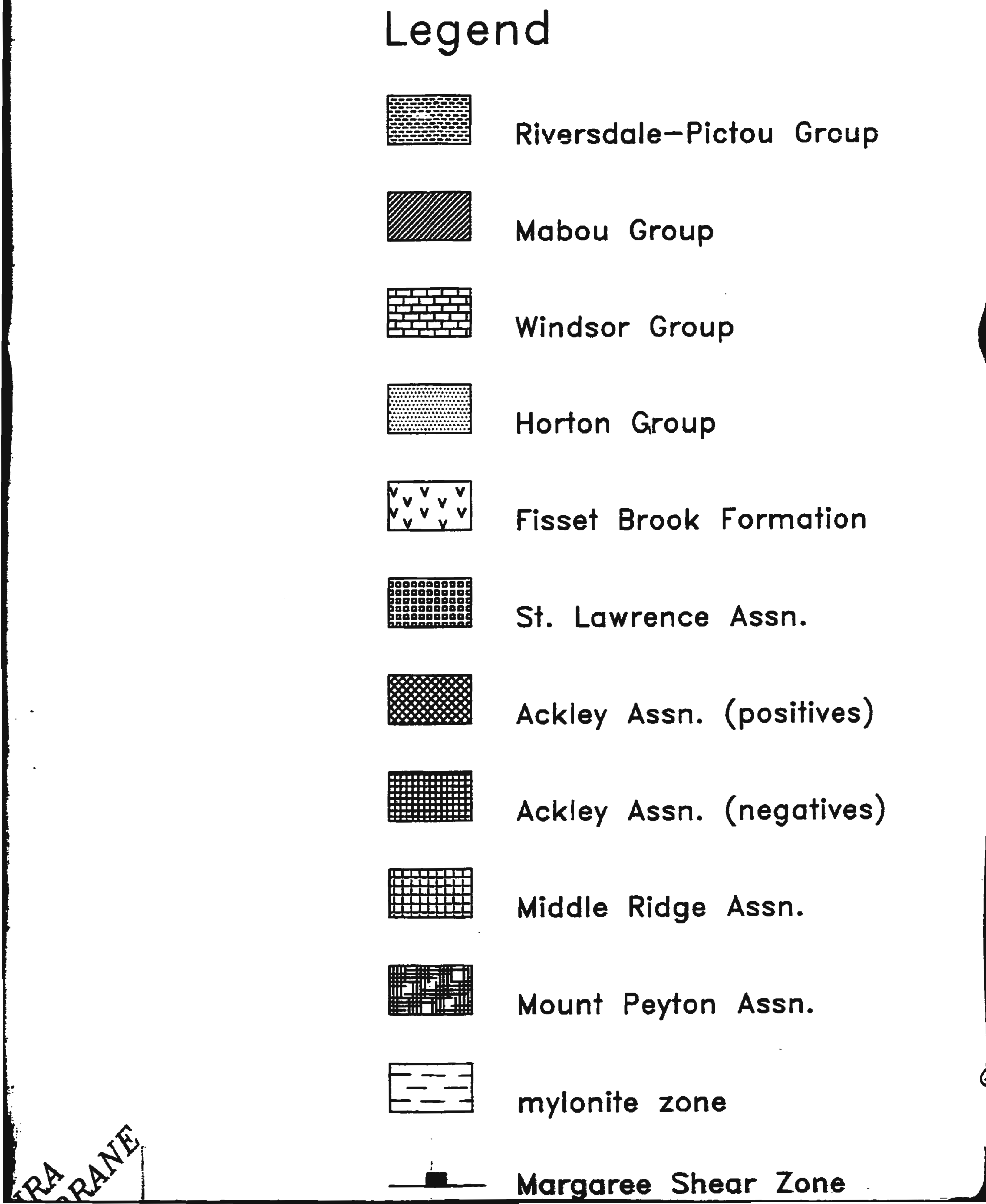
FIGURE II.10c

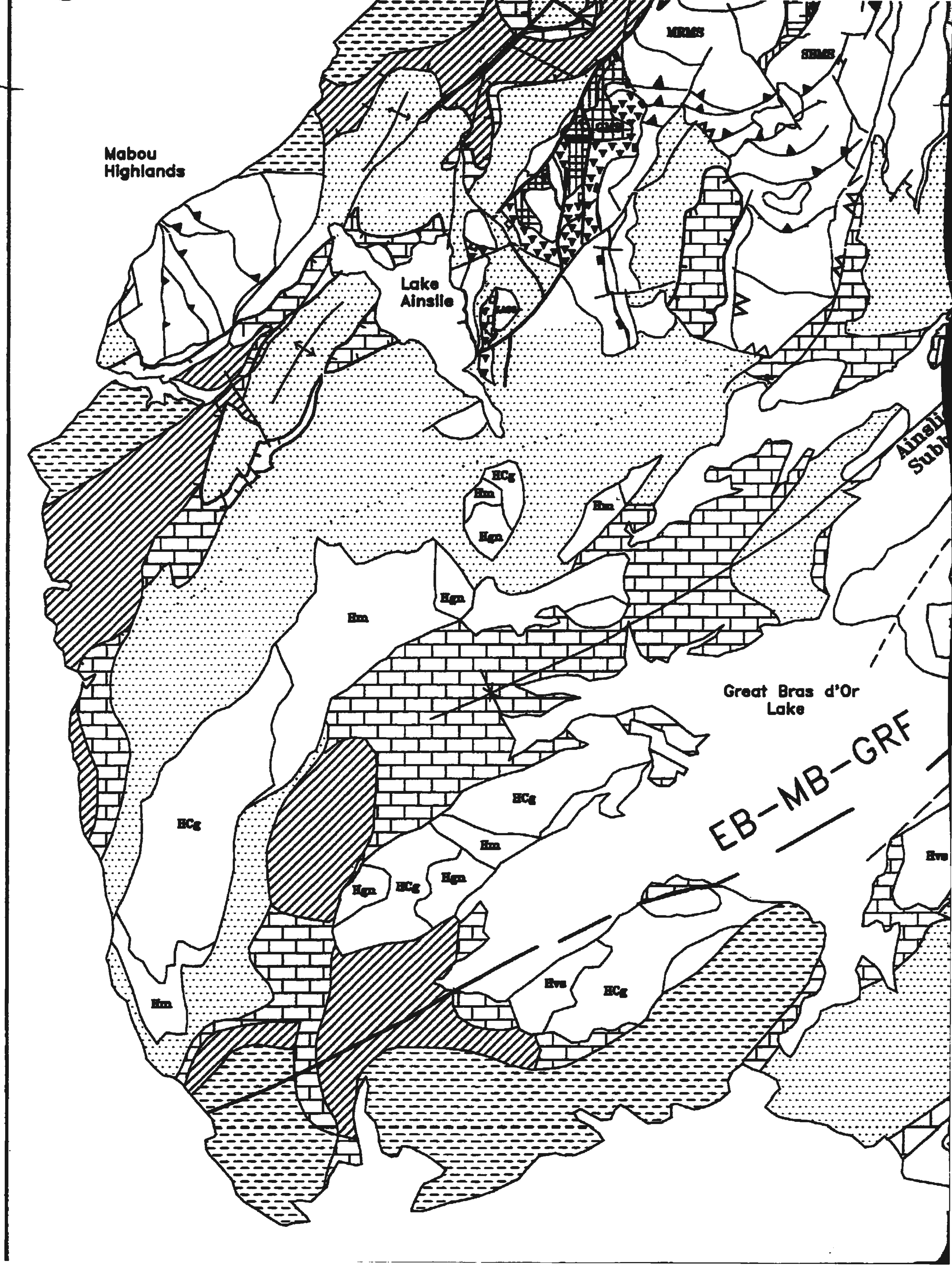


BLAIR RIVER
COMPLEX
RRF
EHSZ
10 km
PG
CBS
MPG
CHP
BCRG
KRDS
THP
MRMS
SBMS

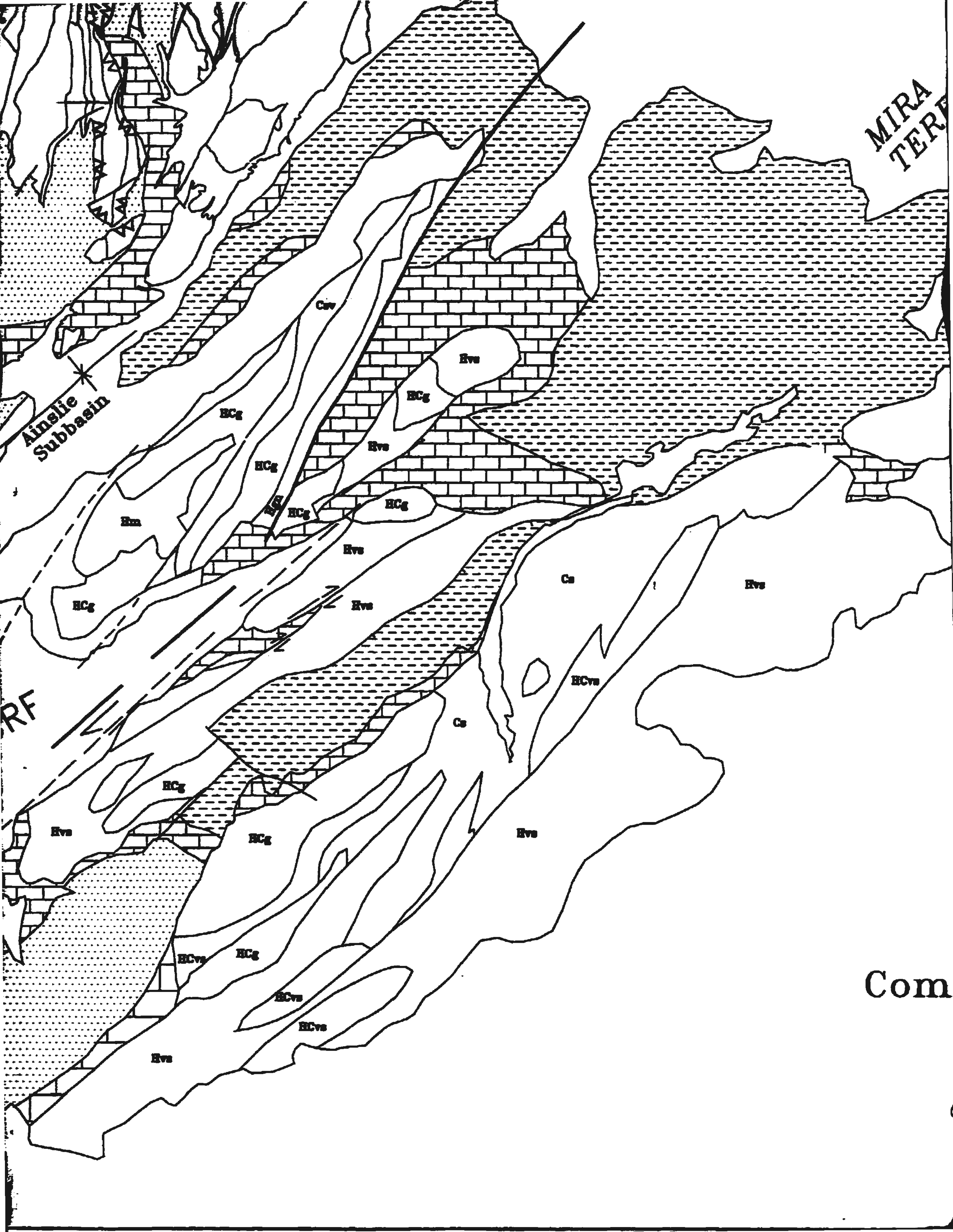


RIVER
LEX
ASPY
TERRANE
WBF
WSG
BBS
AF
RF
MPG
EHSZ
CBD
Ingonish
CBF
CLG
EHSZ
KRDS
BRAS d'OR
TERRANE

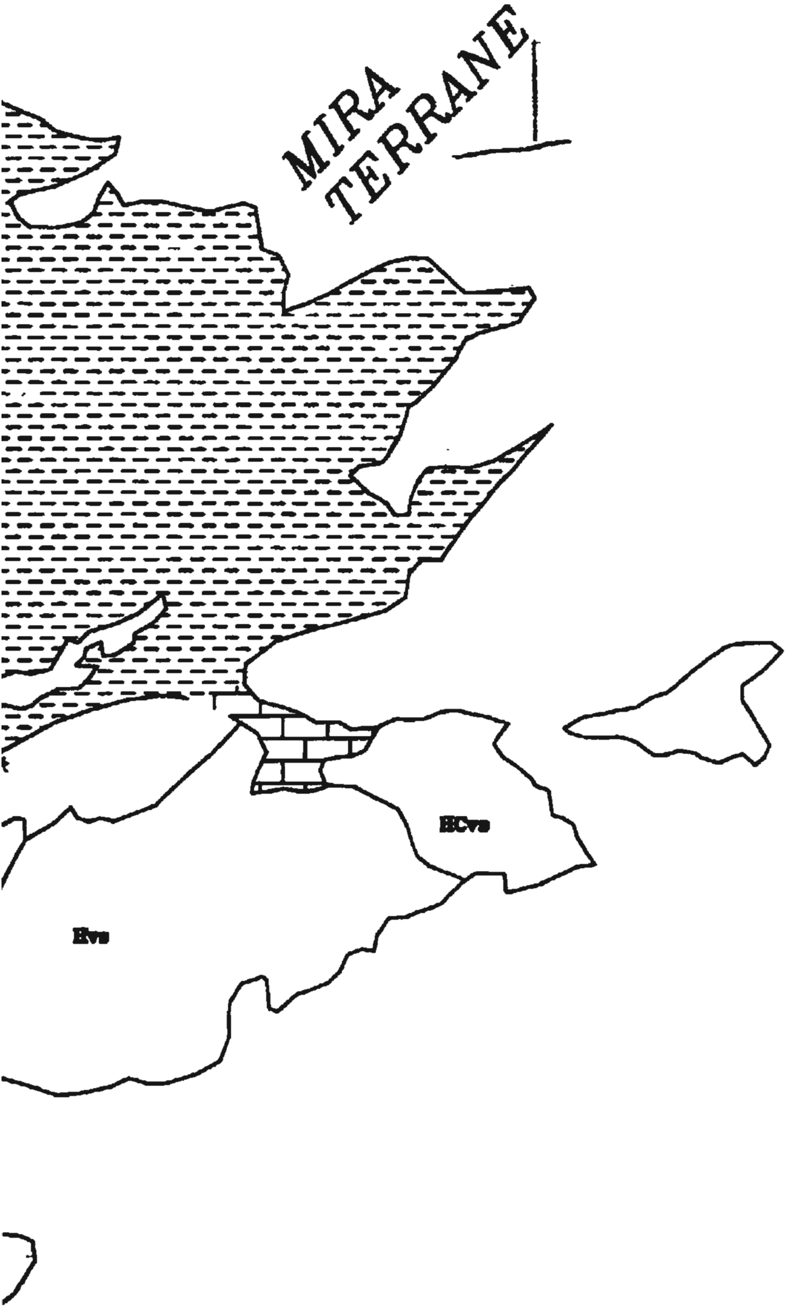

Legend
Riversdale–Pictou Group
Mabou Group
Windsor Group
Horton Group
Fisset Brook Formation
St. Lawrence Assn.
Ackley Assn. (positives)
Ackley Assn. (negatives)
Middle Ridge Assn.
Mount Peyton Assn.
mylonite zone
Margaree Shear Zone



Mabou Highlands
Lake Ainslie
HCg
Hm
Hgn
Great Bras d'Or Lake
EB–MB–GRF
Hvs



MIRA
TERR
Ainslie
Subbasin
Cuv
Hvs
HCg
Hm
RF
Cs
HCvs
Com



mylonite zone

Margaree Shear Z

detachment fault

Ainslie detachmen

reverse fault

Carboniferous thru

steep, late faults

Pre–Late Silurian units (after Barr

Cs: mainly Cambrian sedimentary r
Csv: Cambrian sedimentary & volca
HCg: Late Hadrynian and Early Cam
HCvs: Late Hadrynian and Early Can
Hvs: Late Hadrynian volcanic and s
Hm: Hadrynian metamorphic rocks
Hgn: Hadrynian gneiss

Compilation Map of Cape Breton Isl

(after Barr et al., 1990; Lynch et al., 1994; Kelley

mylonite zone

Margaree Shear Zone

detachment fault

Ainslie detachment

reverse fault

Carboniferous thrusting

steep, late faults

Pre-Late Silurian units (after Barr and Raeside, 1989):

Cs: mainly Cambrian sedimentary rocks
Csv: Cambrian sedimentary & volcanic rocks
HCg: Late Hadrynian and Early Cambrian granitoid rocks
HCvs: Late Hadrynian and Early Cambrian volcanic and sedimentary rocks
Hvs: Late Hadrynian volcanic and sedimentary rocks
Hm: Hadrynian metamorphic rocks
Hgn: Hadrynian gneiss

p of Cape Breton Island Geology

l., 1990; Lynch et al., 1994; Kelley, 1967)

FIGURE VI.4

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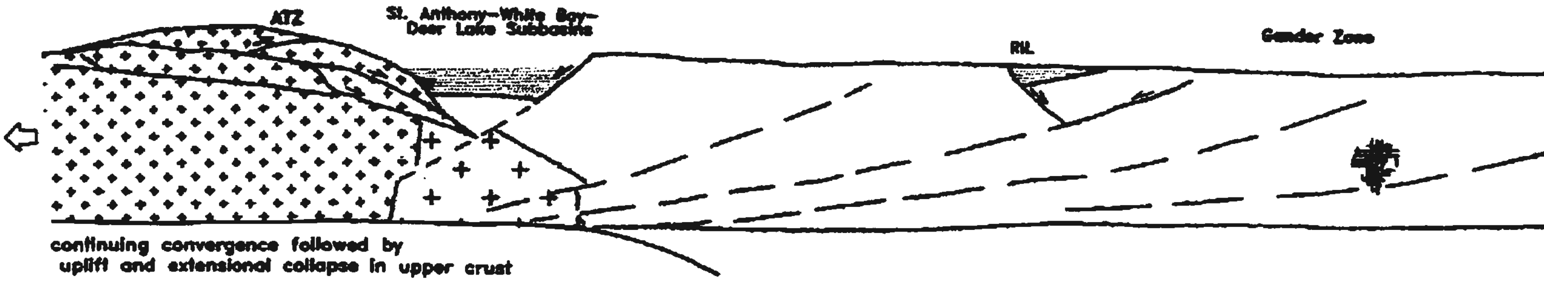
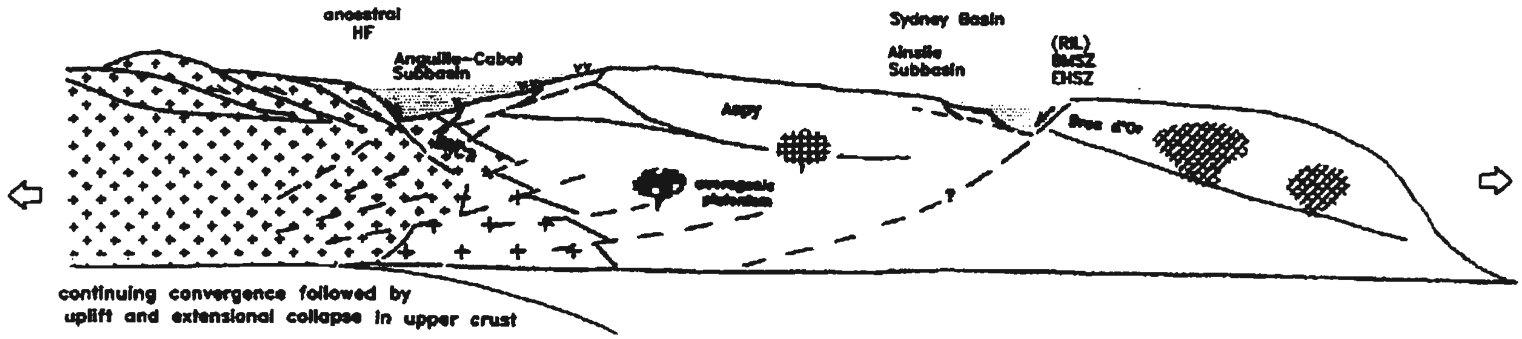


continuing convergence followed by
uplift and extensional collapse in upper crust

early Horton basin development
along collapsed faults

NORTH OF PROMONTORY- PROMONTORY COLLISI

ZONE OF PROMONTORY- PROMONTORY COLLISI



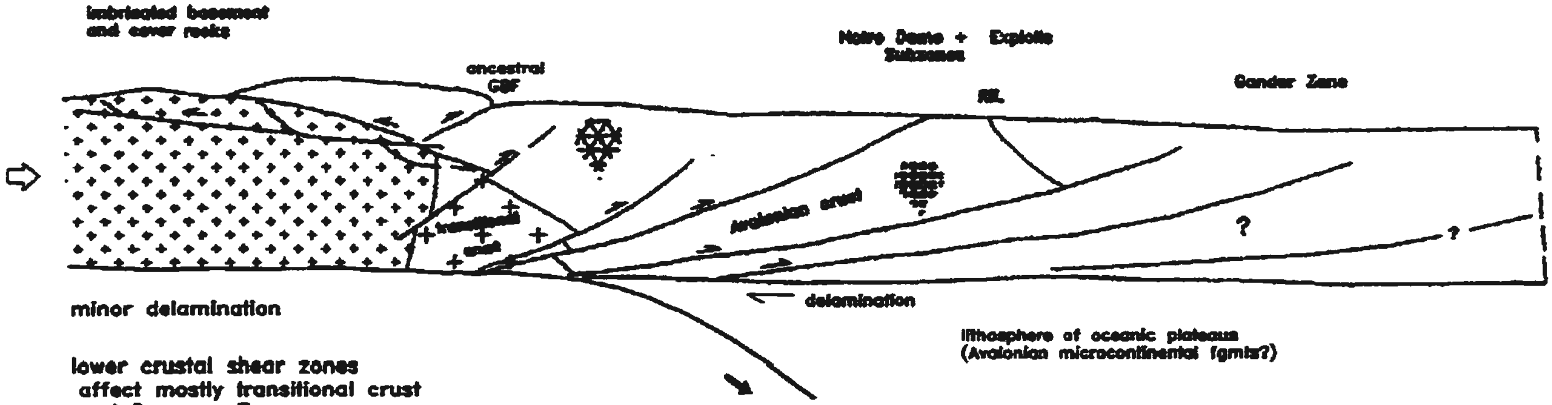
continuing convergence followed by
uplift and extensional collapse in upper crust

early Horton basin development
along collapsed faults

Fisset Bk. volcanism

Middle Devonian

imbricated basement
and cover rocks



minor delamination

lower crustal shear zones
affect mostly transitional crust
and Dunnage Zone

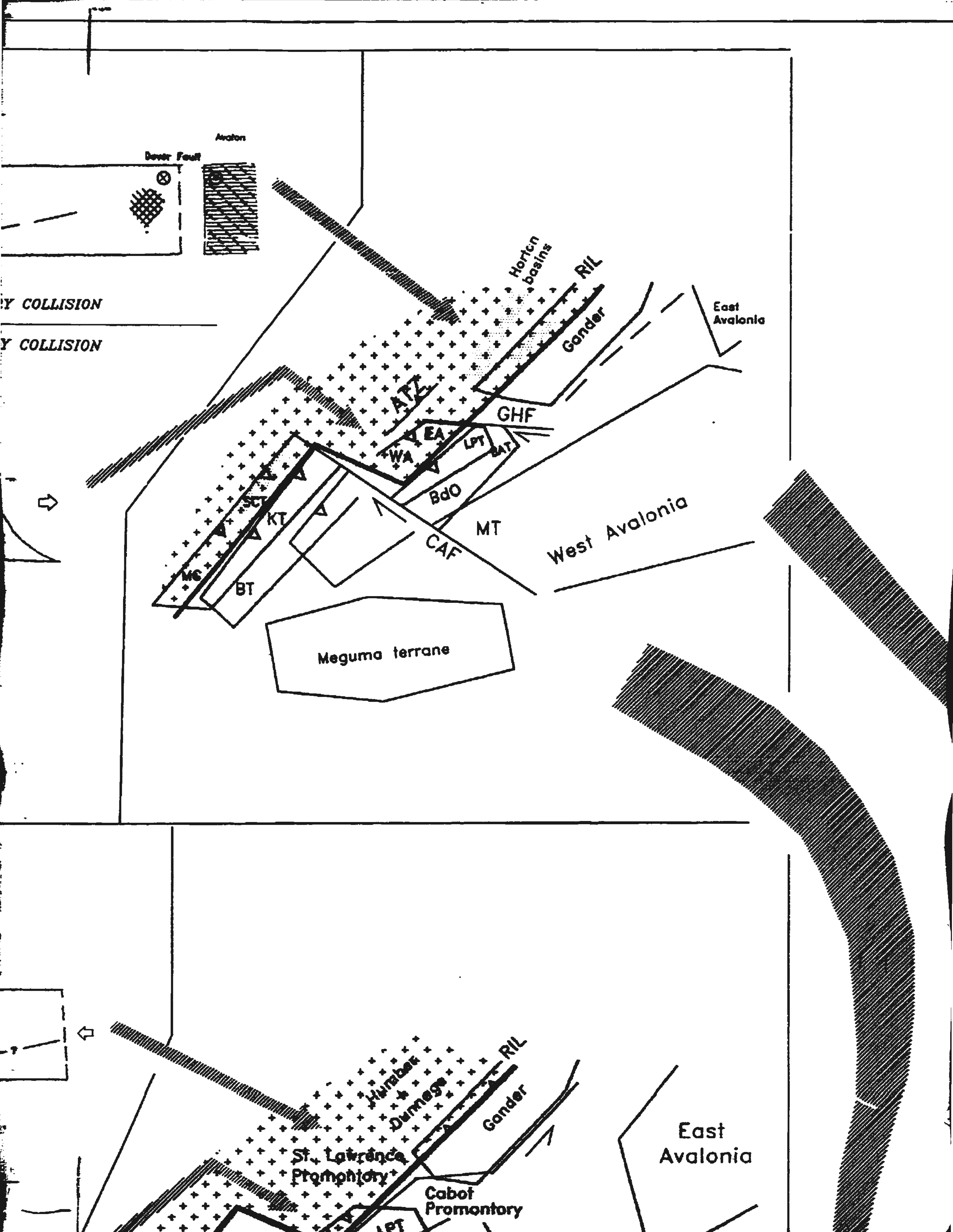
lithosphere of oceanic plateaus
(Avalonian microcontinental fgmts?)

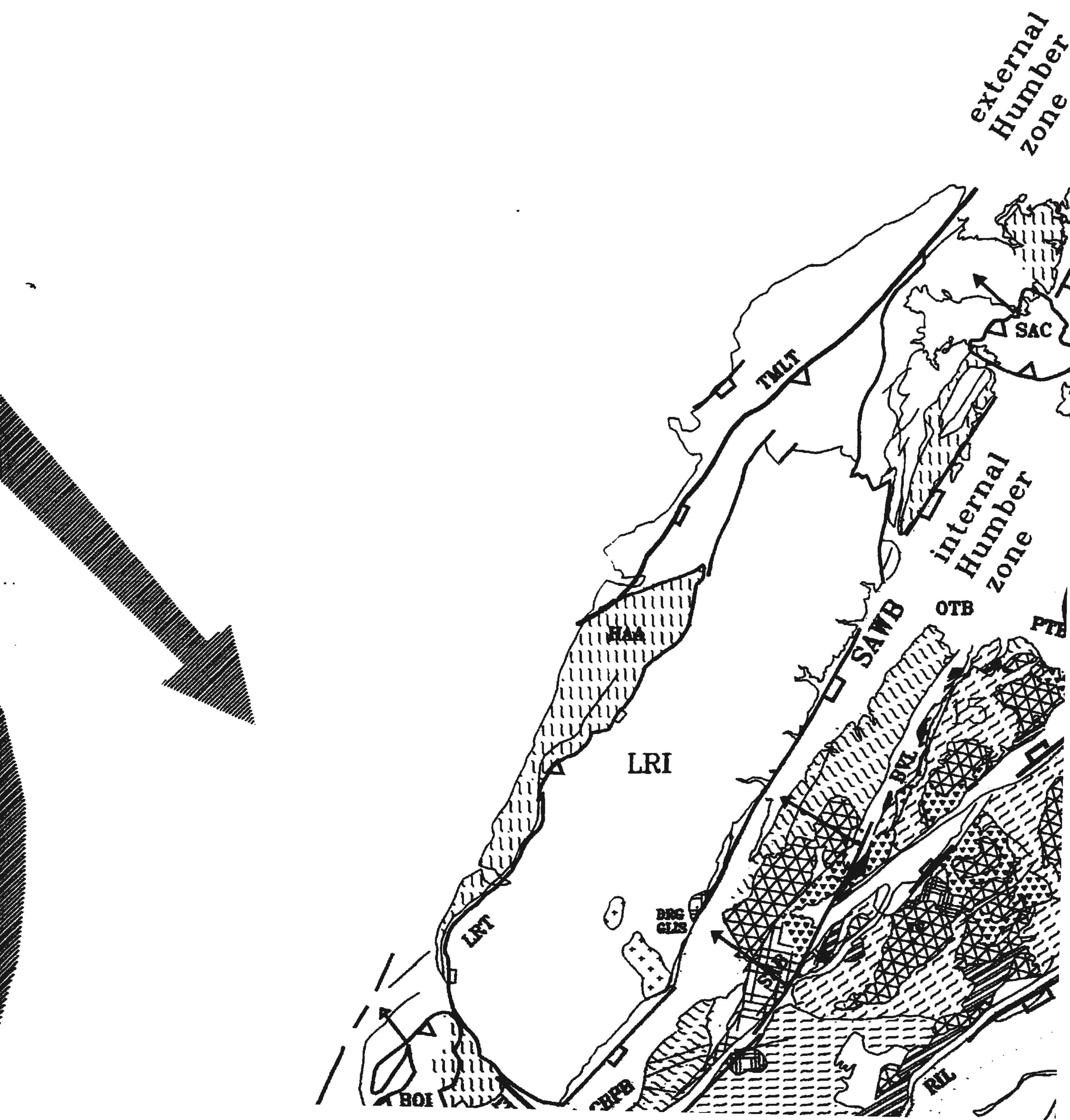
NORTH OF PROMONTORY- PROMONTORY COLLISION

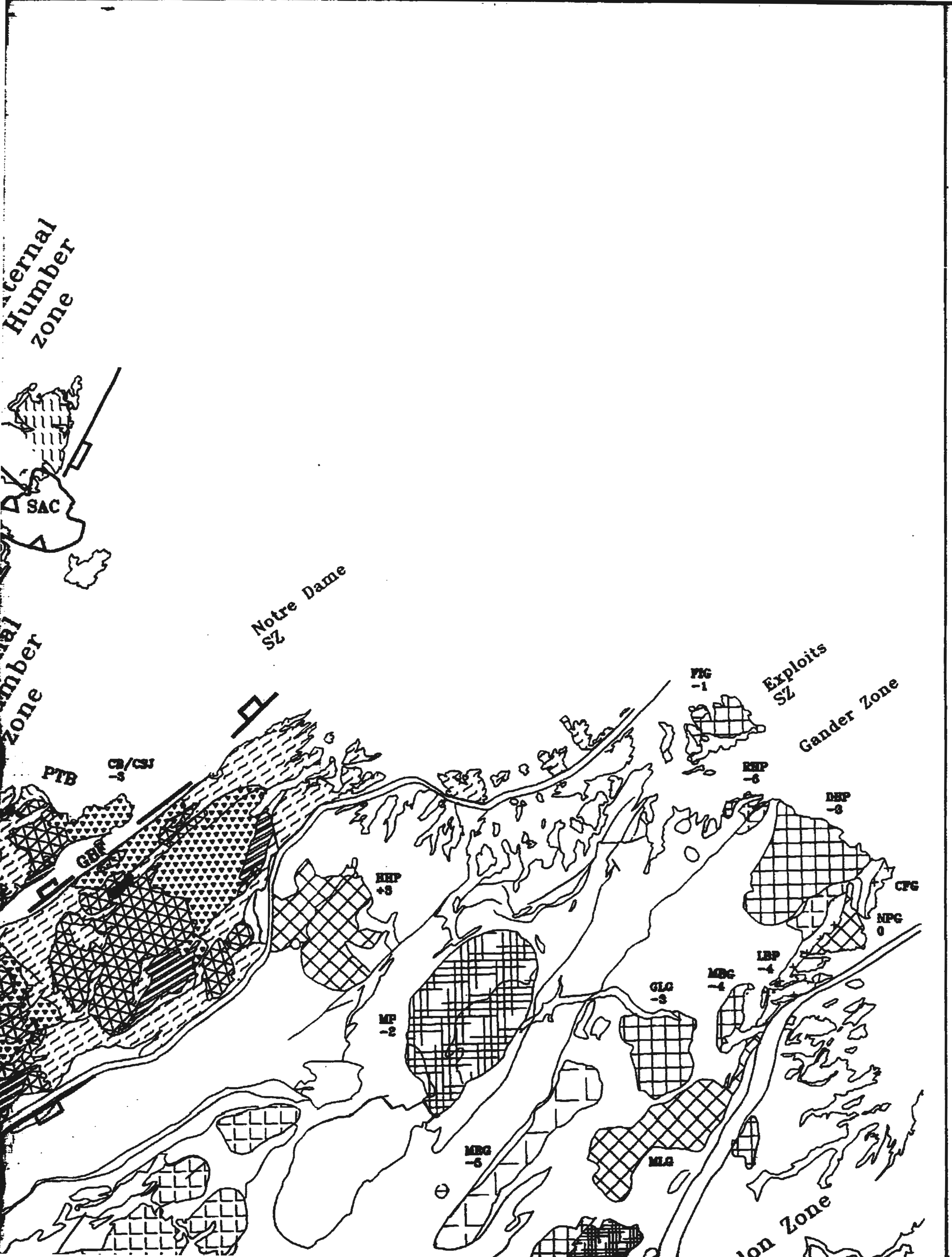
ZONE OF PROMONTORY- PROMONTORY COLLISION

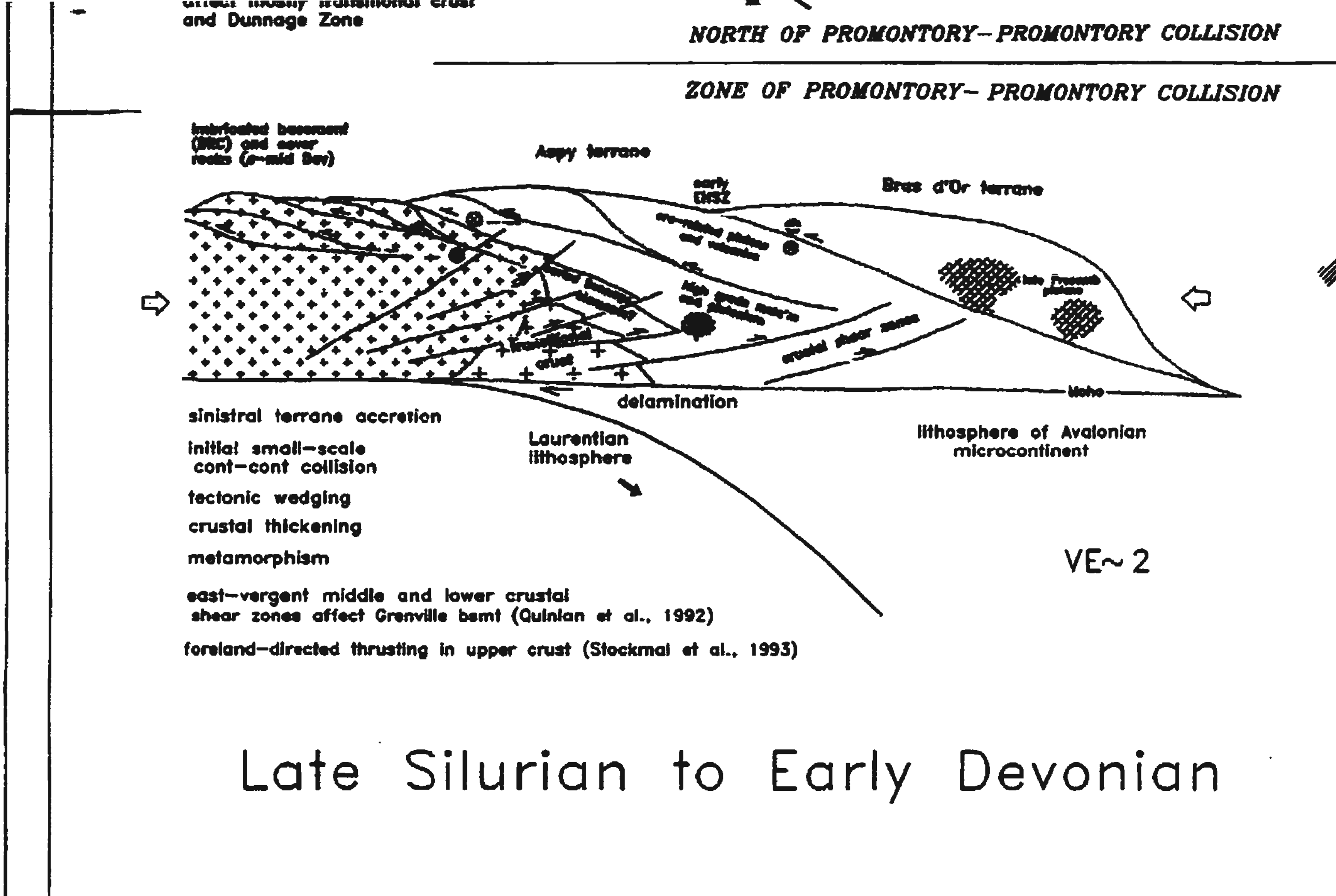
imbricated basement
(BRC) and cover
rocks (p-mid Dev)

Aspy terrane


Avalon
Dover Fault
Y COLLISION
Y COLLISION
Horton basins
RIL
Gander
East Avalonia
ATZ
GHF
EA
LPT
BAT
WA
BdO
SCT
KT
MC
BT
CAF
MT
West Avalonia
Meguma terrane
RIL
Humber + Dunnage
Gander
St. Lawrence Promontory
Cabot Promontory
East Avalonia
LPT


external Humber zone
SAC
TMLT
internal Humber zone
HAA
SAWB
OTB
LRI
BVL
LRT
RIL

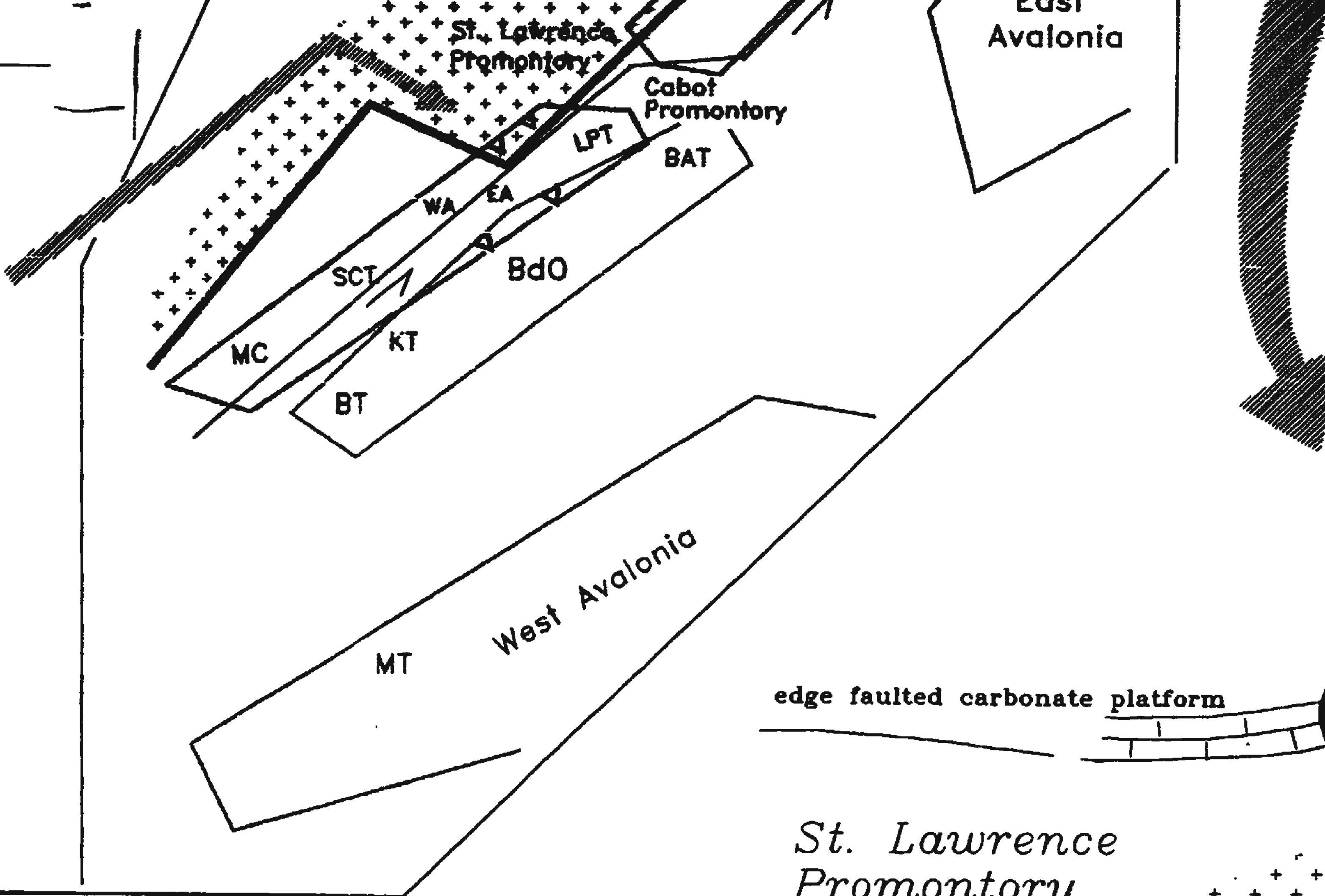

Humber
zone
SAC
Notre Dame
SZ
Exploits
SZ
Gander Zone
PTB
CB/CSJ
GBF
NPG
0
MLG
Zone



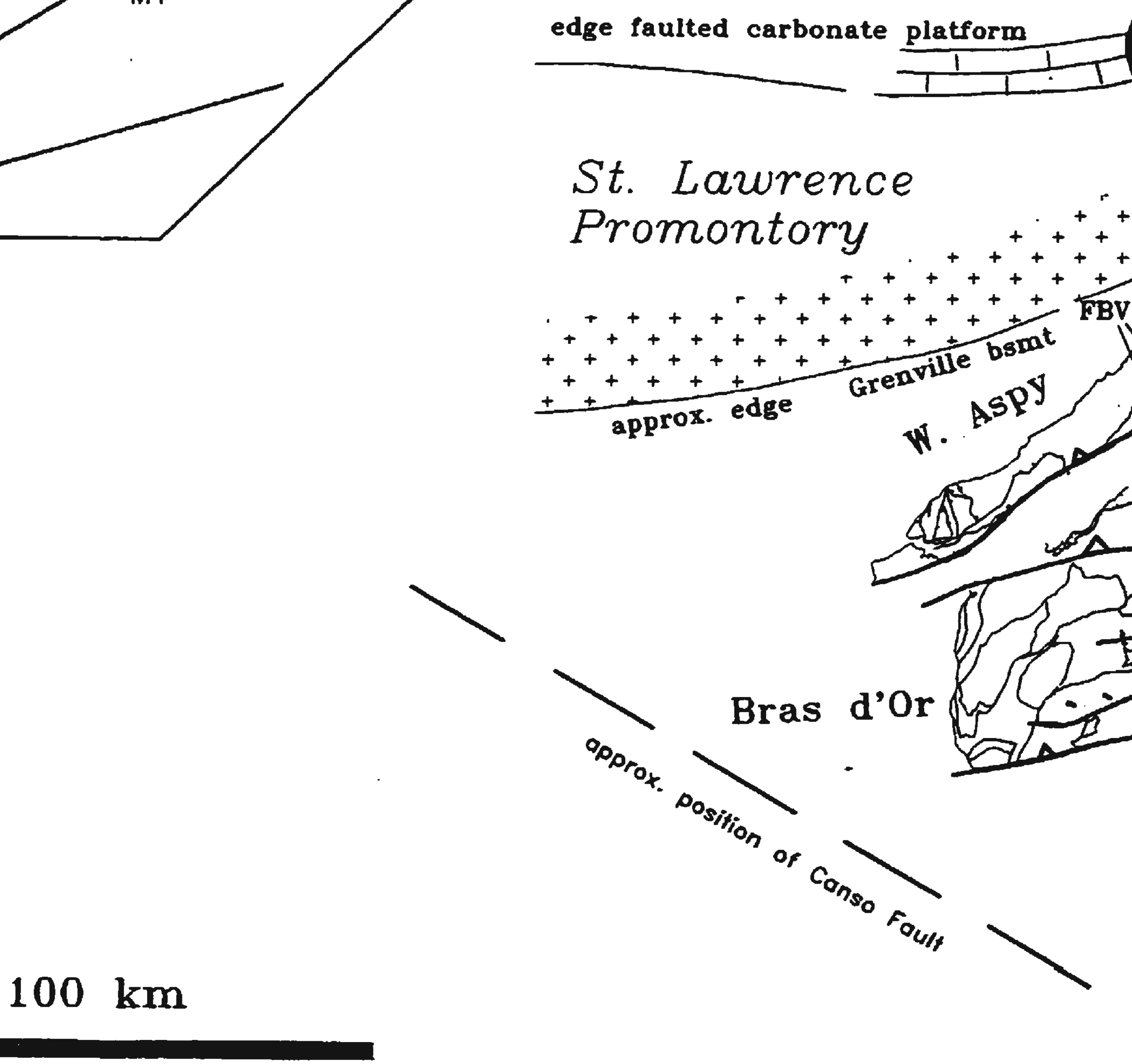
CONCEPTUAL CRUSTAL PROFILES, PLATE/TERRANE CONFIGURATIONS PALEOGEOGRAPHY at the ST. LAWRENCE PROMONTORY: 1. MIDDLE DEVONIAN (380 Ma)

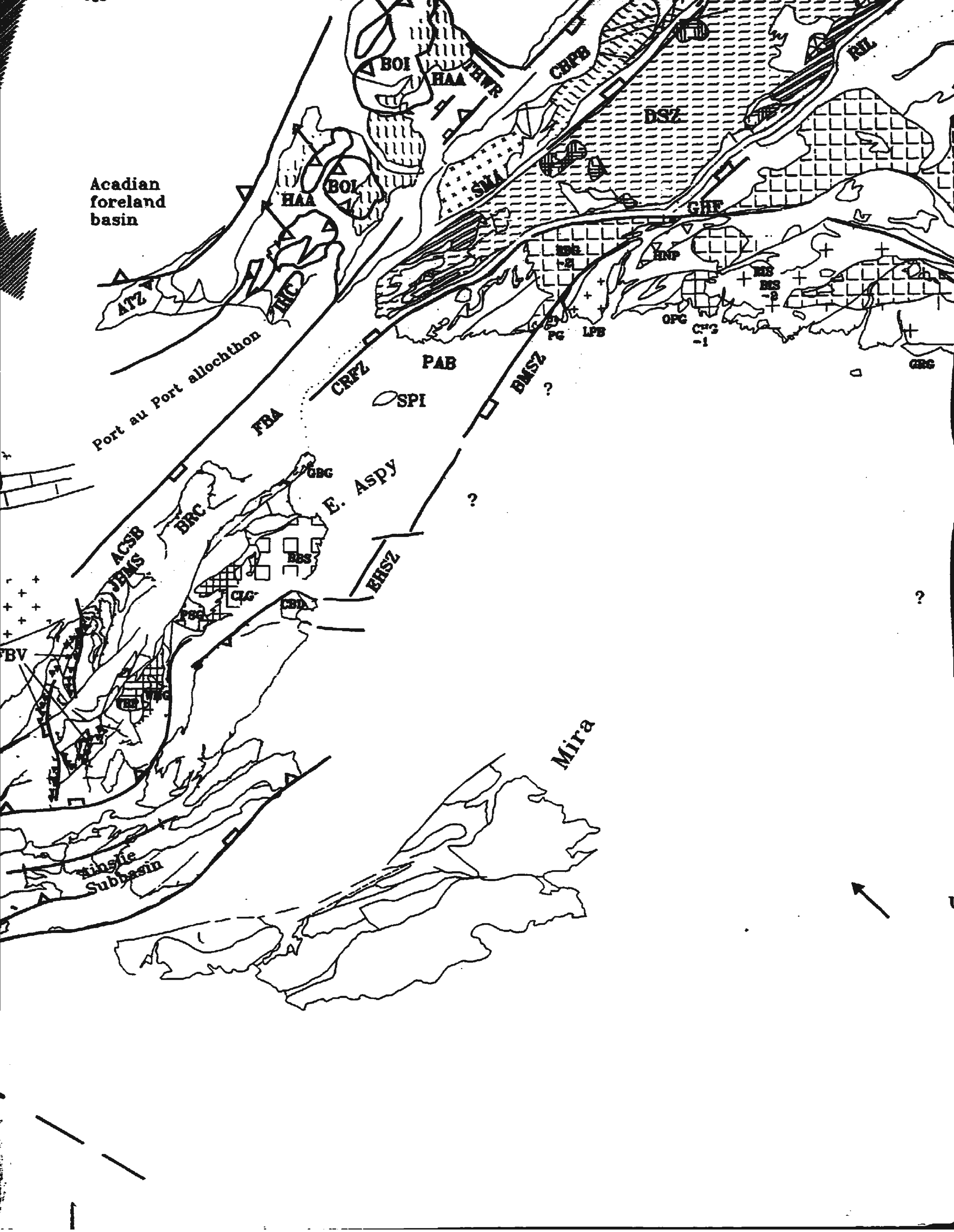
Discussion, references and abbreviations given in text.

FIGURE VII.1

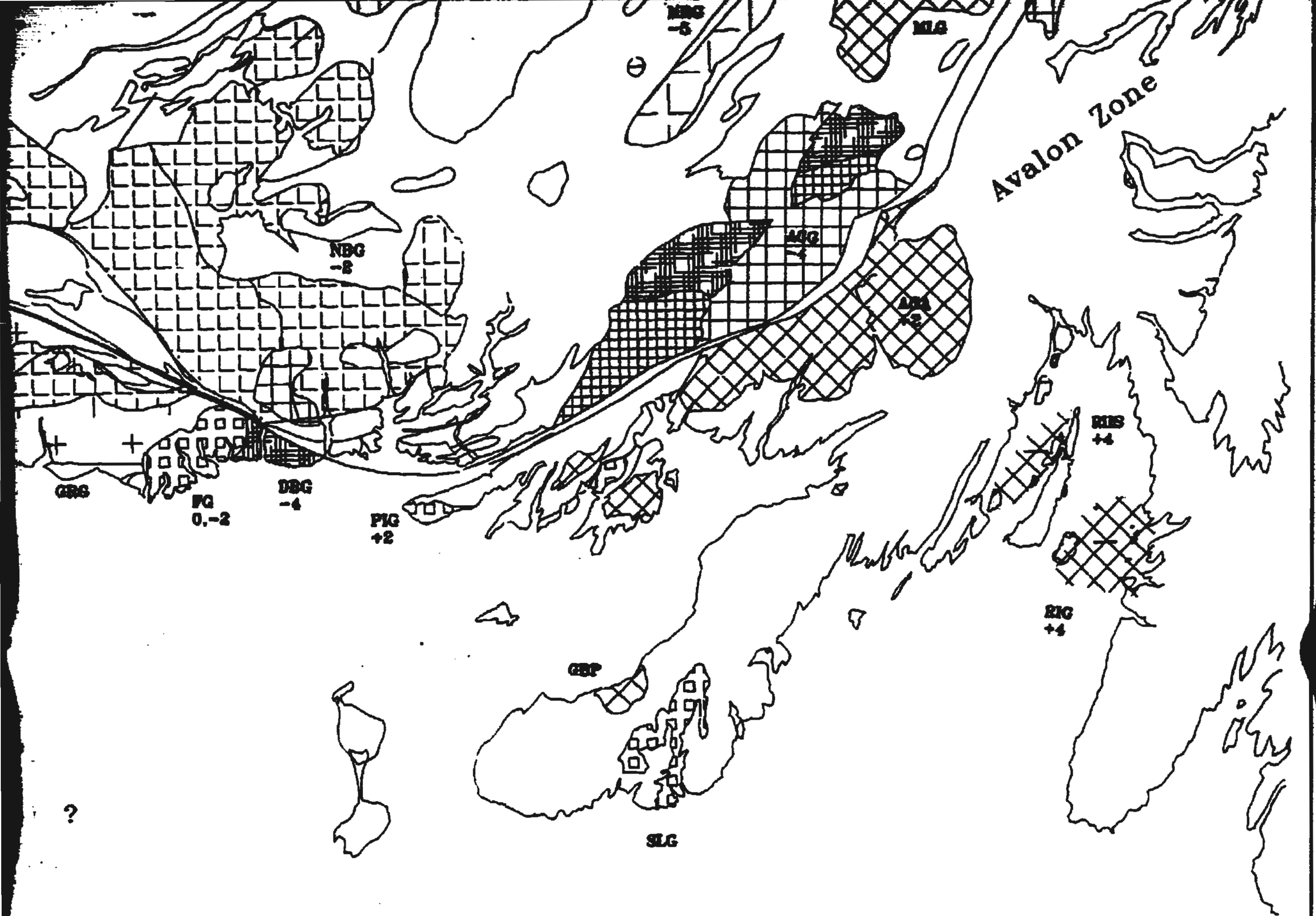

East Avalonia
St. Lawrence Promontory
Cabot Promontory
LPT
BAT
WA
EA
SCT
BdO
MC
KT
BT
West Avalonia
MT

ES,
NS, and
)


edge faulted carbonate platform
St. Lawrence Promontory
FBV
approx. edge Grenville bsmt
W. Aspy
Bras d'Or
approx. position of Canso Fault
100 km



Acadian foreland basin
ATZ
HAA
BOI
BOI
HAA
CHPB
DSZ
SMA
RIL
GHF
HNP
PG
LPB
OPG
PAB
CRFZ
SPI
BMSZ
Port au Port allochthon
FRA
GBG
E. Aspy
BRC
ACSB
JBMS
BBS
CLG
CBD
EHSZ
PSG
FBV
Mira
Ainslie Subbasin
GRG



upper crustal detachment

pre–Horton and incipient
Horton basins

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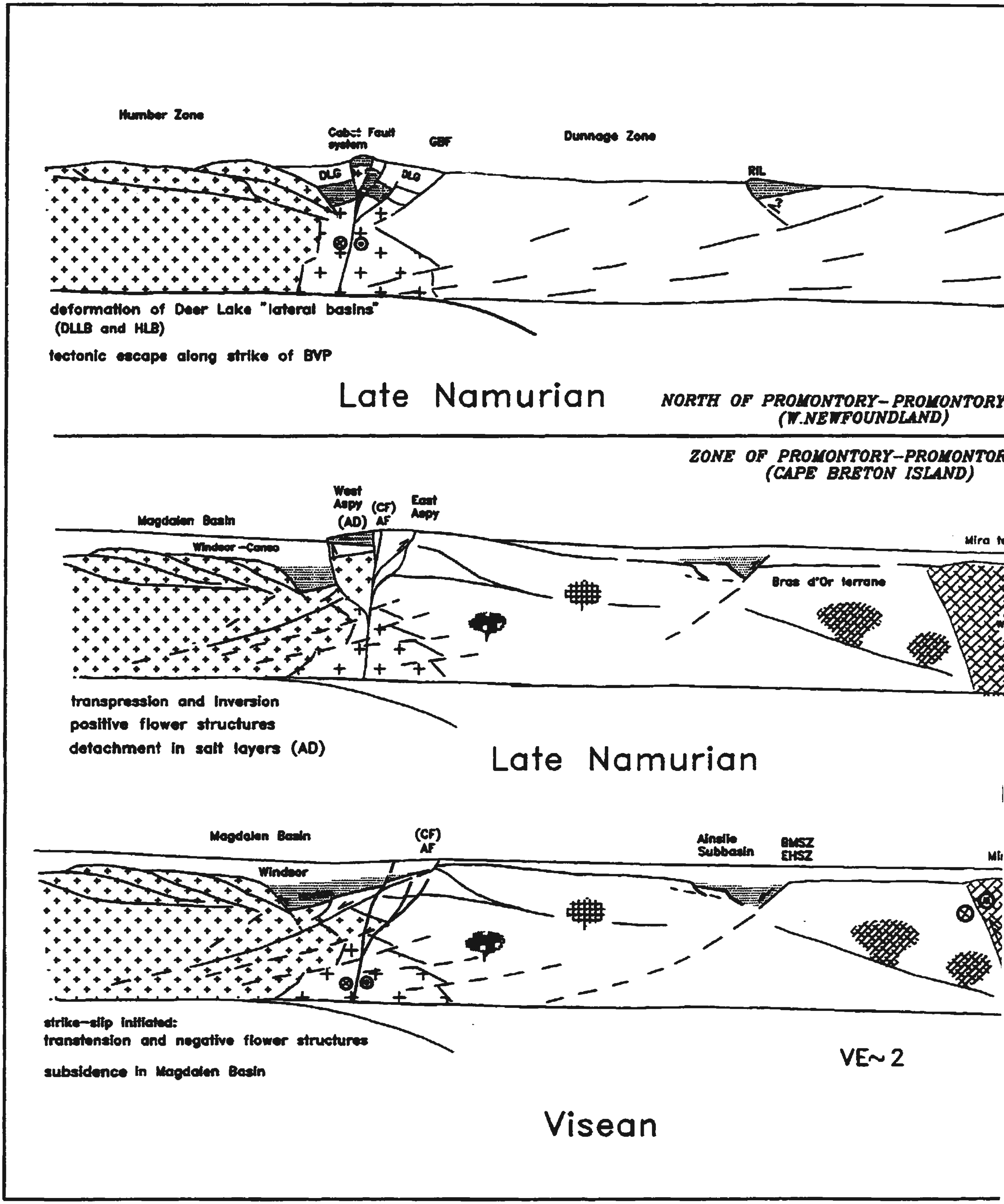
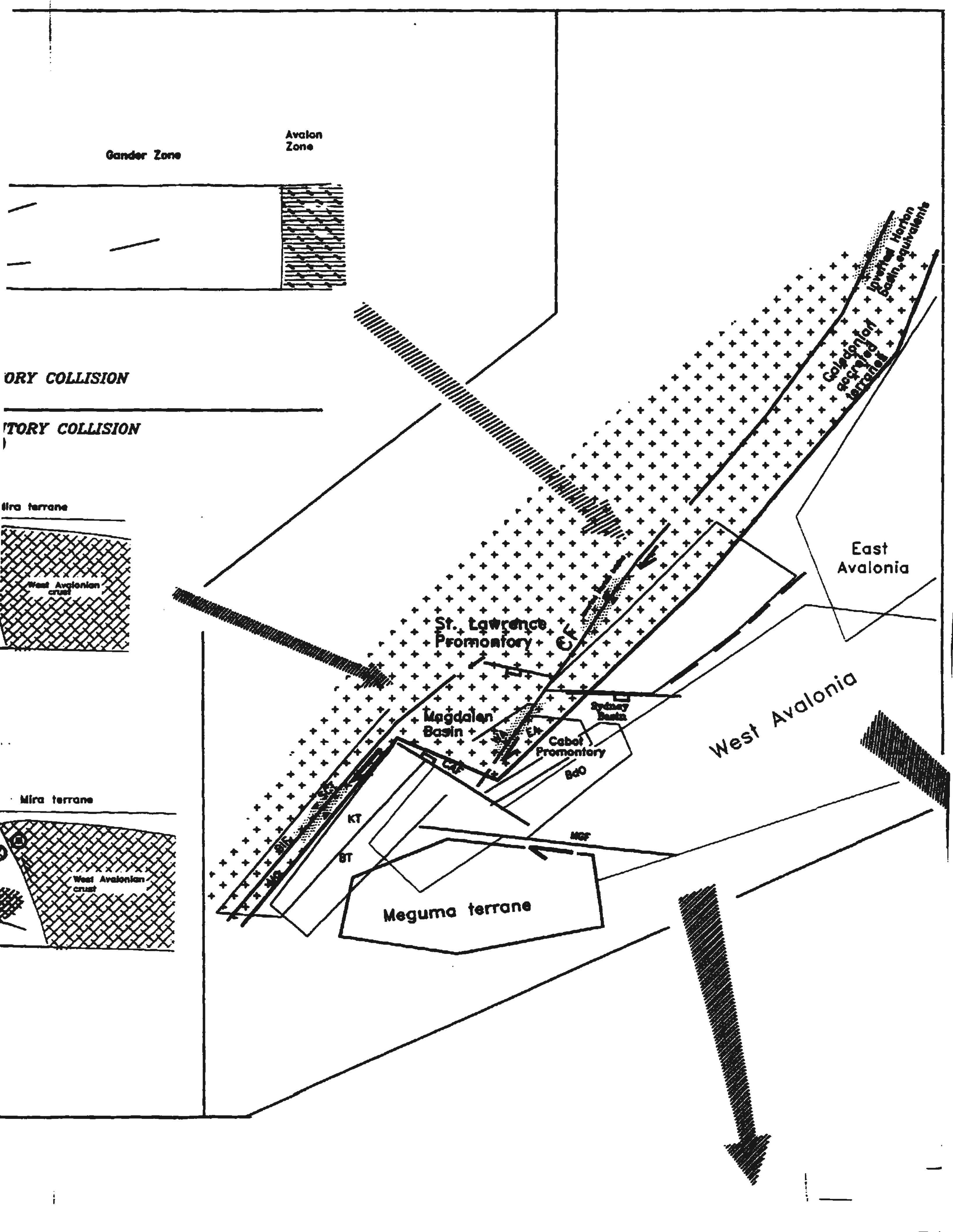
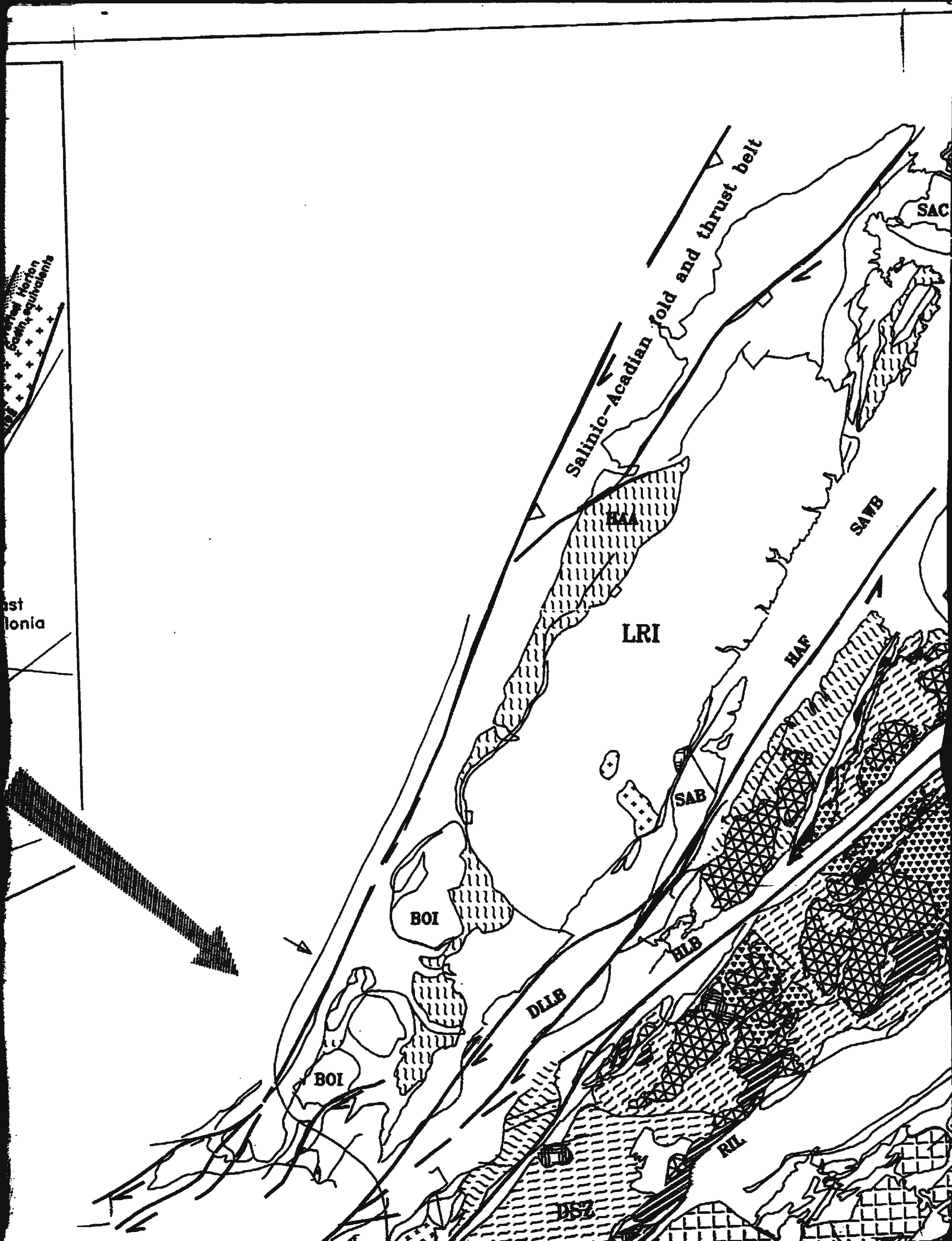
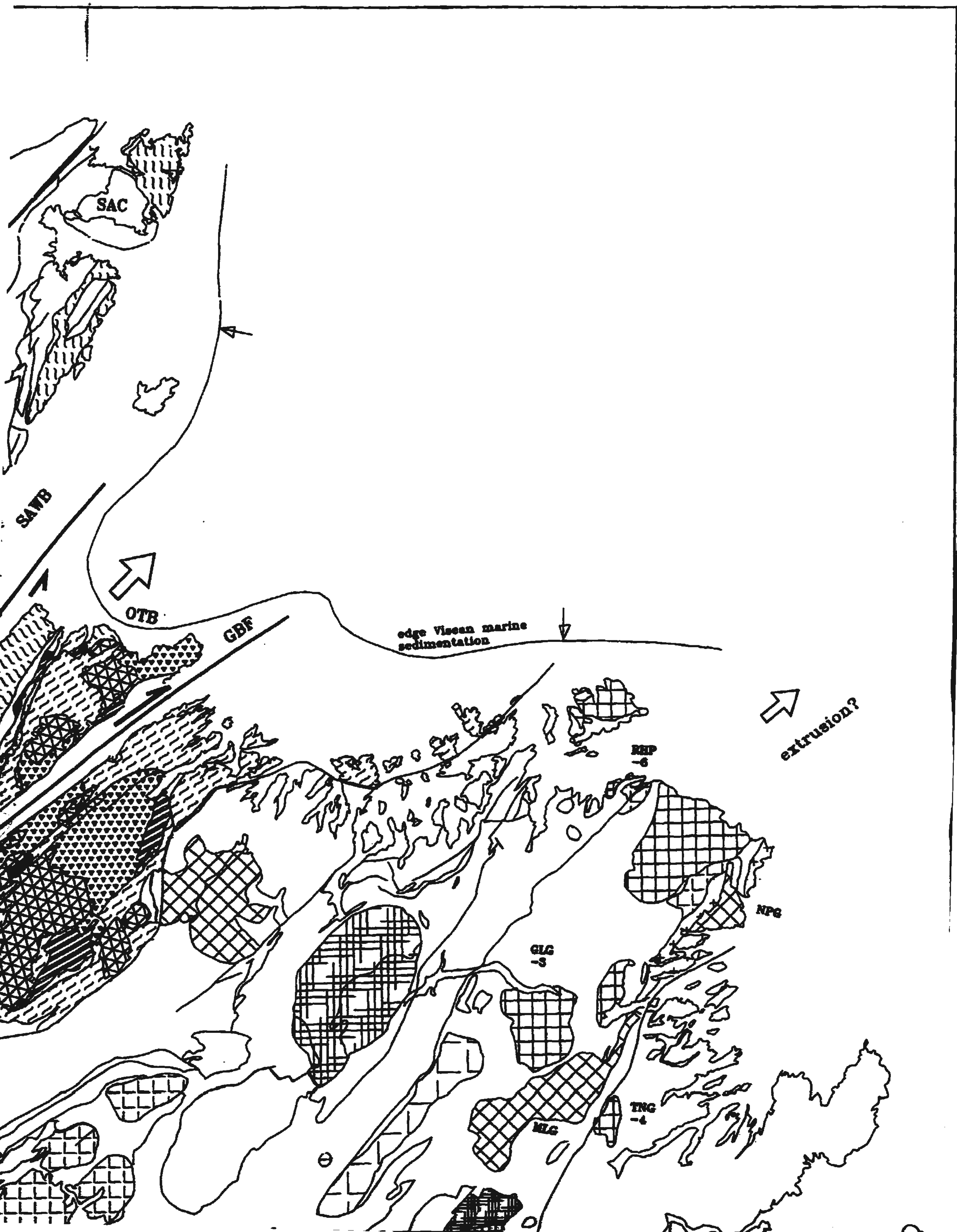

Humber Zone
Cabot Fault system
GBF
Dunnage Zone
DLG
DLG
RIL
deformation of Deer Lake "lateral basins" (DLLB and HLB)
tectonic escape along strike of BVP
Late Namurian
NORTH OF PROMONTORY-PROMONTORY
(W.NEWFOUNDLAND)
ZONE OF PROMONTORY-PROMONTOR
(CAPE BRETON ISLAND)
Magdalen Basin
Windsor-Canso
West Aspy (AD)
(CF) AF
East Aspy
Bras d'Or terrane
transpression and inversion
positive flower structures
detachment in salt layers (AD)
Late Namurian
Magdalen Basin
Windsor
(CF) AF
Ainslie Subbasin
BMSZ
EHSZ
strike-slip initiated:
transtension and negative flower structures
subsidence in Magdalen Basin
VE~2
Visean



Gander Zone
Avalon Zone
ORY COLLISION
TORY COLLISION
Mira terrane
West Avalonian crust
Mira terrane
West Avalonian crust
Inverted Horton Basin equivalents
Caledonian accreted terranes
East Avalonia
St. Lawrence Promontory
Magdalen Basin
Sydney Basin
Cabot Promontory
CAF
BdO
KT
BT
MGF
West Avalonia
Meguma terrane


Salinic-Acadian fold and thrust belt
SAC
HAA
LRI
SAWB
HAF
SAB
BOI
HLB
DLLB
BOI
RIL
DSZ



SAC
SAWB
OTB
GBF
edge Visean marine sedimentation
extrusion?
RHP
-6
NPG
GLG
-3
TNG
-4
MLG

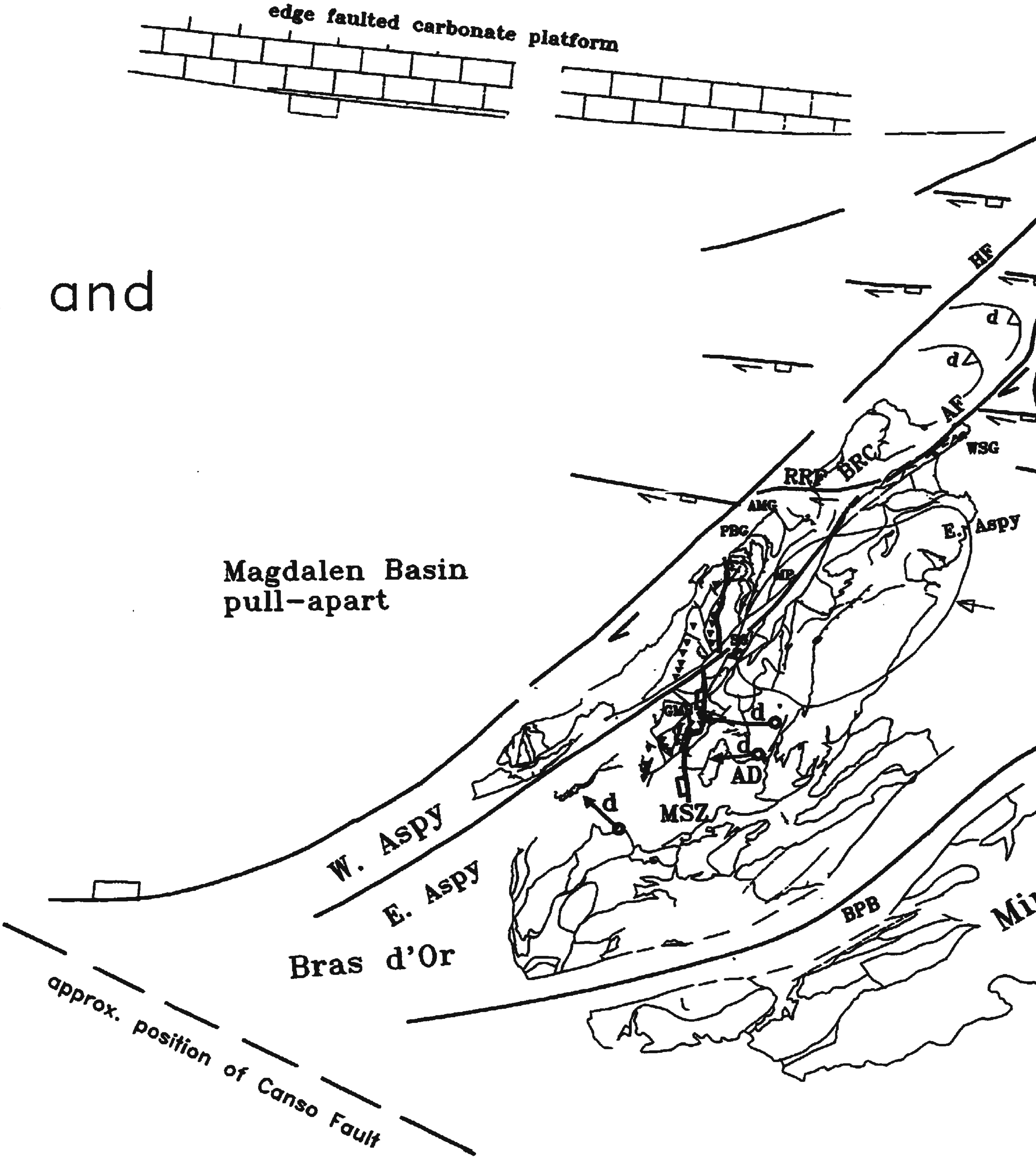
CONCEPTUAL CRUSTAL PROFILES, PLATE/TERRANE CONFIGURATIONS PALEOGEOGRAPHY at the ST. LAWRENCE PROMONTORY: 2. LATE NAMURIAN (320 Ma)

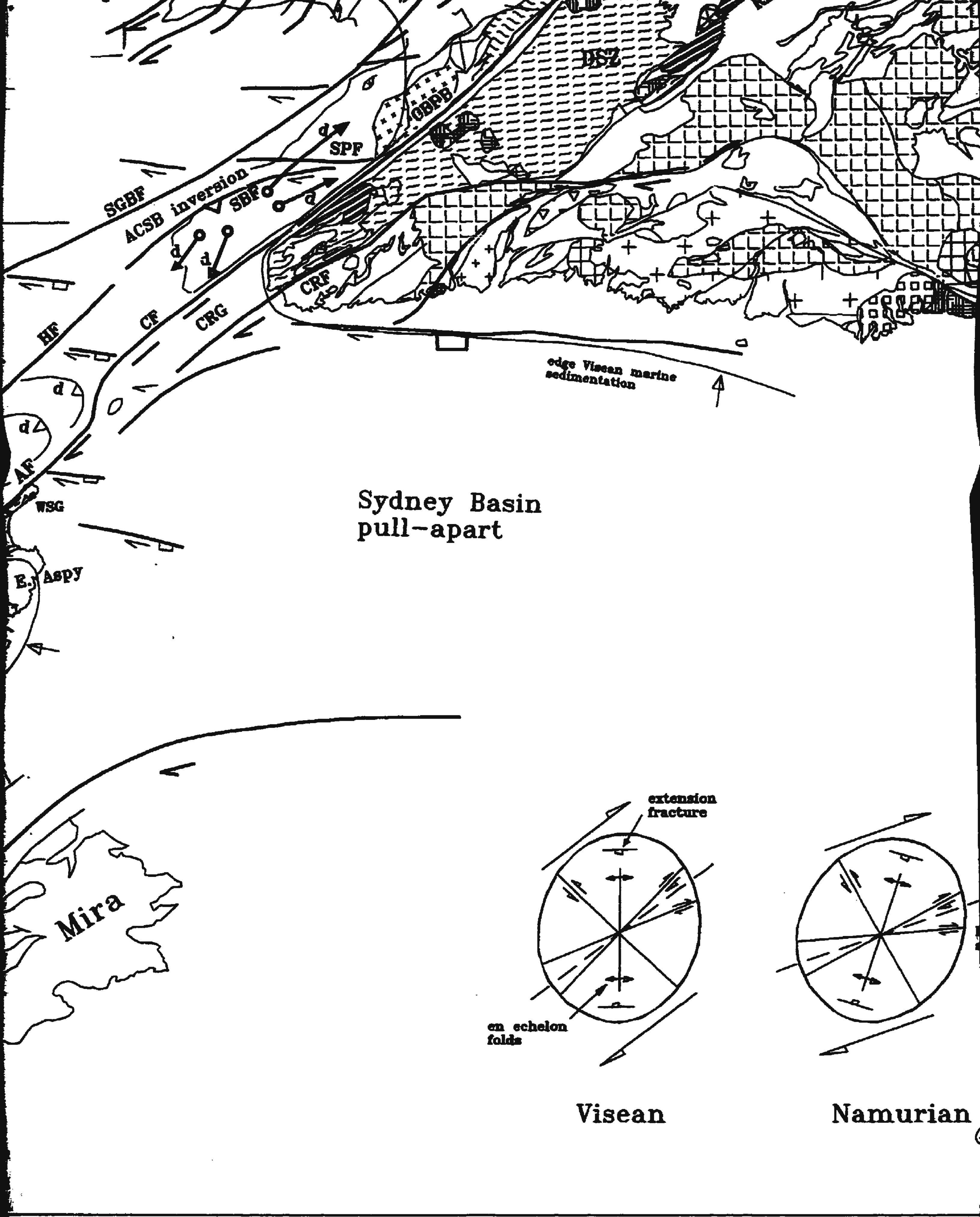
Discussion, references and abbreviations given in text.

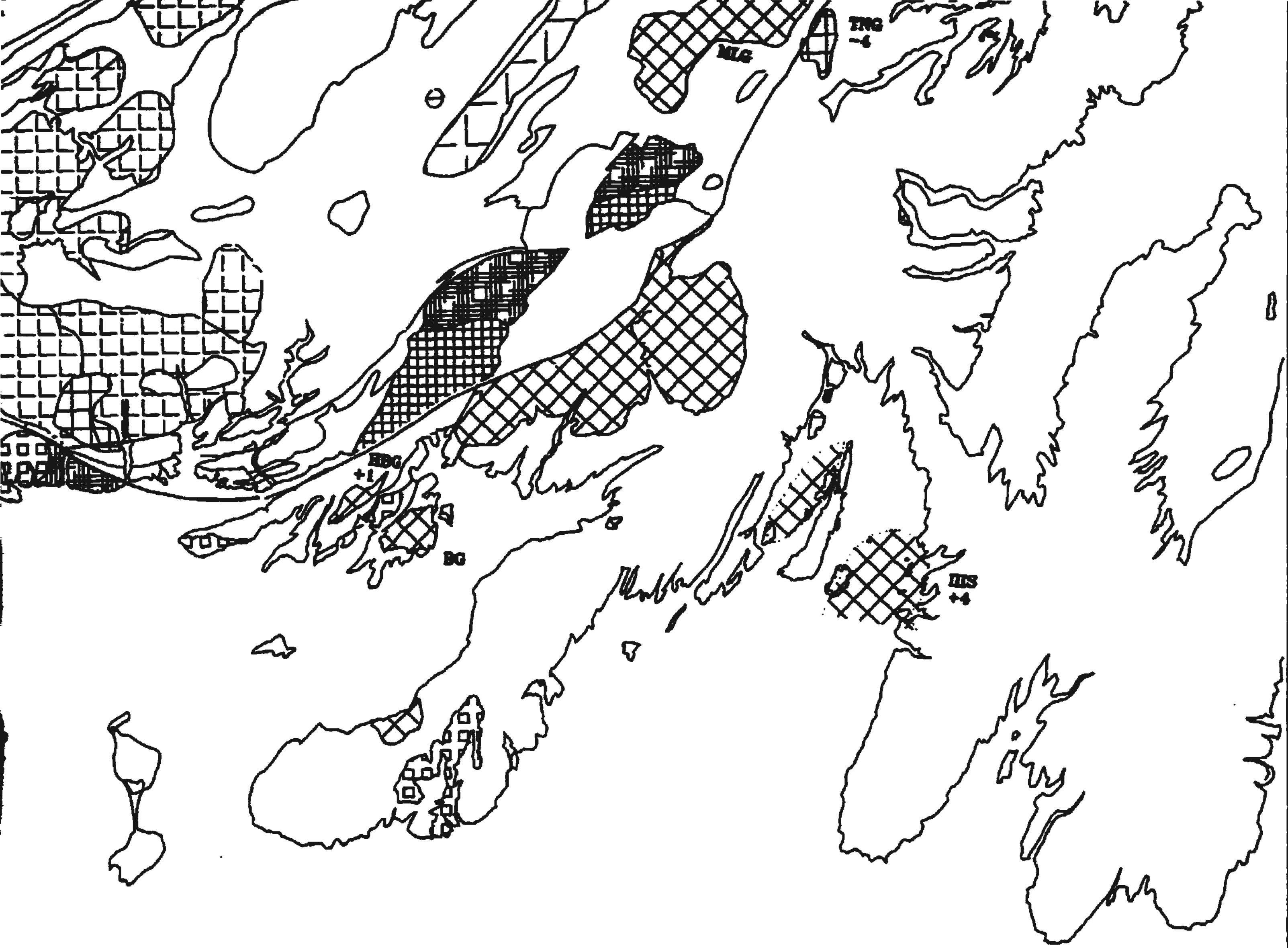
100 KM

FIGURE VIII.1

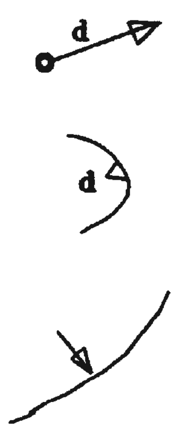
S,
S, and


edge faulted carbonate platform
HF
d
d
AF
WSG
RRF
BRC
AMG
PBG
E. Aspy
Magdalen Basin
pull-apart
d
d
AD
d
MSZ
W. Aspy
E. Aspy
Bras d'Or
BPB
approx. position of Canso Fault


BSZ
GBPB
SPF
SGBF
ACSB inversion
SBF
d
CRF
HF
CF
CRG
edge Visean marine sedimentation
AF
WSG
E. Aspy
Sydney Basin pull-apart
Mira
extension fracture
en echelon folds
Visean
Namurian



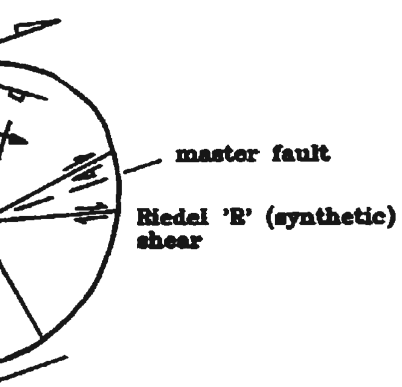
Rocky Brook tectonic lake



Namurian detachment in b/Windsor
(Ainslie Detachment and equivalents)

Namurian-age decollement in b/Windsor

approx. limit of
sedimentation



urian

NOTE TO USERS

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LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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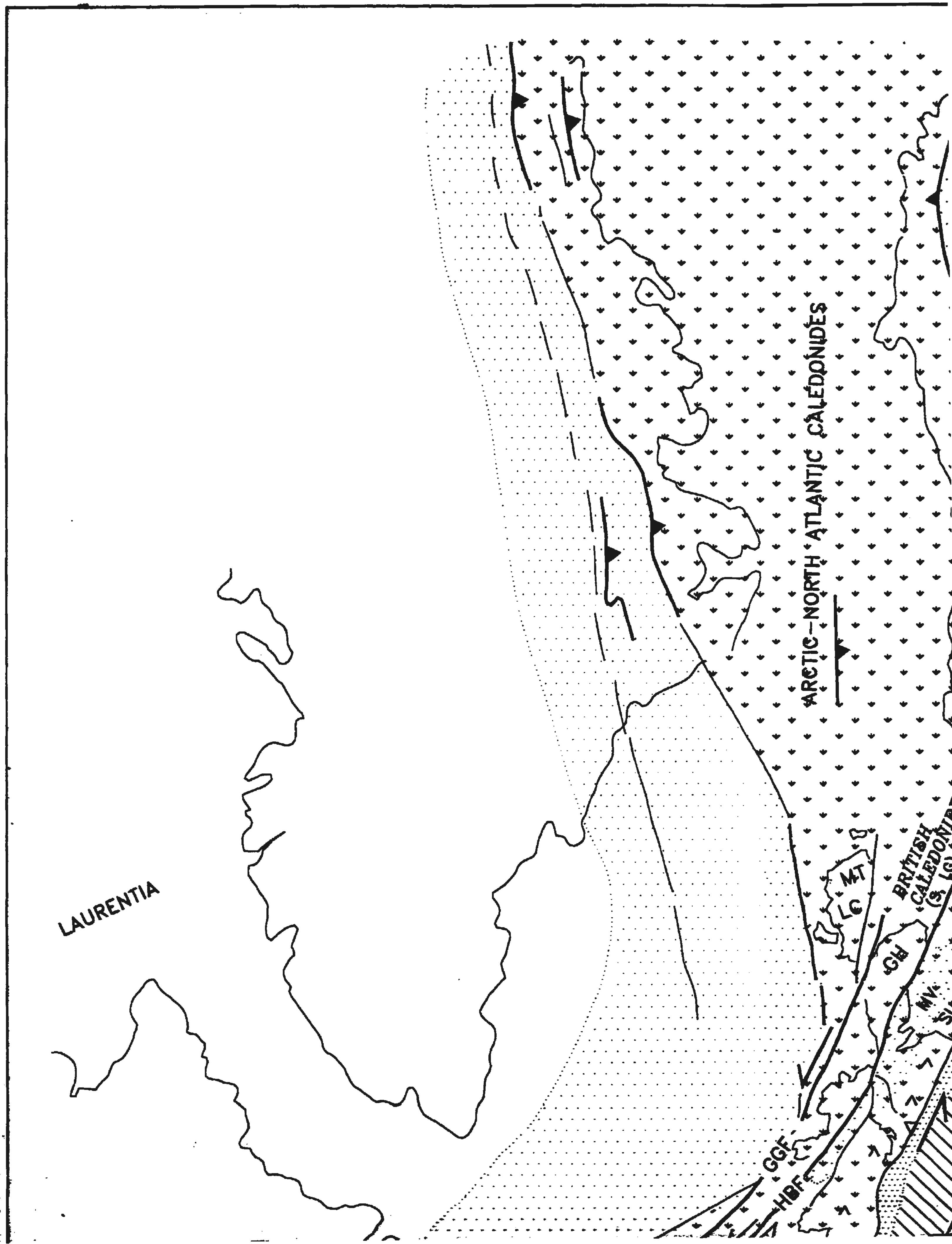


LAURENTIA
ARCTIC-NORTH ATLANTIC CALEDONIDES
BRITISH
MT
LC
GH
MV
GGF
HBF

42
Ea

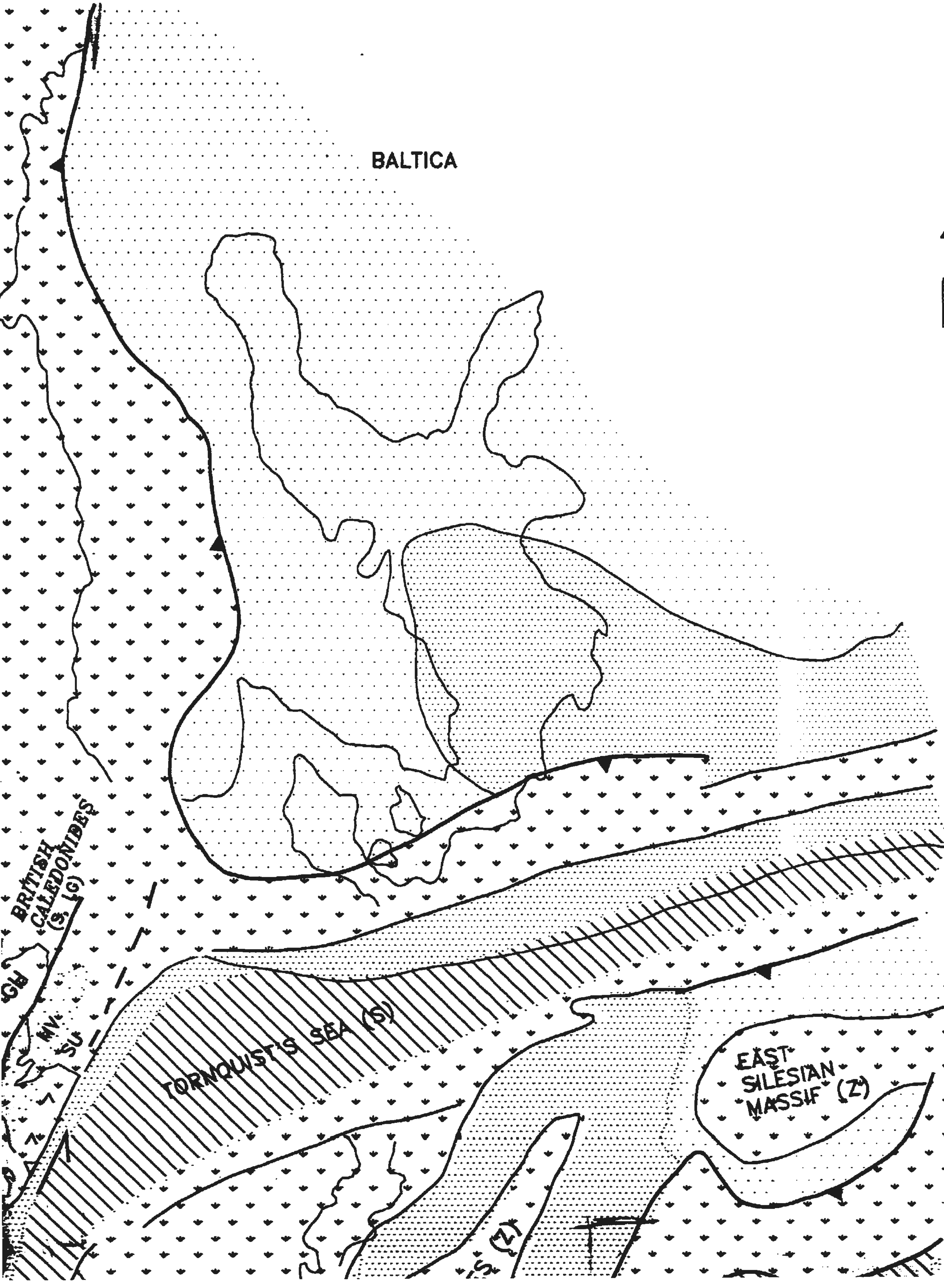
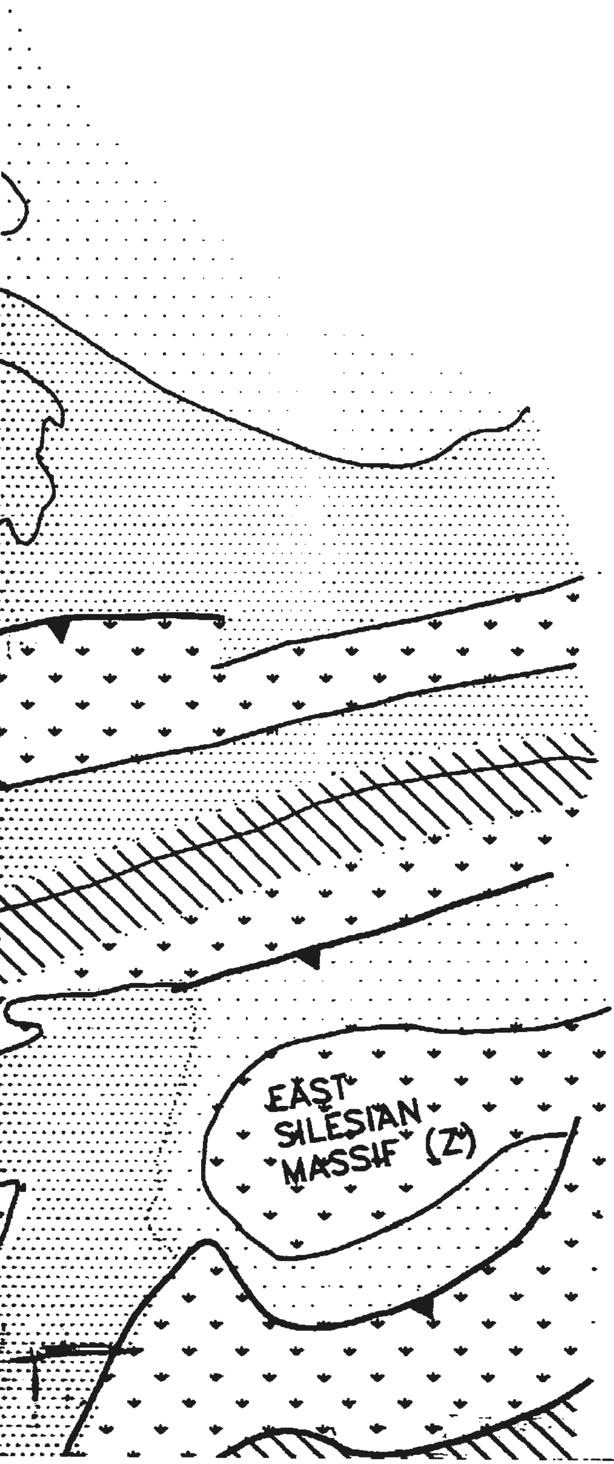
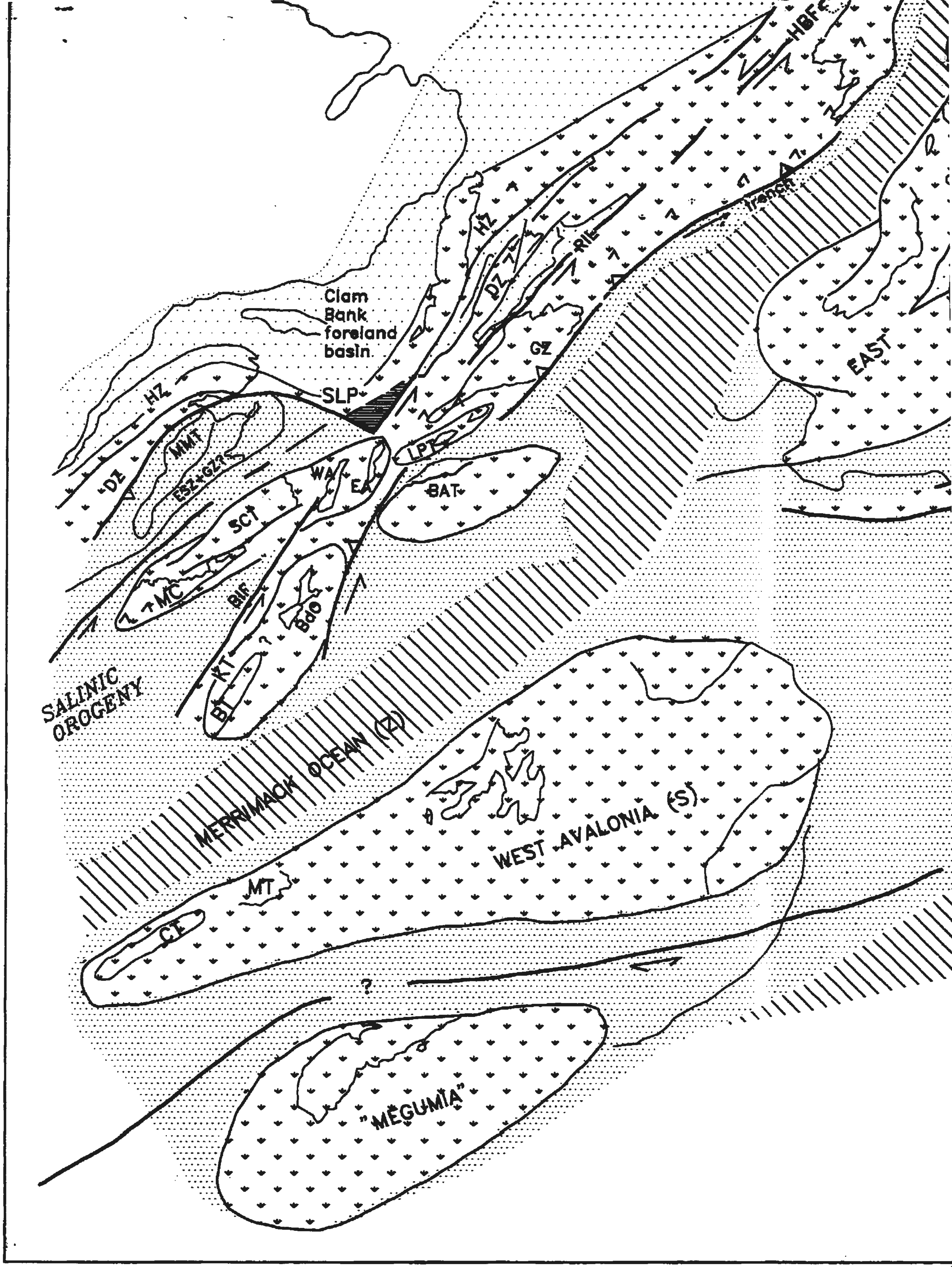

BALTICA
BRITISH
CALEDONIDES
(S, LG)
MV
SU
TORNQUIST'S SEA (S)
EAST
SILESIAN
MASSIF (Z)

FIGURE X.3

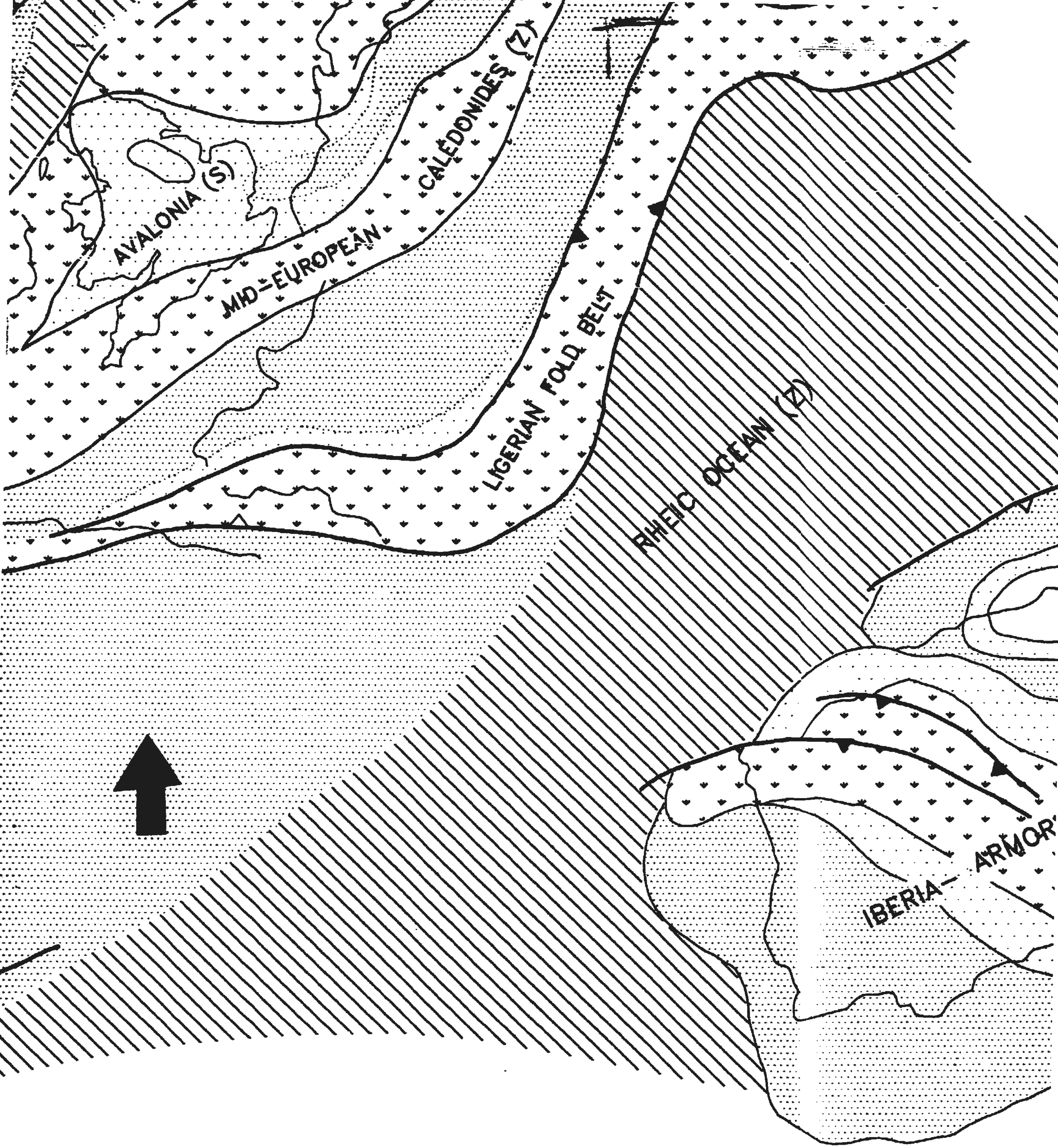
420 Ma
Early Ludlow

400 km

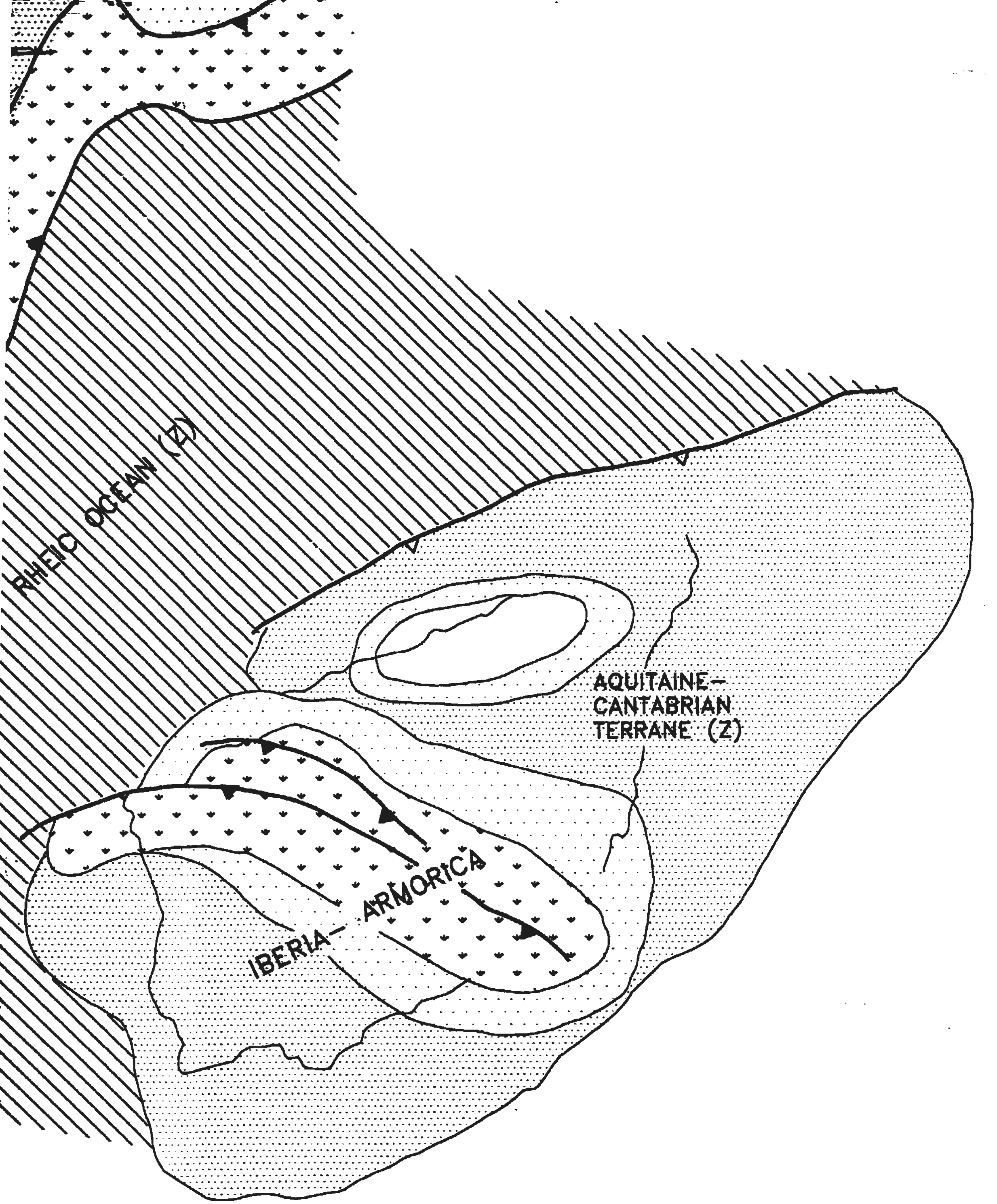




HBFC
trench
HZ
RIL
DZ
GZ
EAST
Clam
Bank
foreland
basin
SLP
HZ
MMT
DZ
ESZ+GZ?
WA
EA
LPT
BAT
SCT
MC
BIF
BdO
KT
BT
SALINIC
OROGENY
MERRIMACK OCEAN (Z)
WEST AVALONIA (S)
MT
CT
?
"MEGUMIA"

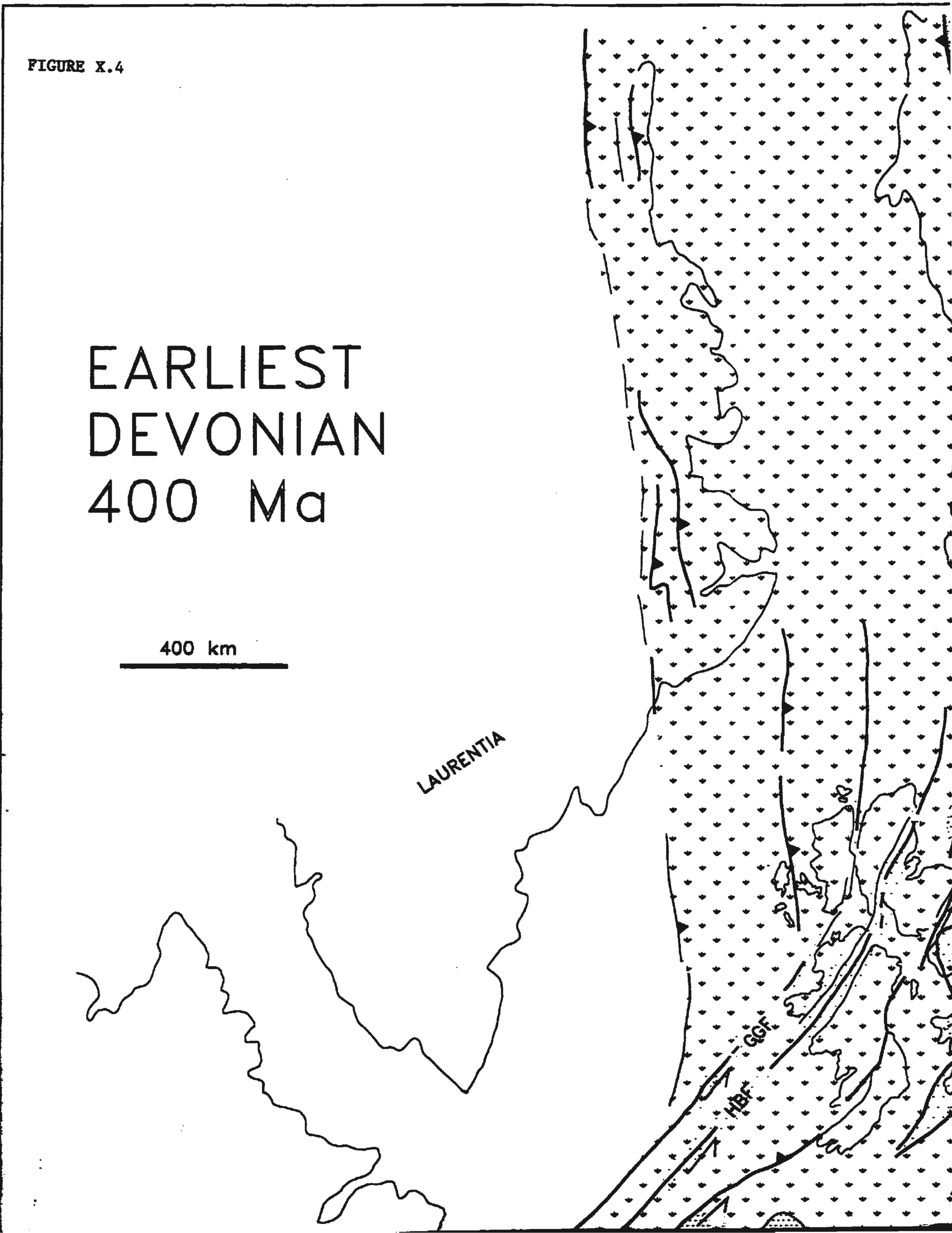


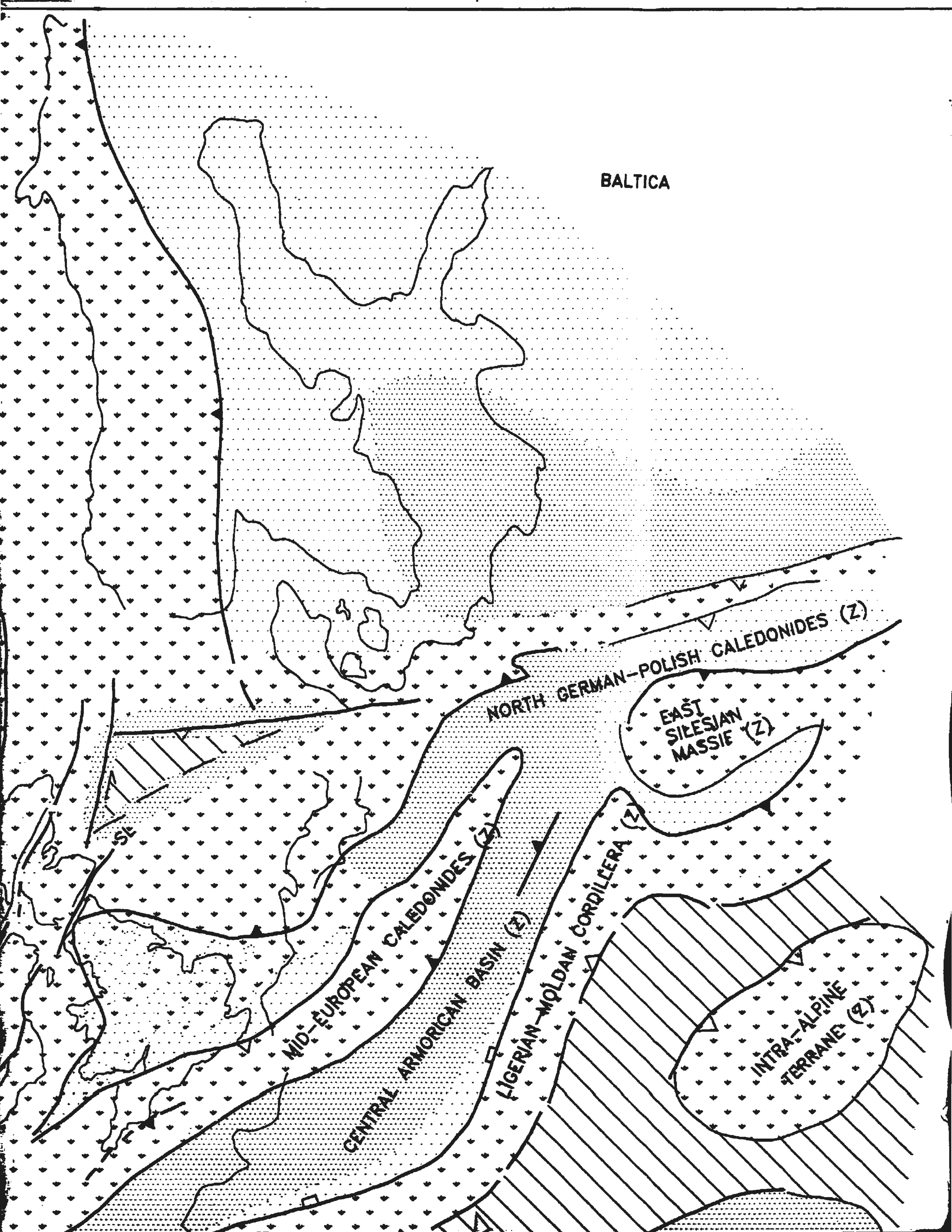
AVALONIA (S)
MID-EUROPEAN
CALEDONIDES (Z)
LIGERIAN FOLD BELT
RHEIC OCEAN (Z)
IBERIA- ARMOR



RHEIC OCEAN (Z)
AQUITAINE-
CANTABRIAN
TERRANE (Z)
IBERIA- ARMORICA

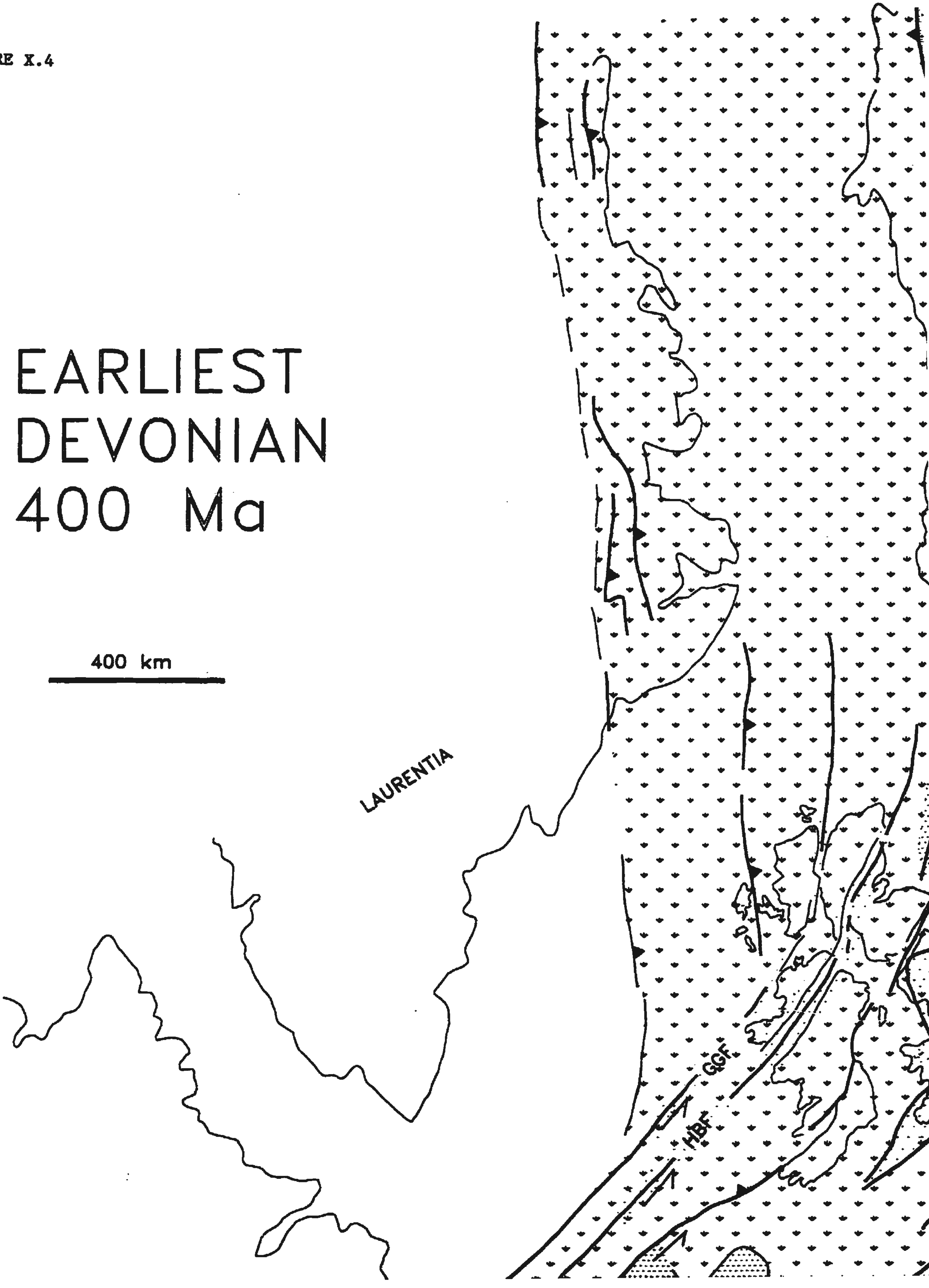
FIGURE X.4

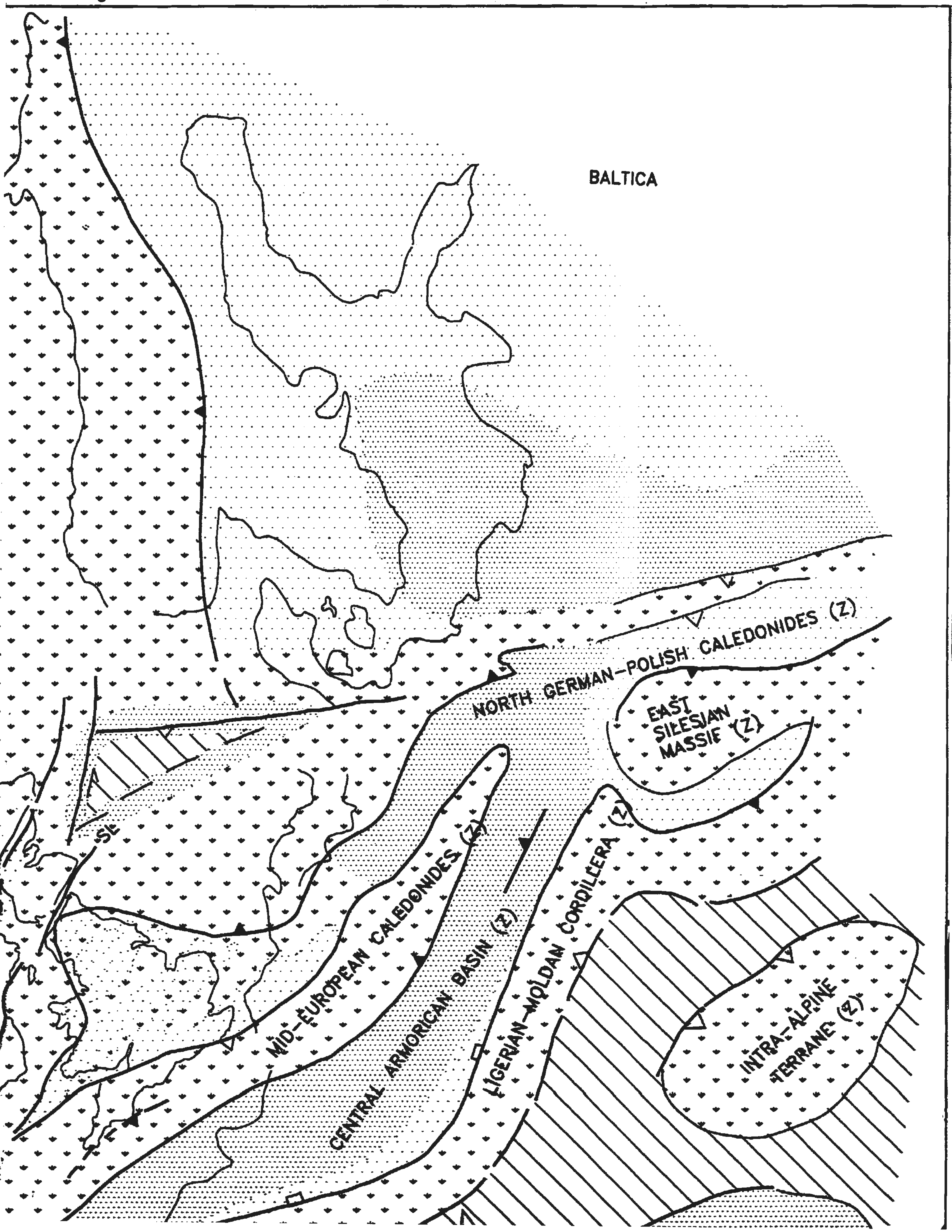




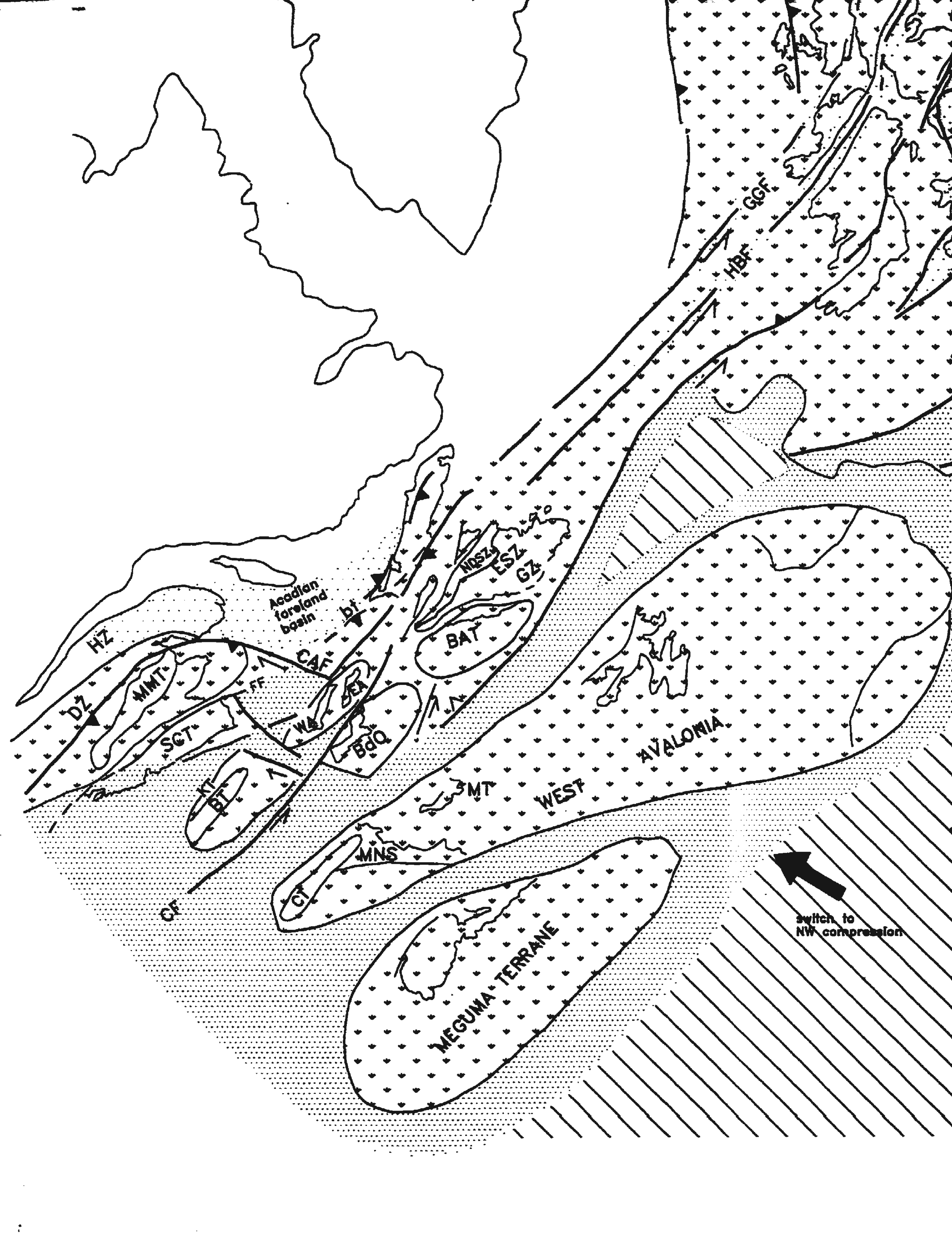
BALTICA
NORTH GERMAN-POLISH CALEDONIDES (Z)
EAST SILESIAN MASSIE (Z)
SL
MID-EUROPEAN CALEDONIDES (Z)
CENTRAL ARMORICAN BASIN (Z)
LIGERIAN-MOLDAN CORDILLERA (Z)
INTRA-ALPINE TERRANE (Z)

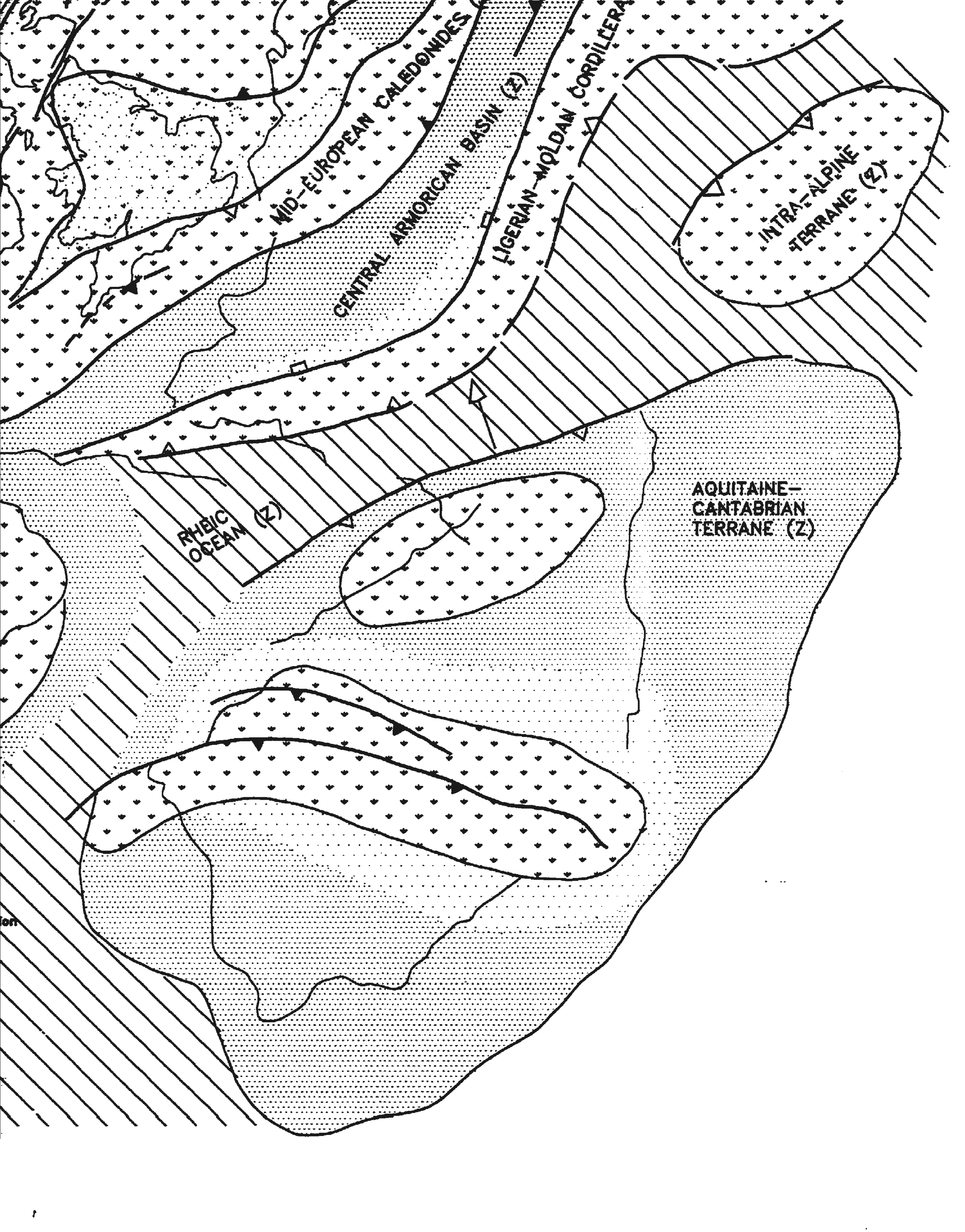
FIGURE X.4





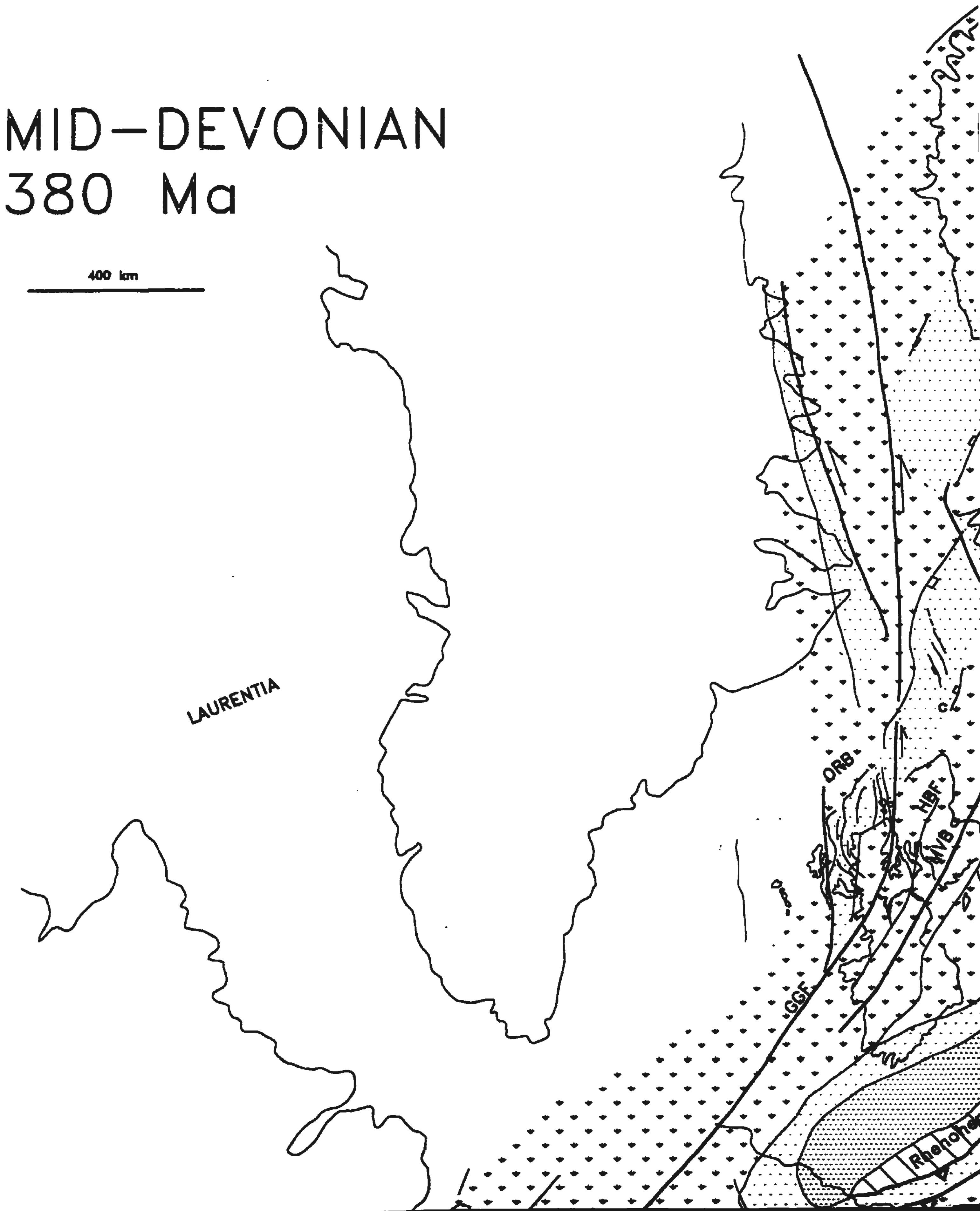
BALTICA
NORTH GERMAN-POLISH CALEDONIDES (Z)
EAST SILESIAN MASSIE (Z)
SL
MID-EUROPEAN CALEDONIDES (Z)
CENTRAL ARMORICAN BASIN (Z)
LIGERIAN-MOLDAN CORDILLERA (Z)
INTRA-ALPINE TERRANE (Z)

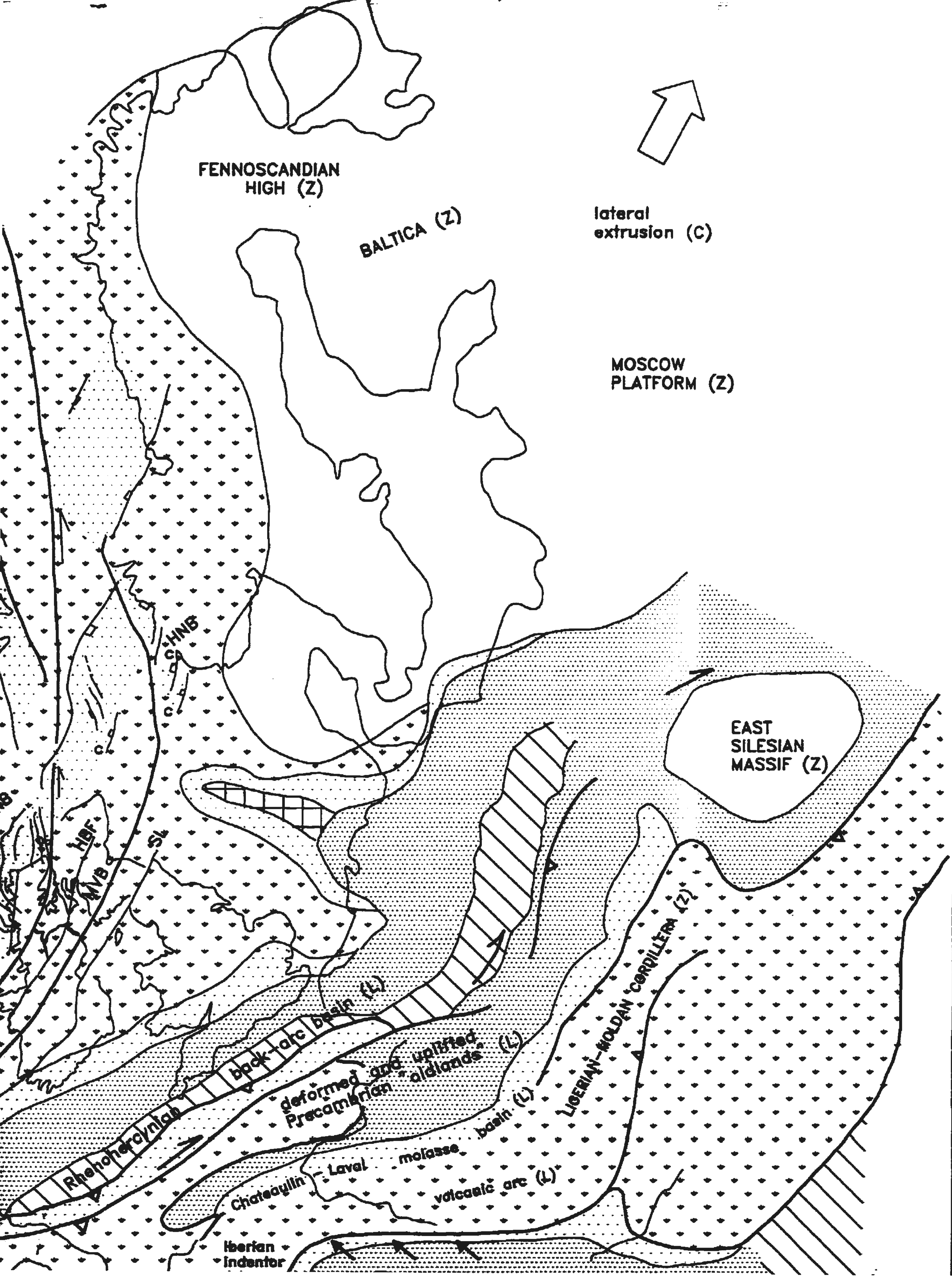

GGF
HBF
Acadian foreland basin
bt
NDSZ
ESZ
GZ
HZ
CAF
BAT
DZ
MMT
FF
EA
WA
SCT
BdQ
KT
BT
MT
WEST
AVALONIA
MNS
CT
CF
switch to NW compression
MEGUMA TERRANE



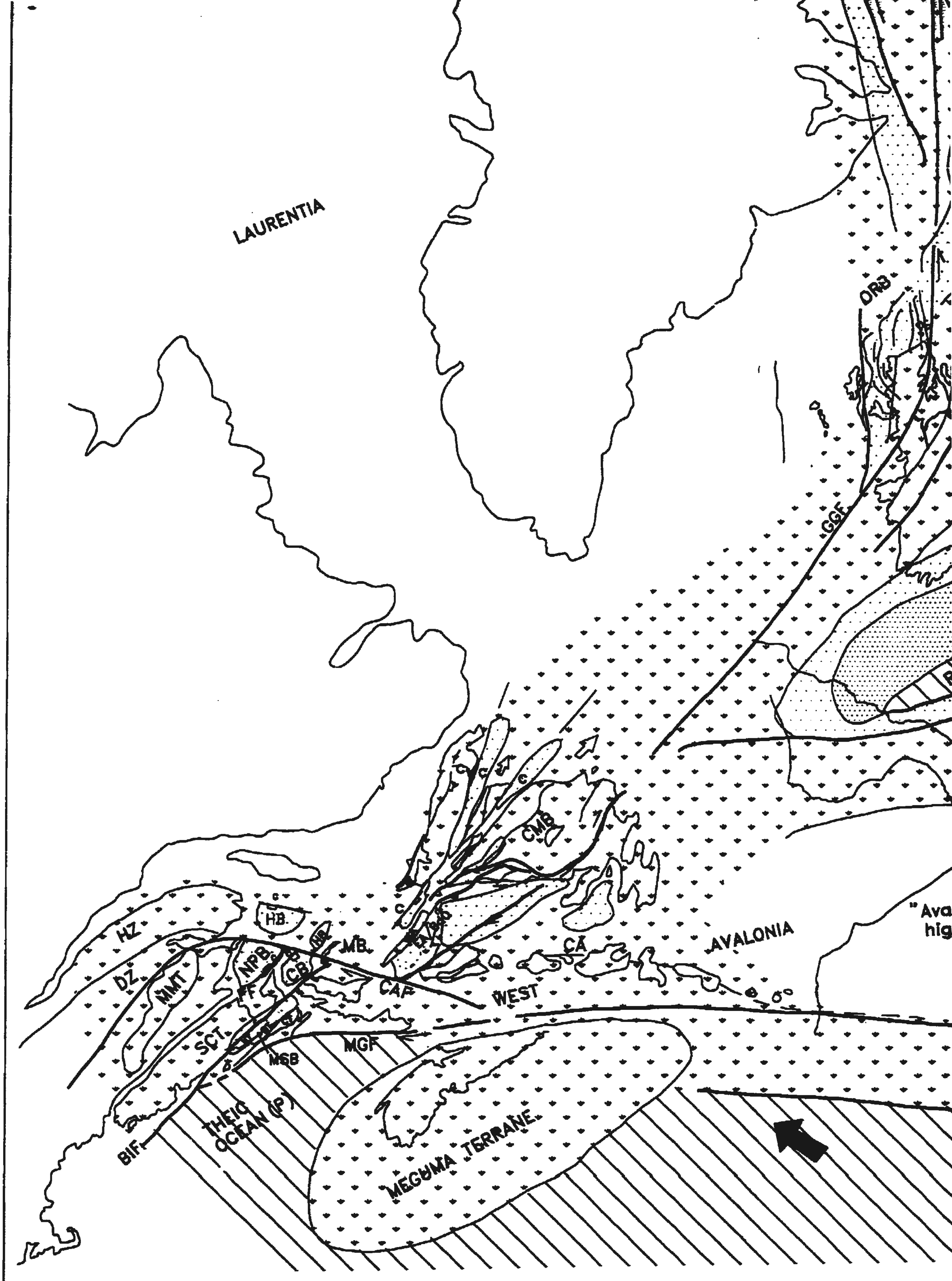
MID-EUROPEAN CALEDONIDES
CENTRAL ARMORICAN BASIN (Z)
LIGERIAN-MOLDAN CORDILLERA
INTRA-ALPINE TERRANE (Z)
RHEIC OCEAN (Z)
AQUITAINE-CANTABRIAN TERRANE (Z)

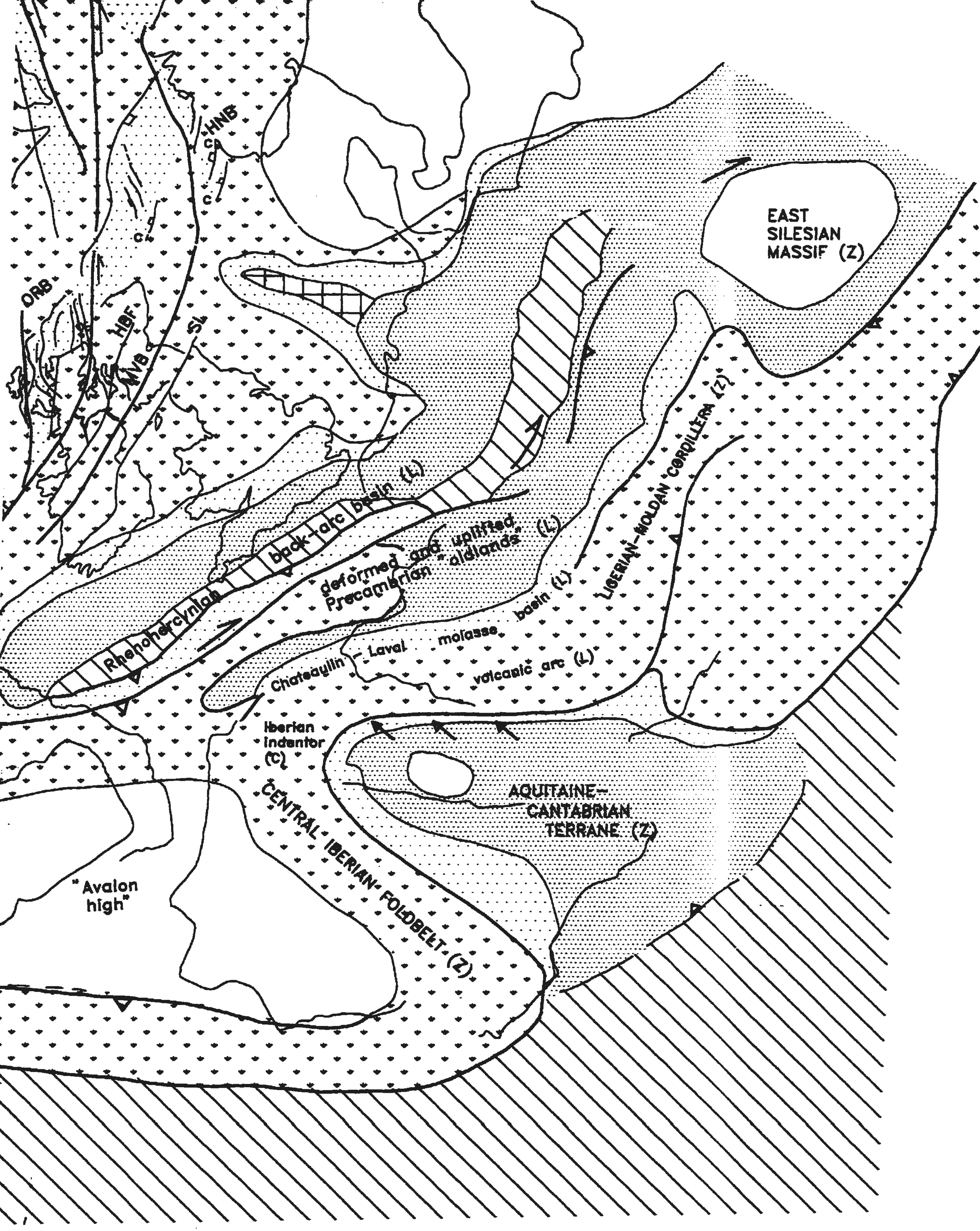
FIGURE X.5





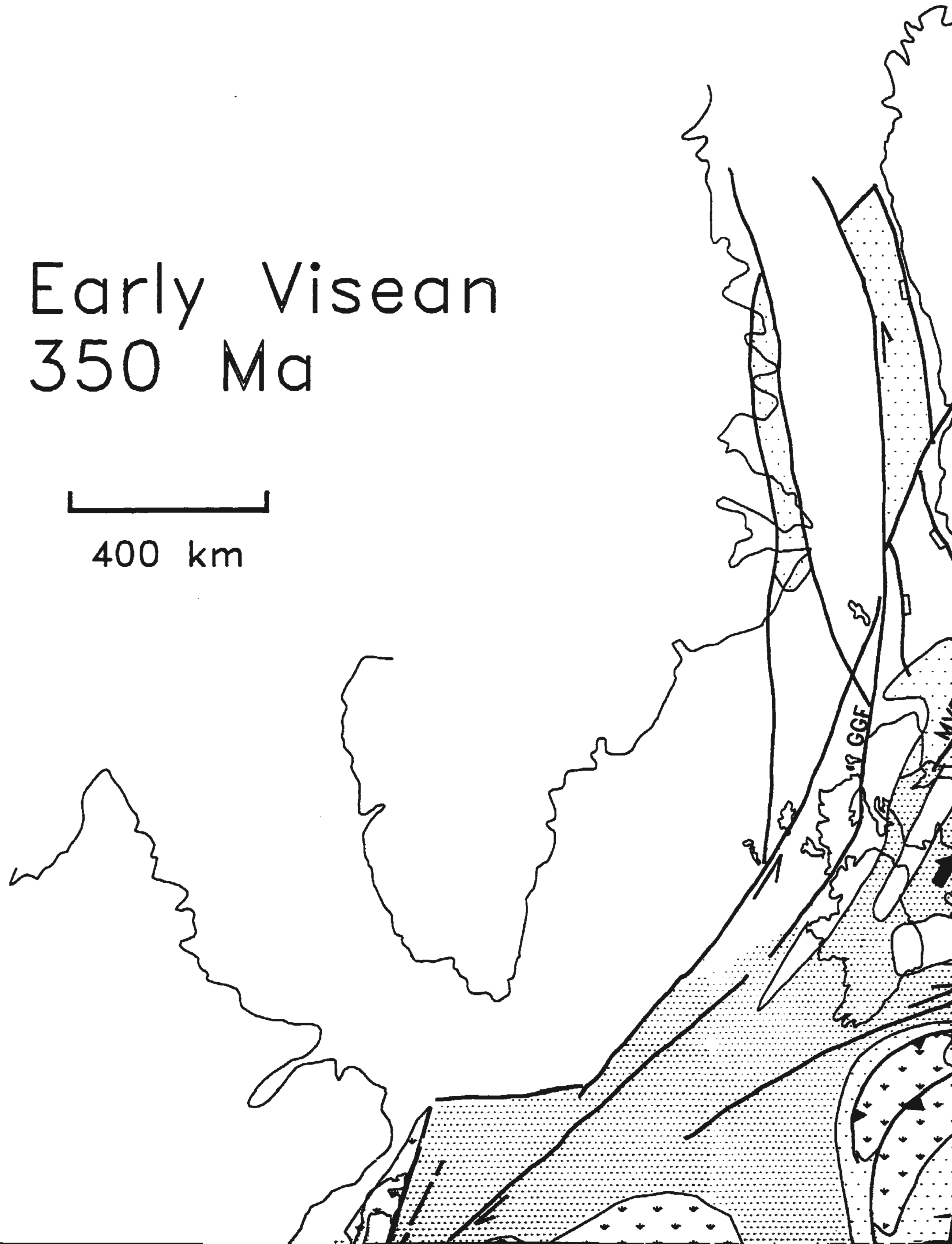
FENNOSCANDIAN HIGH (Z)
BALTICA (Z)
lateral extrusion (C)
MOSCOW PLATFORM (Z)
EAST SILESIAN MASSIF (Z)
HNB
HBF
MVB
SL
Rhenohercynian back-arc basin (L)
deformed and uplifted Precambrian "oldlands" (L)
LIGERIAN-MOLDAN CORDILLERA (Z)
Chateaulin - Laval molasse basin (L)
volcanic arc (L)
Iberian indentor

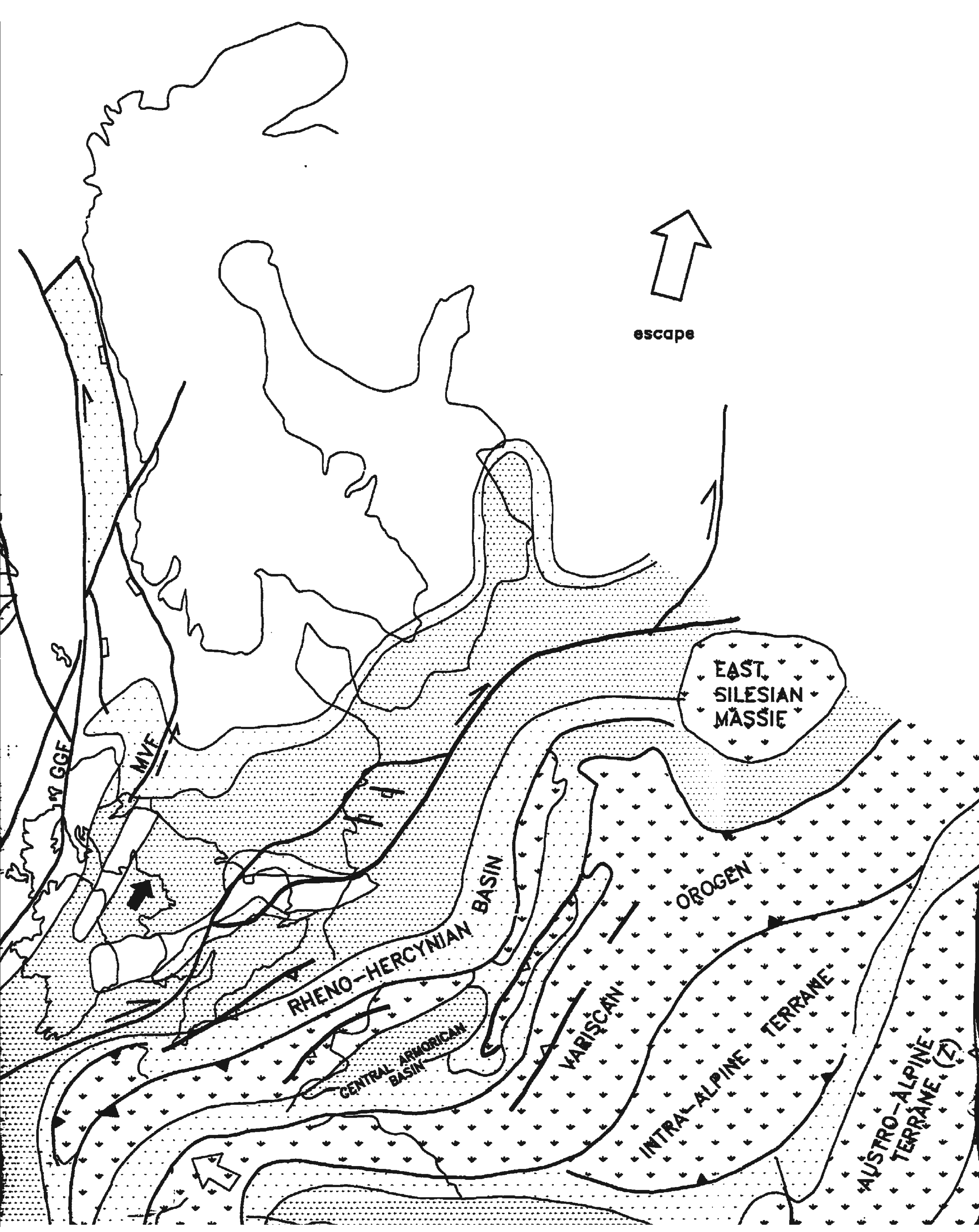

LAURENTIA
ORB
GGF
CMB
HZ
DZ
HB.
MB.
NPB
CB
FF
SCT
CAF
WEST
CA
AVALONIA
MGF
MSB
BIF
THEIC
OCEAN (P)
MEGUMA TERRANE



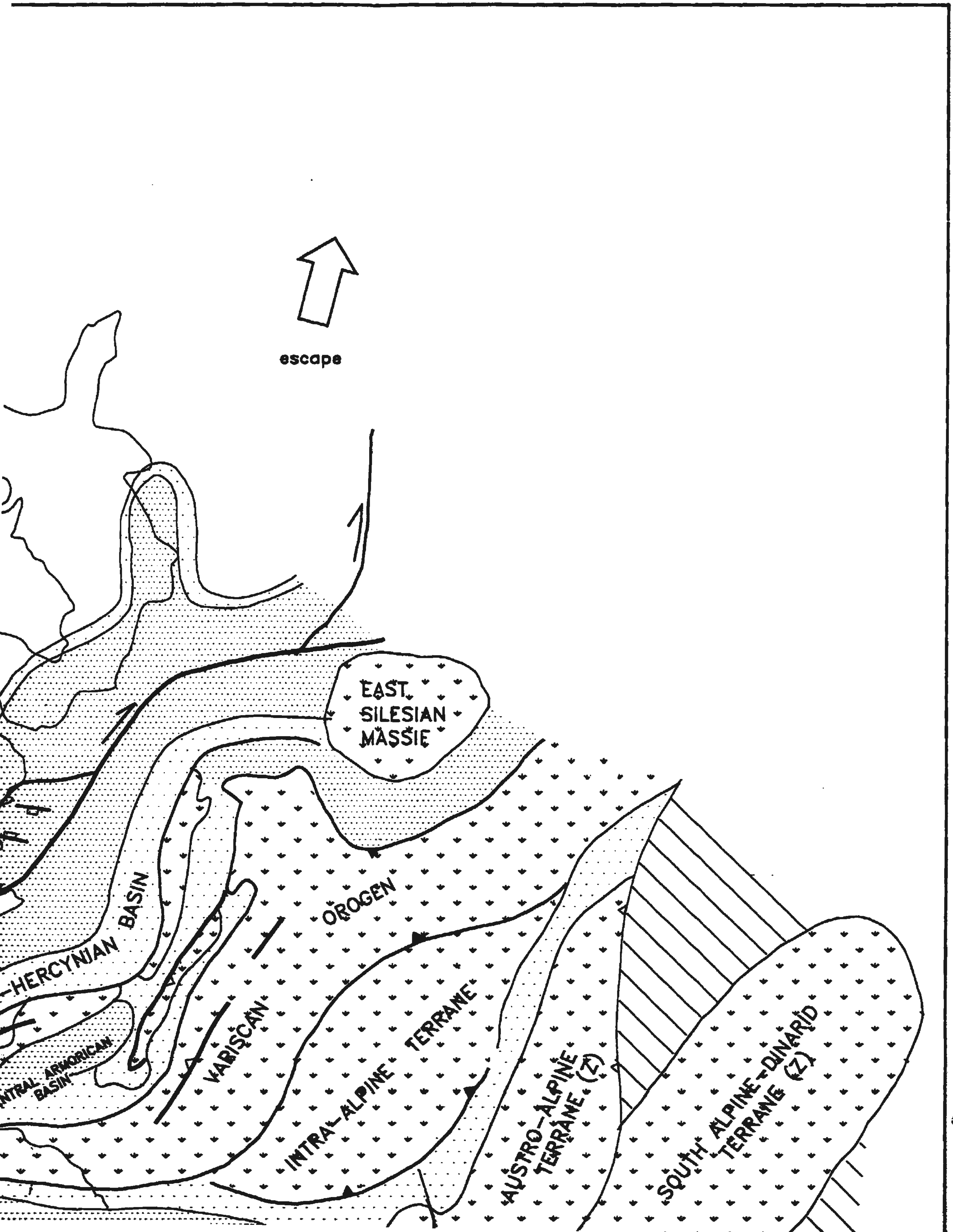
HNB
ORB
HBF
MVB
SL
EAST
SILESIAN
MASSIF (Z)
LIGERIAN-MOLDAN CORDILLERA (Z)
Rhenohercynian back-arc basin (L)
deformed and uplifted Precambrian "oldlands" (L)
Chateaulin - Laval molasse basin (L)
volcanic arc (L)
Iberian indentor (C)
CENTRAL IBERIAN FOLDBELT (Z)
AQUITAINE-CANTABRIAN TERRANE (Z)
"Avalon high"

FIGURE X.6

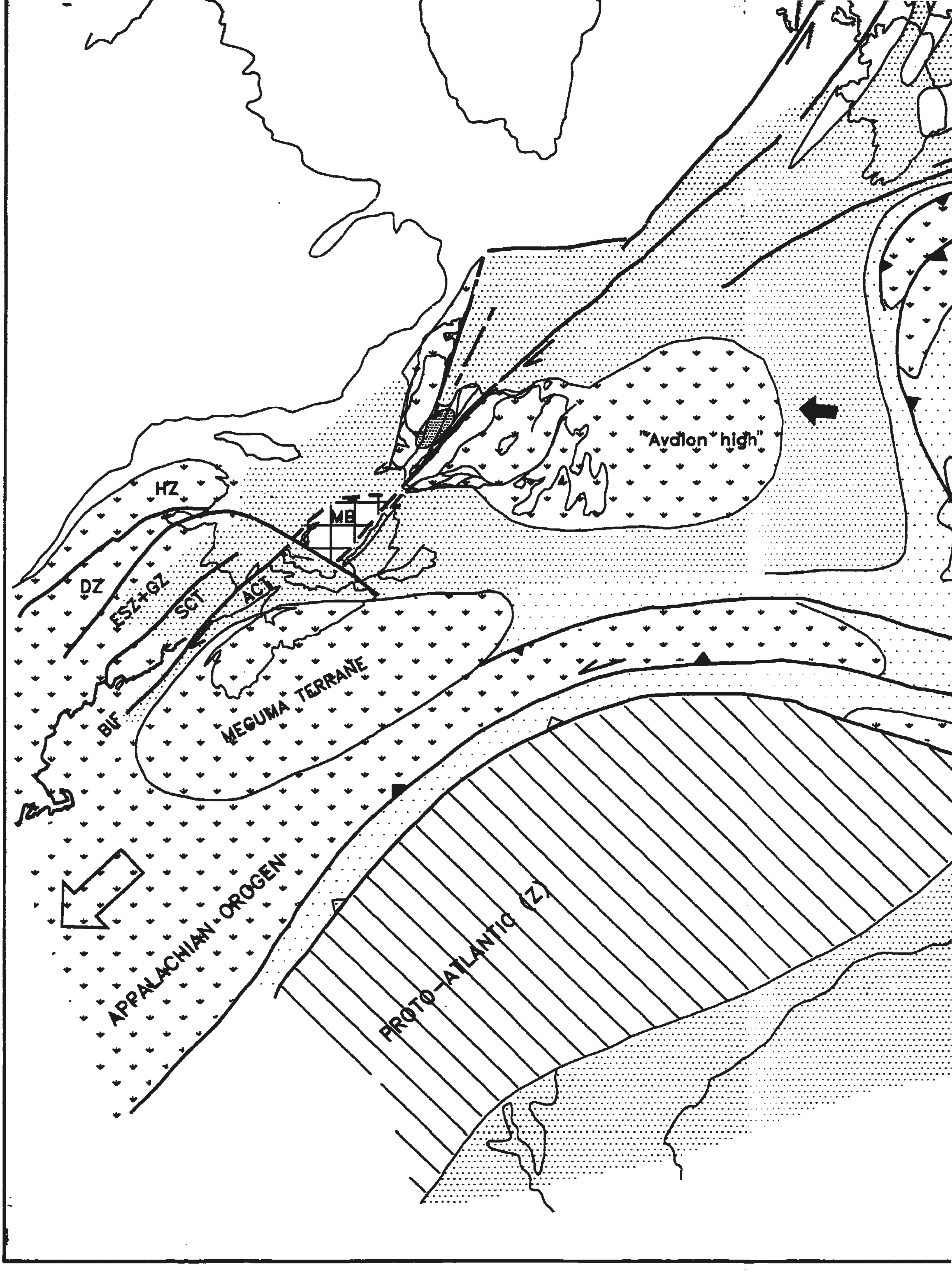




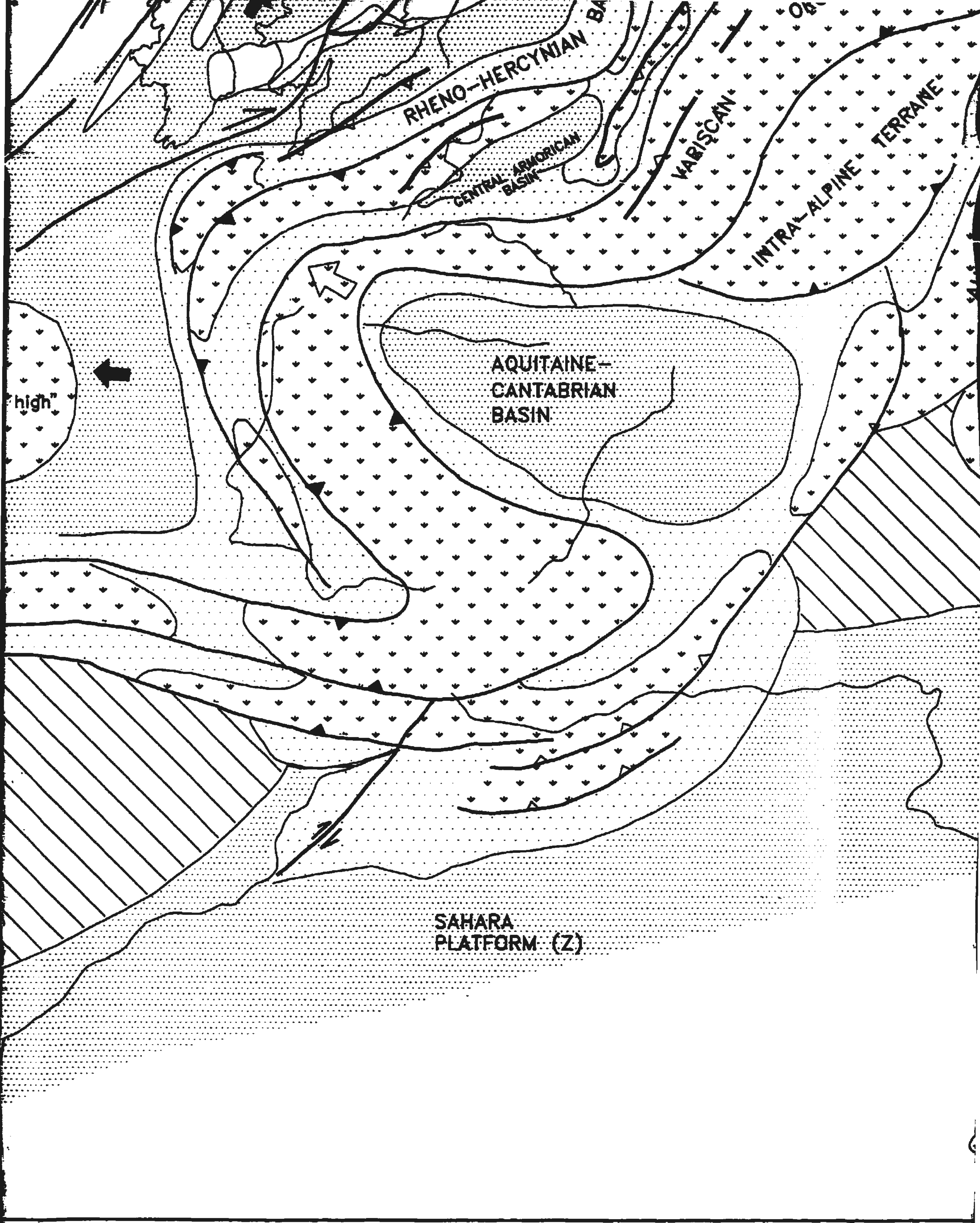
escape
EAST SILESIAN MASSIE
GGF
MVF
RHENO-HERCYNIAN BASIN
OROGEN
VARISCAN
CENTRAL ARMORICAN BASIN
INTRA-ALPINE TERRANE
AUSTRO-ALPINE TERRANE (?)



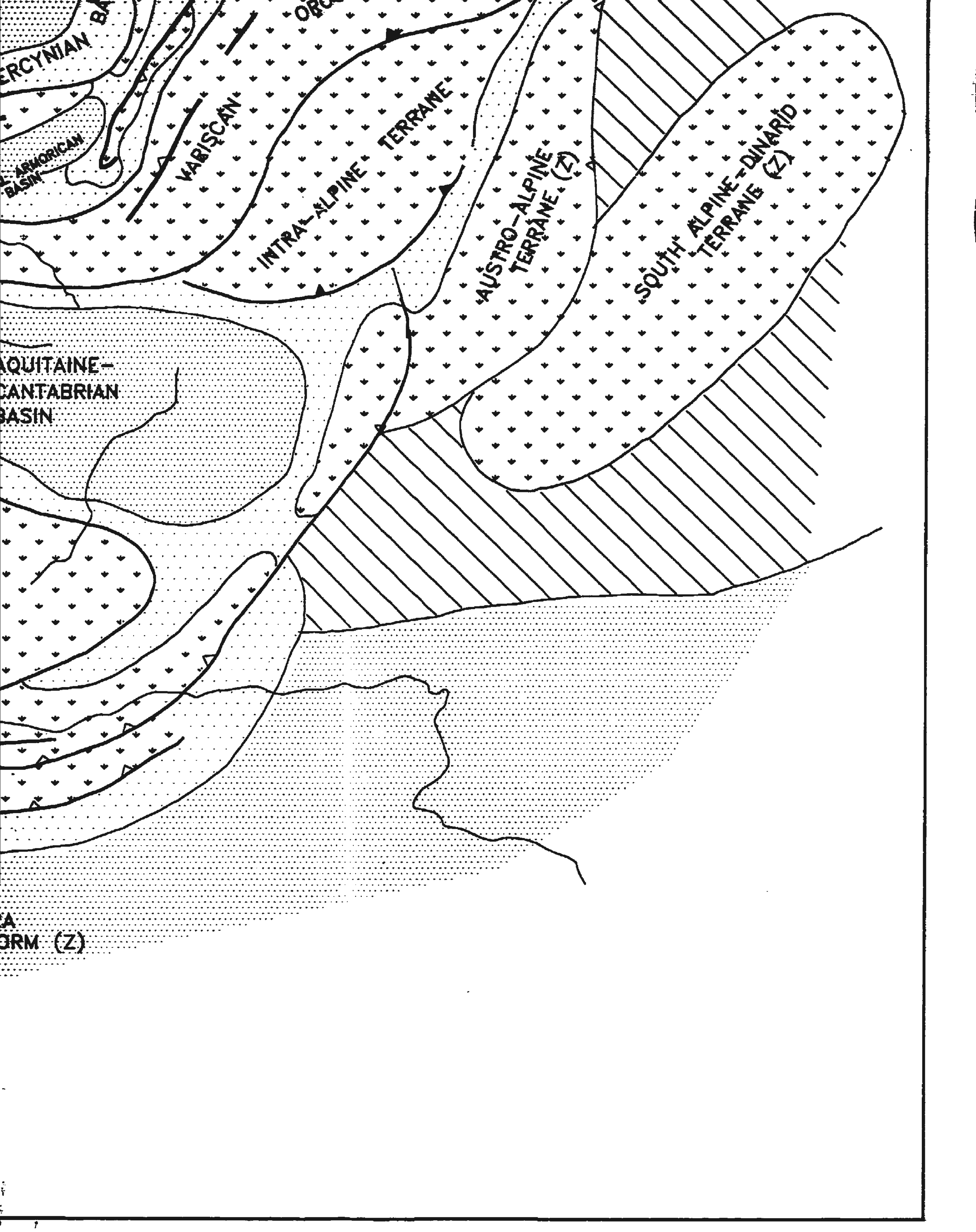
escape
EAST SILESIAN MASSIE
OROGEN
-HERCYNIAN BASIN
VARISCAN
INTRA-ALPINE TERRANE
AUSTRO-ALPINE TERRANE (Z)
SOUTH ALPINE-DINARID TERRANE (Z)
BASIN



"Avalon" high"
HZ
MB
DZ
ESZ+GZ
SCT
ACT
BIF
MEGUMA TERRANE
APPALACHIAN OROGEN
PROTO-ATLANTIC (Z)

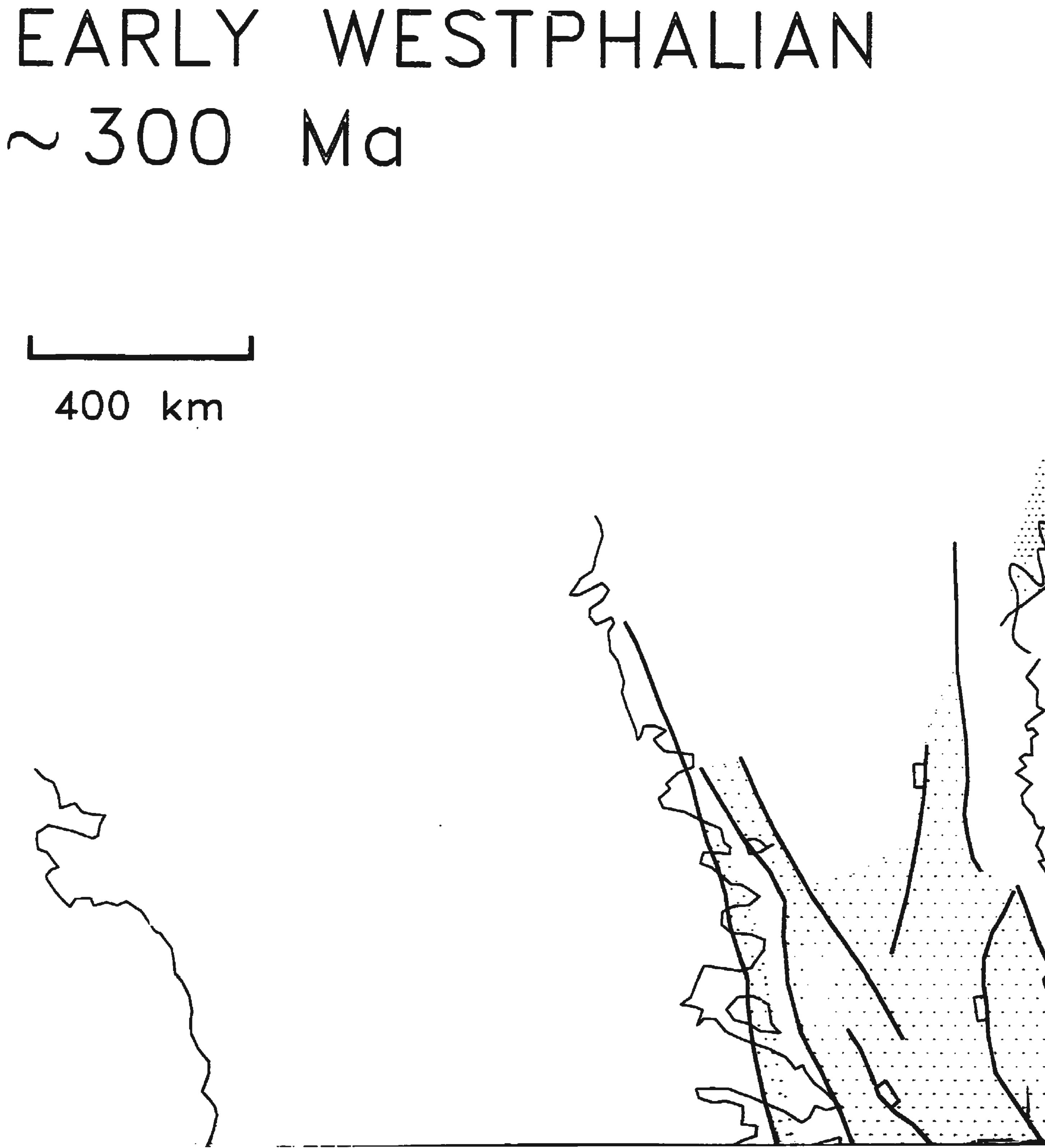


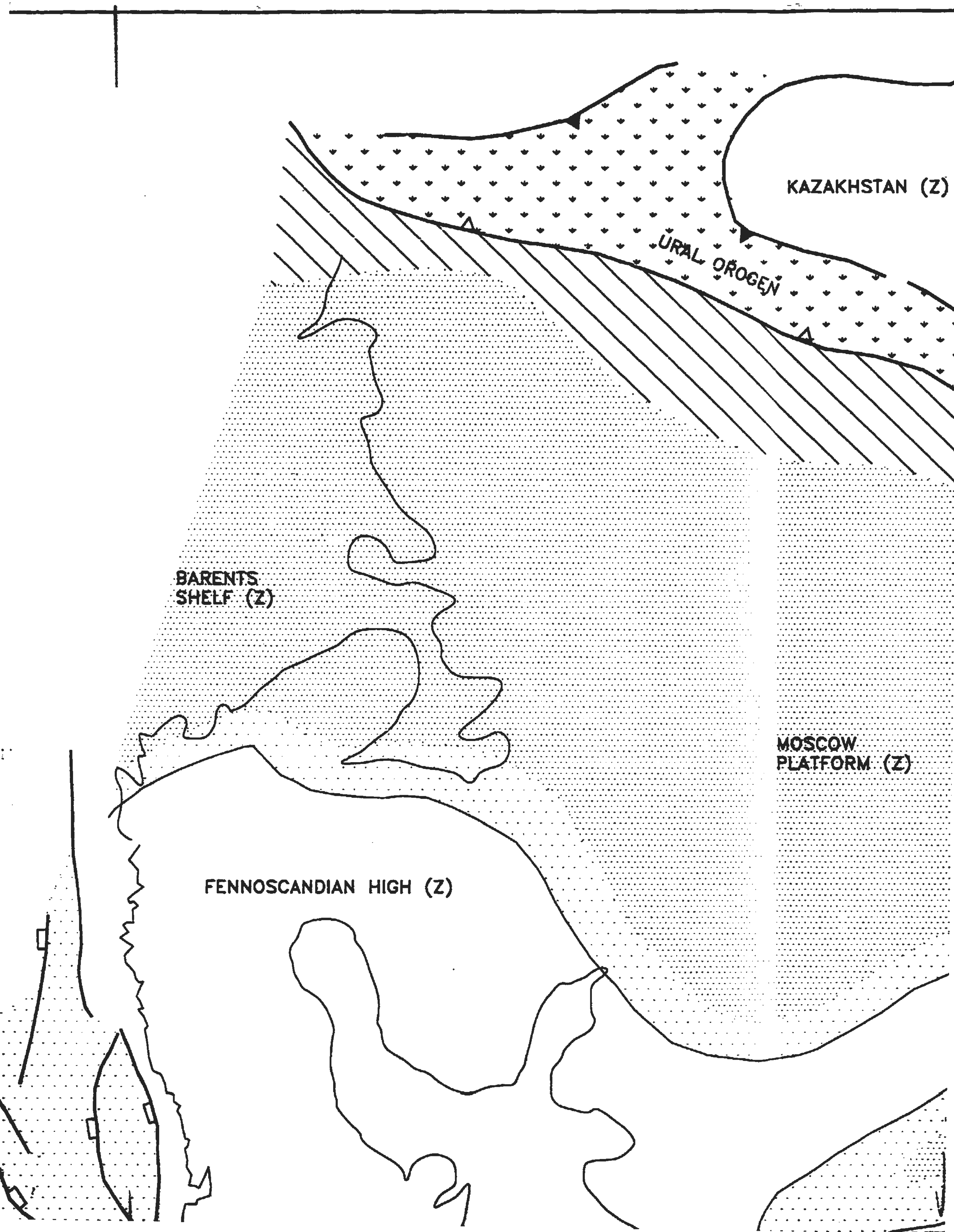
RHENO-HERCYNIAN BA
OC
CENTRAL ARMORICAN BASIN
VARISCAN
INTRA-ALPINE TERRANE
"high"
AQUITAINE-
CANTABRIAN
BASIN
SAHARA
PLATFORM (Z)

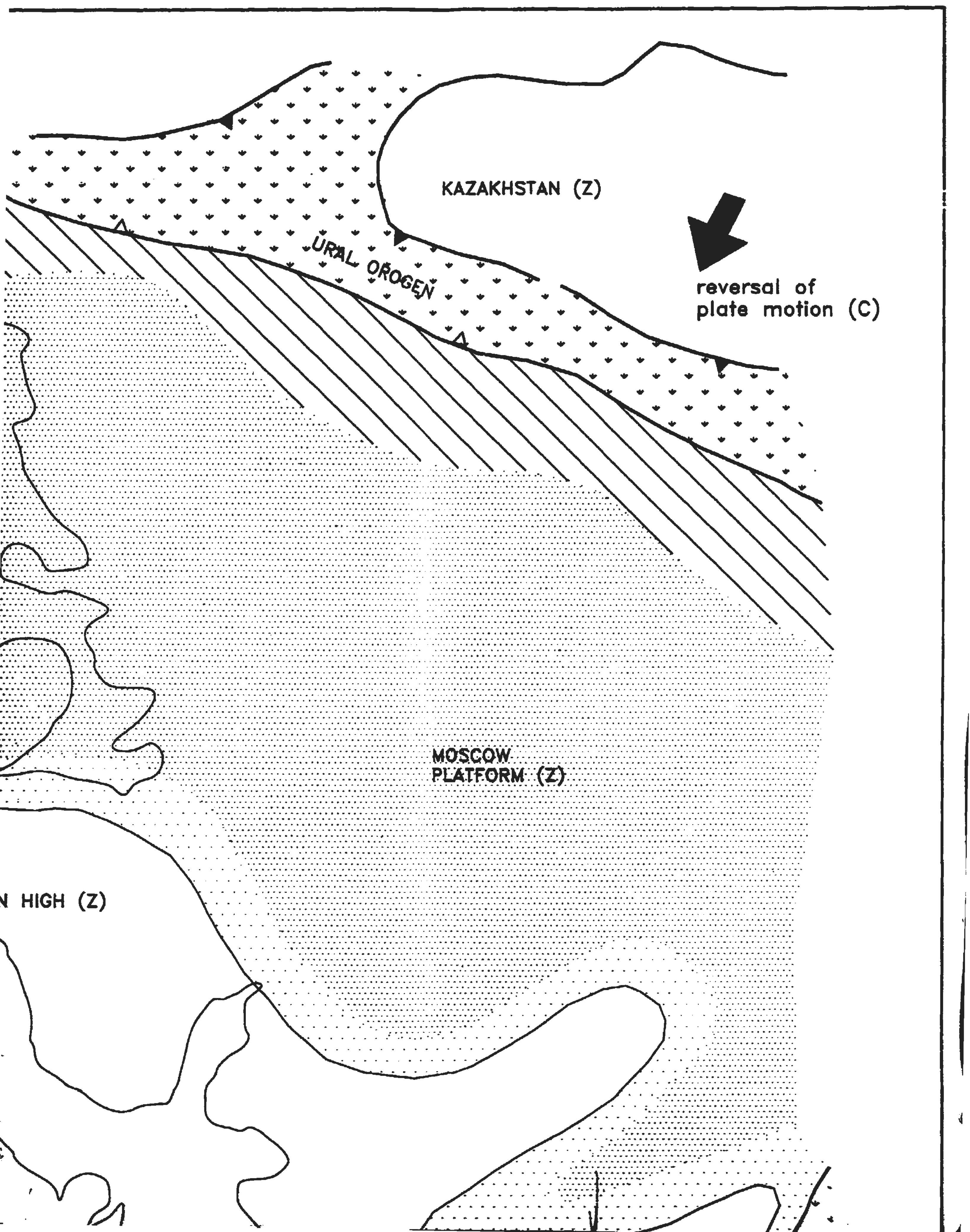


HERCYNIAN
ARMORICAN BASIN
VARISCAN
INTRA-ALPINE TERRANE
AUSTRO-ALPINE TERRANE (Z)
SOUTH ALPINE-DINARID TERRANE (Z)
AQUITAINE-CANTABRIAN BASIN
ORM (Z)

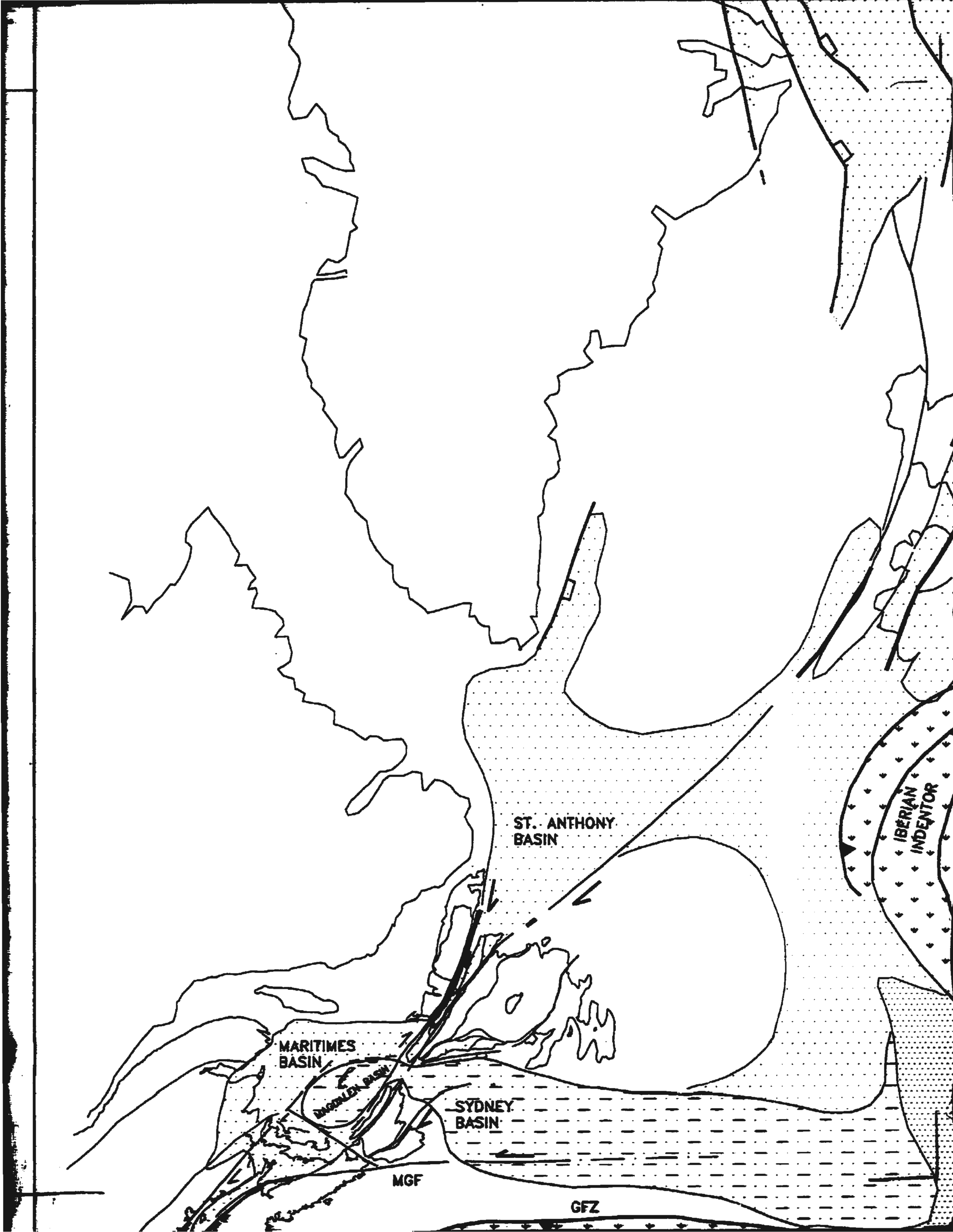
FIGURE X.7

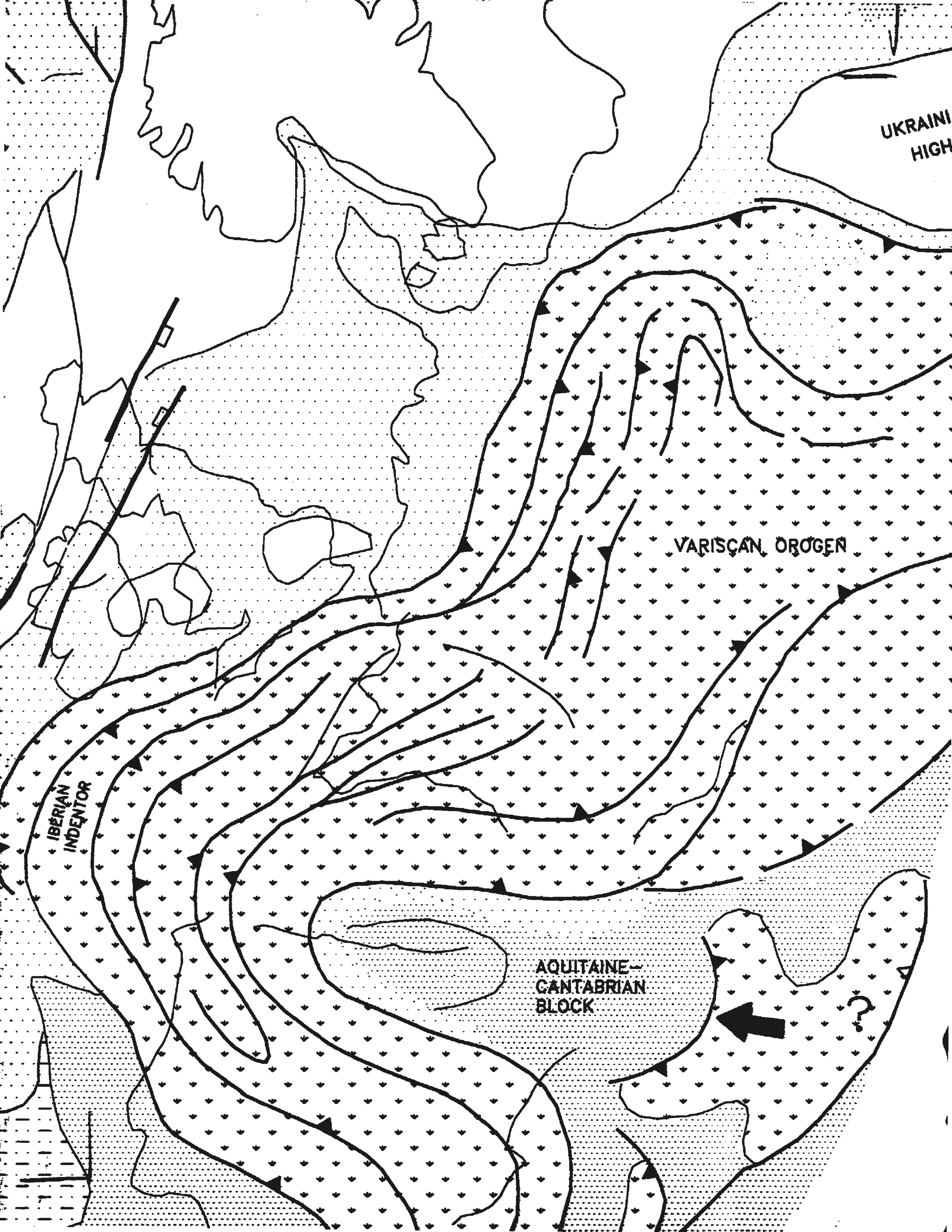


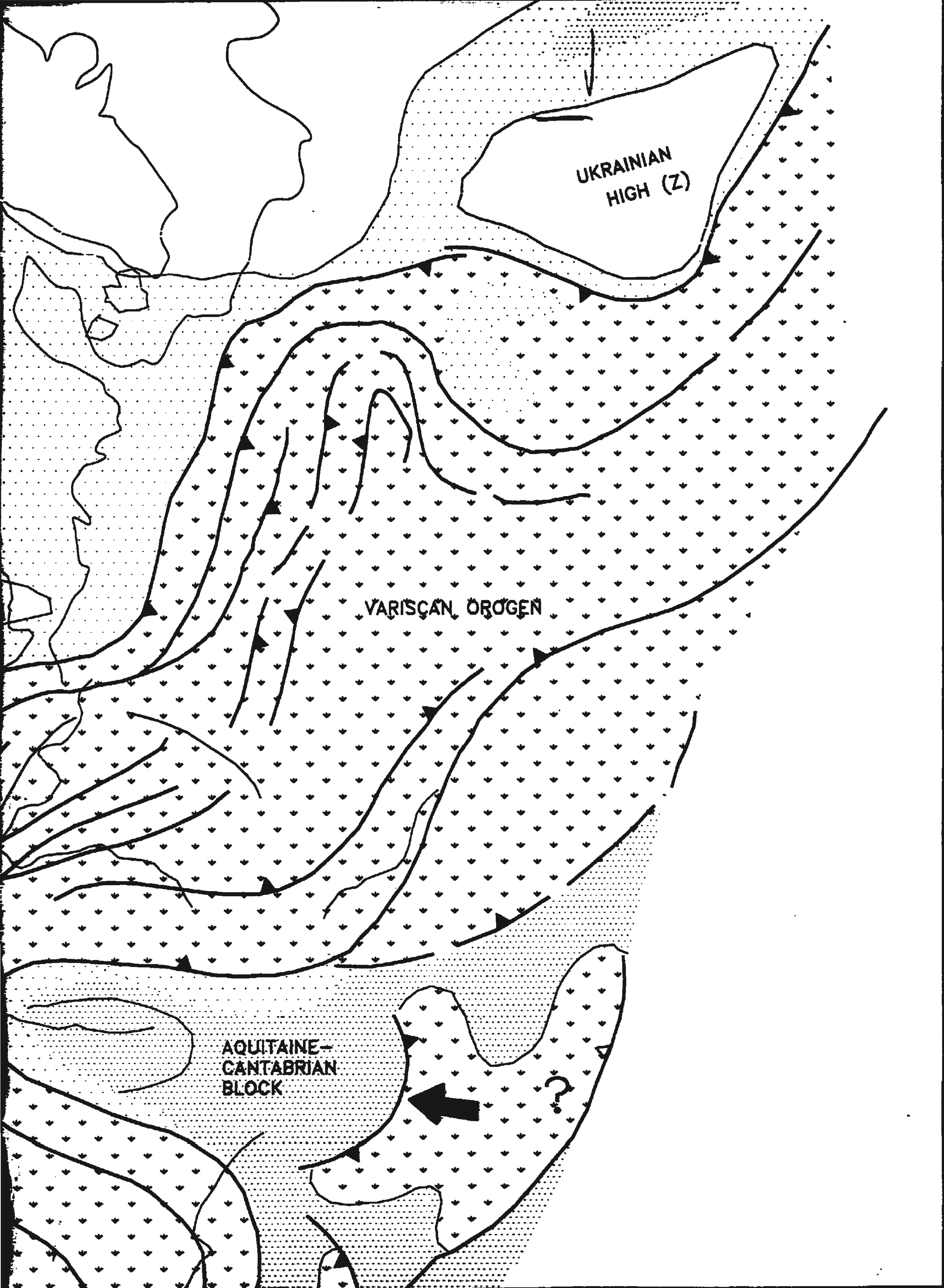

KAZAKHSTAN (Z)
URAL OROGEN
BARENTS SHELF (Z)
MOSCOW PLATFORM (Z)
FENNOSCANDIAN HIGH (Z)

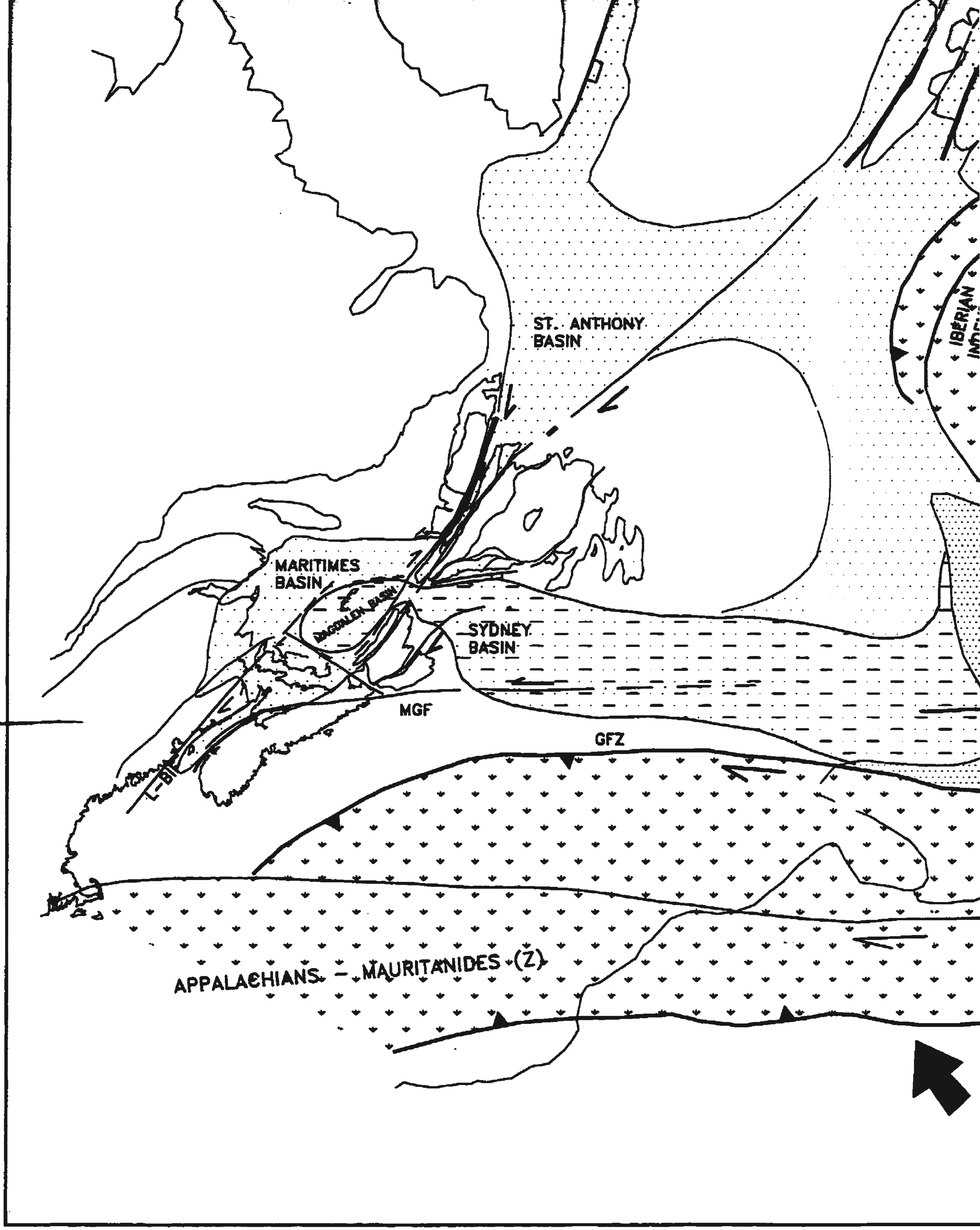


KAZAKHSTAN (Z)
reversal of
plate motion (C)
URAL OROGEN
MOSCOW
PLATFORM (Z)
N HIGH (Z)

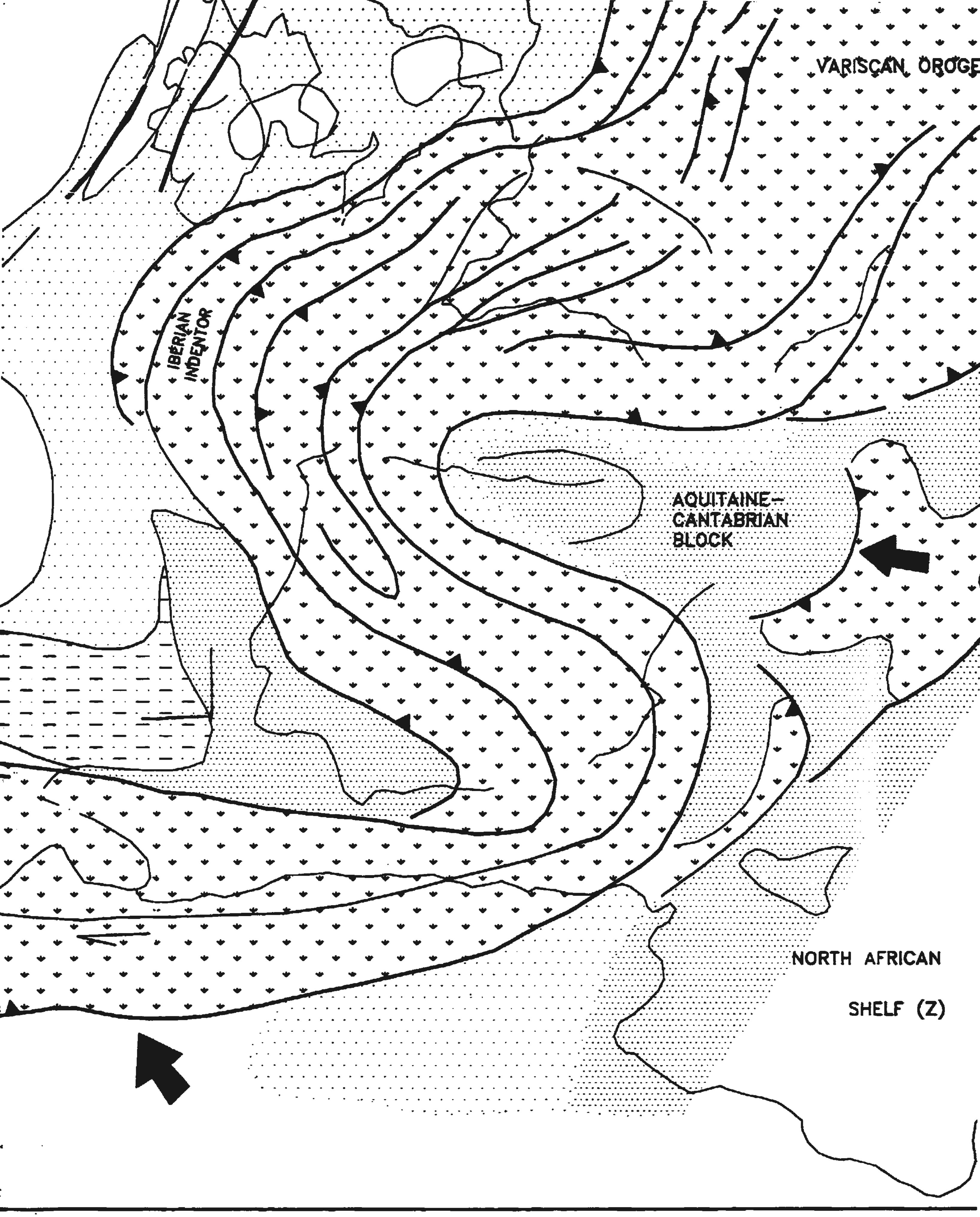

ST. ANTHONY BASIN
IBERIAN INDENTOR
MARITIMES BASIN
MAGDALEN BASIN
SYDNEY BASIN
MGF
GFZ


UKRAINI
HIGH
VARISCAN OROGEN
IBERIAN
INDENTOR
AQUITAINE-
CANTABRIAN
BLOCK
?


UKRAINIAN
HIGH (Z)
VARISCAN OROGEN
AQUITAINE-
CANTABRIAN
BLOCK
?



ST. ANTHONY
BASIN
IBERIAN
MARITIMES
BASIN
MAGDALEN BASIN
SYDNEY
BASIN
MGF
GFZ
L-BI
APPALACHIANS - MAURITANIDES (Z)


VARISCAN OROGE
IBERIAN INDENTOR
AQUITAINE–CANTABRIAN BLOCK
NORTH AFRICAN
SHELF (Z)

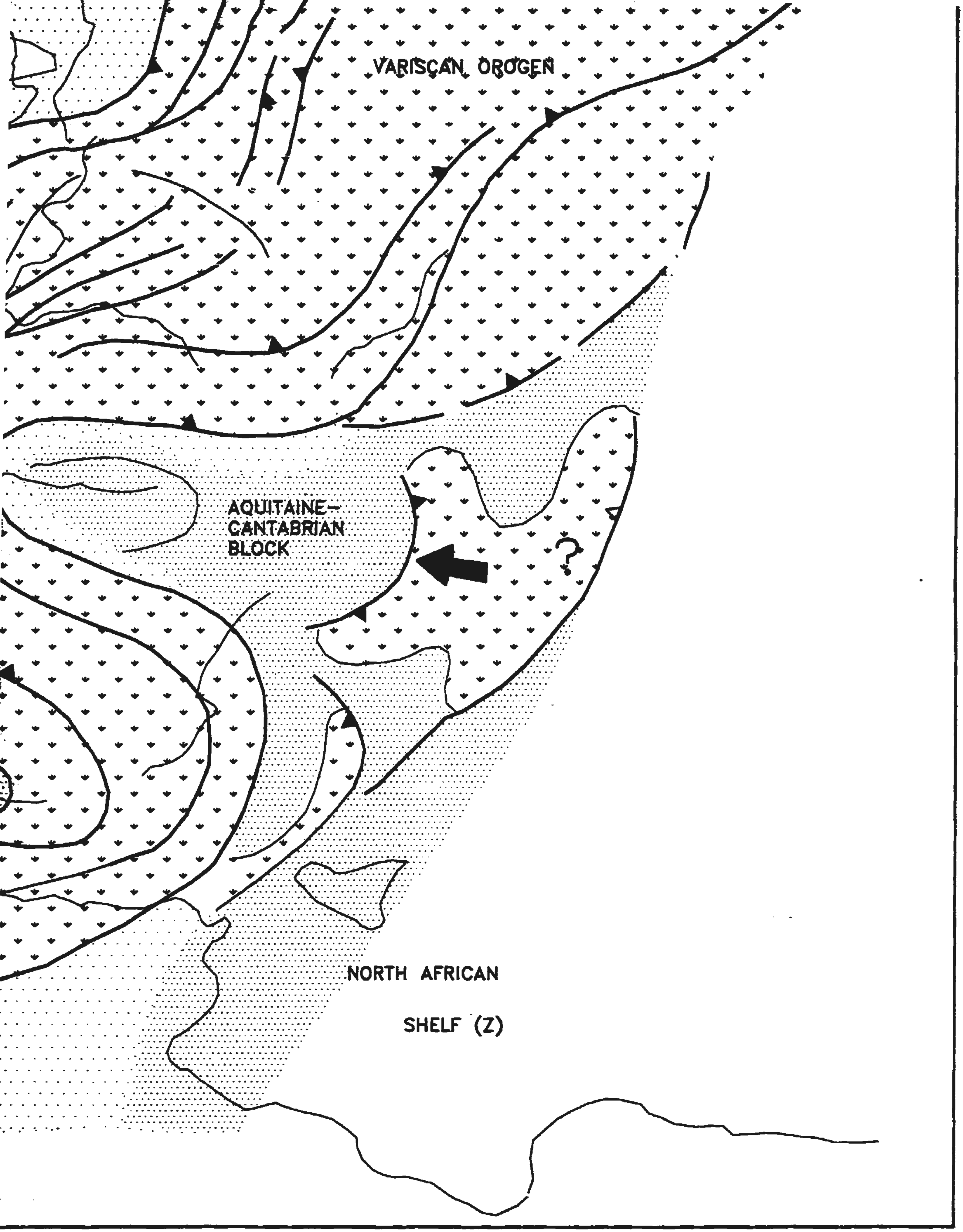
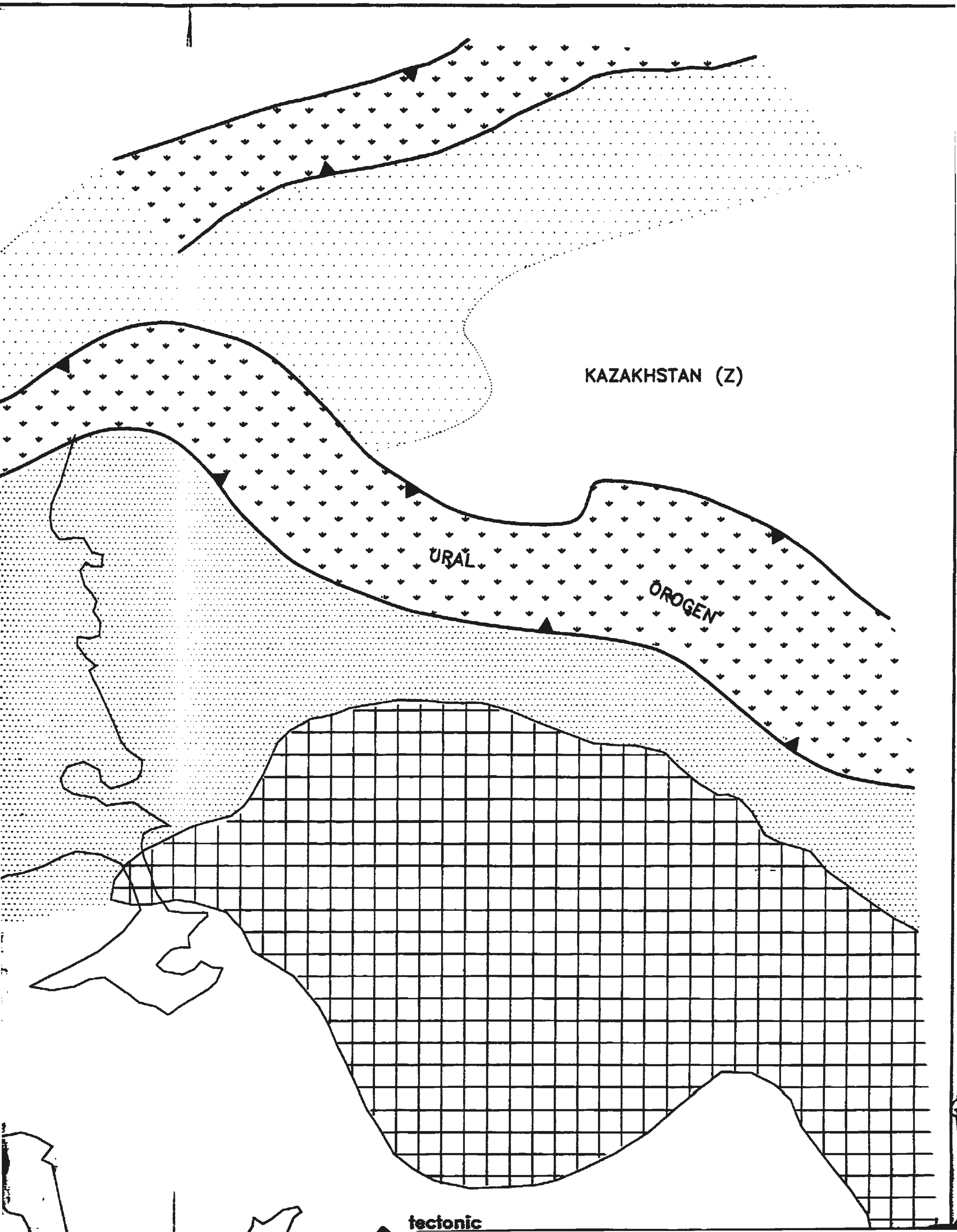
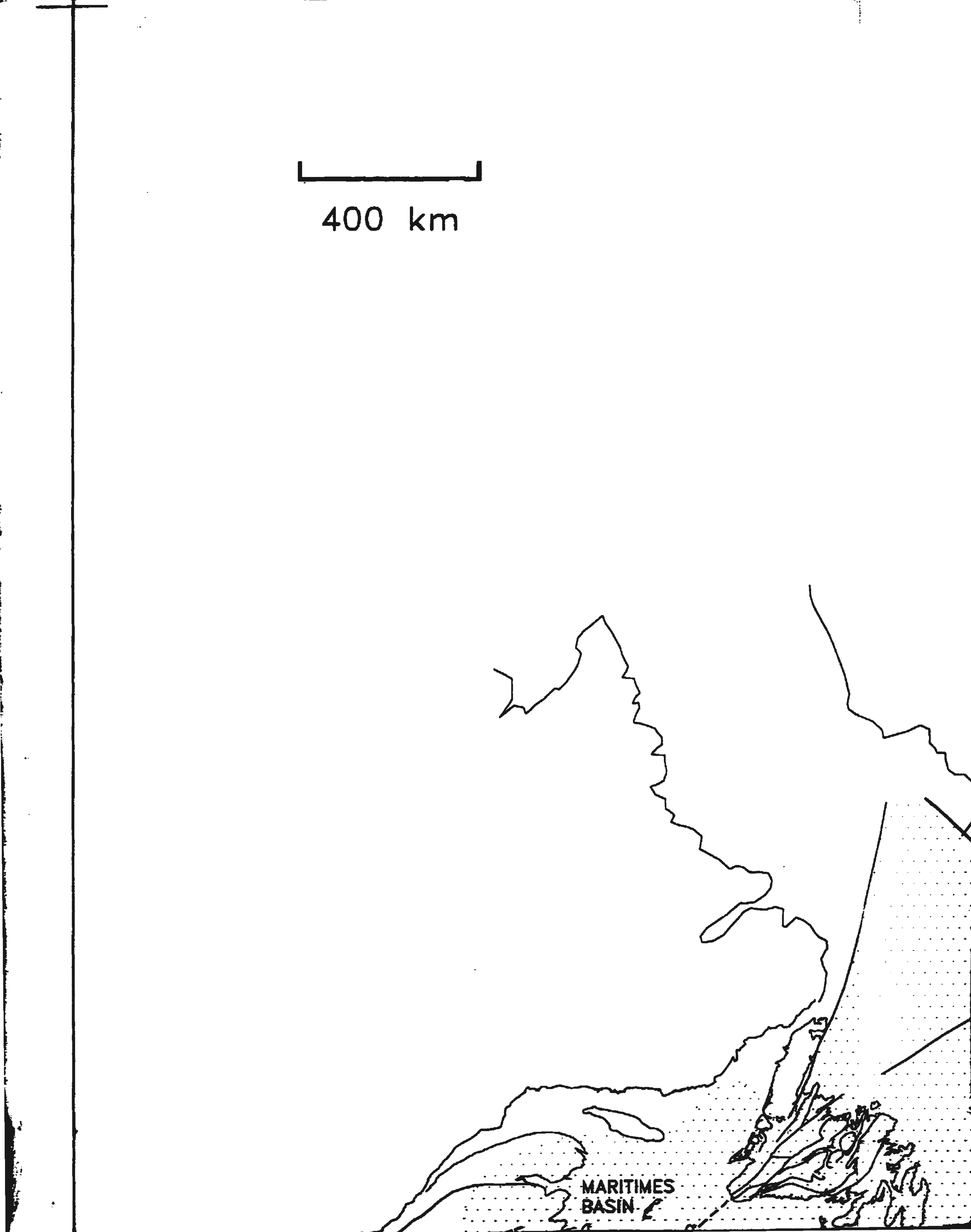

VARISCAN OROGEN
AQUITAINE–
CANTABRIAN
BLOCK
?
NORTH AFRICAN
SHELF (Z)

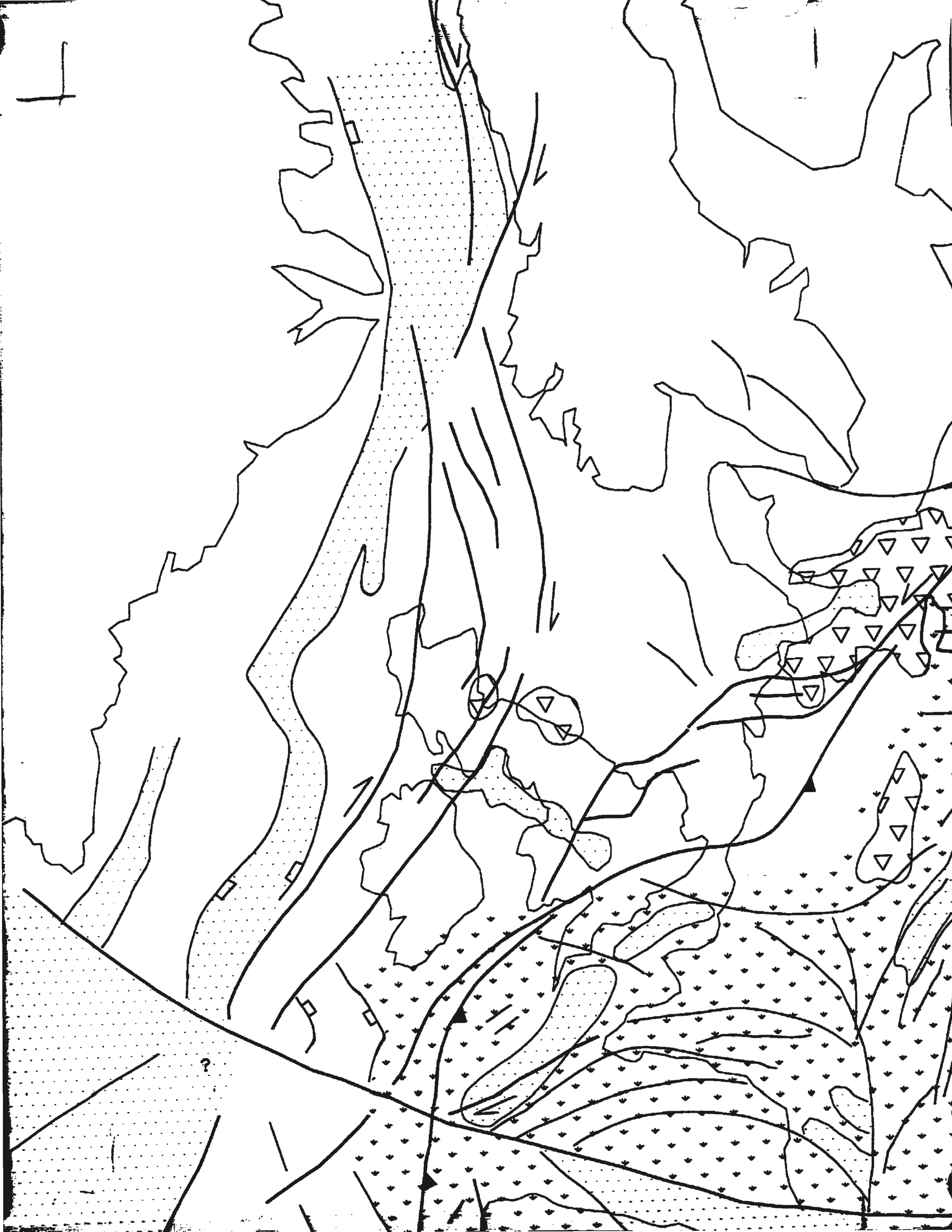
FIGURE X.8

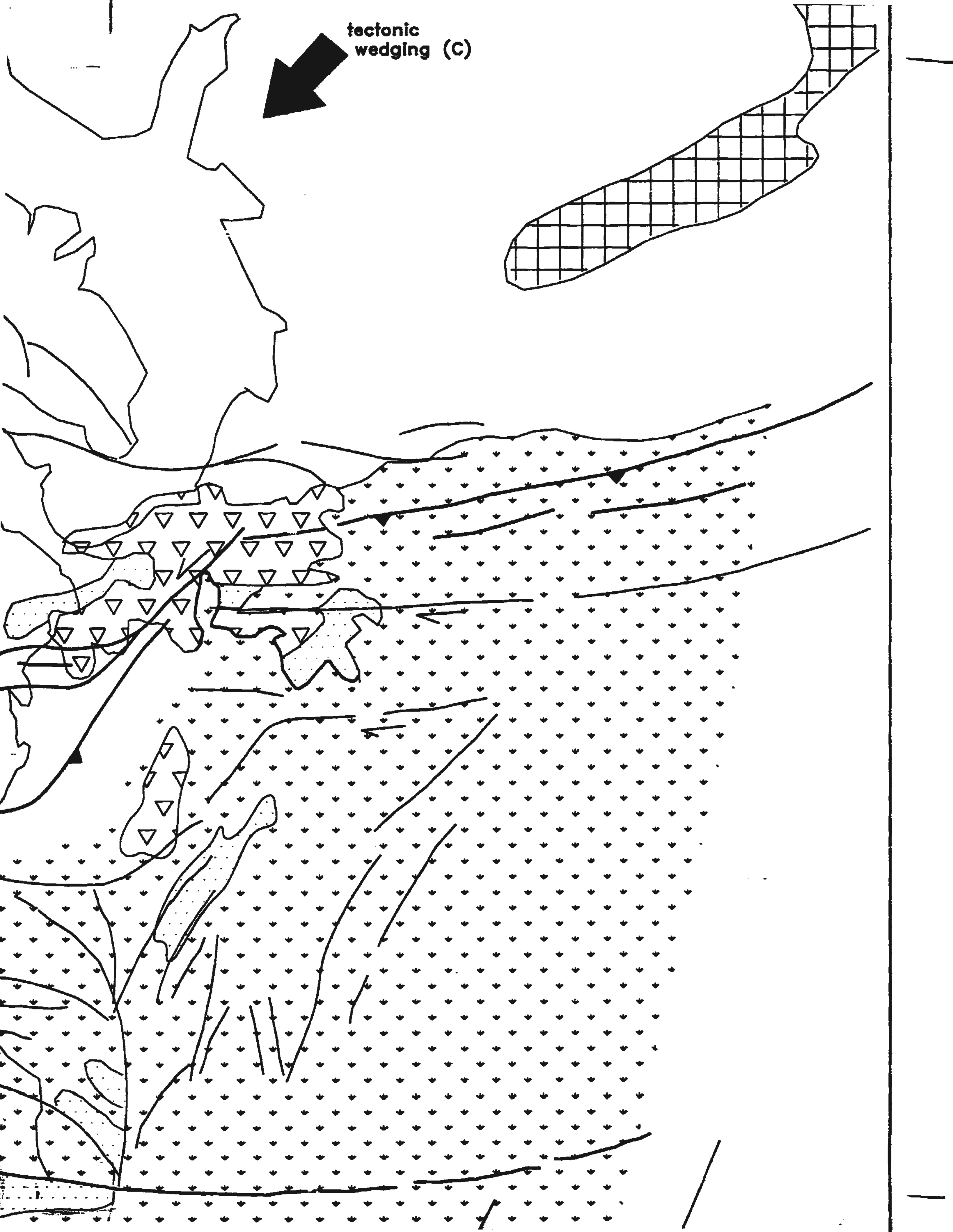
EARLIEST PERMIAN
275 Ma

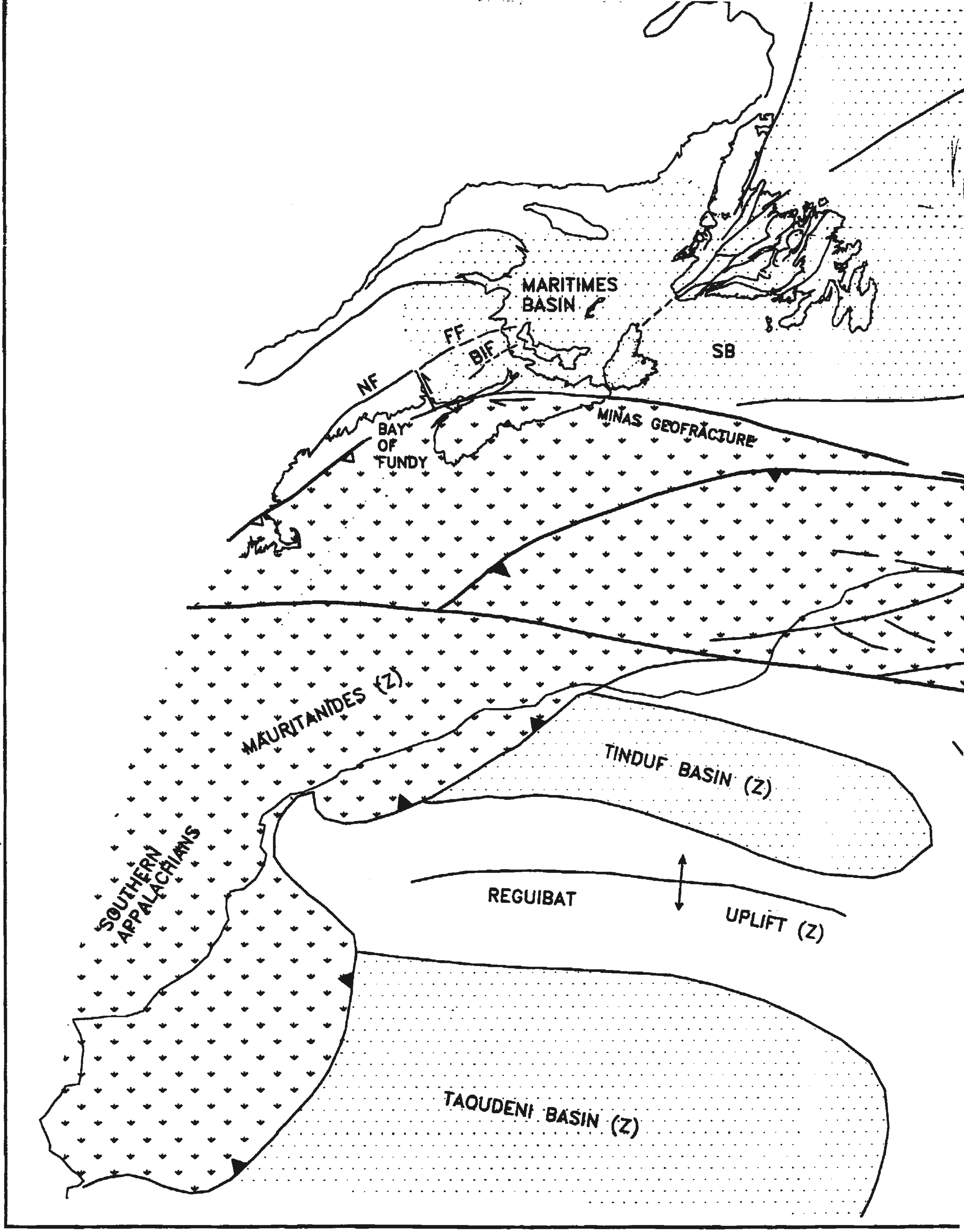

KAZAKHSTAN (Z)
URAL
OROGEN
tectonic

275 Ma



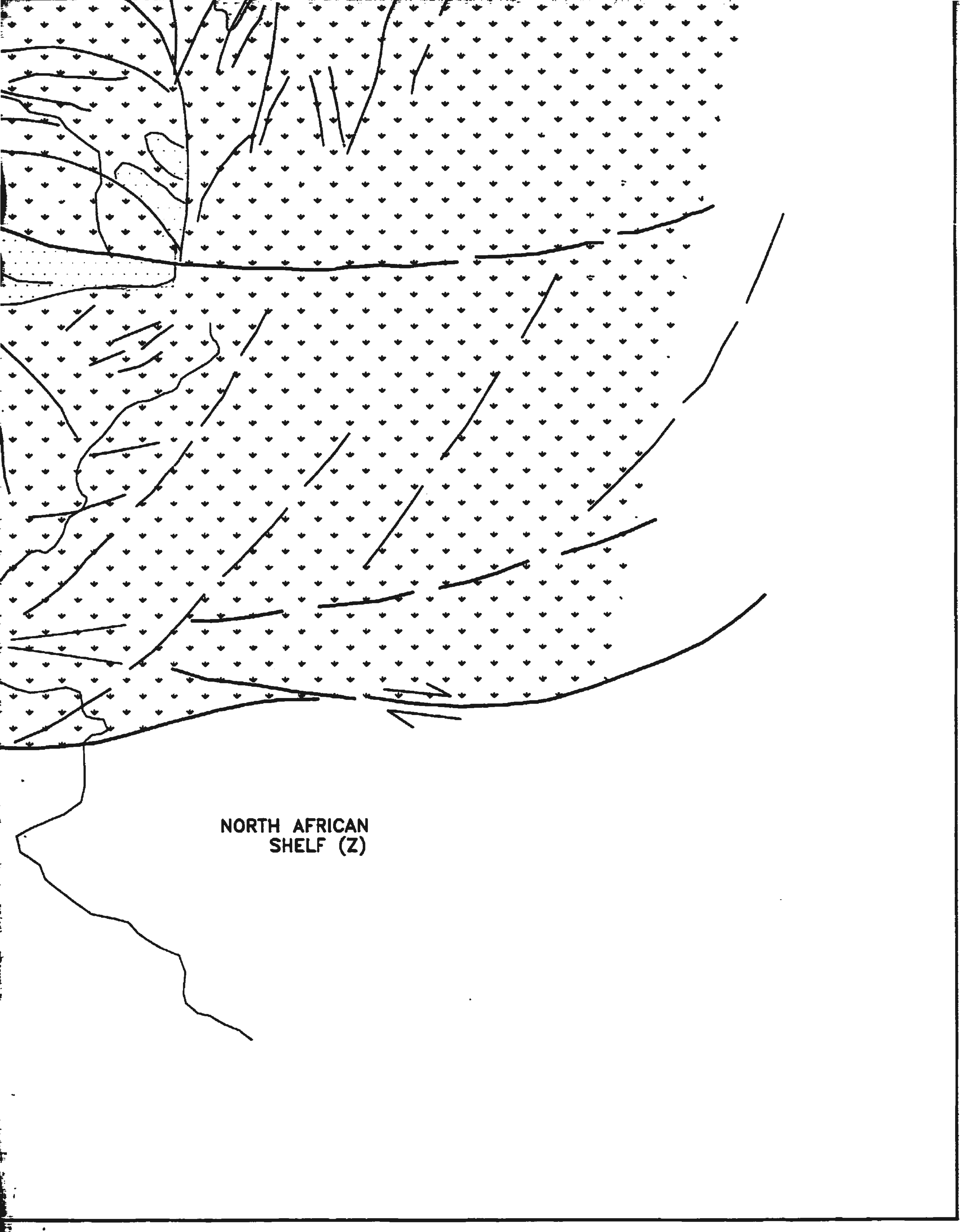


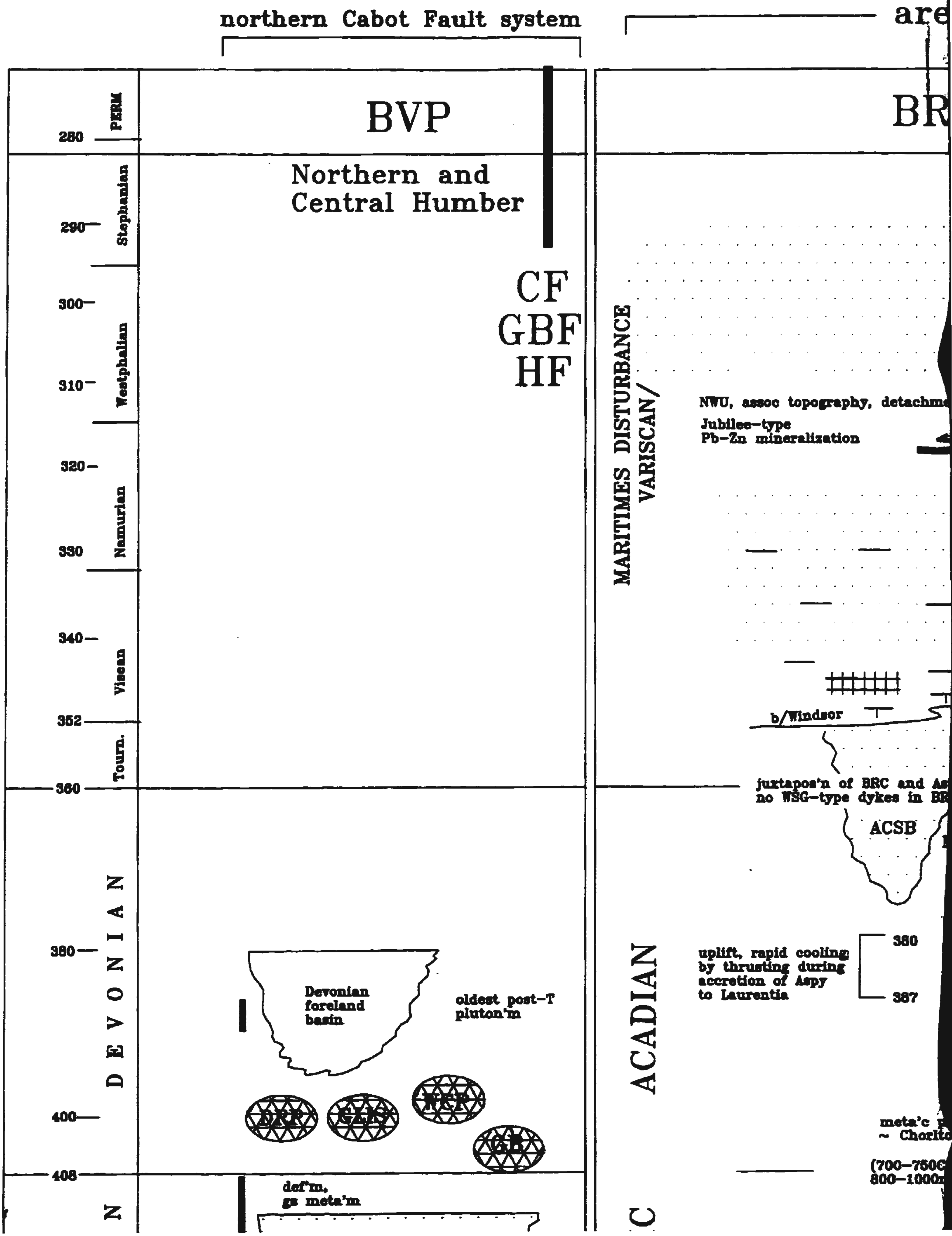

tectonic
wedging (C)

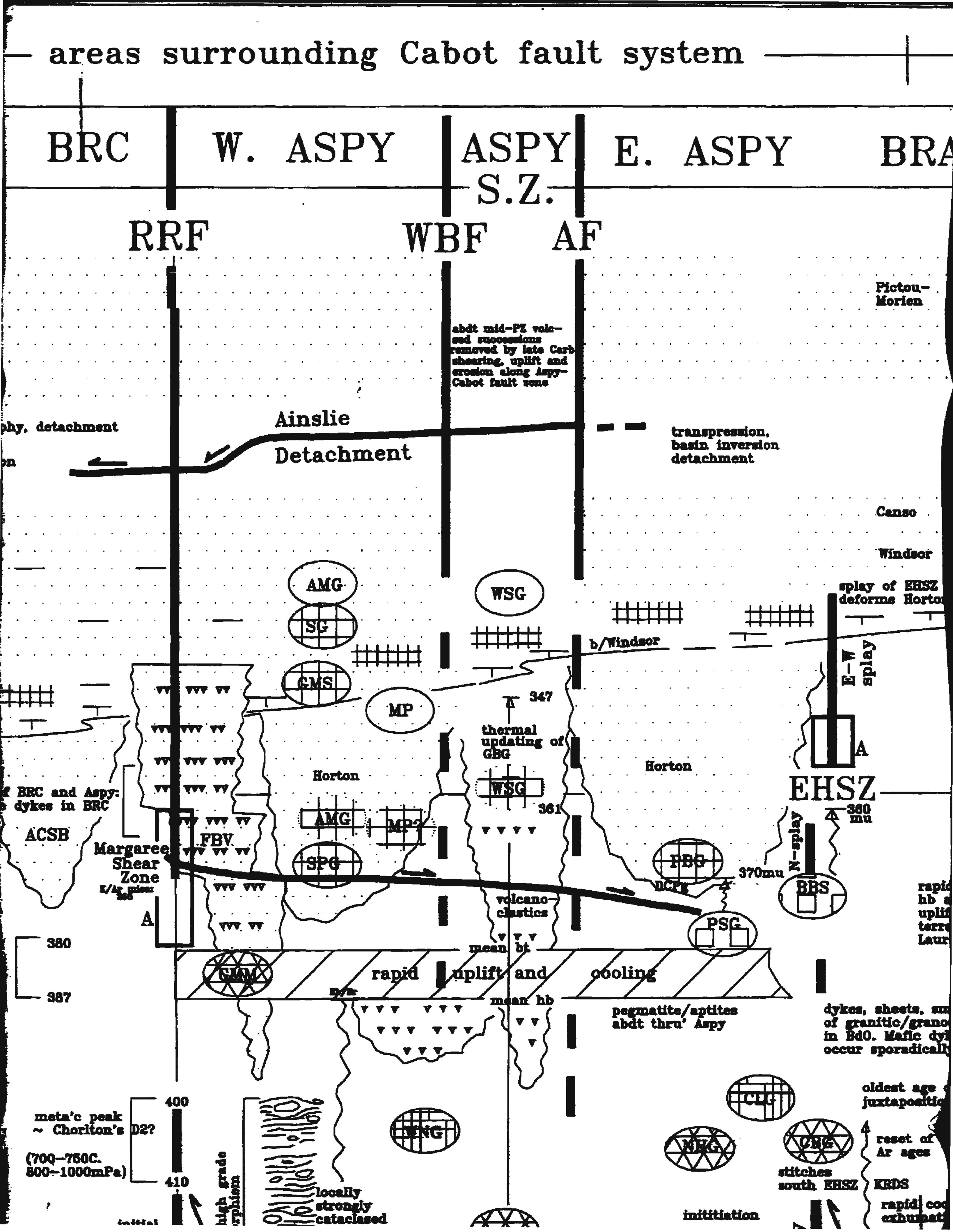


MARITIMES
BASIN
FF
BIF
SB
NF
BAY
OF
FUNDY
MINAS GEOFRACTURE
MAURITANIDES (Z)
TINDUF BASIN (Z)
SOUTHERN
APPALACHIANS
REGUIBAT
UPLIFT (Z)
TAODENI BASIN (Z)

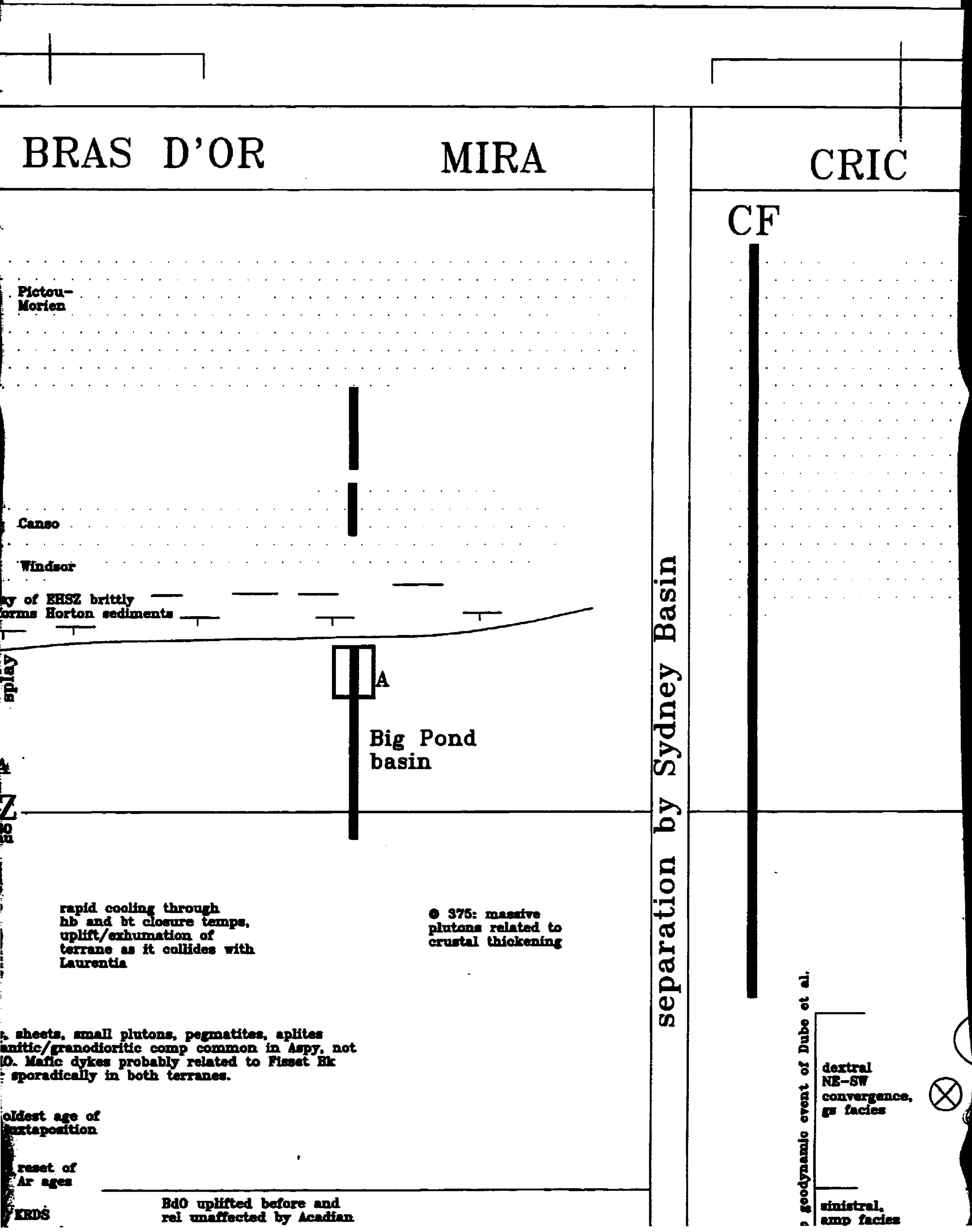

?
GIBRALTAR FAULT ZONE (Z)
AGADIR FAULT ZONE (Z)
(Z)
?


NORTH AFRICAN
SHELF (Z)

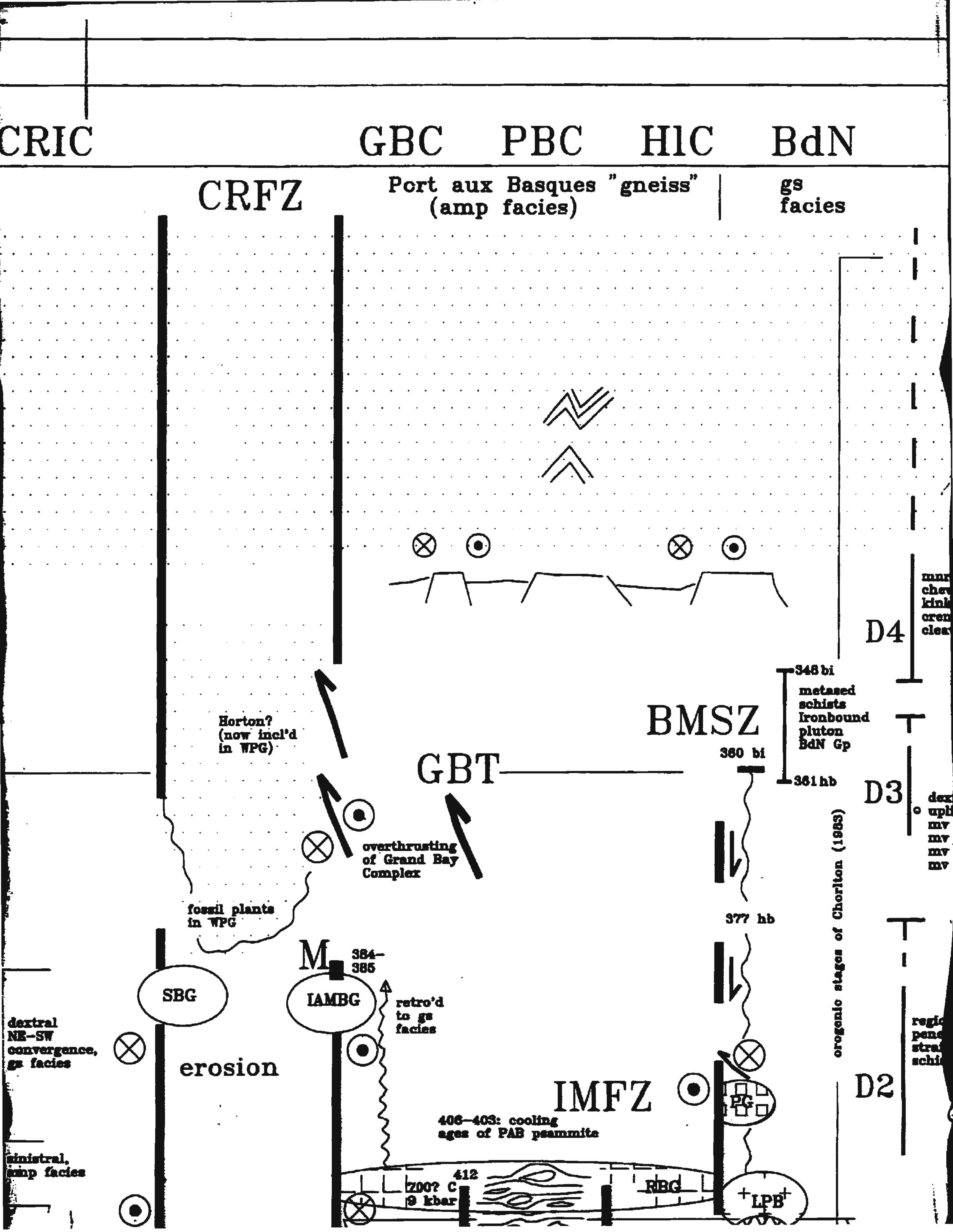

northern Cabot Fault system
are
PERM
280
Stephanian
290
300
Westphalian
310
320
Namurian
330
340
Visean
352
Tourn.
360
DEVONIAN
380
400
408
N
BVP
Northern and Central Humber
CF
GBF
HF
Devonian foreland basin
oldest post-T pluton'm
def'm, gs meta'm
MARITIMES DISTURBANCE VARISCAN/
ACADIAN
C
BR
NWU, assoc topography, detachm
Jubilee-type Pb-Zn mineralization
b/Windsor
juxtapos'n of BRC and As
no WSG-type dykes in BR
ACSB
uplift, rapid cooling by thrusting during accretion of Aspy to Laurentia
380
387
meta'c
~ Chorlt
(700-750C
800-1000



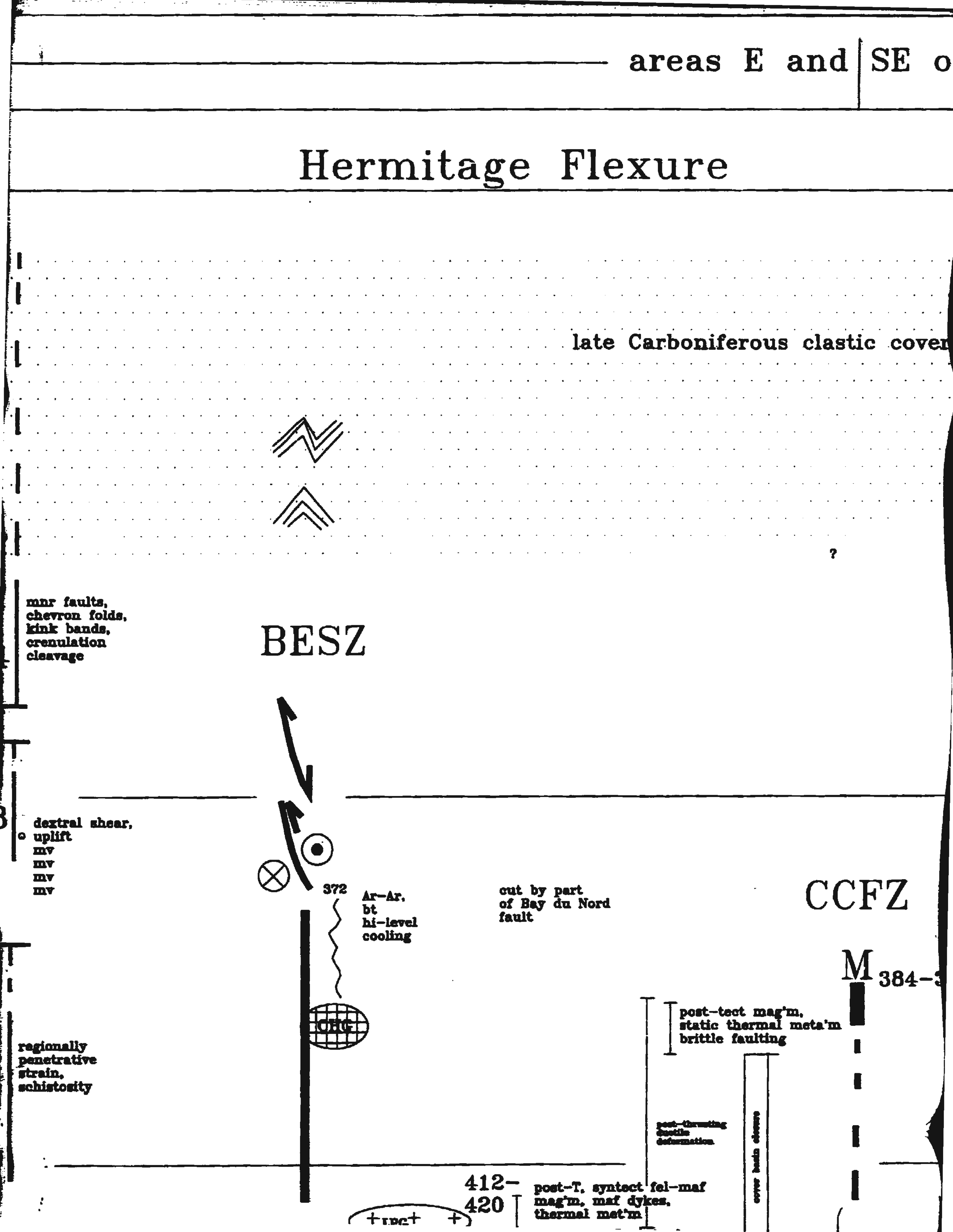
areas surrounding Cabot fault system
BRC
W. ASPY
ASPY S.Z.
E. ASPY
BRA
RRF
WBF
AF
Pictou-Morien
abdt mid-PZ volc-sed successions removed by late Carb shearing, uplift and erosion along Aspy-Cabot fault zone
phy, detachment
Ainslie Detachment
transpression, basin inversion detachment
Canso
Windsor
AMG
WSG
SG
splay of EHSZ deforms Horton
b/Windsor
GMS
MP
347
thermal updating of GBG
E-W splay
Horton
Horton
A
WSG
EHSZ
f BRC and Aspy: dykes in BRC
361
AMG
MP?
380 mu
ACSB
FBV
Margaree Shear Zone
SPG
PBG
N-splay
370mu
BBS
volcano-clastics
PSG
A
380
mean bt
387
GMM
rapid uplift and cooling
mean hb
pegmatite/aplites abdt thru' Aspy
dykes, sheets, of granitic/grano in BdO. Mafic dy occur sporadically
400
CLG
oldest age juxtapositio
meta'c peak ~ Chorlton's D2?
(700-750C. 800-1000mPa)
WNG
NHG
CRG
reset of Ar ages
410
high grade
locally strongly cataclased
stitches south EHSZ
KRDS
inititiation
rapid co exhumat

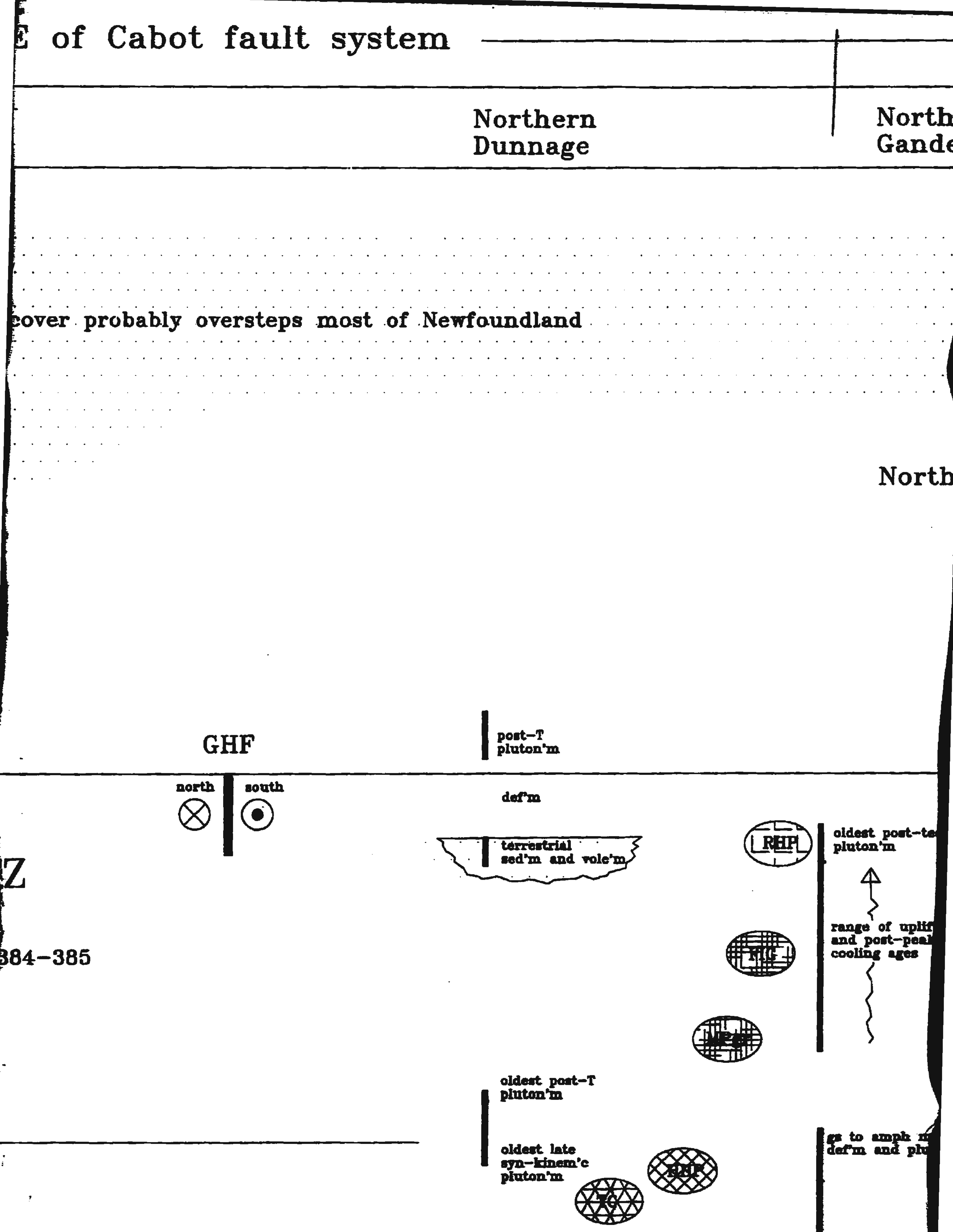


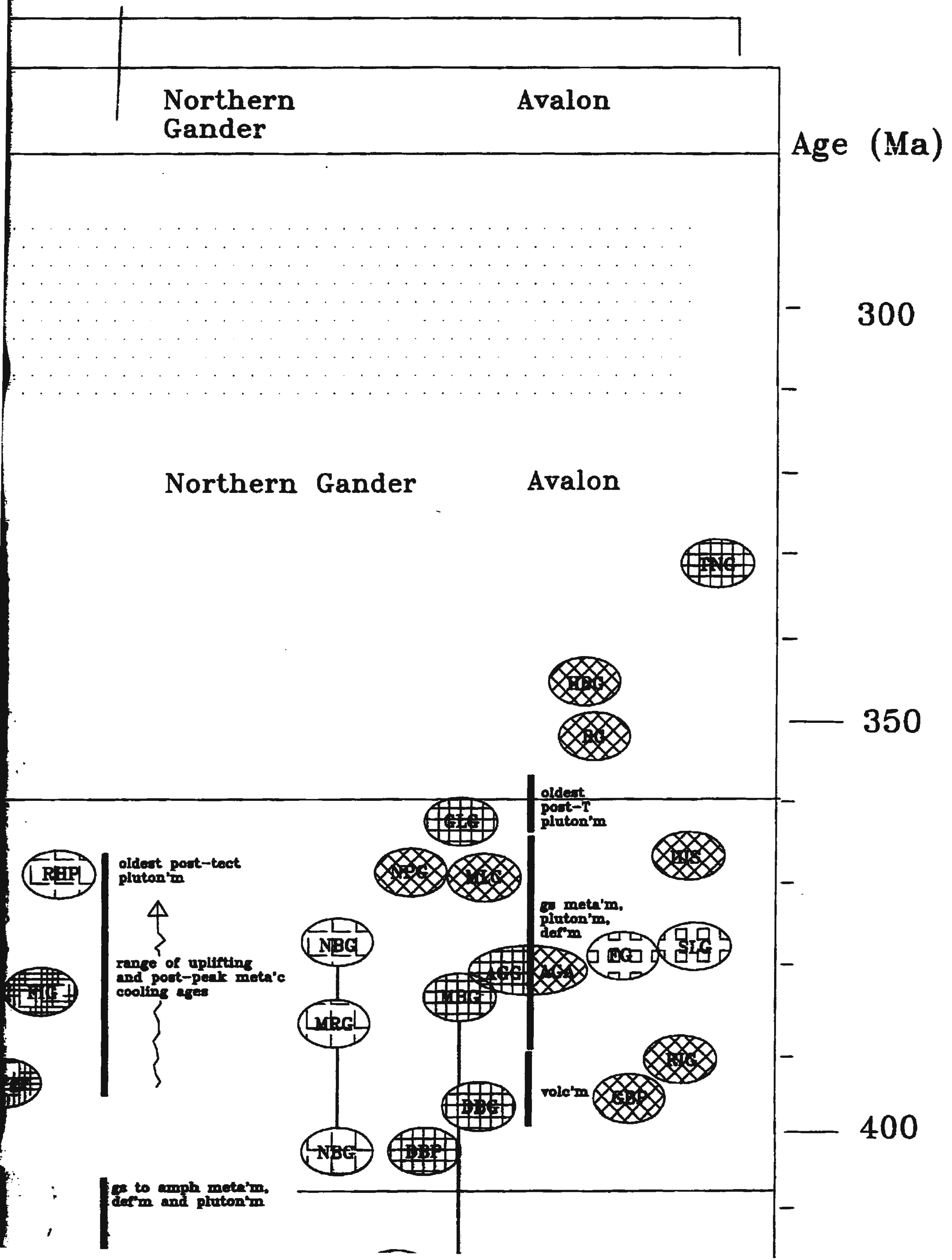
BRAS D'OR
MIRA
CRIC
CF
Pictou-
Morien
Canso
Windsor
y of EHSZ brittly
forms Horton sediments
splay
A
Big Pond
basin
Z
separation by Sydney Basin
rapid cooling through
hb and bt closure temps,
uplift/exhumation of
terrane as it collides with
Laurentia
@ 375: massive
plutons related to
crustal thickening
, sheets, small plutons, pegmatites, aplites
anitic/granodioritic comp common in Aspy, not
dO. Mafic dykes probably related to Fisset Bk
sporadically in both terranes.
oldest age of
juxtaposition
reset of
Ar ages
KRDS
BdO uplifted before and
rel unaffected by Acadian
geodynamic event of Dube et al.
dextral
NE-SW
convergence,
gs facies
sinistral,
amp facies



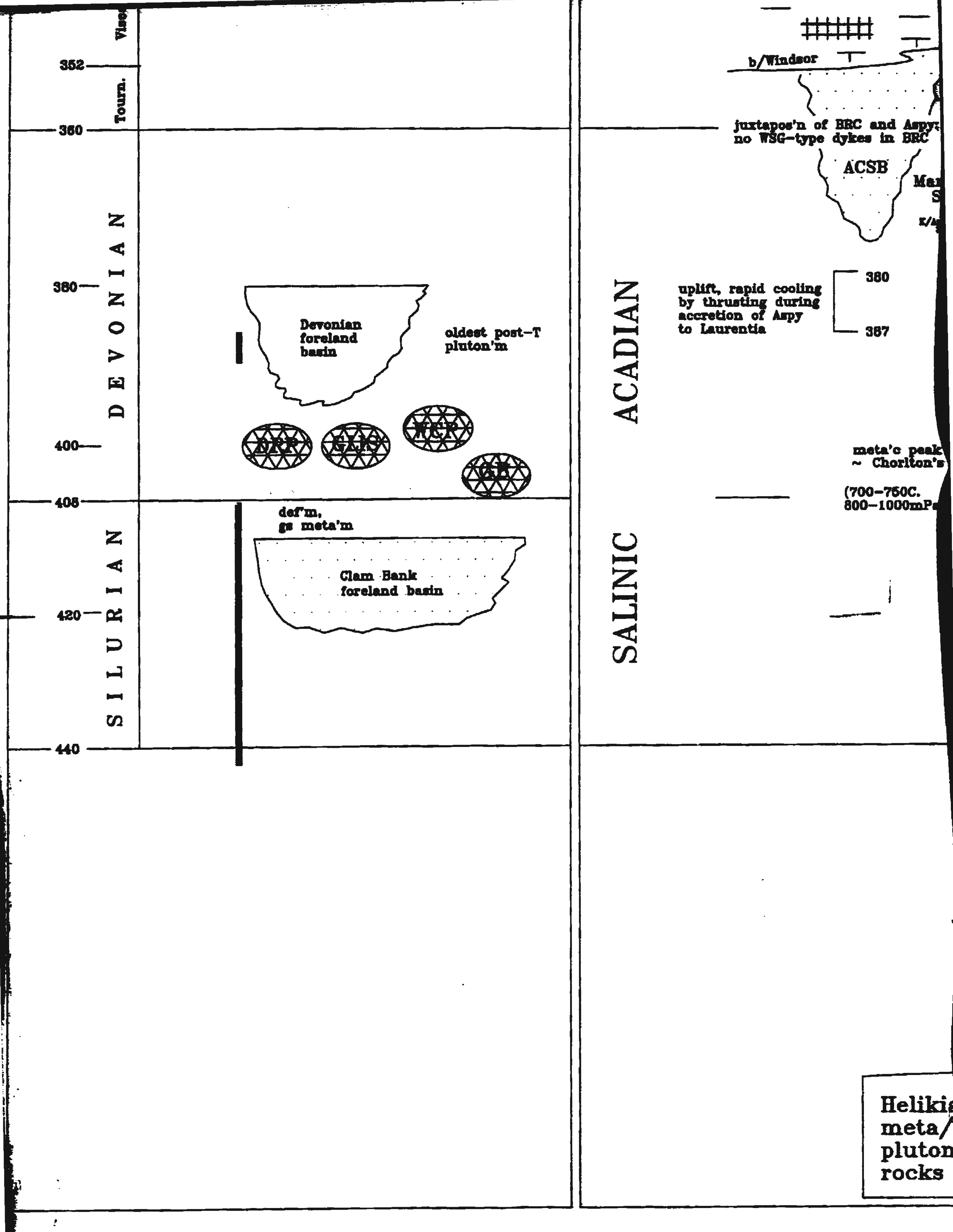
CRIC
GBC
PBC
HlC
BdN
CRFZ
Port aux Basques "gneiss" (amp facies)
gs facies
D4
348 bi
metased schists Ironbound pluton BdN Gp
BMSZ
360 bi
361 hb
D3
Horton? (now incl'd in WPG)
GBT
overthrusting of Grand Bay Complex
orogenic stages of Chorlton (1983)
fossil plants in WPG
377 hb
M
384–385
SBG
IAMBG
retro'd to gs facies
dextral NE-SW convergence, gs facies
erosion
IMFZ
PG
D2
406–403: cooling ages of PAB psammite
sinistral, amp facies
700? C 9 kbar
412
RBG
LPB


areas E and SE o
Hermitage Flexure
late Carboniferous clastic cover
?
mnr faults,
chevron folds,
kink bands,
crenulation
cleavage
BESZ
dextral shear,
uplift
mv
mv
mv
mv
372
Ar-Ar,
bt
hi-level
cooling
cut by part
of Bay du Nord
fault
CCFZ
M
384-
CHG
post-tect mag'm,
static thermal meta'm
brittle faulting
regionally
penetrative
strain,
schistosity
post-thrusting
ductile
deformation
cover basin closure
412-
420
post-T, syntect fel-maf
mag'm, maf dykes,
thermal met'm

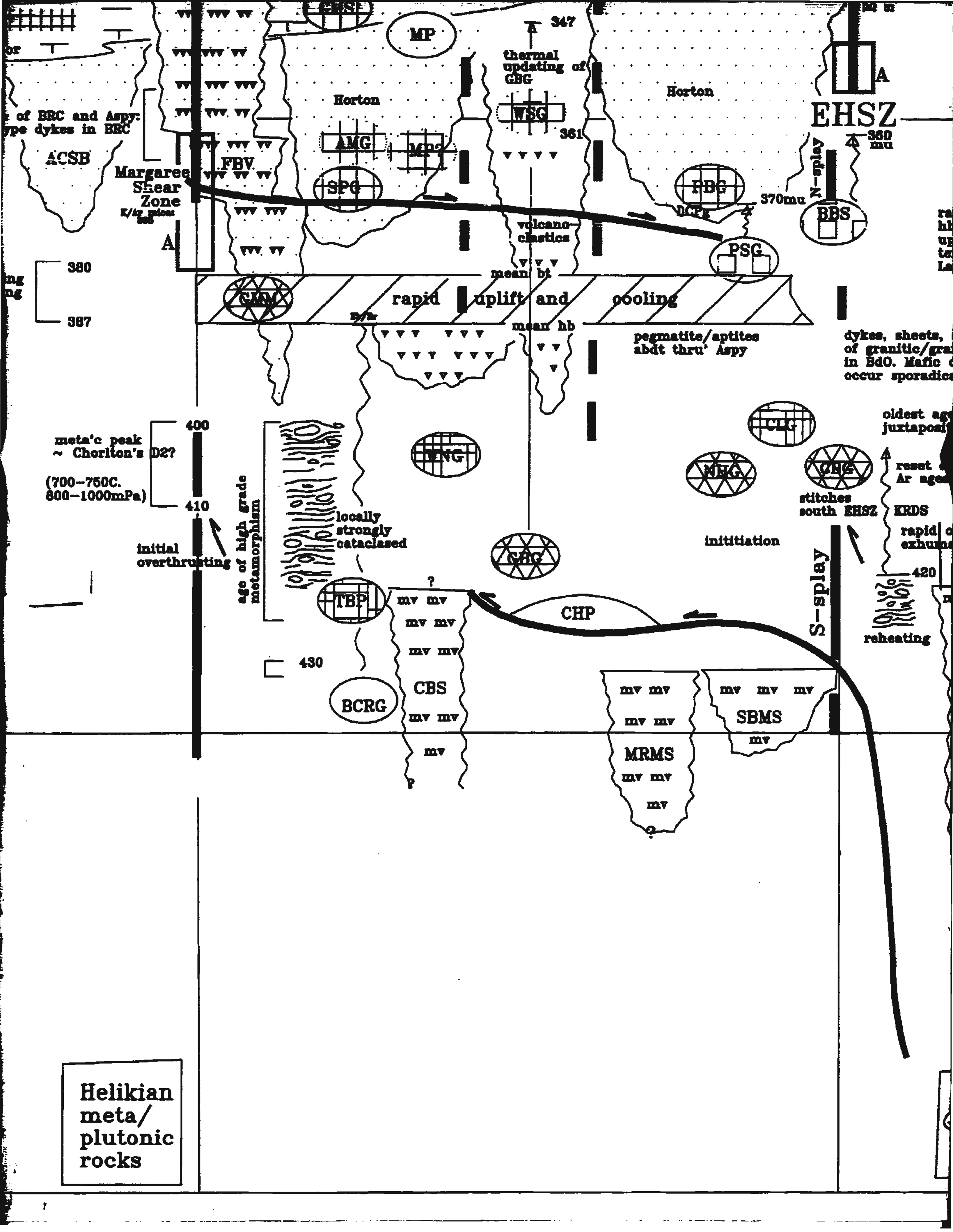

E of Cabot fault system
Northern Dunnage
North
Gande
cover probably oversteps most of Newfoundland
North
GHF
post-T pluton'm
north
south
def'm
terrestrial sed'm and volc'm
RHP
oldest post-te
pluton'm
Z
range of uplif
and post-peal
cooling ages
384-385
oldest post-T pluton'm
oldest late syn-kinem'c pluton'm
gs to amph m
def'm and plu



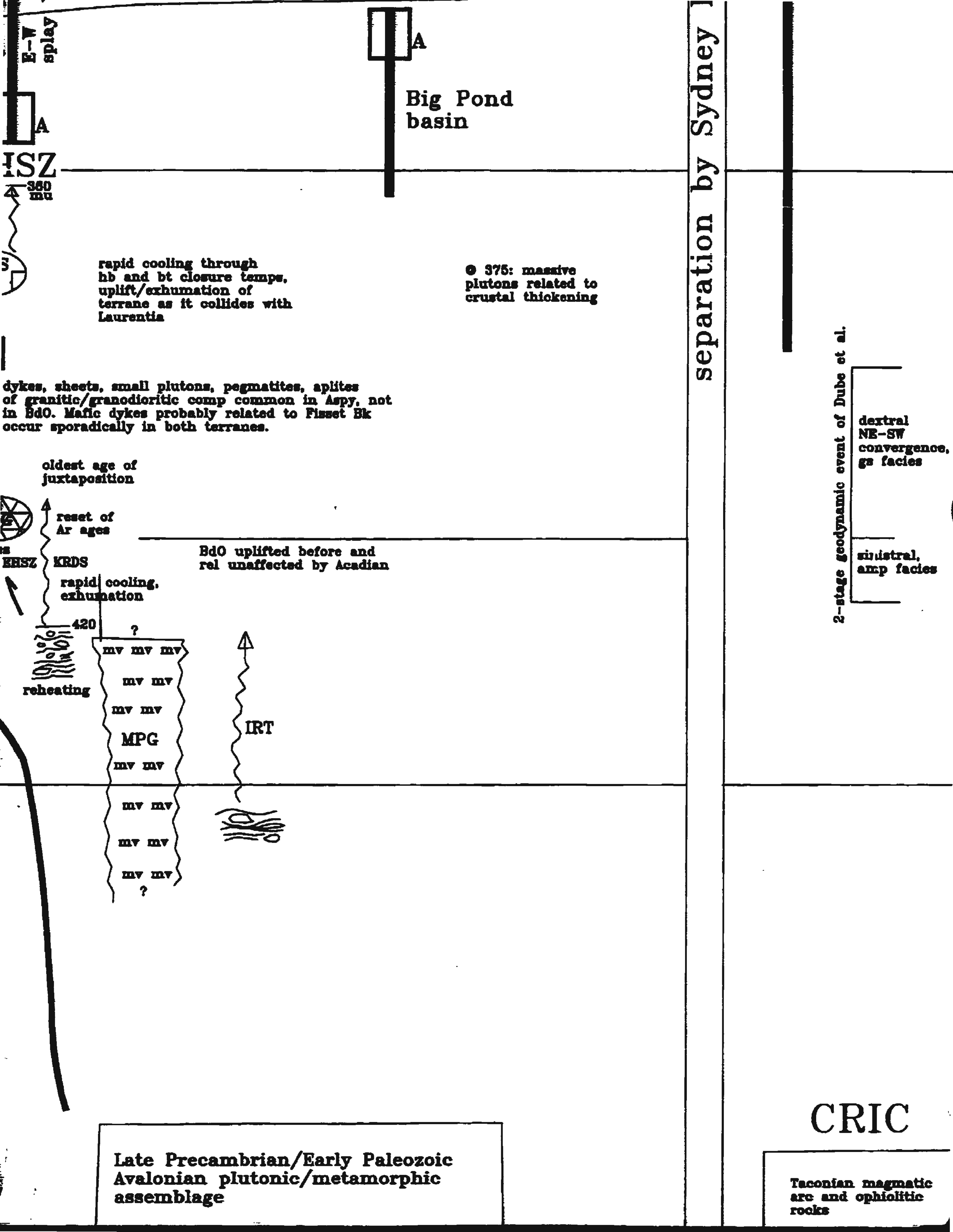
Northern
Gander
Avalon
Age (Ma)
300
Northern Gander
Avalon
350
400
oldest
post-T
pluton'm
oldest post-tect
pluton'm
gs meta'm,
pluton'm,
def'm
range of uplifting
and post-peak meta'c
cooling ages
volc'm
gs to amph meta'm,
def'm and pluton'm
TNG
GLG
RHP
NPG
MLG
NBG
SLG
AGG
AGA
MRG
MBG
DBG
NBG
DBP

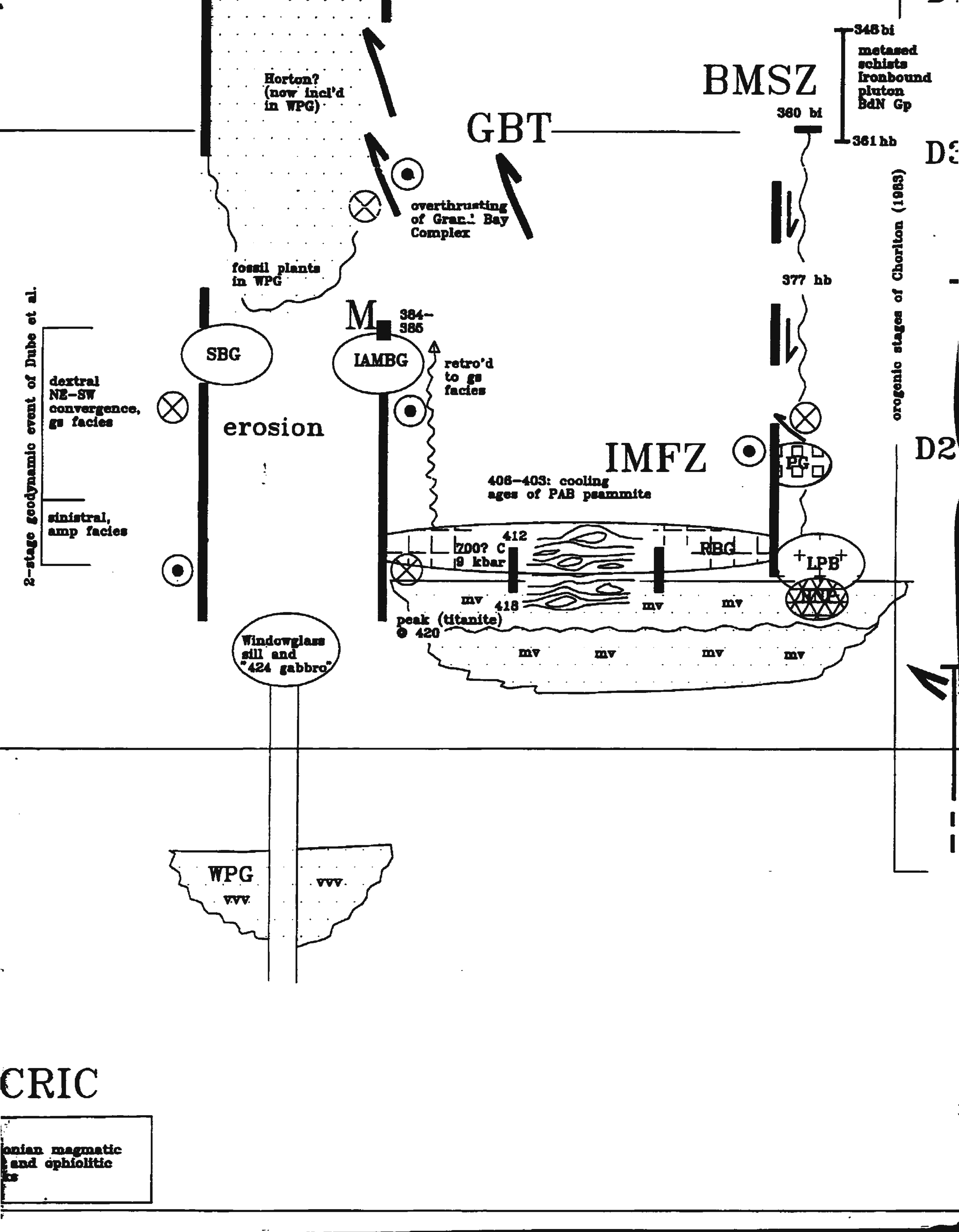


Visé
352
Tourn.
360
DEVONIAN
380
400
408
SILURIAN
420
440
Devonian foreland basin
oldest post-T pluton'm
WCP
GB
def'm, gs meta'm
Clam Bank foreland basin
b/Windsor
juxtapos'n of BRC and Aspy; no WSG-type dykes in BRC
ACSB
ACADIAN
SALINIC
uplift, rapid cooling by thrusting during accretion of Aspy to Laurentia
380
387
meta'c peak
~ Chorlton's
(700–750C.
800–1000mPa

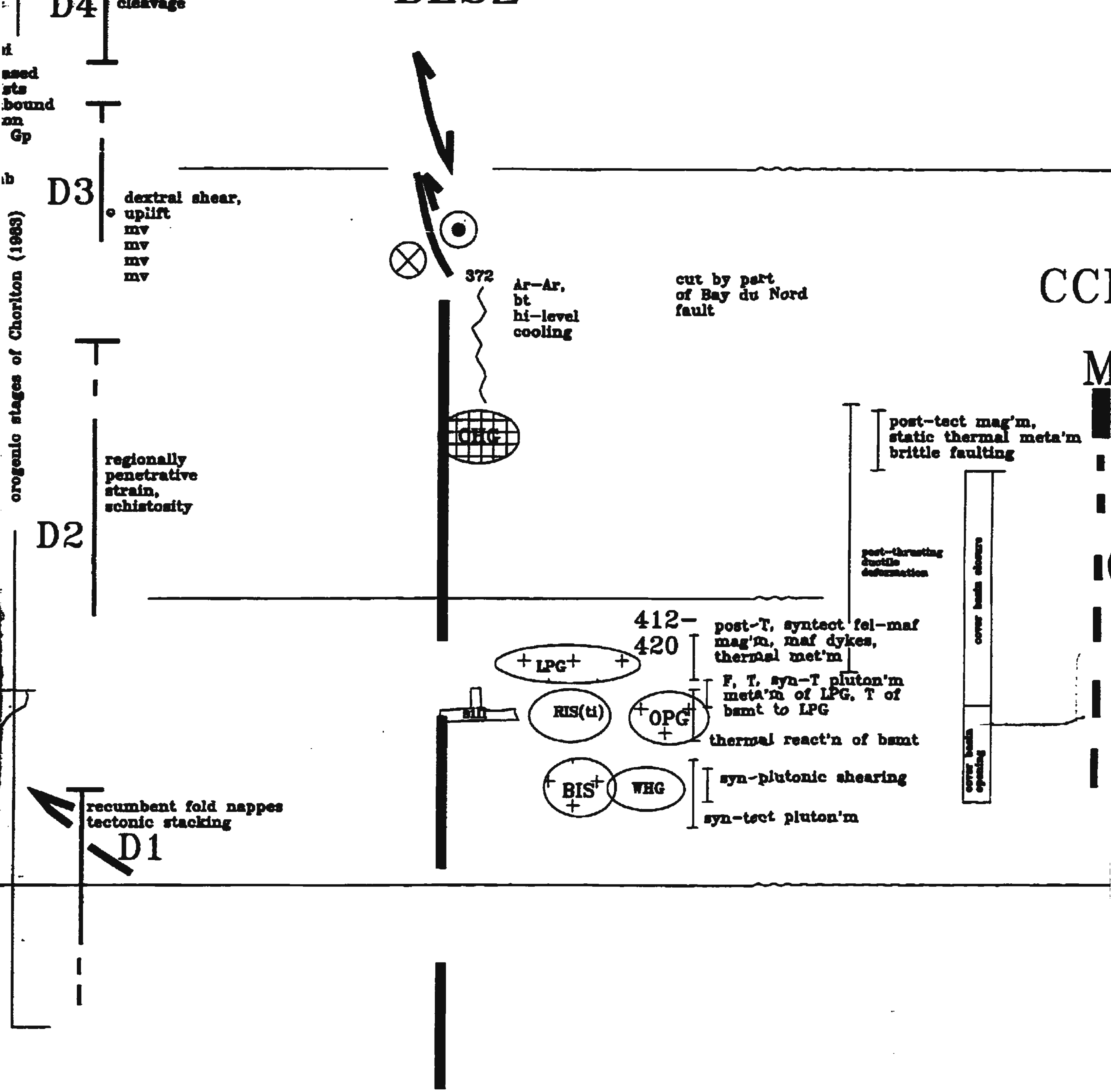


MP
347
thermal updating of GBG
Horton
Horton
EHSZ
A
of BRC and Aspy:
ype dykes in BRC
WSG
AMG
361
360 mu
ACSB
FBV
Margaree Shear Zone
SPG
PBG
370mu
N-splay
DCPs
BBS
volcano-clastics
PSG
A
380
387
mean bt
rapid uplift and cooling
mean hb
pegmatite/aptites abdt thru' Aspy
dykes, sheets,
of granitic/gra
in BdO. Mafic
occur sporadic
400
meta'c peak
~ Chorlton's D2?
(700–750C.
800–1000mPa)
410
initial overthrusting
age of high grade metamorphism
locally strongly cataclased
CLG
oldest ag
juxtapos
reset
Ar age
stitches south EHSZ
KRDS
rapid
exhum
initiation
S-splay
420
reheating
TBP
mv mv
CHP
430
CBS
BCRG
mv mv
SBMS
MRMS
Helikian meta/ plutonic rocks

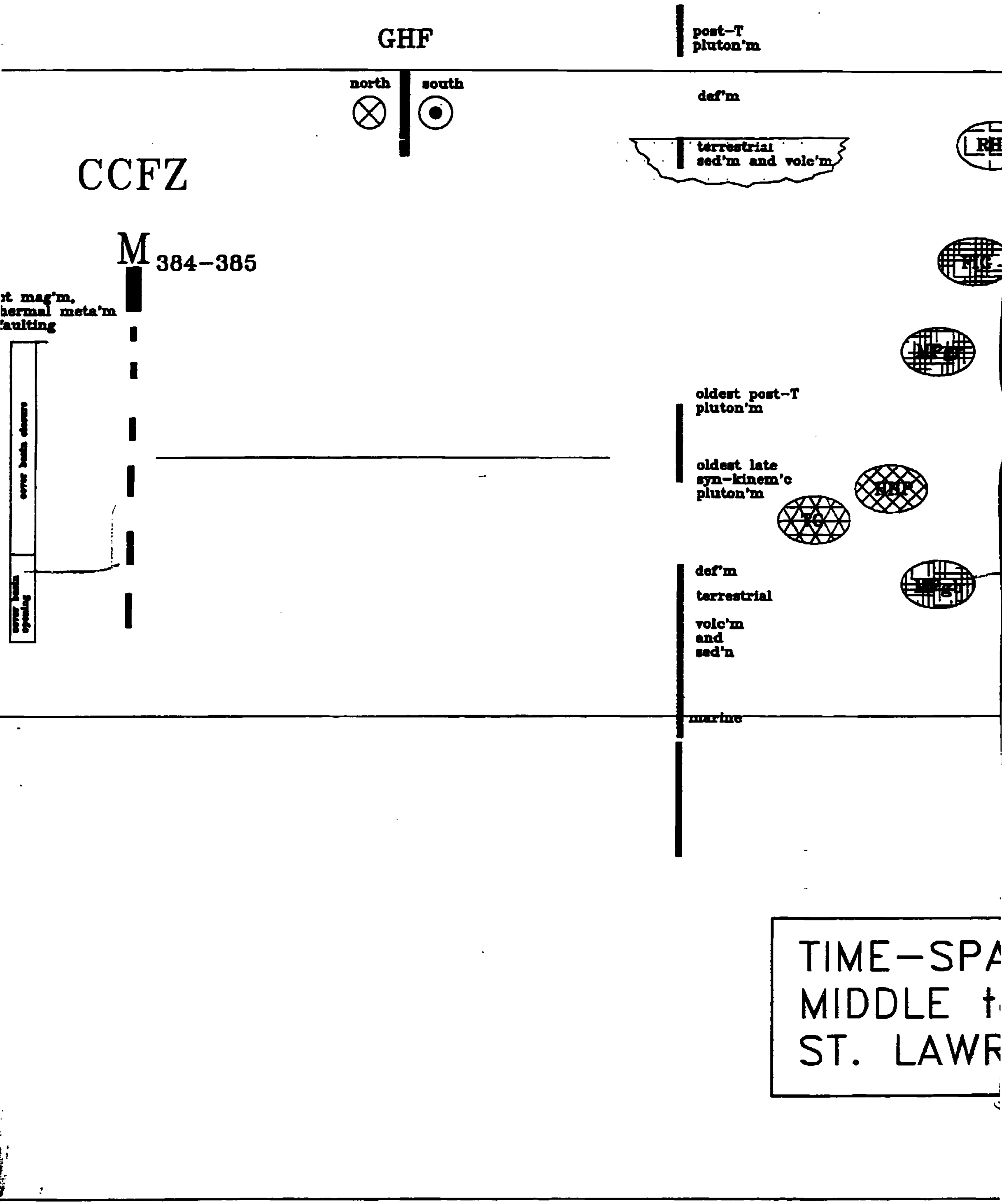

E-W splay
A
A
Big Pond basin
ISZ
380 mu
separation by Sydney
rapid cooling through hb and bt closure temps, uplift/exhumation of terrane as it collides with Laurentia
@ 375: massive plutons related to crustal thickening
dykes, sheets, small plutons, pegmatites, aplites of granitic/granodioritic comp common in Aspy, not in BdO. Mafic dykes probably related to Fisset Bk occur sporadically in both terranes.
2-stage geodynamic event of Dube et al.
dextral NE-SW convergence, gs facies
sinistral, amp facies
oldest age of juxtaposition
reset of Ar ages
EHSZ
KRDS
BdO uplifted before and rel unaffected by Acadian
rapid cooling, exhumation
420
?
mv mv mv
mv mv
mv mv
MPG
mv mv
mv mv
mv mv
mv mv
?
reheating
IRT
CRIC
Late Precambrian/Early Paleozoic Avalonian plutonic/metamorphic assemblage
Taconian magmatic arc and ophiolitic rocks



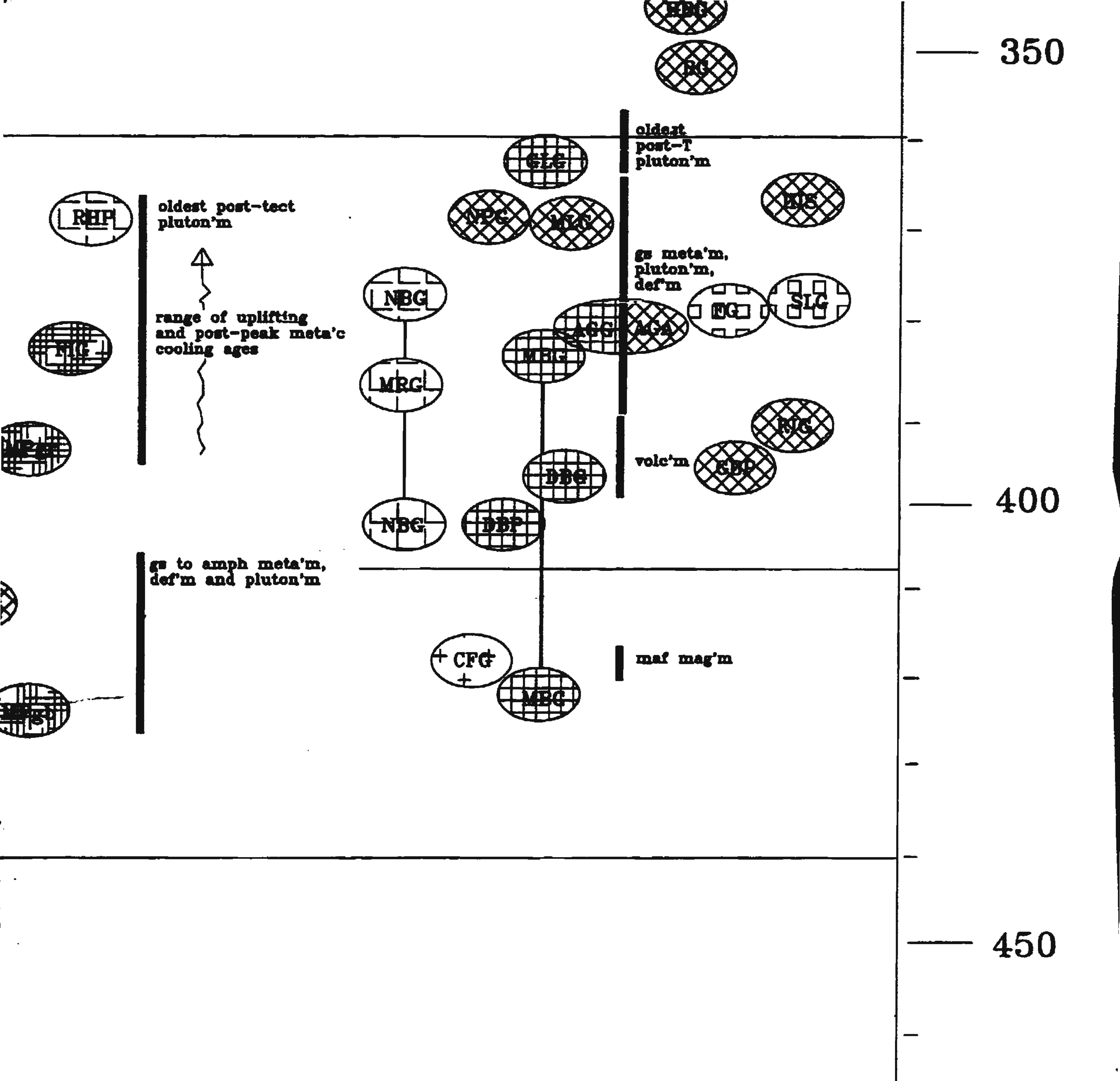
Horton?
(now incl'd
in WPG)
GBT
BMSZ
348 bi
metased
schists
Ironbound
pluton
BdN Gp
360 bi
361 hb
D3
overthrusting
of Gran.! Bay
Complex
fossil plants
in WPG
377 hb
orogenic stages of Chorlton (1983)
2-stage geodynamic event of Dube et al.
M
384–
385
SBG
IAMBG
retro'd
to gs
facies
dextral
NE–SW
convergence,
gs facies
erosion
IMFZ
D2
PG
406–403: cooling
ages of PAB psammite
sinistral,
amp facies
412
700? C
9 kbar
RBG
LPB
418
mv
peak (titanite)
@ 420
Windowglass
sill and
"424 gabbro"
WPG
vvv
CRIC
onian magmatic
and ophiolitic
ks



D4
cleavage
D3
dextral shear,
uplift
mv
mv
mv
mv
orogenic stages of Chorlton (1983)
372
Ar–Ar,
bt
hi-level
cooling
cut by part
of Bay du Nord
fault
CHG
regionally
penetrative
strain,
schistosity
D2
post-tect mag'm,
static thermal meta'm
brittle faulting
post-thrusting
ductile
deformation
cover basin closure
412–
420
post-T, syntect fel-maf
mag'm, maf dykes,
thermal met'm
LPG
F, T, syn-T pluton'm
meta'm of LPG, T of
bsmt to LPG
sill
RIS(ti)
OPG
thermal react'n of bsmt
cover basin opening
BIS
WHG
syn-plutonic shearing
syn-tect pluton'm
recumbent fold nappes
tectonic stacking
D1

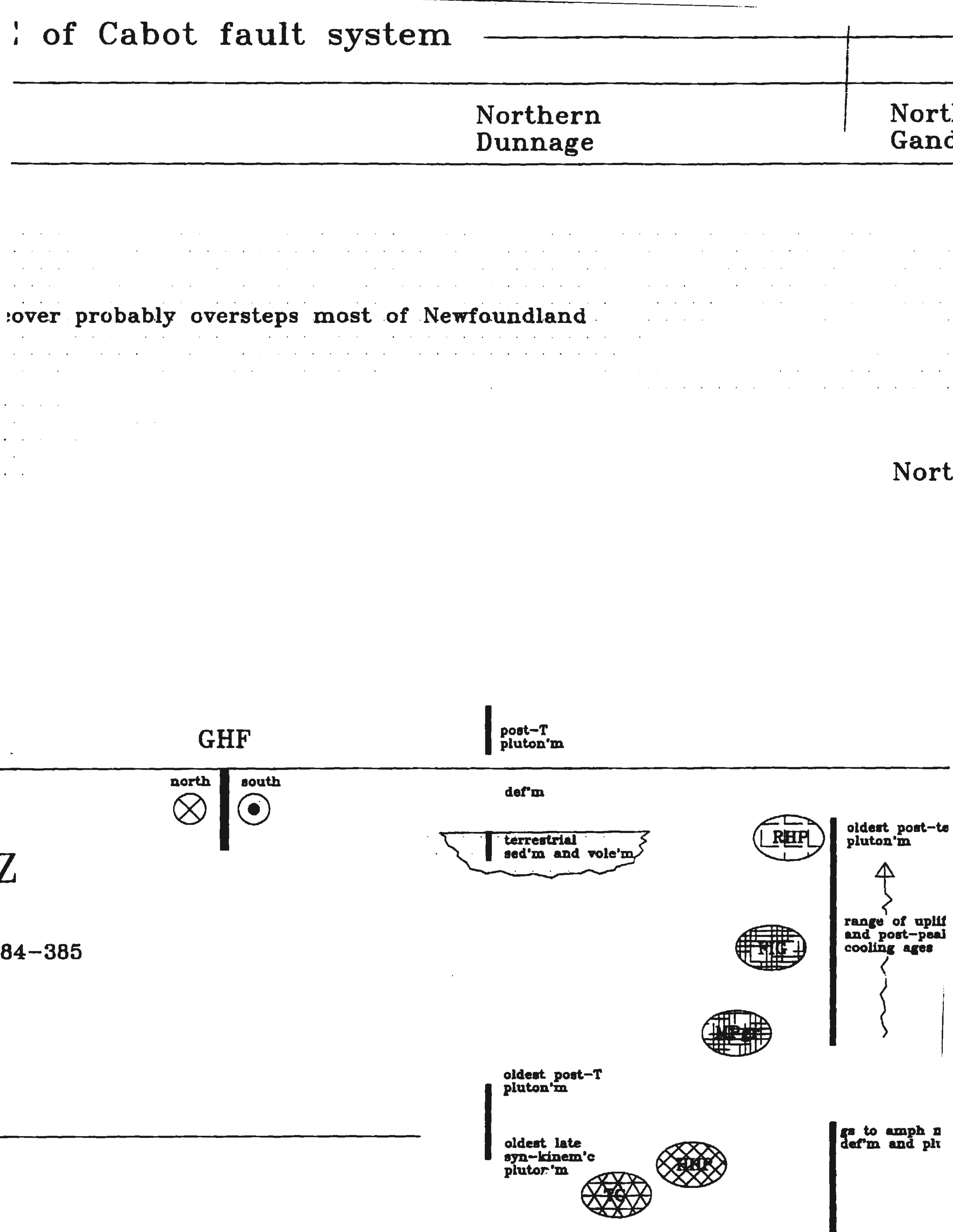


GHF
post-T pluton'm
north
south
def'm
terrestrial sed'm and volc'm
CCFZ
M 384-385
st mag'm, hermal meta'm faulting
oldest post-T pluton'm
oldest late syn-kinem'c pluton'm
def'm
terrestrial
volc'm and sed'n
marine
TIME-SPA
MIDDLE t
ST. LAWR

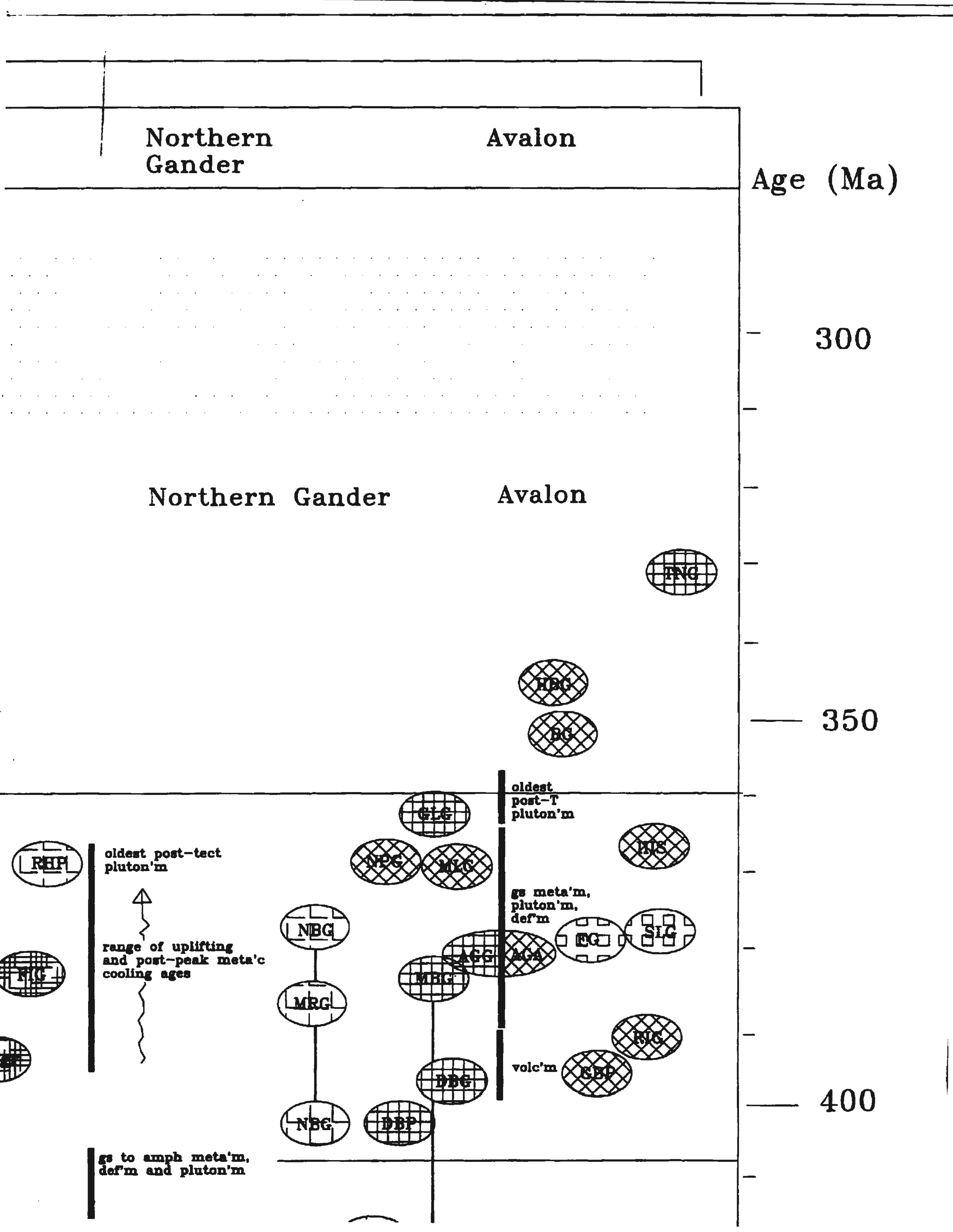


-SPACE DIAGRAM for the
LE to LATE PALEOZOIC at the
AWRENCE PROMONTORY

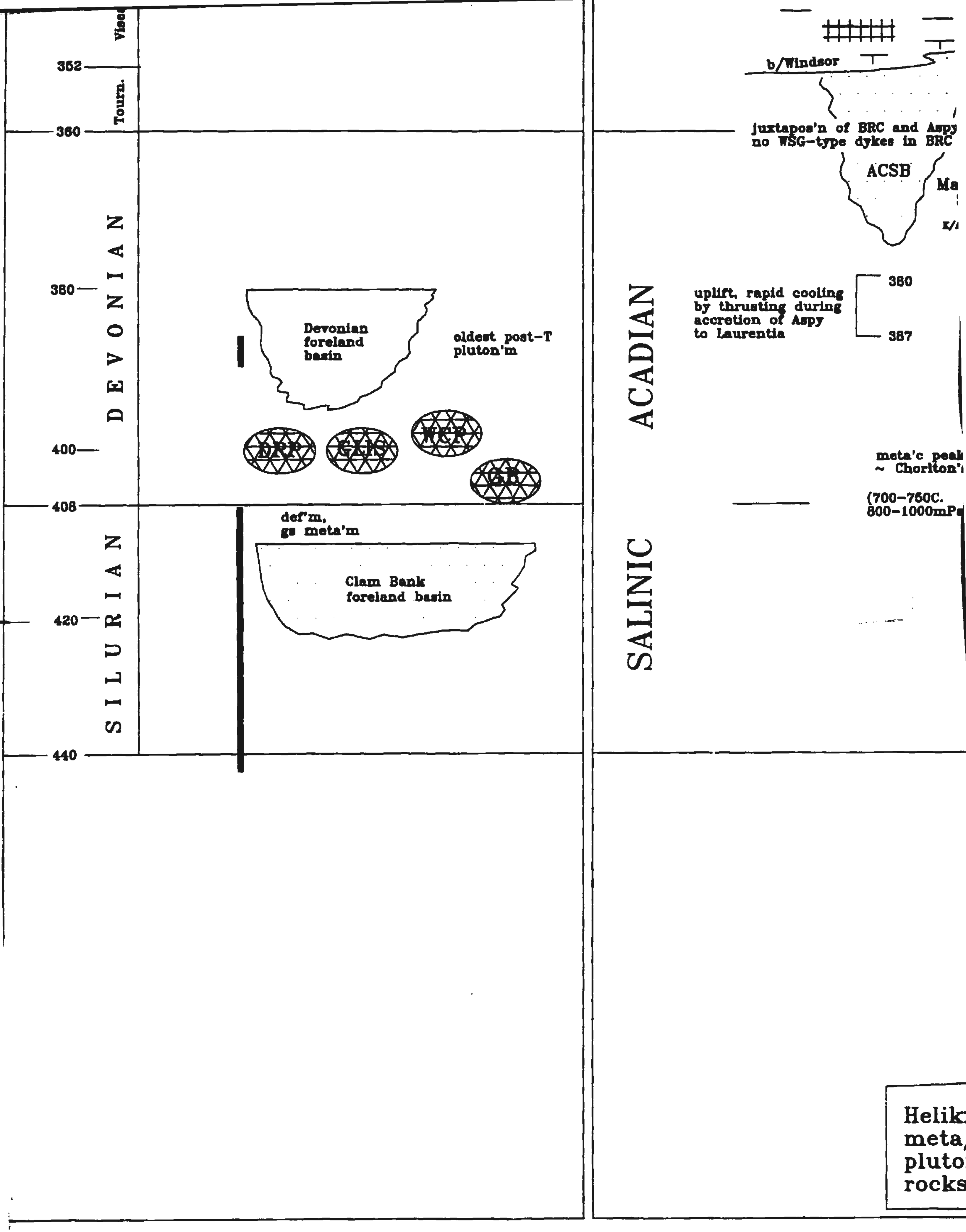
Figure VI.3



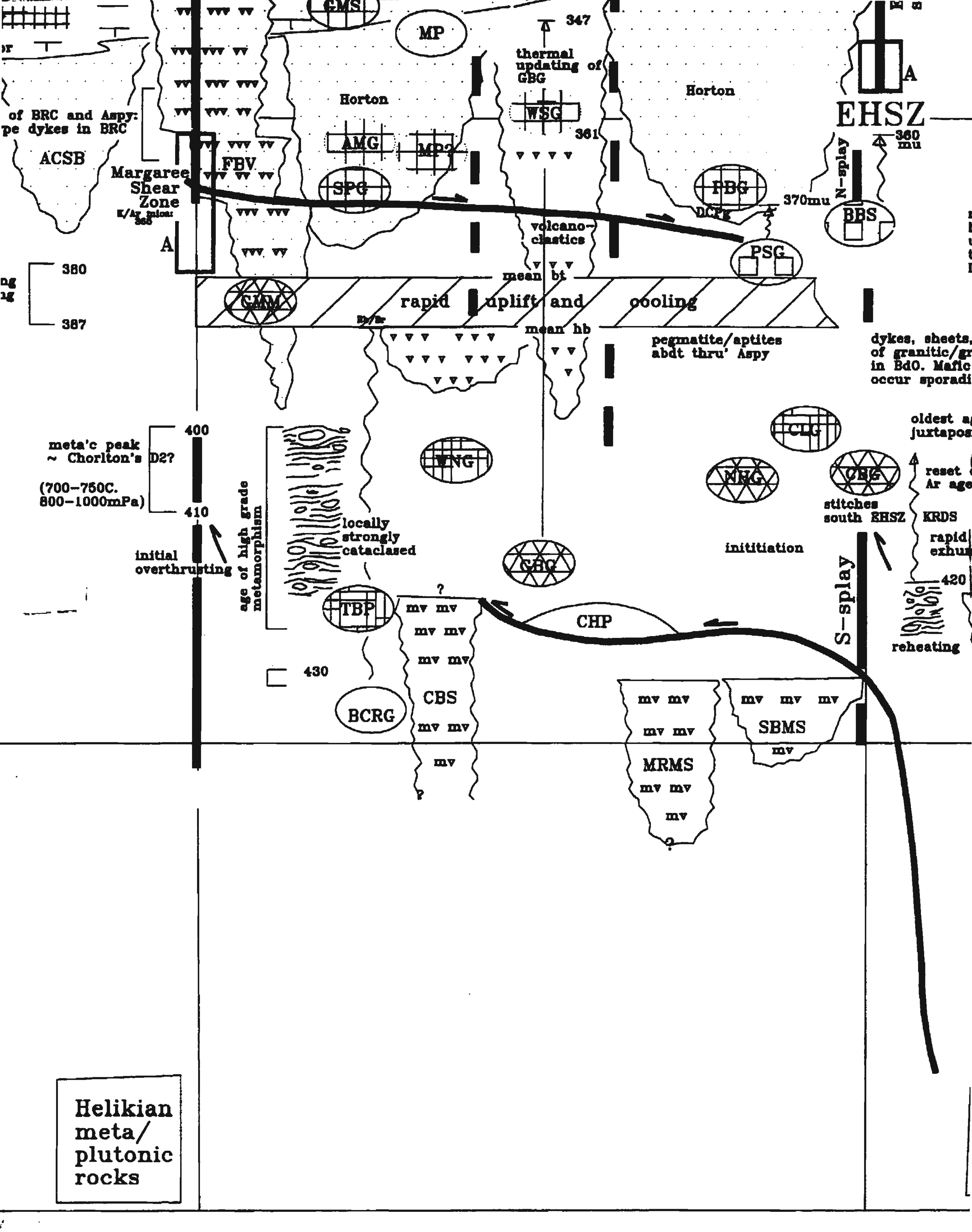
of Cabot fault system
Northern Dunnage
Nort
Gand
over probably oversteps most of Newfoundland
Nort
GHF
north
south
post–T pluton'm
def'm
terrestrial sed'm and volc'm
RHP
oldest post–te pluton'm
Z
range of uplif and post–peal cooling ages
84–385
oldest post–T pluton'm
oldest late syn–kinem'c pluton'm
gs to amph n def'm and plu

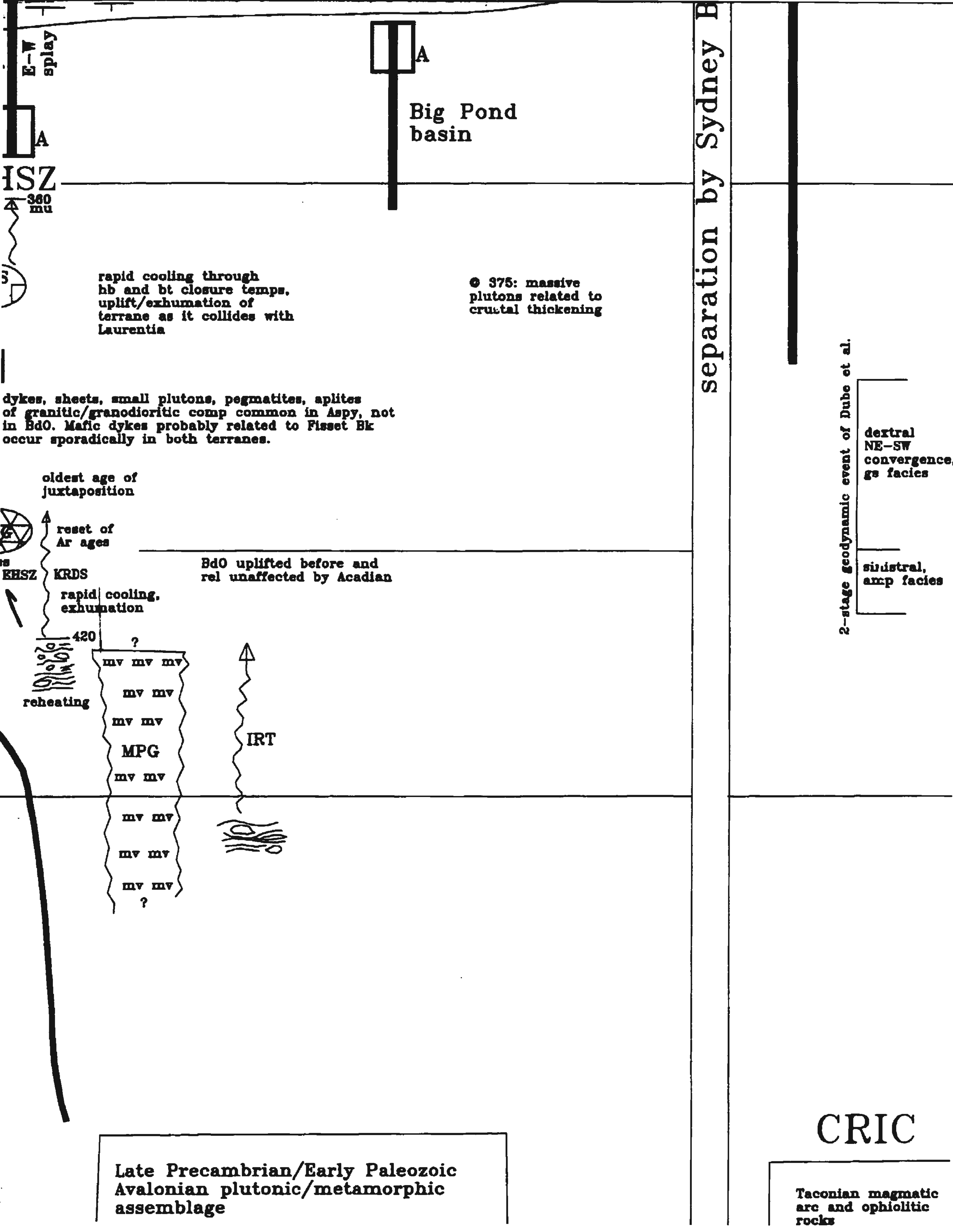


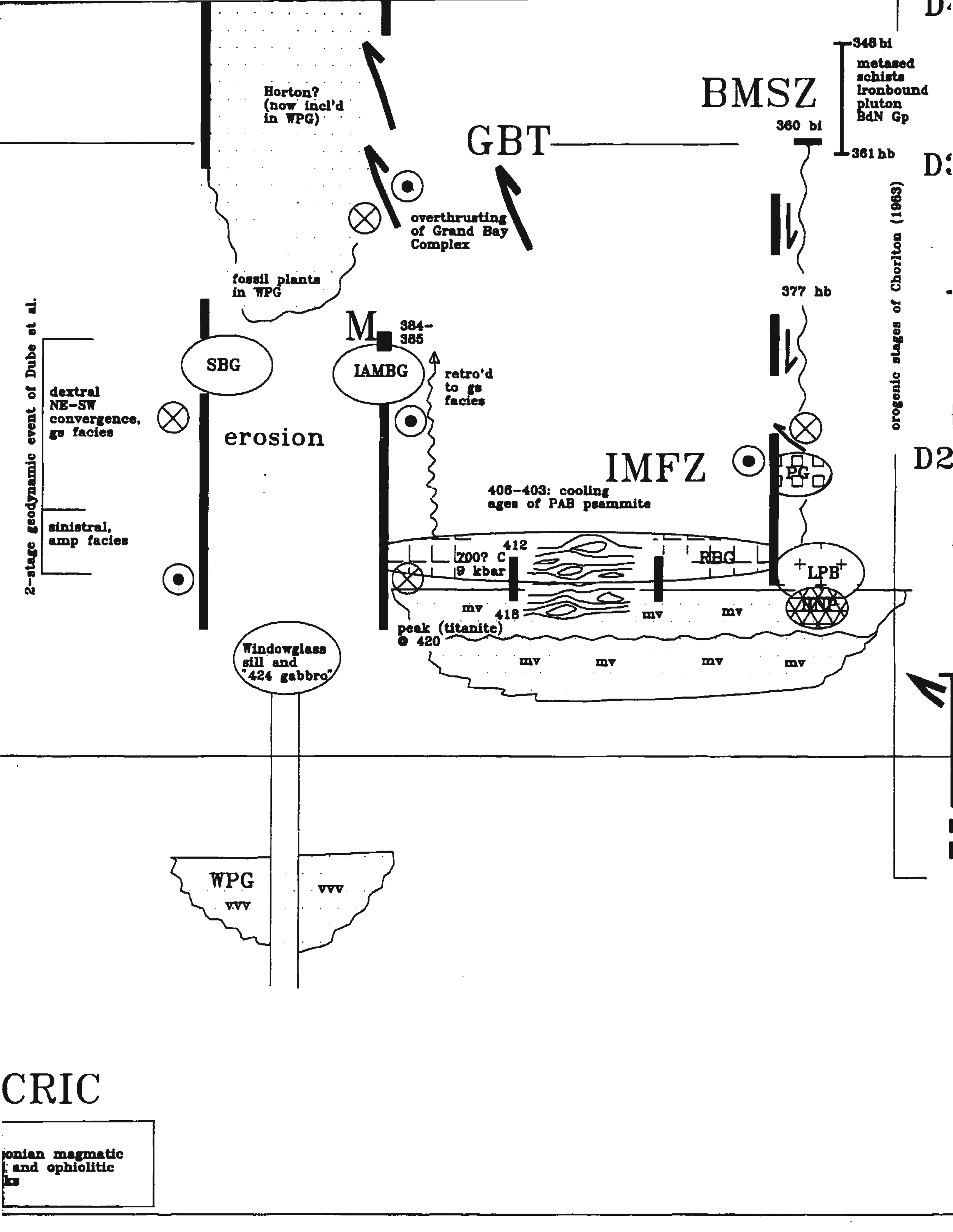
Northern Gander
Avalon
Age (Ma)
300
Northern Gander
Avalon
TNG
HBG
350
BG
oldest post-T pluton'm
GLG
HIS
RHP
oldest post-tect pluton'm
NPG
MLC
gs meta'm, pluton'm, def'm
NBG
range of uplifting and post-peak meta'c cooling ages
FG
SLG
AGG
AGA
FIG
MBG
MRG
RIG
volc'm
DBG
EBP
400
NBG
DBP
gs to amph meta'm, def'm and pluton'm



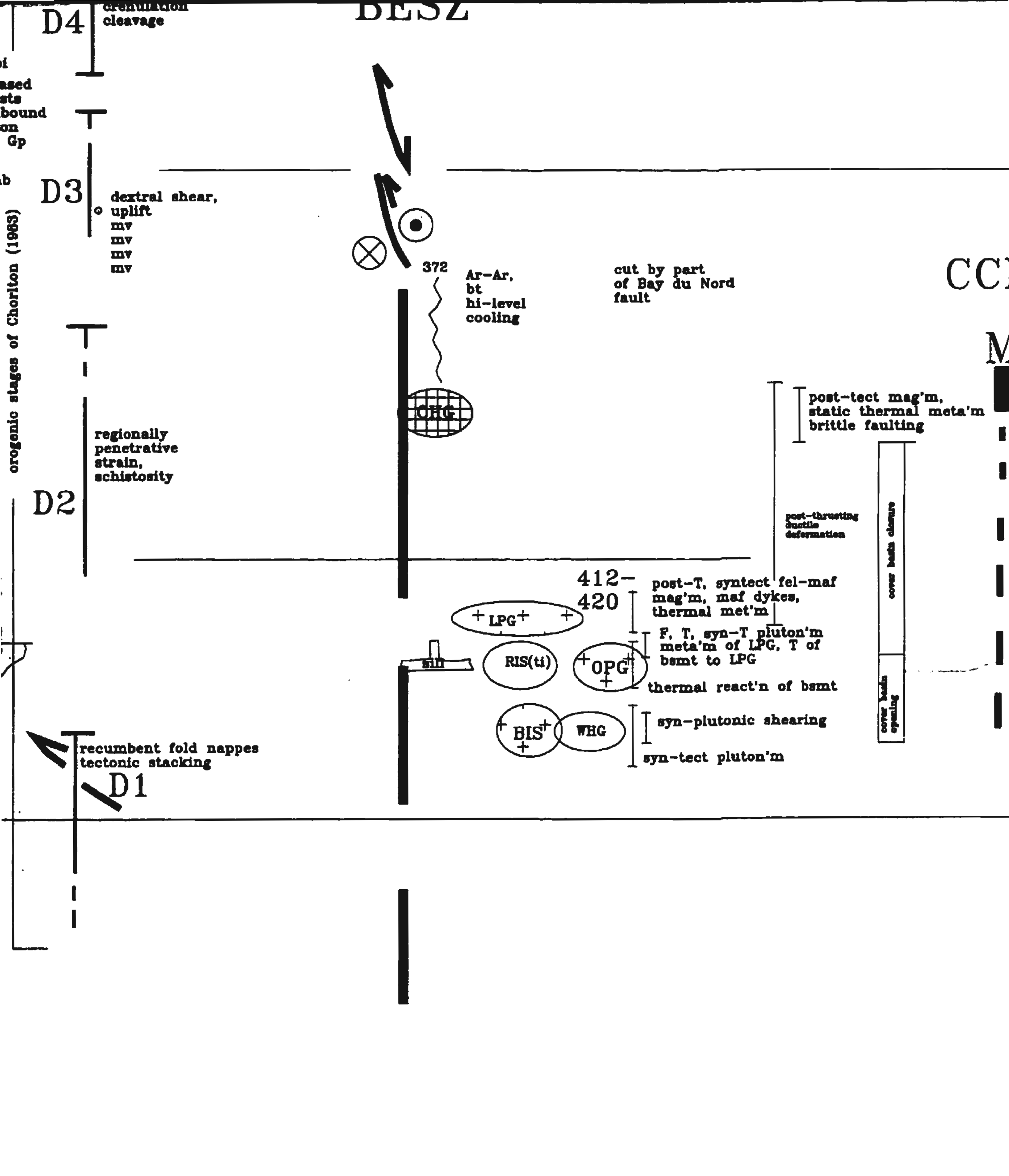
Visé
352
Tourn.
360
DEVONIAN
380
400
408
SILURIAN
420
440
Devonian foreland basin
oldest post-T pluton'm
DRP
GLIS
WCP
GB
def'm, gs meta'm
Clam Bank foreland basin
b/Windsor
juxtapos'n of BRC and Aspy
no WSG-type dykes in BRC
ACSB
Ma
ACADIAN
SALINIC
uplift, rapid cooling by thrusting during accretion of Aspy to Laurentia
380
387
meta'c peak
~ Chorlton's
(700–750C.
800–1000mPa
Helik
meta
pluto
rocks


GMS
MP
347
thermal updating of GBG
Horton
WSG
361
Horton
EHSZ
A
360 mu
N-splay
of BRC and Aspy:
pe dykes in BRC
ACSB
AMG
MP?
FBV
Margaree Shear Zone
K/Ar mica: 368
SPG
PBG
370mu
DCPg
BBS
A
volcano-clastics
PSG
380
387
mean bt
CMM
rapid uplift and cooling
mean hb
pegmatite/aptites abdt thru' Aspy
dykes, sheets,
of granitic/gr
in BdO. Mafic
occur sporadi
400
meta'c peak ~ Chorlton's D2?
(700-750C. 800-1000mPa)
410
initial overthrusting
age of high grade metamorphism
WNG
locally strongly cataclased
CLG
oldest a
juxtapos
NHG
CBG
reset
Ar age
stitches south EHSZ
KRDS
rapid
exhu
initiation
GBG
420
S-splay
TBP
?
mv mv
CHP
reheating
430
CBS
BCRG
mv mv
SBMS
MRMS
mv
?
Helikian meta/plutonic rocks

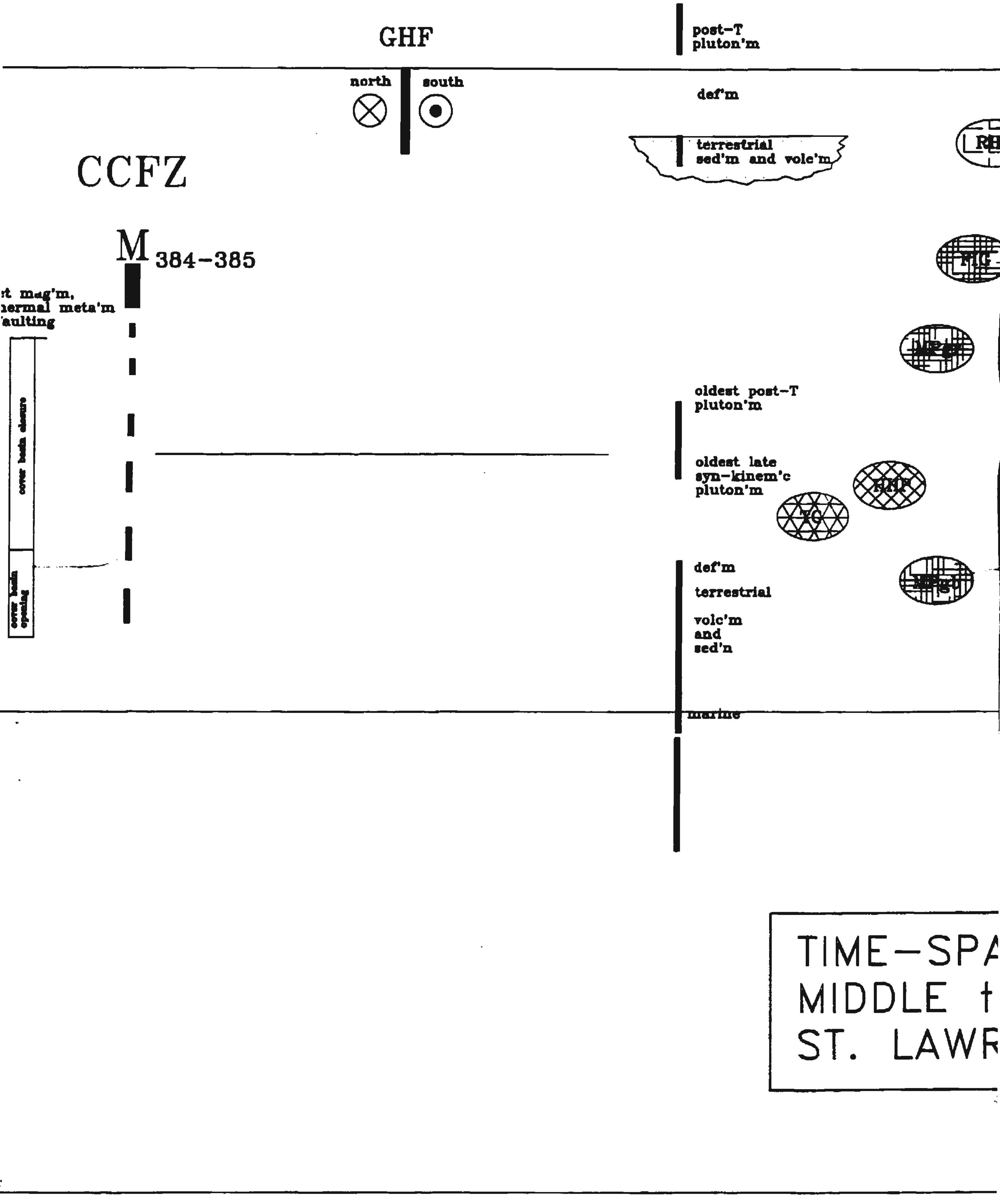

E-W
splay
A
A
ISZ
360
mu
Big Pond
basin
separation by Sydney B
rapid cooling through
hb and bt closure temps,
uplift/exhumation of
terrane as it collides with
Laurentia
@ 375: massive
plutons related to
crustal thickening
dykes, sheets, small plutons, pegmatites, aplites
of granitic/granodioritic comp common in Aspy, not
in BdO. Mafic dykes probably related to Fisset Bk
occur sporadically in both terranes.
2-stage geodynamic event of Dube et al.
dextral
NE-SW
convergence,
gs facies
oldest age of
juxtaposition
reset of
Ar ages
EHSZ
KRDS
BdO uplifted before and
rel unaffected by Acadian
sinistral,
amp facies
rapid cooling,
exhumation
420
?
reheating
mv mv mv
mv mv
mv mv
MPG
mv mv
mv mv
mv mv
mv mv
?
IRT
CRIC
Late Precambrian/Early Paleozoic
Avalonian plutonic/metamorphic
assemblage
Taconian magmatic
arc and ophiolitic
rocks



Horton? (now incl'd in WPG)
GBT
BMSZ
348 bi
metased schists Ironbound pluton BdN Gp
360 bi
361 hb
D3
overthrusting of Grand Bay Complex
fossil plants in WPG
377 hb
orogenic stages of Chorlton (1983)
2-stage geodynamic event of Dube et al.
M
384-385
SBG
IAMBG
retro'd to gs facies
dextral NE-SW convergence, gs facies
erosion
IMFZ
D2
PG
406-403: cooling ages of PAB psammite
sinistral, amp facies
412
700? C 9 kbar
RBG
LPB
mv
418
peak (titanite) @ 420
Windowglass sill and "424 gabbro"
WPG
vvv
CRIC
onian magmatic
and ophiolitic
ks



BESZ
D4
crenulation cleavage
ased
sts
bound
on
Gp
D3
dextral shear,
uplift
mv
mv
mv
mv
orogenic stages of Chorlton (1983)
372
Ar–Ar,
bt
hi-level
cooling
cut by part
of Bay du Nord
fault
CC
M
CHG
post-tect mag'm,
static thermal meta'm
brittle faulting
regionally
penetrative
strain,
schistosity
D2
post-thrusting
ductile
deformation
cover basin closure
412–
420
post-T, syntect fel-maf
mag'm, maf dykes,
thermal met'm
LPG
F, T, syn-T pluton'm
meta'm of LPG, T of
bsmt to LPG
sill
RIS(ti)
OPG
thermal react'n of bsmt
cover basin opening
BIS
WHG
syn-plutonic shearing
syn-tect pluton'm
recumbent fold nappes
tectonic stacking
D1


GHF
post-T
pluton'm
north
south
def'm
terrestrial
sed'm and volc'm
CCFZ
M 384-385
t mag'm,
hermal meta'm
faulting
cover basin closure
cover basin opening
oldest post-T
pluton'm
oldest late
syn-kinem'c
pluton'm
def'm
terrestrial
volc'm
and
sed'n
marine
TIME-SPA
MIDDLE t
ST. LAWR

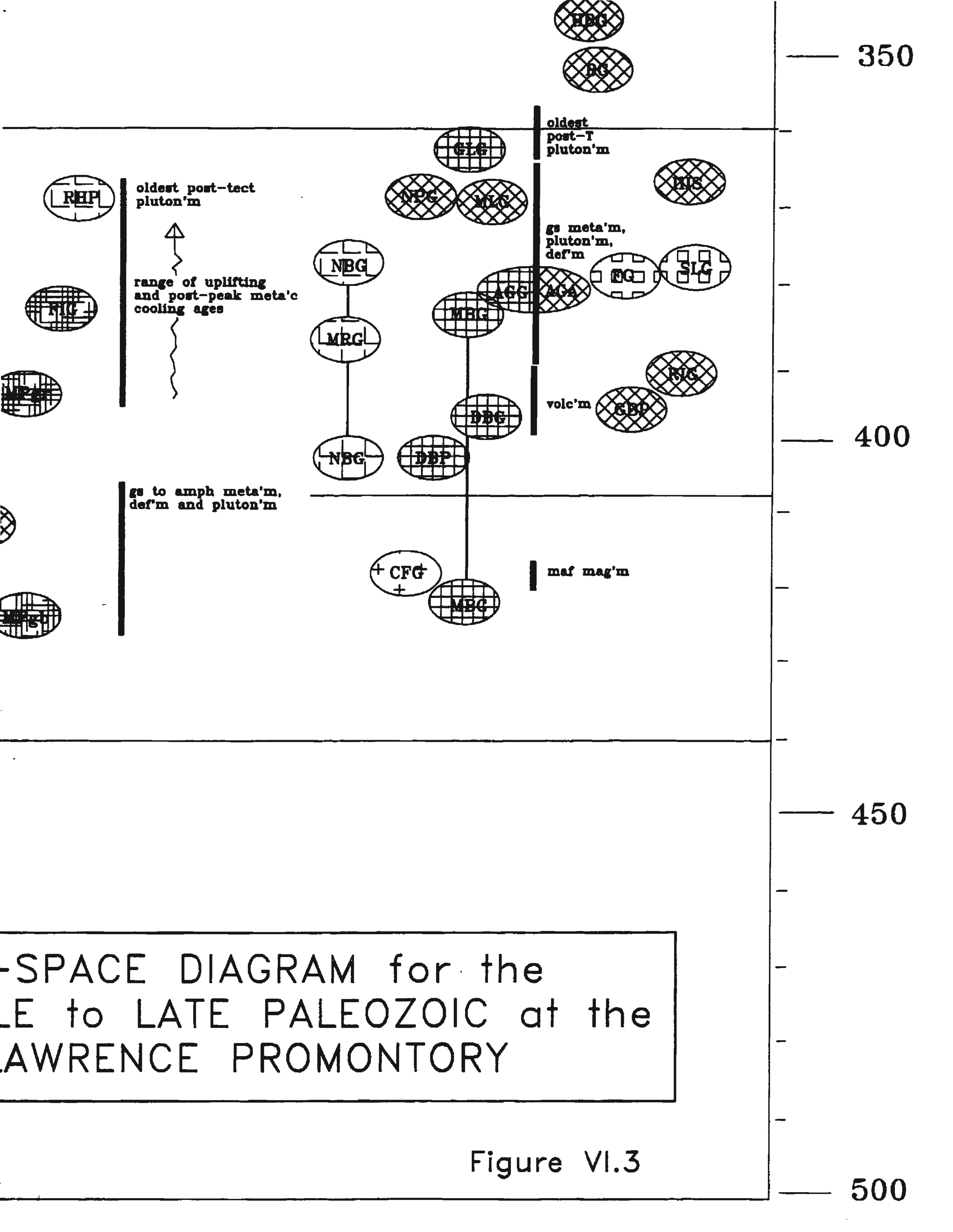
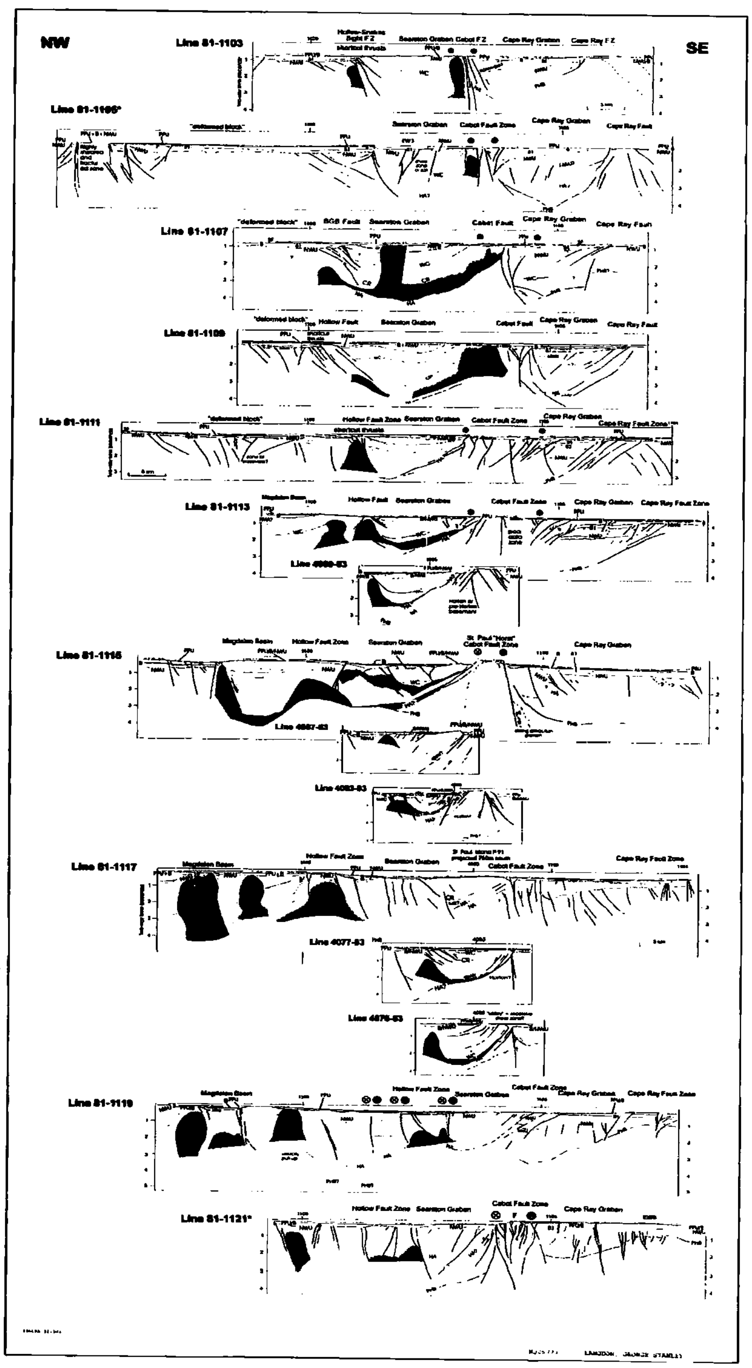
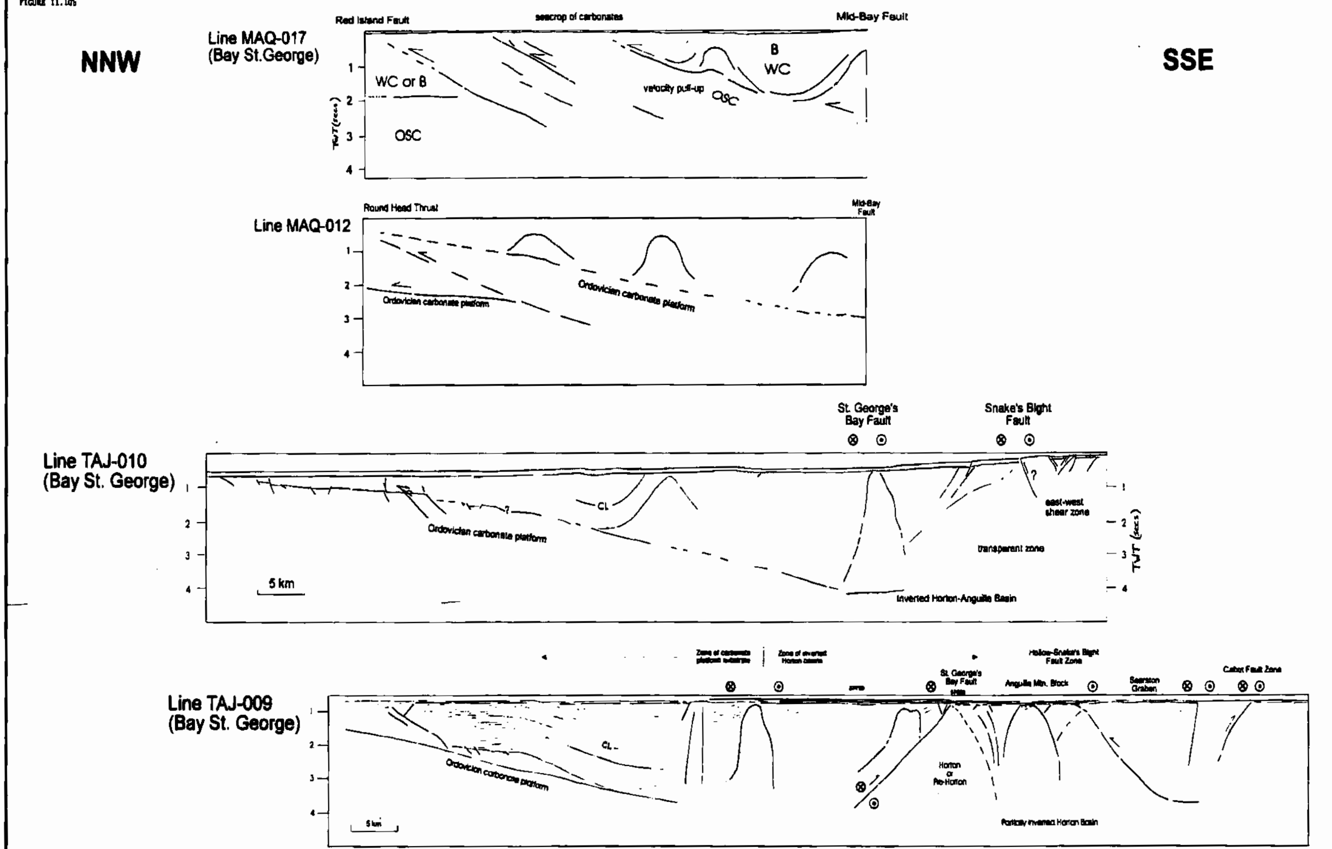

350
400
450
500
BG
oldest
post-T
pluton'm
GLG
RHP
oldest post-tect
pluton'm
NPG
MLG
gs meta'm,
pluton'm,
def'm
NBG
range of uplifting
and post-peak meta'c
cooling ages
FG
SLG
AGG
AGA
MBG
MRG
DBG
volc'm
SBP
NBG
DBP
gs to amph meta'm,
def'm and pluton'm
CFG
maf mag'm
MBG
-SPACE DIAGRAM for the
LE to LATE PALEOZOIC at the
LAWRENCE PROMONTORY

Figure VI.3



NW
SE
Line 81-1103
Line 81-1105*
"deformed block"
Line 81-1107
Line 81-1109
Line 81-1111
Line 81-1113
Line 81-1115
Line 81-1117
Line 81-1119
Line 81-1121*
Searston Graben
Cabot Fault Zone
Cape Ray Graben
Cape Ray Fault Zone
Hollow Fault Zone
Magdalen Basin

FIGURE 11.10b



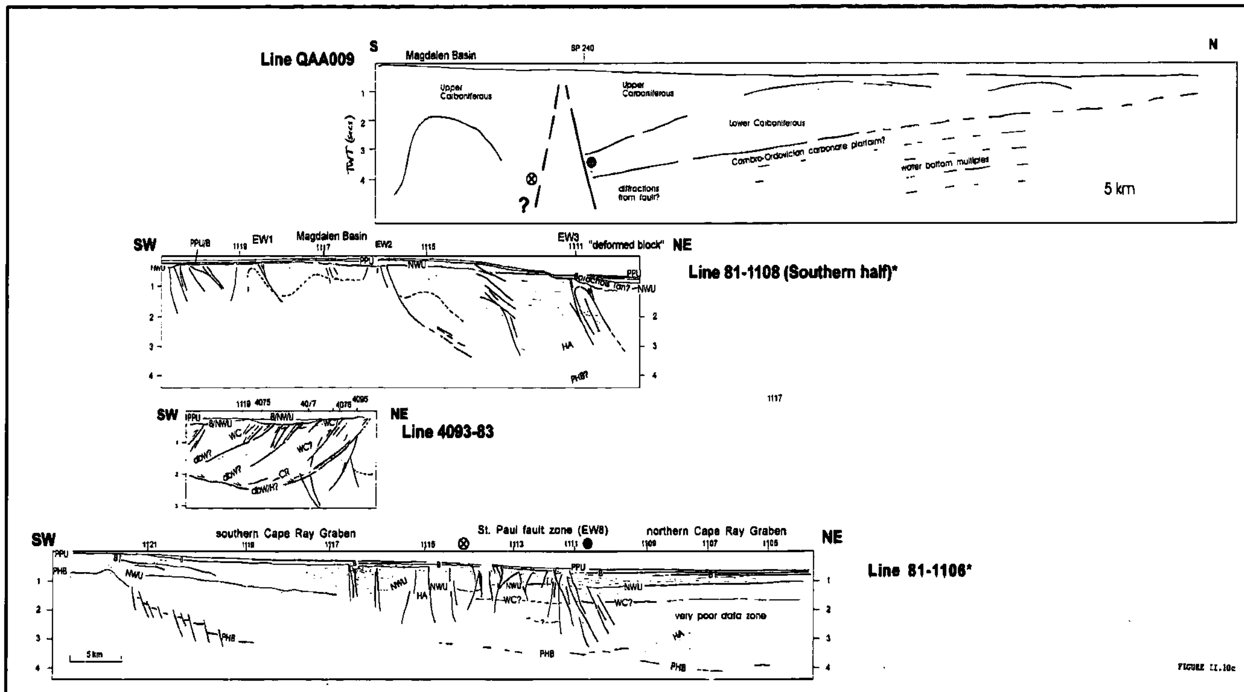
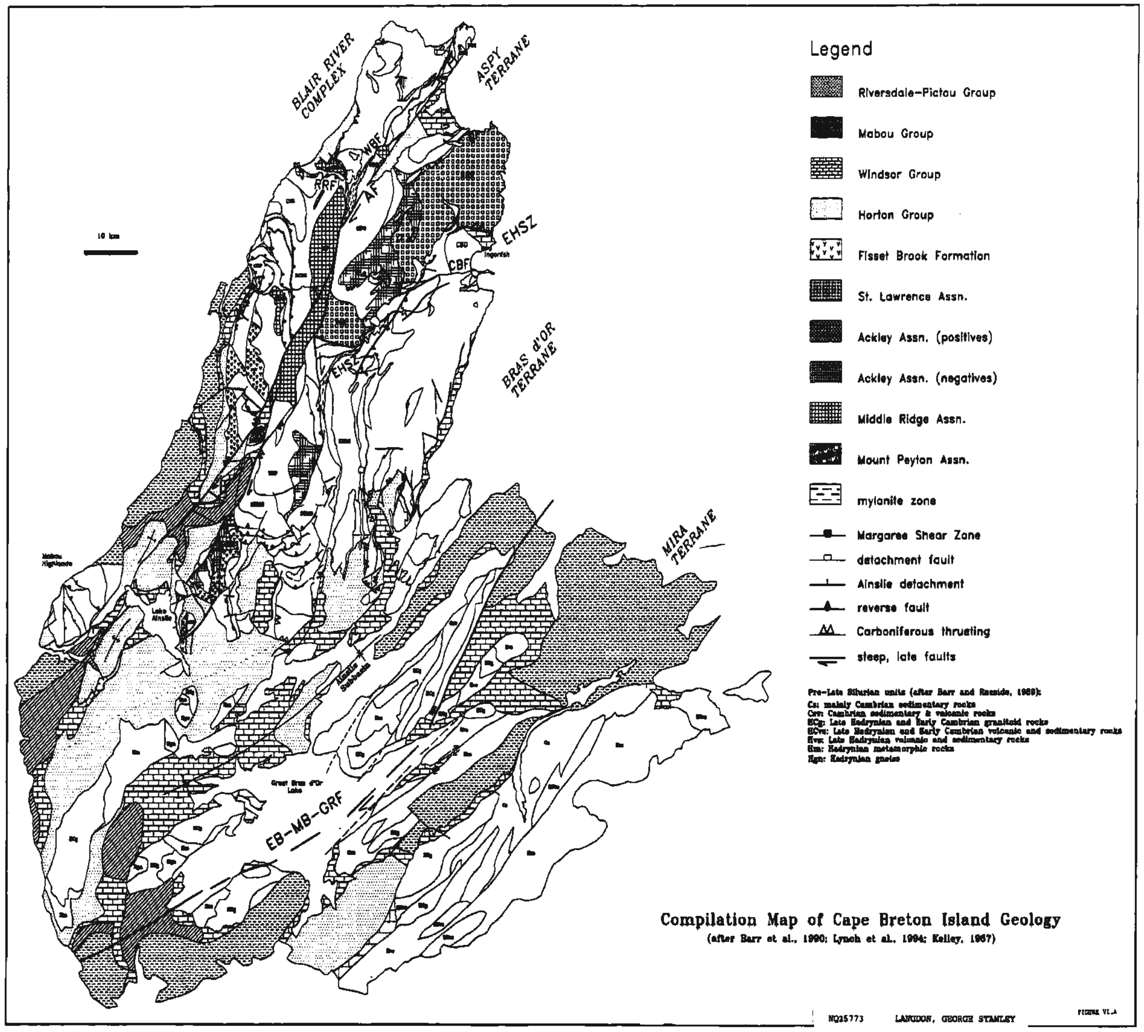


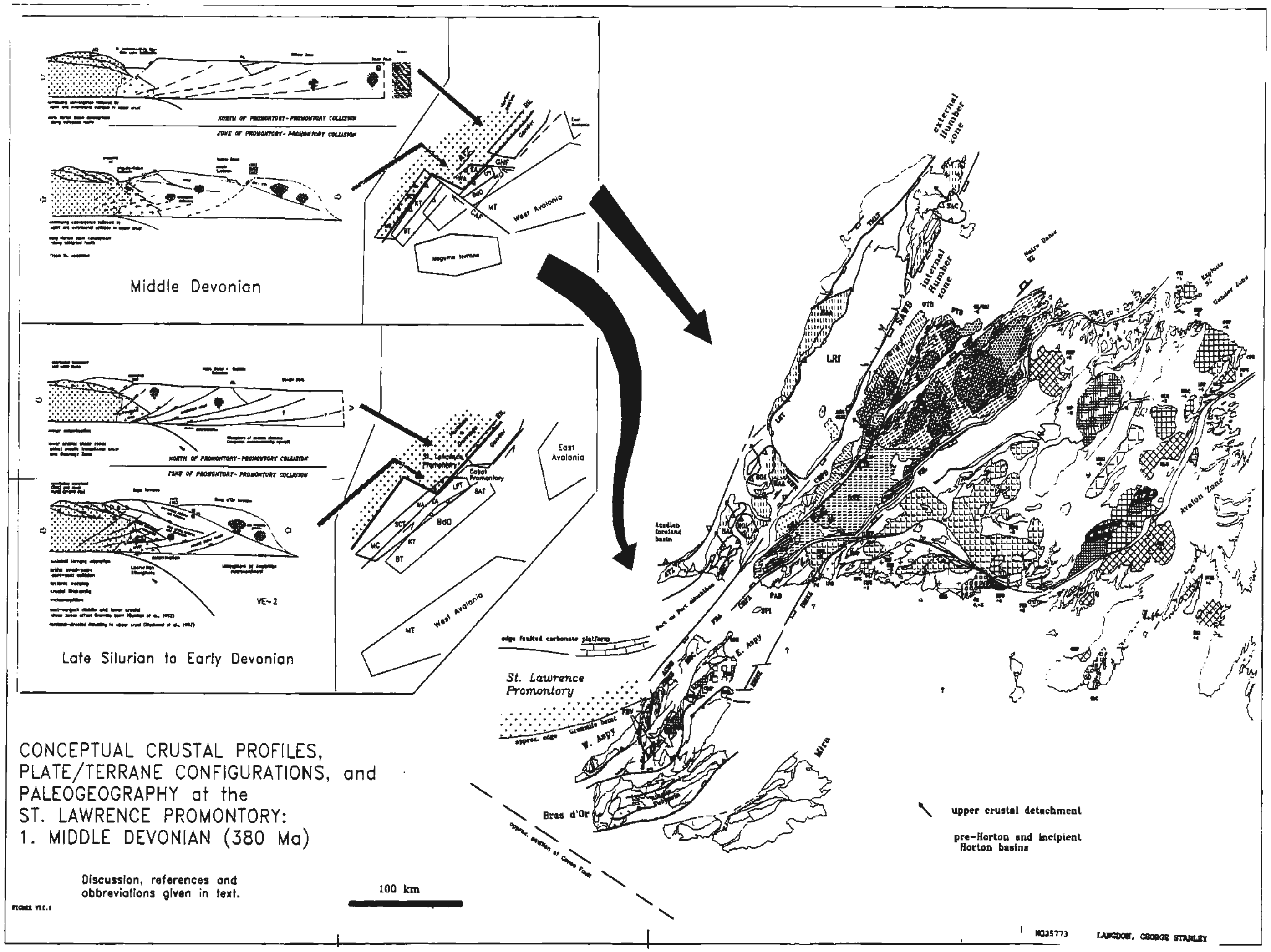
FIGURE II.10c

NQ25773 LANGDON, GEORGE STANLEY



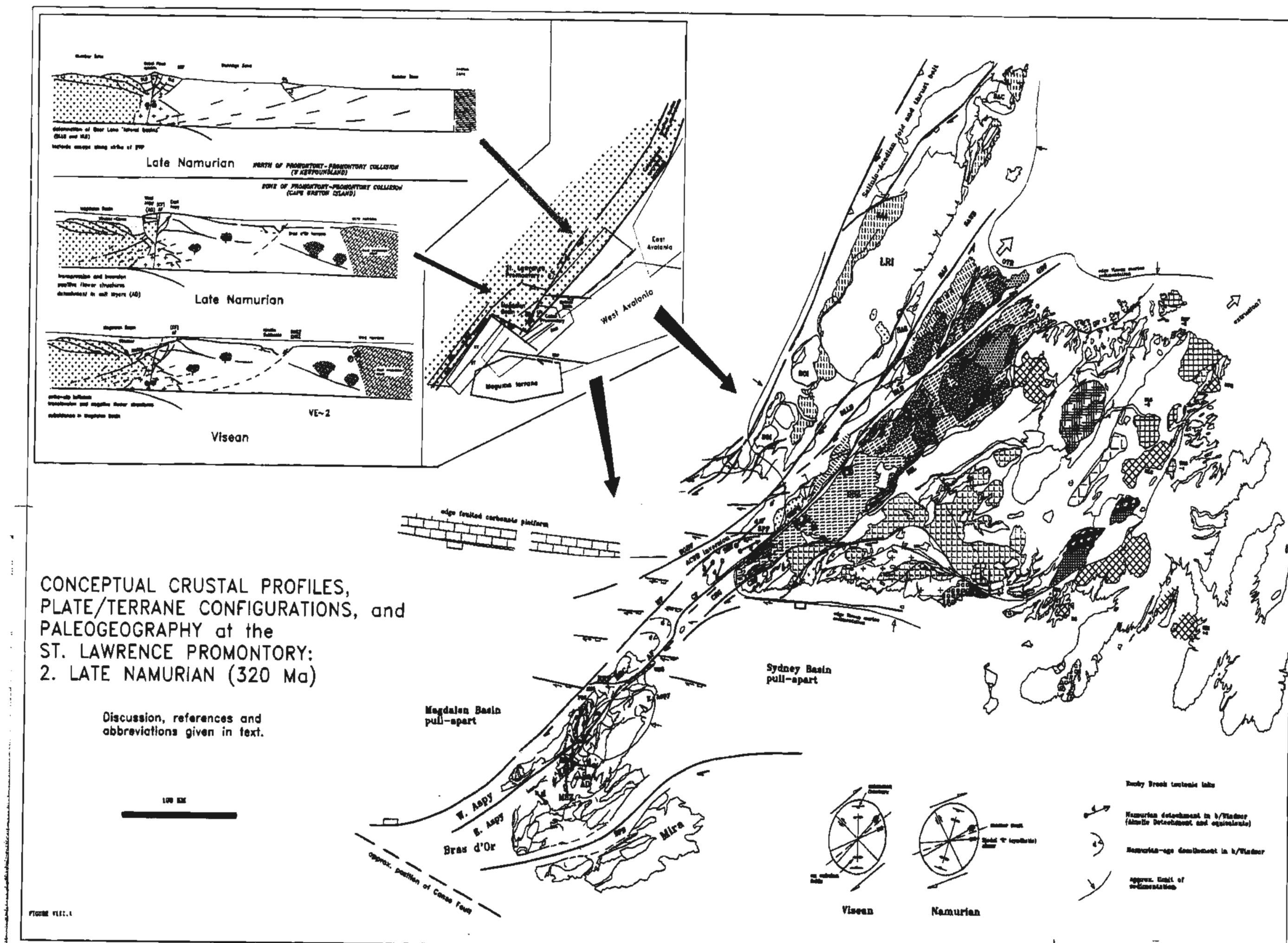
Compilation Map of Cape Breton Island Geology
(after Barr et al., 1990; Lynch et al., 1994; Kelley, 1967)

NQ25773 LANGDON, GEORGE STANLEY FIGURE VI.A



CONCEPTUAL CRUSTAL PROFILES,
PLATE/TERRANE CONFIGURATIONS, and
PALEOGEOGRAPHY at the
ST. LAWRENCE PROMONTORY:
1. MIDDLE DEVONIAN (380 Ma)

Discussion, references and abbreviations given in text.


CONCEPTUAL CRUSTAL PROFILES,
PLATE/TERRANE CONFIGURATIONS, and
PALEOGEOGRAPHY at the
ST. LAWRENCE PROMONTORY:
2. LATE NAMURIAN (320 Ma)
Discussion, references and abbreviations given in text.
Late Namurian
Late Namurian
Visean
VE~2
West Avalonia
East Avalonia
Meguma terrane
edge faulted carbonate platform
LRI
Sydney Basin
pull-apart
Magdalen Basin
pull-apart
W. Aspy
E. Aspy
Bras d'Or
Mira
approx. position of Canso Fault
Visean
Namurian
100 KM
NQ25773
LANGDON, GEORGE STANLEY

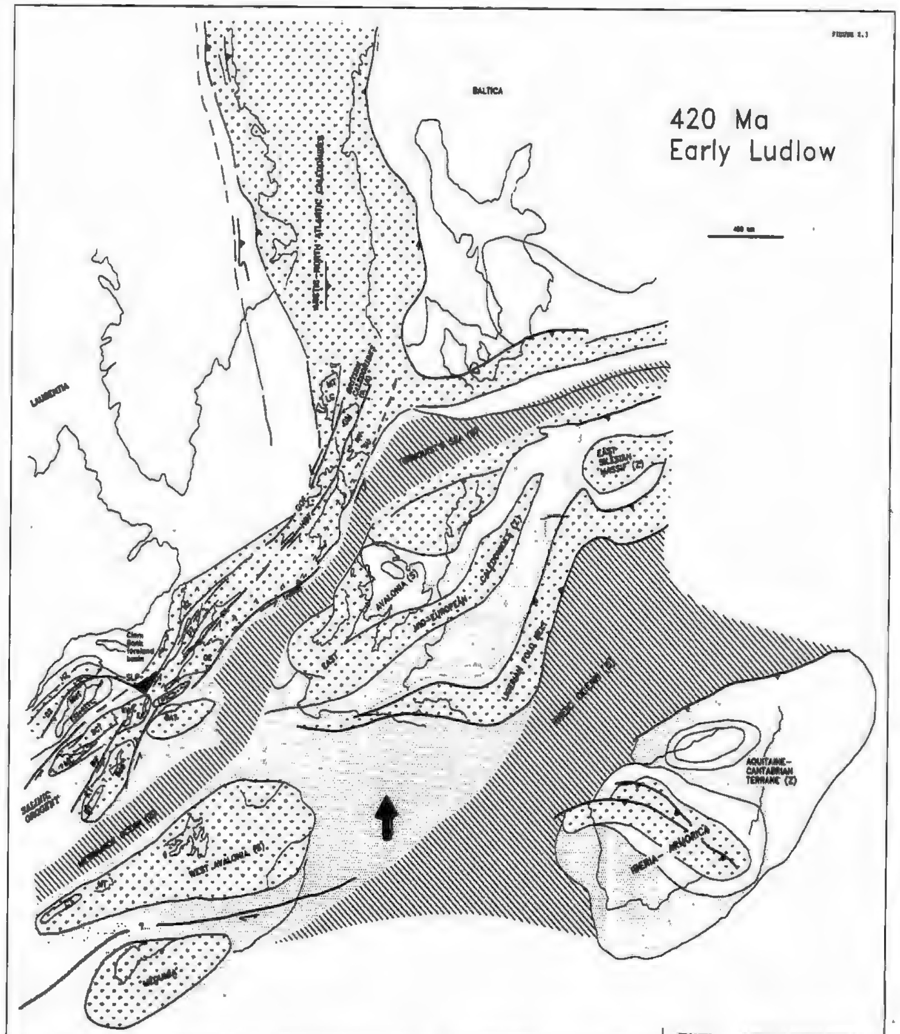


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FIGURE X.4

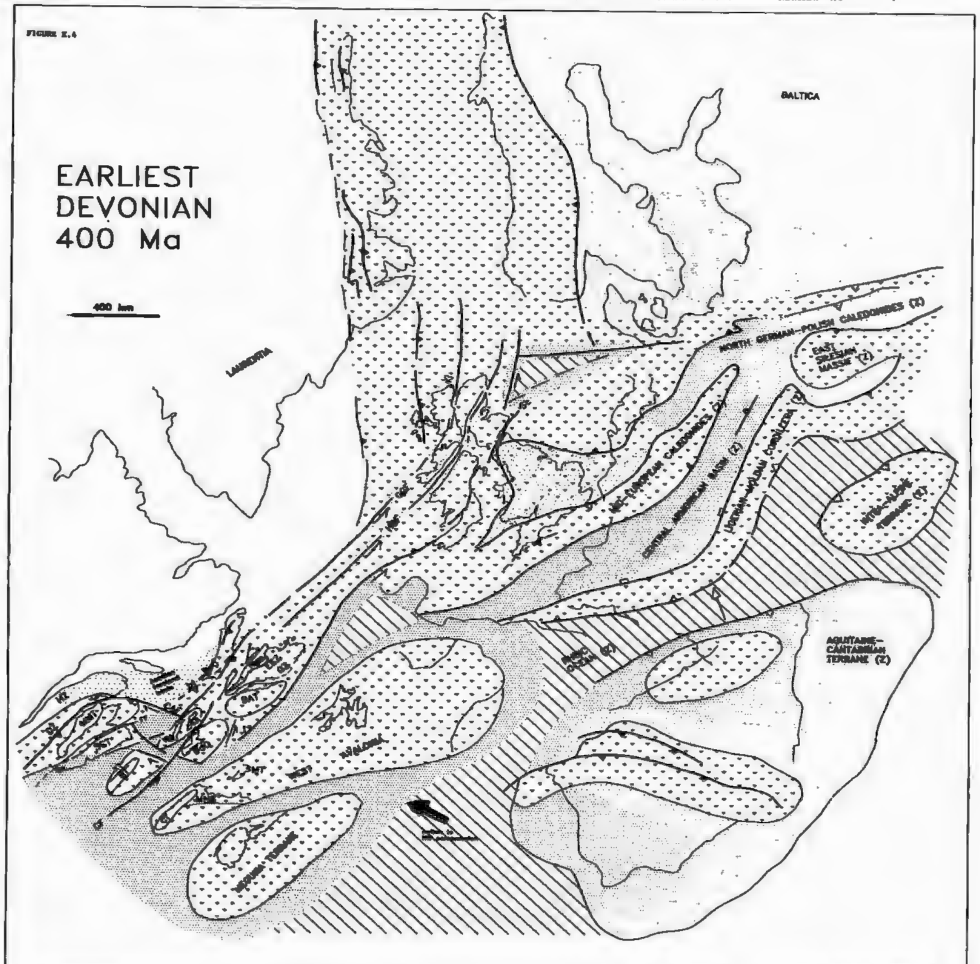

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FIGURE X.5

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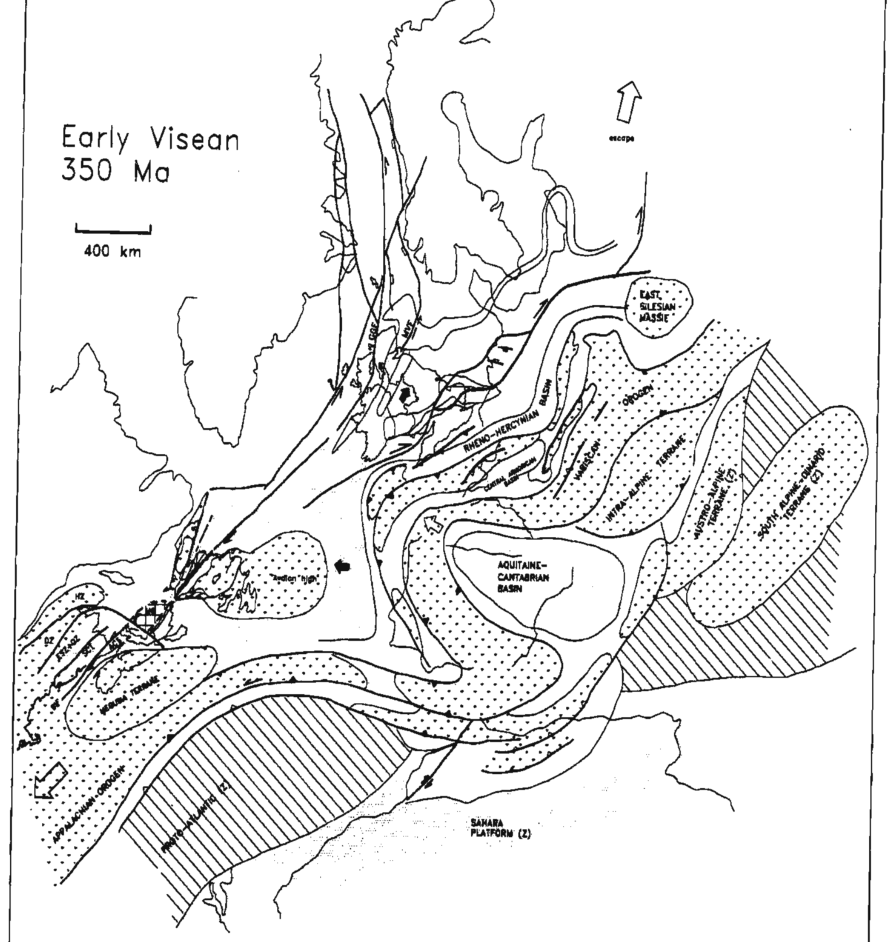
FIGURE I.6



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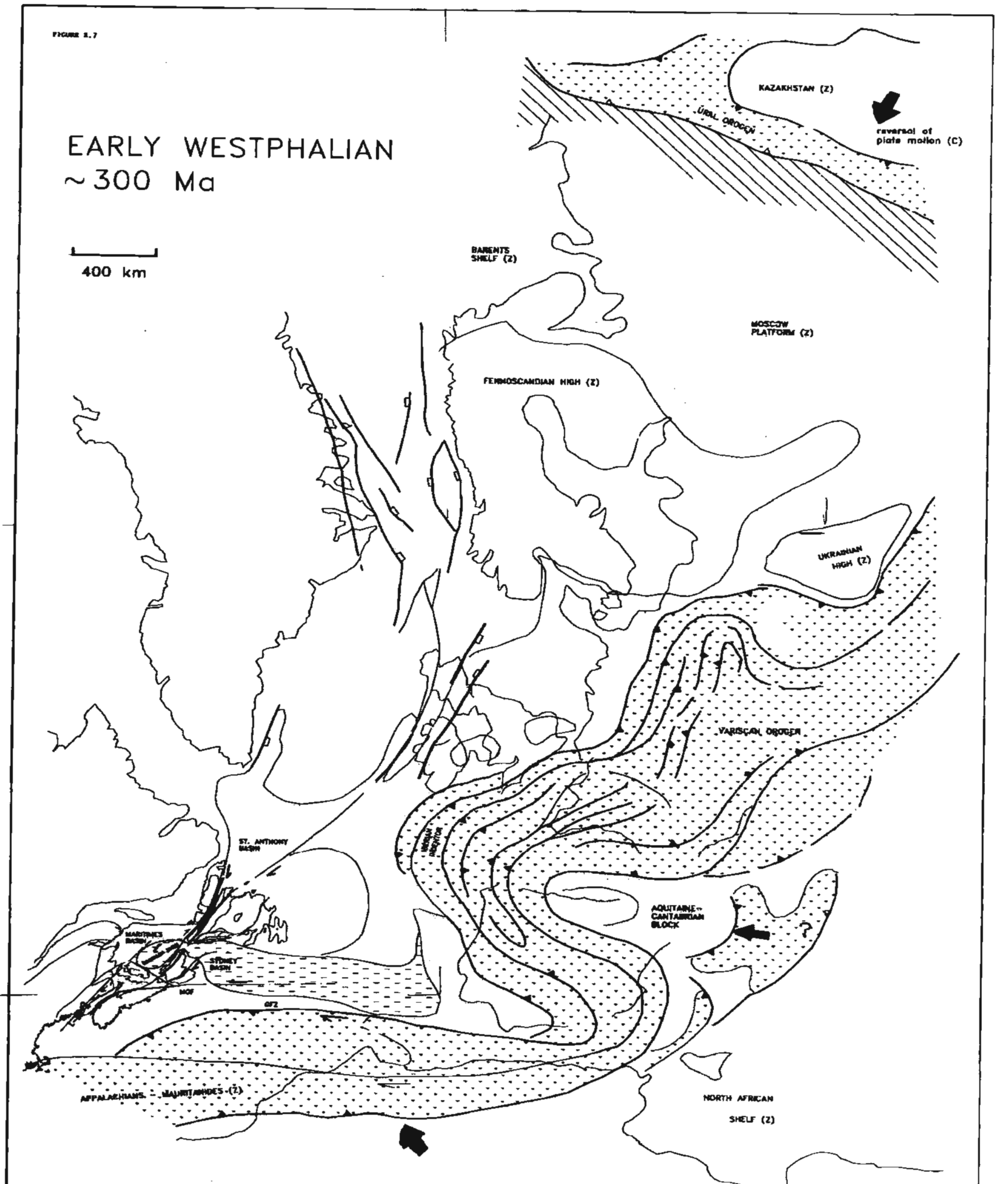
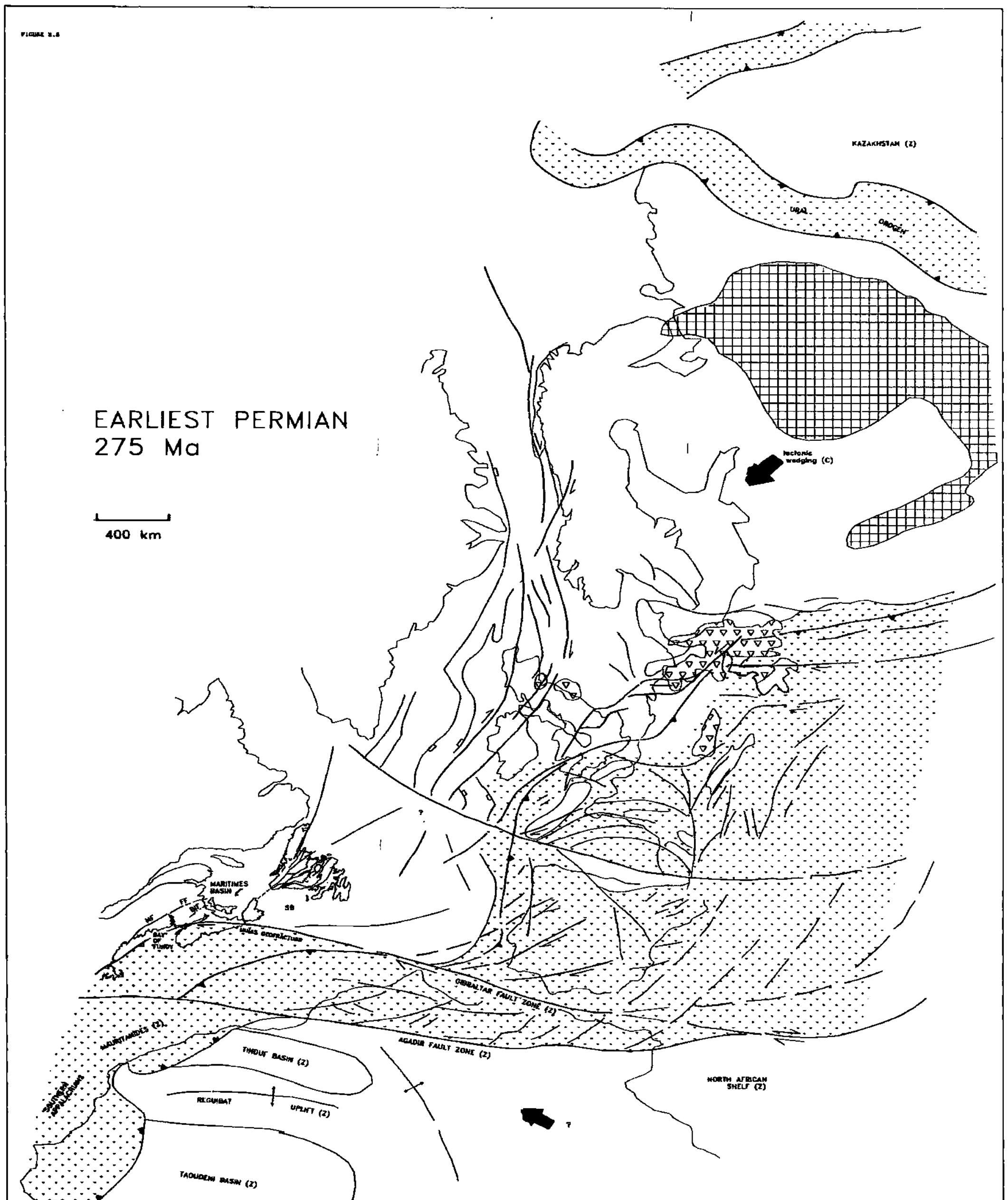
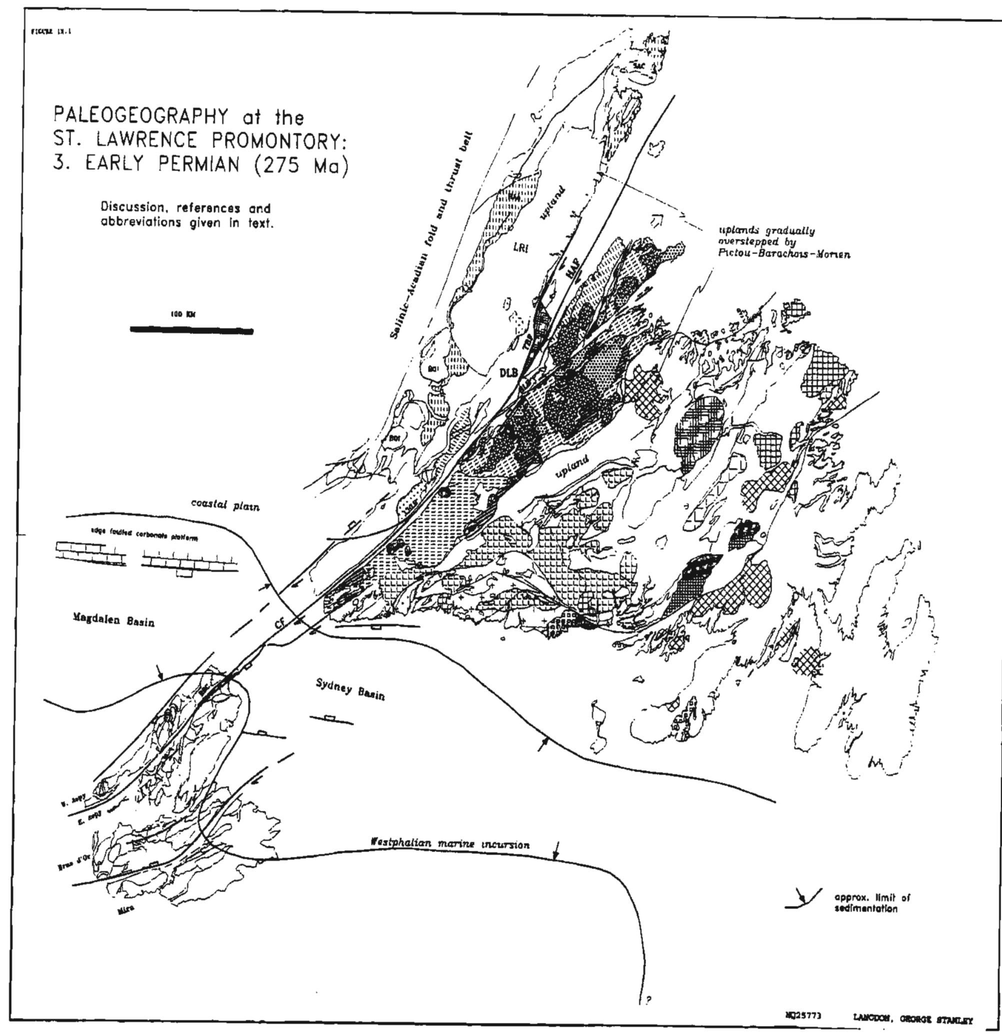
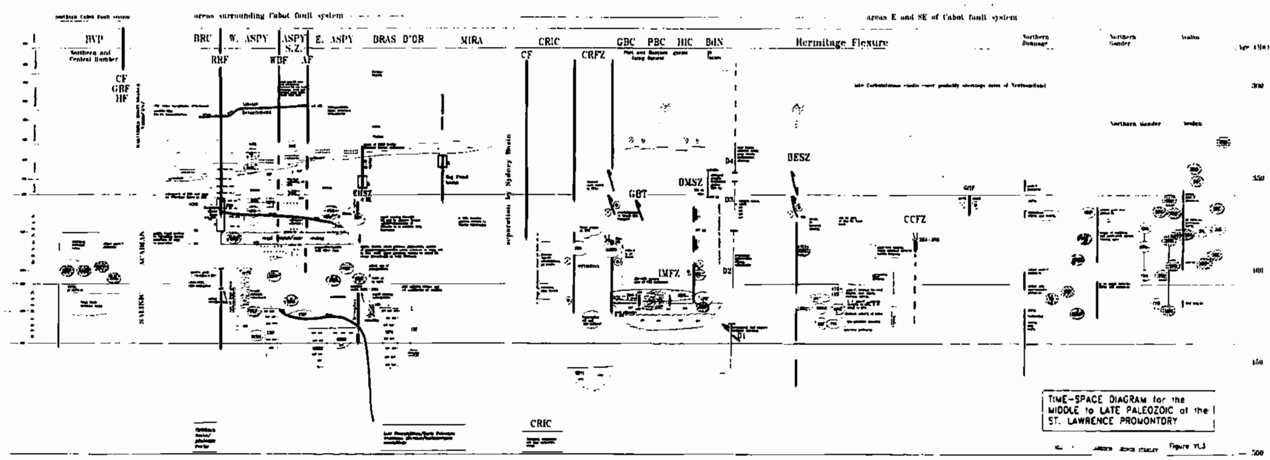
16A


EARLY WESTPHALIAN
~300 Ma
400 km
KAZAKHSTAN (Z)
reversal of plate motion (C)
URAL OROGEN
BARENTS SHELF (Z)
MOSCOW PLATFORM (Z)
FENNOSCANDIAN HIGH (Z)
UKRAINIAN HIGH (Z)
VARISCAN OROGEN
ST. ANTHONY BASIN
MARITIMES BASIN
SYDNEY BASIN
MOF
GFZ
AQUITAINE-CANTABRIAN BLOCK
?
APPALACHIANS - MAURITANIDES (Z)
NORTH AFRICAN SHELF (Z)


EARLIEST PERMIAN
275 Ma
400 km
KAZAKHSTAN (Z)
URAL
OROGEN
tectonic
wedging (C)
MARITIMES
BASIN
SB
BAY
OF
FUNDY
GIBRALTAR FAULT ZONE (Z)
MAURITANIDES (Z)
AGADIR FAULT ZONE (Z)
TINDUF BASIN (Z)
NORTH AFRICAN
SHELF (Z)
SOUTHERN
APPALACHIANS
REGUIBAT
UPLIFT (Z)
TAOUDENI BASIN (Z)


PALEOGEOGRAPHY at the
ST. LAWRENCE PROMONTORY:
3. EARLY PERMIAN (275 Ma)
Discussion, references and
abbreviations given in text.
100 KM
Salinic–Acadian fold and thrust belt
upland
LRI
DLB
uplands gradually
overstepped by
Pictou–Barachois–Morien
upland
coastal plain
edge faulted carbonate platform
Magdalen Basin
CF
Sydney Basin
Westphalian marine incursion
Mira
approx. limit of
sedimentation
MQ25773
LANGDON, GEORGE STANLEY



TIME-SPACE DIAGRAM for the MIDDLE to LATE PALEOZOIC of the ST. LAWRENCE PROMONTORY

Figure VI.1