LITHOFACIES AND PALEOENVIRONMENTS OF THE BECRAFT FORMATION (LOWER DEVONIAN) OF NEW YORK STATE

A Thesis Submitted to the

Temple University Graduate Board in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

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by

Abu Arif

April 1973

Dr. Edwin J. Anderson
Thesis Advisor

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Dr. Edwin J. Anderson, Advisor
Assistant Professor of Geology

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I. ABSTRACT

The Becraft Formation from the Lower Devonian of eastern New York is a crinoid-brachiopod calcarenite which represents a combination of regressive and transgressive lithologies. Three lithofacies are recognized within the Becraft: Facies 1, a shale and biomicrite interbedded with biosparite, deposited in a transitional environment between an offshore zone of mud deposition and an above wave base shoal environment; Facies 2, a massive biosparrudite and biosparite, the prograding shoal, deposited at or above wave base; and Facies 3, a massive fine-grained biosparite, interpreted as reworked shoal sediment deposited during renewed transgression in late Becraft time. The Becraft shoal formed in the strait connecting the Helderberg and New England seas which first opened late in the Gedinnian.

A new time-stratigraphy is developed for the Becraft. The turning point from a regressive to a transgressive sedimentary sequence interpreted from the distribution of gypidulids and changes in sedimentary texture is used as a time-datum for defining the new time-stratigraphic relationships.

II. INTRODUCTION

The Becraft Formation (Lower Devonian) of New York is a crinoid-brachiopod biosparite to biosparrudite which contains progradational and transgressive carbonate lithologies. Anderson (1972) has shown that both progradational and transgressive settings have distinctive sedimentary structure assemblages associated with them. The Becraft Formation, therefore, provides a rare opportunity to study both these settings in terms of lateral and vertical changes in sedimentary structures, textures and fauna evident in these calcarenites. In this study textural and faunal characteristics are emphasized. In addition, the Becraft Formation is unique in that it appears not to have been part of a typical basin margin environment.

The purpose of this study is to distinguish individual Becraft facies and to make a dynamic interpretation of the Becraft environment. Differences among facies of the Becraft are subtle and facies boundaries are highly gradational.

Variables typically used to characterize environments of recent shallow marine calcarenites were utilized to distinguish Becraft facies. These included parameters such as constituent particle composition, matrix, size, fragmentation and sorting (Illings, 1954; Ginsberg, 1956; and Purdy, 1963). Tabulated data from this analysis suggest the development of specific lateral and vertical patterns of environment within the Becraft which are related to its earlier progradational and later transgressive history. This study is a continuation of detailed paleoenvironment work of formations in the Helderberg Group in New York State, begun by Laporte (1967), Anderson (1967), Harper (1969) and Epstein (1971).

III. STRATIGRAPHY

Rickard (1962) described the distribution and the general time-stratigraphic relationship of the Helderberg Group in New York. The Becraft Formation is the basal unit of the Upper Helderberg Group. The stratigraphic units of the Helderberg Group are shown in Figure 1.

HELDERBERG STRATIGRAPHY: The Helderberg Group is mostly fossiliferous limestone containing varying amounts of dolomite and terrigenous clastics. It outcrops in New York in a belt extending eastward from Cayuga Lake to the Hudson River Valley, thence southward to Kingston and southwestward to Port Jervis. The outcrop belt continues southward across northwestern New Jersey and into eastern Pennsylvania. Three outliers are known: Mount Ida, Becraft Mountain in Columbia County, and the Green Pond-Schunemunk Mountain area in New Jersey (Barnett, 1970). The facies within the Helderberg Group are overall time-transgressive and were deposited in a shallow epeiric sea. There are two progradations within the general transgression. The first is a southeasterly progradation of the Manlius tidal flat in central New York (Laporte, 1967). The second is represented by deposition of coarse Becraft calcarenites in the Hudson Valley.

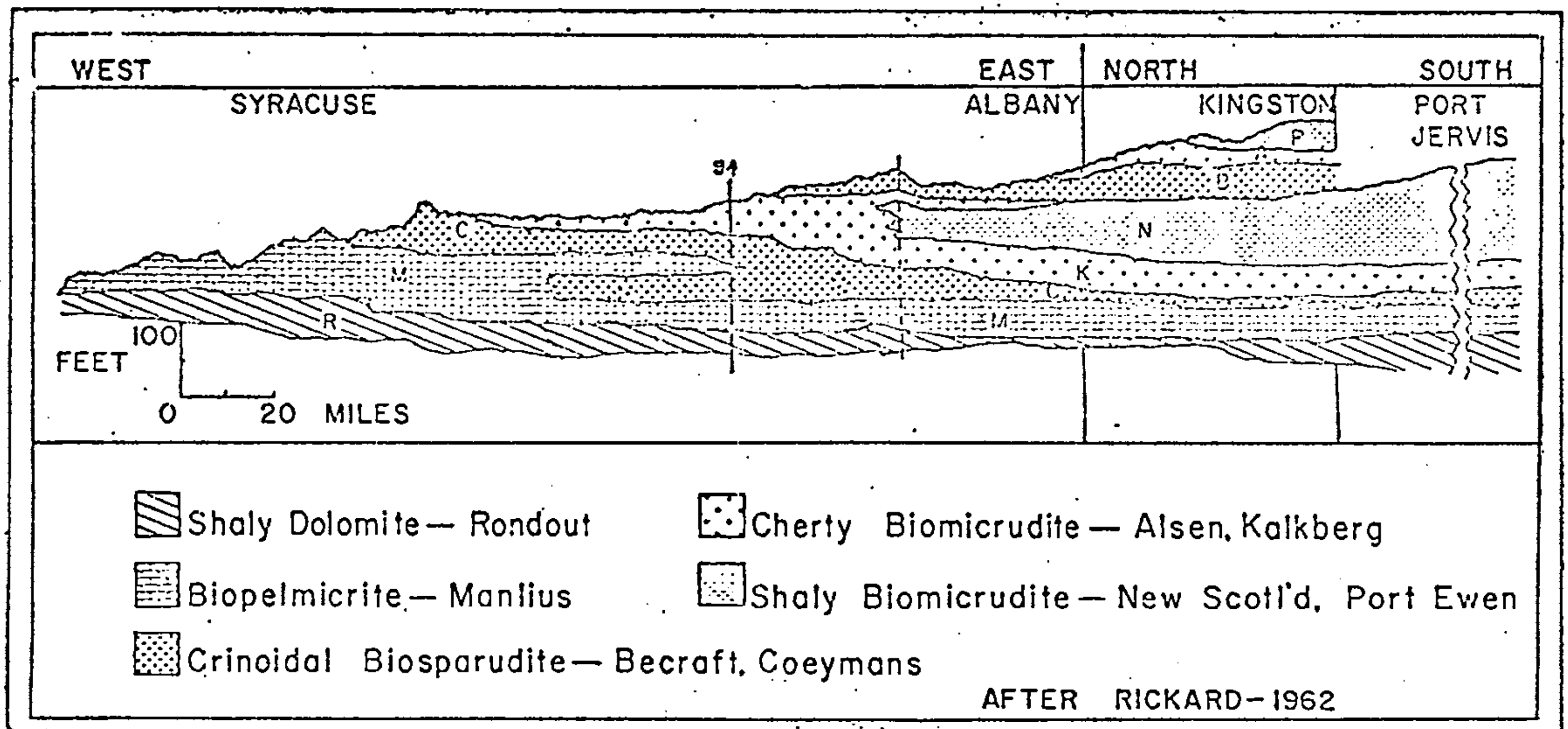
Time-stratigraphic correlation of the Helderberg Group (Figure 2) is based on the following criteria developed by Rickard:

1) Distinctive thin and persistent beds in the Thacher, Elmwood, and Clark Reservation Members of the Manlius.

Figure 1. Stratigraphic units of the Helderberg Group (Lower Devonian) in New York State. Modified after Naylor and Boucot (1965).

	EUROPE	NEW YORK	
LOWER DEVONIAN		Oriskany Group	
	Siegenian	HELDERBERG GROUP	Port Ewen Fm Alsen Fm Becraft Fm
	Gedinnian		New Scotland Fm Kalkberg Fm
			Coeymans Fm Manlius Fm

Figure 2. Time-stratigraphic cross section of the Helderberg Group of New York State showing lithology of individual formations (after Rickard, 1962). Note the intertonguing of the Manlius and Coeymans and also of the Kalkberg and New Scotland Formations.


WEST
EAST
NORTH
SOUTH
SYRACUSE
ALBANY
KINGSTON
PORT JERVIS
94
P
D
N
C
K
M
R
100 FEET
0 20 MILES
Shaly Dolomite — Rondout
Biopelmicrite — Manlius
Crinoidal Biosparudite — Becraft, Coeymans
Cherty Biomicrudite — Alsen, Kalkberg
Shaly Biomicrudite — New Scotl'd, Port Ewen
AFTER RICKARD-1962

2) Locally correlative stromatoporoid biostromes of the Manlius Formation.

3) A bentonite bed in the Kalkberg observed at, at least, six localities in east and central New York.

4) The intertonguing of the Manlius and Coeymans Formations and also of the Kalkberg and New Scotland Formations.

5) Contacts between formations, some of which are laterally gradational.

6) A persistent acme zone of the brachiopod <u>Dicoelosia varica</u> in the eastern portion of the Kalkberg Limestone.

7) The relatively rapid change of the Elmwood, Clark Reservation and Jamesville Members into the middle Coeymans.

However, the above criteria are not found within the New Scotland-Becraft-Alsen part of the stratigraphic section and internal correlation of these rocks is not well established. Based on new evidence this study proposes new time-stratigraphic relationships for the Becraft interval.

<u>BECRAFT STRATIGRAPHIC RELATIONSHIPS</u>: The Becraft Formation was named by Darton (1894) after Becraft Mountain, a Devonian outlier located near Hudson, New York. The Becraft Formation in New York is exposed along a narrow outcrop belt which runs northeast from Port Jackson (locality 2; all locality numbers used in text are those of Rickard, 1962) to Kingston, then north along the Hudson River Valley nearly to Albany. From Albany the outcrop belt swings

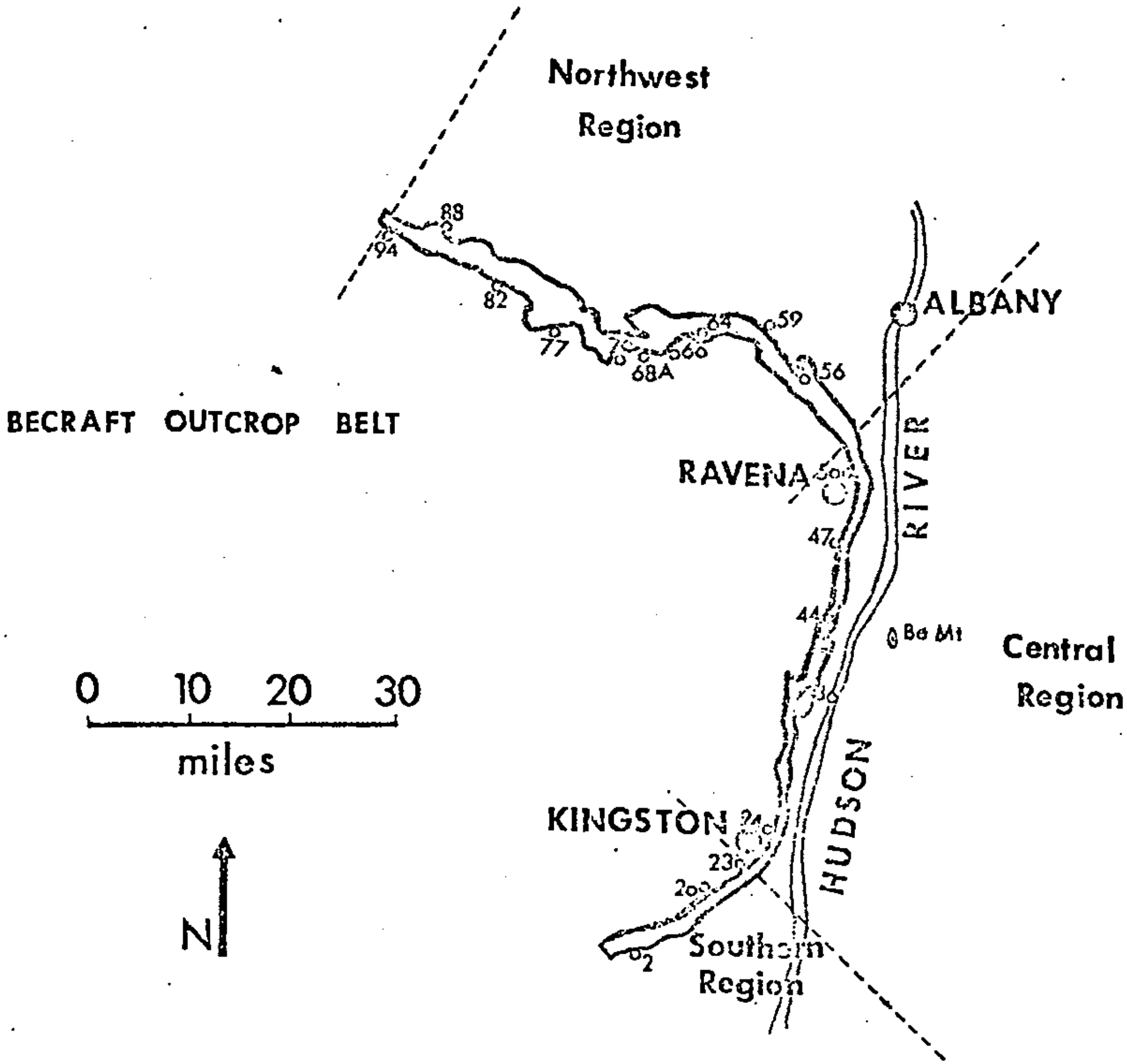
westward to locality 94 at Cherry Valley (Figure 3). The Becraft Formation is unknown west of Cherry Valley. Even the two feet of Becraft-like rock reported in Cherry Valley by Rickard (1962) is hard to differentiate and so is included in the Kalkberg Formation.

Throughout most of its extent the Becraft Formation rests conformably upon the New Scotland, but at Little York and westward it overlies the Kalkberg Formation. The lower contact of the Becraft Formation with the New-Scotland and Kalkberg is gradational. The Becraft Formation is overlain gradationally by the Alsen Formation. West of locality 56 the Alsen is not continuous; exposures occur only at West Township and in the Schohaire Valley. In other areas west of the Helderberg Mountains it is overlain unconformably by the Oriskany Sandstone (Rickard, 1962).

Rickard (1962) described the Becraft as a coarse-grained, crinoidal, dark gray to pink limestone containing brachiopods, bryozoa, trilobites, ostracods, gastropods, and corals. The bedding is usually massive, although thin-bedded limestone with shaly partings occurs in the lower half at several exposures. Although no detailed study has been done on the depositional environment of the Becraft Formation, Rickard (1962) interpreted the Becraft as a shallow neritic environment near wave base.

It is hard to correlate the Becraft stratigraphic interval in northwest New Jersey and eastern Pennsylvania with New York because of the absence of a Becraft fauna and lithology. Rickard (1962) thought that in northwestern New Jersey the Becraft Formation is replaced laterally by the underlying New Scotland, Barnett (1970) indicated that the two and one half feet of the Becraft

Figure 3. Outcrop belt of the Becraft Formation in New York State showing 19 sample localities (Locality numbers after Rickard, 1962). Note the three geographical regions; northwest, central and southern.



Northwest
Region
BECRAFT OUTCROP BELT
ALBANY
RAVENA
RIVER
HUDSON
Central
Region
KINGSTON
Southern
Region
0 10 20 30
miles
N
88
94
82
77
68A
59
56
47
2

Formation referred to by Rickard (1962) at Trilobite Mountain has a lithology similar to the Alsen Formation though it is slightly coarser grained. However, it could be Becraft in age because it contains Gypidula pseudogaleata, a guide fossil of the Becraft (Rickard, 1962, p. 91). Barnett (1970) thus concluded that an undetermined amount of the upper part of the Becraft has been replaced southwestward by the lower part of the Alsen Formation.

Epstein and others (1967, p. 344) proposed the name Minisink Limestone for a thin unit of dark to medium gray, fine-grained, argillaceous limestone which occurs at the Becraft position between the Port Ewen and New Scotland Formations in eastern Pennsylvania and New Jersey, because this lithology is quite different from that of the type Becraft of New York. Epstein and others (1967, p. 35) think that the Minisink continues as far northeast as Trilobite Mountain where it is 20 feet thick, but Barnett (1970) does not agree. He thinks that the Minisink at Trilobite Mountain is the Alsen Formation and at least part of the uppermost New Scotland. This study suggests that the Minisink Limestone of Epstein and others (1967) and the Minisink equivalent, represented by the Alsen Formation and uppermost part of the New Scotland at Trilobite Mountain (Barnett, 1970) are part of the same gradually changing lithosome represented by the Becraft at its type locality at Hudson, New York. The Becraft interval simply becomes finer grained limestone and the underlying and overlying shaly limestones (New Scotland and Port Ewen) become increasingly argillaceous, until the Becraft is replaced by continuous deposition of shaly limestone southwest of Delaware Gap. Thus the Minisink, although fine-grained, is both the coarsest and most lime rich deposit in a vertical sequence just as the Becraft is in New York. On this basis the Minisink is interpreted as a time equivalent extention of Becraft deposits.

IV. METHODS

The position of 198 rock samples collected by Dr. Anderson from 19 localities over the entire range of the Becraft exposure in New York State is given in Table 1 and Figure 4. The locality numbers of all cross sections are those of Rickard (1962) and are located in his Appendix 1 (p. 120-24). Samples at each locality are located in the stratigraphic section by measurement from the upper Becraft contact. Figure 4 is the stratigraphic relationship proposed by Rickard (1962). However all data in subsequent cross sections are plotted on cross sections based on a new time-stratigraphy discussed on page 65.

Polished slabs and thin sections (2 x 3 inches) of all samples were studied under the binocular microscope to determine faunal distribution and lithological and textural characteristics. Thin sections from two localities (36 and 44) were point counted to facilitate the estimation of particle frequency made with the binocular microscope (Table 2, p. 51). Enlarged photographic prints of all thin sections were prepared by using the thin sections as a negative in the enlarger. Becraft textural elements and trends were compared and contrasted by viewing these enlarged negative prints hung in their appropriate vertical and lateral sequences.

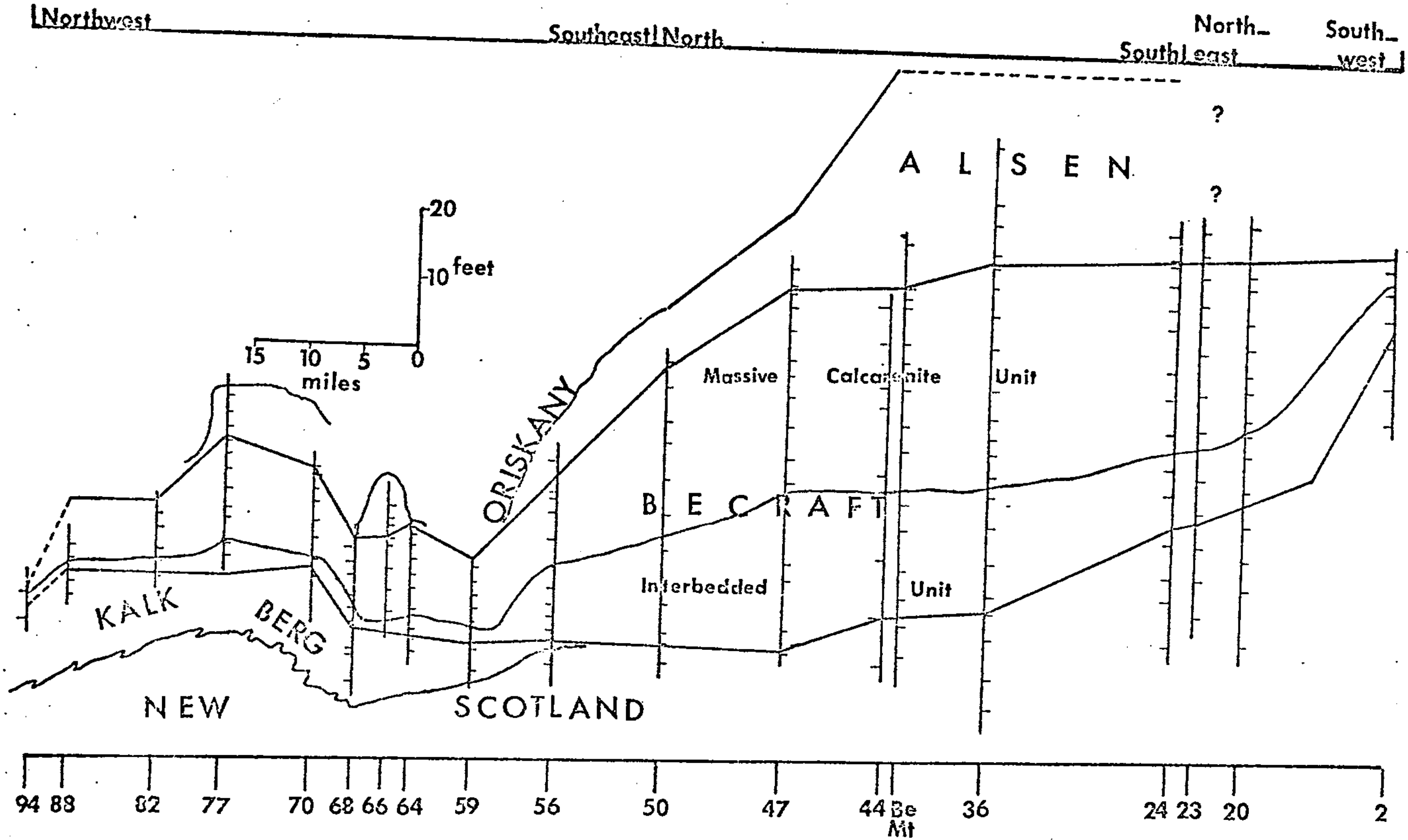
TABLE I

RICKARD'S LOCALITIES, NAMES AND NUMBERS AND
THE NUMBER OF SAMPLES COLLECTED FROM EACH LOCALITY

Locality Number	Number of Samples	Name of the Localities
2	6	Near Port Jackson
20	15	Thruway - Bridge
23	13	Callanan Quarry, S. Kingston
24	15	Hudson Cementon Quarry, Kingston, East
36	21	Cementon Quarry
44	9	Thruway and Rt. 23, Catskill
Be. Mt.	16	Becraft Mountain
47	16	Broncks Lake Thruway
50	12	Ravena Atlantic Cement Quarry
56	12	Clarkville (stream)
59	7	Thacher - Power Line
64A	9	3/4 W Knox
66A	8	1 N.W. W. Berne Road-cut
68	9	Gallupville Waterfall
70	8	Old Quarry Schohairie
77	11	Field Creek, Bannerville
82	5	Hill S-Rt. 20
88	4	W-Sharon Springs, Rt. 20
94	2	Cherry Valley, Rt. 20

Total Localities: 19
Total Samples: 198

Figure 4. Rickard's time-stratigraphic cross section of the Becraft and surrounding Formations between Port Jackson (loc. 2) and Cherry Valley (loc. 94). Vertical lines represent localities and small horizontal lines represent elevations at which samples were collected. The geographic position of localities is shown on Figure 3. Orientation of the line of outcrop is indicated at the top of the diagram. Note two litho-stratigraphic units; a massive calcarenite unit and an interbedded unit.


Northwest
Southeast
North
South
North-
east
South-
west
ALSEN
?
?
20
10 feet
15 10 5 0
miles
ORISKANY
Massive Calcarenite Unit
BECRAFT
Interbedded Unit
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

V. DESCRIPTION OF THE BECRAFT FORMATION

In assembling data for an environmental interpretation of the Becraft Formation, the following characteristics are described:

A. Lithology: (exclusive of texture)

1) thickness and formational contacts

2) bedding and sedimentary structures

3) distribution of shale

4) distribution of red beds (hematite-coated grains)

B. Fauna: Four taxa constitute nearly all of the biota of the Becraft: crinoids, brachiopods, bryozoa and trilobites. The following faunal elements show significant trends and are described in detail:

1) crinoids

a) perforated crinoids

b) scutellum

2) brachiopods (*Gypidula*)

3) bryozoa

4) trilobites

C. Texture:

1) the distribution of matrix and spar

2) allochems are analized using the following parameters:

a) size

b) fragmentation

c) sorting and maturity index

d) clasticity index of crinoids

For purposes of discussion of the distribution of the above Becraft characteristics two litho-stratigraphic units are recognized within the Becraft and are shown in figure 4: an upper unit of massive calcarenite (figure 5a) and a lower unit of interbedded mudstone and calcarenite (figure 5c). In addition three geographical areas are referred to, a central region between Ravena and Kingston where the Becraft is thickest, and two lateral regions, a northwestern region between Ravena and Sharon Springs and a southern region between Kingston and Port Jackson, New York (see figure 3). Across both of the latter the Becraft appears to thin and is replaced by other rocks. The distribution of descriptive data is discussed in terms of the above three regions and two stratigraphic units.

A. LITHOLOGY

1) Thickness and formational contacts. The thickness of the Becraft Formation in the northwest region ranges from 10 feet to 25 feet. South of locality 56 in the central region, the thickness of the Becraft increases to 55 feet (figure 4). The thickness then decreases from Kingston (location 23) to Port Jackson (location 2) south of which the Becraft is replaced by other rocks.

The lower contact of the Becraft Formation with the New Scotland and Kalkberg Formations is gradational. The gradation is seen as an interbedded zone of New Scotland (or Kalkberg) and Becraft lithologies (figure 5d) which is as much as 30 feet thick in the central region but thins to less than a few feet in the northwestern region. The New Scotland and Kalkberg Formations are finer grained (biomicrudite or fossiliferous shale) than the Becraft Formation (calcarenite). The lower formational contact of the Becraft is arbitrarily defined at the occurrence of the

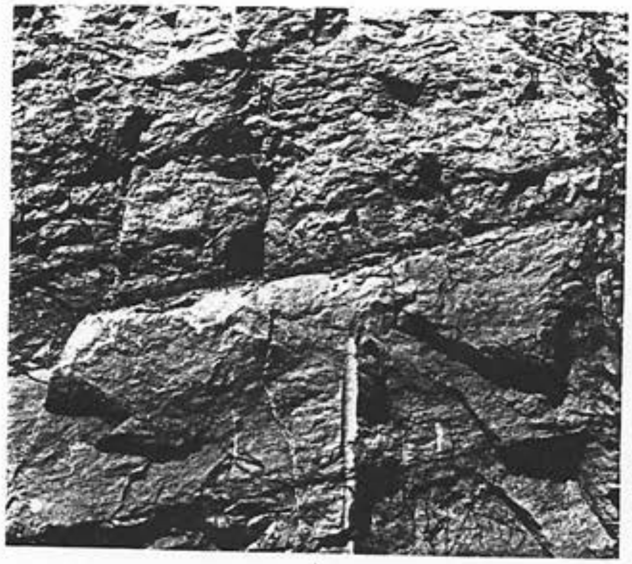
Figure 5. Becraft contacts, bedding and sedimentary structures.

a. Contact between the Becraft and Alsen Formations. Darker fine-grained Alsen is burrowed. The light massive unit in the lower half of the picture is the Becraft. The upper Becraft bed is approximately two feet thick (location 20).

b. Two directions of accretion cross-stratification, the predominant sedimentary structure found in the upper massive unit. The upper bed is 10 inches thick (location 50).

c. Lower interbedded unit; light massive beds of calcarenite with interbedded thin dark shale. Note the marking pen sitting on one of the massive beds (location 50).

d. A thin calcarenite bed in shale from the base of the Becraft. Note the lower contact of calcarenite is sharp whereas the upper contact grades into overlying shale (location 2). Arrow = 5 mm.



a

b

c

d

first coarse bed. Dunn and Rickard (1962) placed the top of the New Scotland Formation at the lowest appearance of green shale and the highest appearance of typical fine-grained, gray New Scotland Limestone. The contact between the Becraft and Alsen Formations is marked by the occurrence of a massive, burrowed, fossiliferous poorly sorted calcarenite and the disappearance of Gypidula. The lithologic gradation is rapid but not erosional (figure 5a). The Oriskany sandstone abruptly overlies the Becraft Formation west of locality 59.

2) Bedding and sedimentary structures. The massive unit which is laterally continuous throughout the exposure of the Becraft is thickest in the central region. Thin shale stringers (less than half an inch thick) are present in the central and southern regions but absent in the massive unit in the northwest region. This unit has a complex assemblage of multiple sets of low-angle accretion cross-stratification and horizontal stratification (figure 5b; see also Anderson, 1972). In contrast, calcarenites of the interbedded unit are single or paired sets of generally high-angle cross-stratification (accretion and avalanche deposits). Some of the beds are graded, their lower contacts are sharp, and their upper contacts are gradational into overlying shales (figure 5; see also figures 22e, f, page 49). Becraft calcarenite beds rarely show evidence of burrowing.

3) The distribution of shale. Significant amounts of shale are found interbedded with Becraft calcarenites. The shale is green to dark gray in color but occasionally red shale is also

found, a result of hematite coatings on grains. The color of the shale changes from dark gray to green from the bottom to top of the interbedded unit (Rickard, 1962). The shale is composed of the minerals chlorite, illite and quartz with smaller amounts of muscovite and feldspar. All the clay minerals are detrital in origin (Borst, 1966). The Becraft has the highest chlorite content of all the formations of the Helderberg Group. Also the quartz/clay ratio of the mudstone in the Becraft is less than that of the New Scotland Formation (Borst, 1966).

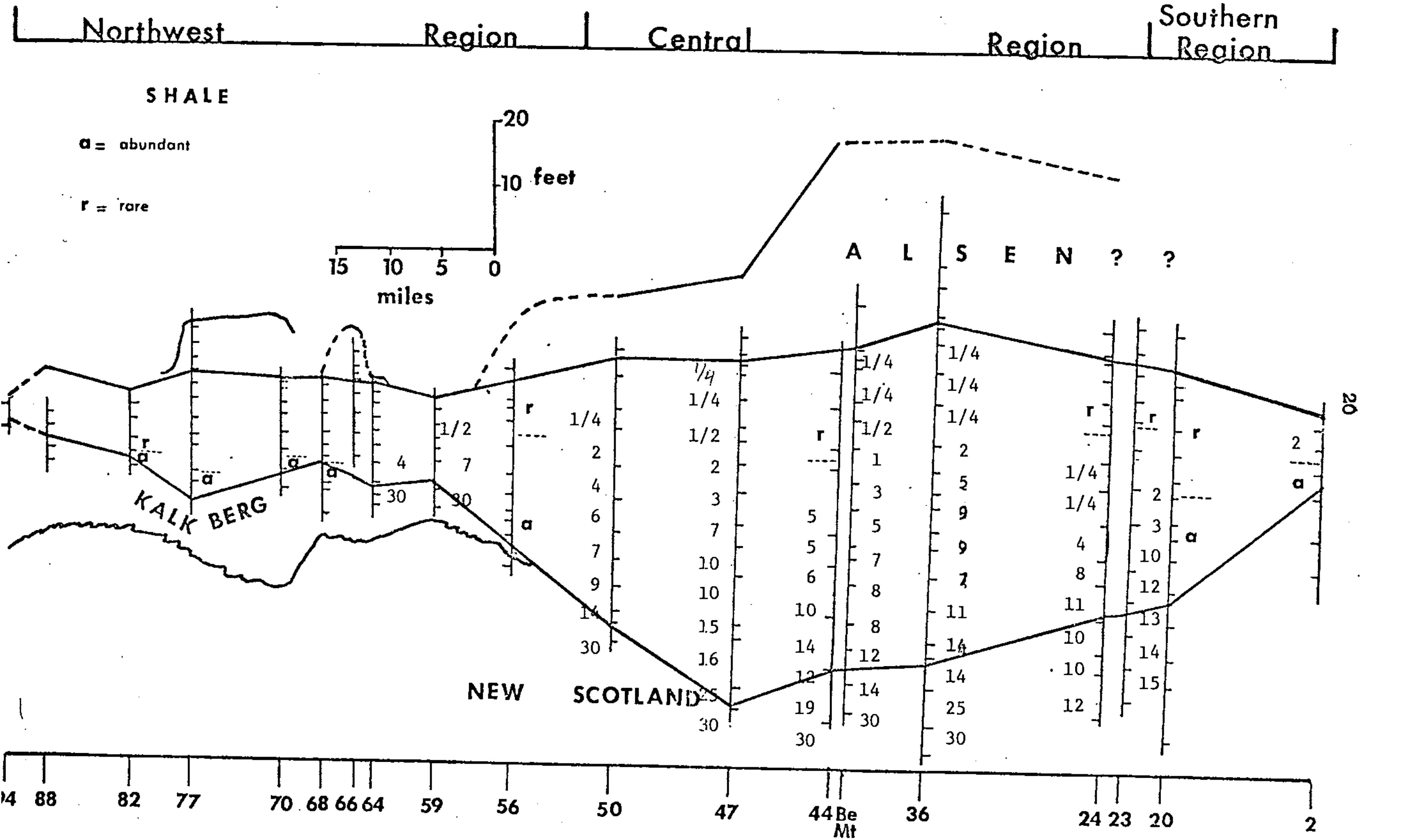
Shale beds range from 1/16 to 6 inches thick, increases in thickness down each stratigraphic section. Stratigraphic sections are divided into five foot intervals and the total thickness of shale within each five foot interval is summed and shown in figure 6. In sections where the shale stringers were not measured, visual estimates are expressed as abundant or rare. The abundance of shale is greatest in the New Scotland Formation and decreases upward in the section and to the northwest (unpublished data, E. J. Anderson).

4) Distribution of red beds (hematite-coated grains). Red beds consisting of hematite-coated carbonate and shale grains occur at two horizons in the central region of Becraft deposition (figure 8) and may represent time significant events (unpublished data, E. J. Anderson).

B. FAUNA

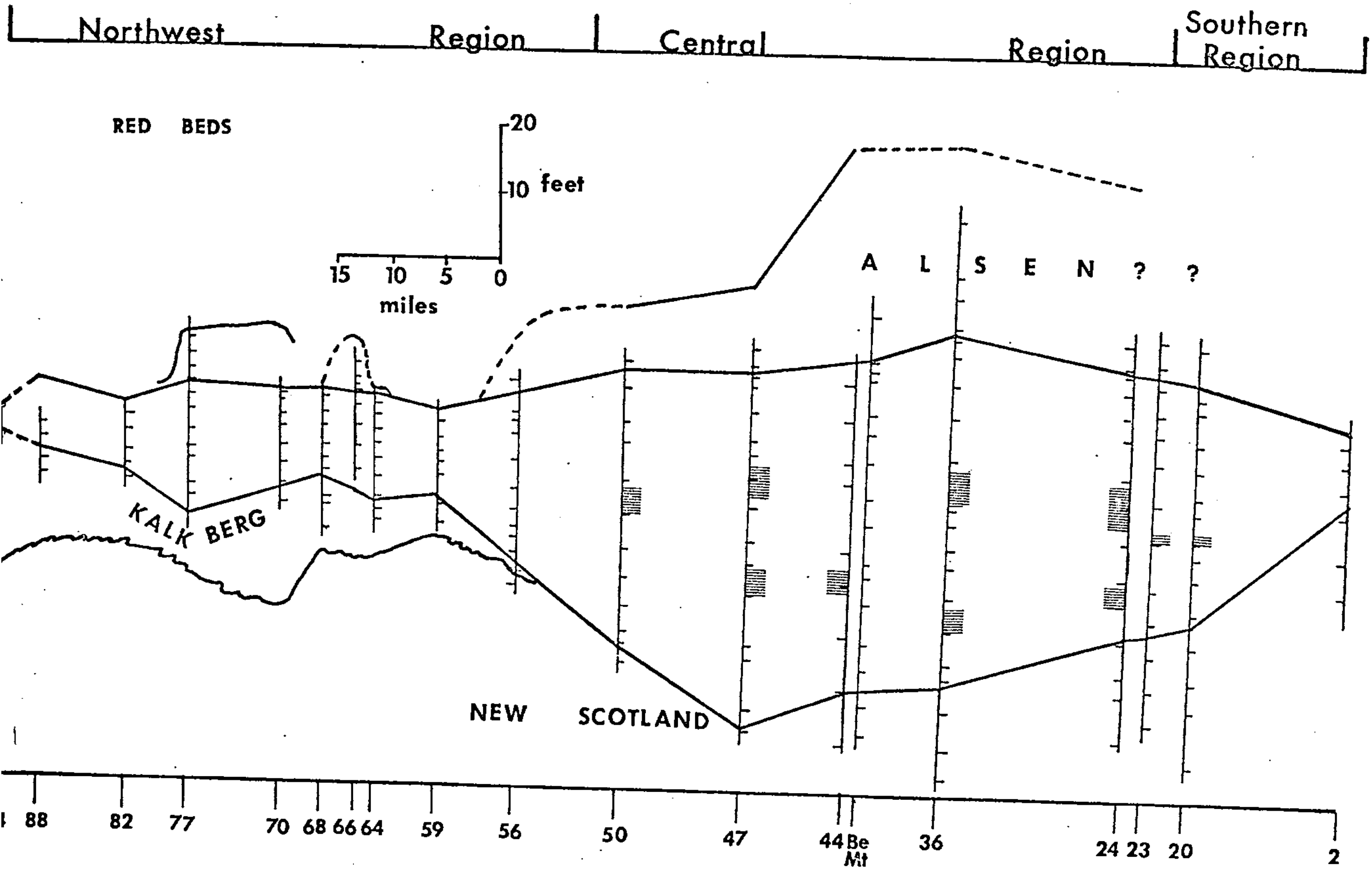
Four taxa constitute nearly the entire biota of the Becraft: crinoids, brachiopods, bryozoa and trilobites. Various taxonomic

Figure 6. Cross section indicating the distribution of shale beds. The numbers are the total thickness of shale in inches in five-foot intervals in the stratigraphic section.



Northwest Region
Central Region
Southern Region
SHALE
a = abundant
r = rare
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

Figure 7. Cross section indicating the distribution of red beds (hematite-coated grains of carbonates and shale). Note that they occur at two horizons.


Northwest Region
Central Region
Southern Region
RED BEDS
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

subdivisions of the biota and in two cases the taxonomic group taken as a whole have distributions which show significant trends. For each of the cases where specific mapable distributions are recognized, the data is plotted and described below. Other faunal elements with apparently uniform or random distributions are simply noted.

1) Crinoids. The most important and abundant biotic constituents of the Becraft are crinoids. These occur throughout the formation and are represented mainly by fragments less than two mm in size. They are abundant in the massive calcarenite unit consisting of about 58% of the total biota. This decreases to 45% of the total biota in the interbedded unit (Table 2, p. 51). Three categories of crinoidal particles are recognized: perforated columnals and plates, the root structure scutellum, and massive (nonperforated) gray columnals and plates. Gray crinoids are (evenly) distributed and are common to abundant throughout the Becraft Formation. Two of the above, perforated crinoids and scutellum, show mapable trends in their particle frequency distribution.

a) Perforated crinoids are fragments of plates and columnals less than two mm in size, which have a well-preserved coarse reticulate stereom (figure 8a). They usually look red under the microscope because of a hematite coating. A few of the perforated crinoid grains at localities 23 and 24 are green; in this case they are possibly coated with chlorite (George Myer, personal communication). The distribution of perforated crinoids

Figure 8. Negative prints of thin sections showing selected Becraft faunal elements.

a. Perforated crinoids (the large light grains) from the lower part of the massive calcarenite unit (location 44). Note the well preserved reticulate stereom. The largest grain = 1.5 mm.

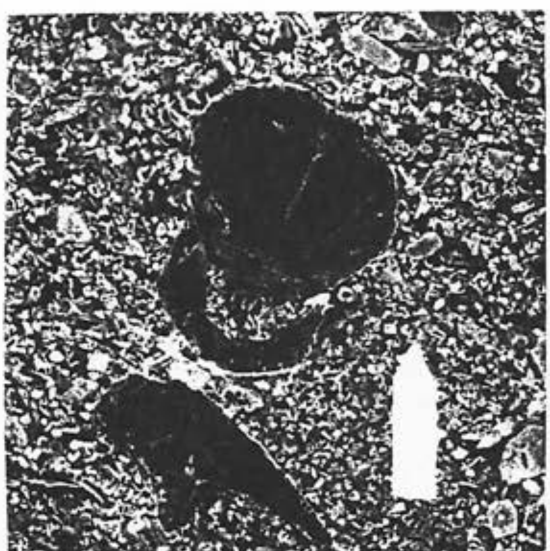
b. Scutellum from the lower part of the massive calcarenite unit (location 59). Note the coarse substrate, arrow = 5 mm.

c. Gypidulid from the upper part of the massive calcarenite unit (location 64). The upper specimen is articulated and is a section through the posterior end. The upper part is a brachial valve and the lower part is a pedicle valve. The lower specimen is a pedicle valve. Note the fine-grained, highly fragmented and moderately sorted sediment of the substrate; arrow = 5 mm.

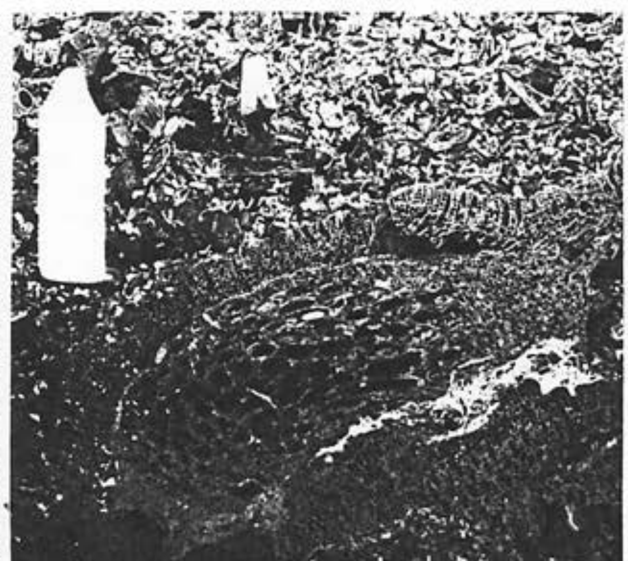
d. Bryozoan X from the lower part of the massive calcarenite unit. Note the spiralling growth form. Also note the encrusting bryozoan (location 44); arrow = 5 mm.

a

b



c



d

is shown in figure 9; frequency is indicated by four categories:

i) abundant -- more than ten grains in a thin section

ii) common -- between ten to five grains in a thin section

iii) rare -- less than five grains in a thin section

iv) absent

These grains are abundant throughout most of the section at localities 47, 44 and 36. They are rare to common at localities 24, 23 and 20 and are restricted to the central part of the stratigraphic section. They are absent from the rest of the Becraft Formation including the locality at Becraft Mountain just five miles east of locality 44. The degree of fragmentation of these grains is greater in the lower half of the three central sections (localities 47, 44 and 36), that is, in the interbedded zone.

b) Scutellum (Aspidcarinus scutellinformis) represents a large crinoid hold fast, fragments of which are usually greater than five mm in size. Complete hold fasts are as much as five cm in size. The shell structure of scutellum is very dense and structureless and shows calcite twinning (figure 8b). Scutellum particle frequency and distribution as determined by thin section is shown in figure 10. Three categories are indicated:

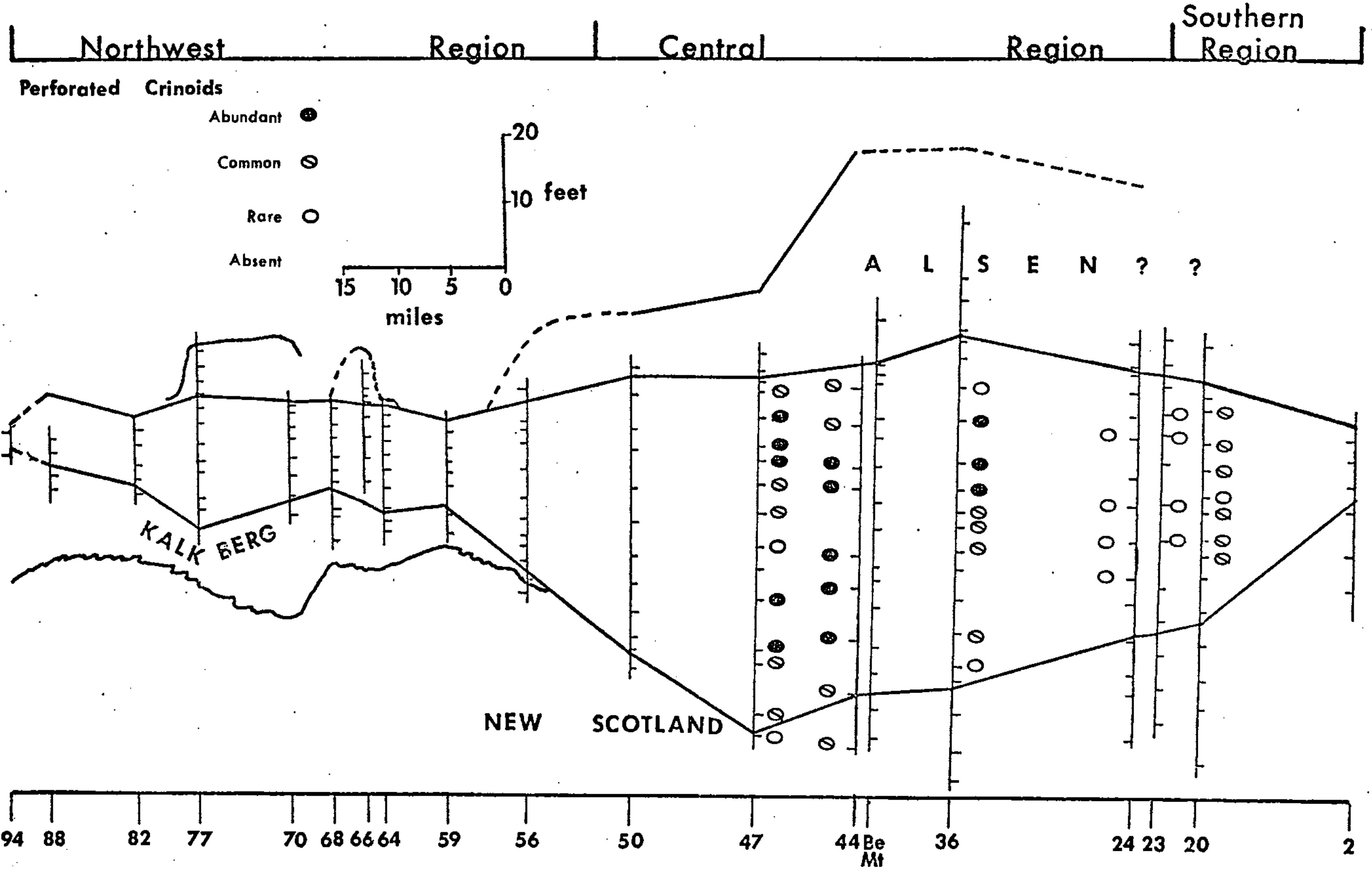
i) common -- more than two fragments

ii) rare -- one or two small fragments

iii) absent

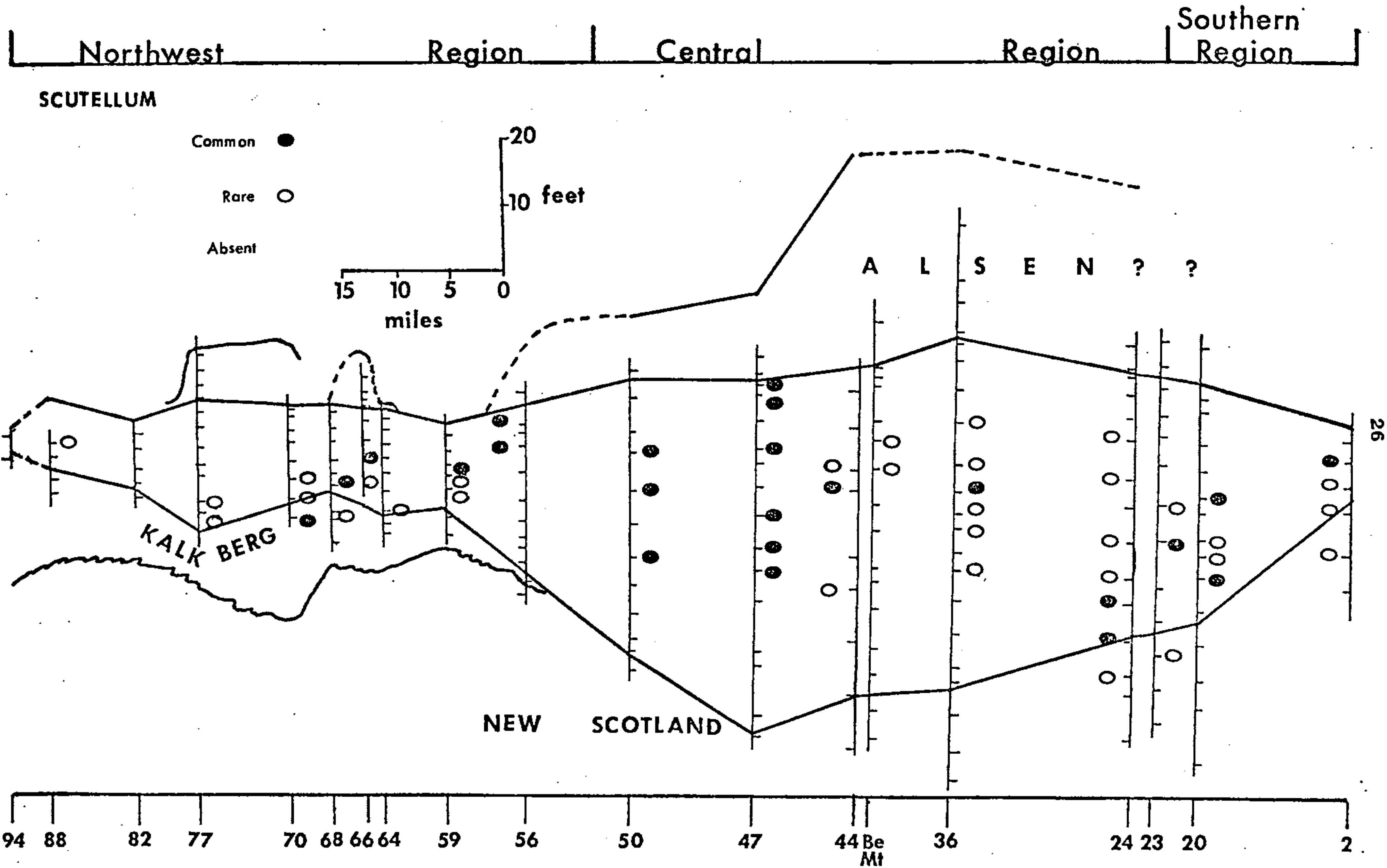
Scutellum is more common at localities 47, 50 and 56 in the massive calcarenite unit. It is generally absent at the top of the Becraft throughout the exposure and in the bottom gradational

Figure 9. Cross section indicating the distribution of perforated crinoids. The four categories are based on the actual numbers of grains counted in a thin section. They are abundant in the central region. Note that the perforated crinoids are totally absent at Becraft Mountain and northwest of locality 47.



Northwest Region
Central Region
Southern Region
Perforated Crinoids
Abundant
Common
Rare
Absent
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
25
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

Figure 10. Cross section showing the distribution of scutellum. The three categories are based on the actual numbers of grains counted in a thin section.


Northwest Region
Central Region
Southern Region
SCUTELLUM
Common
Rare
Absent
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
26
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

zone with the New Scotland, in the central region. They are guide fossils to the Becraft Formation (Rickard, 1962).

2) Brachiopods. Brachiopods are the second most abundant biotic constituent in the Becraft accounting for 18% of the total biota (Table 2, p.51). They have been identified in thin section simply as impunctate, pseudopunctate, and punctate forms. Impunctate and punctate forms appear to be evenly distributed throughout the Becraft. Punctate forms are rare. Pseudopunctate forms are more abundant in the interbedded unit. In addition, one impunctate form, Gypidula pseudogaleata, shows a significant pattern of distribution. Gypidula, a robust pentameroid brachiopod (figure 8c, 22a and b) is a guide fossil to the Becraft Formation. The most commonly preserved part of the shell is the inner prismatic layer which thickens to more than two mm medially near the pedicle umbo. This layer has a distinctive radial prismatic structure which is often selectively replaced by silica.

The particle frequency distribution of Gypidula is shown in figure 11 and includes four categories:

i) abundant -- more than six fragments in a thin section

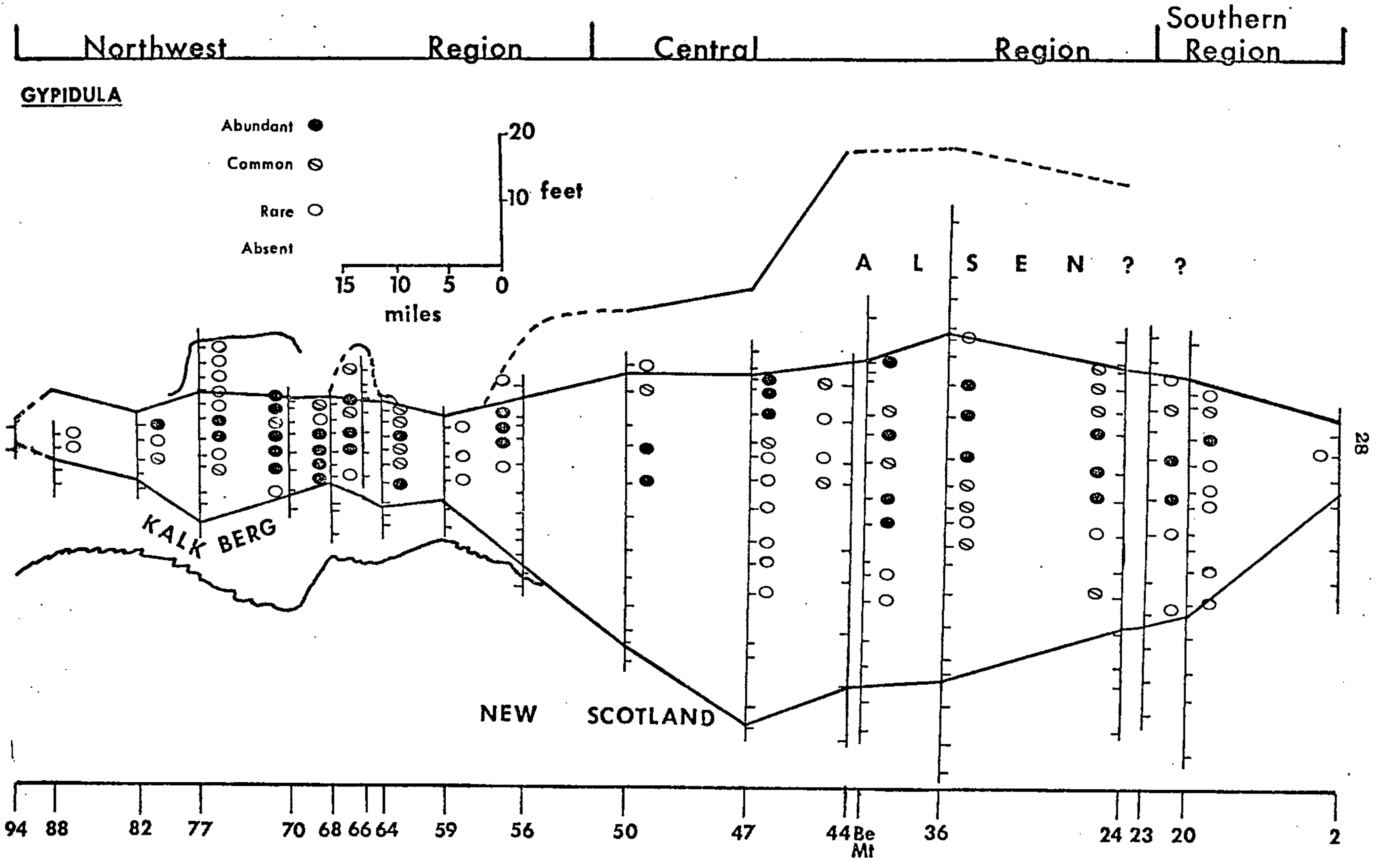
ii) common -- between six and two fragments in a thin section

iii) rare -- less than two fragments in a thin section

iv) absent

Gypidula is common to abundant in the massive calcarenite unit throughout the entire area of Becraft exposure. It is most abundant in the uppermost part of the massive calcarenite unit. It is only a rare element in the interbedded unit.

Figure 11. Cross section indicating the distribution of *Gypidula*. The four categories are recognized from the number of grains counted in a thin section. Abundant gypidulids are found in the upper part of the Becraft.



Northwest Region
Central Region
Southern Region
GYPIDULA
Abundant
Common
Rare
Absent
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
28
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

3) Bryozoa. Four distinct types of bryozoa occur in the Becraft. The first is a ramose or stick-shaped bryozoan, a cryptostome, which is abundant throughout the formation. The second and third types, also found throughout the formation, are two distinct encrusting forms, probably trepostome bryozoa. The fourth, which has a spiralling growth form, could not be identified and is referred to as bryozoa X (figure 8d). When the particle frequency distribution of total bryozoa is observed, bryozoa occur in greater abundance (28% of the total biota) in the interbedded unit than in the overlying massive unit (14% of the total biota). (See Table 2).

4) Trilobites. In thin section trilobites have a distinct dense yellow-brown appearance often marked with fine black lines or dots. Their particle frequency distribution is show in figure 12, and includes four categories:

i) abundant -- more than six fragments in a thin section

ii) common -- between six to three fragments in a thin section

iii) rare -- between three to one fragments in a thin section

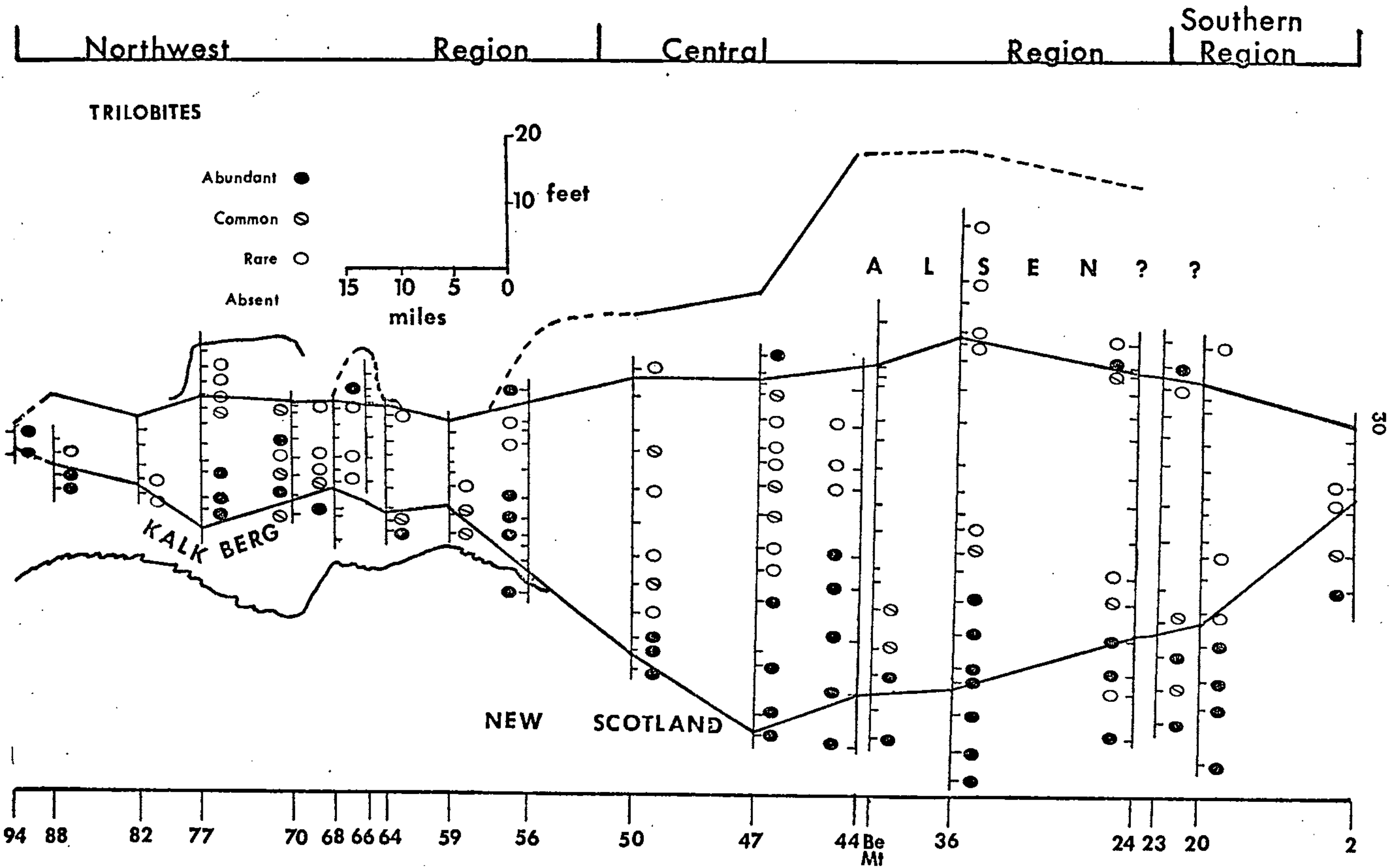
iv) absent

They are found abundantly only in the interbedded unit of the Becraft and upper New Scotland and Kalkberg Formations. They are also found in abundance in the overlying Alsen Formation. Trilobites are most common in the fine-grained interbeds of the interbedded unit and are more fragmented in the coarse interbeds.

C. Texture

Limestone may be characterized by the types and relative amounts of three textural components: matrix, sparry calcite cement and allochems. The relative proportions of matrix and

Figure 12. Cross section indicating the distribution of trilobites. The four categories represent the actual numbers of grains counted in a thin section. High abundance occur in the interbedded unit.


Northwest Region
Central Region
Southern Region
TRILOBITES
Abundant
Common
Rare
Absent
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
30
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

spar cement are important features of the rock because they are a sorting indicator, suggesting current strength or persistence in the environment of deposition. In addition, allochems can be analized directly in several ways utilizing size, fragmentation and sorting to interpret current velocity (Folk, 1962).

Matrix in the Becraft Formation includes four categories:

a) Micrite is carbonate grains one to four microns in diameter generally subtranslucent with a faint brownish cast in thin section (Folk, 1965). It is found with calcisiltite but is less abundant in the mudstone lithology of the interbedded unit of the Becraft.

b) Calcisiltite is fine-grained calcite that has a mean grain size ranging from five to fifteen microns and is detrital carbonate silt, rim-cemented by calcite overgrowths (Lindhom, 1969). It is abundant in the mudstone lithologies throughout the gradational contact interval of the New Scotland and Becraft Formations.

c) Calcareous detritus is fine allochems 15 to 125 microns in size which cannot be specifically identified.

d) Terrigenous mud is fine quartz silt and clay mostly less than 15 microns in grain size which is typically associated with calcisiltite and micrite. It is absent in the northwest region.

The massive calcarenite unit has little or no matrix. In the mudstone of the lower interbedded unit mud matrix is more than 20% of the total rock. Some calcarenite beds in the interbedded unit contain matrix and spar mixed. Mud matrix is rare west of locality 59 in the Becraft above a thin contact zone.

1) Distribution of matrix and spar. Spar is a clear, crystalline cement with a crystal size .02 to .10 mm (Folk, 1965). It is abundant in the Becraft Formation and makes up more than 20% of the total rock in the massive calcarenite unit except where void space has been reduced by significant pressure solution (Table 2). Some beds of sparry rock are also found in the New Scotland and Kalkberg near the gradational contact with the Becraft.

The volume percent of spar to matrix plus spar is calculated and is shown in figure 13. Three categories are recognized:

a) Spar/matrix + spar is less than 5%

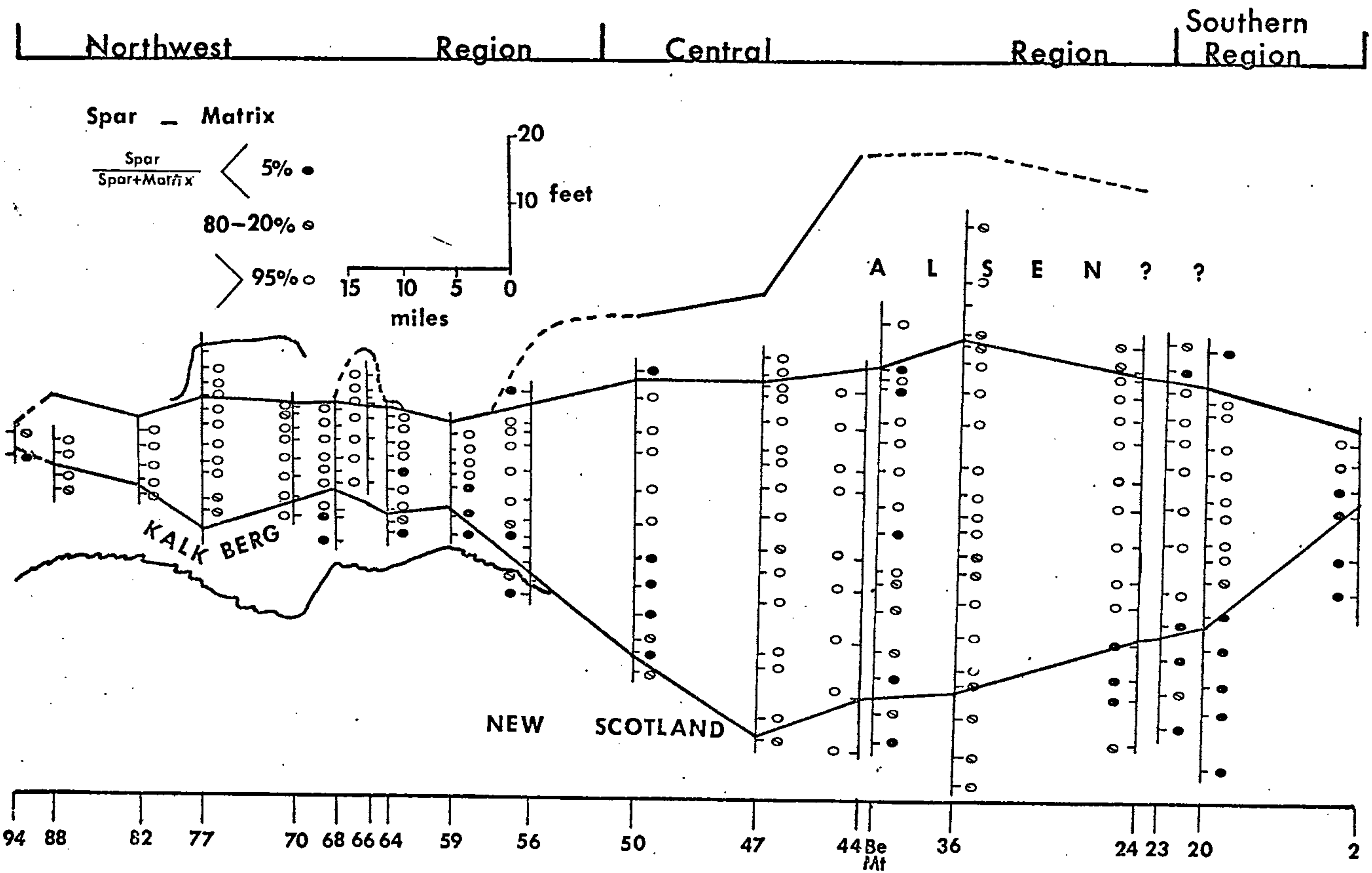
b) Spar/matrix + spar ranges from 80-20%

c) Spar/matrix + spar is greater than 95%

The volume percent of spar to matrix plus spar is greater than 95% in the massive unit of the Becraft. The mudstone lithology of the interbedded unit has spar less than 5%. The volume percent of spar to matrix plus spar ranges from 80% to 20% in some calcarenite interbeds of the interbedded unit.

2) Allochems. Allochems are primarily skeletal fragments, a few intraclasts are found but only in the lower interbedded unit. The allochems in order of abundance are: crinoids, brachiopods, bryozoa and trilobites. The texture of skeletal grains is analized in terms of grain size, fragmentation, sorting and clasticity index for crinoids.

Figure 13. Cross section indicating the distribution of volume percent of spar to matrix plus spar. Three categories are recognized: spar/matrix plus spar less than 5%, spar/matrix plus spar ranging from 80-20% and spar/matrix plus spar greater than 95%. None of the samples fall into the missing categories.


Northwest Region
Central Region
Southern Region
Spar _ Matrix
Spar / Spar+Matrix
< 5%
80–20%
> 95%
20
10 feet
0
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

a) Size is estimated by measuring the longest axis of 25 grains at each corner of the slide. The mean diameter of 100 grains is used as an estimate of mean grain size. Three size categories are recognized:

i) Coarse -- mean grain size greater than 1 mm

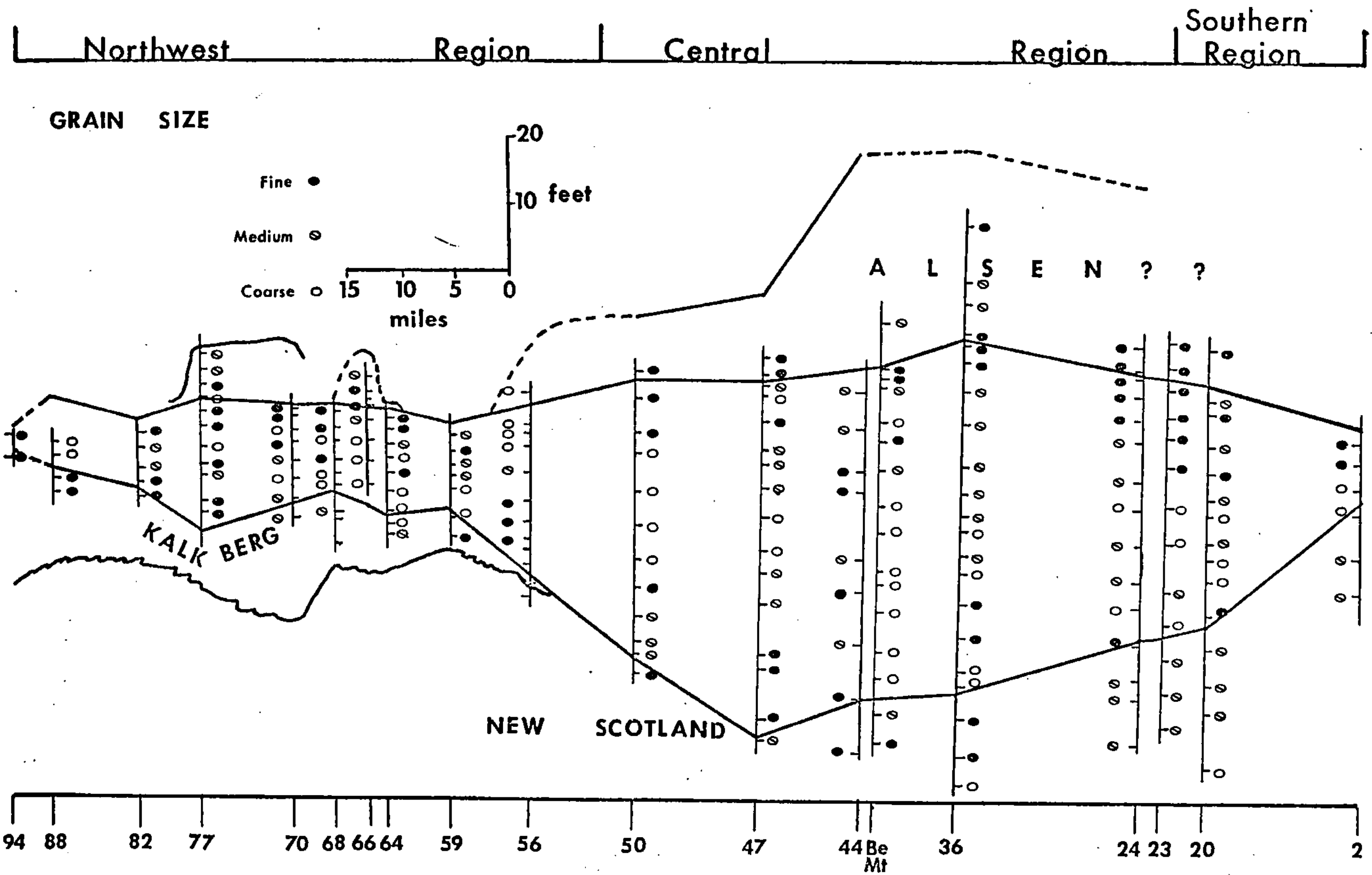
ii) Medium -- mean grain size from 1 mm to 1/2 mm

iii) Fine -- mean grain size from 1/2 mm to 1/8 mm

The distribution of the above three size categories is shown in figure 14. The upper few feet of the massive calcarenite unit which is laterally continuous throughout the exposure consists mainly of fine skeletal grains of crinoids and bryozoa. The Gypidula fragments are coarse to medium. The rest of the massive unit is comprised of coarse to medium calcarenite. However, the calcarenites of the interbedded unit of the Becraft and uppermost New Scotland in the central region are a complex mixture of sizes (fine, medium and coarse). The mudstone lithology of the interbedded unit of the Becraft and uppermost New Scotland not including shale interbeds is biomicrudite and biomicrite.

b) Fragmentation is established in two ways: first, the fragmentation of crinoids and bryozoa are determined separately from thin sections and second, the general fragmentation of all the biotic constituents is determined by visual inspection of negative prints from all the thin sections. Allochems in the Becraft are mostly skeletal grains which differ in microstructure, original size and degree of fragmentation. The size and sorting are related to the process of fragmentation of skeletal materials.

Figure 14. Cross section indicating the distribution of allochem size. Three size categories are recognized: coarse, medium and fine.


Northwest Region
Central Region
Southern Region
GRAIN SIZE
Fine
Medium
Coarse
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

The relative degree of fragmentation of allochems provides evidence for the reworking, deposition and transportation history of the Becraft sediments. The Becraft consists of three significant skeletal elements: crinoids, brachiopods, and bryozoa. Two of these elements, crinoids and bryozoa, which occur throughout the Becraft, are used to define indices of fragmentation. Crinoids increase in abundance higher stratigraphically whereas bryozoa are more abundant lower stratigraphically in the Becraft. Three indices of fragmentation have been arbitrarily defined to estimate the degree of fragmentation in Becraft samples.

Index 1. The degree of fragmentation (i-iii) of crinoids is defined as follows:

i) Highly fragmented--equant fragments of columnals or plates (figure 15a)

ii) Moderately fragmented--one piece containing at least two articulated plates or columnals or five unbroken single columnals or plates (figure 15b)

iii) Little fragmented--two or more pieces, each having at least two articulated plates or columnals in a thin section (figure 15c)

Index 2. The main criterion for recognizing the fragmentation of bryozoa is the size of fragments. Three degrees of fragmentation (i to iii) of bryozoa are as follows:

i) Highly fragmented--no more than one bryozoan fragment between 1/2 and 1 cm and all others less than 1/2 cm (figure 15a)

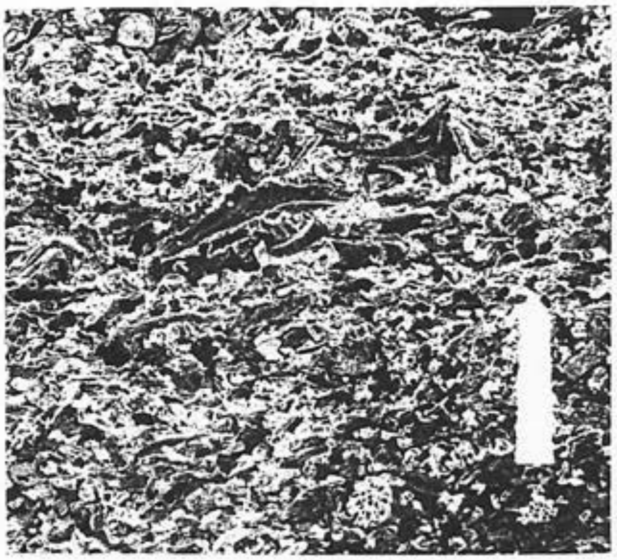
Figure 15. Negative prints of thin sections indicating degree of fragmentation.

a. Fine biosparite from the upper part of the massive calcarenite unit. Note the highly fragmented grains of crinoids, bryozoa and brachiopods (location 68); arrow = 3 mm. (Highly fragmented)

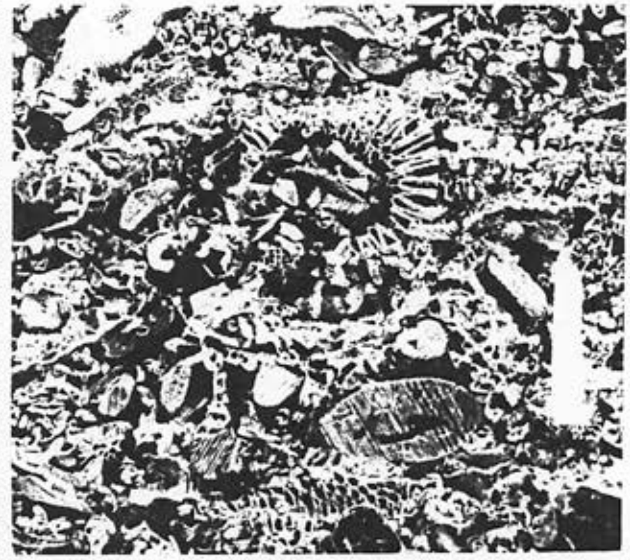
b. Coarse biosparite from the lower part of the massive calcarenite unit. Note the crinoids are disarticulated but moderately large pieces of bryozoa are found (location 23); arrow = 3 mm. (Moderately fragmented)

c. Biosparrudite from the lower part of the calcarenite unit. Note crinoid columnals remain articulated (location 77); arrow = 3 mm.

d. Coarse biosparite from the interbedded unit. Note the bryozoa are little fragmented (Becraft Mountain location); arrow = 3 mm. (Little fragmented).



a



b

c

d

ii) Moderately fragmented--one bryozoan fragment more than 1 cm or two bryozoan fragments more than 1/2 cm in length (figure 15b)

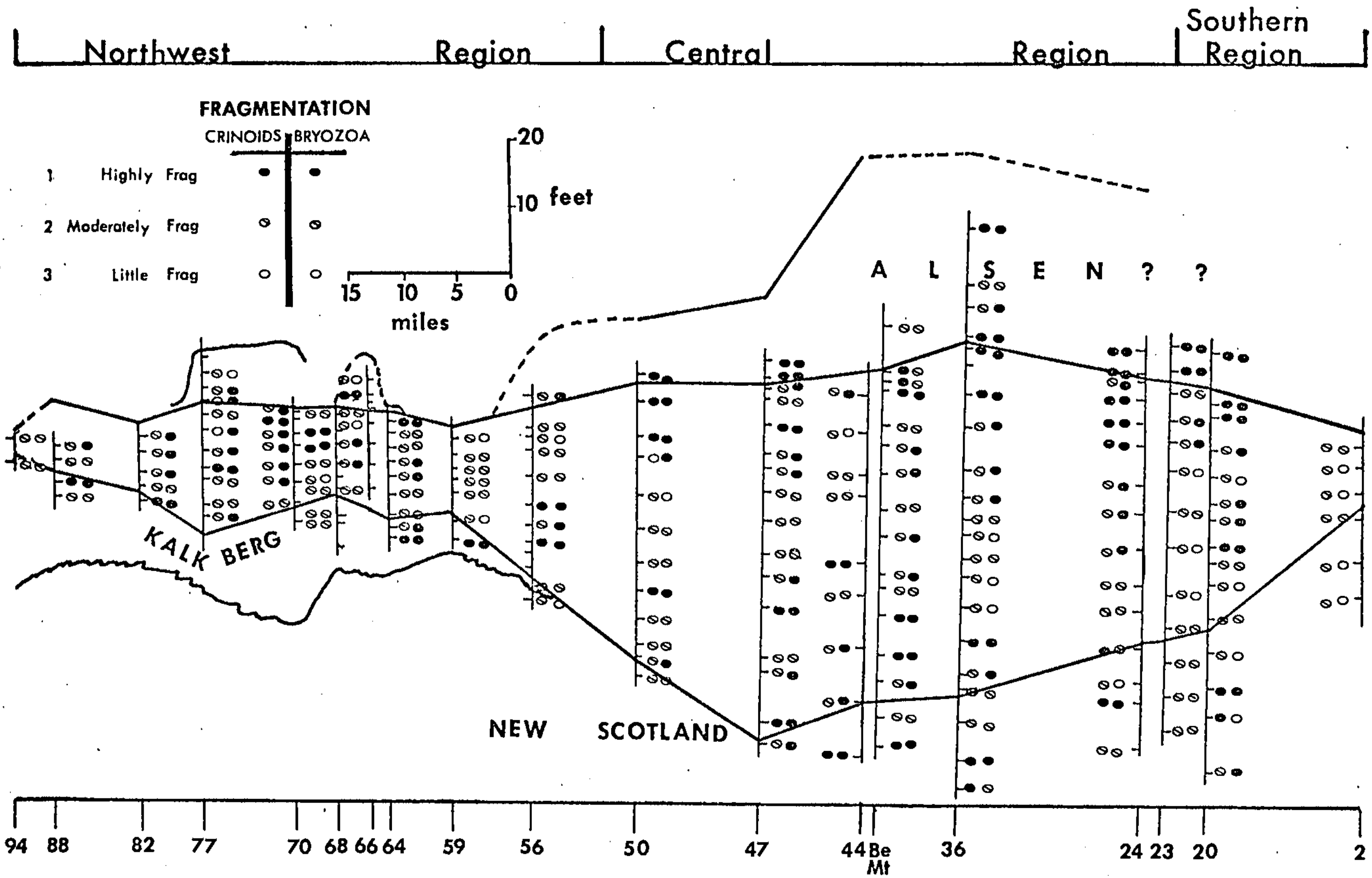
iii) Little fragmented--two bryozoa fragments greater than 1 cm in length in a thin section (figure 15d)

"Little fragmented" crinoids are rare in the Becraft. Most of the crinoidal fragments are in the "moderately fragmented" category. "Highly fragmented" crinoids are found in the upper few feet of the massive calcarenite unit throughout the exposure and occasionally in the lower interbedded unit at localities 56, 47, 44 and 36 (figure 16).

Each of the three degrees of fragmentation of bryozoa are common in the Becraft. "Little fragmented" bryozoa occur most commonly in the lower half of the Becraft both north and south of the basin axis (localities 44, 47 and Becraft Mountain). It is important to note that where crinoids are highly fragmented, bryozoa are also.

A third index of fragmentation was established by visually rating relative fragmentation of all skeletal elements in photographs of thin sections on a scale of 1 to 5. The ratings were made by a second observer. Samples were rated highly fragmented (1) where nearly all skeletal grains were broken into small pieces and "little fragmented" (5) where unbroken skeletal elements were common. All other samples were assigned on a relative basis by visual impressions to the intermediate categories (2, 3, 4). The results were then simplified to three catetories:

Figure 16. Cross section showing the distribution of fragmentation of crinoids and bryozoans. Three degrees of fragmentation of crinoids and bryozoa are recognized: highly fragmented, moderately fragmented and little fragmented.


Northwest Region
Central Region
Southern Region
FRAGMENTATION
CRINOIDS
BRYOZOA
1 Highly Frag
2 Moderately Frag
3 Little Frag
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

i) Highly fragmented (1 and 2) (see figure 15a)

ii) Moderately fragmented (3) (see figure 15b)

iii) Little fragmented (4 and 5) (see figuré 15 c,d)

This quick approximate method produced results parallel to those from the crinoid and bryozoan indices (figure 17).

c) Sorting and Maturity Index is difficult to define in skeletal sands because different organisms undergo progressive fragmentation in different ways. A qualitative estimation of sorting is done in the Becraft and three stages of maturity are defined. Folk (1962) has applied a similar concept of maturity index for carbonate rocks.

i) Moderately sorted and mature (Folk, 1962)--sediments contain little or no mud, and skeletal grains are well sorted but still not rounded (figure 18a). The following Becraft sediments are designated as moderately sorted:

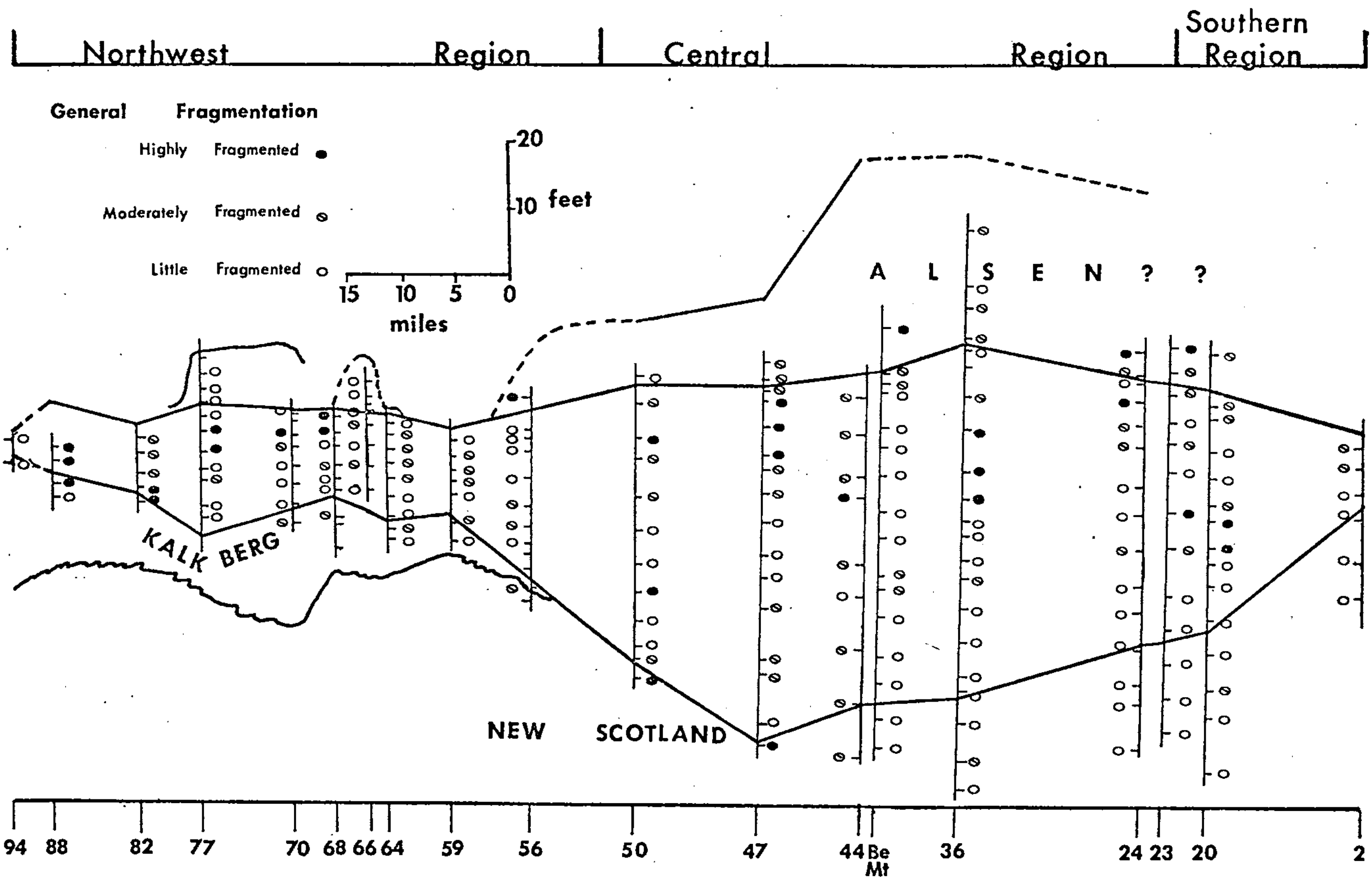
a) The upper part of the massive calcarenite (Gypidulids are excluded because they represent organisms living on the substrate and thus are in part distinct from the substrate itself).

b)/ Some of the calcarenite beds of the lower inter-bedded unit between localities 47 and 36, interpreted later as storm deposits.

The distribution of sorting and maturity index is show in figure 19.

ii) Submature and poorly sorted--sediments contain under five percent matrix, but skeletal grains are still poorly sorted and are not well rounded (figure 18b). Except for the upper part,

Figure 17. Cross section showing the distribution of general fragmentation. This is established by visually rating relative fragmentation of all skeletal elements in negative prints of thin sections. Three categories are recognized: highly fragmented, moderately fragmented and little fragmented.



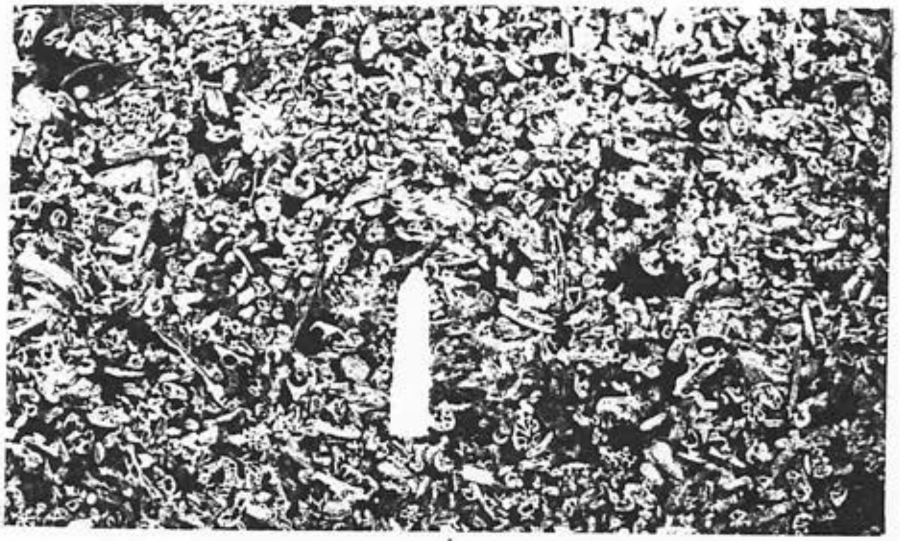
Northwest Region
Central Region
Southern Region
General Fragmentation
Highly Fragmented
Moderately Fragmented
Little Fragmented
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

Figure 18. Negative prints of thin sections indicating the sorting and maturity index.

a) Fine biosparite from the upper part of the massive calcarenite unit. The skeletal sediments are mature and are moderately sorted (location 23); arrow = 3 mm.

b) Coarse biosparrudite from the lower part of the massive calcarenite unit. The sediments are submature and poorly sorted (location 50); arrow = 3 mm.

c) Biomicrudite from the interbedded unit. The sediments are immature and highly unsorted (location 59); arrow = 3 mm.

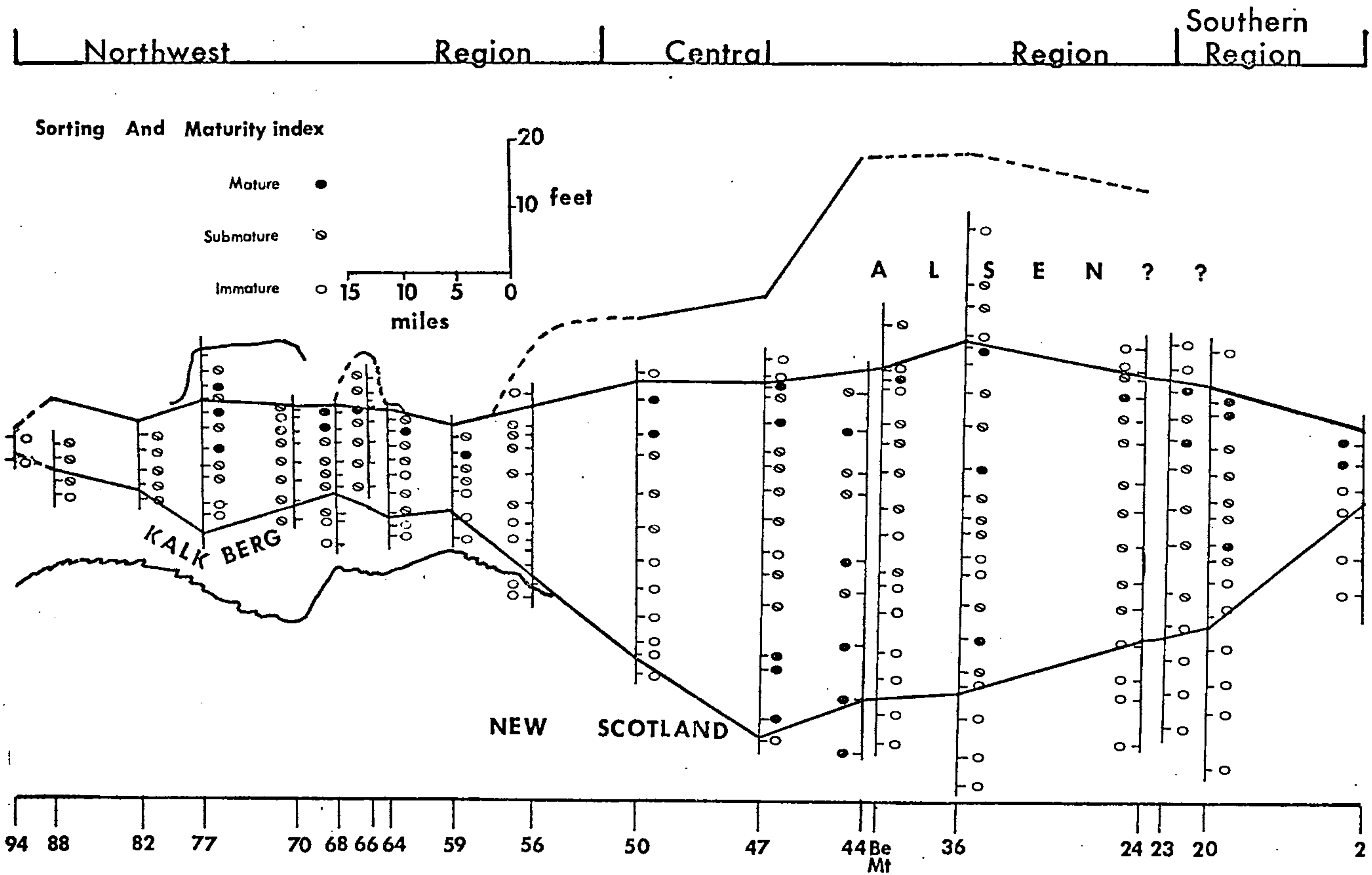


a

b

c

Figure 19. Cross section showing the distribution of sorting and maturity index. Three types of sorting and maturity index are recognized: moderately sorted and mature, submature and poorly sorted and immature and highly unsorted.


Northwest Region
Central Region
Southern Region
Sorting And Maturity index
Mature
Submature
Immature
20
10 feet
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

the massive calcarenite unit is classified in this category. Some of the calcarenite beds of the interbedded unit also belong to this category.

iii) Highly unsorted and immature (Folk, 1961)--the mud content is over 5% and skeletal grains are usually very poorly sorted (figure 18c). All of the rocks in the New Scotland, Kalkberg and Alsen Formations are immature. Some of the calcarenite beds between locality 2 and Becraft Mountain and all the mudstone lithologies of the lower interbedded unit of the Becraft are immature. This indicates a low energy environment.

d) Clasticity Index of Crinoids.is determined by measuring the average apparent diameter of the six largest crinoidal grains (Carozzi, 1964). Scutellum and perforated crinoids are not counted to determine the clasticity index. The distribution of clasticity index is shown in figure 20. Clasticity index values greater than or equal to 4.5 mm are represented by solid circles. The clasticity index is commonly greater than 4.5 mm in the northwest region, at Becraft Mountain and at locality 36. The clasticity index appears to be low in the upper and lower parts of the Becraft.

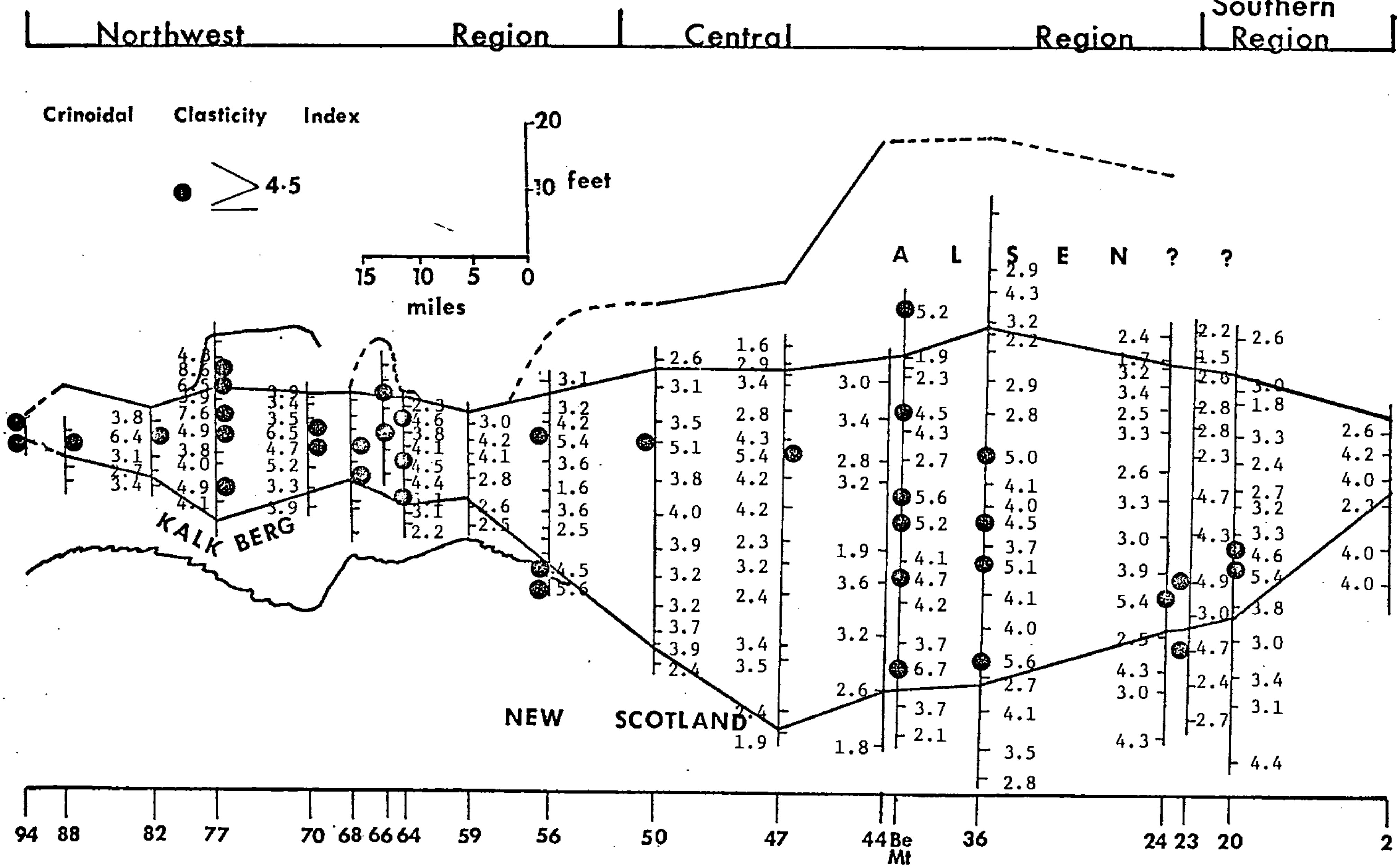
Rao and Mann (1972) relate the clasticity index of crinoids with energy levels. The clasticity index of crinoids generally increases from low energy to high energy, but this relationship is very complex as apparent by their figure 3 (p. 472). Clasticity index of crinoids depends on two factors:

Initial size of stem

Degree of fragmentation

Small stems of crinoids occur in low energy environments but as the agitation of water increases the size of the stems also increases because crinoids grow optimumly in highly agitated conditions.

Figure 20. Cross section showing the clasticity index of crinoids. The numbers represent the average diameter in millimeters of the six largest crinoidal grains. The black solid circle represents clasticity indices greater than or equal to 4.5 mm.



Northwest Region
Central Region
Southern Region
Crinoidal Clasticity Index
≥ 4.5
20
10 feet
0
15 10 5 0
miles
A L S E N ? ?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

But at the same time they get more broken in agitated water and the size of stems is reduced. Therefore a high clasticity index of crinoids occurs where there is high energy but little reworking. Low clasticity index occurs where there is low energy or high energy and persistent reworking.

VI. SUMMARY OF BECRAFT FACIES

The Becraft Formation can be divided into three facies based on field, textural and faunal evidence. Facies 1, the interbedded facies of mudstone and calcarenite; Facies 2, the coarse massive biosparrudite facies; and Facies 3, the fine massive biosparite facies (figures 21 and 22). Facies 2 and 3 are equivalent to the upper massive unit described earlier.

Facies 1 is represented by the lower Becraft which overlies the New Scotland and Kalkberg Formations. It is composed of argillaceous shale and biomicrudite interbedded with fine to coarse biosparite (figure 22e, f). Shale interbeds make up about 30% of the facies near its stratigraphic base and decreases to less than 10% at its top. The lower contact of biosparite beds with shale is sharp (erosional) whereas the upper contact is gradational into an overlying shale (figure 22e, f). A few interclasts of underlying argillaceous or lime mud are found in some biosparites. Most coarse beds show graded bedding fining upward (figure 22e,f). The biosparites show high-angle cross-stratification.

Facies 1 is characterized by variability in its textural parameters. The proportion of spar to spar plus matrix in biosparite interbeds is usually greater than 95% but in some biosparite beds it is as little as 20%. The biosparite interbeds are a complex mixture of sizes (fine, medium and coarse). Crinoids are moderately fragmented but occasionally highly fragmented crinoids are found at localities 56, 47 and 36. Little

Figure 21. Cross section showing the distribution of the Becraft facies. Three facies are recognized. Facies 1 is interbedded shale biomicrite and biosparite; Facies 2 is massive coarse biosparite and biosparrudite; and Facies 3 is massive fine biosparite.

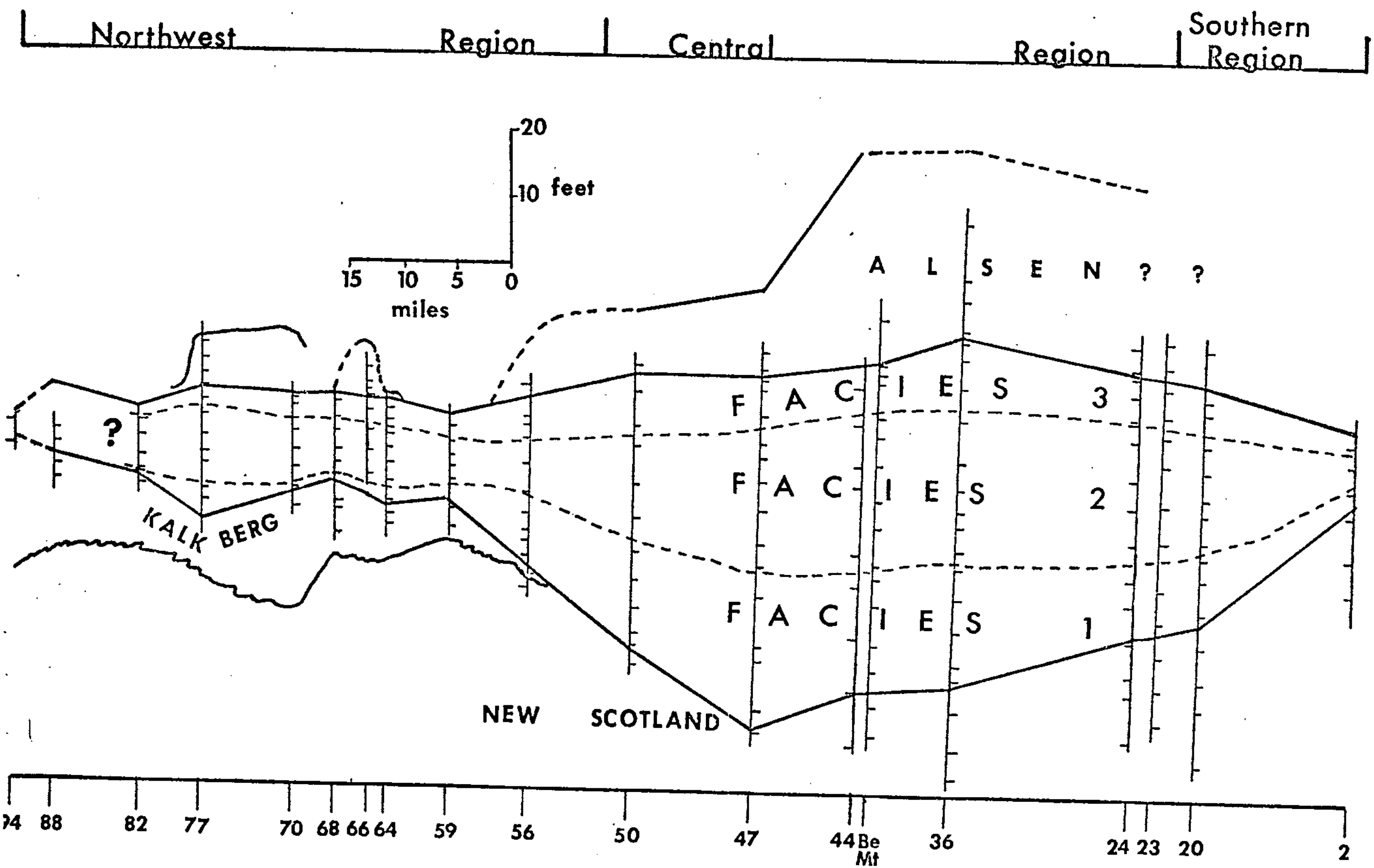

Northwest Region
Central Region
Southern Region
20
10 feet
15 10 5 0
miles
A L S E N ? ?
F A C I E S 3
F A C I E S 2
F A C I E S 1
?
KALK BERG
NEW SCOTLAND
94 88 82 77 70 68 66 64 59 56 50 47 44 Be Mt 36 24 23 20 2

Figure 22. Photographs of rock slabs representative of Becraft facies.

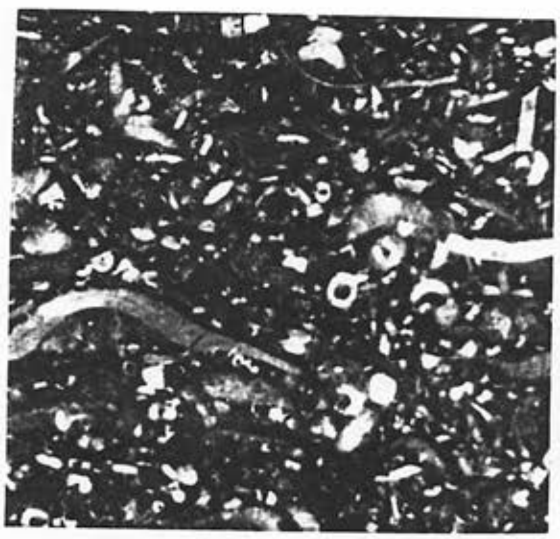
a) and b) Fine reworked biosparite from Facies 1. Note the highly fragmented sediments and the unbroken gypidulids (locations 36 and 50 respectively); arrow = 5 mm.

c) and d) Coarse biosparite to biosparrudite from Facies 2 characterized by moderate fragmentation and poor sorting (locations 50 and 77 respectively); arrow = 5 mm.

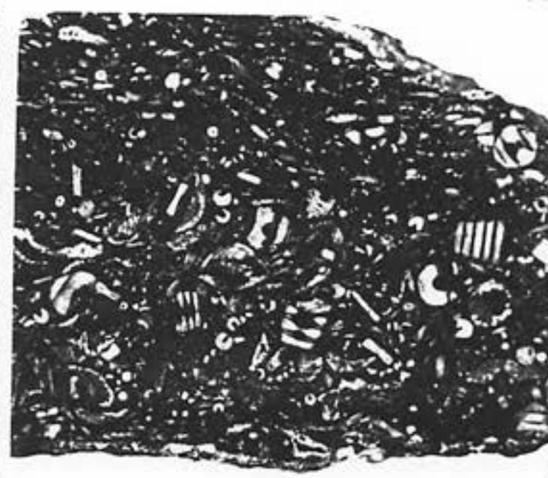
e) and f) Interbedded shale and biosparite of Facies 1. Note in e) the lower sharp contact and fining upwards of the calcarenite; in f) the calcarenite grades into thin shale but has a lower sharp contact (localities 2 and 24 respectively); arrow = 5 mm.

a

b

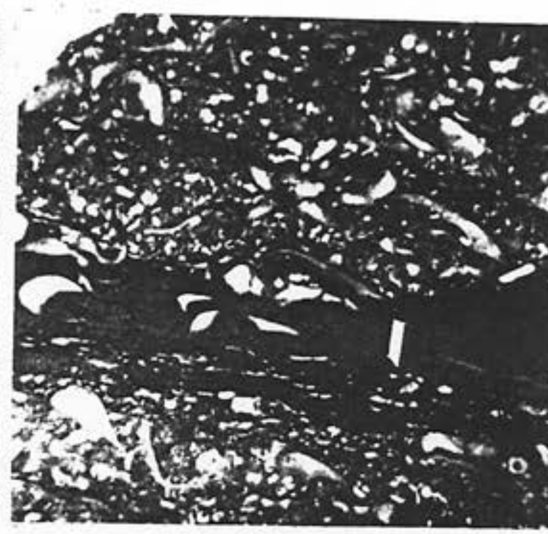


c



d

e



f

fragmented bryozoa occur both south and north of the basin axis (localities 44, 47 and Becraft Mountain), however, they are highly fragmented at the basin axis. The overall sorting is very poor. The crinoidal clasticity index ranges from low to high.

The highest faunal diversity in the Becraft occurs in Facies 1. The faunal constituents are crinoids, bryozoa, brachiopods, trilobites, ostrocods, tentaculitids and corals. Crinoids make up 45% of the total biota (Table 2), but are less abundant than in Facies 2 and 3. Bryozoa make up 28% of the total biota and are more abundant than in Facies 2 and 3, but gypidulids are rare. Trilobites make up five percent of the total biota in Facies 1 and are rare to absent in Facies 2 and 3.

The thickness of Facies 1 varies. It is thickest in the central region where the thickness reaches a maximum of 23 feet at locality 47; in contrast the thickness is negligible in the northwestern region. The lower contact of Facies 1 is placed at the appearance of the first thick biosparite bed, the upper contact is placed at the top of the last lime mud bed or thick shale bed.

Facies 2 is the massive coarse biosparite and biosparrudite which overlies Facies 1 (figure 22c,d). Shale beds are present but are very thin and make up less than two or three percent of the facies. Graded beds are less common in Facies 2 than in Facies 1. The facies has a complex assemblage of multiple sets of accretion and avalanche cross-stratification (Anderson, 1972).

Table 2

A. The average composition for each of three Becraft facies (listed as a percent of total rock) as determined by 300 point counts

	Interbedded Unit	Massive Calcarenite Unit	
	Facies 1	Facies 2	Facies 3
Crinoids	27.0	45.0	43.0
Gypidula	rare	5.0	9.0
Other brachiopods	7.0	11.0	6.0
Bryozoa	17.0	10.0	3.0
Trilobites	3.0	rare	rare
Spar	32.0	21.0	22.0
Matrix	7.0	rare	rare
Other	6.0	5.0	15.0
Total	99.0	97.0	98.0

B. Percentage of total biota

	Facies 1	Facies 2	Facies 3
Crinoids	45.0	59.0	57.0
Gypidula	rare	7.0	12.0
Other brachiopods	12.0	14.0	8.0
Bryozoa	28.0	13.0	4.0
Trilobites	5.0	--	--
Other	10.0	7.0	19.0
Total	100.0	100.0	100.0

It is characterized by very little variability in its textural parameters. The proportion of spar to spar plus matrix is usually greater than 95%. The skeletal fragments are medium to coarse-grained (figure 22c,d). Most of the skeletal material is at most moderately fragmented. The sediment is submature and poorly sorted. The clasticity index of crinoids is high.

The predominant Becraft faunal element, crinoids, reaches its greatest relative abundance in this facies (59% of the biota). Scutellum is common in this facies. Gypidulids are abundant at the upper part of the facies and make up 7% of the total biota. Bryozoa remain diverse but make up only 13% of the total biota (Table 2).

The thickness of Facies 2 varies from 23 feet at locality 36 to less than 10 feet in the marginal (northwest and southern) regions. The base of Facies 2 is placed at the top of the highest biomicrudite bed or thick shale beds while the upper contact is placed at the appearance of massive fine reworked biosparite.

Facies 3 is a massive fine, wave reworked biosparite, which overlies Facies 2 (figure 22a,b). Shale beds are nearly absent. The predominant sedimentary structure is low-angle cross-stratification.

The proportion of spar to spar plus matrix is greater than 95%. The skeletal fragments of crinoids, bryozoa and brachiopods are fine-grained, highly fragmented and at least moderately sorted. The gypidulids are moderately fragmented (figure 8c, p. 23). The clasticity index of crinoids is low.

Crinoids are still the dominant faunal elements. Scutellum is absent. The gypidulids reach their greatest relative abundance in this facies (12% of the total biota).

Total facies thickness varies from 10 feet to 3 feet. This facies is overlain by the Alsen Formation-- a fossiliferous burrowed calcarenite (figure 5a, p. 17).

The main lithological, textural and faunal characteristics of all the three facies are summarized in Table 3.

Table 3

A summary of lithological, textural and faunal characteristics of the three Becraft facies.

		Facies 3	Facies 2	Facies 1
LITHOLOGY	Bedding	Massive	Massive	Interbedded
	Sed. Structures	Low-angle to horizontal stratification	Low to high-angle cross-stratification	High-angle stratification
	Graded bedding		- - -	———
	Shale	present	less than 3%	30% to 10%
TEXTURAL FEATURES	Mud Matrix			Above 20% in the mudstone
	Spar	Above 20%	Above 20%	Above 20% in biosparite interbeds
	Interclasts		- - -	———
	Allochem size	Fine	Coarse to medium	Fine, medium and coarse
	Fragmentation	Highly fragmented	Moderately Fragmented	Little to moderately fragmented
	Sorting	Moderately sorted and mature	Poorly sorted and submature	Highly unsorted
FAUNA	Crinoidal Clasticity Index	Low	High	Low to high
	Gypidula	Most abundant	———	——— - -
	Trilobites		- - - - -	Most abundant
	Scutellum	———	Most abundant	———
	Crinoids	———	———	———
	Brachiopod	———	———	———
	Bryozoa	———	———	Most abundant

VII. GEOGRAPHIC DISTRIBUTION OF FACIES ELEMENTS

The three Becraft facies undergo lateral changes from the central to the southern and northwestern regions.

A. Thickness -- All three facies are thickest in the central region and thin out toward the margins (northwest and southern regions). Facies 1 is well developed only in the central region.

B. Shale -- Shale beds are thickest in Facies 1 and the thickness decreases progressively in Facies 1 and 2.in the central and southern regions. The shale is rare in the northwest region.

C. Scutellum -- Scutellum is found in Facies 2 in the central and southern regions and is rare in the northwest region. It is absent in Facies 1 in the central region but is found in the northwest and southern regions.

D. Perforated Crinoids -- Perforated crinoids are common in all facies in the central region, are absent in the northwest region, and decrease in abundance and stratigraphic range into the southern region. They are absent at Becraft Mountain, five miles to the east of their most abundant point of occurrence near Catskill, New York.

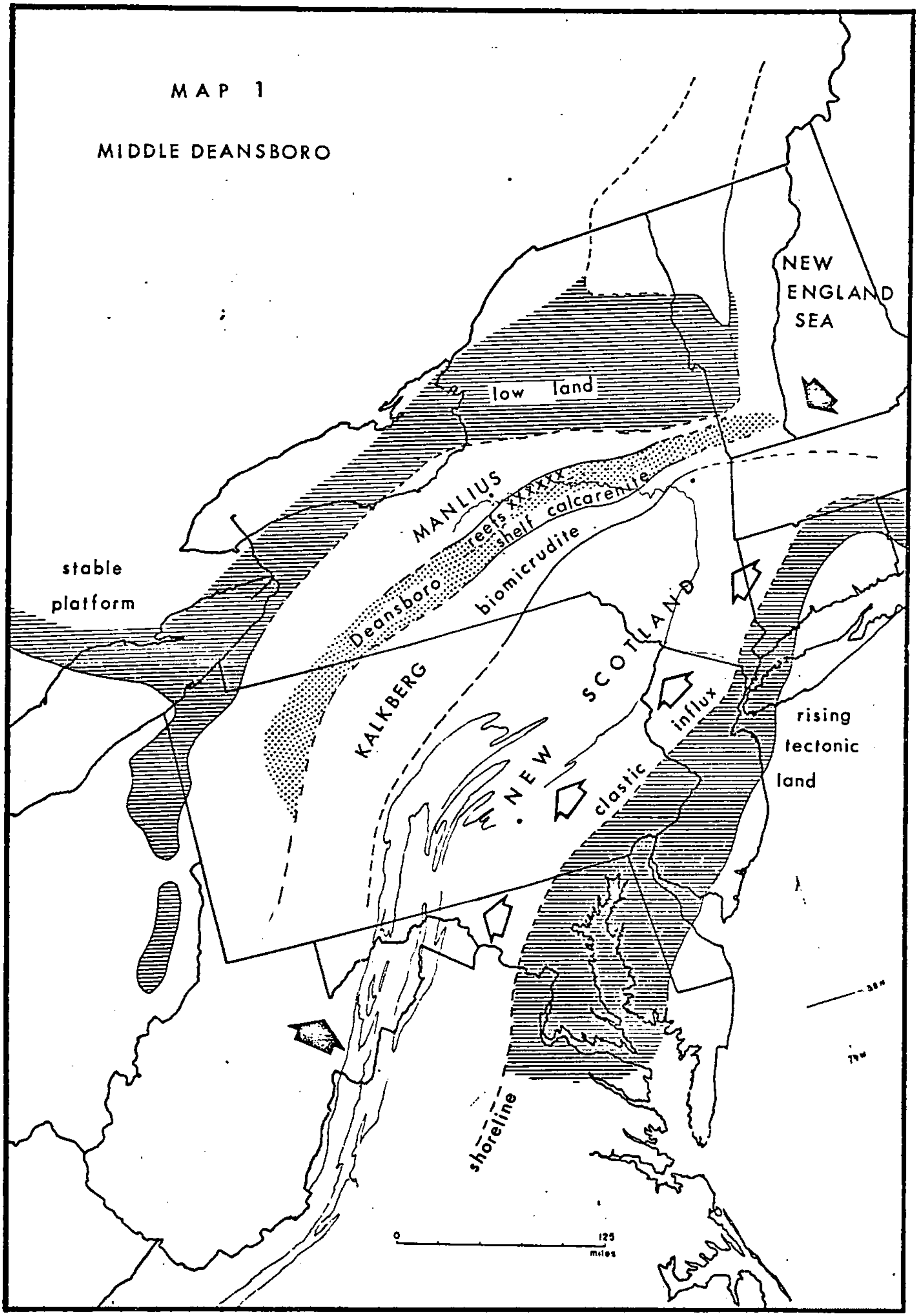
There is also a change in lithology, texture and fauna at Becraft Mountain which lies five miles east of the main line of outcrop. At Becraft Mountain, scutellum is rare; perforated crinoids are absent; the mud content in Facies 1 is more than that found at localities 36, 44 and 47 in Facies 1 and fragmentation is less.

VIII. GEOGRAPHIC FRAMEWORK OF DEPOSITION

The Becraft was deposited in a unique geographic position within the previously defined Helderbergian paleogeography, described by Head (1969) and Anderson (1967). Their paleogeographic maps show a two-sided basin which opens to the southwest and which is constricted to the northeast but which is continuous with the New England sea (Map 1). Quartzite and crinoidal limestone of the Bernardston formation record the extension of the Deansboro or Becraft shallow shelf environment into the New England area. The northwest shoreline is a tectonically stable zone throughout the Lower Devonian but the northeast basin margin is tectonically active providing periodic terrigenous clastic influxes into the predominantly carbonate basin. The basin axis, defined as the line of deepest water in the basin at any given time, runs northeast between Kingston and Catskill, New York. The thickest development of the Becraft occurs on this axis at the narrow connecting point between the Central Appalachian and New England seas.

The Becraft line of outcrop is found on both sides of the basin. In the northwest region (from locality 94 to 50) the Becraft outcrop belt is parallel to the northwest shoreline of the basin. In the southern region (from locality 23 to 2) the outcrop runs parallel to the southeast shoreline. In the central region (from locality 50 to 23) it is perpendicular to the northwest and southeast shorelines of the basin, cutting across the strait which connects the Helderbergian and New England seas (Map 2).

Map 1. Paleogeographic reconstruction of Lower Devonian mid-Deansboro-Kalkberg-New Scotland time (after Anderson, 1967). The basin axis lies along a line connecting the two solid, black arrows. The clastic influx was from the southeast as shown by light arrows.


MAP 1
MIDDLE DEANSBORO
NEW
ENGLAND
SEA
low land
MANLIUS
reefs xxxxxx
shelf calcarenite
Deansboro
biomicrudite
stable
platform
KALKBERG
NEW SCOTLAND
influx
clastic
rising
tectonic
land
shoreline
0
125
miles

IX. ENVIRONMENTAL INTERPRETATION OF FACIES

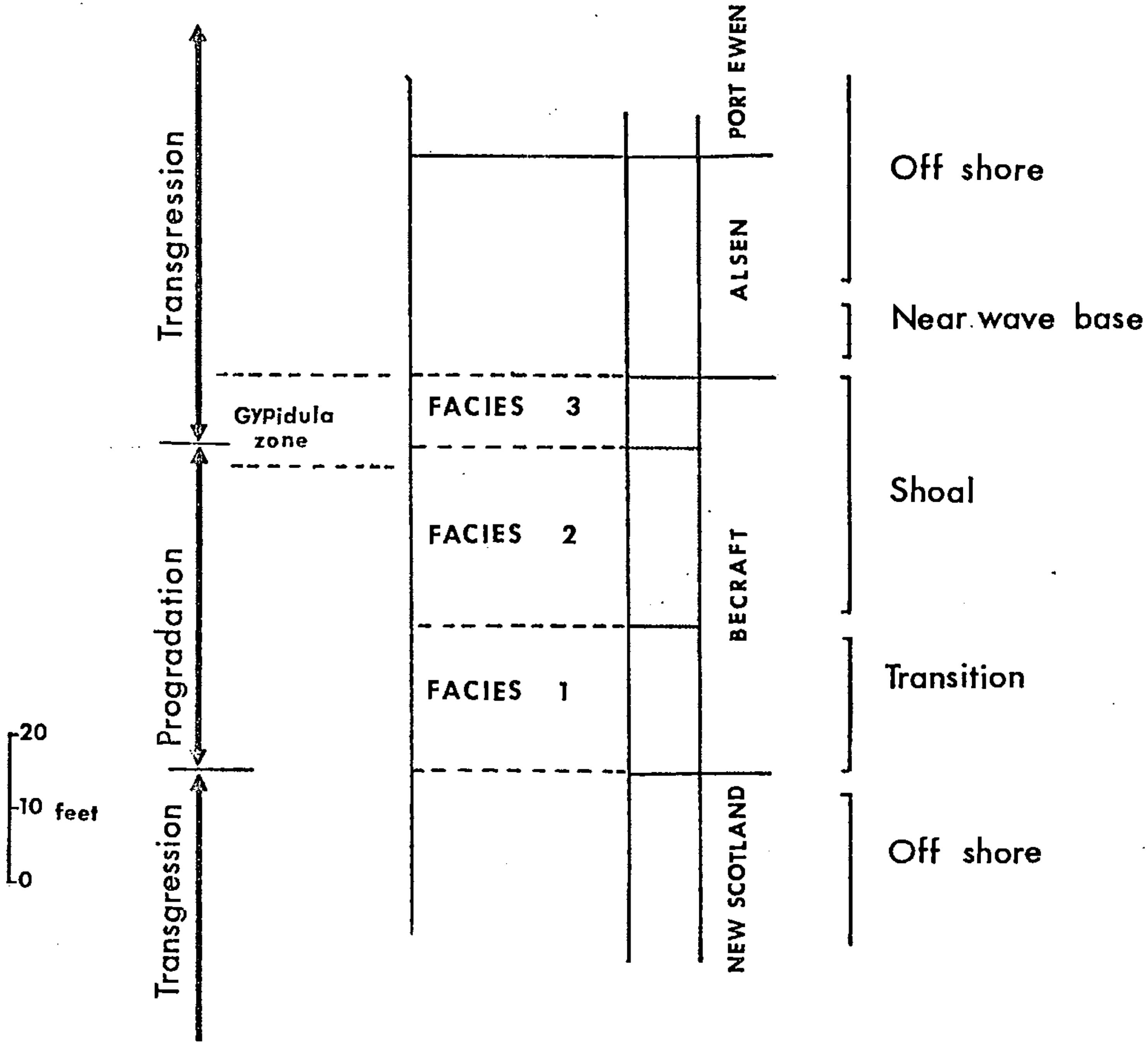
Interpretation of the Becraft facies is based on three types of evidence: geographical, physical and biological.

The geographical evidence includes both the Becraft's lateral and stratigraphic positions in environmental sequences. Stratigraphically the three Becraft facies overlie and underlie more offshore marine deposits and thereby a maximum point of progradation must lie within the Becraft (Figure 23). In its lateral geographic position the Becraft is thickest at the northeast corner of the Central Appalachian sea, which is on the basin axis and at the point of probable connection with the New England sea (see Map 1).

Physical and biological evidence for the interpretation of Facies 1 includes:

1) The interbedding of argillaceous shale and biomicrudite with fine to coarse biosparite.
2) The biosparites show high-angle cross-stratification.
3) The lower contact of each biosparite is erosional over a shale but the upper contact is gradational into an overlying shale.
4) The biosparite shows graded bedding and some of the biosparites contain mud intraclasts.
5) Facies 1 has the highest faunal diversity in the Becraft.
6) Bryozoa are more abundant (28% of the total biota) whereas crinoids are less abundant (45% of total

Figure 23. Vertical section of locality 36 showing the environments of the Becraft facies. Facies 1 represents a transitional environment between offshore deep water and shallow shoal environments. Facies 2 represents a shoal environment. Facies 3 represents a shoal environment that is reworked by renewed transgression.


Transgression
Gypidula zone
Progradation
Transgression
20
10 feet
0
FACIES 3
FACIES 2
FACIES 1
PORT EWEN
ALSEN
BECRAFT
NEW SCOTLAND
Off shore
Near wave base
Shoal
Transition
Off shore

biota) than in Facies 2 and 3.

7) Trilobites are relatively more abundant than in Facies 2 and 3.

INTERPRETATION: Facies 1 is interpreted as forming in the transitional environment between the low energy below wave base zone of New Scotland deposition and the high energy above wave base shoal environment of the upper Becraft (Facies 2 and 3). The dominant environment was that of offshore quiet water, where shale and lime mud were being deposited. The source of the terrigenous mud was from an unstable southeastern land mass. The shale interbeds represent a constant influx of clastics into the basin punctuated by short intervals of deposition of coarse skeletal sands respectively. This is in agreement with Borst (1966, p. 787) who suggested that in the interbedded mudstone and calcarenite unit, the change from mudstone to calcarenite is controlled in the area of sedimentation, not in the source area, and that there was a continuity of sedimentary conditions in time as well as in space.

The lime mud and shale deposition is interpreted as forming in deep water below wave base (depth of the water in the order of 30-60 feet). The faunal diversity, indicated by an abundance of flat brachipods, trilobites and bryozoa and relative paucity of crinoids in the lime mud, also indicates a relatively deep water environment. The interbedded biosparite beds are interpreted as influxes of skeletal fragments from a shallow shoal prograding into the offshore deep water environment probably moved by storms. Cross-bedding (predominantly avalanche deposits) in interbeds of biosparite suggests large scale ripple forms or dunes of skeletal sands migrating into the basin. These interbeds, both the fragmented fine skeletal sands and the coarse graded skeletal sands, might alternatively represent shell beds winnowed from the mud bottom by periodic storm activity. Within Facies 1 the thickness of the calcarenite beds increases upwards while the shale interbeds decrease in thickness as the prograding shoal encroaches on the line of outcrop.

Physical and biological evidence for the interpretation of Facies 2 includes:

1) Coarse biosparite and biosparrudite with little mud represent the most common lithologies.
2) Sedimentary structures include a complex assemblage of accretion and avalanche cross-stratification.
3) The shale beds have diminished to very thin stringers.
4) Skeletal fragments are little to moderately fragmented and submature. Clasticity index of crinoids is high.
5) The fauna is less diverse. Crinoids reach their greatest abundance and bryozoa are less abundant than in Facies 1.
6) Scutellum is mostly restricted to Facies 2.

INTERPRETATION: Facies 2 is interpreted as having been deposited in a shallow shoal environment. The depth of water is 5-30 feet as visualized by sedimentary structures, lithology and abundance of crinoids. Absence of fine beds and lime mud, and the assemblage of accretion and avalanche deposits indicate a higher energy environment than Facies 1. The shale interbeds are very thin because most of the fine sediments were winnowed out by persistent current and wave activity. The crinoids reach their peak abundance because of improved water circulation. Increase of crinoidal frequency and high clasticity index indicate an agitated condition prevailing at or above wave base where conditions are favorable for crinoid growth. Relatively rapid deposition limits mechanical reworking of the sediments as indicated by the high clasticity index of crinoids. Scutellum is related to coarse substrate and is restricted to Facies 2.

Physical and biological evidence for the interpretation of Facies 3 includes:

1) Fine reworked biosparite with no mud.
2) The most common lithology is composed of skeletal fragments of crinoids, bryozoa and brachiopods that are highly fragmented and at least moderately sorted.
3) The predominant sedimentary structure is low-angle cross-stratification.
4) The clasticity index of crinoids is low.
5) _Gypidula_ reaches its peak abundance.

INTERPRETATION: Facies 3 is produced by transgressive reworking of the top of the shoal represented by Facies 2. Only the top of Facies 2 is reworked producing a thin, fine, highly fragmented deposit of crinoids, bryozoa and brachiopods. Gypidulids which are abundant and little fragmented are interpreted as inhabitants on this substrate. This is consistent with the studies of Anderson (1971) and Anderson and Makurath (1972) which suggest that gypidulids have an ecological preference for highly reworked skeletal sand and silt substrates which are best developed in transgressive calcarenite deposits. Although the condition was favorable for the growth of large stems of crinoids the clasticity index of crinoids is low. This is due to the greater amount of reworking in this environment which fragments crinoidal plates producing a low clasticity index. Low-angle cross-stratification is produced by persistent reworking of skeletal debris by waves and currents in less than about ten feet of water.

Several lateral changes in environmental and biological properties indicate lateral environmental changes in the Becraft area of deposition:

1) Shale decreases in abundance from southeast to northwest across the basin and is rare west of locality 50 in the northwest region (Map 3, p. 71). This suggests that the source of terrigenous sediments was in the southeast and that the southeast basin was tectonically more active than the northwest margin. The constant ratio of clay minerals in beds of different sedimentary environments and quartz clasticity values suggests that the source area for detrital materials was the same throughout Helderberg time (Borst, 1966).

2) The clasticity index of crinoids is higher in the northwest region than in the central region in Facies 2. The high clasticity index in the northwest region could be explained because this region received little fine terrigenous sediment which could inhibit the growth of crinoids.

3) The maximum thickness of the Becraft facies is in the central region and thickness decreases towards the northwest and southern regions. This thicker central zone which in New

Scotland time received the deepest water sediments is interpreted as the basin axis into which the Becraft shoal prograded from the northeast. Differences in thickness of the Becraft may simply represent relative differences in water depth laterally across the basin in the area of outcrop as the basin shoaled.

4) The distribution of perforated crinoids is unusual. They are totally absent at Becraft Mountain and northwest of locality 47 where they are most abundant. They occur as far south as locality 2. The distribution of this common distinctive fossil suggests that they are restricted in their habit to the basin axis and are swept by currents from this area to the south. This suggests a clockwise current pattern around the north end of the basin (see Map 4).

X. NEW TIME STRATIGRAPHY

The criteria used for time-stratigraphic correlation of the Helderberg Group developed by Rickard (1962) have been discussed on page 4 . However, those criteria are not taken from the New Scotland, Becraft and Alsen part of the stratigraphic section and internal correlation of those rocks is not well founded. In addition, Rickard's time-stratigraphy assumes approximately equal rates of deposition throughout the basin. The deposition of the thick New Scotland terrigenous clastic wedge and the thick Becraft calcarenite at the basin axis may be important exceptions to this otherwise useful assumption. Thus, an attempt is made to develop a new internal time-stratigraphy for the Becraft based on multiple lines of evidence.

Evidence for time-stratigraphic correlation within the Becraft includes:

A. Evidence of a turning point in a regressive-transgressive cycle:

1.) Gypidulid distribution

2.) Changes in texture

a) overall texture

b) crinoid clasticity

B. Correlation of two thin widespread horizons of skeletal grains coated with hematite

C. Correlation of the interbedded Upper Kalkberg (Epstein, 1971) with the interbedded Becraft.

The Becraft Formation changes vertically (in time) from a progradational to a transgressive lithology. The progradational lithology is a thick sequence of interbedded fine and coarse sediments which grades upward into a massive coarse calcarenite (over 6m thick, Anderson, 1972). The progradational sequence is underlain by the New Scotland Formation -- an offshore lime and terrigenous mud with a diverse faunal assemblage. The regressive sequence is ended by renewed transgression, represented by change from a massive calcarenite to the renewed deposition of offshore carbonate silt and mud -- the fossiliferous Alsen calcisiltite and Port Ewen calcilutite.

The turning point in this regressive-transgressive cycle occurs within the Becraft and is indicated by the following faunal (Gypidula) and lithologic (texture) changes.

1. Anderson (1971) and Anderson and Makurath (1972) have shown that gypidulids have an ecological preference for highly fragmented skeletal sand silt substrates of transgressive calcarenites which are more thoroughly reworked than prograding calcarenite deposits. This preference suggests that the appearance of abundant gypidulids is an approximation of the turning point in the Becraft regressive to transgressive depositional cycle (Figure 11).

2. Stratigraphic textural changes in the Becraft may be described in terms of general texture or in terms of single types of grains.

a) The texture of the upper Becraft is different from the rest of the Becraft. The Becraft as a whole is interbedded coarse calcarenite which is moderately fragmented. But the upper Becraft is a fine-grained deposit of crinoids, bryozoa and brachipods (excluding Gypidula). The crinoids, bryozoa and other brachiopods are highly fragmented and reworked. The gypidulids are abundant in the upper part of the Becraft. The gypidulid pieces are coarse to medium-grained and less fragmented than that of the substrate.

b) The crinoidal clasticity index is usually high (greater than 4 mm) in the massive calcarenite but is low (less than 4 mm) in the upper Becraft. The low clasticity index is concurrent with fine grain size, highly reworked sediments and abundant gypidulids. It appears that the low clasticity index is related to the amount of reworking.

These lines of evidence above all indicate a change in the upper Becraft towards more reworking of skeletal particles. These are correlated with the change from regression (progradation) to transgression which must occur somewhere in the upper Becraft. The crinoid clasticity index provides an indicator of size (and probably fragmentation) of crinoid particles.

Figure 4 shows upper Helderberg stratigraphic relationships as in Rickard (1962). Based on the time indicators developed above, this cross section is redrawn to a new time datum and all other cross sections in this text use this new construction. The selected datum is defined as the midpoint of the zone of common to abundant gypidulids as seen in figure 11. The stratigraphic cross section is then redrawn from this datum.

Reasons for selecting the midpoint of abundant Gypidula occurrence as a time line are as follows:

A. The Gypidula zone midpoint corresponds fairly closely with the base of the most highly reworked deposits (Compare figures 11, 14, 16 and 17).

B. Subsidence may have continued more rapidly at the basin axis resulting in a thicker Gypidula zone between Catskill and Kingston (localities 47-24). Choosing the midpoint offsets the effects of differential subsidence at least for the correlation of the upper Becraft.

C. The datum is convenient and is consistent with a simple interpretation of the related sedimentary environments.

The resulting approximate time-stratigraphic reconstruction is further confirmed by two additional lines of evidence. First, the new reconstruction places the Upper Kalkberg Member, interbedded coarse and fine sediments (defined by Epstein 1971), adjacent to the interbedded lower Becraft. Second, two widespread thin horizons of hematite-coated grains in the middle of the Becraft fall into approximate alignment (figure 7). Deposition of these iron-rich beds may have occurred contemporaneously. Deposition of similar thin iron-rich beds have been interpreted as nearly synchronous events in the Middle Silurian Clinton in New York (Ziegler, et. al., 1970).

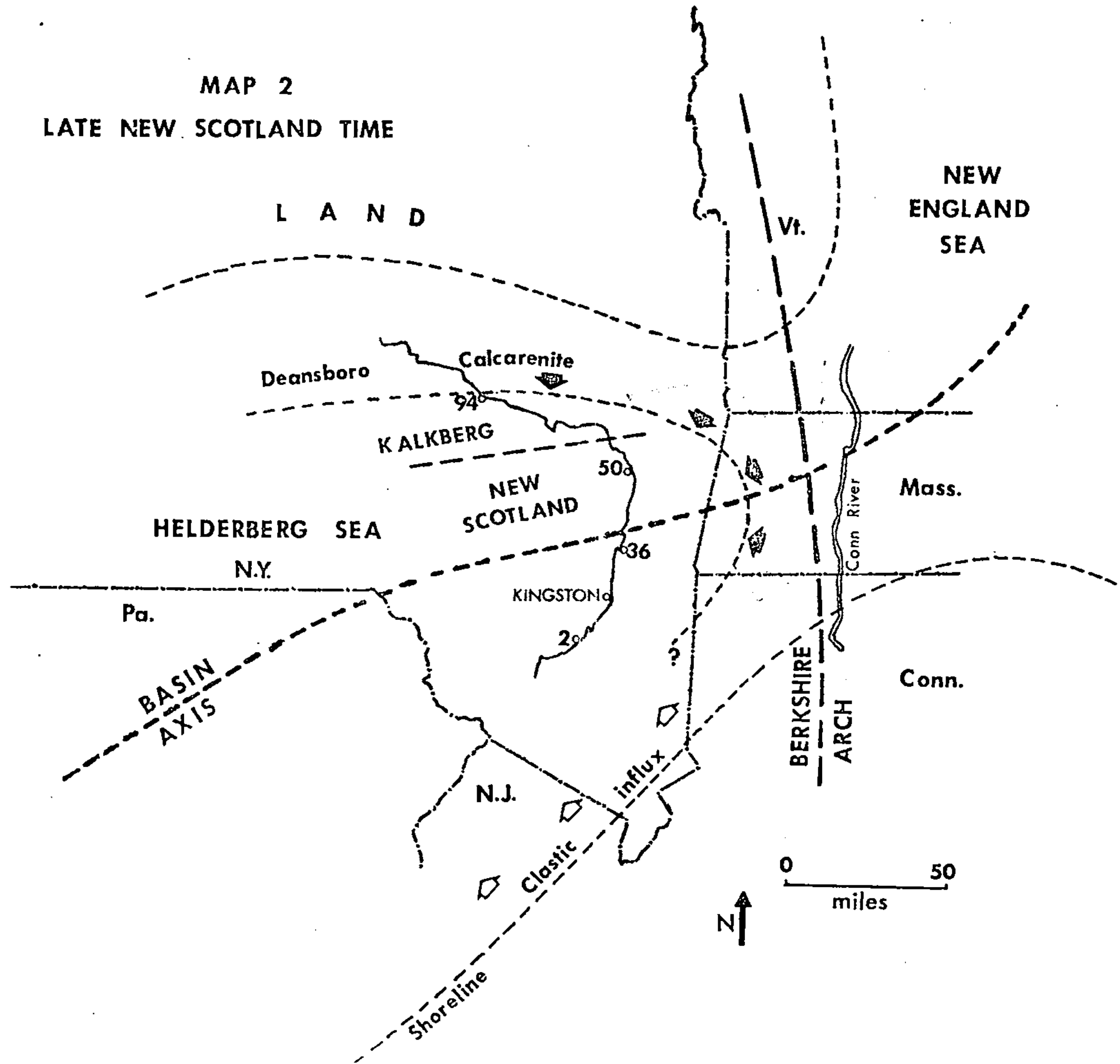
XI. PALEOENVIRONMENT AND PALEOGEOGRAPHY

The changing paleogeography during late Helderberg time can be illustrated by a sequence of paleogeographic maps which show the lateral relationships of environments at four intervals of time.

A. The first interval of time (Map 2) is late New Scotland time which represents the end of a major transgression and the beginning of initial progradation. Most of the central New York area was occupied by the New Scotland basin axis facies -- an open shelf mud environment. The Kalkberg relatively far from the basin axis towards the northwest did not receive much terrigenous sediment because the clastic influx was from the southeast. The Becraft shoal appears to be geographically restricted to the strait which connected the Helderberg and New England seas. The Berkshire arch which separates the Helderberg and New England seas was submerged during the New Scotland time by transgression and provided an ideal starting point for the development of a shoal which prograded southwestward into the Helderberg sea.

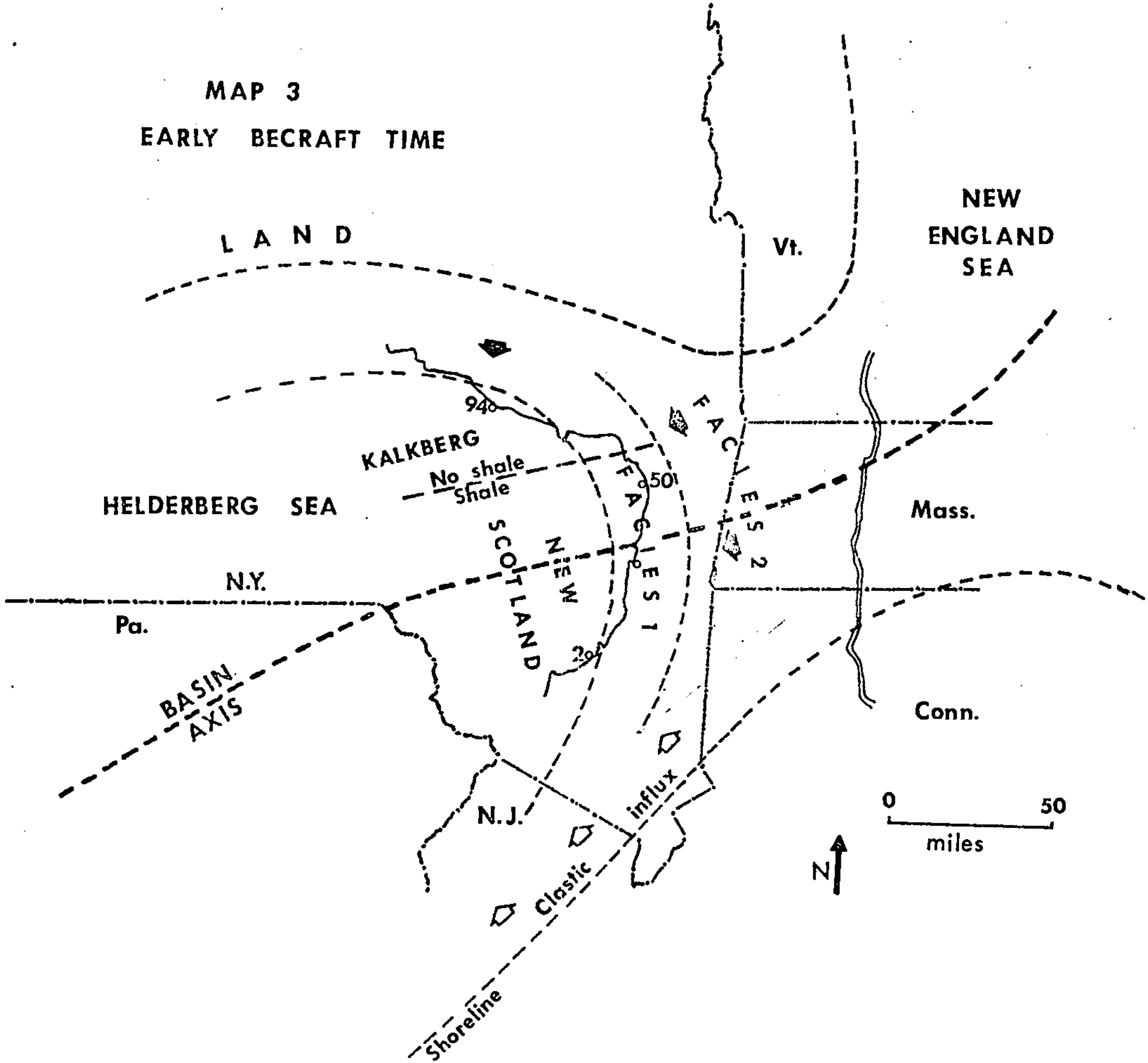
B. The second interval of time (Map 3) is early Becraft time. During this time the crinoidal shoal prograded southeast from the strait well into the New York basin axis area and spread to the basin margins. The clastic influx continued from the southeast but only extended as far northwest as locality 50. Facies 1 has prograded southwest along the basin axis into the area of outcrop. The Kalkberg occupies the western deeper basin margin area.

Map 2. Paleogeographic reconstruction of Lower Devonian-late New Scotland time. It was the beginning of initial progradation as shown by solid arrows. The light screen represents the shoal area.


MAP 2
LATE NEW SCOTLAND TIME
L A N D
NEW
ENGLAND
SEA
Vt.
Calcarenite
Deansboro
94
K ALKBERG
50
NEW
SCOTLAND
HELDERBERG SEA
Mass.
Conn River
36
N.Y.
KINGSTON
Pa.
2
?
Conn.
BASIN
AXIS
BERKSHIRE
ARCH
N.J.
influx
Clastic
Shoreline
0
50
miles
N

Map 3. Paleogeographic reconstruction of Lower Devonian-early Becraft time. The solid arrows show the direction of progradation.

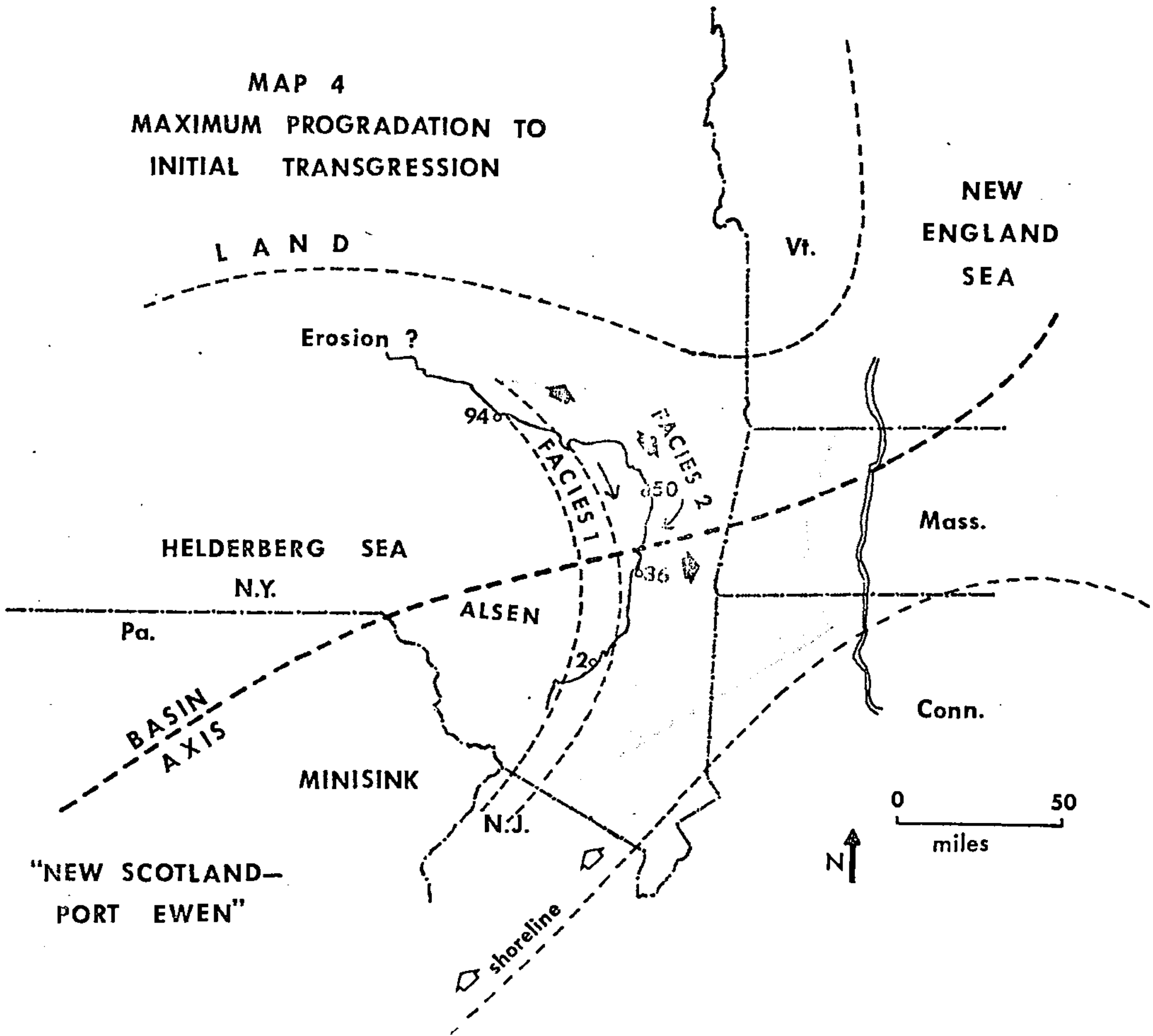
MAP 3
EARLY BECRAFT TIME



C. Interval three represents maximum progradation to initial transgression (Map 4). During this time the progradation of the shallow shoal reaches its maximum and occupies most of the New York State area from Kingston to Cherry Valley along the line of outcrop. At this point in time transgression is reestablished. The terrigenous sediments from the southeast were largely excluded from the shoal area by the clockwise currents and higher agitation of water and were deposited offshore along the basin axis or on the east side of the basin. The Alsen began to be deposited at the offshore edge of the shoal with the onset of transgression. Pre-Oriskany erosion has removed evidence of events on the northwestern basin margin. In the eastern basin margin in Pennsylvania and New Jersey the Minisink Shelf facies was formed. This was an extension of the Becraft environment into more offshore areas.

D. Interval four represents Alsen-Port Ewen time (Map 5). During this time the transgression reached its maximum and the Becraft shoal disappeared. Deep water marine deposits of Alsen and Port Ewen covered the entire New York State basin axis area and received a large portion of terrigenous sediments from the southeast. Facies 3 formed when the shoal was mechanically reworked as a result of the above transgression. Oriskany sands begin prograding into the basin from the southeast basin margin in Pennsylvania.

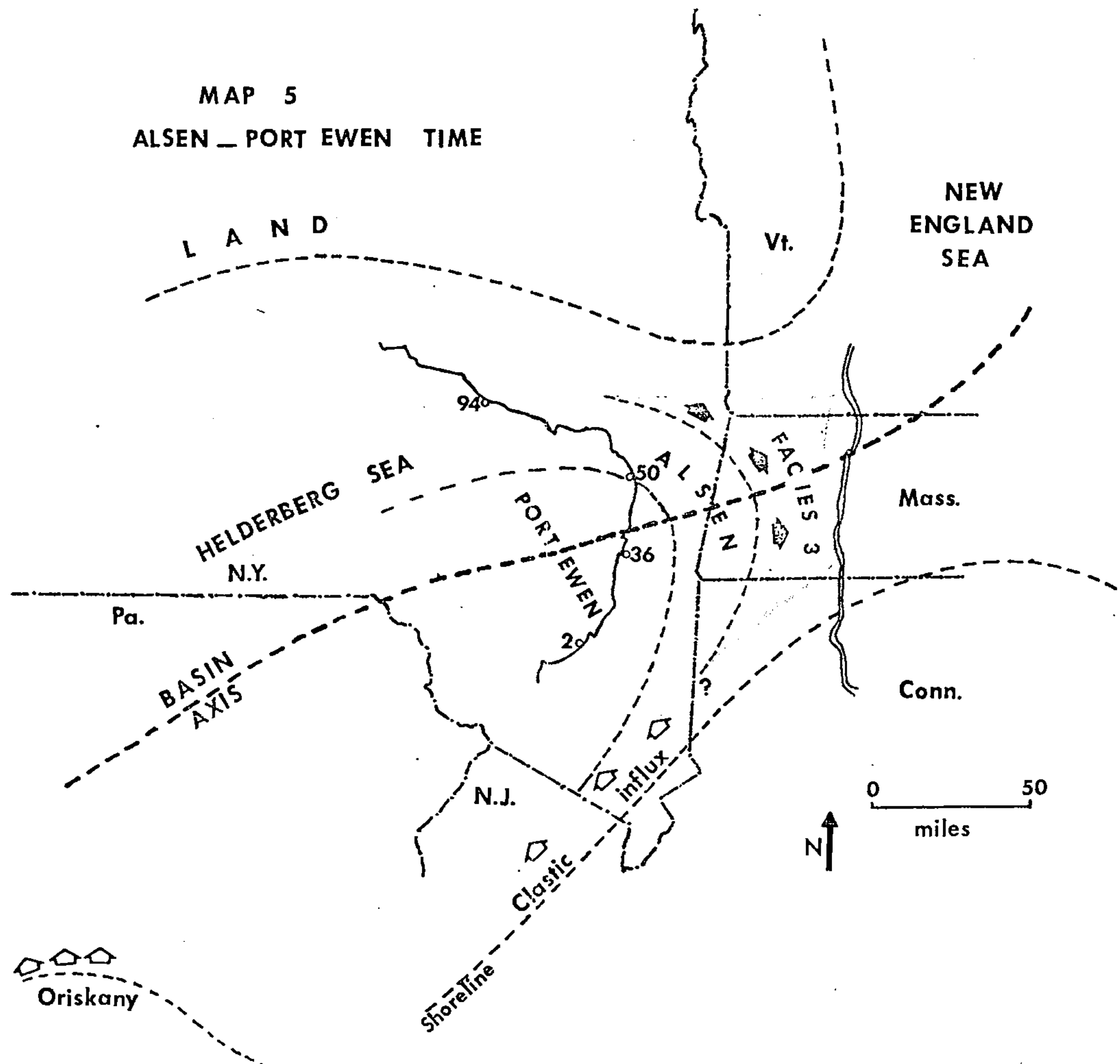
Map 4. Paleogeographic reconstruction of maximum progradation to initial transgression time. The solid arrows show the direction of transgression. The thin arrows represent direction of the currents.


MAP 4
MAXIMUM PROGRADATION TO
INITIAL TRANSGRESSION
LAND
NEW
ENGLAND
SEA
Vt.
Erosion ?
94
FACIES 1
FACIES 2
50
36
Mass.
HELDERBERG SEA
N.Y.
ALSEN
Pa.
2
BASIN
AXIS
MINISINK
N.J.
Conn.
0
50
miles
N
"NEW SCOTLAND–
PORT EWEN"
shoreline

Map 5. Paleogeographic reconstruction of Lower Devonian Alsen-Port Ewen time. This represents the maximum transgression.

MAP 5

ALSEN — PORT EWEN TIME



XII. CONCLUSION

Three major conclusions are drawn in this study of the Becraft Formation:

A. The Becraft is interpreted as representing deposition by a prograding shoal into the northeast corner of the Helderberg sea. The shoal was developed at the strait which connected the Helderberg sea to the New England sea.

B. The Becraft represents deposition by a chronologic sequence of three sedimentary environments. Facies 1 and 2 represent a prograding sequence of two contemporaneous environments, 1) a transitional environment with alternating below wave base and shoal margin sedimentation (Facies 1), and 2) deposition of the shoal itself (Facies 2). Facies 3 is a thin deposit formed by the reworking of the top of the shoal during renewed transgression.

C. A new time stratigraphy for the Becraft is given using the turning point in the Becraft regressive to transgressive cycle as a time-datum.

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