

AGE AND CORRELATION OF THE SOOKE FORMATION  
WITH A SECTION ON ITS PALYNOLOGY

by

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## ABSTRACT

The purpose of this study is to critically review earlier studies of the Sooke Formation, to present a previously unreported microflora and to assign an age to the formation on the basis of paleontological evidence.

The methods used to arrive at the general conclusions consisted of field work and laboratory analyses, supplemented by reference to the literature and to authorities in the fields of palynology, Tertiary invertebrate paleontology and vertebrate paleontology.

The Sooke Formation crops out along the south and southwest coast of Vancouver Island in a series of isolated areas. Each area appears to represent a sedimentary basin. The lithology consists of interbedded conglomerates, sandstones and shales in varying proportions.

Sooke strata contain a well preserved fossil fauna and flora. The fauna consists of one vertebrate and 132 marine invertebrates. The flora consists of a few cones, leaf and wood fragments and a well preserved microflora.

The Sooke Formation is correlated with the upper Blakeley Formation of Washington and shows close faunal

resemblance to the Astoria fauna of Washington and Oregon. It is correlated with the European Aquitanian stage, but may range as high as the Helvetian stage.



## ACKNOWLEDGMENTS

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Mr. I. E. Cornwall of Victoria, Vancouver Island, identified the fossil Cirripeda and discussed their significance. Dr. Wyatt Durham of the University of California at Berkeley identified many invertebrate specimens and commented on their significance. Dr. R. H. Reinhart of Miami University, Oxford, Ohio and Dr. Tadao Kamei of the Desmostylus Research Committee, Japan made many helpful suggestions on the present status of the vertebrate genus, Cornwallius.

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## TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION .....	1
Purpose .....	1
Scope .....	2
Location .....	2
Accessibility .....	3
II. REVIEW OF GEOLOGY AND PALEONTOLOGY .....	4
Previous Studies .....	4
Validity of the Term "Sooke Formation" ....	8
Regional Tertiary Stratigraphy .....	9
The Pacific coast of North America .....	9
Vancouver Island .....	10
Geology of the Sooke Formation .....	12
Stratigraphy .....	12
Discussion of the type section .....	16
Contact relations with other formations.	19
Structure .....	20
Megafossil Studies .....	21
Plant megafossils .....	21
A marine vertebrate .....	22
Marine invertebrates .....	22

CHAPTER	PAGE
III. PALYNOLOGY .....	24
Field procedures .....	24
Laboratory procedures .....	25
Pollen and Spore Study .....	27
Classification .....	30
Pollen and spore classification keys ...	33
IV. AGE AND CORRELATION .....	41
Evidence from Plant Megafossils .....	41
Evidence from the Vertebrate Fossil .....	41
Evidence from Plant Microfossils .....	43
Evidence from the Marine Invertebrate	
Fossils .....	45
V. SUMMARY AND CONCLUSIONS .....	51
SUGGESTIONS FOR FURTHER STUDIES .....	53
SELECTED BIBLIOGRAPHY .....	55

## LIST OF ILLUSTRATIONS

## PLATE

- 1.(a,b) Sea Cliffs, Muir Creek basin: following page 15
- 2.(a,b) Sea Cliffs, Muir Creek basin: following plate 1
- 3.(a,b) Sea Cliffs, Muir Creek basin: following plate 2
4. Microfossils: following page 28
5. Microfossils: following plate 4
6. Microfossils: following plate 5
7. Microfossils: following plate 6
8. Microfossils: following plate 7

## FIGURE

1. Distribution of Tertiary sediments on  
the south and southwest coastal areas  
of Vancouver Island: ~~in pocket~~
2. Sample locality map: ~~in pocket~~
3. Maximum ranges of selected Pacific  
coast Tertiary formations and faunas: ~~in pocket~~
4. Muir Creek Basin: ~~in pocket~~
5. Sooke fauna locality check list: ~~in pocket~~
6. Fauna correlation check list: ~~in pocket~~
7. Table illustrating quality of recovery  
of microfossils from Sooke samples: page 28

## FIGURE

8. Histogram of microfossils (RC 23): following page 28
9. Histogram of microfossils (RC 9): following figure 8
10. Histogram of microfossils (RC 11-3): following figure 9
11. Composite histogram: following figure 10
12. Microfossils common to Burrard and  
Sooke Formations: page 44

Finally, I wish to thank my wife Elaine who gave me the encouragement to finish the study and who contributed substantially by typing all of the material presented here.

## CHAPTER I

## INTRODUCTION

The Sooke Formation is a highly fossiliferous sedimentary rock unit of early Miocene age that crops out in isolated localities along the south and southwest coast of Vancouver Island. The lithology consists of conglomerates, sandstones and shales in varying proportions. Sooke beds were first described by J. Richardson in 1879. Since then, workers have reported a small megafloora, one vertebrate fossil and a large marine invertebrate fauna from the strata.

Purpose

The main objective of this study is a paleontological investigation of the Sooke Formation. A large, previously unknown microflora, recovered from Sooke sediments in this present study, is illustrated and classified. Its affinities with two other British Columbia Tertiary floras are discussed. It is hoped that this information will serve as an additional contribution to the Pacific Coast Tertiary palynological record. The purpose is also to show the stratigraphic and age relationships of this microflora to the Sooke

megafossils. To this end, previously described paleontological data are compiled and both correlations and age determinations based on the fauna are critically reviewed.

### Scope

Paleontological evidence and stratigraphic information were gathered during a one month field season. These field observations are supplemented by using previous workers' lithologic data to provide a regional stratigraphic framework for the paleontological discussion.

The investigation is restricted to the southeastern half of the Sooke Formation (Figs. 1, 2) which was the assigned thesis area. This area is considered to be representative of the formation as it contains both the type section and the most complete sedimentary sequences.

### Location

The Sooke Formation is located along the south and southwest coast of Vancouver Island (Fig. 1). Its known extent is from Becher Bay at the southern tip of Vancouver Island, northwest to and including Owen Point. The thesis area is indicated on Figure 1 and enlarged on Figure 2 includes only the southeastern



portion of the Sooke Formation with the exception of its strata at Becher Bay.

In the thesis area, the Sooke Formation crops out in a series of five isolated localities. These localities appear to represent distinct depositional basins and are, for ease of reference, each designated by geographic names. From south east to north west along the coast these are: Sooke basin, Muir Creek basin, Glacier Point basin, Begg Creek basin and Vye Creek basin.

Within each basin, each outcrop is designated by a special number. For example, the outcrop about one quarter of a mile west of the mouth of Muir Creek, in the Muir Creek basin (Figure 2) is designated RC 23, where RC are the initials of the writer and 23 is the number of the outcrop.

#### Accessibility

The area discussed in this study is accessible all year by car, along highway 14 from Victoria, Vancouver Island. The area from Jordan River to Port Renfrew is accessible by car along a well-travelled logging road only at night and on weekends. All other coastal areas north of Port Renfrew are accessible only by boat.

## CHAPTER II

## REVIEW OF GEOLOGY AND PALEONTOLOGY

Previous Studies

The Sooke Formation has aroused the interest of geologists and especially paleontologists for nearly a century. During this time, at least twenty writers have contributed to the knowledge of the formation. Because the contributions are so numerous, they are listed below in numerical order, beginning with the earliest study.

1. J. Richardson (1878) described two stratigraphic sections near the town of Sooke. The first section, a quarter of a mile up the Sooke River consisted of about 224' of sandstone interbedded with clay. The second section, at Whiffen Spit, was divided into two parts: 139' of sandstones and shales encountered by a borehole beneath the cliffs, and 335' of conglomerate, sandstone and shale interbeds in the cliffs.
2. Dall and Harris (1892) stated that the Sooke beds were Neocene in age. (Clark and Arnold, 1923)
3. J. C. Merriam (1896) published the first faunal

list of Sooke marine invertebrate fossils. His conclusion was that the Sooke beds were of middle Neocene age. In 1897, he published another short faunal list from the Sooke beds. In 1899, he "...republished the descriptions and figured the Sooke species, adding a checklist of the fauna." (Clark and Arnold, 1923, pp. 127, 128.)

4. Dall (1898) "...correlated the Sooke with the Miocene saying it is 'probably later than the Empire or the Astoria Miocene.' " (Clark and Arnold, 1923, p. 128)
5. Arnold (1906 and 1909) agreed with Merriam and "...referred the Sooke to the upper Miocene, the equivalent of the San Pablo of middle California." (Clark and Arnold, 1923, p. 128)
6. Clapp and Allan (1911) referred the Sooke and Carmanah Formations to the Oligocene - Miocene.
7. Clapp (1912) described a 184' stratigraphic section in the vicinity of Coal (Kirby) Creek, and a 101' section near the mouth of Jordan River.
8. Arnold and Hannibal (1913), in a generalized study of marine Tertiary formations of the Pacific Coast, listed a Sooke fauna and concluded that the Sooke Formation was middle Oligocene in age, and, together with the Twin Rivers Formation, had subtropical

faunas (p. 575). They reported that Clapp had established the type section for the Sooke Formation in the sea cliffs between Muir and Kirby Creeks.

9. Clapp and Cooke (1917) described a 528' section along Kirby Creek. They stated that the strata in the Muir Creek Basin were at least 2000' thick. C. E. Weaver identified a faunal collection made by them (pp 336 - 339). He concluded that " 'The Sooke Formation from such evidence as is available is probably the equivalent of the upper portion of the lower Miocene of Washington.' " (p. 339)
10. Clark and Arnold (1918) referred the Sooke beds to the lower Oligocene. In a later study (1923) however, they retracted this age determination and correlated "...the fauna of the Sooke Formation with Weaver's Blakeley, or Acila gettysburgensis horizon." (p. 129) They showed that "The Blakeley zone referred to by Weaver is the Acila gettysburgensis horizon, and is generally, though with some doubt, referred to the upper Oligocene; it may be partially or entirely lower Miocene in age." (Clark and Arnold, 1923, p. 129.) This (1923) report was a monographic study of the fauna of the Sooke Formation. It included a check list of species, numerous photographic plates of the fauna, and the

description of a new coral from the Sooke Formation by T. Wayland Vaughan.

11. I. E. Cornwall (1922) described a few vertebrate fossil remains from the Muir Creek Basin and named them Desmostylus sookensis.
12. O. P. Hay (1923) studied these fossil vertebrate remains, and re-named them Cornwallius sookensis (Cornwall).
13. Hertlein and Crickmay (1925) referred to the Sooke Formation as Miocene in age.
14. I. E. Cornwall (1927) described two fossil barnacles from the Sooke Formation.
15. R. M. Logie (1929) in an unpublished MA thesis at the University of British Columbia reviewed earlier studies and discussed the mode of deposition, the paleontology, and the age of the formation.
16. La Motte (1936) described plant megafossils from the Muir Creek Basin. He called the formation upper Oligocene in age and referred these conclusions to Clark and Arnold, 1923.
17. Durham (1944) described a "Sooke" fauna from the northern Olympic Peninsula of Washington. He presently believes (personal communication, April 26, 1961) this material to be within his Echinophora apta zone which "...in turn falls within the top of

the biozone of Acila gettysburgensis as defined by Schenck".

18. Weaver et al (1944) compiled a correlation chart of the United States Pacific Coast Tertiary formations. In it they included the Sooke Formation which they showed to be lower Miocene in age and equivalent to the upper Blakeley Formation and to the Echinophora apta zone of Durham.
19. Jeletzky (1953) discovered a series of faunas in the sediments of the Hesquiat - Nootka area of the west coast of Vancouver Island. He equated one of these faunas to the Sooke fauna.
20. Danner (1960), in a correlation chart showed the Sooke Formation to be upper most Blakeley and lower two thirds Vaqueros in age.

#### Validity of the Term "Sooke Formation"

Sooke beds were first described by J. Richardson in 1879. In 1896 - 1899, J. C. Merriam described a marine invertebrate fauna from the Sooke beds. In discussions of the unit, subsequent workers (Arnold and Hannibal, 1913; Clapp and Cooke, 1917; Clark and Arnold, 1923 and Weaver et al, 1944.) all referred the term "Sooke Formation" to Merriam. Merriam, however, apparently had no intention of naming the formation as

the term "Sooke Formation" is not found in any of his writings. He consistently referred to the unit as the "Sooke beds".

The term "Sooke Formation" has become "formalized" through almost sixty years of undisputed usage during which time no other term has been suggested to supplant it. The present Code of Stratigraphic Nomenclature (1961, p. 650) defines a formation: "A formation is a body of rock characterized by lithologic homogeneity; it is prevailingly but not necessarily tabular, and is mappable at the earth's surface...". Since the "Sooke Formation", as it is generally understood, fulfills these qualifications and has been used in many recognized publications, it is a valid term.

It is beyond the scope of this paper to formally define the Sooke Formation. The term should be retained in its generally understood sense, and, in some future study, should be defined and a type section should be accurately described. The status of the type section will be treated in the discussion of the geology of the Sooke Formation.

#### Regional Tertiary Stratigraphy

##### The Pacific coast of North America

Tertiary sedimentary bodies are found scattered

along the Pacific coastal areas of North America, from Baja California north to Unalaska. These bodies are typically elongate, narrow and very thick basin-shaped geometrical forms. During their formation, many of the basins were isolated from each other both in space and in time. In origin, the sediments range from marine to continental. Nearly all basins are fossiliferous, the marine sediments yielding faunas and the continental sediments yielding floras.

Figure 3 illustrates the more important Tertiary formations in this region. Maximum ranges of the formations, and their relationships to both European and North American stage names are indicated. The bulk of the information is compiled from Weaver et al (1944), but other sources have also been used. The purpose of this table is to show the most recent conclusions as to the ages of these formations and their relationships with the Sooke Formation.

#### Vancouver Island

Tertiary sedimentary sequences have been reported from the south and south west coastal areas of Vancouver Island (Fig. 1). These sediments are exposed in isolated areas that are separated from one another by either knolls of older rocks or by infillings of younger glacial and superficial deposits. Many of these isolated areas



probably represent distinct depositional basins.

The formations represented in the known basins carry three faunal assemblages (Jeletzky, 1954). The oldest fauna is represented in the Carmanah Formation, the Escalante Formation and Jeletzky's Divisions "A" and "B". It is correlated with the Lincoln fauna of early Oligocene age. The next youngest assemblage is represented by the fauna in sediments above the "Conglomerate at Carmanah Point", (Clark and Arnold, 1923) and Jeletzky's Division "C" and is correlated with the lower Blakeley or Durham's Echinophora rex zone (Durham, 1944) of late Oligocene age. The youngest fauna is represented in the Sooke Formation and in Jeletzky's Division "D", and is correlated with Durham's Echinophora apta zone.

Individual beds within the basins are typically lenticular in shape. Environments of deposition ranged from marine to non marine. The older sediments consist mainly of finer marine clastics, while the younger rock units represent more rapidly fluctuating conditions of deposition and consist of coarser grained, more poorly sorted sediments in cross bedded, lenticular strata.

## Geology of the Sooke Formation

### Stratigraphy

The Sooke Formation consists of a series of basins of sedimentary strata extending from Becher Bay on the south coast of Vancouver Island northwest along the coast to Owen Point.

The thickest known sequence of Sooke beds is in the Muir Creek basin (Figs. 2, 4). The sea-cliffs about a quarter of a mile west of the mouth of Muir Creek expose a 150' section of sediments. Clapp and Cooke (1917) reported that a hole that was drilled at the base of these cliffs penetrated 1560' of sediments without passing through the formation. Thus, the Sooke Formation is more than 1700' thick. The sediments in other basins (Fig. 2) appear to be much thinner than those of the Muir Creek basin, although conclusive evidence to this effect is not available. A 30' thickness of sediments is exposed in the Vye Creek basin. A similar thickness is exposed in the Begg Creek basin. The sediments of Glacier Point basin vary in thickness from three inches to possibly 15 feet. It is termed a basin here, because it was so reported by Clapp and Allan (1911) on their map. The sediments they reported at Glacier Point are at present probably obscured by surficial deposits and a dense forest growth. This

covered interval extends for about two hundred yards along the coast. It is flanked on the west by a very coarse basal conglomerate with a sandstone matrix, and on the east by a few very thin beds of sandstone containing numerous small fragments of volcanic debris. The Sooke basin was reported by Clapp and Allan (1911) as extending from Whiffen Spit, east along the shoreline past the Sooke River for one mile, and up the Sooke River for about four miles. The only exposures the writer could locate in this area and ascribe definitely to the Sooke Formation were in the vicinity of Whiffen Spit. The remainder of the low cliffs along the lower Sooke River and near the town of Sooke consisted of poorly consolidated shell-laden clays and massive clays. The shells were probably of the Indian kitchen - midden type as they consist almost entirely of the shells of edible forms of clams, and are concentrated in vast quantities just below the top soil, along the coast line in this area. The massive clays and poorly consolidated shales and green sands reported by Richardson (1876) near the mouth of the Sooke River must await further studies before being definitely included as part of the Sooke Formation.

Emphasis, in this study, has been on the Muir Creek basin, not only because of its vertical thickness, but

also because it is the only basin with an appreciable inland extent. Furthermore, the sediments of the Muir Creek basin typify sediments in the other basins that were investigated.

In general, the Sooke Formation consists of lenticular interbeds of sandstones and sandy conglomerates and minor shales.

According to Clapp and Cooke (1917, p. 331)

"The sand is angular to subrounded and is composed largely of quartz, plagioclase, feldspar and magnetite grains and small rock fragments, almost entirely fragments of the Metchosin metabasalts. ...Accessory minerals, chiefly biotite, muscovite, hornblende, epidote, chlorite, serpentine and limonite are numerous and occur in relatively large amounts. The sandstones are rather firmly cemented chiefly by abundant calcite, but in places by limonite, and although soft when fresh, hardens with seasoning."

Sandy conglomerate beds and lenses occur throughout the formation. In general, the conglomeratic fragments vary in size from pebbles to cobbles, however, at the base of the formation they may reach diameters of 20 to 30 feet. The conglomeratic fragments are generally subrounded, and composed of basalt, quartz and granitic material. The basal conglomerate consists of angular basalt fragments derived from the underlying Metchosin volcanic rocks. The sandstone matrix is of the same composition as the interbedded sandstone lenses and the sands described above by Clapp. Commonly, the

sandstones and conglomerates intergrade laterally.

In the sea cliffs of the Muir Creek basin a few thin, sandy, fossiliferous or carbonaceous lenses of shale are exposed interbedded with the sandstones and conglomerates. Leaching of the calcium carbonate from the fossil shells in the formation and subsequent re-deposition of this material in the shales has resulted locally in lenses of marl.

Locally, the sediments are fossiliferous. Well preserved mollusca and other invertebrates, composed of their original material, are abundant in shales, marls, sandstones and sandy conglomerates. As the percentage of coarser clastic material increases, the fossils become more fragmental. Fragments of petrified wood, leaf imprints, and carbonized cones have been collected from the Sooke and Muir Creek basins.

Beds of the Sooke Formation are typically lenticular shape. Depositional dips of these beds, all towards the centres of the respective basins, vary rapidly from nearly  $30^{\circ}$  near the flanks of the basins to less than  $5^{\circ}$  at the centres of the basins. Cross bedding is well developed throughout the formation, particularly in the coarser sediments. Attitudes of the foreset beds (Fig. 4) indicate that the sediments were derived from an area of positive relief, north of their present site of deposition.

PLATE 1.

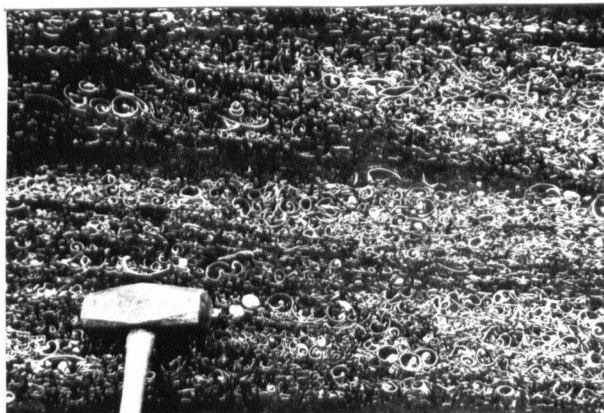


a: Sea cliffs, Muir Creek basin (RC 23). A bedding plane exposed at low tide. Note the white fossil shell fragments and the concretionary structures.



b: Sea cliffs, Muir Creek basin (RC 23); looking east along the coast, at the lower section of the cliffs. Photo by I. E. Cornwall, 1918.

PLATE 2.

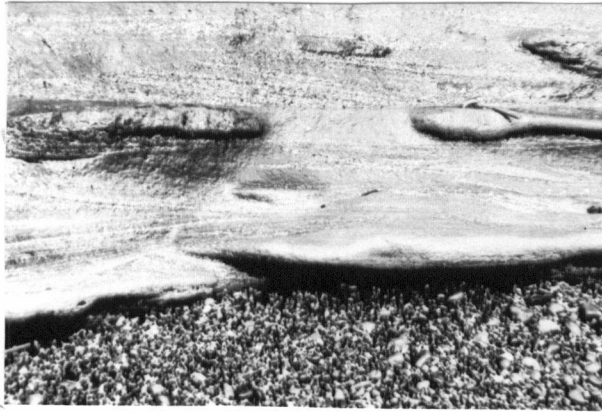


a: Sea cliffs, Muir Creek basin (RC 23). Photograph by I. E. Cornwall, 1918. Note the density of the well preserved fossils. Many fossils are concentrated in the conglomeratic foreset beds.

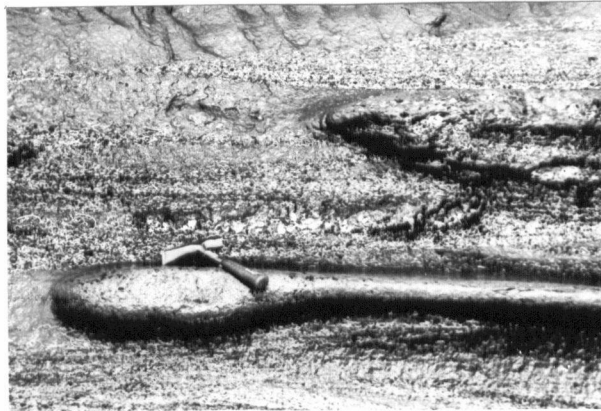


b: Sea cliffs, Muir Creek basin (RC 23). A slumped fragment from the cliffs, looking at bedding planes. Note the density of fossils on the bedding planes.

PLATE 3.



a:



b:

Sea cliffs, Muir Creek basin (RC 23). 3-a shows fossiliferous foreset beds in the face of the cliff. 3-b is a close-up photograph of the right half of 3-a. Both photographs are taken looking north.



Some of these sedimentary features are illustrated by the photographs of the sea cliffs of Muir Creek basin. (Plates 1, 2, and 3.)

#### Discussion of type section

In 1912, Clapp described a 164' section exposed in the cliffs along Kirby Creek. Later, Arnold and Hannibal (1913) stated that Clapp's 164' section was the type section of the Sooke Formation. In 1917, Clapp and Cooke re-described this section and extended its thickness to 497 '. They considered it the most representative section of Sooke sediments. Clark and Arnold (1923, p.129) reported that "The type section of the Sooke Formation is exposed along the beach between Muir and Kirby creeks a few miles west of Sooke Harbor...". It is possible that their concept of the type section differed from that of Clapp and Cooke in that they placed the type section along the beach between Muir and Kirby Creeks while Clapp and Cooke placed it along the lower part of Kirby Creek and included in it the beds along the shore for only a short distance east of Kirby Creek. It is possible that, due to some misunderstanding, they were both referring to the same section. Clark and Arnold did not describe a section in their "type locality", nor has such a section ever been described in any published work.

Following is a description of the type section of the Sooke Formation taken from Clapp and Cooke (1917, p. 332). It was described by them in descending order, however the section is described in ascending order for ease of reference in this study.

INTERVAL	LITHOLOGY
0'- 20'	Unconsolidated, stratified sand and gravel.
20'- 30'	Sandstone - soft, ferruginous, banded yellow and red, and concretionary.
30'- 35'	Conglomerate, fossiliferous.
35'- 100'	Sandstone: coarse to medium grained, buff-colored, cross bedded and concretionary.
100'- 104'	Sandstone: grey, argillaceous and fossiliferous.
104'- 114'	Alternating soft sandstone and marl.
114'- 287'	Unexposed (Mouth of Kirby Creek to road crossing.)
287'- 307'	Sandstone.
307'- 307'8"	Lignite, sandy and impure.
307'8"- 350'	Unexposed.
350'- 355'	Sandstone
355'- 362'	Shale; sandy and micaceous.
362'- 364'	Conglomerate, fine grained.
364'- 381'	Sandstone.
	Protruding knob of meta-basalt.
381'- 417'	Conglomerate; with thin layers of Sandstone.
417'- 421'	Sandstone.
421'- 423'	Fine conglomerate.
423'- 487'	Unexposed.
487'- 497'	Basal conglomerate.

Figure 4 is a diagrammatic study of the sedimentary features in the Muir Creek Basin. The isolated outcrops are plotted individually at their localities. Megafaunal and microfloral localities are plotted on the section to show their relationship to one another,

and to the strata. The sections also demonstrate the rapid facies changes between isolated, adjacent outcrops. The diagrammatic cross section in Figure 4 illustrates the writer's interpretation of a typical cross section of Sooke sediments in this basin. It shows the facies changes, lenticularity of the beds, and the high initial dips. It also shows that correlation of the isolated outcrops, on a purely physical basis, is hazardous.

This type of correlation was used by Clapp and Cooke to set up the 497' type section described above and graphically illustrated on Figure 4. It is doubtful however, that the section is a stratigraphic succession. Intervals a, b, c and d of Clapp and Cooke's section are individual cliffs along Kirby Creek. Interval "a" corresponds to RC 11; and interval "b" to RC 32; interval "c" to a cliff between the mouth of Kirby Creek and RC 32; and interval "d" to a small cliff at the mouth of the creek. The covered intervals correspond to the distance between cliffs. The diagrammatic cross section of Figure 4 shows that another interpretation other than that proposed by Clapp and Cooke is possible. Because of the high initial dips and rapid facies changes, intervals a, b, c, and d of Clapp and Cooke's section may be, at least in part, facies of one another rather than separate sections deposited at different times.

Reference to this section as a properly described type section is subject to question. Correlations of this type of sediment must be based on more than purely physical criteria. Other tools for correlation, such as paleontology and heavy mineral studies should be used to supplement field data. This "type section" should be re-studied using paleontology and other methods to show correlation of beds and their relationships to each other.

Contact relations with other formations.

Clapp and Cooke (1917, p. 334) reported that "The Sooke Formation clearly rests unconformably upon the Metchosin volcanics and the Sooke gabbro." This contact was observed by the writer at locality RC 7 on Tugwell Creek, and in the Begg Creek, Glacier Point and Vye Creek basins. At these localities as at others described by Clapp and Cooke, well developed basal conglomerates were present immediately above the contact. At RC 13, on Kirby Creek, the typical Sooke sandstones overlies volcanic tuffs with minor interbedded agglomerates. The age of these volcanic beds is unknown. They may be equivalent to the Metchosin volcanics, or they may lie stratigraphically between the Metchosin volcanics and the Sooke Formation. More detailed investigations may reveal their age relationships as they are stratified

and contain a few carbonaceous partings along their bedding planes. Too few pollen and spores were found in these beds during this study to indicate their age.

The Sooke Formation is younger than the Carmanah Formation and, should a contact of the two formations ever be found, it would probably be represented by an unconformity.

The Sooke Formation is overlain unconformably by Pleistocene glacial deposits and more recent soils.

### Structure

Clapp and Cooke (1917) discussed the structural geology of the formation. The writer has found no new evidence that might add to their observations. They reported broad folds in the Muir Creek basin, between Muir and Kirby Creeks. The general attitude of the Sooke strata however has resulted mainly from depositional dips. Throughout the Sooke Formation Clapp and Cooke have observed numerous small normal faults with angles of from  $45^{\circ}$  to  $60^{\circ}$ , and strikes that are nearly at right angles to the shore. Their displacement varies from 5' to 15'. The writer has not found any indication of tectonic activity in the area since the deposition of these sediments that would cause such faults to form. His interpretation is that they are small high angle gravity faults that formed throughout the formation during or shortly

after lithification.

### Megafossil Studies

During the past century, at least eighteen workers have contributed to megafossil studies of the Sooke Formation. They studied and reported several fossil plants, the vertebrate fauna and a large marine invertebrate fauna from the Sooke strata.

#### Plant megafossils

Plant megafossils have been collected at two localities in the Sooke Formation. La Motte (1936) reported that a cone, Picea sookensis was discovered at Whiffen Spit in the Sooke basin. In the same paper, La Motte reported ten fossil leaves and one root fragment from the sea cliffs, one quarter of a mile west of the mouth of Muir Creek in the Muir Creek basin. The list he presented is as follows:

Carpinus grandis  
Cinnamomum cf. pedunculatum  
Fagus pacifica  
Hicoria pecanoides  
Laurophyllum sp.  
Magnolia cf. lanceolata  
Quercus consimilis  
Salix californica  
Trochodendroides sp.  
Ulmus racemosa  
 and a root fragment as cf. Acer

During the present study, one cone that has not been identified, was collected from the Whiffen Spit

locality. A number of unidentifiable leaf fragments were found at the Muir Creek basin locality (RC 23). Large and small carbonized wood fragments were collected from both the Sooke basin and the Muir Creek basin.

A marine vertebrate.

Fossil vertebrate remains consisting of teeth, part of a jaw, and a few vertebrae were collected from the sea cliffs about a quarter of a mile west of the mouth of Muir Creek by I. E. Cornwall and Reverend Connell. These remains were identified by Lambe in 1916 as the sea cow or sirenean, Desmostylus hesperus. In 1922, Cornwall described the specimen, and re-named it Desmostylus sookensis. In later studies by O. P. Hay (1925) the fossils were re-named Cornwallius sookensis. (Cornwall)

Marine invertebrates.

The Sooke Formation is well known for its prolific marine invertebrate fauna. These fossils have been collected from all basins with the exception of Becher and Sooke basins. The fauna consists of gastropods, pelecypods, a scaphopod, a cephalopod, brachiopods, an amphineurid, vermes, echinoderms, barnacles and a coral.

Since the earliest Sooke faunal studies by Merriam in 1896, 1897 and 1899, faunal lists have been published by Arnold and Hannibal (1913), Clapp and Cooke (1917),

and Clark and Arnold (1923). Figure 5 is a checklist of the Sooke fauna, showing where the forms were discovered and listing references to their discoveries. For example, Anomia sp. near macroschisma Dehayes (3) was reported by Clapp and Cooke (9) from the sea cliffs between Muir and Kirby Creeks. The numbers (3) and (9) refer to the numbered references in the selected bibliography. This table is patterned after the one by Clark and Arnold (1923) but it lists actual geographic locations, and brings their table up to date.

In the present study, marine invertebrates were collected from the Muir Creek, Begg Creek and Vye Creek basins. New fossils, found by the writer in these localities, that had not been noted by previous workers are designated "RC" on the checklists Figures 5 and 6. These checklists indicate that the Sooke Formation has yielded 65 pelecypods, 54 gastropods, 1 scaphopod, 1 cephalopod, 1 amphineurid, 4 barnacles, 1 coral, 1 vermes, 2 brachiopods and 3 echinoderms.



## CHAPTER III

## PALYNOLOGY

During an investigation of the carbonaceous strata of the Sooke Formation, it was discovered that the finer sediments contained moderate numbers of plant microfossils. Following this discovery, the fine grained sediments were sampled and disintegrated. The residues containing the microflora were mounted on slides, and examined with a microscope. In this section of the thesis, these pollen and spores are illustrated, classified and affinities with other microfloras are discussed. The purpose of this section is to report a new microflora from Miocene strata of the Pacific Coast which may be valuable in the future for regional correlations, dating and paleoecological interpretations.

Field procedures

In order to obtain a good representation of microfossils from any sequence of sediments, three steps are desirable in the sampling technique. First, an attempt should be made to sample the section in some stratigraphic order. Second, samples should represent as small a stratigraphic interval as possible. Third, samples should consist of unweathered material, or of rock from well

beneath the outcrop.

The type section described by Clapp and Cooke (1917) along Kirby Creek was chosen for sampling to provide a microfossil reference section for further correlations. The upper portion of Kirby Creek, and all of the sedimentary sequences along Tugwell Creek and along the coast line between Muir and Kirby Creeks were sampled in detail. Muir Creek was inaccessible to traversing because it was in flood. Traverses up each creek began at the mouth and proceeded upstream. At Kirby Creek, the traverse began near the knoll of volcanics described by Clapp and Cooke (1917), proceeded up the section along the creek, then down the section to its base further upstream. At Tugwell Creek, traverses began somewhere up in the section, and proceeded down to its base about three miles upstream.

Each outcrop was sampled in detail. Sample intervals did not exceed 10' in zones where lithologies were constant for 10' or more. In thinner zones, each lithologic unit was sampled separately. These samples were taken by first removing the weathered surfaces of the outcrops, and then channeling the interval to obtain a representative sample. All samples weighed approximately 150 grams.

#### Laboratory procedures.

In the laboratory, all samples whose components

ranged in size from shale to sandstone inclusively were prepared for maceration. The following are the steps used in the maceration technique:

1. A small but representative cut is taken from each piece of the sample;
2. The cuts are broken into pea-sized fragments, until the bottom of a polythene beaker can be covered with the broken rock;
3. HCl is added to determine the presence or absence of a carbonate. If the test is positive, the carbonate is dissolved by adding HCl to the sample;
4. The carbonate-free sample is washed several times;
5. The sample is placed in HF for 24 hours to dissolve the silica;
6. The sample is washed again several times;
7. The sample is placed in about 2" of HNO<sub>3</sub> to oxidize the carbonaceous remains. This takes from  $\frac{1}{2}$  to 6 hours, and must be checked constantly to insure that the oxidation process stops after the carbonaceous material has been removed, and before the microfossils become oxidized;
8. The residue is washed several times;
9. The residue is placed in a 1% KOH solution for 30 minutes to dissolve the oxidized carbonaceous matter. The KOH also prepares the organic material for the

absorption of safranin dye;

10. The sample is washed several times;
11. A small, representative channel slice is extracted from the sample with a spatula, and is placed on a microscope slide;
12. One drop of safranin dye and a small amount of corn syrup are added to the microfossil residue;
13. Mix the syrup, sample and dye and spread it over  $\frac{3}{4}$  of the surface of the slide. The remainder of the slide is labelled;
14. The slide is left to dry. It must be kept in a horizontal position, or the corn syrup may run off. It must also be kept away from dust, or it may become contaminated.

#### Pollen and Spore Study

Three samples were found to contain a large, well preserved number of microfossils. Three others contained moderately well-preserved microflora whereas the remainder had only a few very poorly preserved microfossils. Figure 7 is a list of all of the samples studied that contained microfossils, and a qualitative note on the recovery of spores and pollen.

<u>SAMPLE NO.</u>	<u>RECOVERY</u>
RC- 1-2-1	poor
RC- 9-1	good
RC-11-2-1	fair
RC-11-3	very good
RC-11-4	very poor
RC-14-1-1	very poor
RC-17-1-1	fair
RC-18-1	very poor
RC-23	excellent
RC-29-1	poor
RC-30-1-1	fair

Figure no. 7, illustrating quality of microfossils from Sooke samples.

In all, 30 samples consisting of sandstone or shale were macerated. Of these, only 8 samples (20%) of the sandstone and shale contained microfossils that could be used in a study of this type.

Plates 4 - 8 illustrate the most common pollen and spore forms recovered from the Sooke sediments. These forms are illustrated by line drawings on centimeter graph paper. The scale was chosen so that each millimeter division on the graph paper represents an actual measurement of 2 microns. The drawings show the microfossils enlarged 500 times. The 103 drawings illustrate 85 different microfossil forms, 83 of which are pollen and spores and 2 whose biological affinities are not known.

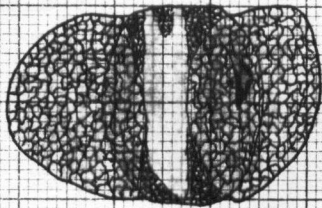
Three samples, RC 23-1, RC 9-1 and RC 11-3 were

# PLATE 4.

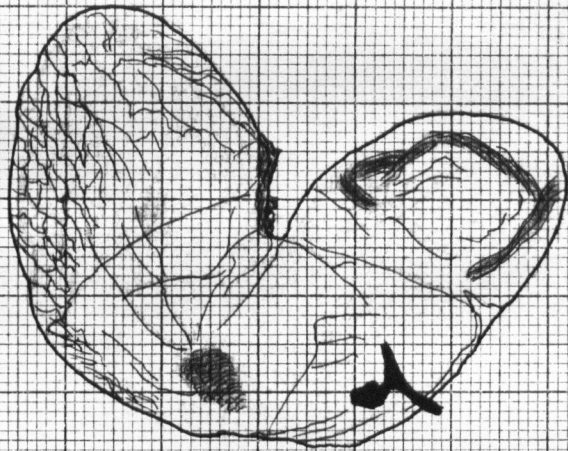
All figures x500

<u>Microfossil Formula</u>	<u>Affiliation</u>
A1-2bx(42x33x61-77)	<u>Pinus</u> sp.
M1-1(11)	fungus spore
E1-1(7)	fungus spore
A1-2by(51x99x96-127)	<u>Picea</u> sp.
E1-1(15x10)	unknown affinities
E1-1(29)	fungus spore
E9-1 (20x14)	<u>Inaperturopollenites</u> sp.
E1-1(18)	Cupressaceae? or Taxodiaceae?
A1-2ax(72x80x107-156)	<u>Abies</u> sp.
E1-1(44-54)	<u>Larix</u> sp.
B1-1(51)	fungus spore?
E1-1(67)	fungus spore or algal cyst
E1-1(18x10)	unknown affinities
E1-1(31x18)	fern spore?
I1-1(23x17 1)	cf. <u>Taxodium</u> sp.
E17-1(16x11)	<u>Tricolpopollenites</u> sp.
H7-1(37x24)	fern spore

# PLATE 4.



A1-2b x (42 x 33 x 61-77)



A1-2by (51 x 90 x 96-127)



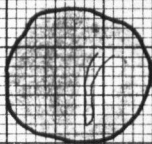
M1-1 (11)



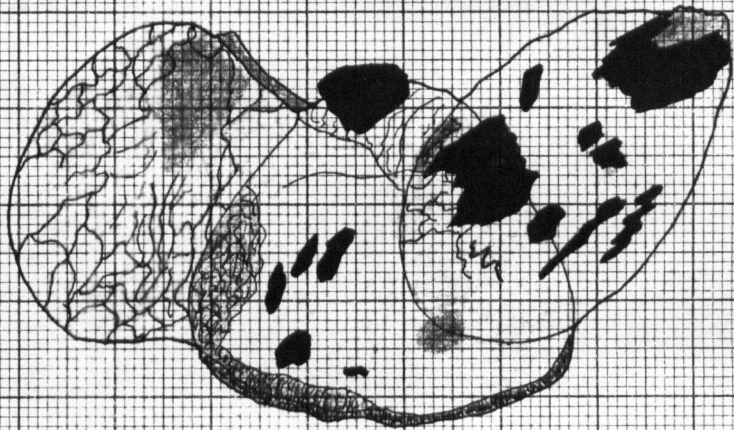
E1-1 (7)



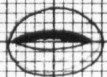
E1-1 (15 x 10)



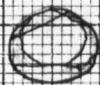
E1-1 (29)



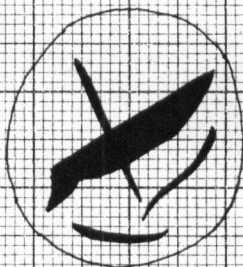
A1-2ax (74 x 80 x 107-154)



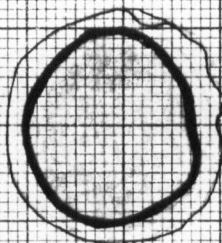
E9-1 (20 x 14)



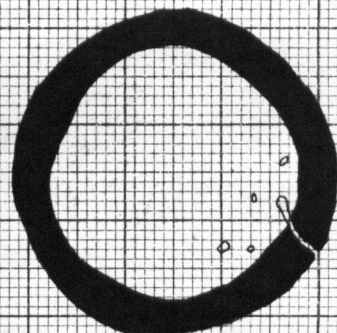
E1-1 (18)



E1-1 (44-54)



B1-1 (51)



E1-1 (67)



I1-1 (23 x 17 + 1)



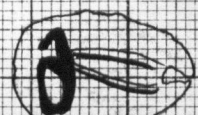
E1-1 (18 x 10)



E1-1 (31 x 19)



E17-1 (16 x 11)



H7-1 (37 x 24)

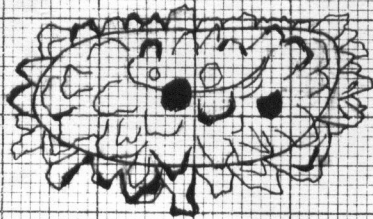
# PLATE 5.

all figures x500.

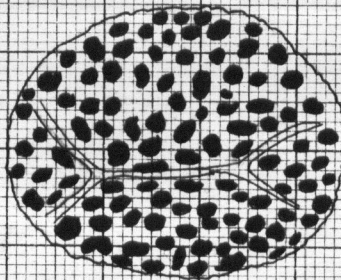
<u>Microfossil Formula</u>	<u>Affiliation</u>
H7-13(55-76x39-44)	<u>Polypodium</u> sp.
H7-20(58-74x41-57)	fern spore
N1-1(28x16)	fungus or algal spore
N1-1(45x23)	fungus spore?
J1-1(36x12)	unknown affinities
N1-1(12x7)	fungus spore?
E9-6(16)	unknown affinities
J25-1(17x8)	<u>Tricolporopollenites</u> sp.
E17-1(24x16)	<u>Angiospermae</u> ?
Incertae Sedis	Body of an insect?
E7-1(40)	unknown affinities
E1-1(22)	<u>Inaperturopollenites</u> sp?
H7-1(39x20)	fern spore?
H7-1(44x26)	cf. <u>Laevigatosporites</u> sp.
E17-6(28x33)	Tricolpate pollen similar to <u>Quercus</u> or <u>Fagus</u>



# PLATE 5.



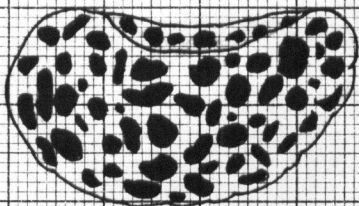
H7-13 (55-76 x 39-44)



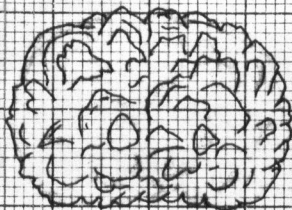
H7-20 (58-74 x 41-57)



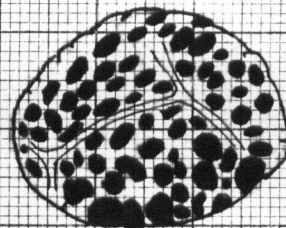
H7-13 (55-76 x 39-44)



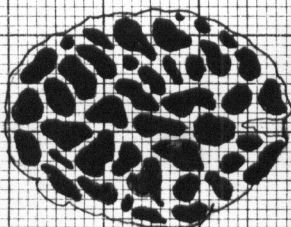
H7-20 (58-74 x 41-57)



H7-13 (55-76 x 39-44)



H7-20 (58-74 x 41-57)



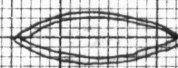
H7-20 (58-74 x 41-57)



N1-1 (28 x 16)



N1-1 (45 x 23)



I1-1 (36 x 12)



N1-1 (12 x 7)



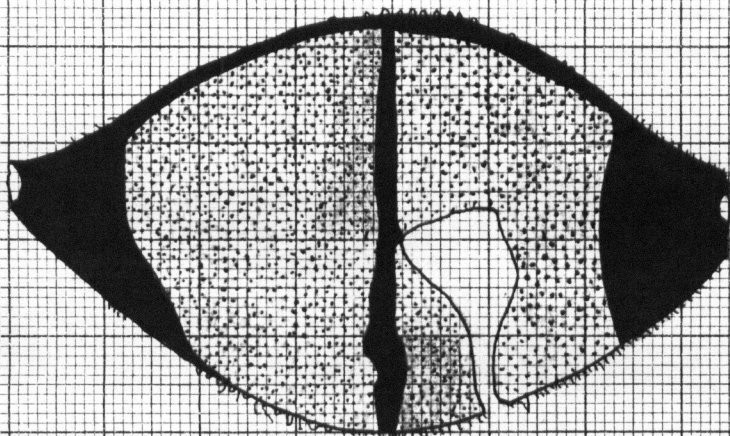
E9-6 (16)



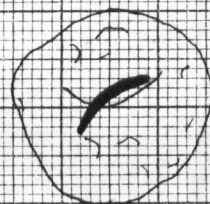
I25-1 (17 x 8)



E17-1 (24 x 16)



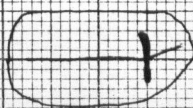
INCEKIME SEP15



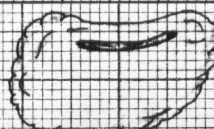
E9-1 (40)



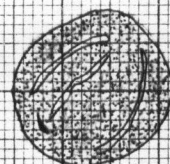
E1-1 (22)



H7-1 (39 x 20)



H7-1 (44 x 26)



E17-6 (28-33)

PLATE 6.

all figures x500

<u>Microfossil Formula</u>	<u>Affiliation</u>
E1-1(96x60)	<u>Pseudotsuga?</u>
H7-1(37-44x23-29)	cf. <u>Laevigatosporites</u> sp.
E1-24(35x36)	unknown affinities
E1-6(34x21)	Angiospermae
E1-1(34x28)	unknown affinities
H7-20(92x63)	fern spore
E9-6(23-25x12-16)	Angiospermae
E1-6(37)	unknown affinities
E17-6(45x34)	Angiospermae
H7-22(56x34)	fern spore
B1-13(59)	cf. <u>Tsuga</u>
H7-6(70x40)	aff. fern?
E5-1(17-18x8-10)	<u>Monosulcites</u> sp. (aff. with the cycads or the Palmaceae)
H7-1(28x17)	cf. <u>Laevigatosporites</u>
E25-1(26x18)	<u>Tricolporopollenites</u> sp. (Anacardiaceae?)
I1-1(22 6x20)	Taxodiaceae
E17-6(26x16)	Angiospermae
E17-6(33x20)	Angiospermae
K1-1(44x10)	fungus spore

# PLATE 6.

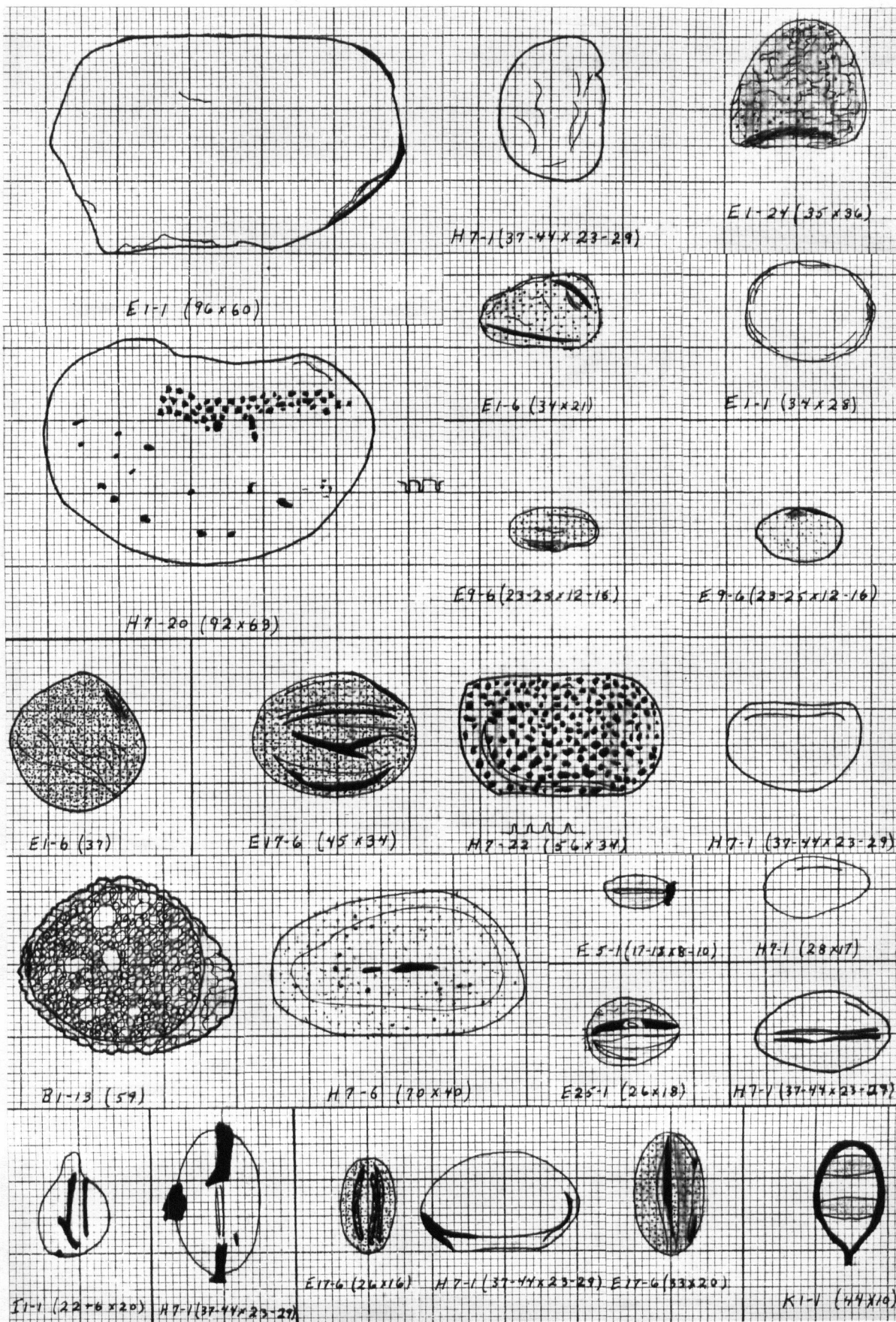


PLATE 7.

all figures x500

<u>Microfossil Formula</u>	<u>Affiliation</u>
B1-6(8)	funga1 spore?
B1-22(15)	funga1 spore?
E1-2(14x36)	unknown affinities
I1-1(31 3x29)	Taxodiaceae
E1-3(35x30)	unknown affinities
B1-24(53x57)	<u>Tsuga</u> sp.
E1-1(96)	cf. <u>Pseudotsuga</u> sp.
B1-5,13(54-59)	<u>Tsuga</u> sp.
E1-24(40)	<u>Inaperturopollenites</u> sp.
J1-1(32x11)	? <u>Monosulcites</u> sp.
Incertae Sedis	
E1-1(44-54)	? <u>Larix</u> sp.
E1-1(57x43)	unknown affinities
E5-22(145-153x61)	fern spore
B1-23,22(61)	fern spore
E1-1(38x26)	cf. Taxodiaceae
E1-6(79x24)	fern. spore



# PLATE 7

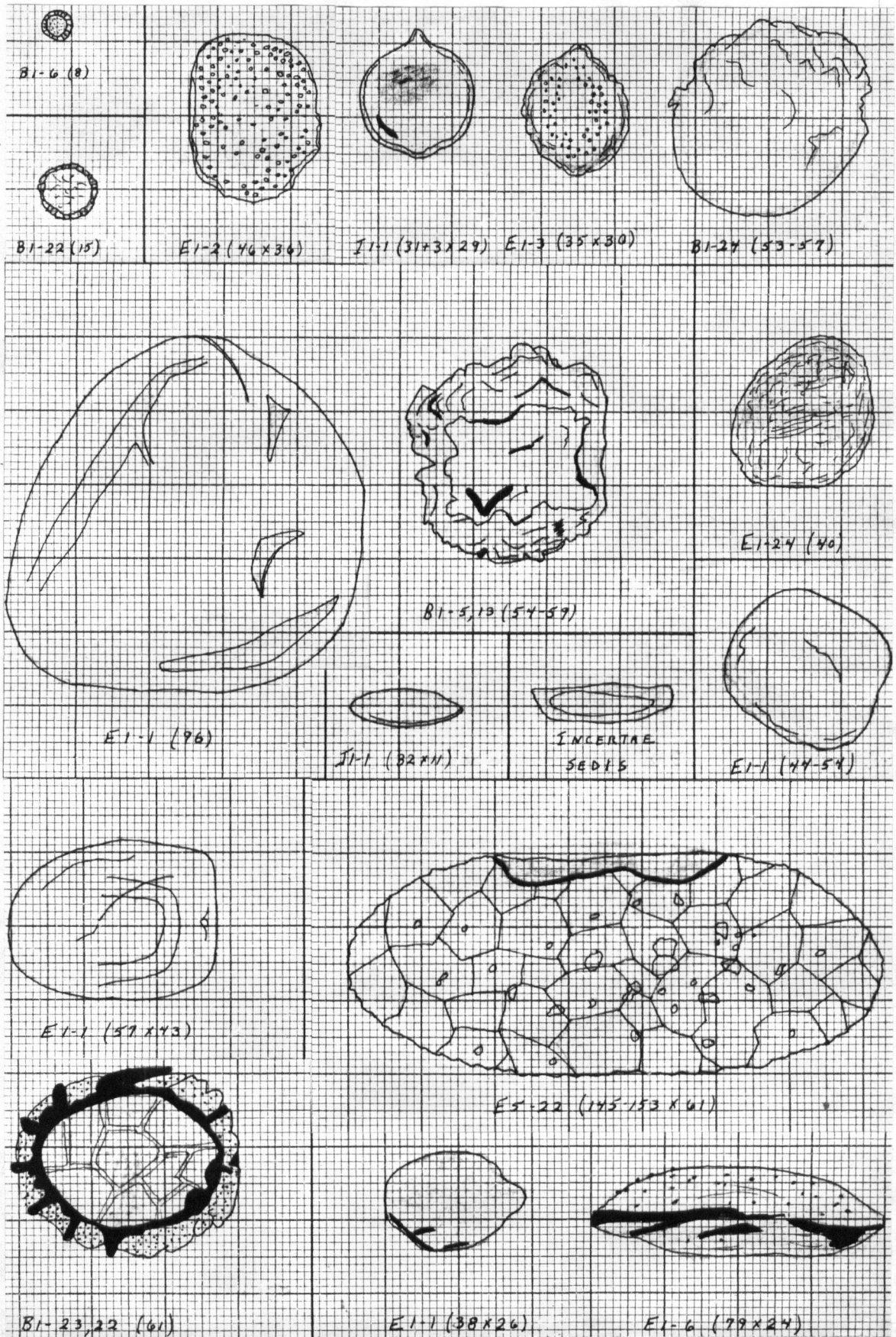
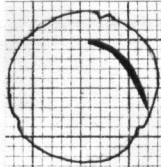


PLATE 8.

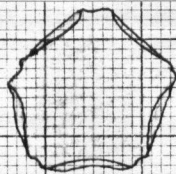
all figures x500

<u>Microfossil Formula</u>	<u>Affiliation</u>
E11-1(31)	cf. <u>Corylus</u> sp.
G12-1(34)	<u>Alnus</u> sp.
G12-1(26)	cf. <u>Pterocarya</u> sp.
E12-1(27)	cf. <u>Pterocarya</u> sp.
G12-1(29)	cf. <u>Alnus</u> sp.
E17-6(32)	<u>Quercus</u> sp.
E11-1(27)	Angiospermae
E8-6(29)	unknown affinities
E11-1(26)	cf. <u>Corylus</u> sp.
F11-1(31)	<u>Carpinus</u> sp.
F1-6(36)	fern spore
F8-22(40x35)	fern spore?
F8-1(35x40)	fern spore
F11-1(20x16)	Angiospermae
F8-1(50)	<u>Deltoidospora</u> sp.
F8-1(71x60)	fern spore
E6-1(68)	fern spore
H7-1(34x24)	unknown affinities
K1-1(17x12)	unknown affinities
E9-1(34x24)	unknown affinities
E5-1(17-18x8-10)	<u>Monosulcites</u> sp. (aff. with the cycads or the Palmaceae)
E17-1(23x15)	Angiospermae
H7-1(72x34)	unknown affinities
H7-13(52x21)	fern spore?
E1-13(14)	fern spore?

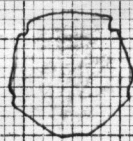
# PLATE 8.



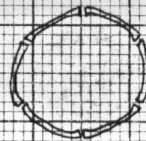
E 11-1 (31)



G 12-1 (34)



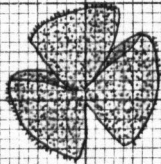
G 12-1 (26)



E 12-1 (29)



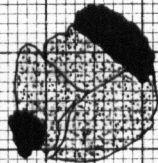
G 12-1 (19)



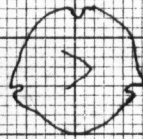
E 17-6 (32)



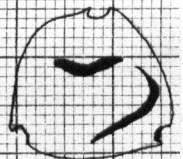
E 11-1 (29)



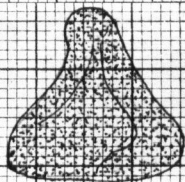
E 8-6 (29)



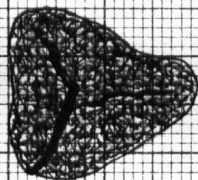
F 11-1 (26)



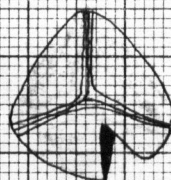
F 11-1 (31)



F 1-6 (36)



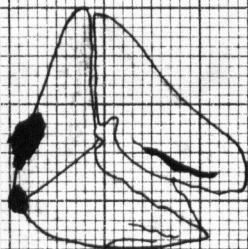
F 8-22 (40 x 35)



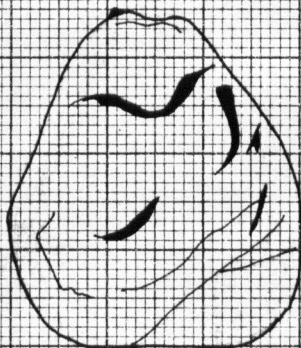
F 8-1 (35-40)



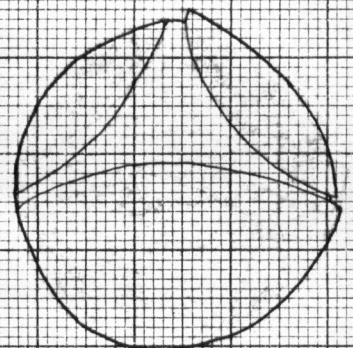
F 11-1 (20 x 16)



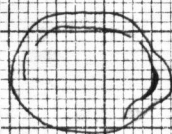
F 8-1 (50)



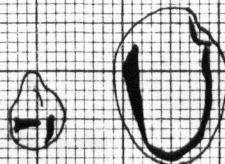
F 8-1 (71 x 60)



E 6-1 (68)



H 7-1 (34 x 24)



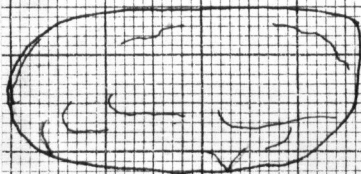
K 1-1 (17 x 12) E 9-1 (34 x 24)



E 5-1 (17-18 x 8-10)



E 17-1 (23 x 15)



H 7-1 (72 x 34)



H 7-13 (52 x 21)



E 1-13 (14)

FIGURE NO. 8.

POLLEN HISTOGRAM

SAMPLE: RC 23

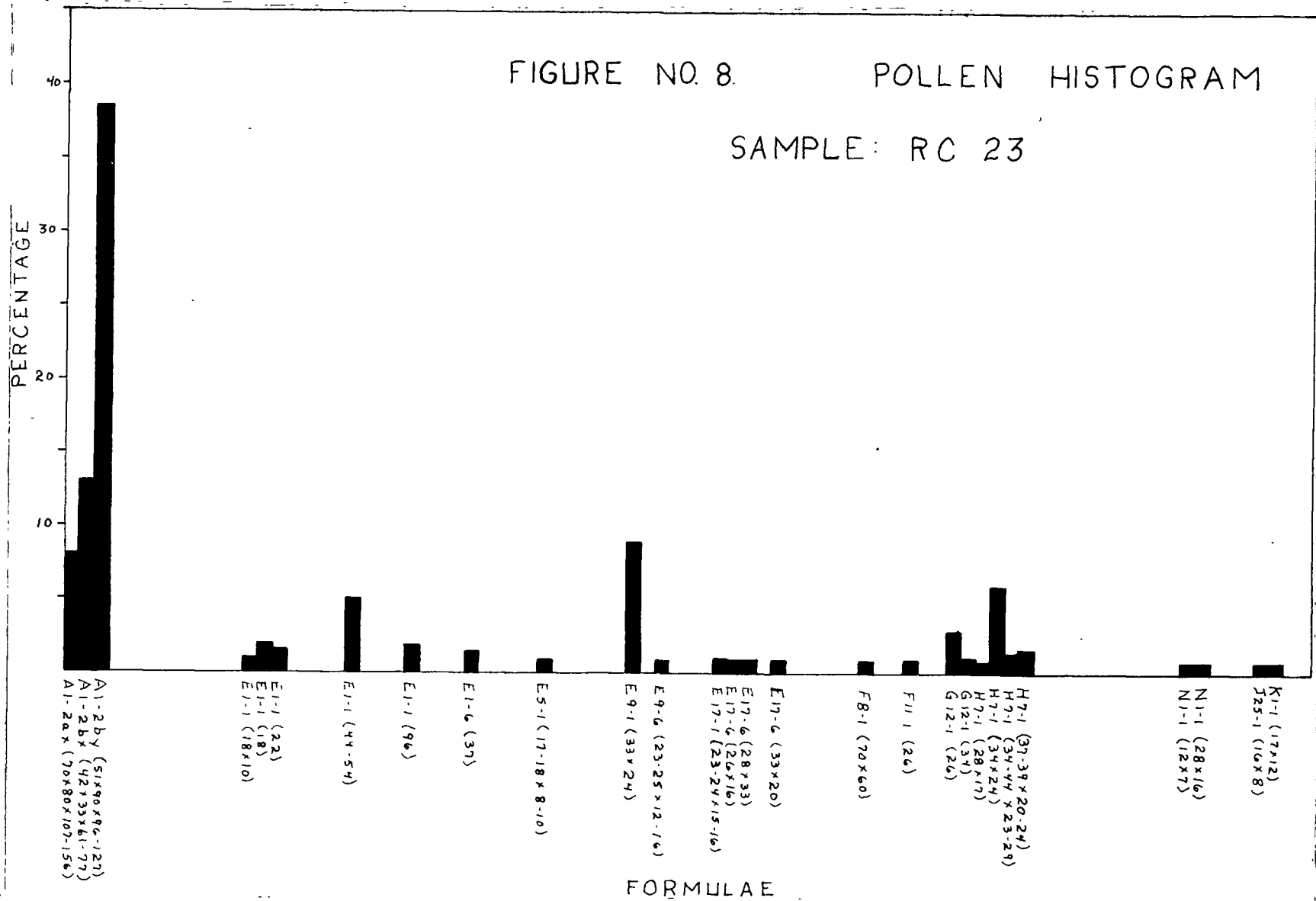




FIGURE NO. 9

POLLEN HISTOGRAM

SAMPLE RC 9-1

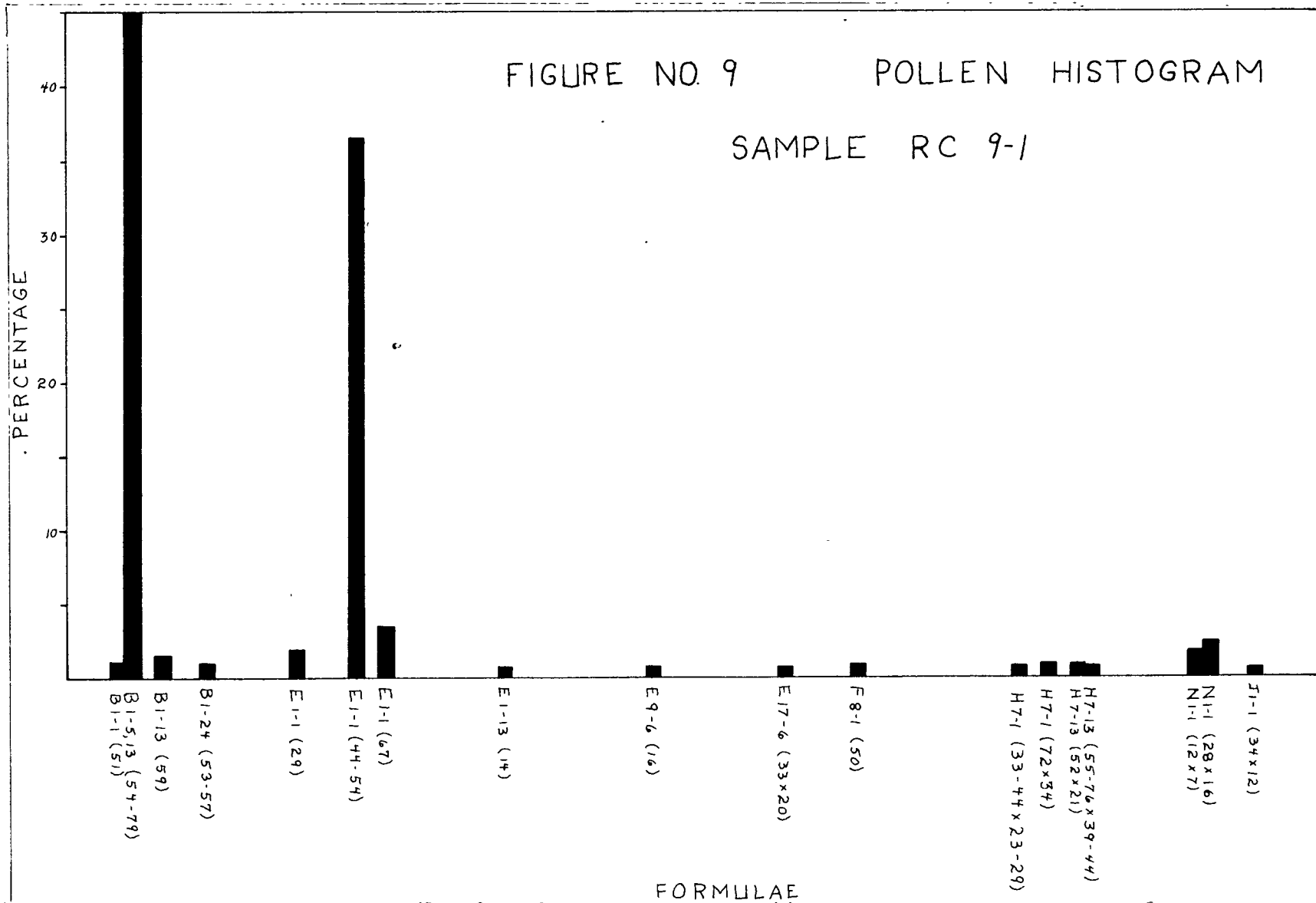


FIGURE NO 10

POLLEN HISTOGRAM

SAMPLE RC 11-3

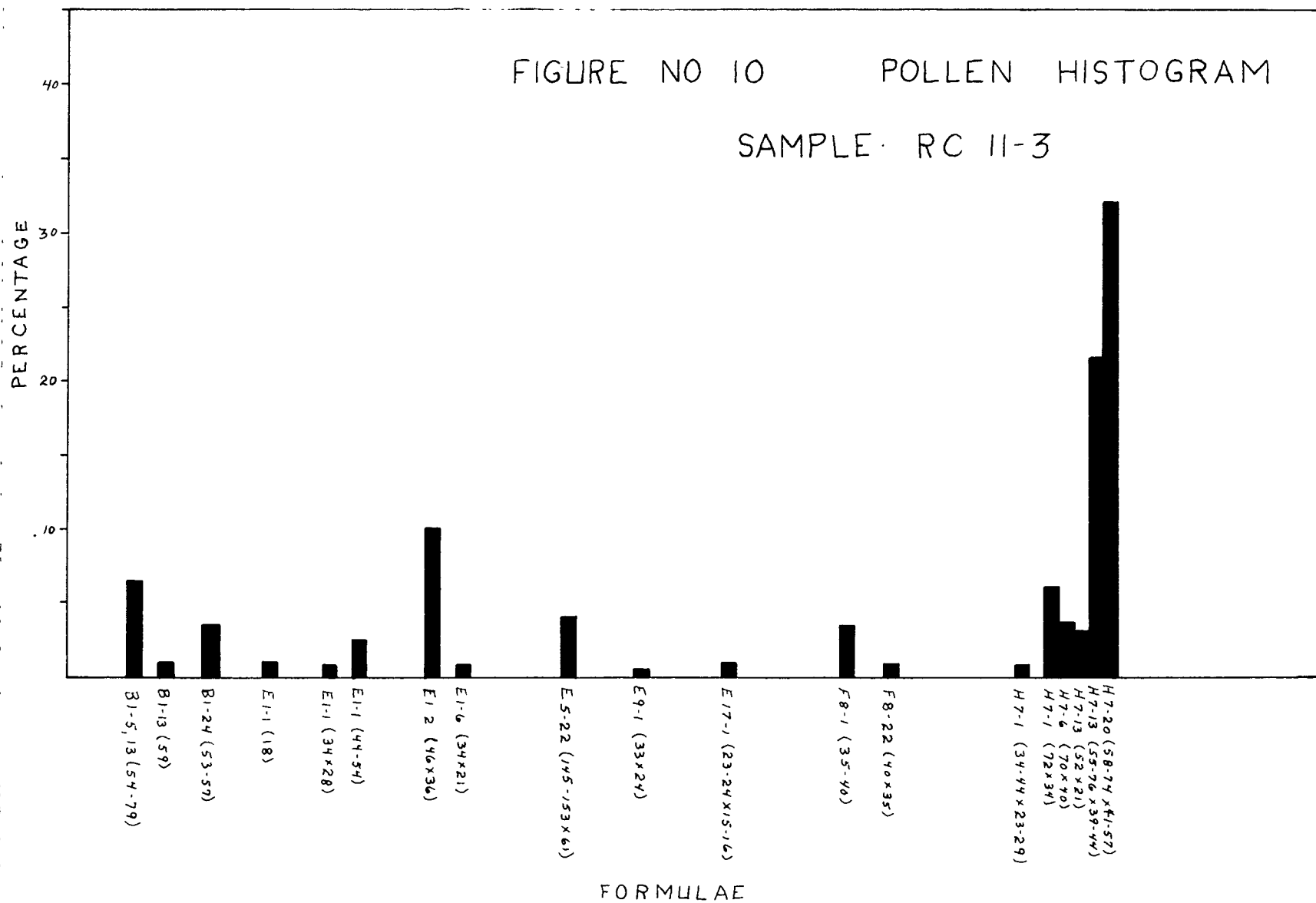
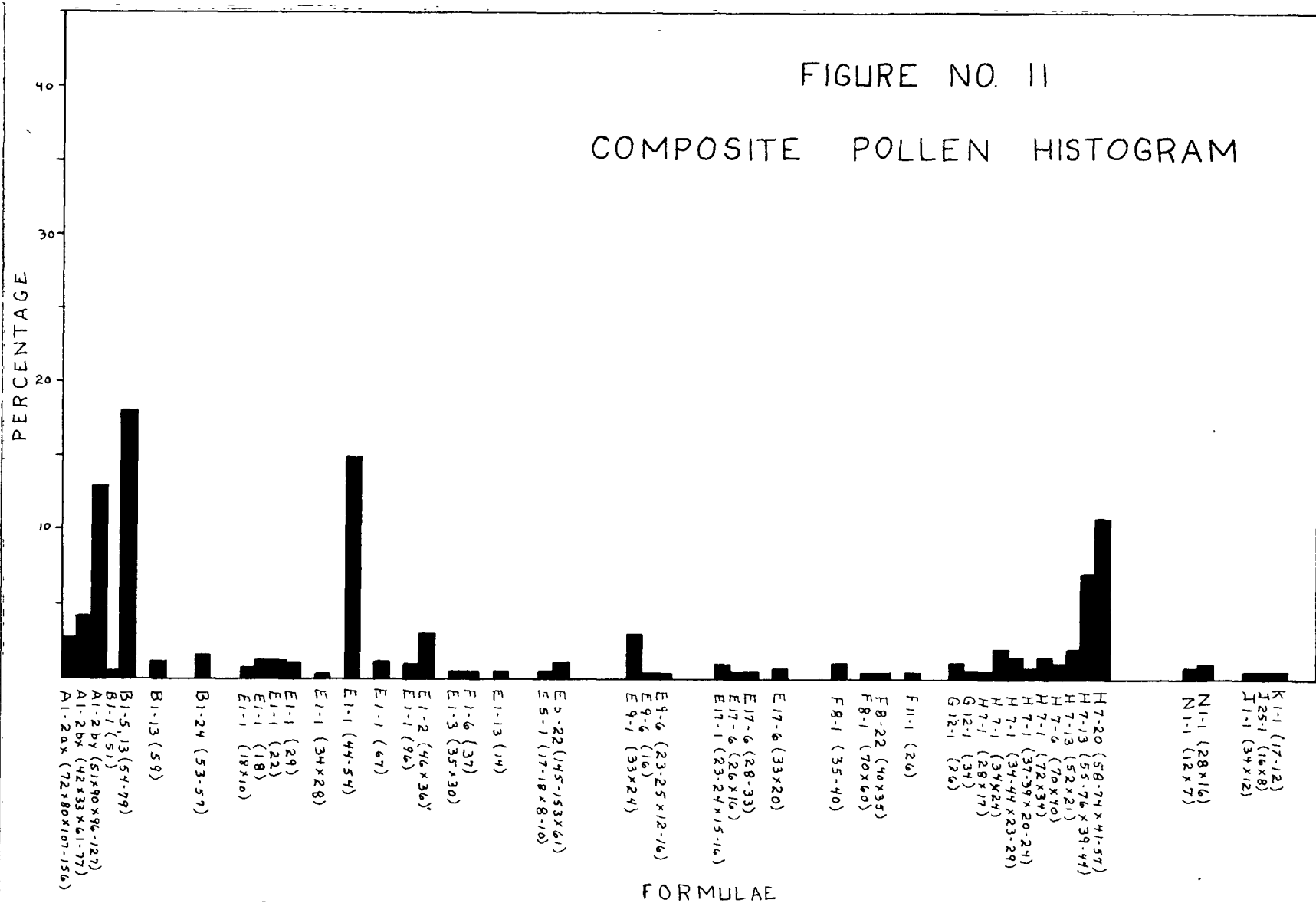


FIGURE NO. 11

COMPOSITE POLLEN HISTOGRAM



chosen to show the relative distribution of microfossils. Two hundred microfossils were counted in each sample, and combined into groups based on an artificial classification. Three histograms were plotted (Figs. 8, 9, 10.) showing the relative percentage of the forms in each sample. A composite histogram designed to show all of the microfossil forms present in the Sooke Formation, and the relative abundance of each form is illustrated by Figure 11.

In Figure 8 (RC 23) Picea is the dominant pollen. Pinus, Abies, Larix(?), ferns and an unknown species are reported from this locality. From the large proportion of saccate grains, together with the variety of species, it appears that the flora of RC 23 was not indigenous to that locality, the grains were probably transported there by air and water. At sample locality RC 9 (Fig. 9) Tsuga and Larix (?) predominate, and fungal spores are abundant. Eighteen species are reported from this locality, mostly as small groups. Saccate grains are absent. It appears that these pollen and spores represented plants that were indigenous to the locality. The vegetation consisted of coniferous trees and a well developed fungal growth. At sample locality RC 11-3 (Fig. 10) ferns predominate, with Tsuga and Larix (?) and an unknown species occurring in large numbers.

Saccate grains are rare. The large, well preserved spores and the general lack of transported forms indicate that foliage represented by the spores and pollen is local in origin. Figure 11 illustrates the relative percentages of microfossil species. It indicates that the Sooke flora consisted of coniferous forests and fern glades similar to associations within the modern coastal rain forest area.

### Classification

There are two methods of arranging plant microfossils systematically. The first is a "natural" classification in which taxa are arranged phylogenetically, and a formal binomial nomenclature is applied. The second is an artificial classification in which informal designates are usually employed for reference. Spores and pollen are fossil plant organs, and represent the taxa of the producing plants. Because of this the formal application of names falls under the jurisdiction of the International Code of Botanical Nomenclature.

A system of nomenclature is important in biology and paleontology because it groups organisms into natural systems and illustrates their mutual relationships. Because of the amount of time involved in nomenclatural research, however, its use in solving

local or regional correlation problems is usually limited. In correlation problems, where the investigator has access to all of the palynological material, both known and unknown, a nomenclature employing designates or formulae is usually sufficient.

The fossil spores and pollen of this study are grouped in a series of artificial categories that are designated by formulae. The grouping is a modified version of Norem's (1958) proposed system of classification.

Norem proposed a series of three keys for the artificial classification of fossil pollen and spores above the generic level. The keys were outlined in what he considered to be the order of decreasing classificatory value. His first key was based on types of apertures, the second on grain ornamentation and the last, on the shapes of the grains. The purpose of his classification was to provide a framework within which other palynologists could study microfossils and apply formal binomial nomenclature to them under the rules of the International Code of Botanical Nomenclature.

The classification used in the present study provides a framework for further nomenclatural studies and also enables the palynologist to apply formulae to the microfossils at the "key" level for local stratigraphic

purposes without recourse to extensive nomenclatural research.

Norem's keys for identification of the microfossils are re-arranged in what the writer considers to be a more realistic order of decreasing classificatory value. Key #1 is based on the outline or shape of the grain, but in a broader sense than Norem's shape-key. Keys #2 and #3 describe apertures and ornamentation of the grains respectively and are very similar to Norem's first two keys. Each formula applied to the microfossil generally consists of four values. The first, a capitalized letter from the alphabet, designates the shape of the grain. The second and third values are numerical and refer to the aperture and ornamentation of the grain respectively. These first three values are found underlined in their respective keys, accompanied by the appropriate descriptive term. The fourth value is enclosed in brackets and refers to the maximum size range of the grain in microns.

Thus, a grain may be designated by the following formula: E7-6(41-44x22-28). The letter "E" signifies that the outline or shape of the grain is circular to subcircular. The number "7" signifies that the aperture is monolete. Number "6" denotes that the ornamentation is granulate. The long axis of the grain ranges in

length from 41-44 microns, and the short axis ranges in length from 22-28 microns.

Exceptions to the general size-range value pattern are found in the Annulate (B), Triangular to Subtriangular (F), Equilateral (G) and Papillate (I) groupings. These are explained as they are encountered in Key #1. Pollen and spore classification keys.

KEY #1 Shape or outline of grains

A. Saccate.

B. Annulate (if the shape is round, only the range of the diameter is indicated in brackets.)

C. Auriculate.

D. Elaterate.

E. Circular to Subcircular.

F. Triangular to Subtriangular. (if the triangle is equilateral, only the range in length of one side is given in brackets, otherwise the range in lengths of two sides of the triangular body are indicated.)

G. Equilateral. (only the range in length of one side is indicated in brackets.)

H. Reniform to Elliptical.

I. Papillate. (the length of the papilla is added to the formula within the size-range brackets;



i.e. (24 2-18) signifies that the grain has a 2 micron long papilla along the longest diameter.)

J. Fusiform.

K. Spatulate.

L. Tetrads.

M. Polyads.

N. Filamentous.

#### Saccate grains

A special formula is used to identify saccate grains:

1 = inaperturate

2 = aperturate

1, 2, or 3 bladders

a = presence of a distal cap

b = absence of a distal cap

x = bladders distinct from the grain

y = bladders continuous with grain

An example of a Saccate grain formula could be:

A1-2ax (57-82x27-42x96-144) where:

A - signifies that the grain is saccate.

1 - signifies that it is inaperturate.

2 - signifies that it has two bladders.

a - signifies that the body has a distal cap.

x - signifies that the bladders are distinct from  
the grain.

(57-82x27-42x96-144) - signifies that the main body  
dimentions of 57-82x27-42 microns, and the entire  
grain including the bladders has the dimentions  
of 57-82x96-144 microns.

### KEY #2 Apertures

#### I. Without apertures

Nonaperturate 1

Plicate 2

Tenuate 3

#### II. With apertures

##### 1. Monoaperturate

monoporate 4

##### 2. Sulcate

monosulcate 5

trisulcate 6

##### 22. Laesurate

monolete 7

trilete 8

##### 222. Colpate

monocolpate 9

## 11. Multiaperturate

## 2. Multiporate

## 3. Mesoporate

diporate 10triporate 11oligoporate 12

## 33. Periporate

oligoperiporate 13polyperiporate 14

## 333. Latiporate

trilatiporate 15

## 22. Multicolpate

## 3. Colpate

dicolpate 16tricolpate 17oligocolpate 18

## 33. Pericolpate

oligopericolpate 19polypericolpate 20

## 333. Laticolpate

dilaticolpate 21trilaticolpate 22oligolaticolpate 23

## 222. Multicolporate

## 3. Colporate

dicolporate 24

tricolporate 25

oligocolporate 26

33. Pericolporate

oligopericolporate 27

polypericolporate 28

333. Multiheterocolpate

heterocolpate 29

perilaterocolpate 30

3333. Syncolpate

spiraperturate 31

zonacolpate 32

KEY #3 Ornamentation

I. Psilate 1

II. Dense 24 (included here because it has the same  
effect as ornamentation.)

III. Sculptural elements present.

1. Sculpture simple and homogenous.

2. Sculptural elements distinct or separate.

3. Sculptural elements more or less  
isodiametric tangentially.

4. Sculptural elements depressed.

punctate 2

44. Sculptural elements raised.

clavate 3  
 columnate 4  
 gemmate 5  
 granulate 6  
 lepidote 7  
 lobate 8  
 papillate 9  
 setose 10  
 spinate 11  
 tuberose 12  
 verrucose 13  
 thin processes 23

33. Sculptural elements more or less  
 elongated tangentially.

4. Sculptural elements depressed.

rivulate 14  
 striate 15  
 vallate 16  
 vermiculate 17

44. Sculptural elements raised.

extervermiculate 18  
 rugate 19

22. Sculptural elements continuous or connected.

3. Sculptural elements more or less  
 isodiametric.

4. Sculptural elements depressed.

areolate 20

44. Sculptural elements raised.

lophate 21

reticulate 22

11. Sculpture complex. (includes more than one form  
of sculpture.)

Use appropriate designates for each type  
of sculpture, and separate each designate  
by a comma.

### Size ranges

Use actual sizes of the grains, measured in microns.  
The first measurement is the long axis, and the second  
is the short axis. Exceptions to these measurements are  
outlined in Key #1. If possible, the maximum size ranges  
of the grains should be used.

There are at least five advantages of the key-  
system outlined above. First, the key-system is very  
rapid and facilitates correlation of strata in local  
basins without nomenclatural research. Second, the  
formulae that are used cannot be confused with formal  
plant names. Third, the keys are based on detailed

morphological criteria and tend to group the microfossils for later nomenclatural studies. Fourth, each formula actually provides a description for the grain in question. Fifth, previously undescribed forms can be added to the keys without disrupting the system.

The key-system is disadvantageous in that the formulae are bulky and probably confusing to one unfamiliar with the technique. Secondly, it is practical for resolving local correlation problems only. It is impractical for regional studies because all references have to be reinterpreted within the scope of the keys. Finally, the method is not suitable for publications because interpretation of the formulae by any reader not familiar with the keys is impossible.

The proposed key-system of classification using formulae is a rapid correlation tool for a biostratigrapher, familiar with the system, provided it is used within a sedimentary basin or other restricted area.

## CHAPTER IV

## AGE AND CORRELATION.

In spite of its flora and well preserved fauna, the age of the Sooke Formation presents a problem. The plant megafossils and the vertebrate fossil are insufficiently well known to be useful for correlation. Known microfossil evidence from Pacific Coast Tertiary sediments is still too meagre to allow any detailed correlations of the Sooke microflora. The marine invertebrates provide the best evidence, but the fauna appears to be of an insular nature because correlatable forms from other Tertiary formations are scarce.

Evidence from Plant Megafossils

La Motte (1936) decided that there was not sufficient evidence to base a correlation on his plant collections. Therefore, he referred the Sooke Formation to Clark and Arnold's (1923) late Oligocene - early Miocene age determination.

Evidence from the Vertebrate Fossil

Cornwallius is only reported from two other formations, the San Gregorio Formation of Baja California (Weaver et al, 1944) and the Cornwallius bearing beds



of Unalaska (Mac Neil et al, 1961).

Reinhart (personal communication, Oct. 4, 1961)  
indicated:

"The geologic range of Cornwallius is upper Oligocene. ...In my opinion, the Oligocene? Cornwallius is the direct ancestor of the middle Miocene Desmostylus. ...The geographic provinces in which Cornwallius has been located are Baja, Mexico; Vancouver Island; Japan. I regard the first two localities as Oligocene. The Japanese specimen is middle Miocene and I made it the type specimen of a new genus Paleoparadoxia. ...In my opinion Cornwallius would not be a good form for correlation because it is unknown except for isolated teeth and it is extremely rare. I would regard a good marine invertebrate fauna, if present, as far superior to the genus Cornwallius for purposes of correlation."

In discussing the Mexican site where Cornwallius was found, Van der Hoof (1941, p. 1985), writes, "This is the northernmost outcrop of the 'Monterey of Darton, 1921'. Invertebrates collected by Darton were determined by Julia Gardner as 'probably Vaqueros.' " In the Weaver et al correlation chart (1944, p. 575) Durham claims that the San Gregorio Formation of lower California contains the "Same species of Cornwallius as in the Sooke Formation of Vancouver Island." Reinhart reported that there is only one locality in Lower California where Cornwallius has been found, (personal communication, Oct. 4, 1961). Thus the "Monterey of Darton" must be the same as Durham's San Gregorio

Formation. In the correlation chart (Weaver et al, 1944) the San Gregorio is in the upper Blakeley Stage, the Echinophora apta zone of the Lower Miocene.

The Unalaskan beds containing Cornwallius are correlated with the Sooke Formation (Mac Neil et al, 1961). No further information on this occurrence is available.

If Cornwallius were more widely distributed, and better documented, it would be a very good correlation fossil. However, at the present time, it has little particular value for correlation excepting in beds where it is diagnostic.

#### Evidence from Plant Microfossils

The amount of published literature describing Tertiary plant microfossils from the Pacific Coast region is small. Information of this nature, concerning Eocene, Miocene and Pliocene floras of British Columbia is in preparation at the University of British Columbia. Two sources of information are particularly important for correlation of the Sooke flora. The first is a paper by G. E. Rouse (1962) on the Eocene Burrard Formation of the Vancouver area. The second consists of pollen and spores from the Skonun Formation of the Queen Charlotte Islands, loaned to the writer by

G. E. Rouse. The Skonun Formation is Pliocene in age (Cox, manuscript).

The Sooke flora was compared with the Burrard and Skonun floras. Three species of the Burrard flora appeared to have correlatives in the Sooke flora. Fig. 12 illustrates these Burrard and Sooke correlatives.

BURRARD FM.		SOOKE FM.	
Rouse's designates	Name	Cox's designates	Name
N 41...	<u>Picea</u> <u>ali-</u> <u>pollenites.</u>	A1-2by (51x90x96-127).	<u>Picea</u> sp.
O 4 ...	<u>Laevigato-</u> <u>sporites</u> <u>ovatus.</u>	H7-1(44x26)....	cf. <u>Laevigato-</u> <u>sporites.</u>
Q 40...	<u>Alnus</u> <u>quinque-</u> <u>pollenites.</u>	G12-1(34).....	<u>Alnus</u> sp.

Figure no. 12, illustrating microfossils common to Burrard and Sooke Formations.

Four species were found in common between the Sooke and Skonun floras. These forms are:

1. A trilete fern spore F8-1(35-40)
2. Tsuga sp. B1-5,13(54-79)
3. Polypodium sp. H7-13(55-76x39-44)
4. Abies sp. A1-2ax(72x80x107-156)

In general the resemblance between the Sooke and Skonun floras appeared to be closer than between the

Sooke and Burrard floras. The correlatives of the Skonun microflora in the Sooke Formation were abundant in terms of numbers of individuals, but not in numbers of species. On the other hand, correlative species of the Burrard microflora were infrequent in the Sooke flora. This conclusion, however, is tentative, because statistical comparisons of the Burrard and Skonun microfloras with the Sooke microflora were not made. With this limitation it appears that the Sooke flora is more closely related to the Skonun flora than to the Burrard flora. Thus, on palynological evidence, the Sooke Formation is closer in age to the Pliocene than to the Eocene.

#### Evidence from the Marine Invertebrate Fossils

The earliest faunal studies of the Sooke Formation were made by J. C. Merriam from 1896 to 1902. Since then, five other major contributions have been made to these marine invertebrate studies.

On the basis of his studies, Merriam concluded that the Sooke beds were of middle Neocene age. Arnold and Hannibal (1913) placed the Sooke Formation in the middle Oligocene. C. E. Weaver, who studied Clapp and Cooke's (1917) faunal collections decided that the "Sooke Formation ... is probably the equivalent of the upper portion of the lower Miocene of Washington."

(Clapp and Cooke, 1917, p. 339). Clark and Arnold (1923) prepared a monograph on the Sooke fauna. They placed the Sooke Formation in the upper Oligocene - lower Miocene Blakeley stage. In the same paper, T. Wayland Vaughan described a new coral from the Sooke Formation. In 1927, I. E. Cornwall identified two barnacles from the Muir Creek basin. Neither Vaughan nor Cornwall added to the solution of the age problem.

Fig. 6 illustrates the relationship of the Sooke fauna with other known Tertiary faunas of the Pacific Coast of North America. The technique here is similar to that of Fig. 5 where the numbers on the diagram correspond to numbers preceeding each reference in the bibliography. Fig. 3 shows the geologic ranges of each formation referred to in Fig. 6 and is compiled mainly from the Weaver et al correlation chart (1944).

Clark and Arnold (1923) correlated the Sooke Formation with the "... Blakeley beds of Washington. This conclusion is based upon the highly ornamented gastropods and pelecypods common to the two." (p. 135). They suggest (p. 137) that "...the Sooke fauna will be found to be characteristic of the upper part of the Blakeley ...". The upper part of the Blakeley is equivalent to the upper part of Weaver's Acila gettysburgensis zone and to Durham's Echinophora apta zone

of the lower Miocene or European Aquitanian stage. This conclusion has been supported by Weaver (1942), Weaver et al (1944), and Jeletzky (1954). Durham states that the "Sooke" fauna of Washington he reported in 1944 "...can be correlated with the San Ramon and Pleito Formations of California." and "...with the upper Poul Creek Formation of Alaska." (personal communication, April 26, 1961). He places his "Sooke" fauna in the Echinophora apta zone. It is the writer's conclusion that Durham's "Sooke" fauna of Washington and the Sooke fauna of southern Vancouver Island are correlative.

One column on Fig. 6 shows the percentage of invertebrates that other Tertiary formations, on the Pacific Coast, have in common with the Sooke Formation. In theory, those formations that have the highest percentage of fossils in common with the Sooke Formation should be the closest correlatives, all other factors remaining equal. It is considered that those faunas having 5% or more correlation with the Sooke fauna are its closest correlatives. These are the Pleito (5%), San Ramon (6%) and Vaqueros (6.7%) Formations of California; the Astoria (13.5%) and Empire (5%) Formations of Washington and Oregon; Durham's "Sooke" fauna (9%) from Washington; and the "Carmanah Point beds, above the conglomerate" (10.5%) described by Clark and

Arnold (1923, p. 136) of Vancouver Island.

The highest percentage correlation is with the Astoria Formation (13.5%). Weaver et al (1944) place the Astoria Formation in the Temblor stage of the middle Miocene, equivalent to the Helvetian stage of European chronology.

The Blakeley and Sooke Formations have only 4.5% of their invertebrates in common. This moderate correlation was explained by Clark and Arnold (1923, p. 136):

"The most conclusive evidence of the stratigraphic position of the Sooke Formation was obtained from the Oligocene beds in the vicinity of Carmanah Point a little to the south of the Indian village of Clo-oose; the top of this section is just beyond and to the south of Carmanah Point lighthouse. A typical Lincoln fauna was found in the lower part of the section, while the Blakeley fauna was found throughout the upper portion. Heavy conglomerates separate the beds containing the faunas".

They go on to describe a fauna from above the conglomerates which is "...of special interest because of the interfingering of typical Blakeley and Sooke faunas" (p. 136). These beds above the conglomerate contain 10.5% of the Sooke fauna which is considered to be a typical Blakeley fauna. The beds are either of early Sooke age or transitional in time between the Sooke and Blakeley faunas. This difference in faunas is thought to be due to environmental differentiation.

According to Clark and Arnold (1923, p. 134):

"The typical fauna of the Blakeley is usually found in rather fine sandstones and shales and undoubtedly lived in marine waters some distance from the shore; but the fauna obtained from the type section of the Sooke represents a shore line facies, a fauna which would be found living on a rocky beach between high and low tide, ...certain elements of this fauna indicate brackish water conditions for at least part of the time. The habitat was probably in or close to an estuary or the mouth of a river."

A number of fossils that have been recorded from the Sooke Formation have geologic ranges that delimit the age to early Miocene at the earliest. These fossils are: Macoma, Panope generosa, Calyptraia mammilaris, Sinum scopulosum and Scutella. They are assigned a range of Miocene to Recent by Schimer and Shrock (1949). Molopophorus has a geologic range of Oligocene to Miocene, and is a very common constituent of the Sooke fauna. Thus the Sooke Formation appears to be restricted in age to the Miocene.

Evidence presented by Clark and Arnold (1923) and by J. W. Durham (personal communication, April 26, 1961) indicates that the Sooke fauna is most likely Aquitanian, (i.e. lower most Miocene) in age (Fig. 3). At the same time, however, Figure 6 indicates an apparently close correlation of the Sooke fauna with the Astoria



(Helvetian) fauna and the Vaqueros (Aquitanean to Helvetian) faunas. Thus the Sooke Formation is most probably Aquitanian in age, but may range from Aquitanian to Helvetian, or from the upper Blakeley to the <sup>Temblor</sup> stages of Pacific Coast terminology.

## CHAPTER V

## SUMMARY AND CONCLUSIONS

The Sooke Formation has never been formally defined and the validity of the type section is open to serious question. Throughout the paper, the term Sooke Formation is used in its generally accepted connotation.

The Sooke Formation is a sedimentary rock unit consisting of interbeds of sandstone, shale and conglomerate in varying proportions, that crops out in isolated localities along the south and south west coast of Vancouver Island. It was deposited in small, apparently disconnected, basins on the slopes of a volcanic rock surface, in a shoreline environment. Facies change rapidly in all directions and depositional dips are fairly steep. Thus correlation of individual beds, on a purely physical basis is hazardous.

The Sooke Formation contains a small megaf flora, one vertebrate fossil, a large marine invertebrate fauna and a moderately large microflora. Since these various fossil types are so intimately related in their stratigraphic positions, they were doubtlessly deposited during the same interval of time. Marine invertebrate evidence from the Pacific Coast Tertiary is extensive,

and the invertebrates have been used to determine the age and correlation of the Sooke Formation. On this basis, the Sooke Formation is considered to be lower Miocene in age, equivalent to the upper Blakeley stage, but may extend as high as the Temblor stage. No additional evidence is available from either the megaf flora or the vertebrate fossil to further delimit this age.

Pacific Coast Tertiary palynological studies are few in number; only two other microfloras were available for comparison with the Sooke microflora. A preliminary comparison indicated that the Sooke microflora was more closely related to the Pliocene Skonun microflora than to the Eocene Burrard microflora. Further palynological studies of the Pacific Coast Tertiary and in particular of the Sooke and related strata may additional information concerning age, correlation and paleoecology.

### SUGGESTIONS FOR FURTHER STUDIES

As a result of this investigation, the following problems have been recognized:

1. In order to resolve the stratigraphy of the Sooke, Carmanah and other Tertiary formations in this area, a palynological setting should be established and the limits of microfossil species closely delimited. Jeletzky (1954) reported that correlatives of the Sooke and Carmanah faunas and with the Acila gettysburgensis fauna above the conglomerate at Carmanah Point, are present in the Hesquiat - Nootka area. Further palynological studies could be made at Carmanah Point, and northwestward along the west coast of Vancouver Island to delimit the formations and their contained microfloras.
2. Paleoecological studies of the relationships of the faunas, floras and sediments would be of much value to the advancement of knowledge. The paleoecology of the Sooke Formation appears sufficiently similar to modern ecological conditions in the same area that a good comparison and contrast could be made.
3. The correlation between the Sooke and Astoria faunas must be explained. Identifications may be in error, or sampling methods or preservation may have provided

poorly representative faunas. In addition, the formations may be much more closely correlative than is presently suspected with the differences in faunas the result of different ecological settings.

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