Note 2 Maps omitted.

STRUCTURE, STRATIGRAPHY, AND PALEONTOLOGY OF AN UPPER TRIASSIC SECTION ON THE WEST COAST OF BRITISH COLUMBIA

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ABSTRACT

The highly deformed section at Open Bay is one of the few good exposures of a thick sedimentary unit within the prebatholithic rocks along coastal British Columbia. It provides new structural information relating to emplacement of a part of the Coast Range batholith and it contains an important Upper Triassic fauna unusually well represented. Structural and paleontological analyses are mutually supporting and are purposely combined in one paper.

Thirteen ammonite genera from 14 localities clearly substantiate McLearn's tentative assignment to the *Tropites subbullatus* zone (Upper Karnian) and suggest a restriction to the *T. dilleri* subzone as defined in northern California.

Contrary to an earlier view, the beds are lithologically similar across the whole bay except for variations in the intensity of deformation and thermal alteration. Their contact with slightly older relatively undeformed flows is apparently a zone of dislocation. Stratigraphic thicknesses cannot be measured with confidence, and subdivision into "Marble Bay Formation" and "Open Bay Group" cannot be accepted. Open Bay Formation is redefined to include all the folded marble and interbedded pillow lava at Open Bay. Lithologic and biostratigraphic correlation is suggested with the lower middle part of the Quatsino Formation on Iron River, 24 miles to the southwest. Basalt flows and pillowed volcanics west of Open Bay are correlated with the Texada Formation within the Karmutsen Group.

The predominant folding is shown to precede, accompany, and follow intrusion of numerous andesitic pods and to precede emplacement of quartz diorite of the batholith. Structural asymmetry is shown to have originated through gentle cross-folding and emplacement of minor intrusives during deformation.

INTRODUCTION

The pre-Coast Intrusive rocks of coastal British Columbia are predominantly volcanic; they contain very few thick sedimentary sections and, of these, only a few occurrences have been measured and described structurally and lithologically in detail or searched systematically for fossils. This paper concerns one of the three such occurrences exposed along the eastern side of Vancouver Island. The section is immediately west of the main batholith, is readily accessible, and has long been known and referred to on the basis of reconnaissance mapping. In spite of its deformation and its metamorphism, it contains an unusually well-developed fauna, apparently the most representative single occurrence of the *Tropites subbullatus* zone yet described in Canada. However, the structure is complex and even the general order of thickness of the strata and the question of whether one or more formations should be recognized has remained unclear. One purpose of this paper is to provide a fuller report on the lithology and the fauna than has been available and to evaluate this section as a stratigraphic reference in the light of its structural complexity. A subsequent paper (by Surdam, Susuki, Carlisle) will discuss a newly studied section on Iron River, 25 miles to the southwest, which is much the opposite—structurally simple, and containing a thick, unmetamorphosed, nearly continuous stratigraphic and faunal record of a large part of the Upper Triassic—and a lithologic and biostratigraphic correlation will be suggested.

Another purpose of the paper is to draw attention to interrelations between the structures at Open Bay and the mid-Mesozoic intrusives. Marked asymmetry of the structural fabric is considered to have resulted partly from cross-folding and partly from the introduction of competent rocks during an initial period of recurrent deformation.

The rocks described are in the westerly part of the Paleozoic–Mesozoic eugeosynclinal assemblage of western North America. Massive volcanic flows and pillowed volcanics are so predominant in this assemblage and nearly all of the sedimentary sections from which stratigraphic paleontology can be worked out are so thin, so lenticular, and so rare that one might wonder whether anything approaching a complete stratigraphic record can be obtained. This is all the more so since, according to a widely accepted hypothesis, the westerly part of the succession is within a volcanic archipelago or island arc and a locus of tectonism. Submarine flows, and pillow lavas in particular, might be expected to be each quite local in distribution. But in spite of all this there is a remarkable uniformity in the gross prebatholithic stratigraphy, as known from the reconnaissance and scattered detailed surveys, along the northern Pacific Coast.

Moreover, since flows and pillowed volcanics accumulate rapidly and in thick units, whereas thinly bedded, fine-grained sediments accumulate over relatively long periods of time, the paleontological record may be much more complete than the ratio of volcanic to sedimentary rock might suggest. Rather than being hostile and unlikely for the development of life and the preservation of fossils, the pervasive submarine–volcanic environment actually may have favored the record in some respects. Volcanism may have contributed nutrients to the ocean and have caused circulation and upwelling of waters which would replenish supplies of phosphorus and other nutrients consumed by organisms near the surface. In any event, many of the interlava sedimentary rocks contain a surprisingly abundant fauna. Most contain an abundance of fetid, micritic, or cryptocrystalline limestone and a great abundance of carbonaceous material with or without pyritic chert. Some of them contain unusual amounts of vanadium which may have been concentrated organically. It appears that the bulk of the fauna settled from an open sea or from embayments in the sea and, in many cases, into a euxinic or near-euxinic basin. Some may have been benthonic and in several places there is a suggestion of animals suddenly killed and preserved by renewed volcanism.

PRESENT STUDY AND ACKNOWLEDGMENTS

Field investigation of the section at Open Bay on Quadra Island was begun in 1959 by Carlisle in connection with a larger study of a part of the western margin of the main Coast Range composite batholith on and near northeastern Vancouver Island, B.C. Exposures along the sea coast at Open Bay were found to be far superior to those inland and to be a key to the age, lithology, and particularly the structure of the whole belt of carbonate rocks adjacent to the batholith on Quadra Island. Abundant fossils, composed of calcite, stand out distinctly on the wave-washed marble whereas only a single occurrence, much weathered, has been found from the much larger area of outcrop of the same rocks in the interior of the island. In 1962, therefore, a plane table map at a scale of 1 in. equals 200 ft was made of the exposures along the mile and a half of sea coast and the fossil localities, structure, and lithology were mapped on field sheets at a scale of 1 in. equals 20 ft. Susuki examined the section briefly in 1962, initiated the collecting of fossils, and subsequently prepared and identified the specimens. Fourteen separate localities were found, several of which are at equivalent horizons. These were collected according to local stratigraphic succession into more than 100 lots.

All of the fossils were given a locality number in the invertebrate fossil collection at the University of California, Los Angeles. To facilitate research on Canadian materials, however, the authors forwarded all of the usable fossil specimens to the Geological Survey of Canada in Ottawa for selection and retention as desired in the National Collection there and a species catalogue number from the Geological Survey of Canada is given for hypotype specimens on file there.

Dr. E. T. Tozer of the Geological Survey of Canada very kindly re-examined the specimens sent to Ottawa, commented upon the identifications, and critically reviewed the stratigraphic and paleontologic sections of the manuscript. His considerate attention has been most beneficial and is thoroughly appreciated. Susuki has benefitted from a critical and helpful review of the manuscript and from several discussions with Norman J. Silberling of the United States Geological Survey, especially with respect to the faunal determinations and correlations. Particular acknowledgments are made to Drs. Athol Sutherland Brown and W. G. Jeffery of the British Columbia Department of Mines and Petroleum Resources and to Professor W. P. Popenoe of the University of California, Los Angeles, for extensive comments and suggestions.

The authors thank E. B. Edwards and C. R. Givens for meticulous collecting of fossils at Open Bay under their direction and also W. R. Van Schmus and T. G. Theodore for earlier work there. All four were supported as senior students at the time by a grant through the Undergraduate Research Participation Program of the National Science Foundation. Drafting of the illustrations was done by Mrs. Opal Kurtz.

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GEOLOGICAL SETTING

Regional Relations and History of Nomenclature

In British Columbia, Triassic eugeosynclinal rocks lying along the coast, west of the main batholiths, are referred, for the most part, to the Vancouver Group (= Vancouver Series, Dawson 1887, p. 10). Triassic volcanics and

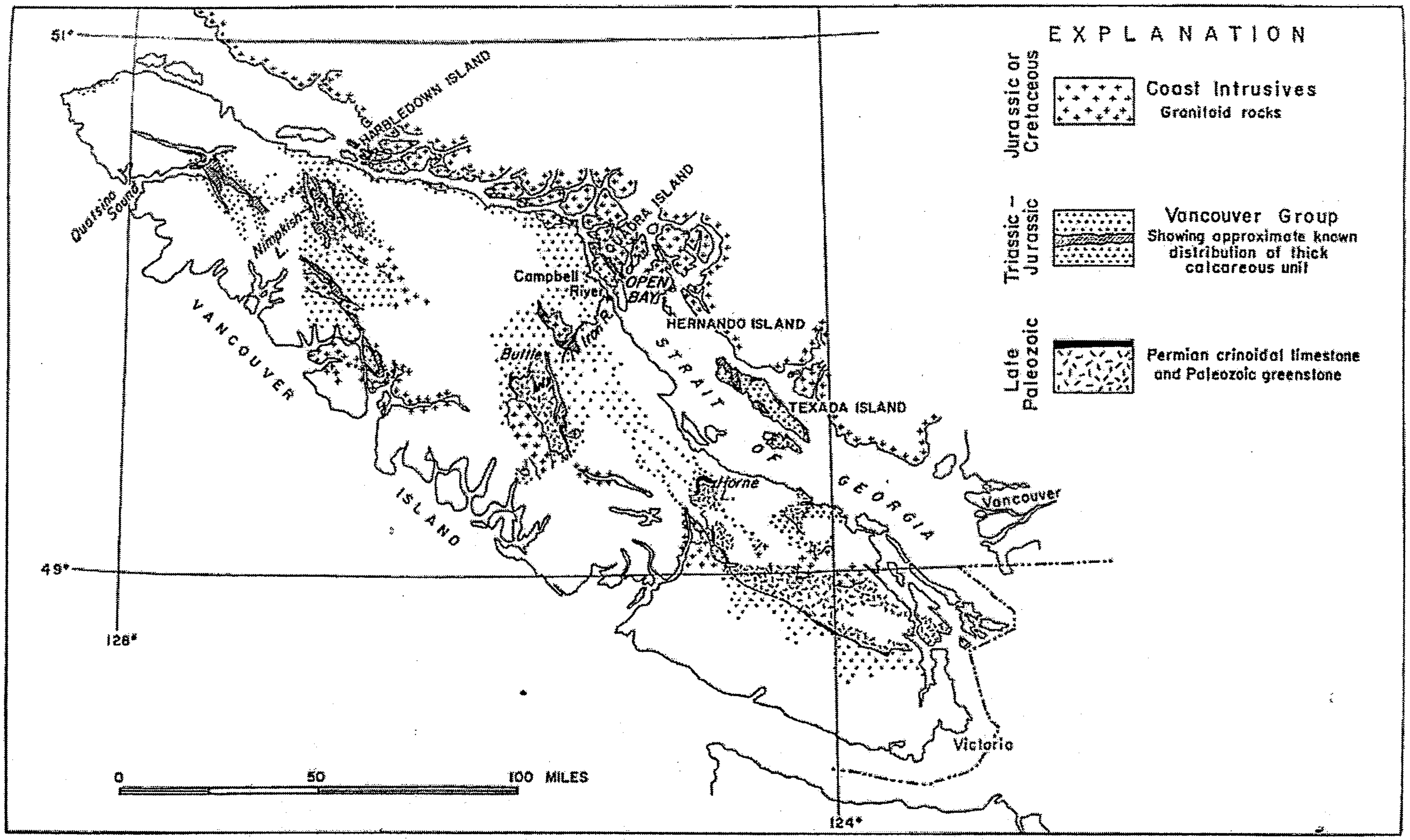

FIG. 1. Vancouver Group and associated rocks on Vancouver Island. (After Gunning 1930; Hoadley 1953; Jeffery 1963; Mathews 1947; Sargent 1941.)

volcaniclastic rocks east of the main Coast Intrusives are generally referred to the Nicola Group (= Nicola Series, Dawson 1879, p. 74B), if they occur in southern British Columbia, or to the Takla Group (Armstrong 1949; Tipper 1959) if they occur in central or northern British Columbia.

Figure 1 shows the location of the section on the northerly side of Open Bay on Quadra Island and it also shows, in a broad and general way, the regional setting. The northwesterly regional grain of the structure is shown by the anticlinoria of Paleozoic greenstones overlain by a characteristic Permian crinoidal limestone—one in the Buttle Lake area in the center of Vancouver Island and another extending southward from Horne Lake—and also by the trend of sedimentary belts in the overlying Triassic Vancouver Group and by the granitoid intrusive bodies. On Vancouver Island and over a large part of the B.C. coast, the Vancouver Group tends to be divisible into three well-marked successions (Table I): (1) a lower succession of several thousand feet

TABLE I

Contrasting subdivisions of the Vancouver group on northern Vancouver Island, not necessarily correlative

<table>
<tr><th colspan="3">West and interior Vancouver Island</th><th>Lithology</th><th>East side Vancouver Island</th></tr>
<tr><td rowspan="4">Vancouver Group</td><td rowspan="2">Bonanza Group</td><td>Upper</td><td>Mainly andesitic volcanics</td><td></td></tr>
<tr><td>Lower</td><td rowspan="2">Sedimentary rocks</td><td rowspan="2">Parson Bay Group (including "Harbledown Formation" and "Parson Bay Formation") / Marble Bay Formation</td></tr>
<tr><td colspan="2">Quatsino Formation</td></tr>
<tr><td>Karmutsen Group</td><td></td><td>Predominantly andesite-basalt flows and pillowed volcanics</td><td>Texada Formation (Group) = "Valdes" Group</td></tr>
</table>

of andesite-basalt flows and abundant pillowed volcanics with sporadic, lenticular sedimentary units mostly only a few inches to a few feet thick (in part, at least, Upper Triassic in age); (2) a middle succession of calcareous, carbonaceous, and argillaceous beds up to approximately 2 500 ft thick (Upper Triassic to possibly Lower Jurassic in age); and (3) an upper succession of non-pillowed, andesitic flows, and pyroclastics with sedimentary units (apparently Lower Jurassic in age). Successions (1) and (3) are not differentiated on Fig. 1 and commonly have not been distinguished in reconnaissance mapping.

One occurrence considered to belong to the middle succession is on northern Texada Island 40 miles southeast of Open Bay (Fig. 1). The sedimentary assemblage has been named the Marble Bay Formation (LeRoy 1908, p. 16; McConnell 1914, p. 17) and consists of thick-bedded, rather pure crystalline limestone and magnesian limestone possibly more than 2 000 ft thick which has been shown by Mathews (1947, p. 36, 53) to rest conformably upon andesite–basalt flows and pillow lavas of the Texada Formation (= Texada Group, Texada Porphyrites, Texada Volcanics) several thousand feet thick. The limestone is folded into a syncline that becomes complex toward the northeastern edge of Texada Island, the synclinal axis swinging from a northerly to a northwesterly trend. The upper limit of the limestone is not exposed and no section has ever been measured or described although Mathews (1947, p. 62) distinguished three compositional members on the basis of their magnesium content. Two collections of fossils (including *Lima* ? sp., *Pecten* n. sp. ?, indeterminate ammonites, *Clionites* ?, gastropods, and coral) from the Marble Bay Formation were considered by McLearn as "probably Triassic." Fossils from sedimentary lenses in the Texada Formation (including *Paratropites* sp. and *Hannaoceras* sp.) are reported as belonging to the Karnian stage (Mathews 1947, p. 36).

A very small occurrence of banded hornfels and skarn adjacent to the granitoid rocks at Iron Point on Ulloa Island is considered to be Upper Triassic on the basis of a fragmentary occurrence of *Monotis*, and a similar occurrence at nearby Hidalgo Point on Hernando Island is Lower Jurassic on the basis of the single ammonite *Arnioites vancouverensis* (Whiteaves) (see Bancroft 1913, p. 76).

Skipping the Open Bay section for now, the only other thick sedimentary assemblage in the Vancouver Group which is well exposed along this easterly coast of Vancouver Island is the calcareous–argillaceous assemblage on Harbledown Island 70 miles northwest of Open Bay (Fig. 1). This was described in a general way by Bancroft in 1913 and named by him the Parson Bay Group. From the lower part of this group Crickmay (1928) has described a fauna containing the pelecypod *Halobia* and also the ammonite *Juvavites*? *knowltoni* Smith, and, from a higher part, another fauna containing *Monotis*. Both faunas are considered Norian in age. In the upper part of the section he found a Jurassic ammonoid fauna and on purely faunal grounds he divided Bancroft's unit into a "Parson Bay Formation" of Upper Triassic (Norian) age, and a conformably overlying "Harbledown Formation" of Jurassic age. An unknown thickness of section lying below the Parson Bay Formation but above a thick succession of andesite–basalts ("Valdes Group") is concealed by water.

One other set of occurrences should be mentioned to complete the background. On northwestern Vancouver Island, Dawson (1887, p. 9) recognized a main succession of sedimentary rocks approximately 2 500 ft thick between the upper and lower volcanics of the Vancouver Group. Dolmage in 1918 "provisionally" named the calcareous part of this succession, which is as much as 2 000 ft thick, the Quatsino Limestone, and Gunning (1930) and Hoadley (1953) retained this name in a threefold subdivision of the Vancouver Group in the Zeballos–Nimpkish area: *Karmutsen Group* for the lower unit of submarine andesite–basalts with minor chert, limestone, and argillite (Upper Triassic in part); *Quatsino Formation* for the conformably overlying calcareous

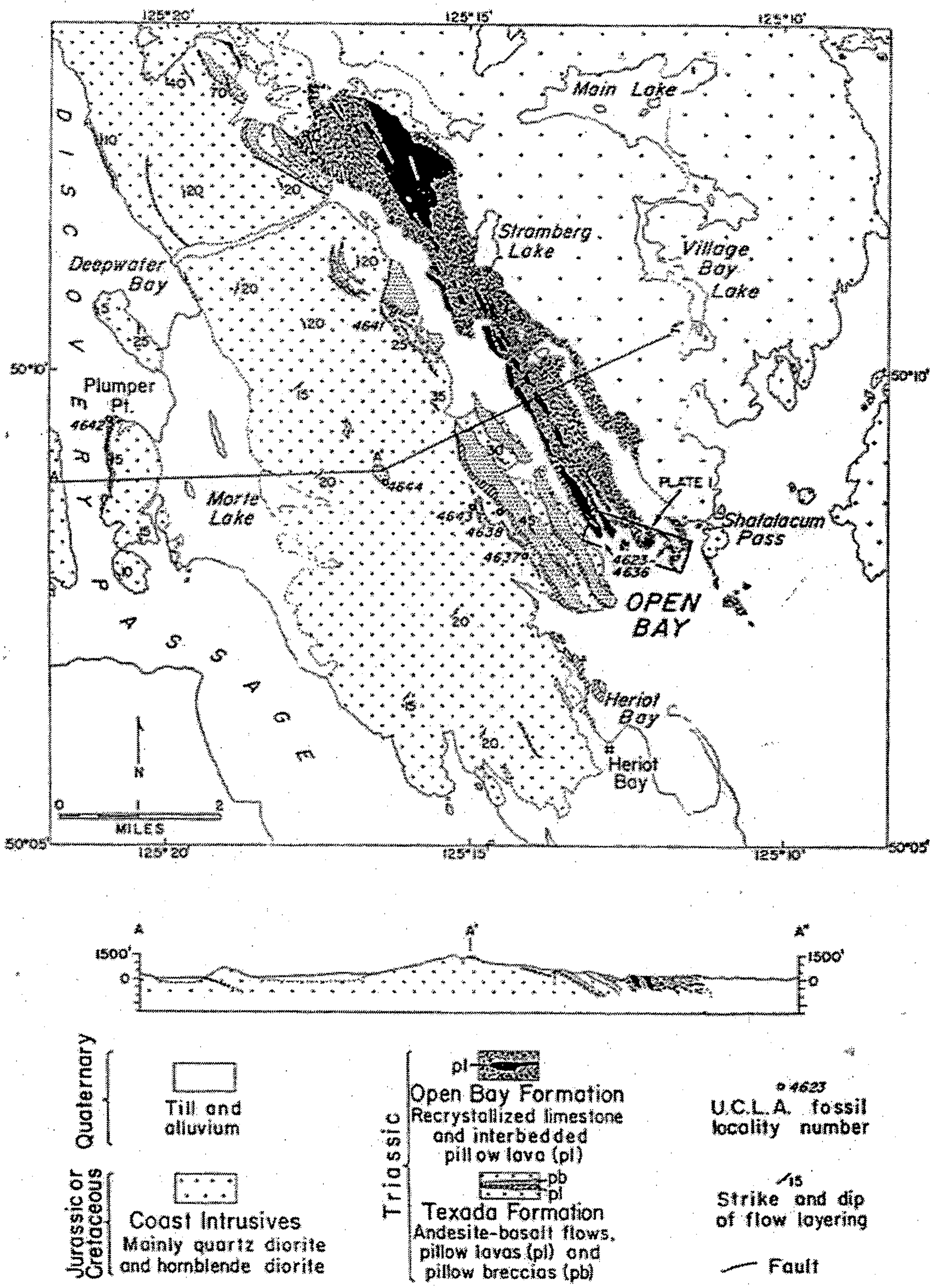

FIG. 2. Generalized geological map of westcentral Quadra Island.

rocks (Upper Triassic); and *Bonanza Group* to include both the conformably overlying tuffaceous and argillaceous sedimentary rocks and also the uppermost unit of andesitic flows, pyroclastics, and very minor limestones of Jurassic (?) age. The ages of these units in the Zeballos–Nimpkish area are based upon some corals, pelecypods, and one ammonite from the lower two units and upon the occurrence of *Monotis subcircularis* about 100 ft above the top of the Quatsino Formation (Hoadley 1953, p. 21). The same subdivisions were recognized by Jeletzky (1954) along the west coast of Vancouver Island.

Thus, we have two sets of names for the units within the Vancouver Group in the northern Vancouver Island area, as shown on Table I. A similar subdivision into (1) Franklin Creek Volcanics; (2) Sutton Limestone; and (3) overlying clastic sedimentary and volcanic rocks and some flows has been recognized on southern Vancouver Island (Fyles 1955).

The section at Open Bay on Quadra Island was first described in 1913 by Bancroft. He felt that he could recognize the Marble Bay Formation on the easterly side of the bay and, on the westerly side of the bay, an overlying unit which he called the Open Bay Group and which, he said, consisted largely of argillite and thin-bedded quartzite or chert. He thought that the Open Bay Group was overlain in turn by the submarine andesite–basalt on the west which he named the "Valdes Group" and which he considered probably correlative with the Texada Formation. Unfortunately the term Valdes (= Valdez) had already been applied to Mesozoic rocks in south central Alaska (Schrader 1900, pp. 408–410). Bancroft made no reference to Dawson's recognition (1887, pp. 20B–22B) of the Vancouver Group on Quadra Island. Cairnes (1914) visited Quadra Island briefly in 1913 and examined many of the mining ventures then in operation in the "Limebelt," a strip of lowland about 1¼ miles wide trending northwesterly from Open Bay for about 8 miles (Fig. 2). He accepted Bancroft's terminology and interpretation of the succession, though he considered the sedimentary rocks to be Mesozoic whereas Bancroft had considered them to be Paleozoic.

H. C. Gunning (in Mathews 1947, p. 36) subsequently recognized that the whole carbonate section at Open Bay is younger than the submarine andesite–basalt on the west and has found Upper Triassic ammonites at the western edge of the bay. These were identified by McLearn as *Hannaoceras*, *Trachysagenites*, *Tropites*, and probably *Discotropites* and *Arcestes* and were considered by him "of probably later Karnian age, representing possibly the fauna of the *Tropites subbullatus* zone" (Mathews 1947, p. 36). This tentative assignment was apparently the first recognition of the *Tropites subbullatus* zone in Canada, although Crickmay in 1930 (p. 26) had suggested a correlation of the lower part of the Nicola Series with the *Tropites*-bearing limestone of California, and elsewhere, without specific reference to the *Tropites subbullatus* zone. The section recorded by Mathews (1947, p. 88) does not show argillites or quartzites referred by Bancroft to the "Open Bay Group" but indicates instead that argillaceous limestone interstratified with volcanic flows or pillow lavas, all with a prevailing northeasterly dip, crop out across the whole bay as follows.

	Thickness, ft
Intensely folded argillaceous limestone and pillow lavas in a belt about 2 000 ft wide on the eastern side of the bay	No thickness given
Argillaceous limestone with at least one greenstone body	500±
Lava	200±
Argillaceous limestone	50−
Ellipsoidal and massive lava	350±
Argillaceous limestone	100+
West edge of Open Bay and "base" of section	

The intense deformation and complexity of structure throughout the section was emphasized by Sutherland-Brown (1958, p. 17). McLearn (1953, p. 1212) suggested, and the present writers support his view, that it is not desirable to divide this assemblage into an Open Bay and a "Marble Bay" Formation. The present writers believe, in addition, that it is not advisable to make a simple correlation with the Marble Bay Formation on Texada Island. In this paper, the term "Open Bay Formation" will be applied to the whole assemblage of deformed carbonate rocks and intercalated pillow lavas exposed in the section at Open Bay and in the Limebelt, i.e. Open Bay Formation will be taken to include the "Marble Bay" (?) Formation as described by Bancroft at Open Bay and also the rocks in the westerly part of the bay which are shown herein to be equivalent.

Contact Relations

Figure 2 is a generalized geological map of nearly all of the central and western part of Quadra Island. The Open Bay section is at the south end of the Limebelt. Limestone, recrystallized to fine- and medium-grained light- to medium-gray marble and covered in large part by till and alluvium up to several tens of feet thick, occupies the topographically lower part of the belt. Interbedded with the limestone and projecting as erosinal highs in this lowland are several elongate bodies of pillowed andesite–basalt and, in the north, one large mass of similar material. West of the Limebelt, forming higher ground, are the massive, amygdaloidal, and porphyritic andesite–basalt flows, pillow lavas, and pillow breccias referred in the past either to the Valdes Group or to the Texada Formation. These volcanic rocks lie on the easterly limb and, in part, on the nose of a broad and irregular anticline plunging at about 15 degrees to the southeast.

The following features might be noted on the map at this stage.

1. In contrast with the deformed Open Bay Formation, the structure in the Texada ("Valdes") volcanic rocks is simple. This is shown especially by the layers of pillow lava and pillow breccias near the top of the formation and on the west side of Quadra Island. Only at the north edge of the map, where the granitoid rocks approach and intrude the volcanics, does the dip of the flows become nearly vertical and in one place overturned steeply to the west.

2. The contact between the Texada ("Valdes") volcanic rocks and the Open Bay Formation is everywhere concealed by glacial till and alluvium. At one place, at the very northern end of the Limebelt a band of foliated limestone about 50 ft thick comes to within 10 ft of the volcanic rocks. The volcanic rocks here are vertical and considerably altered and sheared.

3. The pillow lava within the Open Bay Formation appears as relatively short lenticular bodies, usually aligned, within the folded limestone.

4. The overall trend of the pillow lava lenses (N. 30° W.) is more northerly than the strike of the contact between the Open Bay Formation and the Texada ("Valdes") volcanic rocks. If continued southward the Limebelt structures would butt into the contact of the volcanic rocks with the Open Bay Formation. Likewise the two pillow lavas at the western edge of the Limebelt at Open Bay, and in this sense at the "base" of the section, are traced, with interruptions, into the middle of the Limebelt farther north.

5. On the other hand, some layers in the Texada ("Valdes") volcanic rocks, particularly some pillow breccias near the north end of the Limebelt, appear to be truncated by the concealed contact with the Open Bay Formation.

It is concluded that the contact between the Open Bay Formation and the Texada ("Valdes") volcanic rocks is a zone of detachment and shear and that the base of the Open Bay Formation, therefore, cannot be assumed to be at the contact with the Texada ("Valdes") volcanic rocks on the west side of the bay. The complexity of the structure in the Limebelt (cf. Fig. 12) is not shown on the generalized map (Fig. 2). Two of the lenses of pillow lava, where they can be carefully observed in the good outcrops along the seacoast at Open Bay, are seen actually to form keels of synclines (Fig. 13). Away from the coast, however, exposures are not complete enough to reveal such structures in the lavas.

The Coast Intrusives, mainly quartz diorite and hornblende diorite in this area, are exposed at the eastern edge of Open Bay. The intrusive contact is subparallel to the predominant fold axes and to the pillow lava lenses in the Limebelt for about 5 miles northwestward, after which it trends westward through the Open Bay Formation and into the Texada ("Valdes") volcanic rocks. Skarn and hornfels are developed within a few hundred feet of the contact.

Age and Correlation of the Texada ("Valdes") Volcanic Rocks

In view of the structural discordance between the Texada ("Valdes") volcanic rocks and the Open Bay Formation, their mutual age relation must be established on something more than geographic position and attitude alone. The possibility that the Open Bay Formation could be a thick carbonate unit repeated by faulting from within the lower, volcanic succession in the Vancouver Group should be considered. Enough is known now, however, about this lower, volcanic succession to justify a general correlation of the volcanic rocks on Quadra Island with the lithologically identical pillow-bearing andesite–basalts in the Georgia Strait – Vancouver Island area and to rule out this possibility. On Quadra Island, for example, the minimum thickness of Texada ("Valdes") volcanic rocks, without appreciable structural break and without any carbonate units more than 5 ft thick, is 7 700 ft. If the section continues downward without a major break across Discovery Passage to the west and into rocks of the same lithology on Vancouver Island—the occurrence of similar pillow breccias on the two sides of Discovery Passage suggests that this is the case—then there are several thousand feet more of lavas and pillowed volcanics without an intervening thick carbonate unit. On Texada Island the Texada Formation, lying conformably beneath the Marble Bay Formation and above the upper Paleozoic Anderson Bay Formation, is apparently of the same general order of thickness and of the same lithology including only sporadic lenticular beds of limestone not more than a few feet thick. An essentially similar lithology is found in the several thousand feet of the Karmutsen Group volcanics lying conformably beneath the Quatsino limestone on northwestern Vancouver Island. Furthermore, the volcanic rocks directly above the upper Paleozoic carbonate rocks in the Buttle Lake and Horne Lake areas on Vancouver Island as at Anderson Bay on Texada Island are also of the same general lithology and, at this writing, no carbonate units approaching in thickness the section at Open Bay are known between the Paleozoic carbonates and the top of the lower (volcanic) subdivision of the Vancouver Group in any of these places.

Moreover, the detailed stratigraphy near the top of the volcanic succession and some paleontological evidence supports a correlation of the volcanic rocks on Quadra Island with the Karmutsen Group and the Texada Formation. In all the occurrences mentioned, one or more units of pillow lava and pillow breccia with occasional carbonaceous, cherty, and tuffaceous limestone lenses occur within the massive flows a few hundred feet below the top of the volcanics (Carlisle 1963). Seven fossil localities have been found at the base of pillow lavas within the volcanic rocks on Quadra Island (Fig. 2). The limestones are from a fraction of an inch to as much as 5 ft thick and from a few feet to about 1 000 ft in outcrop length. The two most easterly or stratigraphically highest localities (UCLA Invertebrate Paleontology Collection localities 4 638 and 4 641) are in very carbonaceous, shaley, and cherty limestone and contain only *Halobia* sp., which is abundant as imprints generally about 1 cm across. Commonly these fossils are slightly distorted owing to deformation of the sediment during settling of the overlying pillows. These *Halobia*-rich localities are approximately 500 and 1 200 ft stratigraphically below the highest volcanic rocks exposed. A second group of localities in the volcanic rocks (UCLA localities 4 637, 4 644, 4 643) are from 700 ft to 800 ft stratigraphically below the *Halobia*-rich localities and occur in limestone which is characteristically lighter in color, less carbonaceous, and less fissile than that at the two localities just described. The uppermost occurrence (4 637), ½ mile north of Hyacinthe Bay, is in massive limestone about 3 ft thick above a massive flow and below pillow lava. The fauna is silicified, consisting of undetermined very thin-shelled pelecypods and a single poorly preserved specimen of *Paratropites*. The remaining two localities in this group contain undetermined pelecypods, gastropods, and crinoid stems. The only other occurrence of fossils (UCLA locality 4 642) is at Plumper Point on the west shore of Quadra Island, again at the base of a pillow lava. Although only a few inches thick, the limestone contains abundant silicified crinoid stems, solitary corals, and gastropods. This occurrence is separated from the rest of Quadra Island by a belt of glacial sediments occupying the lowland southward from Deepwater Bay. The lowland is not thought, at this time, to represent a major separation in the section.

The occurrence of *Halobia* and *Paratropites* places these rocks in the Karnian stage of the Upper Triassic, *Paratropites* usually being restricted to the *Tropites subbullatus* zone. *Paratropites* occurs also in the Texada Formation on Texada Island in association with *Hannaoceras* (Mathews 1957, p. 36) and in the uppermost Karmutsen volcanics in the Campbell River area where it is associated with a unique fauna apparently belonging in the lower part of the *Tropites subbullatus* zone (Givens and Susuki 1963).

On purely lithologic grounds, then, the volcanic rocks west of Open Bay on Quadra Island can be assigned with certainty to the Karmutsen Group within the larger Vancouver Group and are correlative with the Texada Formation on Texada Island. Confirming the opinions of Gunning and Mathews, it must be concluded that the Open Bay Formation is younger than these volcanics. In line with the usage of Mathews, the name "Valdes" should be abandoned. The volcanic rocks may be called Texada Formation with the understanding that they are also a part of the Karmutsen Group. At present the Karmutsen Group has not been subdivided, but mapping in progress suggests that a realistic subdivision will be possible.

STRATIGRAPHY AND PALEONTOLOGY OF THE OPEN BAY FORMATION

Fossil Localities, Lithology, and Correlation within the Formation

Many of the fossils at Open Bay are apparently undeformed, others are so badly distorted that they are indeterminable, and still others remain only as light-colored marble lensoids or streaks along the foliation of the marble. Fourteen separate localities (UCLA localities 4 623 to 4 636 inclusive, Fig. 12) were found, several of which are at equivalent horizons. All of these collections fall, on the basis of lithology and fauna, and, to some degree on structural interpretation, into two main stratigraphic positions shown on the several partial columnar sections in Fig. 3. As can be seen, if the correlations are accepted, the total thickness of fossiliferous strata is not very great, some 60 ft of folded and flow-deformed limestone in the upper group of seven sections and a lesser thickness of highly deformed limestone below pillow lava in the lower two sections. The best development of the *Tropites* fauna is in the upper group and actually in only some 30 feet of this. Recognizable ammonites are found in the lower two sections also, but the beds are strongly transposed and most of the fossils are destroyed. Figure 14 shows typical deformation of fossiliferous layers from the upper group of sections. The disruption and

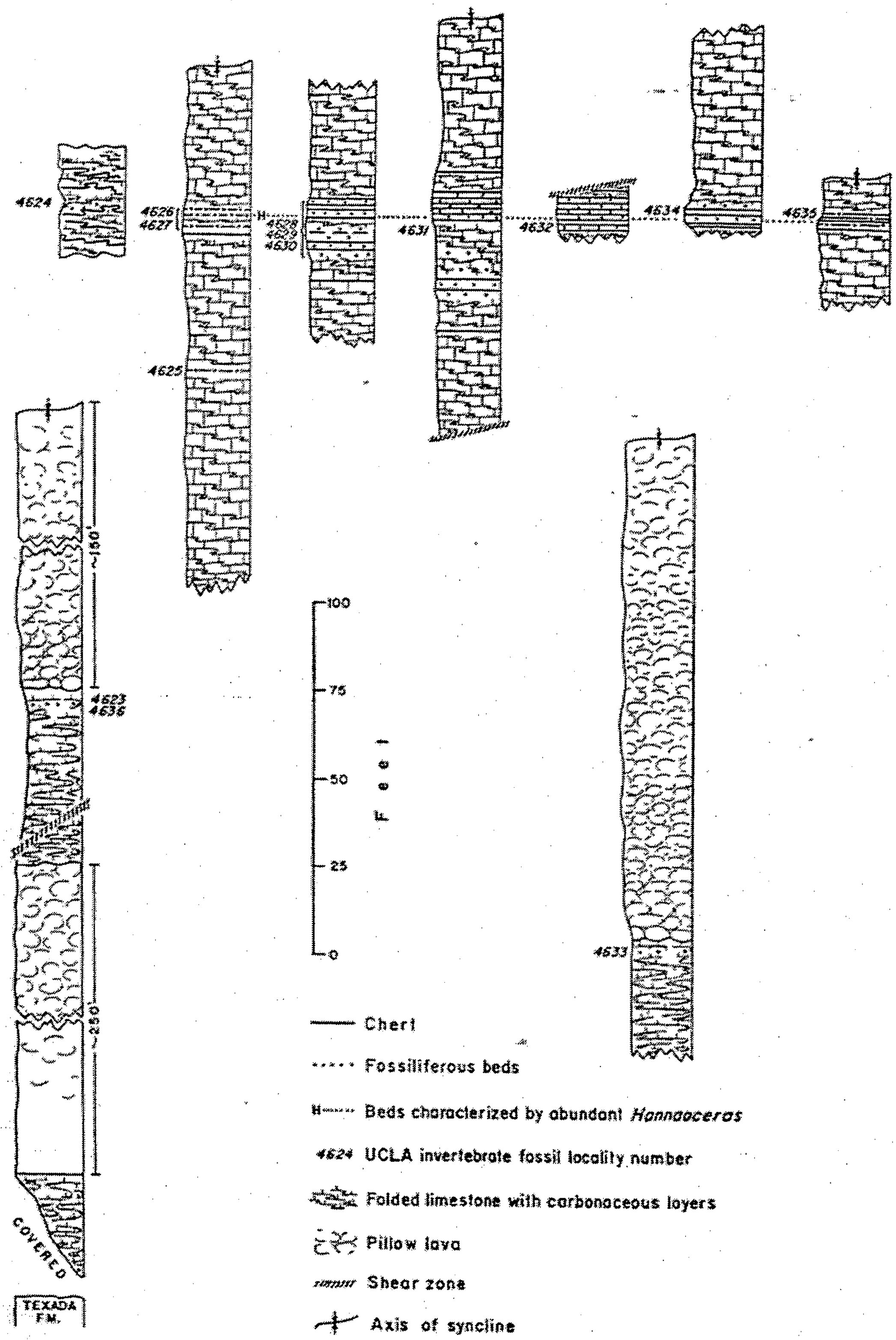

FIG. 3. Partial columnar sections showing the fossiliferous rocks at Open Bay. The *Tropites* fauna is best represented in the upper group of seven sections.

boudinage of the thin, cherty beds is a characteristic manifestation of tectonic stretching of the strata in the direction of fold axes.

The basis for this subdivision and correlation within the Open Bay section must now be discussed. The entire section is shown in Fig. 12, a map, and in Fig. 6, three qualitative profiles taken at right angles to the principal fold axes. Beds containing the fossils, though contorted, can be traced for as much as 300 ft along strike in a few places, and firm correlations across some folds can be made by attention to drag folds and to the detailed lithologic succession. Thus localities 4 626 and 4 627 are in equivalent beds on the two limbs of a syncline. Localities 4 628, 4 629, and 4 630 are all on the complex southwesterly limb of another syncline and are equivalent beds. Locality 4 631 is on the northeasterly limb of this same fold and also in equivalent beds.

The second kind of evidence for the subdivision and correlation is lithological. The well-developed *Tropites* fauna is invariably in light- to medium-gray deformed marbleized limestone associated with chert beds. Some of these chert beds are black and a few inches thick, but in the most fossiliferous horizons they are thinner, reddish-colored, and pyritic. Characteristically they are highly contorted, brecciated, and boudinaged within the thin-bedded marbleized limestone (Fig. 15).

It is thought that particular chert beds can be recognized from one locality to the next though the stratigraphic thickness of the intervening limestone varies up to sixfold owing to thickening and thinning during deformation, and the number of thin chert beds in the heavily fossiliferous portion is variable (Fig. 3). In the field and under the microscope, both the limestone and the chert beds are similar at the several localities. Above and below these fossiliferous strata for an observed structural thickness of as much as 200 ft, the limestone is relatively free of chert and characteristically banded in alternating layers of medium-gray non-fissile recrystallized limestone up to 2 ft thick and layers of black, crudely fissile, very carbonaceous recrystallized limestone, up to 8 in. thick (Fig. 16). The layering is bedding deformed by flexural slip and flow.

Contrary to Bancroft's descriptions, neither thick quartzites nor argillites occur in the Open Bay section. The dark layers are richer in carbon than in clay or clay-derived minerals.

A third kind of evidence for the correlation of the localities is provided by the fauna itself.

Fauna at Open Bay

The assemblage recognized at Open Bay is listed in Table II. Comparison of these forms with the fauna of the *Tropites subbullatus* zone of northern California (Smith 1927) clearly substantiates McLearn's tentative assignment of the Open Bay fauna to this zone. Every genus found at Open Bay is found also in the California section. Occurrences of *Tropites*-bearing fauna in Canada and western United States are shown in Fig. 5 and a comparison of the fauna is shown in Table III (see also Tozer 1961*b*, pp. 10–15).

TABLE II

Fauna at Open Bay showing occurrence of taxa* in the *Tropites dilleri* and *Tropites welleri subzones*† of the *Tropites subbullatus* zone in Northern California

Fauna	*T. dilleri*	*T. welleri*	UCLA invertebrate fossil locality 4623	4624	4625	4626	4627	4628	4629	4630	4631	4632	4633	4634	4635	4636
Spirogmoceras sp.	x								x		x					
Californites cf. *C. careyi* (Smith)	x							x								
Traskites (*Shastites*) cf. *T.* (*S.*) *compressus* (Hyatt & Smith)	x													x		
Traskites (*Stantonites*) cf. *T.* (*S.*) *rugosus* (Hyatt & Smith)	x								x		x					
Hannaoceras sp.	x	x		x	x	x	x	x	x	x	x	x		x		
Tropites dilleri Smith	x							x	x	x	x	x		x		
Tropites cf. *T. dilleri* Smith	x			x		x	x	x	x	x	x	x	x	x	x	
Tropites cf. *T. welleri* Smith		x					x	x	x							
Tropites sp. A	?	?		x				x			x					
Tropites sp. B	?	?					x				x					
Discotropites cf. *D. sandlingensis* (Hauer)	x	x			x	x		x	x		x				x	
Discotropites sp.	?	?					x	x	x	x	x	x		x		x
Paratropites sellai (Mojsisovics)	x					x		x	x		x				x	x
Gymnotropites cf. *G. americanus* (Hyatt & Smith)	x								x							
Tornquistites (?) sp.	x										x					
Bacchites cf. *B. bacchus* (Mojsisovics)	x									x						
Leconteiceras sp.	x					x	x	x			x					
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics	x	x					x	x	x	x	x					
Arcestes sp.	x	x				x	x		x	x	x	x		x	x	
Halobia (?) sp.				x					x						x	
Isocrinus sp.			x										x			x

*Identifications are based mainly on the external morphology; surficial detail and suture lines generally are not preserved.
†Silberling 1956, p. 1152; 1959a, p. 21.

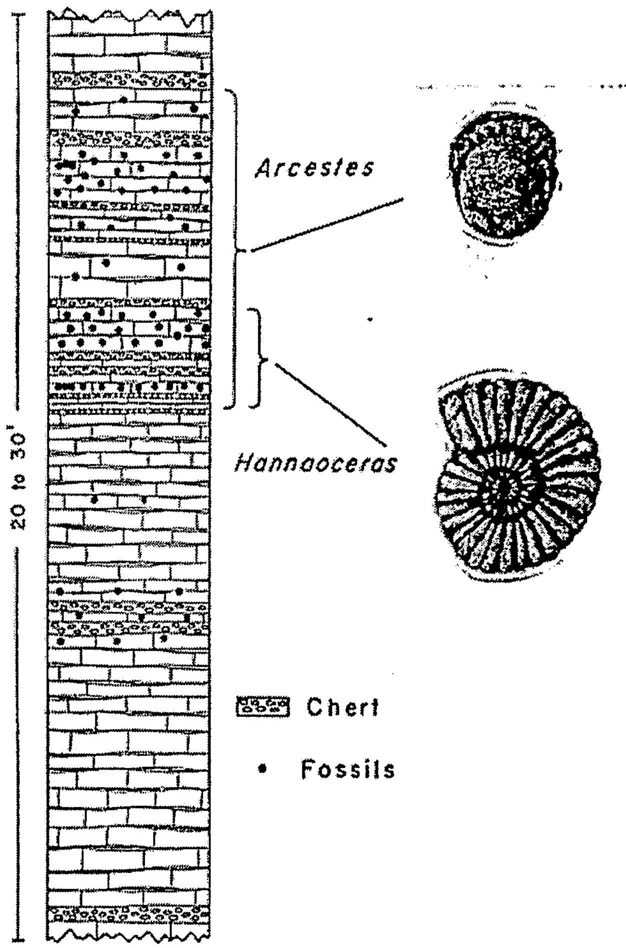

FIG. 4. Restricted distribution of *Arcestes* and *Hannaoceras* within the upper sections of Fig. 3. Other genera are not thus restricted.

The distribution of the fauna within the section at Open Bay is interesting (Fig. 4). All of the genera found range through at least a large part of the *Tropites subbullatus* zone and perhaps farther. Nevertheless, in every locality where the *Tropites* fauna is well developed, *Hannaoceras*, the most abundant genus, is restricted to a single group of limestone beds totalling 1 to 3 ft in apparent thickness associated with from two to four ferruginous cherty layers. These beds are in the lower part of the most fossiliferous 5 to 10 ft of strata, or approximately in the center of the 30 ft, or so, of cherty limestone in which the *Tropites* fauna is best developed. *Hannaoceras* constitutes up to 50% or even 70%, of the forms present. *Arcestes*, the next most abundant genus, is found within this same small interval and also in the beds above it for several feet where it, too, may constitute up to 70% of the forms, but *Arcestes* is nowhere found in the beds below *Hannaoceras*. The reason for these small-scale differences in faunal occurrence is not clear, and certainly no regional or general restriction of the two forms is implied here. It is interesting that neither of

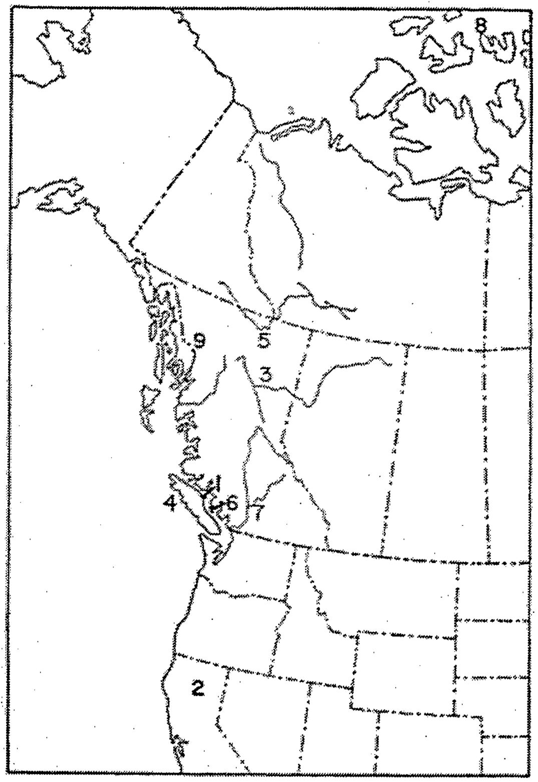

FIG. 5. Location of faunas in Table III.

these abundant genera is recognized as an important guide fossil for the Upper Karnian. Very likely the distributions reflect local environmental factors. In fact, the unusual abundance of ammonites in association with chert beds suggests, especially if the chert is organic in origin, an unusually abundant food supply at certain times and the consequent influx of the predatory molluscs. If the environmental control was purely local and of this nature, it could also have been cyclical, and in this event several successive chert-rich ammonite-bearing sequences could have formed, each showing a similar succession of competitive species. If so, the faunal evidence for correlation of the disconnected sections would be vitiated, but in view of the detailed lithologic similarities, and particularly the spacing and succession of chert beds, the correlations appear reasonably certain.

Tropites is the third most abundant genus overall and, in many beds, it is the dominant form constituting up to 50% of those present. *Tropites dilleri* Smith is very common and is present throughout most of the fossiliferous section, being most abundant in the beds where *Hannaoceras* displays its greatest development (Fig. 8B). *Tropites* supposedly restricted to the *T. welleri* (Silberling 1959*a*, p. 21) or *T. dilleri* (Silberling 1956, p. 1152) subzones of the *T. subbullatus* zone in California are represented, but, considering the fauna as a whole (see Table II), assignment of the beds at Open Bay to the *T. dilleri* subzone is strongly indicated.

Whether or not the precise correlation of the several localities at Open Bay

TABLE III

Comparison of the *Tropites* fauna at Open Bay with other occurrences in Canada and Western United States (based on the distribution of genera)

	Open Bay, Quadra Island (this paper)	Shasta Co., Calif. J. P. Smith 1927	Peace River Foothills McLearn 1960	West Coast Vancouver Is. Jeletzky 1950; 1954	Toad River – Tuchodi Lake Tozer 1961*b*	Texada Island Mathews 1947	Ashcroft Map area Duffell and McTaggart 1952	Arctic region (Canada) Tozer 1961*a*	Iskut River area Souther 1960
Spirogymoceras sp.	x	x							
Californites cf. *C. careyi* (Smith)	x	x							
Traskites (*Shastites*) cf. *T.* (*S.*) *compressus* (Hyatt & Smith)	x	x							
Traskites (*Stantonites*) cf. *T.* (*S.*) *rugosus* (Hyatt & Smith)	x	x							
Hannaoceras sp.	x	x	x	x	x	x			
Tropites dilleri Smith	x	x							
Tropites cf. *T. dilleri* Smith	x	x							
Tropites cf. *T. welleri* Smith	x	x	x						
Tropites sp.	x	x			x		x	x	x
Discotropites cf. *D. sandlingensis* (Hauer)	x	x	x						
Discotropites sp.	x	x			x		x		
Paratropites sellai (Mojsisovics)	x	x				x	x		
Gymnotropites cf. *G. americanus* Hyatt & Smith	x	x							
Tornquistites (?) sp.	x	x							
Bacchites cf. *B. bacchus* (Mojsisovics)	x	x							
Leconteiceras sp.	x	x							
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics	x	x	x						
Arcestes sp.	x	x	x						

shown in Fig. 3 is accepted, it is clear that all of them represent the *Tropites subbullatus* zone and that the same or very closely related beds containing them crop out across at least two-thirds of Open Bay. Except for some of the beds in the skarn zone within a few tens of feet of the contact with quartz diorite of the main Coast Intrusives, the same kinds of lithology can be found from one end of the Bay to the other and also inland for the entire length of the Limebelt. To date fossils have been found inland at only one place (west of the Lucky Jim mine on the road to Granite Bay) where a much weathered *Tropites* sp. was identified. It should be noted that this occurrence lies to the west of the well-defined line of pillow lava lenses, the southeasterly end of which is at the *west* edge of Open Bay and according to an older interpretation, therefore, near the base of the limestone succession. McLearn's suspicion is clearly correct that no simple distinction can be made between an "Open Bay Group" and a "Marble Bay Formation" at Open Bay.

Little significance is attached to the paucity of *Halobia* in the Open Bay

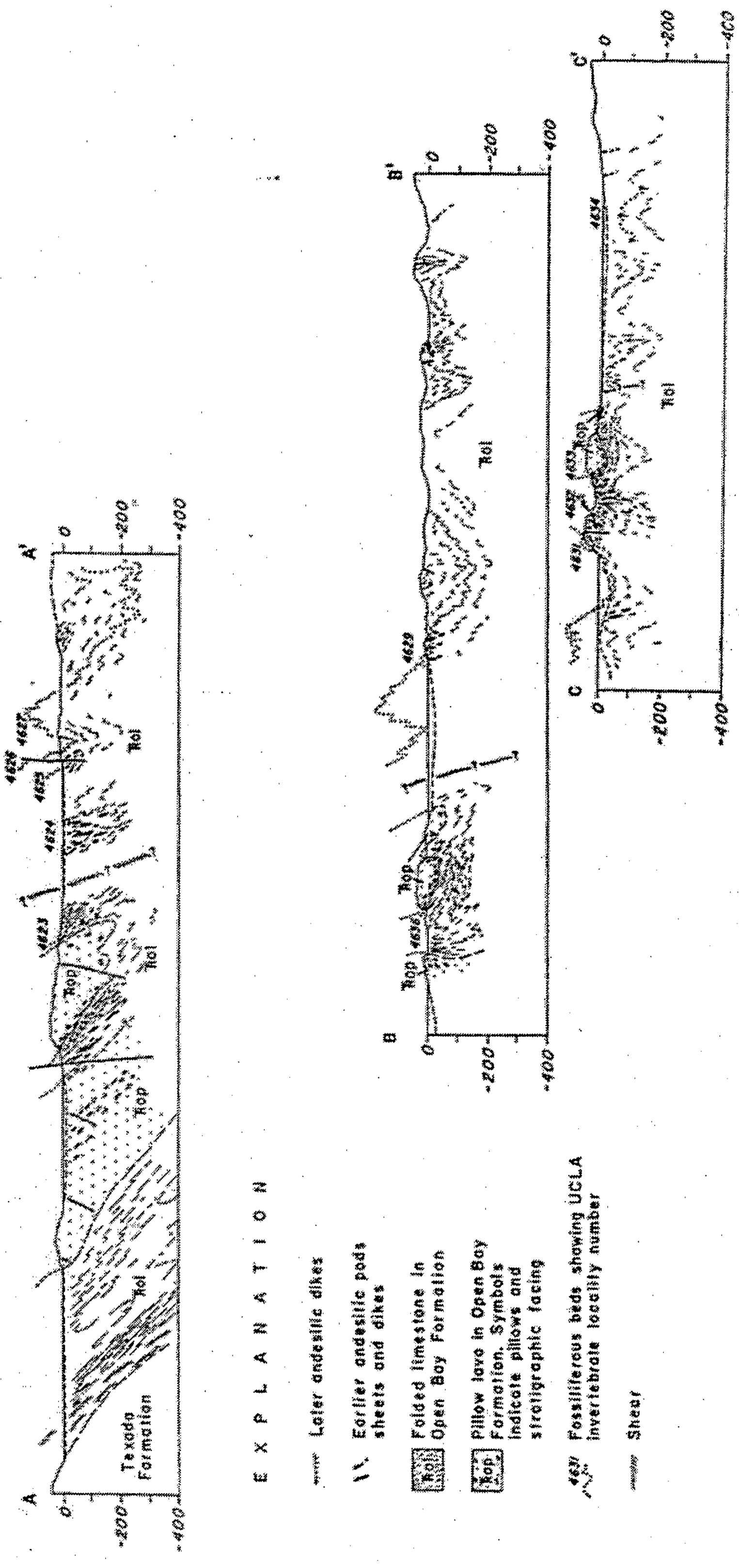

FIG. 6. Qualitative structural profiles, Open Bay.

section as compared to its abundance in the very carbonaceous, very fissile interlava limestones or in similar rocks in other Upper Triassic localities along the coast of British Columbia. *Halobia* tends to occur abundantly mainly in interbeds of dark shaley limestones, the very rocks which, at Open Bay, have taken up much of the flexural slip with consequent destruction of fossils.

STRUCTURE IN THE OPEN BAY FORMATION AND ITS RELATION TO IGNEOUS ACTIVITY

Before considering the lithologic correlation of the Open Bay section itself with other Triassic sections in southwestern British Columbia, attention must be given to the structural relations within it. These bear upon the integrity of the section and upon its relation to the Texada Formation and they also provide an interesting insight into the sequence of events which just preceded emplacement of the Coast Intrusives in this area. The exposures provide excellent examples of the introduction of strength heterogeneities during deformation.

Mesoscopic Folds and Fabric Elements

Bedding

In spite of the strong internal deformation and thickening and thinning of every limestone bed, and in spite of the obvious slippage in the finer grained carbonaceous layers and the disruption of brittle cherty layers, bedding, or some vestige of it in various stages of deformation, is still visible in most outcrops. Primary bedding, therefore, is a principal structural or fabric element, designated here by the symbol S_1.

Folds in Bedding

Folds in S_1 occur at scales from a fraction of an inch to a few hundred feet across. They can be divided on the basis of size into four categories.

The larger folds are nonplane, noncylindrical folds from 200 to 500 ft across as shown on the map (Fig. 12), in three qualitative cross profiles (Fig. 6) and in the illustration of folded pillow lava (Fig. 13). Between 15 and 20 of them occur across Open Bay. Those well-exposed along the seacoast, which is to say those involving pillow lava within the Open Bay Formation, are decidedly asymmetric and overturned, mainly to the west. Axial surfaces are inclined at from about 55° to near vertical and are appreciably curved both in strike and dip. Fold axes, similarly curved, plunge at up to 20°, both to the northwest and the southeast. Although no single fold can be seen in its entire profile these larger folds in the Limebelt are obviously much smaller and much tighter than the very broad folds in the Texada Formation to the west.

Upon these larger folds in the limestone beds (less so in the pillow lavas) are very many lesser folds, roughly 5 to 40 ft across having the appearance and orientation of drag folds and conforming generally in plunge with the larger folds. Both the axes and the axial surfaces are more variable and curved within a given fold or between folds, however, than are those of the larger folds. Axial surfaces are inclined from about 45° northeasterly to 60° southwesterly, but their strikes are generally within 15° of the strike of the enveloping larger fold. The style of folding is "similar" (Fig. 17) and the folds are usually moderately open, their amplitude being about the same as their width. Next to pillow lava, however, these lesser folds tend to be isoclinal, the limbs are tightly appressed and disrupted and much transposition of bedding has occurred. This is well shown on Lost Willie Island, at locality 4 623 and immediately west of the folded pillow lava near locality 4 632 midway across the bay. At this last place, distinctive chert beds can be followed for only short distances in diversely plunging folds; hinges become rootless on one or both sides and the whole orientation of the section is lost in complex isoclinal folding. A few feet farther west, in continuous outcrop, fossiliferous beds of locality 4 624 are in tight recumbent chevron folds beneath a minor southwesterly dipping thrust fault and the stratigraphic facing there cannot be reconciled with that of the pillow lava on the east. Even within the fossiliferous beds the chert–limestone layers are commonly stretched or crumpled or cannot be traced through complex flowage patterns.

Parasitically upon the lesser folds are innumerable minor folds from an inch or so to about 2 ft across, many of which again have the characteristic shapes and orientation of drag folds but have axial surfaces more variable and curved than the enveloping folds. Commonly the axial surfaces are divergent or fanned though, again, the general direction of the fold axes may be parallel to the axes of the lesser and larger folds. Commonly the minor folds are disharmonic (Fig. 18), successive beds being folded in markedly different form but with the same overall curvature. Some axial surfaces of folds branch in a complex pattern. One frequently sees, especially near the hinges of folds, the common tendency for thinner competent interbeds of chert or cherty limestone to be more strongly and irregularly folded than thicker competent interbeds. Some thick chert beds

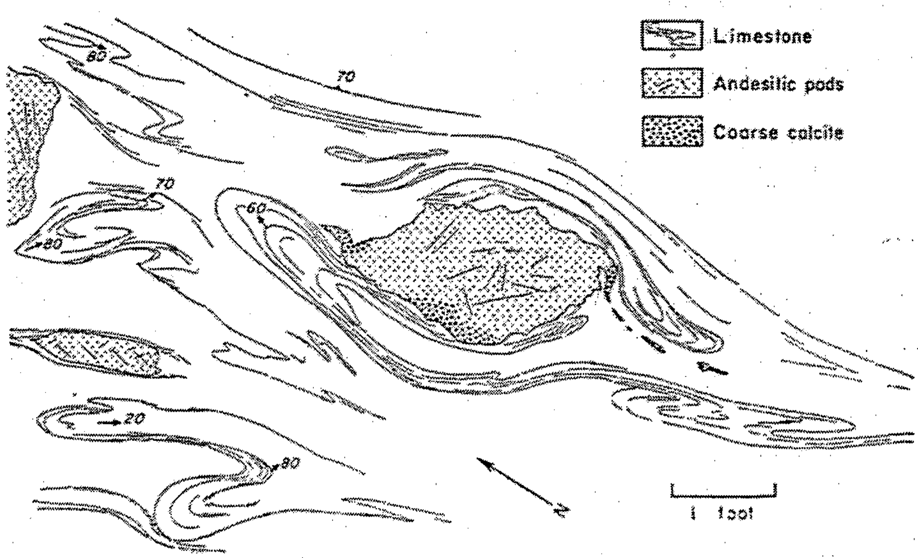

FIG. 7. Minor folds deformed by local adjustment around deformed andesitic pods, near fossil locality 4 625.

show lobate or ptigmatic folds. Nevertheless, in many places, the several axial surfaces tend to have a common line of intersection, at least locally, which is the fold axis for the several folds. The axes of these minor folds are readily measured in the field and where consistent over an appreciable area, they define a fabric element B_1.

In addition there are many minor folds whose orientation is quite unrelated to the larger or lesser folds and is obviously a result of local adjustment where limestone has been forced to flow around buttresses or fragments of more competent rock (Fig. 7).

A fourth category of folding—microfolds on the bedding and transposed bedding surfaces—results in the almost pervasive lineations discussed below (Fig. 19).

Foliation

Metamorphic foliation (S_2) expressed through the preferred orientation of calcite grain boundaries, by alignment of crenulations in light and dark layers, and, in a few places, by the orientation of metamorphic hornblende crystals, is developed in varying degrees through much of the section. Usually it is consistent in attitude over appreciable areas and where bedding can still be followed is clearly parallel to the axial surfaces of folds in S_1. Within a few tens of feet of the folded pillow lava bodies where the adjacent, less competent, marble has taken the bulk of the strain and transposition of bedding parallel to axial surfaces is intense, S_2 is the dominant fabric element and is commonly expressed by well-developed cleavage. Elsewhere cleavage is only weak or not apparent at all and shear is not obviously an important mechanism of deformation. Otherwise the style of foliation is essentially the same wherever it is seen varying only in the intensity with which it has been developed. Although fossils are rarely preserved in areas of strong bedding transposition, the development of strong axial plane foliation itself, as at locality 4 631, does not necessarily destroy fossils. In fact, the crumbly character of the recrystallized limestone in such places enhances the differential resistance of the fossils to erosion.

Lineation

Lineation (L_1) parallel to the axes of most folds in S_1 is expressed by the hinges of crenulations or microfolds in S_1, as mentioned above, by the preferred orientation of calcite grain boundaries; in a few places by the long axes of metamorphic hornblende crystals; and, in some areas of strong bedding transposition, by small chert boudins or rods and by light and dark streaks of marble derived from the earlier crenulations. Well-developed foliation surfaces always show lineation in one form or another. Lineation L_1 also is expressed very crudely in pillow lava near the hinges of folds by elongation of the pillows. Ideally, elongation of fossils should provide a measure of L_1 also, but, in fact, the deformation of the beds containing fossils has been so influenced by very local inhomogeneities in strength, as discussed below, that the elongations are random.

Lineation L_1 tends to be rectilinear over fairly large areas and in some places is much more consistent in direction than are minor fold axes. This again is thought to reflect, in part, the fact that many of the minor folds are not truly parasitic upon larger folds but represent local adjustment around buttresses or competent blocks of rock introduced late in the deformation sequence. In areas where the northwesterly trend of major and minor fold axes is strong and consistent, however, direction L_1 tends to agree precisely with fold axes.

A second lineation, L_2, has been recognized on Lost Willie Island along the axes of small folds and crenulations in S_2.

Intrafold Pods, Sheets, and Dikes

At this point attention must be given to a third group of rocks: In addition to the pillow lavas and the recrystallized limestone with ubiquitous thin carbonaceous layers and relatively few cherty beds, one of the most noticeable features in the section at Open Bay and throughout the Limebelt is the occurrence within the limestone of innumerable irregularly shaped pods, crude lenses or lenticular sheets from a few inches to 100 ft in length composed of greenstone or andesite (Fig. 7; Fig. 20). The long direction of the pods or sheets in map view has a pronounced northwesterly preferred orientation essentially parallel to the traces of the axial surfaces of the folds. Commonly several lenticular pods of similar size and with a common northwesterly orientation lie along a single northwesterly line, the limestone bands pinching and bulging around each pod, and the first impression that one gets is that these are ordinary boudins formed by the disruption and distortion of competent andesite sills in the limestone during deformation of the whole section. There are several pods, however, which lie irregularly athwart fold axes. Commonly also, the pods are in clusters with random sizes and positions, rather than in line, but still having the preferred northwesterly orientation (Fig. 8). Closer examination may reveal that the sides of the pods are highly cuspate or irregular and there are even occasional fingers of greenstone a fraction of an inch to a few inches across and up to several inches long which project from the pods across the adjacent limestone layers or, in some cases, along the layers as small sills. A marble rim, whiter and slightly more coarsely crystalline than the rest of the limestone, is found to completely surround many of the pods, including several pods having a relatively small amount of deformation in the immediately adjacent limestone. This is interpreted as thermal recrystallization around an intrusive. Finally, as shown in Fig. 21, some of the pods are not boudin-like lenses at all, but have a large part of their mass in arms which project across the folded limestone as dikes or dislocated dikes.

The pods are not easily observed in three dimensions but in the dozen or so places where both the dip and the strike of the more tabular pods can be seen, their attitude is closely parallel to the axial surfaces of the predominant folds in the limestone, that is to say, parallel to the metamorphic foliation, S_2. In at least two places, the pods or lenticular sheets occupy the axial surfaces themselves of lesser folds. In only three places were pod sheets seen to curve around the crest and down the limbs of a fold. Otherwise pod sheets were not seen in matching positions across fold axes. About midway across Open Bay, at fossil

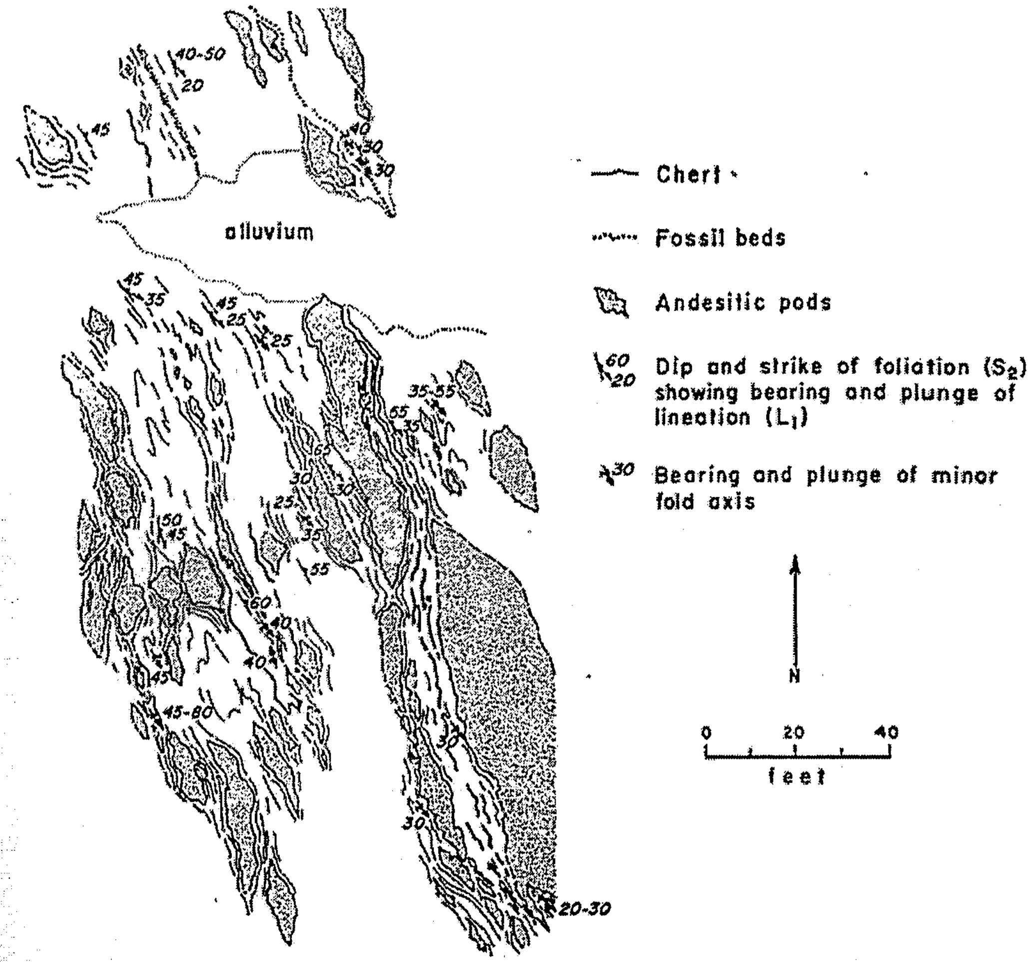

FIG. 8. Aligned andesitic pods in folded limestone at fossil locality 4 624.

locality 4 632, a lenticular sheet of the same altered andesite occupies a small westward dipping thrust fault and near its southerly end the sheet appears to be folded itself.

The andesite pods and sheets, therefore, are intrusive bodies, most of which were emplaced after an initial period of strong folding of the limestone. The bulbous shapes of the pods, and the intense crenulation of the adjacent limestone suggests that both rocks were in a highly mobile condition at the time of intrusion.

But it is also perfectly clear that many of the pods or pod sheets are deformed themselves. Dike-like apophyses are disrupted and folded along the same trend as folds in the limestone. Some pods have sharp, fractured terminations. Others show typical boudinage features, particularly drawn-out tapering ends as if the pods were pulled apart along the northwesterly–southeasterly trend. This, along with the boudinage of some cherty layers, implies a stretching of the section along the axial surfaces of folds and presumably along the axial direction itself. Small pods are commonly deformed and oriented around the tapering ends of larger ones. At least one of the three pod sheets mentioned above as curving around the crest of a fold in limestone appears to have been folded after emplacement. And, in thin section, most pods show strong internal deformation, fracturing, preferred orientation of grains and pervasive alteration of minerals.

More significantly, many pods are cut by later andesitic green dikes from a few inches to a few feet thick which transect the whole section, but are themselves disrupted, folded along northwesterly–southeasterly axes and in some instances, boudinaged by the subsequent deformation. The fractured ends of these dikes are commonly separated a few feet along axial surfaces of the folds (most commonly in a left sense). Many of the dikes are folded about minor fold axes and, in turn, the axial surface foliation, S_2, in the limestone is commonly deformed around the disrupted ends of dikes (Fig. 22). Such late deformation around broken dikes and parts of andesitic pods and their apophyses explains the very discordant character of the folding in the limestone adjacent to these more competent bodies.

It appears, therefore, that folding along substantially the same northwesterly axes, beginning before intrusion of the pod sheets, continued throughout their emplacement and the emplacement of some later andesitic dikes as well. The section became increasingly inhomogeneous; minor folding adjacent to the new intrusives was increasingly discordant and some earlier formed minor folds and lineations were deformed. However, much of the best defined foliation and lineation is consistent in attitude over fairly large areas, more so than are the minor folds, suggesting that, in large part, it has resulted from early foliation and lineation reinforced later in the folding episode or that it is entirely late in origin.

A few still younger, reddish or grey unaltered andesite dikes cut all the structures described. Some of these are along vertical northeasterly fractures, others occupy flat to gently dipping fractures, both attitudes being common for fractures in the granitic rocks to the east. One such dike on the northeast edge of the map area (Fig. 12) cuts both folded limestone and quartz diorite. A half dozen coarse-grained quartz diorite porphyry dikes from 2 to 20 ft wide occupy steep northeasterly fractures in the middle of the Open Bay section and tongues or irregular dikes and dikelets of similar composition, clearly apophyses from the main Coast Intrusives, have filled northwesterly fractures on the easterly edge of the bay and on islands closer to the main granitic mass. None of these younger dikes are obviously folded though they are cut by minor faults. Immediately east of the area shown on the map (Fig. 12) the main body of quartz diorite transects folded limestone and andesitic pod sheets. Strong foliation and lineation in the contact skarn has controlled the distribution of coarse vesuvianite crystals but the vesuvianite crystals themselves are neither appreciably distorted nor rotated within their matrix. Apparently folding along the northwesterly axes was not significant after emplacement of the granitic mass.

Geometric Relations

Approximately 480 minor fold axes (B_1) and lineations (L_1) were measured in the limestone across the whole of Open Bay and plotted in the usual way on an equal-area stereonet lower hemisphere (Fig. 9). Most of the fold axes and the lineations, whether pre- or post-intrusive pod sheets, lie close to a pronounced N. 44° W.–S. 44° E. trend and they plunge either gently to the northwest (20°) or gently to the southeast (30°). In addition to these maxima there are weak maxima for axes plunging gently to the north-northeast and for others plunging gently south-southwest. About 200 metamorphic foliations (S_2) were measured the poles of which (Fig. 9) might be construed as defining an axis. However, since the composite diagrams for all the fold axes and all the foliation poles show several maxima, and since there was already reason, from the curvatures of axes and axial planes of folds, to suspect repeated deformation, 10 subareas having apparently greater homogeneity than the area as a whole were delineated and separate projections were made for each. These are shown in Fig. 9.

It can be seen that the northwesterly–southeasterly trend of lineations, minor fold axes, and foliations is predominant over the larger part of the bay, though subareas I and X adjacent to folded pillow lava and subareas VIII and IX near the batholith contact are notable exceptions. Except for subareas V and X, each diagram has a single reasonably unique maximum—or an incomplete girdle with a maximum—for lineations and minor fold axes and, where measurements could be obtained, each diagram has a fairly well-defined concentration or an incomplete girdle of poles to S_2.

East-westerly Flexing, Unfolded B_1 Axis

Wherever S_2 is well defined and substantially uniform in attitude, as in subareas I, II, III, IV, and VI, axial plane foliation dipping steeply to the northeast is associated with lineations and minor fold axes plunging gently to the southeast whereas axial plane foliation dipping steeply to the southwest is associated with lineation and minor fold axes plunging gently to the northwest. This is true statistically as shown in the diagrams and it is also true in most particular observations where S_2 and L_1 or B_1 can be measured in association although locally and in detail there are erratic culminations and depressions on the minor folds and other irregularities related largely to the intrusive pods and sheets mentioned above. Nevertheless the overall relationship is clear enough and along with the observed curvatures in the axes of larger folds, it suggests gentle cross-folding or flexing on a fairly broad scale. From the pattern of maxima it is possible to postulate a particular axis of cross-folding if one assumes that the predominant northwesterly folding had been plane, upright, and along rectilinear horizontal axes producing an initially vertical axial plane foliation, S_2, and a horizontal lineation, $L_1 = B_1$. Later (Fig. 10*a*) gentle upright folding on a second rectilinear axis, B_2 (an axis of rotation) then would have caused either one or both of the initial S_2-pole and $L_1 = B_1$ maxima to spread from their peripheral positions in stereographic projection along small or large circles centered on B_2. Maxima might be expected on these new girdles corresponding to limbs on the second folds. Consider alternative possible

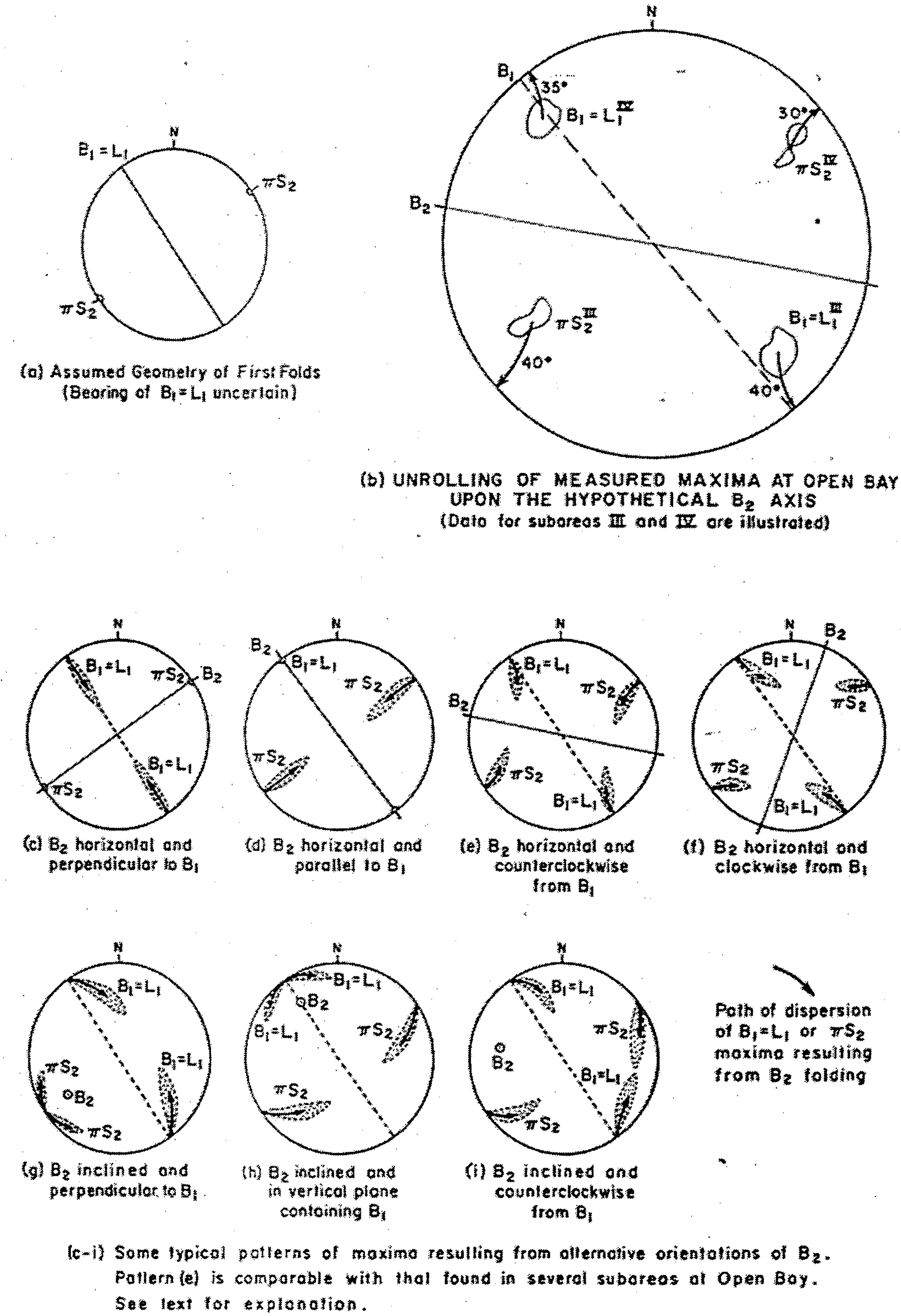

FIG. 10. Determination of second fold axis B_2. The method involves comparison of patterns of $L_1 = B_1$ and S_2-poles after rotation upon hypothetical B_2 in several alternative orientations.

orientations of the postulated axis, B_2 (Fig. 10*c–i*). Of the several patterns of girdles and maxima resulting from alternative orientations of B_2, under the assumptions stated, only one (Fig. 10*e*) resulting from an approximately horizontal B_2 axis bearing counterclockwise from B_1, compares with the pattern found in the part of Open Bay under consideration. Only in this one are the maxima diametrically opposed in alternate quadrants with $L_1 = B_1$ and S_2-pole maxima associated as in Fig. 9 subareas I, II, III, IV, and VI, and about equally removed from the periphery. If one then tests the conclusion by unrolling the observed Open Bay maxima to the peripheral circle around a postulated horizontal B_2 axis bearing N. 80° W. (Fig. 10*b*) he finds that a similar amount of rotation is required for each associated foliation–lineation pair, as it should be, and that the maxima end up in positions indicating an original bearing of N. 35° to 40° W. for the B_1 axis.

The assumptions in the above reconstruction that the initial folds were along approximately horizontal axes and that cross-folding was relatively gentle and upright seem reasonable in view of the continuity of apparently identical *Tropites*-bearing limestone along the several miles of the Limebelt and of strings of pillow lava lenses, which, significantly, are along a strike of N. 30° W. The assumption of an initially vertical S_2 is reasonable but not critical especially if folding on B_2 is gentle, a variety of initial inclinations for S_2 producing a diffuse girdle after B_2 folding (as in subarea V apparently) but not reversing the relationships with $L_1 = B_1$ maxima. Undoubtedly much first-formed axial plane foliation was refolded about the persistent northwesterly axes, as the discussion of subarea X will illustrate, although, as noted already, the foliation is remarkably consistent in attitude over large areas, suggesting that it was formed late in the folding episode or was strongly reinforced by slip and hence retained its vertical or near-vertical attitude before rotation on B_2. In view of the repeated folding about B_1 axes during intrusion of pods and sheets and considering the many inhomogeneities resulting from blocks of pillow lava, intruded pods, sheets, and granitic bodies, the coincidence on the stereogram of maxima from the several subareas after unrolling is thought to be close enough to support the sequence of folding suggested.

Late Localized Folding on Steep Axes

In subareas VIII and IX, near the batholith contact, minor fold axes (B_1) bear north-southerly or south-southwesterly with a wide range of plunges and the limestone is strongly flow deformed though largely unfoliated. The change in trend of B_1, actually a completely gradational swing from the predominant northwesterly trend on the north and west, appears in the field to be related to the main granitic mass and apophyses from it, in which case it is a late structure. Probably the same can be said for the age of the atypical east-westerly trend in subarea I: the anomalous attitudes are near a long N. 80° W. shear and a related bend in the adjacent body of folded pillow lava. Late shears of this general trend are common throughout the Limebelt and many can be traced as linears into both the Texada volcanics and the batholithic rocks.

Some of the character of this late folding is shown in subarea X, a seaward

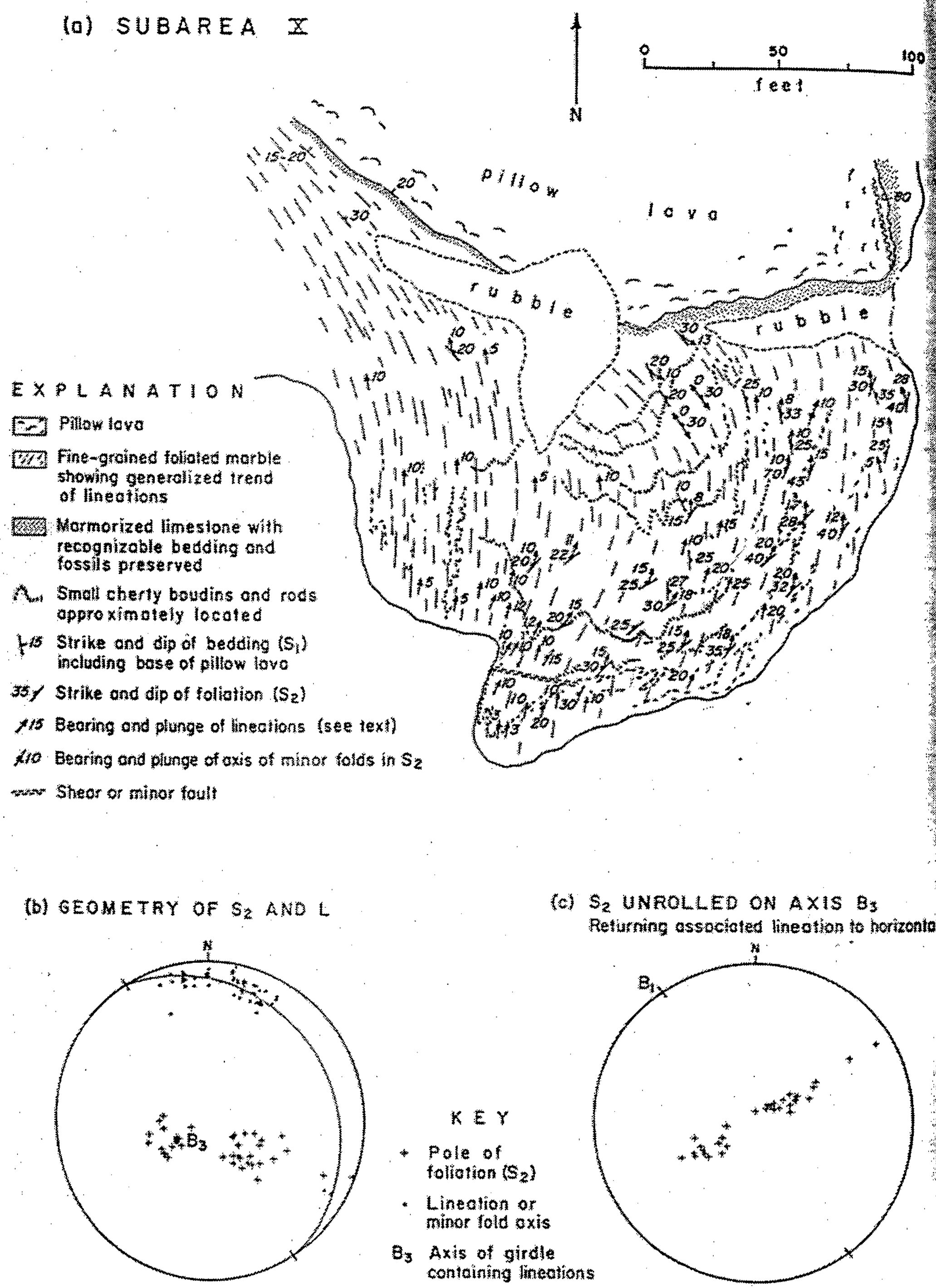

FIG. 11. Determination of fold axis B_3 in subarea X.

extension of subarea I. The same pillow lava as in subarea I lies in the trough of a compound syncline, again bent in map view and having an overall gentle plunge to the northwest (Fig. 11). Bedding with quite recognizable fossils in the limestone adjacent to the pillow lava becomes increasingly distorted away from it and, within a few feet, ammonites are seen to change progressively into white calcite lensoids and streaks. Everywhere else the bedding is strongly transposed. Even so, it can be followed in a general way around parts of the outcrop and through several minor folds from the arrangement of small cherty boudins or rods which were derived apparently from thin, cherty layers in the bedding (Fig. 23). Foliation, S_2, is very well developed, as it usually is near folded pillow lava, and is itself folded and crenulated in a slightly chevron, asymmetric style. The folds and crenulations in S_2 result in a lineation (designated L_2) along their axes. An essentially parallel lineation produced by light and dark streaks of marble lying within the foliation, when examined on sawn surfaces, was seen to be derived from appressed hinges of earlier crenulations in S_1 and therefore is taken to be an expression of L_1. Alignment of the small cherty boudins and rods is probably of the same origin. Approximate measurements of L_1 can be obtained also in parts of the outcrop from axes of minor folds in S_1 indicated roughly by the layers rich in cherty boudins and rods. The angular difference between L_1 and L_2, where the two can be distinguished, is never more than a few degrees and, in effect, L_1 and L_2 are parallel; folding of S_1 and S_2 was along essentially parallel axes. As shown on the map and stereogram (Fig. 11*a*,*b*) all of these elements are involved in the late folding; the broad unbroken bend in map view mentioned above. The two S_2-pole maxima on the stereogram reflect the limitation of outcrop and the chevron style of crenulation, one limb of the crenulations usually predominating greatly over the other. The lineations, L_1 and L_2, not differentiated on the stereogram, describe a girdle about a very steep axis, B_3. If, again, one makes the working assumption that L_1 and L_2 were initially horizontal and then unfolds the foliation around B_3 by rotating each S_2-pole and its associated lineation through an angle sufficient to return the lineation to horizontal, the result (Fig. 11*c*) is a very well-defined girdle of S_2-poles centered on the horizontal fold axis bearing N. 35° W. The perfection of the S_2-pole girdle so produced is arresting and appears to justify the working assumption. Once again we have evidence of strong folding and refolding on persistent northwesterly axes followed, presumably much later, by gentle flexing on an entirely unrelated axis. Subarea X is not sufficiently large to show the broad flexing about axis B_2 discussed in connection with Fig. 10.

In retrospect, it is noted that the data for subarea I fit fairly closely on the pattern for subarea X. The two subareas merely lie on different parts of a single sigmoidal fold about a steep B_3 axis related, it seems, to the late west-northwesterly shearing (see Fig. 12). Similar patterns related to late northwesterly shears are common in the Limebelt.

DISCUSSION AND EVALUATION OF THE SECTION AT OPEN BAY

Three episodes of deformation of the rocks at Open Bay have been mentioned.

The first and predominant deformation, preceding, accompanying, and following intrusion of very abundant andesitic pods, sheets, and dikes and followed by emplacement of quartz diorite of the main Coast Intrusives, was the progressive and recurrent flexural-slip folding along the northnorthwesterly trend. The resulting lineations in the bedding and in the foliation are so pronounced and so consistent in initial attitude, not only at Open Bay but throughout the Limebelt and in some occurrences away from Quadra Island, as well, that they obviously represent a major axis of regional folding. The axes in the Quadra Island area apparently were horizontal and the folding plane upright. With introduction of the andesitic pods and sheets during deformation, the succession of limestone and subordinate pillow lava became increasingly inhomogeneous. Limestone was forced to flow around the stronger bodies and to buckle disharmoniously. Bedding transposition and slip parallel to the foliation continued throughout the period of deformation. Discontinuities within the section and at the contact of the Open Bay Formation with the Texada Formation suggest late localized shearing along the north-northwesterly trend parallel to the foliation. Boudinage of thin, cherty beds and many andesitic pods implies stretching along the fold axis direction. Since Upper Triassic (?) and Lower Jurassic sedimentary rocks on Ulloa and Hernando Islands, 15 miles southeast of Open Bay, have structures and attitudes apparently identical with those at Open Bay and since Lower Jurassic sedimentary and volcanic rocks (Bonanza Group) 25 miles to the southwest on Vancouver Island rest conformably upon Upper Triassic (Karnian) limestones, the first episode of folding apparently did not begin until the Early or Middle Jurassic. The Bonanza Group at the Vancouver Island locality is intruded by quartz diorite and related rocks which are overlain in turn by Upper Cretaceous sandstones.

The second deformation, gentle folding upon approximately horizontal east-westerly axes appears to have been regional also. The northwesterly and southeasterly plunges of lineations and fold axes throughout the Limebelt, in the Triassic (?) and Jurassic rocks of Ulloa and Hernando Islands and in the very broad folds in the Texada Formation are about the same as those at Open Bay. Figure 1, as mentioned earlier, shows, in a general way, similar plunges on northwesterly-trending folds over a still larger area. The age of the gentle east-westerly folding at Open Bay cannot be determined from data there, but it would not be surprising to find that the east-westerly shortening represented by the first episode of folding was followed by relaxation in that direction and slight north-southerly shortening after emplacement of mid-Mesozoic intrusives, as has been the pattern elsewhere in the Western Cordillera.

Certainly the third deformation, local folding about steep axes related to north-northwesterly fracture zones and shears transecting the whole of Quadra Island, is later than the main Coast Intrusives. At several places in the Limebelt, the steep foliation in the limestone is seen to be twisted along such shears and around the ends of pillow lava lenses. Commonly, however, the shears are occupied by late dikes.

The net result of the deformations, particularly the first, is that stratigraphic thicknesses cannot be measured as they can be in undeformed or gently deformed sections, discontinuities in the section are extremely difficult to assess and projections of strata in depth are highly uncertain. The structural thicknesses given in Fig. 3 may misrepresent stratigraphic thicknesses by a factor of two or three and the stratigraphic position of the two pillow lava flows near the west edge of the bay may be entirely different from that shown. If the apparent continuation of these two lavas is traced northward along the series of lenticular bodies of pillow lava, it is found to lie near the middle of the Limebelt and a thick mass of folded *Tropites*-bearing limestone, identical with that at Open Bay lies between it and the Texada Formation. The Open Bay Formation is so highly distorted throughout the whole Limebelt that, even if it did once rest depositionally on the Texada Formation, it must have been sheared away from it. Though the amount of section missing is unknown, some tentative estimates can be made from the following.

The only lithologic or local biostratigraphic correlation possible at this time is with a part of the undeformed nearly continuous Upper Triassic sedimentary section on Iron River 24 miles to the southwest (Surdam, Carlisle, Susuki 1963). In the lower part of that section, now assigned to the Quatsino Formation, a *Tropites* fauna, including *Tropites dilleri* Smith, occurs in a unit of evenly banded, medium-gray, non-fissile limestone with partings of dark grey, fissile, very carbonaceous limestone, and some interbedded black chert. In spite of the metamorphism in the Open Bay section, the lithologic similarity is striking. This banded unit is only 110 ± 10 ft thick on Iron River but it is overlain by 330 ft of carbonaceous limestone, part of which belongs to the Norian stage, and underlain by not less than 200 to 400 ft of poorly bedded limestone with thin carbonaceous partings. This lower limestone, in turn, rests conformably upon flows and pillowed volcanics of the Karmutsen Group which have the same appearance and composition as those of the Texada Formation on Quadra Island. If original thicknesses were similar in the Iron River and Open Bay sections and if the *Tropites*-bearing units are indeed equivalent, then not less than 200 to 400 ft of limestone are missing at the fault contact between the Open Bay Formation and the Texada Formation on Quadra Island. In fact, the amount of section missing may be much more than this since the thickly bedded Marble Bay Formation on Texada Island, which rests directly upon Texada flows and pillowed volcanics and is unlike the *Tropites*-bearing, banded, and cherty units at Iron River and at Open Bay, is possibly more than 2 000 ft thick.

SYSTEMATIC PALEONTOLOGY

A complete systematic paleontology has been placed in the Depository of Unpublished Data, National Science Library, National Research Council, Ottawa, Canada.*

Identifications are based on external features. The septa are not visible,

*Photocopies may be obtained upon request to the Depository.

and no effort was made to etch out the suture patterns because of the possibility of damaging the few well-preserved specimens.

The Treatise on Invertebrate Paleontology, part L, Mollusca 4, 1957, was followed for the systematic arrangement of ammonoid families.

The following symbols are used in this paper for the measurement of the shell: HS, height of shell = maximum diameter; WS, width of shell = whorl width; HW, height of whorl; WU, width of umbilicus. Owing to the many imperfections resulting from distortion and weathering of the specimens, many of the measurements are not precise. All hypotypes are deposited with the Geological Survey of Canada (GSC), Ottawa. All photographs are by Susuki.

FAMILY TRACHYCERATIDAE Haug, 1894
GENUS *Spirogmoceras* Silberling, 1956
Spirogmoceras sp.
Figs. 24, 25, 26, 27

Hypotypes.—GSC cat. Nos. 18002, 18003.

Locality of hypotypes.—UCLA Invert. Paleo. Coll. loc. Nos. 4629-1, 4631-2.

Dimensions of hypotypes.—GSC No. 18002, HS, 12 mm; WS, 7 mm; HW, 6 mm.

Discussion.—The six species of *Trachyceras* (*Protrachyceras*) described by Smith (1927, pp. 78–81) from Shasta County, California, have been synonymized and placed in a new genus *Spirogmoceras* by Silberling (1956, p. 1152), with *S. shastense* as the type species. The two hypotype specimens from Open Bay compare very closely with *S. shastense* in the adolescent growth stage. *Spirogmoceras* is one of the restricted genera helpful in the recognition of the *Tropites dilleri* subzone.

FAMILY CLIONITIDAE Arabu, 1932
GENUS *Californites* Hyatt & Smith, 1905
Californites cf. *C. careyi* (Smith)
Figs. 28, 29, 30

Cf. *Clionites* (*Californites*) *careyi* (Smith), 1927, U.S. Geol. Survey Prof. Paper 141, p. 92, Pl. 46, Figs. 1–12.

Hypotype.—GSC cat. No. 18004.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4628-1.

Dimensions of hypotype.—HS, 17 mm; WS, ?; HW, 6 mm.

Discussion.—Although small, this specimen has features characteristic of the genus *Californites*. The two described species of *Californites*, *merriami*, and *careyi*, were separated by Smith on the basis that *C. careyi* possesses a broader and more robust whorl. This specific separation makes one suspect that Smith's later erected species *C. careyi* is but a robust variation of *C. merriami*. No attempt is made to revise this group, but since the Open Bay species is somewhat more robust that *C. merriami*, the specimen figured is here compared with *C. careyi*.

GENUS *Traskites* Hyatt & Smith, 1905

SUBGENUS *Shastites* Hyatt & Smith, 1905

Traskites (*Shastites*) cf. *T.* (*S.*) *compressus* (Hyatt & Smith)

Figs. 32, 33

Cf. *Clionites* (*Shastites*) *compressus*, Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, p. 188, Pl. 43, Figs. 1–15.

Hypotype.—GSC cat. No. 18005.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4634-2.

Dimensions of hypotype.—HS, 24 mm; WS, 10 mm ?; HW, 11 mm ?; WU, 7 mm ?.

Discussion.—This poorly preserved specimen is figured to record the occurrence of *Traskites* (*Shastites*) at Open Bay. From preserved morphologic features, this species compares most favorably with *T.* (*S.*) *compressus* in the fine sigmoidal radial ribs and the narrowness of the whorl.

SUBGENUS *Stantonites* Hyatt & Smith, 1905

Traskites (*Stantonites*) cf. *T.* (*S.*) *rugosus* (Hyatt & Smith)

Figs. 31, 34

Cf. *Clionites* (*Stantonites*) *rugosus* Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, p. 185, Pl. 41, Figs. 15–26.

Cf. *Clionites* (*Stantonites*) *rugosus* Hyatt & Smith, 1927, U.S. Geol. Survey Prof. Paper 141, pp. 89–90, Pl. XLI, Figs. 15–26.

Hypotype.—GSC cat. No. 17982.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-3.

Dimensions of hypotype.—HS, 16 mm; WS, 7 mm ?; HW, 6 mm ?; WU, 7 mm ?.

Discussion.—It is difficult to distinguish the young forms of *Clionites*, *Californites*, and *Traskites* for they pass through similar growth stages. Not until adolescence is reached can the differences be recognized. Contrary to Smith's statement (1927, p. 90), "the adolescent stages are so much like the mature forms that no description is necessary," in the adolescent stage only four rows of spiral nodes are discernible: (1) on the umbilical shoulder; (2) midway on the flank; (3) on the ventral shoulder; (4) adjacent to the ventral furrow, which is also the highest point on the whorl, while, in the mature specimens figured by Smith (1927, Pl. 41, Fig. 15), two additional rows of nodes have been added to the flanks. The whorl section in the adolescent stage is almost equidimensional; in the mature form the height has greatly increased over the width.

FAMILY CHORISTOCERATIDAE Hyatt, 1900

GENUS *Hannaoceras* Tomlin, 1931

Hannaoceras sp.

Figs. 35, 36, 37, 38, 44, 45

Hannaoceras sp., Tozer, 1962, Geol. Survey Canada Paper 62–19, Pl. 8, Figs. 5*a*, 5*b*.

Hypotypes.—GSC cat. Nos. 17977, 17978, 17997, 18880.

Locality of hypotypes.—UCLA Invert. Paleo. Coll. loc. Nos. 4629-2, 4631-1.

Dimensions of hypotypes.—GSC No. 17977, HS, 18 mm; WS, 6 mm ?; HW, 7 mm; WU, 6 mm ? GSC No. 17978, HS, 18 mm; WS, ?; HW, 6 mm ?; WU, 7 mm ? GSC No. 17997, HS, 15 mm ?; WS, ?; WU, 6 mm ? GSC No. 18880, HS, 13 mm; WS, 5 mm; HW, 5.5 mm; WU, 5 mm.

Discussion.—In spite of its abundance, the poor preservation of *Hannaoceras* at Open Bay somewhat hinders comparison with occurrences elsewhere. All the specimens appear alike except in the fact that figured specimen No. 17977 (Fig. 35) differs in having a very slight indentation on the venter. If not the result of physical processes, this indentation or partial furrow would place this specimen in the *H.* (*Sympolycyclus*) group, while all the other specimens certainly belong to the *H.* (*Hannaoceras*) group. Because of weathering, the radial ribs on most specimens have been secondarily narrowed and the interspaces widened and deepened. A feature not previously recognized on specimens from other areas is the spiral concavity or furrow on the flank just above the umbilical shoulder on the Open Bay forms.

A new specific name is not justified here, although the fewer radial ribs and the spiral concavity on the flanks make these forms separable from other described species.

Family TROPITIDAE Mojsisovics, 1875
Genus *Tropites* Mojsisovics, 1875
Tropites dilleri Smith
Figs. 39, 40, 41, 42, 43, 46, 47, 48, 49

Tropites dilleri Smith, 1904, Calif. Acad. Sci. Proc., 3d ser., v. 1, p. 393, Pl. 46, Figs. 3, 4; Pl. 47, Fig. 3.
Tropites dilleri Smith, Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 29, Pl. 68, Figs. 1–13.
Tropites dilleri Smith (revised) Silberling, 1959, U.S. Geol. Survey Prof. Paper 322, p. 43.
Tropites subbullatus Hauer, Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 141, p. 67, Pl. 34, Figs. 1–14; Pl. 79, Figs. 1–10.
Tropites morloti Mojsisovics, Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 31, Pl. 69, Figs. 13–24.

Hypotypes.—GSC cat. Nos. 17983, 17984, 17986.

Locality of hypotypes.—UCLA Invert. Paleo. Coll. loc. Nos. 4631, 4629-2.

Dimensions of hypotypes.—GSC No. 17983, HS, 17 mm ?; WS, 22 mm ?; HW, 9 mm ?; WU, 9 mm. GSC No. 17984, HS, 14 mm; WS, 14 mm ?; HW, 8 mm ?; WU, 7 mm. GSC No. 17986, HS, 22 mm; WS, 22 mm ?; HW, 15 mm ?; WU, 7 mm.

Discussion.—*Tropites dilleri* Smith, as revised by Silberling (1959, p. 43), includes the following species.

Tropites discobullatus Smith (not Mojsisovics, 1893)
torquillus Smith (not Mojsisovics, 1893)
dilleri Smith, 1904
subbullatus Hyatt & Smith, 1905 (not Hauer, 1850)
armatus Smith, 1927
morloti Smith (not Mojsisovics, 1893)
occidentalis Smith, 1927

This revision of *Tropites dilleri* will be followed in this paper.

The figured specimens from Open Bay are represented by forms that (1) have a greater width than height (Figs. 39, 40, 41) and relate closely to Smith's *T. morloti*, and (2) those whose height and width are about equal (Figs. 42, 43, 46, 47, 48, 49) and compare most favorably with Smith's *T. dilleri* and *T. subbullatus*.

T. dilleri (revised) differs from *T. welleri* (revised) in the finer ribbing, both spiral and radial; greater angle between radial ribs and ventral keel; finer spiral striae better developed than the radial ribs; and considerable weakening of the radial ribs before they reach the keel furrow. It differs from *T. morani* (revised) in the wider umbilicus, umbilical knots, and the stronger development of the spiral striae.

Tropites cf. *T. dilleri* Smith
Figs. 59, 60, 61

Cf. *Tropites troquillus* Mojsisovics, Smith, 1927, U.S. Geol. Survey Prof. Paper 141, pp. 28–29, Pl. LXVIII, Figs. 14–31.
Cf. *Tropites dilleri* Smith (revised) Silberling, 1959, U.S. Geol. Survey Prof. Paper 322, p. 43.

Hypotype.—GSC cat. No. 17985.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4627.

Dimensions of hypotype.—HS, 27 mm ?; WS, 17 mm ?; HW, 14 mm ?; WU, 5 mm ?

Discussion.—The figured specimen is most closely related to *T. torquillus* Mojsisovics (of Smith) from Shasta Co., California. A cast of a specimen (GSC No. 18877; Fig. 63) collected by H. C. Gunning from Open Bay was kindly sent by Dr. Tozer of the Geological Survey of Canada for comparison. The two specimens are without question very similar. The GSC specimen is in a better state of preservation, radial ribs are more pronounced, umbilical shoulder more angular but only half of the specimen is exposed making it difficult to describe properly for consideration as a new species. Inasmuch as both specimens compare closely with *T. torquillus*, included by Silberling (1959, p. 43) in *T. dilleri*, this species will be compared to *T. dilleri*.

Tropites cf. *T. welleri* Smith
Figs. 50, 51, 52

Cf. *Tropites welleri* Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 33, Pl. 78, Figs. 5–17.
Cf. *Tropites welleri* Smith (revised) Silberling, 1959, U.S. Geol. Survey Prof. Paper 322, pp. 45–46.

Hypotype.—GSC cat. No. 17988.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4629-2.

Dimensions of hypotype.—HS, 35 mm ?; WS, 24 mm ?; HW, 19 mm ?; WU, 9 mm ?

Discussion.—The only well-preserved representative of this species from the Open Bay collection compares best with *T. welleri* (revised), except for the angle between the radial ribs and ventral keel which is generally greater than for *T. welleri* (20°–30°; Silberling 1959, p. 44). The size relation of the rib–keel angle is similar to *T. johnsoni*. Other than the rib–keel angle relationship to

T. johnsoni, the Open Bay specimen is closely related to *T. welleri*, in the equal number of umbilical knots (13), fine spiral lines sharply defined, lacking knots at the point of bifurcation on the ventral shoulder, showing no swelling at the ventral end of radial ribs, and having sharply defined dichotomous ribs near the umbilical region.

Tropites sp. A
Figs. 56, 57, 58

Hypotype.—GSC cat. No. 17987.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-2.

Dimensions of hypotype.—HS, 25 mm ?; WS, 16 mm ?; HW, 14 mm ?

Discussion.—No specific identification is attempted, for much of the flanks and umbilical areas are too poorly preserved. The coarseness of the radial ribs and the wide angle between the radial ribs and keel are characteristic of this species.

Tropites sp. B
Figs. 53, 54, 55

Hypotype.—GSC cat. No. 18000.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-3.

Dimensions of hypotype.—HS, 18 mm; WS, 12 mm ?; HW, 12 mm ?

Discussion.—The figured specimen varies considerably from other described species, and possesses features not confined to any other given species. The angle of 40° between the radial ribs and ventral keel, less pronounced concave forward radial ribs, and the knots on the umbilical shoulder are the characteristic features of this specimen.

GENUS *Discotropites* Hyatt & Smith, 1905
Discotropites cf. *D. sandlingensis* (Hauer)
Fig. 67

Cf. *Ammonites sandlingensis* Hauer, 1850, Haidinger's Naturwissenshaftliche, Abh., III, pp. 10–11, Pl. 3, Figs. 10–12.
Cf. *Eutomoceras sandlingensis* (Hauer), Mojsisovics, 1893, Abh. Geol. Reichsant., Wien, Band 6, Halfte 2, p. 285, Pl. 130, Figs. 11–13; Pl. 131, Figs. 1–11.
Cf. *Discotropites sandlingensis* (Hauer), Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, pp. 63–65, Pl. 35, Figs. 1–12; Pl. 36, Figs. 1–26.
Cf. *Discotropites sandlingensis* (Hauer), McLearn, 1960, Geol. Survey Canada, Memoir 311, p. 73, Pl. 8, Fig. 7.

Hypotype.—GSC cat. No. 17975.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4625.

Dimensions of hypotype.—HS, 47 mm ?; WS, 16 mm ?; HW, 28 mm ?; WU, 8 mm ?

Discussion.—The radial ribs of this specimen are more nearly like those of *D. gemmellaroi* Smith, but the other morphological features, particularly the fine spiral striations, lack of distinct knots on the ribs, abruptly tapering venter, compare more favorably with those of *D. sandlingensis*. A re-evaluation of *Discotropites* from Shasta Co., California, may reveal that many of Smith's species are only variations within one species.

Discotropites sp.
Figs. 65, 66

Hypotype.—GSC cat. No. 17976.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-3.

Dimensions of hypotype.—HS, 22 mm ?; WS, 10 mm ?; HW, 11 mm ?; WU, 5 mm ?.

Discussion.—This species differs from *D. sandlingensis* in lacking a tapered venter and in having more poorly defined spiral striations and a broader ventral keel with narrow, but pronounced, adjacent furrows.

GENUS *Paratropites* Mojsisovics, 1893
Paratropites sellai (Mojsisovics)
Figs. 62, 64, 68, 69, 70, 71, 72

Tropites (Paratropites) sellai Mojsisovics, 1893, Abh. Geol. Reichsanstalt Wien, Band 6, Halfte 2, pp. 242–243, Pl. 114, Figs. 2, 4–10; Pl. 115, Figs. 5, 6, 9–11; Pl. 113, Fig. 23.
Paratropites sellai (Mojsisovics), Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, pp. 54–56, Pl. 30, Figs. 6–10; Pl. 31, Figs. 1–26.
Paratropites sellai (Mojsisovics), Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 45, Pl. 24, Figs. 14–16; Pl. 30, Figs. 6–10; Pl. 31, Figs. 1–26.

Hypotypes.—GSC cat. Nos. 17980, 17998, 17999.

Locality of hypotypes.—UCLA Invert. Paleo. Coll. loc. Nos. 4629-1, 4631.

Dimensions of hypotypes.—GSC No. 17980, HS, 23 mm; WS, 17 mm ?; HW, 13 mm ?. GSC No. 17998, HS, 16 mm; WS, 11 mm ?; HW, 9 mm ?. GSC No. 17999, HS, 29 mm; WS, 15 mm ?; HW, 17 mm ?.

Discussion.—The Open Bay specimens are indistinguishable from Smith's *P. sellai* from Shasta Co., California.

Variations among growth stages of *P. sellai* of Smith are well illustrated by the three figured specimens from Open Bay. No. 17998, the smallest of the three, is flat ventered, is laterally compressed, and has whorls wider than they are high. At a larger size, as illustrated by No. 17980, the shape becomes globose and the venter evenly rounded, but the whorl proportions remain the same. The largest of the three, No. 17999, assumes a compressed shape, has whorls that are higher than wide, and a rounded narrow venter, but little change occurs in shape or direction of the radial ribbing, and the ventral keel is only slightly narrowed.

GENUS *Gymnotropites* Hyatt & Smith, 1905
Gymnotropites cf. *G. americanus* Hyatt & Smith
Figs. 74, 75, 76

Cf. *Paratropites (Gymnotropites) americanus* Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, p. 56, Pl. 32, Figs. 1–10.
Cf. *Paratropites (Gymnotropites) americanus* Hyatt & Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 46, Pl. XXXII, Figs. 1–10.

Hypotype.—GSC cat. No. 17996.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4629-1.

Dimensions of hypotype.—HS, 16 mm; WS, 8 mm; HW, 10 mm.

Discussion.—Because of the absence of sutures and the immaturity of this specimen, it is only tentatively assigned to *G. americanus*, the species to which it seems to show the closest relationship.

FAMILY TROPICELTITIDAE Spath, 1951
GENUS *Tornquistites* Hyatt & Smith, 1905
Tornquistites (?) sp.
Figs. 79, 80

Tornquistites Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, p. 59.

Hypotype.—GSC cat. No. 18001.
Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-1.
Dimensions of hypotype.—HS, 14 mm ?; WS, 4 mm ?; HW, 5 mm ?; WU, 6 mm ?.

Discussion.—The morphologic distinction between *Tornquistites* and *Tropiceltites* is extremely small, and only in well-preserved specimens can a separation of the two be made. Despite the closeness of the two genera, *Tornquistites* is used provisionally here solely because of the whorl cross section. In *Tropiceltites*, the greatest width of the whorl is at the flared ventral shoulders with the flanks tapering rapidly inward to the umbilical shoulders, while in *Tornquistites*, the flanks are nearly parallel sided and not flared outward as in *Tropiceltites*. There is also a resemblance of the Open Bay species to *Lecanites*, from which it differs in possessing a weak ventral keel.

FAMILY HALORITIDAE Mojsisovics, 1893
GENUS *Bacchites* Smith, 1927
Bacchites cf. *B. bacchus* (Mojsisovics)
Figs. 73, 77, 81

Cf. *Jovites* (*Bacchites*) *bacchus* (Mojsisovics), Smith, 1927, U.S. Geol. Survey Prof. Paper 141, p. 53, Pl. 14 Figs. 1–5.

Hypotype.—GSC cat. No. 18879.
Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4630.
Dimensions of hypotype.—HS, 34 mm; WS, 27 mm ?; HW, 23 mm ?.

Discussion.—The similarity of the Open Bay specimen to both Smith's *B. bacchus* from Shasta Co., California, and Mojsisovics' species from the Hallstatt, Austria, section is very close, especially to the former. *Epiculites corpulentus* described by McLearn (1960, Pl. 18, Figs. 5*a*–5*b*) from the Peace River Foothills, B.C., Canada, shows some external resemblance, but differs in the larger umbilicus, well-defined umbilical shoulder, and coarser, bifurcating radial ribs. In North America, *B. bacchus* is rare and restricted to the *Tropites dilleri* subzone.

GENUS *Leconteiceras* Smith, 1914
Leconteiceras sp.
Fig. 78

Leconteiceras Smith 1914 U.S. Geol. Survey Prof. Paper 83, p. 38.

Hypotype.—GSC cat. No. 17979.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631.

Discussion.—This poorly preserved specimen is the first record of this genus outside of Shasta Co., California.

GENUS *Sagenites* Mojsisovics, 1879
SUBGENUS *Trachysagenites* Mojsisovics, 1893
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics
Figs. 82, 83, 84, 87

Sagenites (*Trachysagenites*) *herbichi* Mojsisovics, 1893, Abh. Geol. Reichsanstalt Wien, Band 6, Halfte 2, p. 180, Pl. 101, Fig. 3; Pl. 102, Figs. 1–6.
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics, Smith, 1904, Calif. Acad. Sci., Proc., 3d series, Vol. 1, p. 399, Pl. 46, Figs. 7, 8; Pl. 47, Figs. 5, 6.
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics, Hyatt & Smith, 1905, U.S. Geol. Survey Prof. Paper 40, p. 39, Pl. 26, Figs. 1, 2; Pl. 27, Figs. 1–4; Pl. 28, Figs. 1–18.
Sagenites (*Trachysagenites*) *herbichi* Mojsisovics, Smith, 1927, U.S. Geol. Survey Prof. Paper 141, pp. 60–61, Pl. 26, Figs. 1, 2; Pl. 27, Figs. 1–4; Pl. 28, Figs. 1–18.
Trachysagenites herbichi (Mojsisovics), Tozer, 1962, Geol. Survey Canada Paper 62-19, Pl. 8, Figs. 15*a*–15*b*.

Hypotypes.—GSC cat. Nos. 17981, 18878.

Locality of hypotypes.—UCLA Invert. Paleo. Coll. loc. Nos. 4631, 4631-2.

Dimensions of hypotypes.—GSC No. 17981, HS, 58 mm; WS, 29 mm ?; HW, 34 mm. GSC No. 18878, HS, 22 mm; WS, 16 mm; HW, 14 mm.

Discussion.—The two figured specimens probably represent a mature and an immature form, both showing growth stages typical of *S.* (*T.*) *herbichi*. At first glance, they appear to be separate species.

The larger mature specimen, partially distorted and with weathered flanks, does not show the characteristic shape of *S.* (*T.*) *herbichi* as illustrated by Smith (1927, Pl. 26, Figs. 1, 2; Pl. 27, Figs. 1–4). Smith's species probably represents an inflated variant of the species and the type of *S.* (*T.*) *herbichi* Mojsisovics (1893, Pl. 102, Figs. 6*a*–6*b*) shows less inflation than Smith's specimens from Shasta Co., California. The shell width of the Open Bay form is quite similar to *S.* (*T.*) *shastensis* Smith, but the radial and spiral ribs and nodes are finer. A similar comparison is made with *S.* (*T.*) *hystrix* Gemmellaro (1904, Pl. 12, Figs. 5, 7).

The figured hypotype, GSC No. 18878 is small, and distortion has probably increased the height of the shell considerably, but sufficient features are present for specific identification. The young forms of *S.* (*T.*) *herbichi* seem to be characterized by their subglobose character, whorls proportionally wider than high, but their sculpture does not differ from that of the mature forms.

FAMILY ARCESTIDAE Mojsisovics, 1875
GENUS *Arcestes* Suess, 1865
Arcestes sp.
Figs. 85, 86

Hypotype.—GSC cat. No. 17974.

Locality of hypotype.—UCLA Invert. Paleo. Coll. loc. No. 4631-3.

Dimensions of hypotype.—HS, 13 mm ?; WS, 11 mm ?; HW, 7 mm ?.

Discussion.—Of the many specimens of this genus in the collection, the specimen figured is the best preserved. One partial constriction is the only feature visible on the surface.

REFERENCES

ARMSTRONG, J. E. 1949. Fort St. James map-area, Cassiar and coast districts, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 252.

BANCROFT, J. A. 1913. Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B.C. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 23.

CAIRNES, D. D. 1914. The limebelt, Quadra (South Valdes) Island, B.C. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Sum. Rept. 1913, 58–75.

CARLISLE, D. 1963. Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia. J. Geol. 71, 48.

CRICKMAY, C. H. 1928. The stratigraphy of Parson Bay, British Columbia. Univ. Calif. Publ. Bull. Dept. Geol. Sci. 18, 51.

——— 1930. The Jurassic rocks of Ashcroft, British Columbia. Univ. Calif. Publ. Bull. Dept. Geol. Sci. 19, 23.

DAWSON, G. M. 1879. Report on a portion of the southern interior of British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Rept. 1877–78 (Not examined).

——— 1887. Report on a geological examination of the northern part of Vancouver Island and adjacent coasts. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Ann. Rept. 2 (N.S.).

DOLMAGE, V. 1918. Quatsino Sound and certain mineral deposits of the west coast of Vancouver Island, B.C. Can. Dept. Mines Tech. Surv. Geol. Surv. Can., Sum. Rept. 1918, Part B, 30–38.

DUFFELL, S. and MCTAGGART, K. C. 1952. Ashcroft map-area, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 262.

FYLES, J. T. 1955. Geology of the Cowichan Lake area, Vancouver Island, British Columbia. B.C. Dept. Mines, Bull. 37.

GEMMELLARO, G. C. 1904. I cefalopodi del Trias superiore della regione occidentale della Sicilia. Giorn. Sci. Nat. Econ. Palermo, 24.

GIVENS, C. R. and SUSUKI, T. 1963. Late Triassic fauna from interlava sediments of east-central Vancouver Island (Abstr.) Geol. Soc. Am. Spec. Paper No. 76, 203.

GUNNING, H. C. 1930. Geology and mineral deposits of the Quatsino–Nimpkish area, Vancouver Island. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Sum. Rept. 1929, Part A, 94–143.

HAUER, F. R. V. 1850. Ueber neue Cephalopoden aus den Marmorschichten von Hallstatt und Aussee. Haidinger's Naturwiss. Abhandl. III.

HOADLEY, J. W. 1953. Geology and mineral deposits of the Zeballos–Nimpkish area, Vancouver Island, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 272.

HYATT, A. and SMITH, J. P. 1905. The Triassic cephalopod genera of America. U.S. Geol. Surv. Profess. Paper 40.

JEFFERY, W. G. 1963. Preliminary geological map Buttle Lake area, Vancouver Island. B.C. Dept. Mines and Petrol. Resources.

JELETZKY, J. A. 1950. Stratigraphy of the west coast of Vancouver Island between Kyuquot Sound and Esperanza Inlet, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Paper 50-37 (Prelim. rept.).

——— 1954. Geological history of west coast of Vancouver Island and Quatsino Sound (Abstr.). Geol. Soc. Am. Bull. **65**, 1269.

LEROY, O. E. 1908. Preliminary report on a portion of the main coast of British Columbia and adjacent islands included in New Westminster and Nanaimo districts. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Rept. No. 996.

MCCONNELL, R. G. 1914. Texada Island, B.C. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 58.

MCLEARN, F. H. 1953. Correlations of the Triassic formations of Canada. Geol. Soc. Am. Bull. **64**, 1205.

——— 1960. Ammonoid faunas of the Upper Triassic Pardonet formation, Peace River foothills, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 311.

MATHEWS, W. H. 1947. Calcareous deposits of the Georgia Strait area. B.C. Dept. Mines, Bull. No. 23.

MATHEWS, W. H. and MCCAMMON, J. W. 1957. Calcareous deposits of southwestern British Columbia. B.C. Dept. Mines, Bull. No. 40.

MOJSISOVICS, E. VON. 1875. *In* M. Neumayr. Die Ammoniten der Kreide und die Systematikder Ammonitiden. Deut. Geol. Ges. Z. **27**, 854.

——— 1893. Die Cephalopoden der Hallstätter Kalke. Das Gebirge um Hallstatt. Abt. 1. Abhandl. Geol. Reichsanst. Wien, Band 6, Hälfte 2.
MOORE, R. *et al.* 1957. Treatise on invertebrate paleontology, Part I, Mollusca 4 (Geol. Soc. Am.).
SARGENT, H. 1941. Supplementary report on Bedwell River area, Vancouver Island, British Columbia. B.C. Dept. Mines, Bull. No. 13.
SCHRADER, F. C. 1900. A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska in 1898. U.S. Geol. Surv. 20th Ann. Rept. Pt. 7, 341–423.
SILBERLING, N. J. 1956. "*Trachyceras* zone" in the Upper Triassic of the western United States. J. Paleontol. 30, 1147.
——— 1959*a*. Pre-Tertiary stratigraphy and Upper Triassic paleontology of the Union District Shoshone Mountains, Nevada. U.S. Geol. Surv. Profess. Paper 322.
——— 1959*b*. Upper Triassic marine mollusks from the Natchez Pass formation in northwestern Nevada. J. Paleontol. 35, 535.
SMITH, J. P. 1904. The comparative stratigraphy of the marine Trias of western America. Calif. Acad. Sci. Proc. 3rd Ser. 1, 321.
——— 1914. The Middle Triassic marine invertebrate faunas of North America. U.S. Geol. Surv. Profess. Paper 83.
——— 1927. Upper Triassic marine invertebrate faunas of North America. U.S. Geol. Surv. Profess. Paper 141.
SOUTHER, J. G. 1960. Tulsequah, British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Prelim. Map 9-1960.
SPATH, L. F. 1951. Catalogue fossil Cephalopoda in the British Museum (Natural History), Part 5, The Ammonoidea of the Trias (II) (London).
SURDAM, R. C., SUSUKI, T., and CARLISLE, D. 1963. Upper Triassic section on Iron River, Vancouver Island, British Columbia (Abstr.): Geol. Soc. Am. Spec. Paper No. 76, 226.
SUTHERLAND-BROWN, A. 1958. *In* Airborne magnetometer surveys, 1956–57 (B.C. Dept. Mines), pp. 15–19.
TIPPER, H. W. 1959. Revision of the Hazelton and Takla groups of central British Columbia. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Bull. 47.
TOZER, E. T. 1961*a*. Triassic stratigraphy and faunas, Queen Elizabeth Island, Arctic Archipelago. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Mem. 316.
——— 1961*b*. The sequence of marine Triassic faunas in western Canada. Can. Dept. Mines Tech. Surv. Geol. Surv. Paper 61-6.
——— 1962. Illustrations of Canadian fossils, Triassic of western and Arctic Canada. Can. Dept. Mines Tech. Surv. Geol. Surv. Can. Paper 62-19.

EXPLANATION OF FIGS. 13–88

FIG. 13. A "larger" fold in pillow lava and limestone near fossil locality 4 633. The light-colored band is marmorized limestone at the base of the pillow lava. Photo taken looking northwesterly.

FIG. 14. Fossiliferous strata at locality 4 624. The small boudins are composed of chert.

FIG. 15. Crenulated fossiliferous limestone and interbedded chert at locality 4 631. Photo taken looking northerly.

FIG. 16. Typical light and dark (carbonaceous) banded limestone showing parasitic minor folds immediately north of locality shown in Fig. 3. Photo taken looking northwesterly.

FIG. 17. "Lesser" and minor folds in fossiliferous cherty limestone at fossil locality 4 630. Photo taken looking northwesterly.

FIG. 18. Disharmonic minor folds in interbedded chert (dark) and limestone near fossil locality 4 630. Photo taken looking northwesterly.

FIG. 19. Microfold lineation, L_1, and axial plane foliation, S_2, in interbedded chert and limestone near fossil locality 4 629. Photo taken looking northeasterly.

FIG. 20. Boudin-like andesitic pod surrounded by thin marmorized zone in folded carbonaceous limestone 200 ft north of fossil locality 4 632. Photo taken looking northwesterly.

FIG. 21. Andesitic pod with intrusive apophyses extending into folded limestone in subarea IX (see Fig. 9). Photo taken looking northerly.

FIG. 22. Foliation, S_2, deformed around broken and displaced end of one of the later, but not latest, andesitic dikes. Photo taken at fossil locality 4 629 looking northeasterly.

FIG. 23. Folded foliation in subarea X, Lost Willie Island. The band enriched in small light-colored cherty boudins and rods (beneath the hammer) is considered to represent an original chert-rich bed or beds and, hence, its configuration is S_1. S_2 is locally parallel with the hammer handle.

NOTE: Magnification of Figs. 24–88 (×2), except Figs. 50–52, 63, 67, 82, 87, 88 (×1).

FIGS. 24, 25. *Spirogmoceras* sp., anterior and lateral view of hypotype, GSC No. 18 003, UCLA loc. No. 4 631-2.

FIGS. 26, 27. *Spirogmoceras* sp., anterior and lateral views of hypotype, GSC No. 18 002, UCLA loc. No. 4 629-1.

FIGS. 28, 29, 30. *Californites* cf. *C. careyi* (Smith), ventral, lateral, and anterior views of hypotype, GSC No. 18 004, UCLA loc. No. 4 628-1.

FIGS. 31, 34. *Traskites* (*Stantonites*) cf. *T.* (*S.*) *rugosus* (Hyatt & Smith) lateral and ventral views of hypotype, GSC No. 17 982, UCLA loc. No. 4 631-3.

FIGS. 32, 33. *Traskites* (*Shastites*) cf. *T.* (*S.*) *compressus* (Hyatt & Smith), ventral and lateral views of hypotype, GSC No. 18 005, UCLA loc. No. 4 634-2.

FIGS. 35, 36. *Hannaoceras* sp., lateral and ventral views of hypotype, GSC No. 17 977, UCLA loc. No. 4 631-1.

FIGS. 37, 38. *Hannaoceras* sp., lateral and ventral views of hypotype, GSC No. 17 997, UCLA loc. No. 4 629-2.

FIGS. 39, 40, 41. *Tropites dilleri* Smith, anterior, ventral, and lateral views of hypotype, GSC No. 17 983, UCLA loc. No. 4 692-2.

FIGS. 42, 43, 46. *Tropites dilleri* Smith, anterior, ventral, and lateral views of hypotype, GSC No. 17 986, UCLA loc. No. 4 631.

FIG. 44. *Hannaoceras* sp., lateral view of hypotype, GSC No. 18 880, UCLA loc. No. 4 631.

FIG. 45. *Hannaoceras* sp., lateral view of hypotype, GSC No. 17 978, UCLA loc. No. 4 631-1.

FIGS. 47, 48, 49. *Tropites dilleri* Smith, ventral, lateral, and anterior views of hypotype, GSC No. 17 984, UCLA loc. No. 4 631.

FIGS. 50, 51, 52. *Tropites* cf. *T. welleri* Smith, anterior, lateral, and ventral views of hypotype (XI), GSC No. 17 988, UCLA loc. No. 4 629-2.

FIGS. 53, 54, 55. *Tropites* sp. B, ventral, lateral, and anterior views of hypotype, GSC No. 18 000, UCLA loc. No. 4 631-3.

FIGS. 56, 57, 58. *Tropites* sp. A, ventral, lateral, and anterior views of hypotype, GSC No. 17 987, UCLA loc. No. 4 631-2.

FIGS. 59, 60, 61. *Tropites* cf. *T. dilleri* Smith, ventral, lateral, and anterior views of hypotype, GSC No. 17 985, UCLA loc. No. 4 267.

FIGS. 62, 64. *Paratropites sellai* (Mojsisovics), anterior and lateral views of hypotype, GSC No. 17 980, UCLA loc. No. 4 629-1.

FIG. 63. *Tropites* sp., lateral view of plaster cast of GSC No. 18 877, Open Bay, Quadra Island; H. C. Gunning, Collector. (Permission granted from GSC for the use of the specimen.)

FIGS. 65, 66. *Discotropites* sp., lateral and ventral views of hypotype, GSC No. 17 976, UCLA loc. No. 4 631-3.

FIG. 67. *Discotropites* cf. *D. sandlingensis* (Hauer), lateral view of hypotype, GSC No. 17 975, UCLA loc. No. 4 625.

FIGS. 68, 69, 70. *Paratropites sellai* Mojsisovics, ventral, lateral, and anterior views of hypotype, GSC No. 17 998, UCLA loc. No. 4 631.

FIGS. 71, 72. *Paratropites* cf. *P. sellai* Mojsisovics, ventral and lateral views of hypotype, GSC No. 17 999, UCLA loc. No. 4 629-2.

FIGS. 73, 77, 81. *Bacchites* cf. *B. bacchus* (Mojsisovics), ventral, lateral, and anterior views of hypotype, GSC No. 18 879, UCLA loc. No. 4 630.

FIGS. 74, 75, 76. *Gymnotropites* cf. *G. americanus* Hyatt & Smith, ventral, lateral, and anterior views of hypotype, GSC No. 17 996, UCLA loc. No. 4 629-1.

FIG. 78. *Leconteiceras* sp., ventral view of hypotype, GSC No. 17 979, UCLA loc. No. 4 631.

FIGS. 79, 80. *Tornquistites* (?) sp., lateral and ventral views of hypotype, GSC No. 18 001, UCLA loc. No. 4 631-1.

FIGS. 82, 87. *Sagenites* (*Trachysagenites*) *herbichi* Mojsisovics, ventral and lateral views of hypotype (X1), GSC No. 17 981, UCLA loc. No. 4 631-2.

FIGS. 83, 84. *Sagenites* (*Trachysagenites*) *herbichi* Mojsisovics, lateral and ventral views of hypotype, GSC No. 18 878, UCLA loc. No. 4 631.

FIGS. 85, 86. *Arcestes* sp., anterior and ventral views of hypotype, GSC No. 17 974, UCLA loc. No. 4 631-3.

FIG. 88. Slab showing the abundance of *Tropites* and *Hannaoceras*.

NOTE: Figs. 13–88 follow.

PLATE I

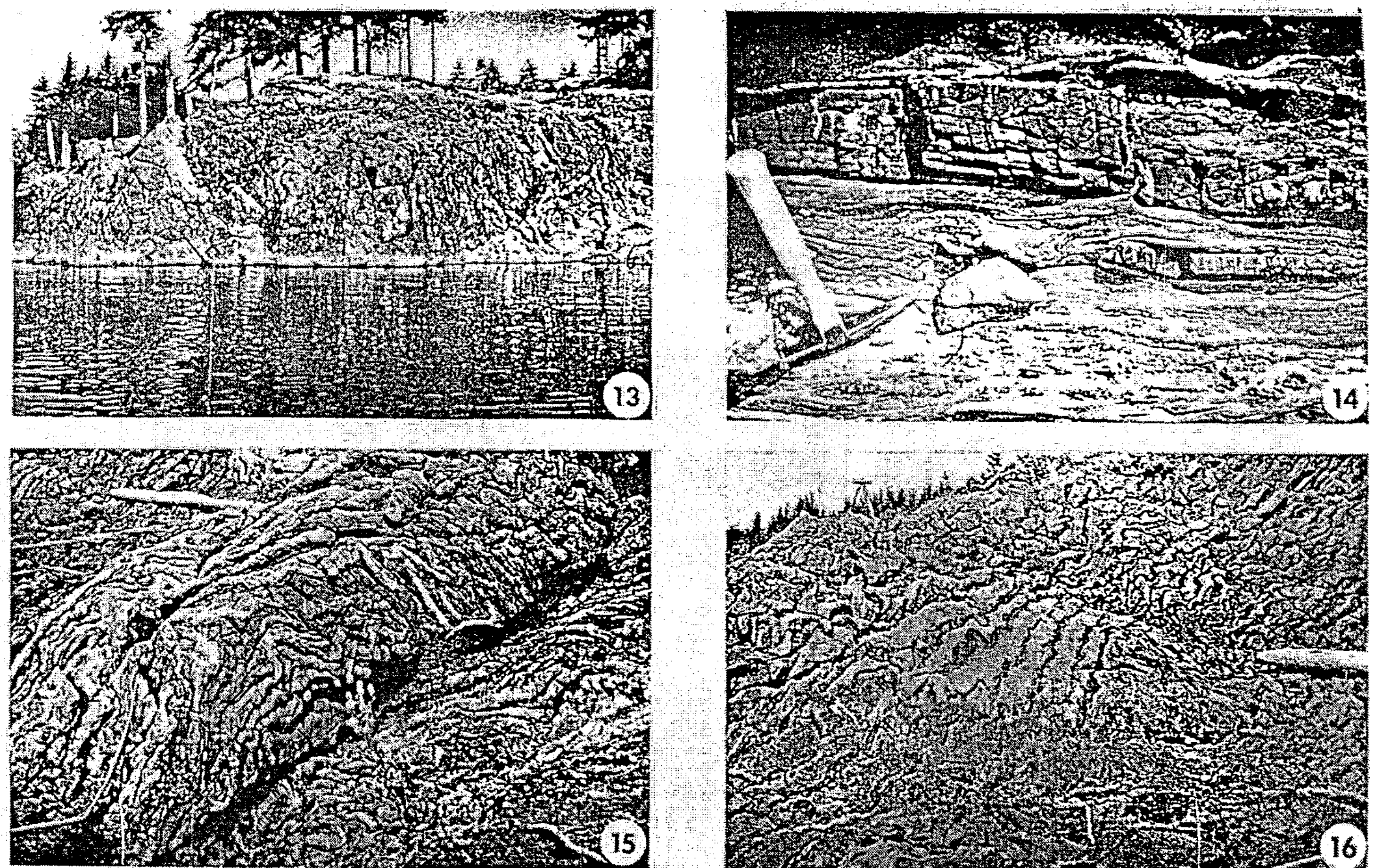

PLATE II


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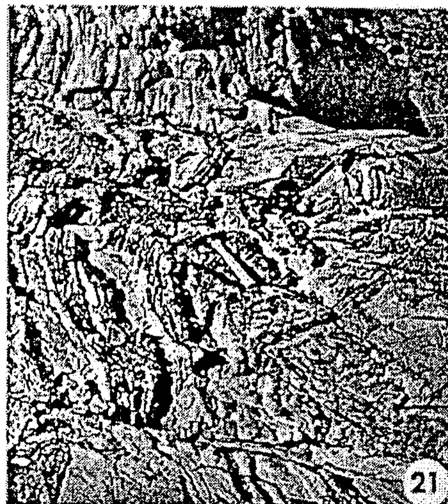
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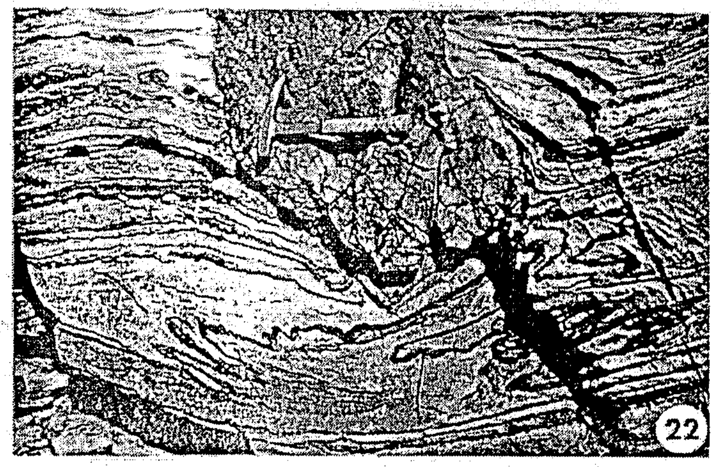
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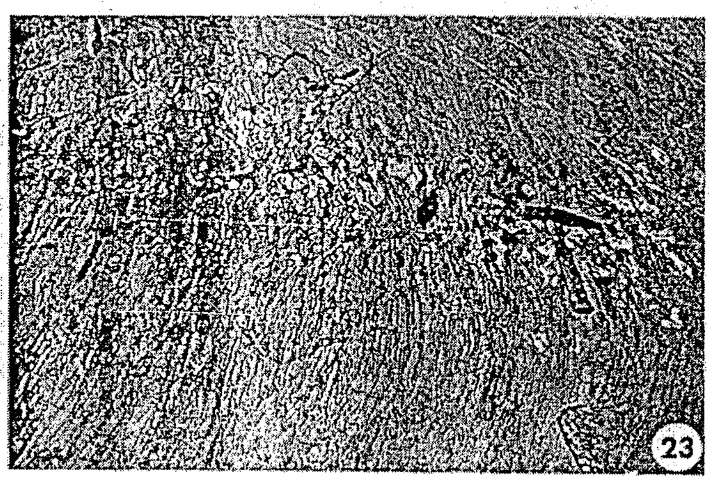
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PLATE IV

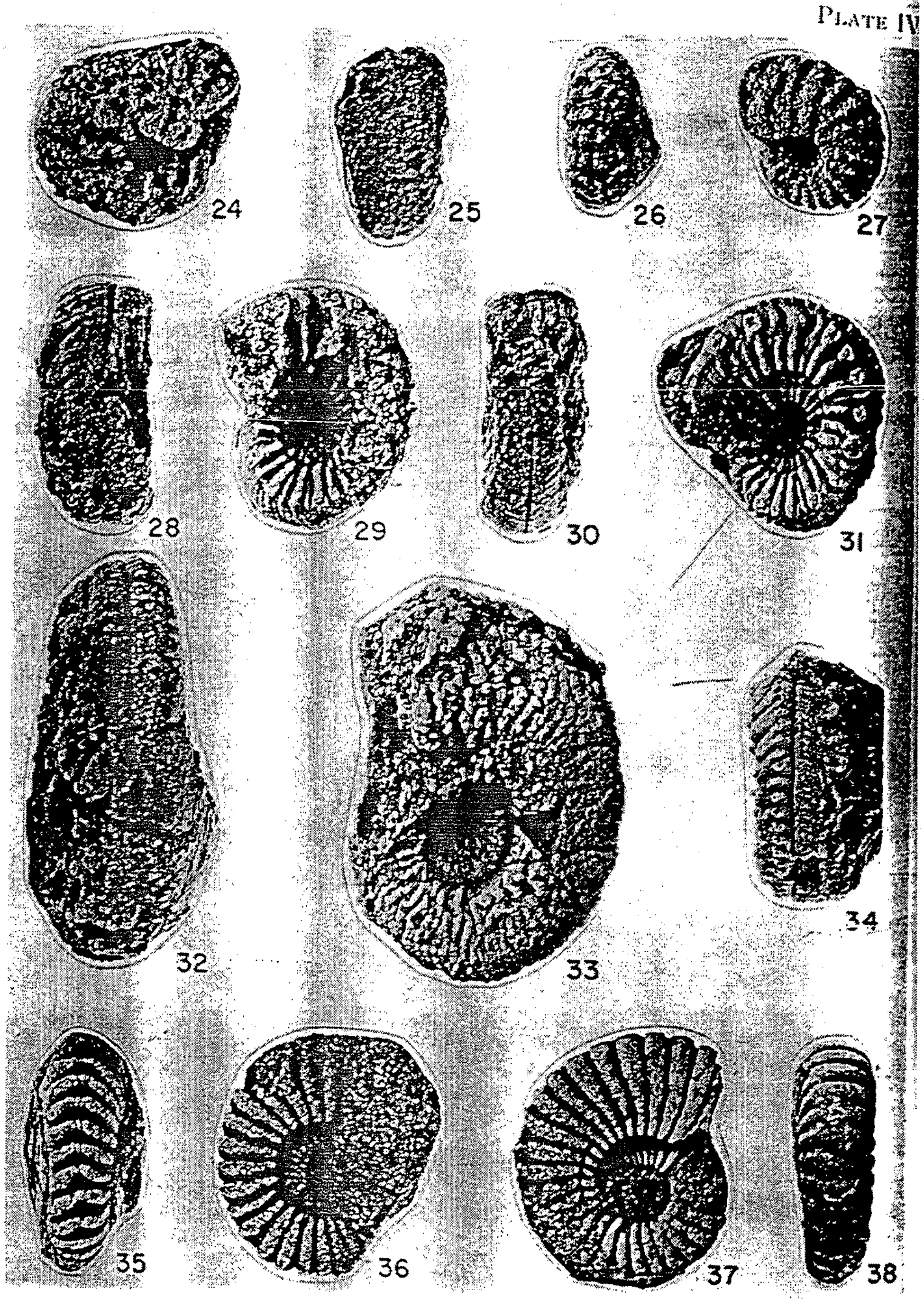
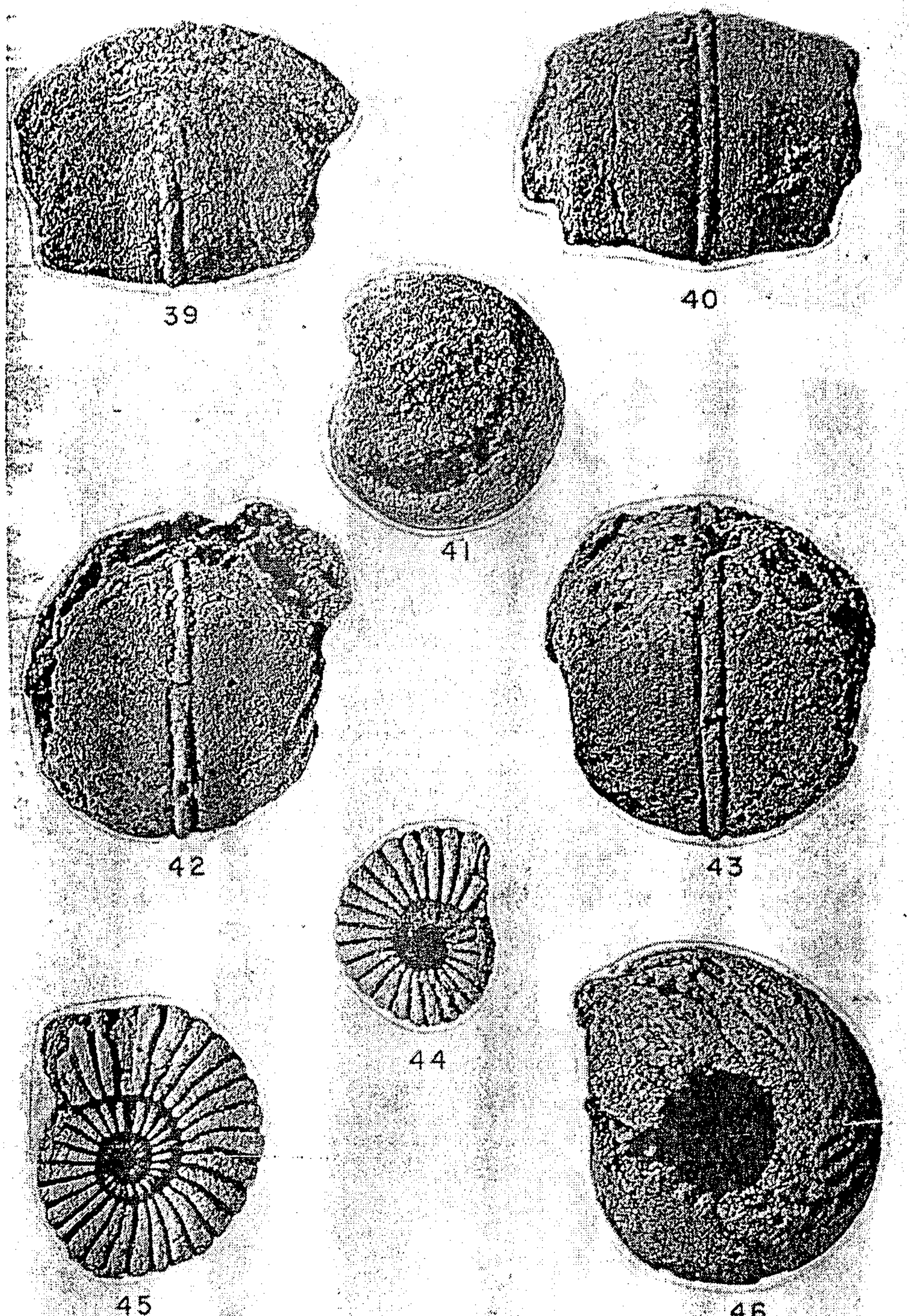


Plate V



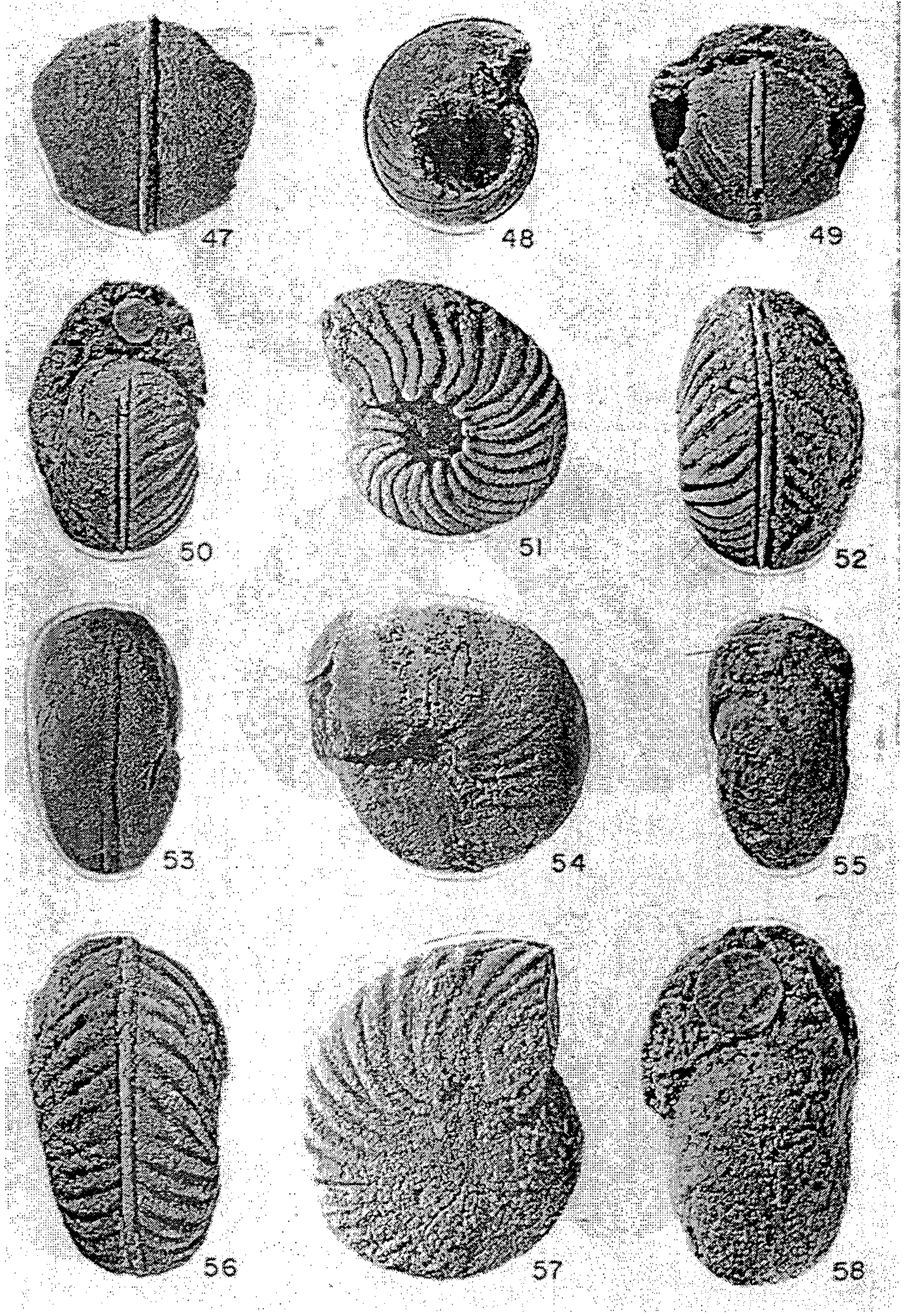

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PLATE VII