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R. W. Carrett

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 69-14

SOME SALIENT FEATURES OF EARLY MESOZOIC HISTORY OF INSULAR TECTONIC BELT, WESTERN BRITISH COLUMBIA

(Report and 2 pocket figures)

J. A. Jeletzky

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ABSTRACT

Thick submarine Karmutsen volcanics and the basal beds of Quatsino limestone (Karnian and? older) are ubiquitous in the Insular Tectonic Belt indicating an extension of the subsiding pre-Norian basin well to the west and east.

The upper (Norian) part of Quatsino limestone is restricted to the central zone of the belt extending from Iron River to the northern end of Graham Island and is laterally replaced by predominantly argillaceous clastics of the Sedimentary division of Bonanza Subgroup to the southwest and by argillites of Parson Bay Formation to the northeast. This indicates the formation of a northwest-trending depositional trough in the early Norian. The apparently continuous, clastic-free central zone of this trough was gradually narrowing during the Norian and was fragmented by a late Norian uplift into the southeastern (Buttle Lake area) and northwestern (Queen Charlotte Islands) segments where the deposition of Quatsino limestone apparently continued until the end of the Norian. This uplift produced the first Mesozoic source areas and introduced a complex facies pattern of clastic (upper Thinly bedded member, Arenaceous member) and calcareous (Sutton limestone) sediments in the intervening northwestern part of Vancouver Island and farther south along its west coast at least to the Barkley Sound-Cowichan Lake area. This shallow water regime was terminated by the latest Triassic (early Rhaetian?) orogenic phase which flexed the Triassic rocks into several gentle, northwest-trending folds and faulted them (judging by the concurrent outburst of volcanism).

The crests of latest Triassic anticlines became source areas providing pyroclastics, volcanic clastics, and lavas to the two residual northwest-trending, partly marine troughs situated in the Neroutsos Inlet-Hecate Cove area and along the west coast of Vancouver Island between Esperanza Inlet and Klaskino Sound.

The latest Triassic orogenic phase and the concurrent volcanic activity did not affect the eastern side of Vancouver Island, the islands in Queen Charlotte Strait, and the Queen Charlotte Islands where the deposition of marine argillites and limestones (upper parts of Parson Bay and Quatsino formations) continued into the Jurassic. The areally limited character of this orogenic phase resulted in the subdivision of the Insular Tectonic Belt into a southwestern tectonically and volcanically active zone and a northeastern tectonically and volcanically quiescent zone. This tectonic and depositional pattern persisted to the end of the Lower Jurassic.

Some 12,000 to 15,000 feet of volcanics with considerable interbeds of marine sediments (Volcanic division of the Bonanza Subgroup) were deposited during the Lower Jurassic in the active zone. In contrast, only 2,000 to 3,500 feet of argillites and limestones (Harbledown and Maude formations) were deposited at the same time in the quiescent zone which was obviously "sediment starved". The sedimentary interbeds of the Volcanic division appear to be the tongues of the Harbledown and Maude formations of the quiescent zone.

The Lower Jurassic depositional and structural pattern was annihilated by the Middle Jurassic orogeny and the accompanying batholithic Coast Intrusions. This orogeny transformed all of the Insular Tectonic Belt into a tectonic land and caused the "migration" of volcanism (Yakoun volcanics) from the Lower Jurassic active zone into the Lower Jurassic quiescent zone.

SOME SALIENT FEATURES OF EARLY MESOZOIC HISTORY OF INSULAR TECTONIC BELT, WESTERN BRITISH COLUMBIA

INTRODUCTION AND ACKNOWLEDGMENTS

Diagnostic fossils found during the last twenty years in structurally complex and lithologically diverse Triassic and Lower Jurassic rocks of the Insular Tectonic Belt of British Columbia have revealed an unexpected complexity in its early Mesozoic history. This belt, as defined by Sutherland Brown (1966, p. 83), comprises the area seaward from the present mainland coast to the continental slope. The geological history is revealed principally by sections exposed on Vancouver Island and the Queen Charlotte Islands.

This paper is an attempt to summarize the stratigraphic and biochronologic information now available and to utilize this information for the interpretation of some salient depositional and structural events of the Triassic and Lower Jurassic phase of the geological history of this belt. Although the interpretations offered appear to be reasonable and satisfactory to the author in the light of now available, often unevenly distributed and scarce information, they may well be subject to considerable future adjustment and reappraisal

Except where otherwise indicated, all Triassic invertebrate fossils have been identified and dated by E. T. Tozer. All Lower Jurassic invertebrate fossils have been identified and dated by Dr. Hans Frebold, except where otherwise indicated.

The report was critically read by Drs. Hans Frebold, J. E. Muller, H. W. Tipper, E. T. Tozer, and J. O. Wheeler. E. T. Tozer has furthermore assisted in editing the report.

TRIASSIC DEPOSITIONAL BASIN AND TROUGH

Karmutsen (Karnian and? earlier) time

The earliest clearly recognizable Mesozoic event within the Insular Tectonic Belt is the ubiquitous effusion of basaltic lavas, aquagene tuffs, and breccias of the Karmutsen Subgroup[1] (see Fig. 1). This more than

1 The Karmutsen and Bonanza groups are treated as subgroups because of the writer's desire to perpetuate the usage of the term Vancouver Group for all pre-batholithic Mesozoic rocks of the Insular Tectonic Belt.

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14,000-foot-thick (Surdam, 1968, p. 15; Sutherland Brown, 1968, p. 39; Muller and Carson, 1969, p. 11) extremely monotonous, volcanic unit was deposited mainly or entirely subaqueously.

All diagnostic fossils found in limestone interbeds and lenses near the top of the Karmutsen Subgroup represent the upper Karnian Dilleri Zone (Jeletzky, 1954b, p. 12; Carlisle and Susuki, 1965; Muller and Carson, 1969, p. 13; Tozer, 1967, pp. 82, 83). Diagnostic fossils of the Dilleri Zone have been reported from the lower part of the Quatsino limestone on Vancouver Island (Tozer, 1967, p. 82) but this anomalous locality is in severely disturbed rocks that possibly represent a fault block of a limestone interbed forming part of the Karmutsen Subgroup.

The next younger Welleri Zone is present in higher beds of the Quatsino Formation on both Vancouver Island and in the Queen Charlotte Islands. The latter occurrence is in the Karnian part of the Quatsino Formation (= Kunga Formation) (Sutherland Brown, 1968, p. 60; Tozer, 1967, p. 82)[1].

Cessation of basaltic effusions of the Karmutsen Subgroup is, therefore, believed to have taken place at the end of the time of the Dilleri Zone throughout the Insular Tectonic Belt. The essentially conformable Karmutsen-Quatsino contact appears, therefore, a regionally isochronous datum plane (Fig. 1).

The rare occurrence of reworked volcanic debris or more mature clastics near the top of the Karmutsen Subgroup (e.g. in Buttle Lake area; Surdam, 1968, pp. 18, 22 or at the mouth of Marble River; Jeletzky, in preperation) apparently reflects local reworking of tops of volcanic piles by waves or currents. Judging by the localization of such areas in the central part of the wide outcrop belt of the submarine Karmutsen lavas, this reworking and the deposition of interlava limestones probably took place far from any shoreline of the Karmutsen basin. The extreme paucity of reworked volcanic debris and volcanic clastics in the Karmutsen Subgroup of the west coast of Vancouver Island (Jeletzky, in preparation) indicates the absence of a western volcanic land in this part of the Insular Tectonic Belt, in contrast to the time of deposition of the Bonanza Subgroup (see below). The same appears to be true of the easternmost known exposures of the Karmutsen Subgroup on Harbledown Island (as Valdez Formation; Crickmay, 1928, p. 54, 59), Texada and Quadra Islands (Muller and Carson, 1969).

The rocks of the Karmutsen Subgroup were apparently deposited in a wide-open, rapidly subsiding oceanic basin, the shores of which were situated well to the west and east of the now exposed parts of the Insular Tectonic Belt.

---

1 The term Kunga Formation, introduced by Sutherland Brown (1966; 1968, p. 50) for late Triassic to early Jurassic rocks of Queen Charlotte Islands, is superfluous in the writer's opinion. The lower two "members" of Kunga Formation are lithologically and stratigraphically identical with the Quatsino Formation of the more southerly areas while its upper "member" is identical with the type Harbledown Formation. The latter names are used instead of Kunga Formation in this report.

Late Karnian and Norian time

Like the Karmutsen Subgroup, the Quatsino Formation (including such equivalents as the Marble Bay Formation and the limestone members of Kunga Formation; see Muller and Carson, 1969, p. 14, and Sutherland Brown, 1968, p. 57) is ubiquitous within the Insular Tectonic Belt. The thickness and time limits of this important limestone unit exhibit some regular, paleogeographically and structurally significant variations.

The Quatsino limestone of the Quatsino Narrows-Victoria Lake area (Jeletzky, 1954a, p. 1269; in preparation) is at least 2,500 feet thick and represents a considerably longer time interval than the only 100- to 550-foot-thick Quatsino limestone of the west coast of Vancouver Island (i.e. between Esperanza Inlet and Klaskino Inlet; the sections in Klaskino Inlet were studied jointly with J.E. Muller in 1968). The Quatsino limestone of the Quatsino Narrows-Victoria Lake area definitely includes the basal Norian Kerri Zone (Tozer, 1967, p. 38, etc.) and probably includes the younger Norian Dawsoni, Magnus, and Rutherfordi Zones as well because of the presence of specifically indeterminate Halobia (GSC loc. 23270) and apparent absence of Monotis in its upper part. The Quatsino limestone of the west coast, in contrast, only represents the upper Karnian Welleri Zone (Tozer, 1967, p. 82) and questionably (see in the previous section) the Dilleri Zone. The previously mentioned younger zones occurring in the Quatsino limestone of Quatsino Narrows-Victoria Lake area are inferred to occur within the overlying Bonanza argillites on the west coast of Vancouver Island. This is indicated by the occurrence of early Norian Halobia alaskana in the lower part of the Thinly bedded member on Union Island (Tozer, 1967, p. 81). The Quatsino-Bonanza contact is, therefore, markedly diachronous in the northeast-southwest direction on the northern part of Vancouver Island, as most or all of the at least 1,500-foot-thick upper member of the Quatsino limestone becomes laterally replaced by the lower part of the Thinly bedded member between the Quatsino Narrows-Victoria Lake area and the adjacent segment of the west coast (Fig. 1).

The Quatsino-Bonanza contact appears to be similarly diachronous east of the Quatsino Narrows-Victoria Lake area. The presence of Halobia alaskana (Crickmay, 1928, pp. 54, 59; Tozer, 1967, p. 81) in the basal part of the Parson Bay Formation of Harbledown Island indicates that rocks of Bonanza (i.e. of its Sedimentary division) facies extend at least to the base of the Norian Stage. The presence of Mojsisovicsites kerri and Halobia alaskana in the Bonanza sediments of the Nimpkish map-area (Tozer, 1967, p. 81) indicates similar lowering of the Quatsino-Bonanza contact east of Victoria Lake.

The above described early to middle Norian facies relationships appear to indicate emergence of sizable source areas to the east and west of the extremely broad late Karnian (i.e. Karmutsen and early Quatsino time) depositional basin of northern Vancouver Island and its transformation into a recognizable northwest-southeast-trending depositional trough. Gradual narrowing of the essentially clastic-free central part (i.e. Quatsino Narrows-Victoria Lake belt) of the trough appears to reflect progressive expansion and (?) elevation of these budding tectonic lands throughout early and middle Norian time.

The apparent paucity or complete absence of arenaceous to psammitic material in the Parson Bay Formation and in the lower and middle parts of the Thinly bedded member, and the exclusively open sea character of their faunas, indicates their deposition far from respective shorelines. The eastern shore of the early to middle Norian depositional trough of northern Vancouver Island was probably situated well within the present Coast Mountains while its western shore was situated beneath the Pacific Ocean some distance to the west of the present west coast.

The almost exclusively limestone sections of the Quatsino Formation measured by Surdam et al. (1964, p. 226) and Surdam (1968, p. 20, Fig. 6) in the Buttle Lake map-area, which are almost as thick as and have even wider time limits (at least from late Karnian to early upper Norian) than those of the Quatsino Narrows-Victoria Lake belt, appear to represent the southeastern continuation of the central part of the early to middle Norian trough of northern Vancouver Island.

The section near Sproat Lake where the basal Norian Kerri Zone occurs in bedded shale overlying the Quatsino limestone of Welleri Zone age (Muller and Carson, 1969, p. 16) appears to represent the southwestern limb of the same trough. The same appears to be true of only 100- to 550-foot-thick sections of Quatsino limestone measured by Jeletzky (1954b) on the west coast of Vancouver Island between Esperanza Inlet and Clayoquot Sound. These sections are unfortunately represented by marbles and skarns and consequently unfossiliferous.

The sections of Quatsino Formation (i. e. of limestone members of Kunga Formation) measured by Sutherland Brown (1968, pp. 57, 58) on Queen Charlotte Islands are somewhat thinner than those of the Quatsino Sound and Buttle Lake areas. Because of the reportedly continuous succession of these calcareous to argillaceous sediments they are believed to include the same Norian zones (from Kerri to Lower Suessi Zone inclusive) as the Iron River section (Surdam et al., 1964, p. 226; Muller and Carson, 1969, p. 16) and so should represent the northwestern extension of the previously discussed central zone of the early to middle Norian depositional trough of northern Vancouver Island. The lithologic uniformity of the Quatsino Formation on Queen Charlotte Islands (Sutherland Brown, 1968, p. 56) suggests that the central zone of the depositional trough extended across the islands. If so, the northeastern and southwestern limbs of the trough are concealed beneath the sea in that area.

The data available suggest that the early to middle Norian depositional trough extended at least from the Sproat Lake and Iron River areas in the southeast to the northwestern end of Graham Island in the northwest (Fig. 2). Throughout its inferred extent, the axial zone of the trough seems to correspond more or less closely with cores of northwesterly-trending anticlinoria of Vancouver Island and Queen Charlotte Islands (compare Sutherland Brown, 1966, p. 85, Figs. 6-12).

Late Norian time

Beginning in Lower Suessi (*Monotis subcircularis*) time clastic sedimentation spread over considerable parts of the axial zone of the early to middle Norian depositional trough. So far as is known, only in the Buttle

Lake area and in Queen Charlotte Islands did calcareous sediments (black carbonaceous limestone) of Quatsino Formation continue to be deposited at least into early late Norian (i. e. Lower Suessi) time. The prevalence of calcareous deposition during the late Norian may yet be found more apparent than real even in these two areas when more detailed work is done there.

The data on hand suggest tectonic fragmentation of the apparently continuous clastic-free central zone of the early to middle Norian depositional trough at the onset of late Norian (Suessi) time. A complex facies pattern of pelitic, arenaceous and calcareous sediments emerged at the onset of Suessi time at least in the part of the belt separating its southeastern (Buttle Lake area) and northwestern (Queen Charlotte Islands) parts. In this part of the belt, as shown by sections in northwestern Vancouver Island, the more or less arenaceous and/or tuffaceous argillites of the upper Thinly bedded member appear to pass laterally within short distances across and along the strike into greywackes and psammites of the Arenaceous member or into black to light grey limestones of the Sutton Formation. These facies relationships suggest the emergence of source areas within the northern Vancouver Island segment of the depositional trough, which comprised at least the Quatsino Sound-Victoria Lake area and the Klaskino Inlet-Esperanza Inlet section of the west coast, already at the onset of Lower Suessi time. The data available are insufficient to localize most of these source areas more precisely. It seems likely, however, that they represented the barely budding nuclei of the early Rhaetian anticlines and fault scarps discussed in the next section, as their locations appear to coincide at least in some instances. The existence of a northwest-southeast-trending late upper Norian tectonic land a few miles to the east of the eastern shore of Neroutsos Inlet is, for example, inferred from facies relationships of the rocks concerned (Jeletzky, 1969, p. 128, in preparation). The Sutton limestone outcrops on the shores of Neroutsos Inlet north of Jeune Landing and farther west on the southern shore of Quatsino Sound but appears to be laterally replaced by the approximately contemporary tuffaceous greywackes containing Monotis salinaria (Schlotheim) and Monotis cf. subcircularis Gabb. in the headwaters of Lippy Creek within a couple of miles northeast of Jeune Landing. Western to southwestern direction of paleoslope is inferred from slump folds occurring in these partly turbiditic greywackes.

LATEST TRIASSIC (RHAETIAN?) OROGENIC PHASE AND RESULTING FACIES AND PALEOGEOGRAPHIC CHANGES

All over northern Vancouver Island, and southwest at least to Cowichan Lake area (see in Tozer, 1967, p. 79), late Norian (upper Suessi Zone) neritic limestones of the Sutton Formation and approximately equivalent rocks comprising tuffaceous argillite, greywacke (with some psammites) and waterlain volcanic tuffs, are overlain by mostly coarse to very coarse, waterlain breccias and conglomerates of the Waterlain breccia unit (Jeletzky, 1950, pp. 12, 13; 1969, p. 129, in preparation).

The facies of the Waterlain breccia unit vary laterally even more extensively than those of the underlying rocks of the Upper Suessi Zone. In some sections, as for example on the southern side of Bucholz Channel in Quatsino Sound; on the northwestern side of Mushroom Point; on Union and

Walters islands near Kyuquot Channel; and apparently also on Cowichan Lake, the basal part of the unit is represented by obviously marine limestone breccia, mixed sedimentary-volcanic breccia, intermediate (andesitic?) pillow lava, and pillow breccia, volcanic conglomerate or waterlain volcanic tuff with marine interbeds apparently gradationally overlying zoogenic or bioclastic shallow water limestones of the Sutton Formation. In many other sections of the Waterlain breccia unit, as for example those between the mouth of Porritt Creek and the southeastern base of Mushroom Point (Jeletzky, 1950, p. 10), in several unpublished sections between Kyuquot Sound and Klaskino Inlet, and in those 3 1/2 miles northeast of Jeune Landing, Neroutsos Inlet (Jeletzky, 1969, p. 129, in preparation), the limestone breccia and marine interbeds are poorly developed or missing and the overlying mixed sedimentary-volcanic or predominantly volcanic breccias, pillow lavas and pillow breccias, conglomerates, and/or waterlain volcanic tuffs overlap disconformably to regionally unconformably the more or less deeply eroded surface of the Sedimentary division of the Bonanza Subgroup. The coarseness, degree of rounding in conglomerates and breccias, and lithologic composition of above listed rock varieties is extremely variable. Mixed or predominantly sedimentary breccias and conglomerates strongly predominate in some sections while waterlain tuffs with interbeds of marine tuffaceous clastics (Jeletzky, 1950, pp. 12, 13; 1969, pp. 126, 129) predominate in other adjacent sections. Yet other sections of the Waterlain breccia unit consist largely or entirely of waterlain or unsorted volcanic breccias and/or poorly rounded volcanic conglomerates. That the tuffs and breccias are waterlain is indicated by the calcareous and argillaceous matrix and by the occurrence of marine shells.

In most sections where they are present, the limestone breccias, sedimentary breccias, mixed breccias, and conglomerates are essentially restricted to the lower few feet to the lower few hundred feet of the Waterlain breccia unit. Its upper few hundred to (?) 2,500 feet mostly lack limestone breccia and related rock types. There are, however, some sections where various tuffaceous clastics, tuffaceous limestones, and waterlain pyroclastics occur at intervals throughout the thickness of the Waterlain breccia unit. One of the best such sections is exposed on the northern side of Quatsino Sound east of Quatsino village (Jeletzky, 1969, p. 126). Others are concentrated between Smith and Julian coves opposite Quatsino village (Jeletzky, in preparation).

The best known example of an unconformity between the Sedimentary division and the overlying Waterlain breccia unit of the Volcanic division of the Bonanza Subgroup, and which indicates the latest Triassic orogenic phase, occurs in sea bluffs halfway between Porritt Creek and Mushroom Point (Jeletzky, 1950, p. 10 and geol. map). There, the coarse, green-grey, waterlain volcanic breccia (pillow breccia?) and andesitic? pillow lava of the Waterlain breccia unit overlap regionally unconformably the Monotis subcircularis-bearing beds (GSC loc. 19321) of the Thinly bedded member. Only 1 1/2 miles farther northwest and on the same limb of the anticline, the same M. subcircularis-bearing beds are overlain by more than 800 feet of late Norian rocks, including the Sutton limestone (= Limestone member of Jeletzky, 1950). The typically developed limestone breccia of the Waterlain breccia unit occurs nearby in strongly disturbed outcrops (Jeletzky, 1950, pp. 8, 10, 12). An even greater regional unconformity is inferred to exist in

the northeasternmost part of Malksope Inlet where unusually thick and coarse psammites of the Waterlain breccia unit contain numerous fragments and pebbles of basic amygdaloidal lavas similar to those of the Karmutsen Subgroup. If the pebbles are from the Karmutsen as the writer believes, the whole thickness of the Sedimentary division of the Bonanza Subgroup and the Quatsino Formation was eroded away prior to the deposition of the Waterlain breccia unit of the Volcanic division near the head of Malksope Inlet. Similar structural relationships between the Sedimentary and Volcanic divisions of Bonanza Subgroup were observed by the writer in several other sections on the west coast of Vancouver Island.

The above data indicate that the deposition of marine strata of the Sedimentary division was followed by an orogenic phase[1] on the northwestern part of Vancouver Island (Fig. 1). The same seems to be true of the southeast-trending belt extending along its west coast at least as far south as the Barkley Sound-Cowichan Lake area. These latest Triassic tectonic movements apparently not only uplifted the rocks of the Sedimentary division but also faulted and flexed them into a number of northwest-trending folds.

Granitoid pebbles are characteristically absent throughout the Waterlain breccia unit. This suggests that the latest Triassic orogenic phase was not accompanied by sizable intrusions of granitic rocks.

The previously described facies and structural relationships indicate that some parts of the belt affected by the latest Triassic orogenic movements (presumably the crests of broad anticlinal folds) were elevated well above sea level, subjected to varying amounts of erosion, and became source areas of coarse clastic sediments. Other, sometimes adjacent, parts of the belt (presumably those representing the axial parts of synclinal folds) were much less elevated and continued as depositional troughs.

There were apparently at least two such residual, northwest-trending marine troughs. One occupied the site of the present Neroutsos Inlet (including its shores), northern shore of Quatsino Sound between Quatsino village and Hecate Cove, and extended for an unknown distance southeast and northwest therefrom. This trough is defined by the abnormally great thickness (up to 2,500 feet) of the Waterlain breccia unit in the Smith Cove, Julian Cove and Quatsino village sections and the occurrence of considerable interbeds of various marine clastics and limestones through much or all of the thickness of the unit in these same sections (Jeletzky, 1969, p. 126, in preparation). East of Neroutsos Inlet in the headwaters of Lippy Creek, the Waterlain breccia unit does not appear to exceed several hundred feet in thickness and appears to lack any significant interbeds of marine clastics and limestones (Jeletzky, 1969, p. 129, in preparation). This area apparently was situated at or within the eastern source area of the Neroutsos Inlet trough. This conclusion is supported by the previously discussed facies changes of late Norian rocks in the same area.

Another residual northwest-trending trough apparently extended along the west coast of Vancouver Island at least in the interval between the Esperanza Inlet and Klaskino Sound. Its existence is inferred from the

1 As interpreted by the writer, an "orogenic phase" or "orogeny" implies a demonstrable or probable occurrence of folding of the rocks occurring beneath the unconformity in addition to their uplift and erosion. Batholithic intrusions of granitic rocks may or may not accompany an "orogeny".

restriction of outcrops of Sutton limestone (and those of the more finely grained, partly marine facies of the Waterlain breccia unit) to the outer coast and offshore islands. Conversely late upper Norian clastic rocks and the more coarsely grained, predominantly nonmarine and volcanic facies of the Waterlain breccia unit are concentrated farther inland (e. g. in the inner parts of Malksope and Ououkinsh inlets and Klaskino Sound area). This trough is believed to occur beneath the sea off the entrance to Klaskino Sound and to extend southeastward to the Cowichan Lake area.

Very little is known about the width and character of the uplifted belt which separated the West Coast residual trough from that of Neroutsos Inlet because of the scarcity of the outcrops of the Sedimentary division and the Waterlain breccia unit in that belt. The same applies to the uplifted latest Triassic belt situated closely east of Neroutsos Inlet and Hecate Cove.

In the axial parts of the Neroutsos Inlet and West Coast residual troughs the marine regime apparently persisted uninterruptedly or almost uninterruptedly well into (Jeletzky, 1950, pp. 12, 13) or to the end of the deposition time (Jeletzky, 1969, p. 126) of the Waterlain breccia unit in spite of an abrupt replacement of the mostly fine grained sediments of the Upper Suessi Zone by the mostly coarse grained pyroclastics and psammites of the Waterlain breccia unit.

The coarse clastics of the Waterlain breccia unit have characteristically undergone little abrasion, rounding, and sorting before their burial in calcareous marine oozes which later became an argillaceous to limy matrix. This suggests extremely rapid transportation and burial caused by the very strongly diversified relief of the region following the latest Triassic orogenic phase. During the time of deposition of the Waterlain breccia unit, marine troughs apparently existed side by side with precipitous mountain ranges east of the Neroutsos Inlet-Hecate Cove area and in a southeast-trending belt extending along the west coast of Vancouver Island (Fig. 2). The general physiography was probably similar to that of recent island arcs (i. e. Indonesian Archipelago).

Strong volcanic activity must have started at least within elevated parts of northwestern Vancouver Island from the onset of the latest Triassic orogenic phase, suggesting more or less extensive faulting of these areas. The ensuing rapid increase of volcanic activity, and an even more rapid erosion of resulting volcanic piles, is clearly reflected in the previously mentioned characteristic upward replacement of sedimentary breccias almost exclusively by volcanic breccia and conglomerate in most sections of the Waterlain breccia unit. It seems likely that as the source areas were rapidly eroded, the intervening depositional troughs were equally rapidly filled up by the resulting sedimentary debris and by great masses of airborne pyroclastic fragments. Both kinds of fragments were commonly deposited in a marine environment as indicated by their burial in the locally fossiliferous (marine shells) calcareous and argillaceous matrix.

The above discussed orogenic phase occurred immediately after the deposition of the reliably dated (Tozer, 1967, pp. 78-80) late upper Norian (Upper Suessi Subzone) Sutton Formation and preceded the deposition of the upper, predominantly volcanic, part of the Waterlain breccia unit. The locally unconformable relationship of the Waterlain breccia unit with the underlying late Norian sediments (see pp. 6, 7) and the presence of a presumably Triassic marine fauna (Jeletzky, 1969, p. 126) in the uppermost

beds of the same unit in Quatsino Sound, indicates its latest Triassic, presumably Rhaetian age. The orogenic phase, therefore, occurred in early Rhaetian and/or (?) latest Norian time and was of extremely short geological duration. It is referred to as the latest Triassic orogenic phase in this report.

TECTONICALLY AND VOLCANICALLY QUIESCENT ZONE OF THE LATEST TRIASSIC

The latest Triassic orogenic phase and the concurrent volcanic outburst apparently did not affect the eastern side of Vancouver Island and Queen Charlotte Islands (Figs. 1, 2). The late Triassic rocks of the northeastern part of the Insular Tectonic Belt, appear to be represented either by black, often tuffaceous argillites of the upper Parson Bay Formation (Crickmay, 1928, pp. 56, 59) or by black carbonaceous limestones of the upper Quatsino Formation with interbeds of tuffaceous argillites (Sutherland Brown, 1966, p. 98, Fig. 6-11; 1968, pp. 57, 58; Surdam et al., 1964, p. 226; Surdam, 1968, p. 20, Fig. 6).

The late Upper Triassic sediments appear to grade imperceptibly into early Lower Jurassic (Sinemurian) black argillites or limy argillites and very fine grained volcanic tuffs in all better known parts of the northeastern zone of the Insular Tectonic Belt (Sutherland Brown, 1966, p. 98, Fig. 6-11; Surdam, 1968, p. 20, Fig. 6).

Crickmay (1928, pp. 56, 59) inferred a disconformity and a hiatus embracing most or all of the Rhaetian and Hettangian stages between the Parson Bay and Harbledown formations. This conclusion appears to be untenable, however, being based solely on the apparent absence of faunas concerned within an admittedly (Crickmay, loc. cit.) perfectly continuous sequence of beds.

The evidence available indicates that during latest Triassic (late upper Norian and Rhaetian) time the tectonically and volcanically quiescent zone became restricted to the Queen Charlotte Islands and most or all of the eastern side of Vancouver Island and Queen Charlotte Strait islands (at least as far southeast as the Buttle Lake map-area) of the Insular Tectonic Belt (Figs. 1, 2). The areally limited character of the latest Triassic orogenic phase and the accompanying outburst of volcanic activity resulted in subdivision of the Insular Tectonic Belt into an active zone and a quiescent zone. The active zone is represented by the sections in northwestern Vancouver Island; the quiescent zone by those of easternmost Vancouver Island, the islands in Queen Charlotte Strait, and Queen Charlotte Islands.

LOWER JURASSIC TECTONIC AND DEPOSITIONAL PATTERN

The tectonic and depositional pattern produced by the latest Triassic orogenic phase apparently persisted essentially unchanged during Lower Jurassic time.

Predominantly Volcanic Sequence of Tectonically and Volcanically Active Zone

The deposition of the Volcanic division of the Bonanza Subgroup, initiated in the latest Triassic (Rhaetian or? latest Norian) by the deposition of the Waterlain breccia unit, continued throughout the Lower Jurassic over most or (?) all of the tectonically and volcanically active zone. The Volcanic division is well developed and obviously was deposited everywhere in the northwestern part of Vancouver Island west of 126° W. East of this meridian outcrops are few. Those known (e.g. on Cowichan Lake, Fyles, 1955, p. 23; in Sproat Lake area; Muller and Carson, 1969, p. 16; in Kennedy Lake area, Eastwood, 1968, pp. 26, 27) appear nevertheless to be readily assignable to the individual sedimentary or volcanic units of the division recognized on the northwestern part of Vancouver Island on the basis of their stratigraphic position and lithology. It is assumed accordingly that the Volcanic division was originally deposited in the same facies over most or all of the western half of southeastern Vancouver Island but was either subsequently eroded or has been sufficiently metamorphosed to be now unrecognizable in most areas.

The data available suggest subdivision of the Lower Jurassic part of the Volcanic division into four volcanic units separated by at least three persistent sedimentary units (Fig. 1). As pointed out in the following description, none of the recognized volcanic or sedimentary units of the division has yet been traced throughout the whole of the northwestern part of Vancouver Island (as defined previously in this section). For paleogeographic and stratigraphic reasons presented below, it is believed, however, that most of them were originally deposited over most or all of this area with the possible exception of its southwestern margin (i.e. on the west coast proper) where most of the sedimentary units may pinch out and eastern margin (i.e. the belt near the east coast) where most or all of the volcanic units may pinch out.

Basal Jurassic Volcanic Unit

Over much of the tectonically and volcanically active zone of the Insular Tectonic Belt (Fig. 2) the Waterlain breccia unit is overlain, apparently conformably, by a 5,000- to 7,000-foot-thick unit of largely unsorted to very poorly sorted, lavender to maroon, intermediate (andesitic?) to acid (dacitic to ? rhyolitic) pyroclastics and lavas. The more acidic phases of this Basal Jurassic volcanic unit are mostly rich in phenocrysts of pink to orange feldspar (Jeletzky, 1950, pp. 16-19; 1969, p. 126, in preparation). This feldspar is a sodic plagioclase according to J.E. Muller (pers. comm., 1968).

The best sections of the Basal Jurassic volcanic unit are on Rugged Point in the Kyuquot-Esperanza area (Jeletzky, 1950, pp. 17, 18) and on the northern shore of Quatsino Sound in front of Quatsino village (Jeletzky, 1969, p. 126).

The apparently predominantly or entirely subaerially deposited (see p. 21) volcanics of the Basal Jurassic volcanic unit appear to blanket indiscriminately all known facies of the Waterlain breccia unit. This suggests the

substantial bevelling of strongly elevated tectonic lands and the complete filling of residual marine troughs produced by the latest Rhaetian orogenic phase prior to the deposition of the Basal Jurassic volcanic unit.

The apparent absence of the Basal Jurassic volcanic unit in Sproat Lake (see Muller and Carson, 1969, pp. 16, 17; this paper Fig. 2) and Kennedy Lake areas (see Eastwood, 1968) is probably due to erosion resulting from early Pliensbachian (see p. 22) tectonic movements.

The Basal Jurassic volcanic unit yielded no fossils. In Quatsino Sound it overlies apparently conformably (Jeletzky, 1969, p. 126) the presumably Rhaetian uppermost beds of the Waterlain breccia unit. The Hettangian (?) Cherty limestone and Grey volcanic units occur between the top of the Basal Jurassic volcanic unit and the base of reliably dated (Jeletzky, in preparation) Sinemurian argillites. Thus, although a latest Triassic (Rhaetian) dating of the Basal Jurassic volcanic unit is possible, the unit is provisionally dated as Hettangian.

Cherty Limestone Unit

Dark grey to black, thinly bedded to laminated, cherty limestones with numerous laminae, thin layers, inclusions and lenses of black to dark grey chert and minor interbeds of calcarenite, calcareous clastics, and calcareous pyroclastics, at least 350 feet thick, outcrop repeatedly between the eastern shore of Neroutsos Inlet and southeastern shore of Ahwhichaolto Inlet (Jeletzky, in preparation). The best sections known are on the eastern tip of the largest of Koskimo Islands and on the adjacent part of the southern shore of Quatsino Sound. At the eastern tip of the largest of Koskimo Islands the Cherty limestone unit conformably overlies volcanic rocks lithologically identical with those of the Basal Jurassic volcanic unit as exposed on the southern shore of Quatsino Sound for about 3/4 of a mile east of Cleagh Creek. This presumably marine unit yielded no diagnostic fossils but is tentatively placed in the Hettangian stage because of its inferred stratigraphic position between the Rhaetian Waterlain breccia unit and the Sinemurian argillites described below.

The Cherty limestone unit is not known beyond Quatsino Sound and possibly pinches out to the south and west.

Grey Volcanic Unit

At least 600 feet of dull-grey, bluish grey or dull lavender, mostly massive volcanic rocks conformably overlie the Cherty limestone unit on the southern shore of Quatsino Sound, opposite Koskimo Islands (Fig. 1). These volcanics appear to grade upward into some 1,000 feet of similarly coloured, intermediate, amygdaloidal pillow lavas with considerable interbeds of coarsely porphyritic lavas and volcanic breccia (pillow breccia?). The best sections are on both sides of Forward Inlet between Robson Island and Winter Harbour and on the southern shore of Quatsino Sound opposite Koskimo Islands. The Grey volcanic unit is not known beyond Quatsino Sound and probably is replaced laterally by lavas and pyroclastics lithologically similar to those of the Basal Jurassic volcanic unit to the south. For example, only

lavender to maroon volcanics rich in phenocrysts of pink to orange feldspar were observed in Tahsish Inlet and around Fair Harbour, Kyuquot Sound, closely beneath the calcareous facies of the Sinemurian argillites.

The unfossiliferous pillow lavas and breccias of the Grey volcanic unit grade upward into Sinemurian argillites and must, therefore, be either of upper Hettangian or basal Sinemurian age; the former age is favored in this report (Fig. 1).

Sinemurian Argillites

At least 1,300 feet of predominantly argillaceous rocks separate the Grey volcanic unit or its lavender to maroon equivalents (as in Kyuquot Sound) from the Basal Pliensbachian volcanic unit. This sedimentary unit is widespread in Quatsino Sound area (Jeletzky, in preparation) and on the eastern flank of Kyuquot Basin between Eelstow passage and the mouth of Artlish River. The Kyuquot Sound sections of the unit contain much limestone and their age remained uncertain until the discovery of diagnostic Sinemurian ammonites on the southern side of Moketas Island by J.E. Muller's party (unpublished intradepartmental fossil report, 1968). The unit may, therefore, be present all over the northwestern part of Vancouver Island.

In its best known sections in Quatsino Sound (as for example on Robson Island and on the southern shore of Quatsino Sound for about one half mile east of an unnamed point opposite Salmon Island; Jeletzky, in preparation). Sinemurian argillites are subdivisible into a Lower argillite member at least 500 feet thick, an Intermediate waterlain tuff member 100 to 150 feet thick, and an Upper argillite member 120 to at least 700 feet thick. The argillite members contain variable but always subordinate greywacke, pure to arenaceous grey limestone, and waterlain pyroclastic rocks. Westward the ratio of arenaceous and pyroclastic rocks appears to increase markedly, the argillites become increasingly more arenaceous and tuffaceous, and some conglomerate interbeds appear. The Upper argillite member thins out to some 120 feet in the northwestern corner of Browning Inlet. A paleogeographical interpretation of these facies changes is attempted on page 21.

All studied sections of the calcareous facies of Sinemurian argillites in Tahsish Inlet consist of impure limestone with interbeds of dark grey argillites and do not seem to be subdivisible into members. These sections are at least as thick as their Quatsino Sound equivalents.

According to Dr. Hans Frebold (unpublished intradepartmental fossil reports and personal communication, 1969) the writer's fossil collections from Sinemurian argillites contain Arniotites kwakiutlanus and Echioceras (Melanippites) harbledownensis faunas. The former fauna is of the lower Sinemurian age whereas the latter corresponds to the uppermost Sinemurian Raricostatum Zone of International Standard. J.E. Muller's fossil collections (unpublished intradepartmental fossil reports, 1968) also contain the intervening Asteroceras aff. A. obtusum fauna. The unit spans therefore, most or (?) all of the Sinemurian Stage (Fig. 1).

Sinemurian argillites are an extremely important horizon marker being the only abundantly fossiliferous, regionally persistent sedimentary unit known within the Volcanic division of the Bonanza Subgroup.

Basal Pliensbachian Volcanic Unit

At least 600 feet of green-grey, mostly waterlain pyroclastics (mostly coarse to medium volcanic breccia), grey, green or speckled lavender, amygdaloidal to porphyritic, intermediate lava flows, and considerable, mostly coarse volcanic clastics gradationally overlie the Sinemurian argillites in the western part of the Quatsino Sound area. The best sections are on Robson Island and on the southern shore of Quatsino Sound on the nameless rocky point overlooking Mahatta Logging Camp from the east. The lavas of this unit commonly exhibit well-developed pillow structure and some volcanic breccia appear to be pillow breccias. The Basal Pliensbachian volcanic unit is apparently present on Markale Peninsula and in Fair Harbour, Kyuquot Sound atop of the calcareous facies of the Sinemurian argillites but was not studied in any detail in these sections. It was not definitely identified anywhere else within the tectonically and volcanically active zone of the Insular Tectonic Belt. However, it may be present throughout the outcrop area of Sinemurian argillites (i. e. all over the northwestern part of Vancouver Island).

Although unfossiliferous, the unit is placed in the basal Pliensbachian Stage as it overlies conformably the uppermost Sinemurian *Echioceras* (*Melanippites*) *harbledownensis* zone.

The Basal Pliensbachian volcanic unit appears to thin out markedly eastward between Forward Inlet and Koprino Harbour in Quatsino Sound. It seems likely that the unit pinches out completely between Koprino Harbour and Rupert Inlet (Fig. 1).

Lower Pliensbachian Argillites

On the southern shore of Quatsino Sound opposite Koprino Harbour (i. e. on both sides of Mahatta Logging Camp) the Basal Pliensbachian volcanic unit is overlain conformably by an at least 150-foot-thick unit of dark grey mostly clay argillite interbedded with some arenaceous limestone, greywacke, and calcareous grit. The top of the unit was not seen (Jeletzky, in preparation).

Poorly preserved ammonites, which may be of early Pliensbachian age according to Dr. Hans Frebold, were found by the writer (GSC loc. 24311) near the visible top of the unit in the Mahatta Logging Camp section. Accordingly the unit is tentatively placed in the lower Pliensbachian.

Lithologically identical and presumably correlative, dark grey, marine argillites were observed on Catala Island and in the bed of Tatchu Creek in the Kyuquot-Esperanza area, west coast of Vancouver Island (Jeletzky, unpubl.). These several hundred-foot-thick argillites form an interbed in the dark grey, intermediate volcanic rocks of the Bonanza Subgroup. No diagnostic fossils have been found in these argillites but their occurrence in close proximity of and apparently stratigraphically below Pliensbachian-Toarcian greywacke unit equivalent to the Maude Formation of Queen Charlotte Islands (Jeletzky, 1954b, p. 13), supports their suggested lithologic correlation with the lower Pliensbachian argillites of Quatsino Sound.

Dark Grey Volcanic Unit

At least several hundred feet of dark grey, strongly amygdaloidal andesitic (?) lavas interbedded with some similarly coloured fine to coarse pyroclastic rocks outcrop along the shore for about one-half mile north of the mouth of Tatchu Creek and in its bed for several hundred yards above the mouth (Jeletzky, 1950, geol. map). The Dark grey volcanic unit represents the second youngest known unit of the Bonanza Subgroup as it is overlain paraconformably by arenites and psammites of the Pliensbachian-Toarcian greywacke unit north of Tatchu Creek. Poor outcrops of the Dark grey volcanic unit occur on the northern shore of Esperanza Inlet between Tatchu Point and Peculiar Point, on High Rocks off Yellow Bluff, and apparently on the southwestern end of Catala Island (Jeletzky, 1950, geol. map). On Catala Island the volcanic rocks, believed to represent the basal part of the Dark grey volcanic unit, grade downward into black marine argillites tentatively correlated with the Lower Pliensbachian argillites of Quatsino Sound.

This unit is not definitely known to occur elsewhere within the tectonically and volcanically active zone of the Insular Belt. An isolated section of lithologically similar andesitic (?) lavas outcropping on the eastern side of Browning Inlet in Quatsino Sound (Jeletzky, in preparation) could, however, belong to this unit (Fig. 1).

Pliensbachian-Toarcian Greywacke Unit (Maude Equivalent)

Up to 3,000 feet of sedimentary rocks overlie the Dark grey volcanic unit in the Kyuquot-Esperanza area (Jeletzky, 1954a, 1954b, p. 13), west of Browning Inlet in Quatsino Sound (Jeletzky, in preparation), and south of Sproat Lake in Alberni map-area (Muller and Carson, 1969, p. 16). The principal outcrop areas in Kyuquot-Esperanza area are at Peculiar Point and on the seashore between Tatchu Creek and Porritt Creek. The top of the unit is only exposed in Sproat Lake section (Muller and Carson, 1969, p. 16; this paper, Fig. 2) where it is overlain by volcanic rocks apparently equivalent to Yakoun Formation of Queen Charlotte Islands (see p. 22).

The Pliensbachian-Toarcian greywacke unit is cut by large dykes and small cupolas of the Coast Intrusions (Jeletzky, 1954a; 1954b, pp. 13, 14) and occurs beneath the equivalents of the Yakoun volcanics. Therefore, it comprises the youngest known sedimentary unit of the Volcanic division of the Bonanza Subgroup.

The basal few hundred feet of the Pliensbachian-Toarcian greywacke unit consist of coarse- to fine-grained greywacke with considerable interbeds and lenses of grit and pebble conglomerate. Grit and fine pebble-conglomerate may be locally prevalent in this part of the unit (e. g. on high dry rocks about 1,000 yards south of the mouth of Porritt Creek). In contrast, grit and pebble-conglomerate are either rare or absent in its younger beds largely represented by fine- to coarse-grained greywacke with considerable interbeds of dark grey marine argillite and black, carbonaceous to coaly, plant-bearing argillite.

In the Kyuquot-Esperanza area grits and conglomerates of the basal part of the Pliensbachian-Toarcian greywacke unit yielded the ammonite genus Fanninoceras (Jeletzky, 1954b, p. 13) now known to be early

Pliensbachian (Frebold, 1967, p. 1148). In the Maude Formation of Queen Charlotte Islands Fanninoceras occurs only 30 feet stratigraphically above beds containing early Pliensbachian ammonites (Frebold and Tipper, in press). The basal beds of the Pliensbachian-Toarcian greywacke unit, therefore, appear to be only slightly younger than the lower Pliensbachian argillites of Quatsino Sound and the presumably correlative black argillites of the Kyuquot-Esperanza area.

The marine argillites and greywackes of the middle part of the Pliensbachian-Toarcian greywacke unit yielded Trigonia (s. lato) ex gr. costata Sowerby and some ammonites, which were identified as Toarcian Harpoceras (Grammoceras) (s. lato) sp. indet. by Jeletzky (1954b, p. 13). However, these ammonites have been recently studied by Dr. Hans Frebold who comments as follows: "The ammonites were found in beds considered by the collector to be of Toarcian age. They are small (maximum diameters about 30 mm) and commonly preserved as fragments or imprints. Most of them have sigmoid or falcoid ribs, an oval cross-section with keel with shallow sulci or just flattened zones on each side. There are no specimens with falcate ribs.

"None of these specimens could be identified with Harpoceras or other closely related Harpoceratinae and none of them could be identified with one or another of the Harpocertinae described by F. H. McLearn from Queen Charlotte Islands. Furthermore Dactylioceras, which in Queen Charlotte Islands is associated with Harpoceras, is absent in the Vancouver Island fauna. It can be stated confidently that the two faunas are different in composition and age.

"Larger and better preserved specimens are necessary for definite identification and age-determination. Ammonites similar in general outline and ribbing are certain Arieticeras and Programmoceras, both of late Pliensbachian age, or certain Grammoceras (late Toarcian) and certain Fontannesia of middle Bajocian age."

The ammonites concerned occur stratigraphically well above early Pliensbachian beds of the Pliensbachian-Toarcian greywacke unit. Therefore, and because of their morphological similarity with Grammoceras recognized by Jeletzky (1954b, p. 13) and confirmed by Dr. Hans Frebold (see above), the writer places them questionably in Grammoceras and tentatively places the middle part of the unit into the late Toarcian pending the discovery of more diagnostic fossils. The admittedly possible late Pliensbachian age of these beds is discounted for the time being. Their middle Bajocian age appears to be improbable on general stratigraphical and paleogeographical grounds.

The upper part of the Pliensbachian-Toarcian greywacke unit yielded no diagnostic fossils but is tentatively included in the Toarcian stage together with the middle part of the unit.

At least 1,000 feet of moderately hard to soft, dark to light grey, pebble-conglomerate, coarse-grained greywacke and grit outcrops on the west side of Browning Inlet in the bed of Kwatleo Creek (Jeletzky, in preparation). This sequence contains variable amounts of waterlain pyroclastics, mainly in its basal part. Both contacts are covered and presumably faulted because nearby rocks are shattered. No fossils were found in these rocks. This sequence is tentatively correlated with coarser lower part of the Pliensbachian-Toarcian greywacke unit of the Kyuquot-Esperanza area to

which the lithology of its sedimentary types is remarkably similar (Fig. 1). This sequence occurs, furthermore, in a downfaulted block adjacent to outcrops of argillite tentatively assigned to the Lower Pliensbachian argillites (Jeletzky, in preparation).

The greenish grey, brown weathering shale and greywacke outcropping south of Sproat Lake in the Alberni map-area (Muller and Carson, 1969, p. 16) is lithologically similar to the Pliensbachian-Toarcian greywacke unit of the Kyuquot-Esperanza area, and also contains Trigonia (s. lato) ex gr. costata Sowerby. These lithological and faunal similarities suggest that the rocks of Sproat Lake represent a southern extension of this unit (Fig. 2). The absence of any rocks comparable with the older parts of the Volcanic division of the Bonanza Subgroup in the Sproat Lake section (Muller and Carson, 1969, p. 16) appears to be attributable to their complete removal by erosion prior to the deposition of the Pliensbachian-Toarcian greywacke unit (Fig. 2). This hypothesis of the early Pliensbachian uplift (see p. 22) agrees well with the coarse clastic, commonly conglomeratic character of the basal few hundred feet of Pliensbachian-Toarcian greywacke unit in the Kyuquot-Esperanza and Browning Inlet areas.

Sedimentary Sequence of Tectonically and Volcanically Quiescent Zone

As in latest Triassic time, the periodic Lower Jurassic volcanic outbursts recorded by volcanic units of the Volcanic division of the Bonanza Subgroup (Fig. 1) apparently did not affect the eastern side of Vancouver Island, the islands of Queen Charlotte Strait, and Queen Charlotte Islands. The Lower Jurassic rocks of this northeastern part of the Insular Tectonic Belt appear to be represented exclusively or almost exclusively by more or less tuffaceous argillites and impure limestones interbedded with varying amounts of fine-grained (argillite-like) waterlain volcanic tuffs (Crickmay, 1928; Dawson, 1887, p. 72B-74B; Surdam et al., 1964, p. 226; Surdam, 1968, p. 20, Fig. 6; Sutherland Brown, 1966, 1968).

Tuffaceous Argillites of Buttle Lake Area

Lower Jurassic limy, tuffaceous argillites ("Limy tuffs" of Surdam, 1968, p. 20) conformably underlying Norian limestones of the Quatsino Formation at Iron River, east of Buttle Lake, contain Sinemurian fossils 200 feet above their base (Surdam, 1968, p. 20, Fig. 6). Because of an invariably argillaceous grain size, apparent absence of any erosional intervals, and close stratigraphic-lithologic similarity with more fossiliferous Harbledown (i.e. Black argillite member of Kunga Formation; see p. 2, footnote 1) and Maude Formations of Queen Charlotte Islands (Frebold, 1967, p. 1148; Sutherland Brown, 1968) the beds at Iron River are believed to include Rhaetian, Hettangian, Pliensbachian, and Toarcian sediments as well. The total thickness of the Tuffaceous argillites does not exceed 750 feet (Surdam, 1968, p. 20, Fig. 6).

Harbledown Formation of Queen Charlotte Strait

The exposed thickness of black, noncalcareous argillite of the Harbledown Formation does not exceed 1,600 feet in its type section (Crickmay, 1928, p. 59). The top is cut off by granitic Coast Intrusions (Crickmay, 1928, p. 52) and the contact with the underlying calcareous argillites of the Parson Bay Formation appears to be gradational.

According to Dr. Hans Frebold (unpublished fossil reports and personal communication, 1968) the type Harbledown Formation contains the same Sinemurian ammonite faunas as the Sinemurian argillites of Quatsino Sound.

Because of an apparently gradational contact with calcareous argillites of Parson Bay Formation, which extends upward at least into the Lower Suessi Zone (Crickmay, 1928, pp. 55, 56; Tozer, 1967, pp. 39, 71, 81), the unfossiliferous argillites underlying the Sinemurian beds of the Harbledown Formation are believed to represent the late upper Norian, Rhaetian, and Hettangian stages.

The uppermost 560 feet of the type Harbledown Formation did not yield any diagnostic fossils (Crickmay, 1928, p. 59) and so cannot be dated. The presence of Acanthopleuroceras sutherlandbrowni Frebold (manuscript name) in the Harbledown argillites of Balaklava Island (see below) suggests, however, that the uppermost part of the type Harbledown Formation may include some lower Pliensbachian beds correlative with the Maude Formation of Queen Charlotte Islands.

According to Dawson (1887, pp. 72B-74B), the Hope-Galiano (now Nigei Island) Island group on the South side of Queen Charlotte Strait is underlain mostly by dark flaggy argillites and quartzites invaded by extensive Coast Intrusions. Volcanic rocks referable to the Volcanic division of the Bonanza Subgroup seem to be scarce or absent throughout this group of islands.

Ammonites comparable with lower Sinemurian Arniotites vancouverensis have been recorded from these argillites near Port Alexander on Nigei Island (Dawson, 1887, p. 73B) and lower Pliensbachian Acanthopleuroceras cf. A. sutherlandbrowni Frebold (manuscript name) has been identified by Dr. Hans Frebold (unpublished intradepartmental fossil report, 1968) in fossil collections recently obtained by J. E. Muller from similar argillites on Balaklava Island.

The lower Jurassic argillites and quartzites of the Hope-Nigei Island group appear to represent the marginal southwestern part of the tectonically and volcanically quiescent zone of the Insular Tectonic Belt and are referred tentatively to the Harbledown Formation rather than to the Sinemurian argillites of the Volcanic division of the Bonanza Subgroup (Fig. 2). No information is available about their relationships with underlying and overlying rock units but they are believed to be essentially similar to those of the type Harbledown Formation and its equivalents on Queen Charlotte Islands (Crickmay, 1928; Sutherland Brown, 1968).

Harbledown and Maude Formations of Queen Charlotte Islands

The Harbledown Formation (= Black argillite member of Kunga Formation of Sutherland Brown, 1968; see p. 2, footnote 1) is up to 1,900 feet thick, grades downward into the black carbonaceous limestone member of the Quatsino Formation, and is conformably overlain by shales, argillites and lithic sandstones of the Maude Formation (Sutherland Brown, 1968, p. 39). It contains Arniotites (Lower Sinemurian) and Echioceras (Melanippites) harbledownensis (Upper Sinemurian) faunas (Sutherland Brown, 1968, p. 61; Frebold and Tipper, in press). Because of its stratigraphic position and conformable relationships with adjacent rock units this: "flaggy black argillite member extends presumably from the Suessi Zone through to nearly the end of the Sinemurian, although no definite Rhaetian nor Hettangian are recognized" (Sutherland Brown, 1968, p. 61).

Because of the similar stratigraphic position and lithologic identity with the type Harbledown Formation, the Harbledown equivalent of Queen Charlotte Islands is believed to have been continuous with the latter.

The up to 600-foot-thick interbedded grey shale, blocky dark grey argillite, light grey calcareous shale, and greenish grey lithic sandstone of the Maude Formation appear to be unconformably overlain by pyroclastics of the Yakoun Formation (Sutherland Brown, 1968, p. 39, 61-66).

The faunas of the Maude Formation have recently been revised by Dr. Frebold (Frebold, 1967; Frebold and Tipper, in press; Sutherland Brown, 1968, p. 64). Frebold recognized three faunas. The lowest, 150 feet above the base, has Tropidoceras and Acanthopleuroceras and is Lower Pliensbachian. The middle fauna, with Fanninoceras, is also Lower Pliensbachian. The upper assemblage, which occurs within 50 feet of the top of the formation (Sutherland Brown, 1968, p. 65) is the Toarcian fauna with Harpoceras and Dactylioceras originally described by F.H. McLearn. The only comparable fauna known elsewhere in the tectonically and volcanically quiescent zone of the Insular Tectonic Belt, is the lower Pliensbachian fauna with Acanthopleuroceras sutherlandbrowni Frebold (manuscript name) identified recently by Dr. Hans Frebold in collections made by J.E. Muller from Harbledown argillites on Balaklava Island. It is not known whether the apparent absence of younger Maude faunas within this zone outside of Queen Charlotte Islands is due to the erosional or igneous destruction of the corresponding rocks, collection failure, or lateral facies changes.

Relationships of Sedimentary Lower Jurassic Sequences to the Volcanic Division of Bonanza Subgroup

The lithology of above described, exclusively or prevailingly, sedimentary Lower Jurassic rocks of the quiescent zone contrasts strongly with that of the previously discussed, predominantly volcanic and much thicker rocks of the Volcanic division of Bonanza Subgroup (Figs. 1, 2). Their diagnostic faunas are, however, identical with those occurring in the sedimentary interbeds of the Volcanic division. This indicates the essential contemporaneity of these two lithologically dissimilar rock sequences, and their being but different Lower Jurassic facies deposited side by side within the Insular Tectonic Belt.

The entirely or largely sedimentary sequences of the northeastern side of Vancouver Island, the islands of Queen Charlotte Strait, and Queen Charlotte Islands obviously formed part of a continuous (at least from Queen Charlotte Islands to Buttle Lake map-area) tectonically and volcanically quiescent zone which existed in this part of the Insular Tectonic Belt from the end of the late Karnian and (?) earlier Karmutsen volcanic outburst until Toarcian time. Except for an apparently existing (Dawson, 1887, pp. 72B-74B) transitional zone to the previously discussed adjacent tectonically and volcanically active zone of early Jurassic time, this quiescent zone apparently was not affected to any extent either by the recurrent outbreaks of volcanic activity or by the latest Triassic orogenic phase and the early Pliensbachian uplift (Figs. 1, 2). The only obvious influence of these volcanic outbreaks within the early Jurassic quiescent zone of the Insular Tectonic Belt is the greater or lesser admixture of fine (argillite-like), obviously airborne volcanic tuffs in its marine sediments. This is remarkable, considering that the volcanic-rich type area of the Bonanza Subgroup in Nimpkish Lake map-area is situated only 15 to 16 miles south of the exclusively sedimentary and essentially contemporary type sections of the Parson Bay and Harbledown formations. The writer prefers to disregard for the time being the admittedly possible but as yet unsubstantiated tectonic juxtaposition of these sections by a major strike-slip fault concealed beneath Johnstone Strait. He assumes, therefore, that this close proximity of Lower Jurassic volcanic and sedimentary facies is a natural phenomenon and that neither pyroclastic fragments (except for the previously mentioned very fine volcanic dust) nor lava flows of the Volcanic division were spreading for more than a few miles away from their sources.

Scarcity of Sediment in Tectonically and Volcanically Quiescent Zone

The tectonically and volcanically quiescent zone of the Insular Tectonic Belt (Fig. 2) only accumulated between 2,000 and 3,500 feet of predominantly fine-grained clastic and calcareous sediments during its rather prolonged existence (from late upper Karnian to Toarcian inclusive). This thin sedimentary column contrasts with the many thousand feet thick (at least 15,000 to 20,000 feet) predominantly volcanic sequence which accumulated during the same time in the adjacent tectonically and volcanically active zone of the belt (Figs. 1, 2). The quiescent zone was thus obviously "sediment starved" in spite of its occurrence inside the extremely mobile Early Mesozoic orogenic belt of western British Columbia.

The "sediment starved" character of the quiescent zone of the Insular Tectonic Belt apparently indicates:

1. The absence of any nearby large source areas to the east (i.e. within the western part of the present Coast Mountains) throughout late Triassic and early Jurassic time.

2. Apparent absence of any larger, strongly elevated nearby source areas to the west (i.e. near northeastern boundary of tectonically and volcanically active zone of the Insular Tectonic Belt) throughout late Triassic and early Jurassic time; and

3. That the lava flows and most of the pyroclastic fragments of the Volcanic division of the Bonanza Subgroup apparently only spread for a few miles (see p. 19) beyond the easternmost vents and fissures of the active zone.

It would thus appear that a low relief characterizing the eastern part of the Lower Jurassic active belt hindered any extensive spread of lava flows into the quiescent zone.

The Cherty limestone unit, Sinemurian argillites, lower Pliensbachian argillites, and Pliensbachian-Toarcian greywacke unit of the Volcanic division appear to be but sedimentary tongues of Harbledown and Maude formations (Figs. 1, 2). These tongues appear to expand gradually (in their time spans but not in thicknesses) eastward, northeastward, and northwestward at the expense of the intervening volcanic units of the Volcanic division until they merge into a much thinner continuous sedimentary sequence (Harbledown and Maude formations) somewhere near the eastern, northeastern and northern coasts of Vancouver Island. The delineation of the tectonically and volcanically active zone of the Insular Tectonic Belt shown in Figure 2 is based solely on compilation of rather scarce and possibly unreliable data available in the literature. More detailed field work now in progress in this part of the Insular Tectonic Belt may necessitate its adjustment or partial revision.

Volcanic Cycles of the Volcanic Division

The above discussed stratigraphic sequence of predominantly volcanic rocks of the Volcanic division reveals the cyclical character of the uppermost Triassic and Lower Jurassic volcanism in all better known areas of the tectonically and volcanically active zone.

The more or less widespread occurrence of four volcanic units separated from each other by equally widespread sedimentary units suggests the occurrence of at least four regionally valid (i.e. within the tectonically and volcanically active zone of the belt) volcanic cycles in the Volcanic division of the Bonanza Subgroup. Each of these cycles begins with accumulation of considerable thicknesses of subaerially and/or subaqueously deposited lavas and pyroclastics and ends with deposition of fine clastic (mainly argillites) and/or calcareous (mainly impure limestone), predominantly or entirely marine sediments. The suggested sequence of these cycles is:

1. Waterlain breccia unit - Basal Jurassic volcanic unit - Cherty limestone unit.
2. Grey volcanic unit - Sinemurian argillites.
3. Basal Pliensbachian volcanic unit - lower Pliensbachian argillites; and
4. Dark grey volcanic unit - Pliensbachian-Toarcian greywacke unit.

Judging by the thicknesses of extruded volcanic rocks, the above mentioned four volcanic episodes of the Volcanic division were unequally strong. The first (i.e. the apparently Rhaetian-Hettangian) volcanic episode must have been by far the strongest of all. The second (i.e. the Hettangian? or Grey volcanic unit event) must have been considerably stronger than the later two events which apparently resulted in accumulation of no more than a

few hundred feet of lavas and/or pyroclastics each. This suggests that a gradually declining trend was superimposed on the generally cyclical character of the Lower Jurassic volcanic activity within the tectonically and volcanically active zone of the Insular Tectonic Belt. The Bonanza outburst of volcanism appears therefore to have been connected with the previously discussed latest Triassic orogenic phase, reached its peak soon after its end (i.e. during the time of deposition of the Basal Jurassic volcanic unit), and was on the decline during the late Hettangian to Toarcian time.

Lower Jurassic Depositional Environments and Tectonic Movements of Tectonically and Volcanically Active Zone

Basal Jurassic Environments

As already mentioned, the facies of the Basal Jurassic volcanic unit apparently remains essentially the same throughout most (or all?) of the tectonically and volcanically active zone of the Insular Tectonic Belt. Its pyroclastic rocks appear to be largely or completely angular and unsorted throughout personally investigated parts of the zone. Marine interbeds and pillow structures are unknown to the best of the writer's knowledge, suggesting a largely or entirely subaerial deposition of lavas and pyroclastic rocks of the Basal Jurassic volcanic unit. These data and the ensuing, apparently fairly widespread transgression of Cherty limestone sea (see below) suggest that the volcanics of the Basal Jurassic volcanic unit were deposited on a relatively flat lowland which subsided as fast as, or faster than, the volcanic piles were accumulating. If so, the strongly diversified relief created within the active zone by the latest Triassic (early Rhaetian or ? latest Norian orogenic phase (see pp. 8, 9) must have been essentially bevelled prior to the deposition of the early Hettangian? Basal Jurassic volcanic unit. This inference finds additional support in the previously discussed "sediment starved" nature of the adjacent tectonically and volcanically quiescent zone.

The predominantly fine-grained, calcareous lithology of the Hettangian(?) Cherty limestone unit in all its known sections suggests that the sea that covered the active zone at this time transgressed over a relatively flat lowland and that any adjacent western and southern source areas of that time were of a low relief.

Pillow lavas and pillow breccias abound in most studied sections of the Grey volcanic unit in Quatsino Sound, being particularly prominent in its westernmost outcrops in Forward Inlet. This, and the apparently complete absence of erosionally reworked, more or less rounded and sorted pyroclastics, suggests the largely or entirely subaqueous mode of deposition of rocks of the Grey volcanic unit.

Sinemurian and Lower Pliensbachian Environments and Tectonic Movements

The predominantly fine-grained (argillaceous to calcareous) lithology of Sinemurian argillites in most of their known outcrops indicates that most of the active zone was subjected to essentially the same depositional environment as prevailed during the time of deposition of the Cherty

limestone unit. Some coarse clastics (including limestone breccia and conglomerate) occur, however, in the westernmost studied sections of Sinemurian argillites in Forward and Browning inlets. The intervening Waterlain volcanic member of the Sinemurian argillites appears, furthermore, to thicken westward in Quatsino Sound, and the Upper argillite member of this unit thins out westward and appears to be largely replaced laterally by the poorly rounded conglomerates and coarse to fine volcanic breccias of the lower part of the Basal Pliensbachian volcanic unit in the westernmost sections studied. This suggests the occurrence of an uplift (or uplifts?) during Sinemurian time and the resulting emergence of a sizable, sufficiently strongly elevated and volcanically active Sinemurian source area in close proximity to the present west coast of northern Vancouver Island. The exact location and extent of this source area are uncertain but it seems likely that it was situated just off the west coast and extended at least from Cape Scott to Esperanza Inlet.

The Sinemurian western source area apparently remained active in earliest Pliensbachian time judging by considerable amounts of poorly sorted coarse clastics and somewhat rounded waterlain pyroclastics deposited in the Quatsino Sound area during the time of deposition of the Basal Pliensbachian volcanic unit. The latter area itself probably remained a lowland or a shallow sea. The largely subaqueous mode of deposition of poorly sorted coarse clastics and more or less reworked pyroclastics of the Basal Pliensbachian volcanic unit is indeed suggested by their intercalation with considerable pillow lavas and pillow breccias in several sections.

The above sketched earliest Pliensbachian depositional environment may have extended along the west coast of Vancouver Island at least as far south as Esperanza Inlet.

In the western part of Quatsino Sound, coarse clastics and waterlain pyroclastics of the Basal Pliensbachian volcanic unit grade upward into the Lower Pliensbachian argillites. The same seems to be true, furthermore, of the Kyuquot-Esperanza area. The resumption of deposition of fine grained sediments in the western part of northern Vancouver Island suggests a bevelling of most or all of the Sinemurian to earliest Pliensbachian western source area and the temporary cessation of the volcanism within it.

Too little is known about the areal extent and the lithology of the Dark grey volcanic unit to attempt an environmental-structural evaluation of this "moment" of early Pliensbachian time.

Pliensbachian-Toarcian Environments and early Pliensbachian Uplift

The predominantly coarse clastic lithology of the lower part of the Pliensbachian-Toarcian greywacke unit contrasts strongly with the predominantly argillaceous lithology of earlier sedimentary units of the Volcanic division, including the lower Pliensbachian argillites. The deposition of these coarse clastics near the southwestern margin of the tectonically and volcanically active zone of the Insular Tectonic Belt in the Kyuquot-Esperanza area and the western part of Quatsino Sound and the apparent presence of a major erosional interval underneath the Pliensbachian-Toarcian greywacke unit in the Sproat Lake area (Fig. 2) suggest the occurrence of an early (but not earliest) Pliensbachian uplift in these parts of the

zone at least. It is assumed that the coarse, nearshore to nonmarine sediments of the Pliensbachian-Toarcian greywacke unit passed laterally eastward, northward and northwestward into argillites and limestones of the Maude and Harbledown formations but the latter rocks are so far unknown outside of the quiescent zone.

The facies relationships of the Lower Jurassic rocks of the active zone discussed in the previous sections suggest that, like the coarse clastics and erosionally reworked volcanics of Sinemurian-earliest Pliensbachian time, the coarse clastics of the Pliensbachian-Toarcian greywacke unit were derived from a western source area (a tectonic land) that probably represented a northwest-trending narrow cordillera which was situated immediately seaward of the present west coast of Vancouver Island and extended at least from Cape Scott to Barkley Sound.

The Sinemurian and early Pliensbachian uplifts probably were the first two pulses in a series of tectonic movements comprising the interregional Middle Jurassic orogeny which closed the early Mesozoic phase of geological history of the Insular Tectonic Belt. The apparent absence of folding or faulting attributable to Sinemurian and early Pliensbachian tectonic movements suggests their nonorogenic nature. No angular discordances were, furthermore, observed either within the Sinemurian argillite unit or at the base of the Pliensbachian-Toarcian greywacke unit.

RESULTS OF MIDDLE JURASSIC OROGENY

In Queen Charlotte Islands the Pliensbachian-Toarcian argillites and limestones of the Maude Formation are overlain by the Bajocian pyroclastics and less predominantly by arenaceous to psammitic clastics of the lower Yakoun Formation (Sutherland Brown, 1968, pp. 61, 68; this paper, Fig. 2). Although locally in at least apparent conformity, the contact between Maude and Yakoun formations is regionally unconformable in the writer's opinion because it laps onto the older formations (Sutherland Brown, 1968, p. 68).

In the Buttle Lake map-area the Lower Jurassic tuffaceous argillites, which on lithologic and stratigraphic grounds are assumed to include beds equivalent to the Maude Formation, are overlain by at least 2,000 feet of andesitic lava flows and pyroclastics (Surdam, 1968, p. 20, Fig. 6; this paper, Fig. 2). This volcanic unit was correlated with the Volcanic division of the Bonanza Subgroup by Surdam (1968, p. 20). In the writer's opinion, however, the lithology and stratigraphic relationships of this unit suggest its equivalence with the Yakoun Formation of Queen Charlotte Islands.

In the Alberni map-area about 1,000 feet of light coloured lava, tuff, and breccia of intermediate latitic to andesitic composition was recently discovered by J.E. Muller (Muller and Carson, 1969, p. 17). This unit is also believed to be correlative with the Yakoun Formation of Queen Charlotte Islands rather than with any part of the Volcanic division as it overlies sedimentary rocks apparently equivalent to the Pliensbachian-Toarcian greywacke unit of Kyuquot-Esperanza area. Muller and Carson (1969, p. 16) have tentatively referred this unit to the Volcanic division of the Bonanza Subgroup but have suggested that: "the volcanic rocks of Sproat area are younger than those occurring on the west coast".

Middle Jurassic volcanic and sedimentary rocks are unknown in the northwestern part of Vancouver Island (Jeletzky, 1954a, p. 1269) where nearly all known outcrop areas of the Volcanic division are concentrated. The only known outcrop area of Yakoun volcanics within the Lower Jurassic tectonically and volcanically active zone of the Insular Tectonic Belt is that of the Alberni map-area, well outside of this part of Vancouver Island.

In the best known parts of the Lower Jurassic quiescent zone, namely the Buttle Lake area and the Queen Charlotte Islands, deposition of the presumably deep water predominantly argillaceous clastics and limy oozes of the Harbledown and Maude formations was abruptly terminated in or shortly after the Toarcian. This regime was replaced abruptly by one of volcanism, as testified by the appearance of the Yakoun Formation.

Most of the Middle Jurassic Yakoun volcanics and subordinate volcanic clastics within the Insular Tectonic Belt appear to be nonmarine deposits. Even in the Queen Charlotte Islands where the Yakoun Formation contains marine interbeds with Bajocian and Callovian ammonite faunas, the rocks commonly include coal beds and fossil wood. The marine fossils are restricted to a few thin shale interbeds (Sutherland Brown, 1968, pp. 68, 69). This suggests that the Insular Tectonic Belt was largely transformed into a tectonic land by the Middle Jurassic orogeny. Judging by the apparently complete absence of Middle Jurassic rocks from the northwestern part of Vancouver Island (Jeletzky, 1954a, p. 1269; and unpublished) this part of the belt underwent the greatest uplift and represented a source area throughout Bajocian and Bathonian time. It would appear that volcanic activity either became greatly weakened or ceased in the Lower Jurassic active zone at essentially the same time as it was initiated in the zone that was quiescent in the Lower Jurassic. The volcanism, so to say, migrated east and northwest at the onset of Middle Jurassic orogeny.

It seems likely that most or all of the Lower Jurassic quiescent zone of the Insular Tectonic Belt was tectonically and volcanically activated by the Middle Jurassic orogeny which began early in Bajocian time, judging by the middle Bajocian fossils collected low in the Yakoun Formation of Queen Charlotte Islands (McLearn, 1949; Sutherland Brown, 1968, p. 76).

It is believed that the tectonic land erected by Middle Jurassic orogeny within the Insular Tectonic Belt occupied the place of the present Georgia and Queen Charlotte straits and extended northwestward at least to Queen Charlotte Islands where the Yakoun Formation exhibits some marginal? marine interbeds. Southward this tectonic land extended at least into the Sproat Lake area and eastward it probably extended almost to the Tatlayoko Lake and Harrison Lake areas (Jeletzky, 1965, p. 72; Tipper, 1969, p. 85). It may have extended southwestward beyond the present day west coasts of Vancouver Island and Queen Charlotte Islands. So far as known, only the early to mid-Callovian seas began to encroach upon the marginal parts of this tectonic land (Jeletzky, 1950, pp. 19-32; McLearn, 1949; Sutherland Brown, 1968, p. 76; Tipper, 1969, p. 85). The Upper Jurassic marine troughs, however, had an entirely different configuration, surrounding rather than penetrating the Middle Jurassic tectonic land (Jeletzky and Tipper, 1968, pp. 74-77, Fig. 7). These residual Upper Jurassic marine troughs formed part of the late Mesozoic phase of geological history of the Insular Tectonic Belt which is beyond the scope of this paper.

The data now available about the Middle Jurassic history of the Insular Tectonic Belt suggest that the Middle Jurassic orogeny and the accompanying batholithic Coast Intrusions (Jeletzky, 1954a, p. 1269) have annihilated the previously described Lower Jurassic tectonic pattern produced there by the latest Triassic orogenic phase (Fig. 2). The Middle Jurassic orogeny represents, therefore, the veritable turning point in the geologic history of the Insular Tectonic Belt.

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