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MARINE JURASSIC ROCKS IN NELSON AND SALMO AREAS SOUTHERN BRITISH COLUMBIA

By

Hans Frebold

THE QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
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Preface

Fossils in the collections of the Geological Survey of Canada indicate the presence of Marine Jurassic sediments in southern British Columbia. In 1956 and 1957 the author visited the localities from which the fossils were obtained and studied the stratigraphy and made further collections. From a study of all these collections it is apparent that a sea existed in this region through part of the Early Jurassic and up into the Middle Jurassic. The great thickness of sediments deposited in this sea indicates that it occupied a region of considerable subsidence. The data clearly refute, therefore, the hypothesis that this part of British Columbia was, during the Jurassic, in the centre of a geanticlinal landmass supposed to have extended from the International Boundary well into British Columbia.

The fossils on which these conclusions are based are described, and some general opinions regarding the Jurassic palæogeography and stratigraphy of these parts of British Columbia are presented.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, June, 1958

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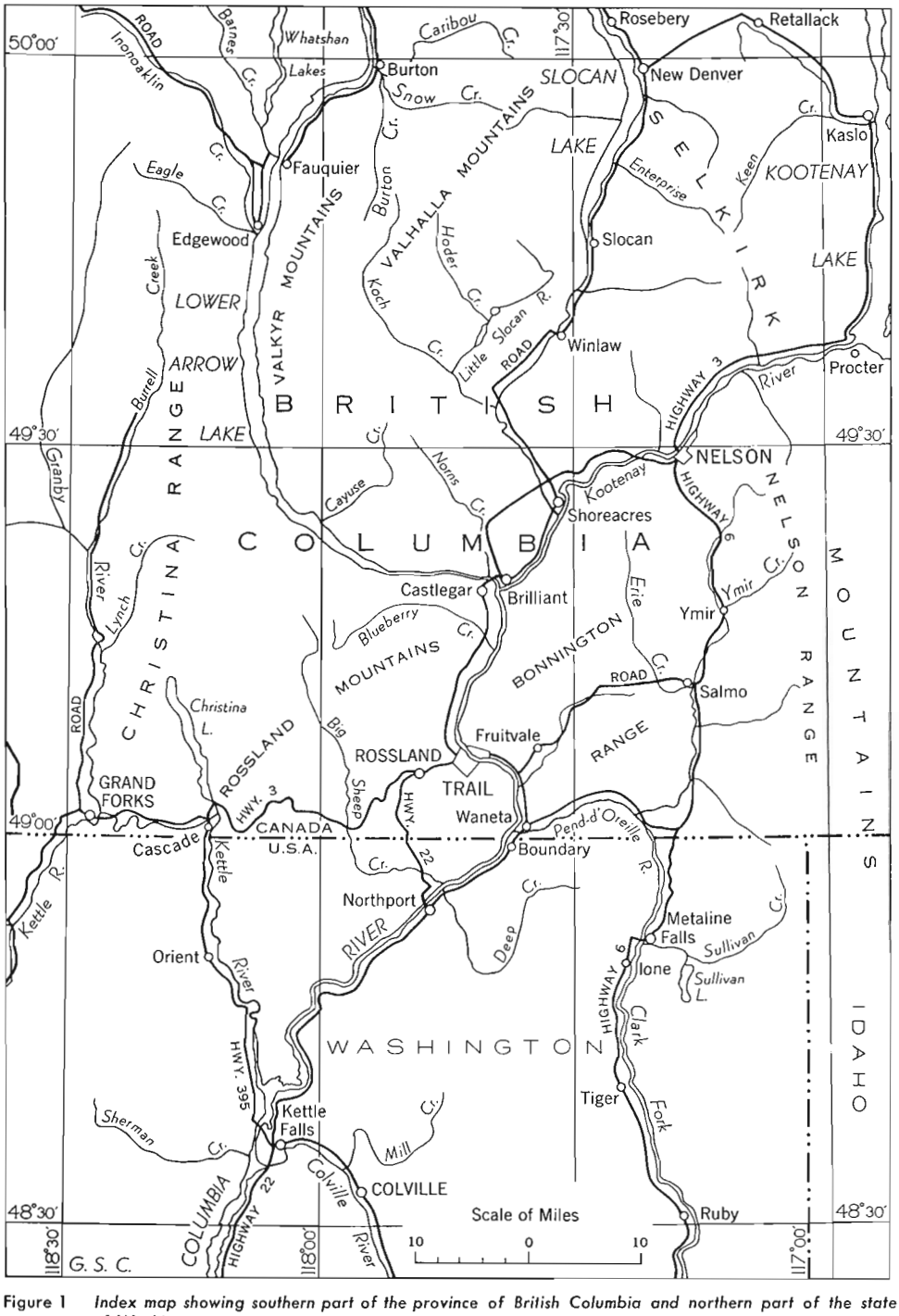

Figure 1 *Index map showing southern part of the province of British Columbia and northern part of the state of Washington.*

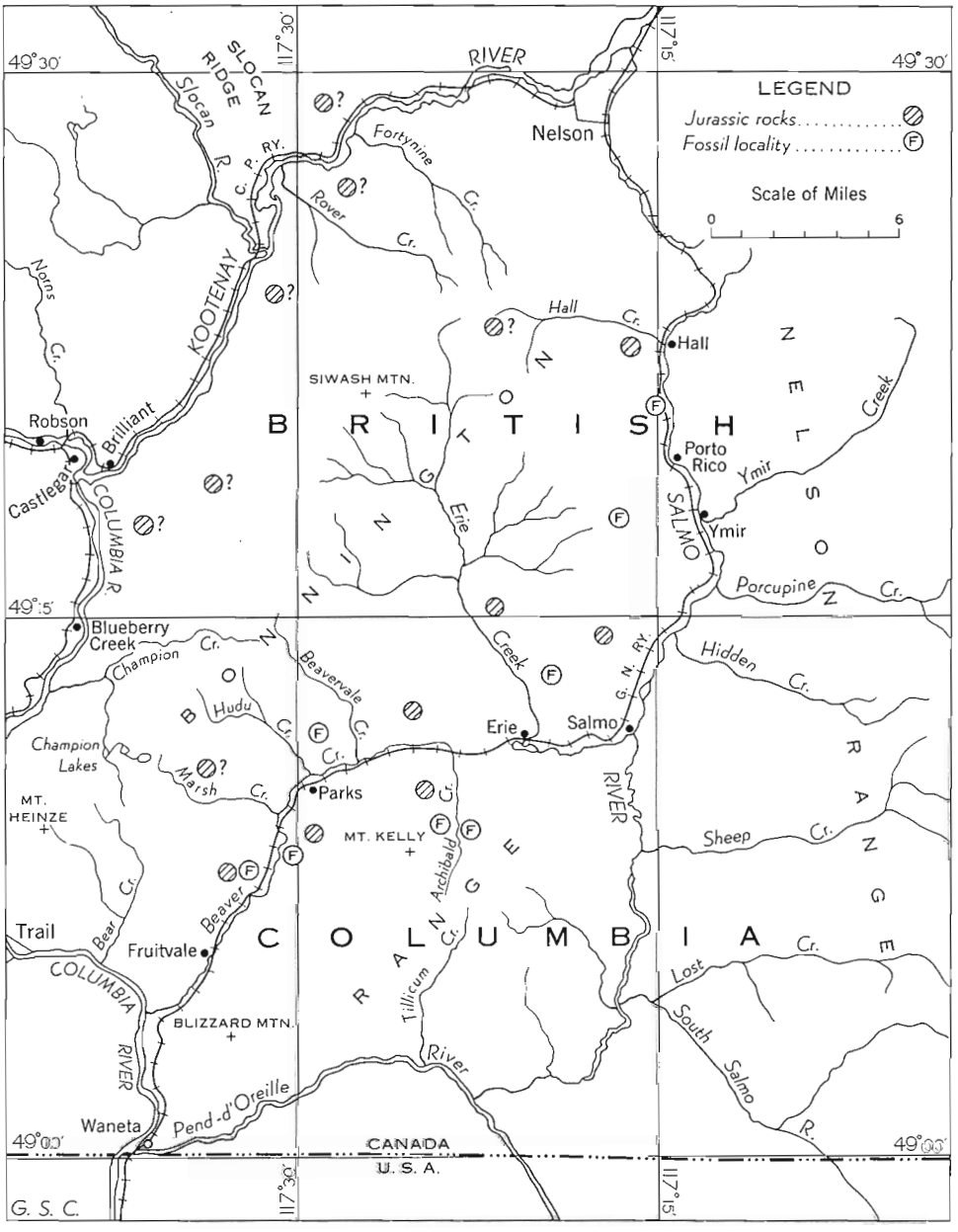

Figure 2 *Distribution of marine Jurassic rocks and fossil localities in the Nelson and Salmo areas, British Columbia. (Mainly after Little, 1956.)*

Marine Jurassic Rocks in Nelson and Salmo Areas Southern British Columbia

Summary

The marine fossils hitherto found in Nelson, Salmo and Caribou Creek areas (*see* Figures 1 and 2) indicate the presence of three subdivisions of the Jurassic system. The ammonites (Arnioceratids) found in Archibald Creek, in the coquina bed on the ridge northeast of Parks, Beaver Creek, and in the Caribou Creek area 6 miles northeast of Burton, Lower Arrow Lake, all indicate a Sinemurian (early Lower Jurassic) age for the rocks concerned. The Harpoceratids in the upper part of the Elise formation, found between Hall and Porto Rico, suggest a Toarcian (late Lower Jurassic) age, and the questionable *Sonninia* and other Harpoceratids found in the Hall formation, 2.7 miles southwest of Porto Rico station, probably belong to the Bajocian (lower Middle Jurassic). The correlations based on these fossils are summarized on Table I, p. 12.

The presence of marine Jurassic rocks in Nelson, Salmo and Caribou Creek areas, and the great thickness of the formations concerned, prove the existence of a Jurassic geosynclinal sea in this area which was previously considered to be part of a geanticlinal landmass 'Jurozephyria'. The writer has shown (1957) that reasons previously given in favour of such a landmass do not hold. Volcanic islands, however, probably existed in this area at different times during the Jurassic period. The near-shoreline or shallow-water character of some of the sediments, for instance the coquina bed northeast of Parks, may be explained by the presence of such islands.

The distribution of these thick marine deposits is, as shown by Little (1949, 1950, 1956) and others, restricted. This may be explained, at least partly, by the transition of these deposits into more highly metamorphosed rocks. Thus, Little considered it possible that the Hall formation is replaced northeastward by gneisses.

Introduction

The Mesozoic sedimentary rocks in Nelson and Salmo areas have been subdivided into a number of groups and formations. In his most recent publication Little (1956) distinguishes the Ymir group, which in his opinion is Triassic (?) and earlier, and the Elise, Hall, and Beaver

Mountain formations, which were supposed to be Triassic (?), Jurassic, and Cretaceous (?) in age. Both the Elise and Beaver Mountain formations are mainly volcanic units which were supposed to be separated from each other by the predominantly sedimentary Hall formation. Where it is impossible to distinguish the Elise from the Beaver Mountain formation, the two are very similar, the term Rossland Volcanic group (in a more restricted sense than that originally used) was retained (Little, 1950, p. 29). The lithology of all these units has recently been described by Little (1949, 1950, 1956), Mulligan (1951, 1952), and McAllister (1951).

The Jurassic age of some of the sediments, particularly those of the Hall formation and those believed to be equivalent to the Hall, was established by the preliminary fossil identifications of F. H. McLearn and the author, published in reports by Little (1950) and Mulligan. These fossil determinations are revised in this paper, and the description of other fossils, found during the writer's field work in 1956 and 1957, is added. Among these recently found fossils is an ammonite fauna in some shaly beds in the upper part of the Elise formation which makes possible a rediscussion of the age and mutual relationship of this formation with other units. Of equal importance is the discovery in 1957 of some distinctive ammonites in the highly fossiliferous beds on top of the ridge northeast of Parks station. The age of these beds hitherto was doubtful and had been roughly determined as Jurassic or Cretaceous (Frebold *in* Little, 1950, p. 28).

Also included in this account is the description of a Jurassic ammonite found in the Caribou Creek area, 6 miles northeast of Burton, where the northernmost known occurrences of the Rossland group are present.

Little (1950, p. 29) rightly pointed out that the relationships of the various lithological units, some of which are very similar to one another, can only be determined if the fossiliferous rocks are delineated. The description of even very unsatisfactorily preserved fossils is therefore given. The presence of these marine Jurassic beds in this part of southern British Columbia is an important aid in interpreting the palæogeography of Jurassic time in Western Canada.

During the preparation of this paper the author received from H. W. Little much detailed information on the results of his field work in these parts of southern British Columbia.

Fossil Localities

Archibald Creek

Five collections were made by Little on Archibald Creek, which joins Beaver Creek from the south close to Meadows station (*see* Figure 2).

Four localities are on the west and one on the east side of the creek. The four on the west side are between the first and second tributaries joining Archibald Creek from the west, and are at the following elevations; 3,700, 3,950, 4,000, and 4,100 feet.

According to Little (personal communication), the rock in which the fossils were found is argillite with minor amounts of sandstone and some latite dykes. Some of the beds are disturbed and possibly faulted.

The ammonites collected at all four localities belong to the family Arnioceratidae and the form here described as *Arnioceras* (*Melanhippites*) sp. indet. was found at the 3,700-, 3,950-, and 4,100-foot elevations. The specimens collected at the 4,000-foot elevation are too poorly preserved for detailed comparison but apparently belong to the same group.

On the east side of Archibald Creek only small indeterminable imprints of ammonites were found.

During the 1957 field season Little's localities on the west side of Archibald Creek were revisited and some additional ammonite fragments were collected. These also are Arnioceratids.

Ridge Northeast of Parks, Salmo Map-area

On the west slope of the ridge, about 7,200 feet N5°E from Parks station, Salmo map-area, Mulligan (1951, p. 80) found a few hundred feet of sediments in fault contact with aphanitic greenstone. At the base of an overlying bed of agglomerate, at one locality, abundant marine fossils form a coquina a few inches thick. According to Mulligan, massive augite porphyry at the top of the ridge apparently overlies the agglomerate, but as the structure is complex, detailed mapping would be required to establish the precise relationships of the rocks.

The fauna found in the coquina bed consists of numerous pelecypods, corals, a few gastropods, and belemnite fragments, and some Arnioceratids that were found in 1957 and that permit a more precise age determination of this bed than was possible before.

The locality is approximately 1,600 feet above the road to Parks village (*see* Plate V, figure B). According to the preliminary map of Salmo map-area (Little, 1950), the fossils occur in a wedge-shaped block of rocks assumed to be in fault contact with rocks of the Elise formation to the west and east and bounded on the north by volcanic rocks of the Beaver Mountain formation. The contacts have not actually been proven to be faults and both the volcanic rocks north of the fossil locality and those to the east and west may all belong to the Beaver Mountain formation. The interpretation of the stratigraphy and structure of this area

may have been partly based on the assumption that the fauna concerned was of Late Jurassic or Cretaceous age, but this has now been disproved.

Mulligan (1951, p. 80) mentioned that a fauna similar to that from the ridge northeast of Parks station occurs at the base of an agglomerate bed near the end of the long northeast ridge of Mount Kelly. These fossils have not been seen by the writer.

East Side of Beaver Creek

This locality is at elevation 2,700 feet on the east side of Beaver Creek, about 2 miles north of Fruitvale.

The only fossil found so far at this locality is an ammonite and its imprint, which may belong to *Arnioceras* sensu lato.

On Highway Between Hall and Porto Rico

In outcrops on the highway between Hall and Porto Rico some sedimentary rocks lie interbedded with volcanic rocks. Both rocks were placed in the upper part of the Elise formation (Little, 1949; McAllister, 1951). McAllister (1951, p. 29) described the sedimentary rocks as "primarily black slates and argillites resembling those of the Ymir group". According to the same author "it is probable that these beds were laid down in small lakes on the lava surfaces" and he considered their age to be Late Triassic or Early Jurassic (McAllister, 1951, p. 30).

A restudy of these rocks in 1956 and 1957, proved, however, the marine origin of the sediments and established their age as younger than that assumed by McAllister. At the locality on the highway between Hall and Porto Rico, 1½ miles north from the northern bridge in Porto Rico (*see* Plate V, figure A), dark, greyish weathering shale is exposed both below and above a body of porphyritic augite andesite. The dip is steep towards the west. The sediments contain numerous though poorly preserved, flattened Harpoceratids. One of the specimens resembles *H. exaratum* Young and Bird. The same forms are present both below and above the volcanic rock. In addition some indeterminable pelecypods occur. At other outcrops a few fossil remains were found, among them a harpoceratid ammonite. The ammonites probably indicate a Toarcian (late Lower Jurassic) age for the beds concerned.

About 2.7 miles Southwest of Porto Rico Station

At this locality dark argillites are exposed in which a number of small Harpoceratids and one imprint with whorl fragments here described as *Sonninia* (?) sp. indet. were found. Also indeterminable pelecypod remains are present. The age of these beds is probably Bajocian (lower Middle Jurassic).[1]

[1]*See* Postscript, p. 17.

Caribou Creek Area

In the Caribou Creek area, 6 miles northeast of Burton (Lower Arrow Lake) at the top of a switchback, west of Independence Creek, J. A. Mitchell of the British Columbia Department of Mines collected a loose piece of rock with the imprint of an Arnioceratid. This rock belongs to the Rossland group, which is exposed in this area, and a Sinemurian (early Lower Jurassic) age is indicated by the ammonite.

Systematic Description of Fossils

ARNIOCERATIDAE

Representatives of the family Arnioceratidae are characteristic of the lower part of the Canadian Jurassic and were first described by Whiteaves from Vancouver and Queen Charlotte Islands (Whiteaves, 1887, p. 110B; 1889, pp. 144-148) under the names *Arniotites* and *Celtites* respectively. Whiteaves was of the opinion that these forms were of Triassic age but both he and Hyatt, to whom the material had been sent, pointed out their close relationship to *Arnioceras*. Hyatt (*see* Whiteaves, 1887, p. 111B) wrote about one of the forms described by Whiteaves as *Celtites* (?) *vancouverensis* (1887, pp. 110B, 111B) "It is remarkably *Arietites*-like in aspect, and if it were from the Lower Lias the exact genus could be pointed out without difficulty as *Arnioceras*." Crickmay (1928, p. 60), who had studied the stratigraphy of Parson Bay, Harbledown Island off the northeast coast of Vancouver Island, also demonstrated the close relationship of Whiteaves' *Arniotites* to *Arnioceras* and placed these forms in the Sinemurian (early Lower Jurassic). He included in *Arniotites*, forms with a prolonged smooth stage of the young forms and created the genus *Melanhippites* (op. cit., p. 61) for those ribbed in early stages of the ontogenetic development. This difference seems to be persistent and the maintenance of *Melanhippites*, at least as a subgenus, seems to be justified at the present stage of knowledge of these usually unsatisfactorily preserved forms. However, the writer agrees with Arkell (1956, p. 544) that it is doubtful if *Arniotites* or *Melanhippites* can be distinguished generically from *Arnioceras*.

Representatives of this group are known in Canada's lower Jurassic from the following regions (*see* Frebold, 1953, stratigraphic chart): a) British Columbia: Vancouver Island, Parson Bay, Queen Charlotte Islands, Takla map-area, west Peace River, Sikanni Chief River; b) southern Yukon; c) eastern Rocky Mountains and parts of the Foothills: Fernie, Crowsnest, Banff, Snake Indian Valley. To these localities can now be added Salmo map-area, southwest of Nelson, and the Caribou Creek area, 6 miles northeast of Burton, Lower Arrow Lake.

The *Arnioceras*-like ammonites of Salmo area were found at Archibald Creek, and on the ridge northeast of Parks (*see* Figure 2). As all are poorly preserved no definite generic or specific determination can be made; some of the specimens, however, seem to be more closely related to *Melanhippites* Crickmay than to *Arniotites*.

Arnioceras (*Melanhippites*) sp. indet.

Plate I, figures 1, 2

The specimen figured on Plate I, figure 1, which was found on the west side of Archibald Creek at elevation 3,700 feet, is the largest specimen of this group of ammonites collected in Salmo area. At a diameter of about 150 mm. the width of the umbilicus is about 75 mm. and the height of the last whorl about 22 mm. Remnants of another whorl indicate that the specimen was still larger. There are about 62 to 65 slightly arcuate, fairly strong, undivided ribs on the last whorl. Ribs are present also on the innermost whorls, where they are straight. Due to the unsatisfactory preservation no keel or suture-line is visible.

The smaller specimen (Plate I, figure 2), which was collected on the west side of Archibald Creek at elevation 4,100 feet, has, at a diameter of about 69 mm., a 41-mm. wide umbilicus and a whorl height of about 18 mm. The ribs are straight on the inner whorls but become slightly arched on the last. Neither keel nor suture-line is preserved.

Specimens apparently belonging to the same species are also found at elevation 3,950 feet in the same area.

The specimens described are similar to *Melanhippites harbledownensis* Crickmay (1928, p. 61, plate 3, plate 4, figures a-d) from the Harbledown formation of Parson Bay and to *"Arniotites* or *Celtites"* from Forward Inlet, northwest coast of Vancouver Island, described and figured by Whiteaves (1889, p. 147, plate 19, figure 4). All these forms are Arnioceratids but detailed comparison cannot be made because of their incomplete preservation. It is unfortunate that none of the Archibald Creek specimens shows the keel on the venter, which is probably due to poor preservation. The same applies to the keels of the specimens referred to from Vancouver Island and Parson Bay, which are only partly preserved (Whiteaves, 1889, plate 19, figure 4; Crickmay, op. cit., plate 3) or entirely missing (Crickmay, op. cit., plate 4, figures a, d).

Arnioceras sp. indet.

Plate I, figures 3, 4a, b; Plate IV, figure 2

The fragments illustrated on Plate I, figures 3 and 4a, b, were found in the coquina bed on the ridge northeast of Parks station. The fairly

strong undivided ribs become weaker in the upper part of the flanks. On the venter is a keel, which is bordered on both sides by flattened zones.

The specimen illustrated on Plate IV, figure 2 is an imprint on a loose piece of rock collected by J. A. Mitchell from west of Independence Creek, Caribou Creek area, 6 miles northeast of Burton east of the north end of Lower Arrow Lake. The area where the fragment was found is underlain by the Rossland group. The rubber cast made from this evolute ammonite shows a type of ribbing similar to that of the specimens collected at Archibald Creek. Unfortunately no better specimens have as yet been found in this area.

Harpoceratidae

The ammonite fauna collected from outcrops on the highway between Hall and Porto Rico occurs in a lens of dark, greyish weathering shales that lies in the mainly volcanic rocks that form the top part of the Elise formation. This fauna is too poorly preserved for any detailed determinations, the ammonites being preserved only as imprints.[1]

Harpoceras aff. *exaratum* Young and Bird

Plate III, figure 1

The specimen figured on Plate III, figure 1 is the largest *Harpoceras* so far found in the upper part of the Elise formation. It is entirely compressed. There is a high ventral keel, the ribs on the preserved part of the last whorl are very narrowly spaced, sickle-shaped, and thin. The lower part of the last whorl is broken off, thus making visible the preceding whorl on which faint, fine, sickle-shaped ribs, more widely spaced than those of the last whorl, are present.

Because of its unsatisfactory preservation the specimen cannot be specifically identified. The type of ribbing on the last whorl suggests affinities to *Harpoceras exaratum* Young and Bird. Representatives of this group occur in the Toarcian (late Lower Jurassic) of the Fernie group in the Canadian Rocky Mountains and Foothills (Frebold, 1957, p. 47; Pl. 17, fig. 1; Pl. 18, figs. 2, 3), but the Fernie specimens have stronger and more widely spaced ribs.

Harpoceras sensu lato sp. indet.

Plate III, figures 2, 3, 4, 5

From the many poorly preserved specimens collected the presence of probably different species and perhaps genera is evident. No direct identifications can be made.

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[1]*See* Postscript, p. 17.

The specimen illustrated on Plate III, figure 2 has a diameter of about 49 mm. There is a high keel on the venter and numerous sickle-shaped ribs on the flanks, some of which seem to be subdivided.

The imprint of a whorl fragment (Plate III, figure 3) that may belong to the same species shows sharply bent sickle-shaped ribs. The specimen illustrated on Plate III, figure 4 also has sickle-shaped ribs which are traceable down to the umbonal region. Forms like these specimens seem to be common in this faunal assemblage.

The whorl fragment illustrated on Plate III, figure 5 has widely spaced ribs which are less sickle-shaped than those of the other specimens and which are divided into two or three branches at about half the height of the flanks. The narrow venter has a keel in the centre and possibly another keel on each side at the junction of the flanks with the ventral region. Detailed comparisons of these poorly preserved specimens with known species and genera are impossible.

Sonninia (?) sp. indet.

Plate IV, figures 1a, b

The ammonite illustrated on Plate IV, figure 1 was found at elevation 6,500 feet, about 2.7 miles southwest of Porto Rico. It is preserved as a longitudinally stretched imprint and a whorl fragment. The part of the ammonite preserved as an imprint measured about 115 mm. in diameter with a whorl height of about 44 mm. and an umbilical width of about 50 mm. Exact measurements cannot be taken because of the deformation of the specimen. The inner whorls of this ammonite have almost straight and fairly strong ribs which are divided into two branches somewhat below half the height of the flank. The point of division is marked by a strong node. These nodes become smaller and eventually disappear entirely on the last whorl preserved in the imprint and they are also absent on the larger whorl fragment. With the disappearance of the nodes the ribs become more curved and weaker. At this stage they are slightly arcuate and between two dichotome ribs undivided secondaries may be intercalated. The number of ribs has also increased. The venter shows a keel bordered on each side by flattened zones. The ribs cease abruptly at the junction of venter and flanks.

When first examined it was considered possible that it might be a *Stephanoceras* on account of the sculpture of the inner whorls, but the presence of the keel, which was revealed by further preparation of this poorly preserved and very breakable specimen, excludes this possibility.

Both the type of ribbing described and the presence of a keel place this specimen in or related to the genus *Sonninia*, but an exact determination is impossible.

Associated with this specimen are some indeterminable fragments of imprints of smaller *Harpoceras*-like ammonites.

Cardinia aff. *regularis* Terquem

Plate II, figures 1, 2, 3, 4

In the coquina bed on the ridge northeast of Parks, specimens belonging to *Cardinia* are very frequent. There are many impressions and more or less fragmentary specimens. Rubber casts (as those illustrated on Plate II, figures 1, 2) made from the impressions give a fairly good picture of the outline and sculpture. The two specimens figured are a left and a right valve respectively. The umbo is in the anterior part; it is pointed in the specimen of figure 2 and is not preserved in the specimen of figure 1. The specimen of figure 2 is more or less ovate in outline with the maximum height at the umbo. From there it decreases fairly rapidly both backwards and forwards. The ventral margin is almost straight with both ends well rounded. The posterior margin is slightly convex, the anterior rounded. Both the posterior and anterior margins curve into the ventral margin. The specimen of figure 4 probably belongs to the same species as that of figure 2. Its anterior adductor impression is well defined and deeper than the posterior adductor. The specimen illustrated on Plate II, figure 1, is a fragment with the posterior part and the umbo missing. Both the specimens of figures 1 and 2 are strongly runcinate as are all representatives of *Cardinia* occurring in this coquina bed. In their general outline and sculpture the specimens of *Cardinia* figured show similarities to *Cardinia regularis* Terquem (1855, p. 297, Pl. XX, fig. 2) from the lowermost Lias of Luxembourg. The material is not well enough preserved to decide if more than one species are present in this bed.

The genus *Cardinia* is known to be common in the lowermost Lias of certain regions, as for instance northwest Europe, but was hitherto unknown from the Canadian Jurassic.

Trigonia littlei n. sp.

Plate II, figures 6a, b, c, 7, 8

Representatives of *Trigonia* are fairly common in the coquina bed on the ridge northeast of Parks. All the specimens figured here are rubber casts of impressions.

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The shell is moderately convex and ovately trigonal. The strong marginal carina, which is bordered anteriorly by an ante-cardinal groove, divides the shell into two parts. The posterior part is further subdivided by the inner, much less prominent, carina into the escutcheon and a wide area that is concave and has a faint median carina, visible in figures 6a, b, and 7. The escutcheon is considerably smaller than the area. On both the area and the escutcheon are very fine dense horizontal striae with minute knots, which may have been caused by the crossing of the horizontal striae with still finer radial elements. Some stronger radial elements are visible on the area of the smallest specimen (figure 8). The marginal carina is crossed by fine horizontal elements (*see* figure 6a). No radial striae were observed on the remainder of the shell which has well-developed concentric ridges. The teeth of the left valve are illustrated in figure 6c.

Other Trigonias found in Lower Jurassic beds elsewhere are clearly distinguished from this new species, which was named for Dr. H. W. Little

Goniomya aff. *heteropleura* Agassiz

Plate II, figure 5

The specimen illustrated in Plate II, figure 5, is preserved as an imprint of parts of both right and left valves. It was found in the coquina bed on the ridge northeast of Parks. The general outline of this specimen is not determinable. Its sculpture is not V-shaped as in most Goniomyas but has horizontal rib parts. Forms with this type of ribbing are known from the lower Lias of Europe, where they are described as *Goniomya heteropleura* Agassiz (1845, p. 24, pl. 1d, figs. 9-10) or *G. rhombifera* Quenstedt (1858, p. 82, pl. 10, fig. 5). Troedsson (1951, p. 195, pl. 10, fig. 16) who found Agassiz's species in the lower Pliensbachian (middle Lower Jurassic) in Scania, mentions that in Northwest Germany this species ranges as high as the *Amaltheus* beds.

The genus *Goniomya* is commonly considered to be limited to the Jurassic and Cretaceous, but a collection made in 1943 by C. O. Hage in the Upper Triassic Pardonet formation of the Sikanni Chief River area includes a *Goniomya* sp., as yet undescribed, that has the same type of sculpture as *G. heteropleura* Agassiz and the form collected at Parks. On account of the unsatisfactory preservation of the latter specimen its relationships to Agassiz's species and the Triassic specimen from Sikanni Chief River cannot be determined.

Lima aff. *compressa* Terquem

Plate IV, figure 3

The right valve of a *Lima* that was found in the coquina bed on the ridge northeast of Parks is preserved as a fragmentary imprint from which

the rubber cast figured was made. The specimen is semicircular, very little convex, and has a small obtuse beak. Only part of the posterior ear is preserved. The sculpture consists of many fine, somewhat undulating radial ribs, most of them of equal size. A few thinner ribs are intercalated. The radial ribs, which become thinner towards the beak, are crossed by still finer concentric striae. Fine, more or less flattened knots are developed on the points of crossing of the radial and concentric elements.

Lima compressa Terquem (1855, p. 319, Pl. XXII, fig. 4) from the Hettangian (lowermost Lower Jurassic) of Luxembourg has a similar outline and sculpture but is smaller than the specimen from Parks. This specimen is too poorly preserved to be identified. A few other fragments found in the same bed seem to indicate the presence of more representatives of *Lima*.

Other Forms

In the highly fossiliferous coquina bed on the ridge northeast of Parks corals are very frequent. These are not dealt with in this paper. Fragments of other pelecypods than those described are also present and among them Pectinids are fairly frequent. Their very unsatisfactory preservation (*see* Plate II, figures 9, 10) does not justify describing them here. The same applies to the gastropods and the few fragments of belemnites but further collecting may result in finding better material of some of these forms.

Age and Correlation

The fossils found so far in the marine Jurassic rocks of the Nelson, Salmo, and Caribou Creek areas are:

1. Archibald Creek, Salmon map-area: *Arnioceras* (*Melanhippites*) sp. indet.
2. Ridge northeast of Parks, Salmo map-area: *Arnioceras* sp. indet., *Trigonia littlei* n. sp., *Goniomya* aff. *heteropleura* Agassiz, *Cardinia* aff. *regularis* Terquem, *Lima* aff. *compressa* Terquem, gastropods, belemnite fragments and corals.
3. East side of Beaver Creek: *Arnioceras* sp. indet.
4. West of Independence Creek, Caribou Creek area (6 miles northeast of Burton): *Arnioceras* sp. indet.
5. Highway between Hall and Porto Rico, Nelson area: *Harpoceras* aff. *exaratum* Young and Bird, *Harpoceras* sensu lato sp. indet., indeterminable pelecypods.
6. About 2.7 miles southwest of Porto Rico station, Salmo map-area: *Sonninia* (?) sp. indet., small Harpoceratids, indeterminable pelecypods.

The ammonite genus *Arnioceras* is characteristic of part of the Sinemurian stage of the Lower Jurassic. Accordingly the faunas at localities 1, 2, 3, and 4, which contain ammonites belonging to this genus, can be placed in this stage. None of the pelecypods associated with *Arnioceras* at locality 2 contradicts this age determination. Most of them have affinities with species of the European Lower Jurassic.

The fauna at locality 5 consists exclusively of poorly preserved Harpoceratid ammonites. One of these shows affinities with *Harpoceras exaratum* Young and Bird which is a Toarcian species and which also occurs in the Toarcian of the Fernie group. A Toarcian (late Lower Jurassic) age is suggested for this fauna.

The *Sonninia* (?) found at locality 6 suggests a possible middle Bajocian (early Middle Jurassic) age for the rocks concerned.

Table I

Tentative Correlation of the Sequence in the Archibald Creek and Parks Areas with the Sequence in the Porto Rico-Hall area

(*See* Postscript, p. 17.)

Archibald Creek and Parks areas	Porto Rico-Hall area
	Beaver Mountain formation (volcanic rocks)
Beaver Mountain formation (volcanic rocks)	Hall formation (mainly sedimentary rocks) *Sonninia* (?) (middle Bajocian)
	Harpoceratids (Toarcian)
	Elise formation (mainly volcanic rocks, some sedimentary in upper part)
Arnioceratids (Sinemurian) So-called "Hall formation" (mainly sedimentary rocks)	
	Ymir group (mainly sedimentary rocks)

The faunas found thus indicate the presence of parts of three different stages, i.e., Sinemurian (early Lower Jurassic), Toarcian (late Lower Jurassic) and Bajocian (early Middle Jurassic).

Considering the great estimated thickness, 4,000 feet, of the sedimentary rocks concerned the discovery of only three zones is surprising, but there are a number of reasons for this scarcity of fossils. Some of the rocks concerned are so metamorphosed that the contained fossils may have been destroyed. Furthermore, good outcrops are rare and some fossil beds may have been overlooked. This possibility is best illustrated by the fact that the area was studied and mapped several times before the first fossils were found. Finally, certain fossil zones may be absent because of the nature of the palæogeographic conditions during Jurassic times.

Local Correlations

The faunas, from localities 1, 2, 3, and 4, all of which contain representatives of *Arnioceras*, can be roughly correlated with one another despite some considerable lithological and faunal differences. Faunas from 1 and 3, which are in argillite facies, contain nothing but ammonites, whereas the fauna from 2, the coquina bed northeast of Parks, contains in addition to ammonites numerous pelecypods and corals, and some gastropods. It cannot be stated whether these changes take place in the horizontal extension of exactly the same bed or whether small differences in the stratigraphic position of the beds concerned are involved.

All the sedimentary rocks of the Rossland group that yielded *Arnioceras* have hitherto been placed in the Hall formation. These *Arnioceras* occurrences are, with the exception of the single specimen found in the Caribou Creek area (6 miles northeast of Burton), situated in the Beaver Creek, Archibald Creek, and Park areas, all of which are outside and to the southwest of the type area of the Hall formation, which is Hall Creek. This fact must be considered in discussing the Hall formation.

No Arnioceratids were found in the Hall formation in the type area or immediately neighbouring areas, and, as the group there overlies the Elise formation the upper part of which has yielded Toarcian ammonites, no *Arnioceras* can be expected in it. Indeed faunas younger than that of the upper Elise formation should be present and this seems to be the case. The *Sonninia* (?) found in the lower part of the Hall formation in the Porto Rico area suggests a Bajocian age. The so-called "Hall formation" of the Archibald Creek, Beaver Creek, and Parks areas, which yielded the *Arnioceras* faunas, can therefore not be equivalent in time to the Hall group in the type area. The so-called "Hall formation" of Salmo area is therefore older than the upper part of the Elise formation, with its Toarcian Harpoceratids, and may rather be correlated with the lower part of the

Elise formation or even with part of the Ymir group, which underlies the Elise formation. Both Mulligan and Little (personal communication) have already stated that the rocks of the Hall formation as they used it (which also included the rocks of the so-called "Hall formation" in Archibald Creek) are very similar to and may be mistaken for those of the Ymir group. Such a mistake seems to have been made in the Archibald Creek area. In this connection it should be made clear that no Elise formation has been proved to underlie the so-called "Hall formation" in the Archibald Creek and Parks regions. The few relatively small, isolated areas mapped as Elise formation there consist of rocks similar to, but not certainly identifiable with, those of the Elise and the Beaver Mountain formations. Furthermore, Little (1950, p. 29) stated that the Elise and Beaver Mountain formations resemble each other so much that "it is only when the fossiliferous sedimentary rocks of the Hall formation are delineated that the volcanic rocks can be placed in their proper stratigraphic position with confidence" (*see also* Mulligan, 1952, pp. 4, 5). As the volcanic rocks in the Parks area, previously considered as equivalents of the Elise formation, are in supposed faulted contact with the sedimentary rocks of the so-called "Hall formation" (Little, 1950, map), their place in the stratigraphic sequence is unknown and they may actually belong to the Beaver Mountain formation.

The volcanic rocks that overlie the so-called "Hall formation" in the Archibald Creek and Parks areas were placed by Little (1950) and Mulligan (1952) in the Beaver Mountain formation, which was a logical consequence of the Beaver Mountain formation being found on top of the Hall formation in the type area. However, as shown above, the so-called "Hall formation" in Archibald Creek and Parks areas is actually older than the true Hall formation at Hall Creek, and should be regarded, at the present stage of our knowledge, as equivalent in time to the lower part of the Elise formation or possibly even of the upper part of the Ymir group in the Hall area. Accordingly the lower part of the beds mapped as the Beaver Mountain formation in the Archibald Creek and Parks areas could be correlated with the upper part of the Elise formation of the Porto Rico and Hall areas. Similarly, the upper part of the beds mapped as the Beaver Mountain formation in the Archibald Creek and Parks areas would then probably be equivalent in time to the Hall formation and Beaver Mountain formation in the Porto Rico and Hall areas. These tentative correlations are summarized in Table I.[1]

Regional Correlations

The Jurassic rocks of Nelson and Salmo map-areas have yielded faunas that indicate the presence of only three small units of the Jurassic system,

[1]*See* Postscript, p. 17.

i.e., part of the Sinemurian, part of the Toarcian, and part of the Bajocian, the first two in the lower and upper parts of the Lower Jurassic and the last in the lower part of the Middle Jurassic. Further discoveries of fossils may amplify the sequence and offer the basis for more detailed regional correlations. Some of the more important subdivisions known from other parts of Western Canada and not hitherto found in Nelson and Salmo areas are: the Hettangian, known from the Tyaughton Creek area and other parts of British Columbia, the lower Callovian and the Oxfordian all known from the Fernie group in the Canadian Rocky Mountains and Foothills and from various localities in British Columbia. Beds of Hettangian age could be expected below the *Arnioceras* beds and equivalents of the lower Callovian and the Oxfordian could be represented in the Hall formation above the bed with *Sonninia* (?). As this ammonite occurs near the bottom of the Hall formation and as the thickness of the formation is about 4,000 feet, there would be ample room for representatives of these stages.

The *Arnioceras* beds at Archibald Creek, Beaver Creek, Parks, and in the Caribou Creek area can be correlated with beds of the same age widely distributed both in other parts of British Columbia, in southern Yukon, in the Rocky Mountains and Foothills, and in the Canadian Arctic coast region. The Toarcian beds of the Hall-Porto Rico area can be correlated with deposits of this age in parts of British Columbia (for example: the west coast of Vancouver Island, Tyaughton Creek, McConnell Creek, Stikine). Equivalents of these beds are also widely distributed in the Fernie group in which they are present almost everywhere the Fernie is found. On the Canadian Arctic Islands Toarcian occurs in Prince Patrick, Cornwall, and Axel Heiberg Islands (Frebold, 1958). The youngest fossil bed (with *Sonninia* (?)) known so far in the Porto Rico area has probably its equivalents in other parts of British Columbia, as at Hudson Bay Mountain and McConnell Creek, and in the Fernie group of the Rocky Mountains and Foothills. Sonninids and *Witchellia* are the index fossils found at the various localities.

Remarks On Palæogeography

The Jurassic sediments dealt with in this paper were originally much more widespread and the writer believes that those adjoining areas from which as yet no Jurassic sediments are known and which separate the marine Jurassic deposits in the Nelson, Salmo, and Caribou Creek areas from marine Jurassic rocks to the west and east were also once covered by marine Jurassic deposits.

The present east and west boundaries of the Jurassic deposits in this part of southern British Columbia are, according to Little (personal communication), as follows (*see* Figure 1): to the east a line running about straight south from Nelson and to the west the Christina Lake region where the boundary is formed by a big fault. To the south, the Jurassic deposits extend about 12 miles into the United States, to just east of Kettle River (*see* Weaver, 1920). The most northerly known occurrences, described by McConnell and Brock (1904), are in the Caribou Creek area northeast of Burton. One of the Arnioceratids described in this paper (p. 7) came from this latter area. Not all occurrences in southern British Columbia are directly connected with one another. Between some of them are banded gneisses, which, according to Little (personal communication), may be strongly metamorphosed Jurassic sediments. Little observed that west of Hall Creek, for instance, the fossiliferous argillaceous and arenaceous rocks to the west and southwest of the head of Hall Creek grade into rocks of higher grades of metamorphism in which relict bedding gradually gives way to gneissic banding. Still farther to the west relict bedding again becomes visible and finally strata that are little metamorphosed occur. Little's suggestion about the nature of these rocks is here accepted as the probable explanation for the apparently limited distribution of Jurassic sediments in this part of southern British Columbia.

The presence of marine Jurassic rocks proves that this part of southern British Columbia, at least during some of the Jurassic, i.e., parts of the Sinemurian, Toarcian, and Bajocian, was covered by a sea. This region had been considered previously to have been a land which, in the opinion of Schuchert (1923) and others, extended from the United States for hundreds of miles north into the interior of British Columbia, separating the Pacific geosyncline from the sea lying where now are the Rocky Mountains, Foothills, and plains. As shown in a previous paper (Frebold, 1957, pp. 37-41) the reasons given in favour of the presence of this coherent Jurassic landmass do not agree with the facts. The thickness of the Jurassic beds, which reaches about 4,000 feet in Nelson and Salmo areas, indicates a strong, geosynclinal subsidence, particularly if compared with the small thickness of the Jurassic Fernie group to the east where the sediments deposited are only between 200 and 1,200 feet thick. The intercalation or close association of marine Jurassic beds with volcanic rocks (Elise and Beaver Mountain formations) in Nelson and Salmo areas shows that the conditions in this area were those characteristic of eugeosynclinal zones.

The sediments of the Hall formation were previously (Drysdale, 1917) considered to be nonmarine, mainly because marine fossils were unknown

and some plant remains were found. Also the shaly interbeds in the upper part of the Elise formation were regarded as limnitic (McAllister, 1951, p. 30). After the marine fossils were found in the Hall formation and in the shaly part of the Elise formation the marine origin of all these shales became evident. These shales are therefore considered to have been deposited in a part of a sea comparatively far from land.

The presence of a coarse coquina bed in the *Arnioceras* zone northeast of Parks may indicate the presence of the shoreline of one of the volcanic islands that probably existed in this sea. The rich fauna contained in this coquina bed proves that conditions were favourable in this *Arnioceras* sea, conditions that cannot be recognized from the contemporaneous shaly deposits in which only ammonites were found. The presence of many corals may even suggest the existence of coral reefs. Volcanic eruptions, which probably resulted in the formation of volcanic islands, took place also during the Toarcian, at which time the younger part of the Elise formation was formed.

The Sinemurian, Toarcian and Bajocian faunas discovered so far in this part of southern British Columbia immigrated into the area at times when general and widely extended transgressions are known to have taken place in Western Canada. Their presence in this area is therefore not surprising.

The great thickness of that part of the Hall formation, which is younger than its lower beds with *Sonninia,* indicates the probable continuation of marine conditions in post-Bajocian times. As no younger faunas were found, it is not possible to state the time involved. Possibly the sea stayed in this region during the Middle and perhaps part of the Late Jurassic. It is, however, very probable that towards the end of Jurassic time this part of southern British Columbia and the Rocky Mountain Trench to the east had become land, which, by erosion, was the source of the Lower Cretaceous deposits in the east. The Kootenay formation of the Rocky Mountains and Foothills was thus the first deposit that originated from this land.

Postscript

During field work carried out by the writer in 1958 and while this paper was in the press, numerous Harpoceratids were found on a mine road close to Arlington Mine, west of Erie Creek, in rocks previously (Little, 1950) mapped as Beaver Mountain formation. These ammonites, which are similar to but better preserved than those found in the Elise formation between Hall and Porto Rico, prove that at least parts of the Elise and Beaver Mountain formations are of the same age, i.e., Toarcian, as suggested in the tentative correlation table on page 12.

Those rocks in Hall Creek previously mapped by Little (1950) as Beaver Mountain formation and as overlying the Hall formation (*see* correlation table, p. 12) are by the same author (personal communication) now considered to belong to the Elise formation. According to Little's recent interpretation of the structure in the Hall Creek area, the Elise formation forms the limbs of a syncline in the centre of which is the Hall formation.

A re-definition of the lithological units of the Mesozoic in the Nelson and Salmo areas which is beyond the scope of this paper, is now being prepared by Little. The above-mentioned Harpoceratids from the Arlington Mine area will be described by the writer in another paper.

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PLATES I to V

PLATE I

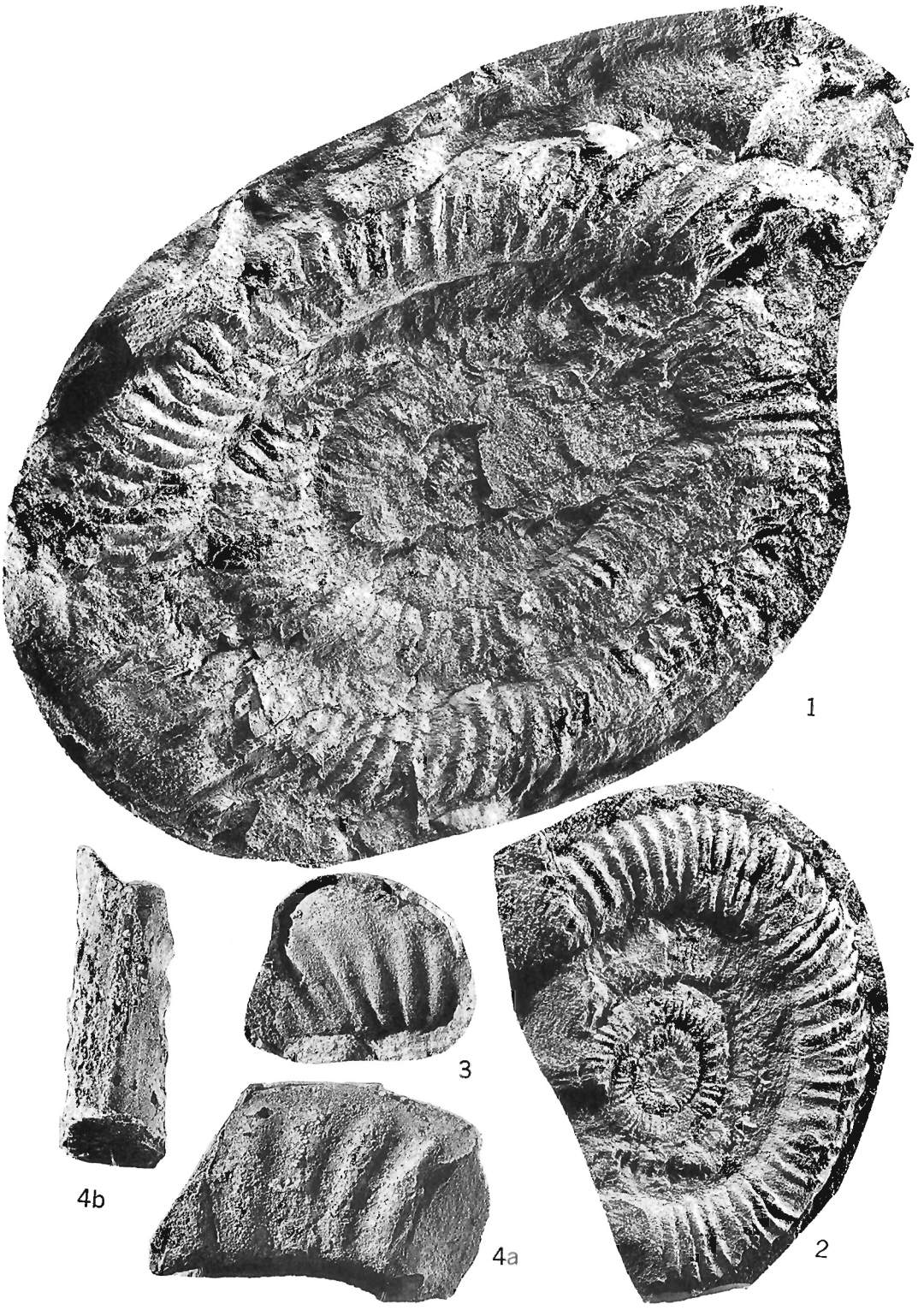


PLATE I

(All fossils are in natural size)

Figure 1. *Arnioceras* (*Melanhippites*) sp. indet. Lateral view. West side of Archibald Creek, Salmo area. Sinemurian. G.S.C. No. 13712 (page 6).

Figure 2. *Arnioceras* (*Melanhippites*) sp. indet. Lateral view. West side of Archibald Creek, Salmo area. Sinemurian. G.S.C. No. 13713 (page 6).

Figure 3. *Arnioceras* sp. indet. Rubber cast. Whorl fragment. Lateral view. Coquina bed on ridge northeast of Parks station. Salmo area. Sinemurian. G.S.C. No. 13714 (page 6).

Figures 4a, b. *Arnioceras* sp. indet. 4a lateral, 4b ventral view of the same whorl fragment. Coquina bed on ridge northeast of Parks station. Salmo area. Sinemurian. G.S.C. No. 13715 (page 6).

PLATE II

(All fossils are in natural size)

Figure 1. *Cardinia* aff. *regularis* Terquem. Rubber cast. Left valve. Coquina bed on ridge northeast of Parks station. Salmo area. Sinemurian. G.S.C. No. 13716 (page 9).

Figure 2. *Cardinia* aff. *regularis* Terquem. Rubber cast. Right valve. Same bed and locality as figure 1. G.S.C. No. 13717 (page 9).

Figures 3, 4. *Cardinia* aff. *regularis* Terquem. Right valves. Same bed and locality as figure 1. G.S.C. No. 13718 (page 9).

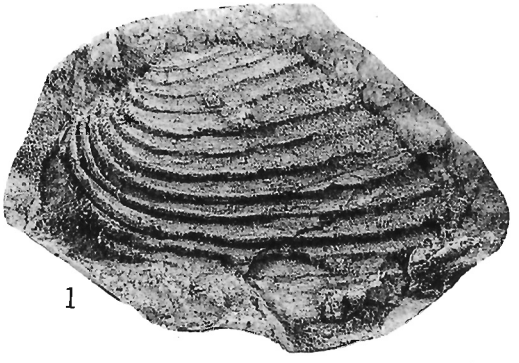
Figure 5. *Goniomya* aff. *heteropleura* Agassiz. Rubber cast. Both valves. Same bed and locality as figure 1. G.S.C. No. 13719 (page 10).

Figures 6a, b, c. *Trigonia littlei* n. sp. Rubber cast. 6a left valve, 6b area, escutcheon and teeth, 6c teeth. Same bed and locality as figure 1. Holotype. G.S.C. No. 13720 (page 9).

Figure 7. *Trigonia littlei* n. sp. Rubber cast. Left valve. Same bed and locality as figure 1. Paratype. G.S.C. No. 13721 (page 9).

Figure 8. *Trigonia littlei* n. sp. Rubber cast. Same bed and locality as figure 1. Paratype. G.S.C. No. 13722 (page 9).

Figures 9, 10. *Pecten* sp. indet. Same bed and locality as figure 1. G.S.C. Nos. 13723, 13724 (page 11).



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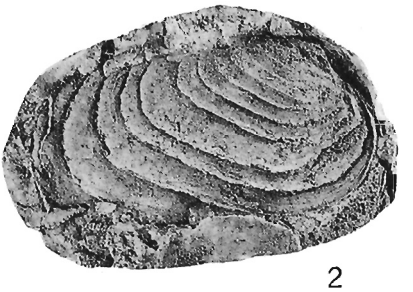

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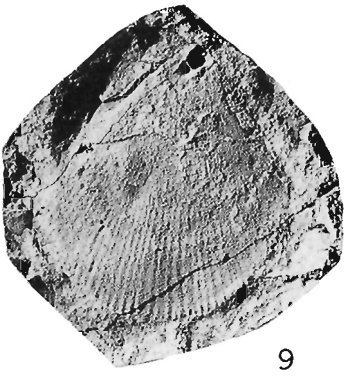

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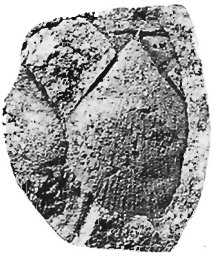

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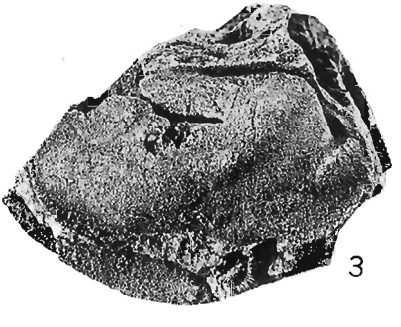
5

6a

6c

6b

7



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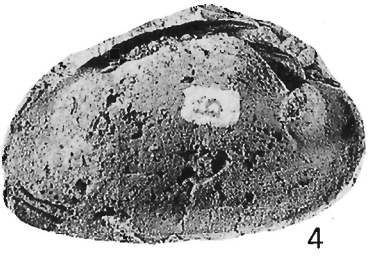

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PLATE III

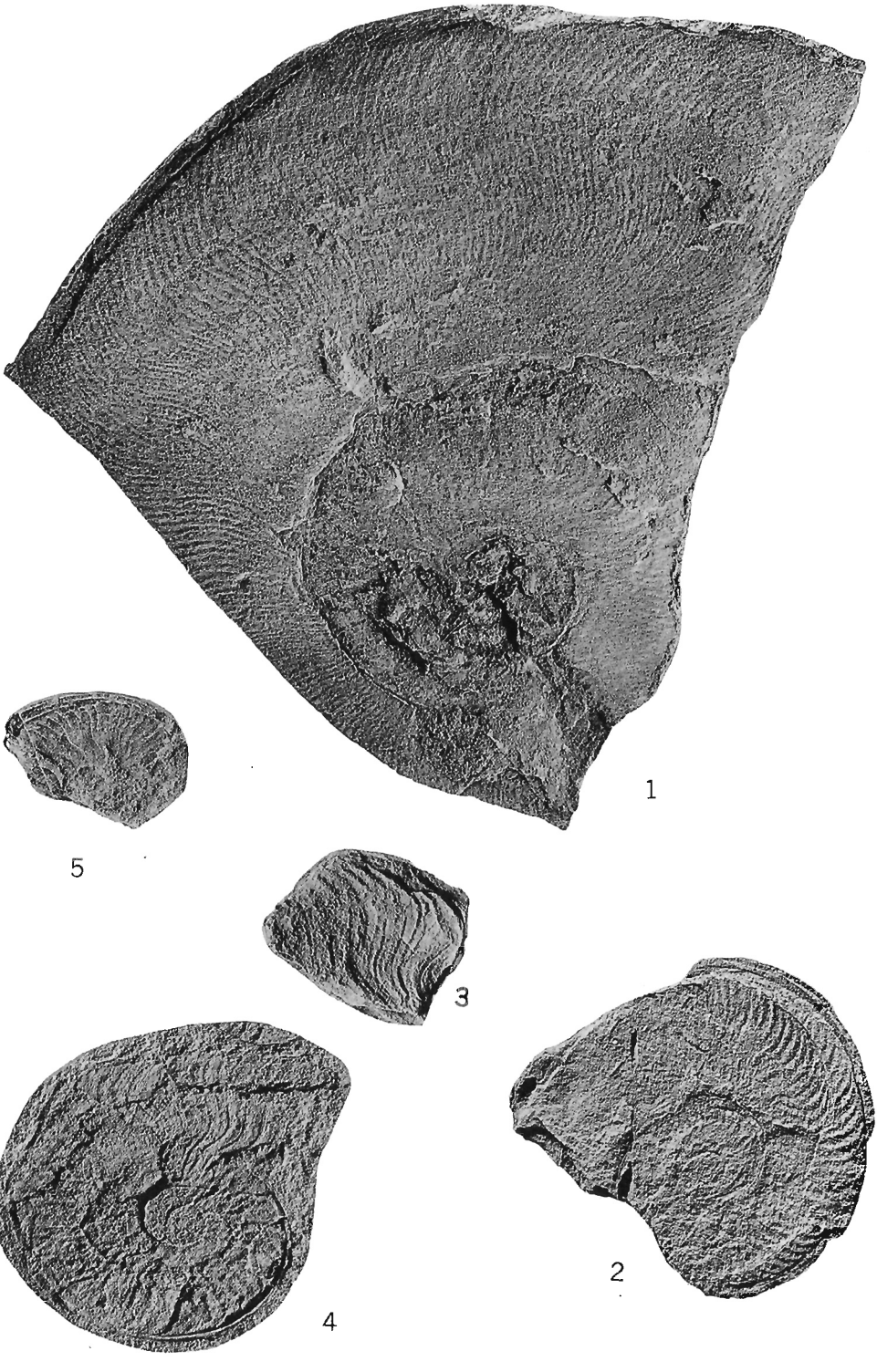


PLATE III

(All fossils are in natural size)

Figure 1. *Harpoceras* aff. *exaratum* Young and Bird. Lateral view. Upper part of Elise formation. Highway between Hall and Porto Rico. Toarcian. G.S.C. No. 13725 (page 7).

Figure 2. *Harpoceras* sensu lato sp. indet. Lateral view. Same bed and locality as figure 1. G.S.C. No. 13726 (page 7).

Figure 3. *Harpoceras* sensu lato sp. indet. Whorl fragment. Lateral view. Same bed and locality as figure 1. G.S.C. No. 13727 (page 7).

Figure 4. *Harpoceras* sensu lato sp. indet. Lateral view. Same bed and locality as figure 1. G.S.C. No. 13728 (page 7).

Figure 5. *Harpoceras* sensu lato sp. indet. Whorl fragment. Lateral view and part of venter. Same bed and locality as figure 1. G.S.C. No. 13729 (page 7).

PLATE IV

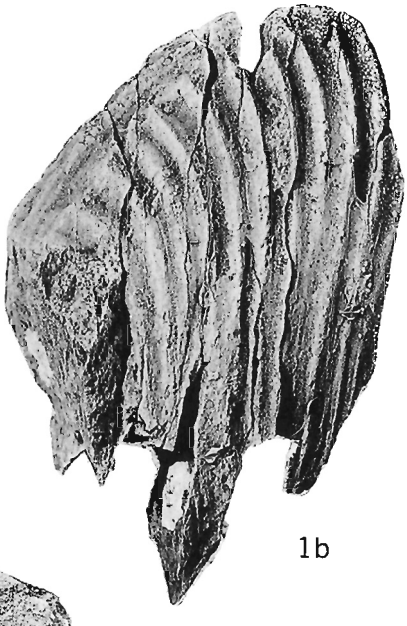
(All fossils are in natural size)

Figures 1a, b. *Sonninia* (?) sp. indet. 1a rubber cast. Lateral view. 1b whorl fragment of same specimen, lateral view and venter. South side of Barrett Creek, about 2.7 miles southwest of Porto Rico. Bajocian. G.S.C. No. 13730 (page 8).

Figure 2. *Arnioceras* sp. indet. Rubber cast. Lateral view. West of Independence Creek, Caribou Creek area, 6 miles northeast of Burton. Sinemurian. G.S.C. No. 13731 (page 6).

Figure 3. *Lima* aff. *compressa* Terquem. Rubber cast. Right valve. Coquina bed on ridge northeast of Parks station. Salmo area. Sinemurian. G.S.C. No. 13732 (page 10).

1a



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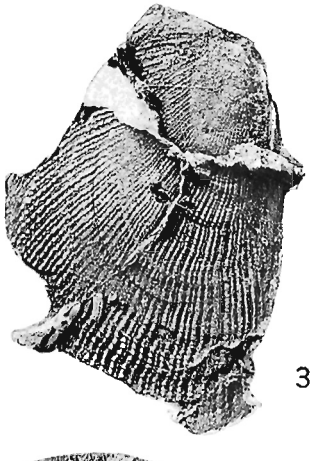

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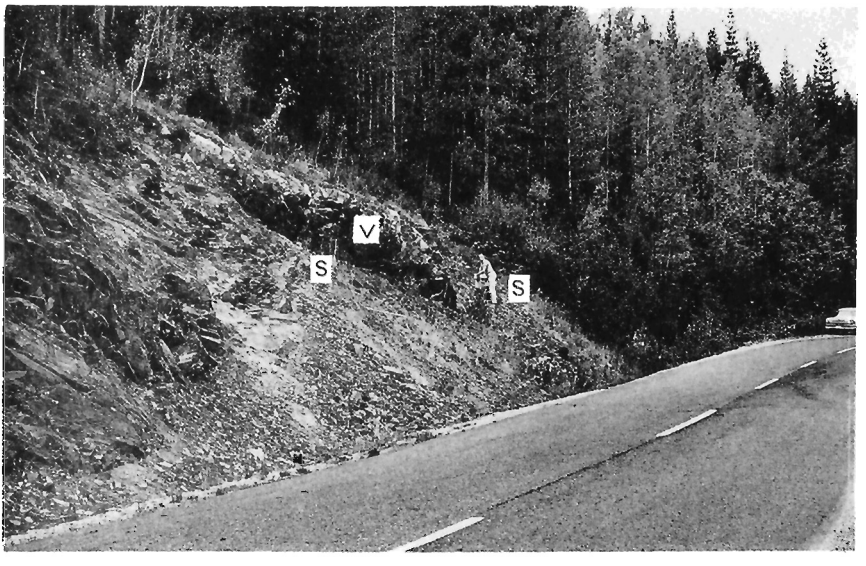
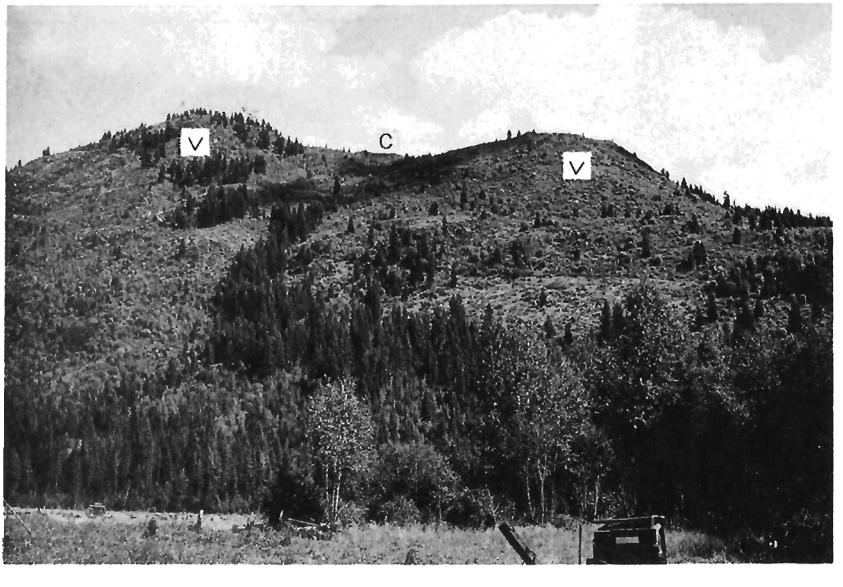
PLATE V



A



B

PLATE V

Figure A. Upper part of Elise formation. Highway between Hall and Porto Rico. S = Shale with *Harpoceras* fauna, V = volcanic rock.

Figure B. Ridge northeast of Parks station. V = volcanic rock, C = coquina bed with Sinemurian fauna.