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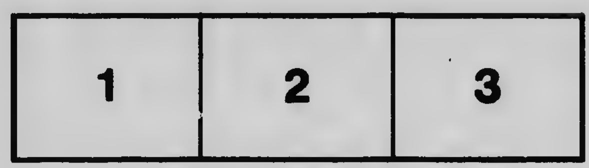
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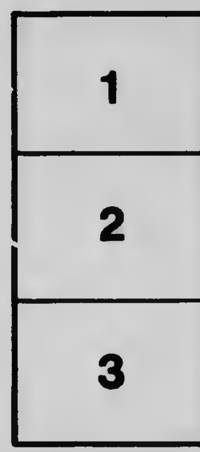
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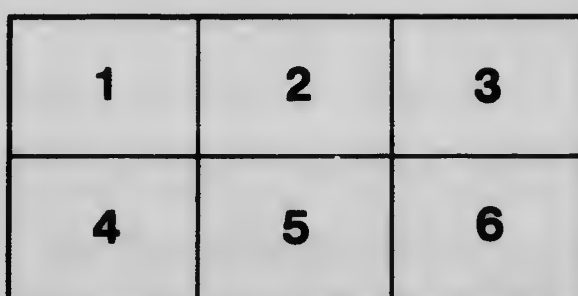
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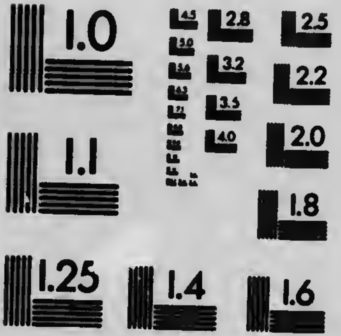

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Museum Bulletin No. 2

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ILLUSTRATIONS

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GEOLOGICAL SERIES, No. 13.

I.—The Origin of Granite (Micropegmatite) in the Purcell Sills.

By S. J. SCHOFIELD.

INTRODUCTION.

Of late years, the assimilation-differentiation hypothesis, in connexion with the larger problems of petrogenesis, has received some measure of support from the study of the gabbro and associated granites occurring as sills in various parts of the world.

The purpose of this paper is the examination and discussion of this hypothesis with reference to the origin of the so-called "secondary" granite in sills; especially in those of East Kootenay, B.C. This is all the more desirable since the East Kootenay sills show a general type of phenomena common throughout the world, and since they present such exceptional opportunities for study.

The problem was suggested by Professor R. A. Daly of Harvard University and was studied in connexion with the geological mapping of East Koot v, B.C., during the field seasons of 1909, 1910, 1911, and 1 .

Previously Daly studied occurrences of similar phenomena and published several interesting papers.[1] Daly's main conclusions are as follows:—

(1) "The Moyie intrusive is an enormously thick sill composed in greatest part of a peculiar hornblende gabbro slightly acidified at the lower contact. An equally abnormal biotite granite

[1]Daly, R. A., Geol. Surv. Can., Ann. Rep., 1904, p. 91A.
Daly, R. A., Amer. Jour. Sci., vol. 20, 1905, p. 185.
Daly, R. A., Festschrift zum siebzigsten Geburtstage von H. Rosenbusch, 1906, p. 203.

merging irregularly into micropegmatite, forms a zone in the uppermost part of the sill, while a fourth zone of rock intermediate in composition between the granite and gabbro and, on the respective sides, transitional into those rocks, occurs between the thick basic zone and the much thinner granite zone."

(2) "The sedimentary formation cut by the sill comprises a very thick series of ancient sandstones highly quartzose but generally containing alkaline and soda-lime feldspars and always carrying mica."

(3) "At the time of intrusion the quartzitic strata lay flat."

(4) "At both contacts of the sill, the igneous rock contains foreign blocks shattered off from the quartzites. These blocks often show evidence of magmatic corrosion."

(5) "The field-relations and the chemical and optical study of sill-rocks and quartzites suggest that the material of the granite-micropegmatite zone is of derived origin. Most of that material resulted from the solvent action of the gabbro magma on the quartzite blocks and on the main sill-contacts. Some of the constituent elements of the granite may have been taken from the gabbro, which, on account of its superior and great volume, shows no appreciable modification by such loss."

(6) "The asymmetry of the intrusive body is believed to be owing to the stratification of the sill by the action of gravitative adjustment. The product of assimilation whether at the lower main contact or about quartzite blocks immersed in the gabbro, possessed less density than the gabbro magma, rose through that magma and collected at the top of the sill. The intermediate rock represents a zone of incomplete differentiation."

(7) "The assimilation and concomitant differentiation are exhibited in other sills of the region, but, on account of the relatively small thickness and consequently smaller share of heat energy possessed by those sills, the action did not develop true granite."

(8) "Following the solidification of these sills, they were faulted and tilted to their present position in the fault-blocks of the Purcell Mountain range."

(9) "More or less perfect pa... ..s to the Moyie sill have been described by various workers in Minnesota and Ontario. In all

of these instances there is the same genetic relation of gabbro, granite and siliceous sediments or schists. An important special feature of the extraordinarily thick and extensive sheet of the Sudbury district in Ontario is an apparent case of the gravitative differentiation of the famous sulphide ores of that district."

New facts gained in the present writer's study of the same phenomena have led him to the following conclusions:—

(a) That the sills were formed from practically simultaneous injections of a series of magmas—varying from acid to basic—in distinct sills.

(b) That these magmas are differentiation products of a subcrustal or intercrustal magma.

(c) That after intrusion, the magma of those sills composed of basic material solidified without differentiation.

(d) That in the case of those sills composed of the more acid magma, differentiation under influence of gravity took place and the granitic portions formed in this way with little or no aid from assimilation.

(e) That the hornblende of the sills is secondary after augite.

GENERAL GEOLOGY OF THE PURCELL RANGE.

The Purcell range, as shown on the accompanying map, lies in southeastern British Columbia, between Kootenay river on the east and Kootenay lake on the west. The range for the most part is made up of sedimentary rocks called the Purcell series, of Pre-Cambrian age. This series, with a thickness of about 23,000 feet, is folded into broad anticlines and synclines striking in a northerly direction and is broken by a few subsidiary normal faults. These orogenic movements were accompanied or closely followed by an intrusion of granite, especially in the western part of the range.

The Purcell series consists mainly of argillaceous quartzites, and argillites, with subsidiary amounts of purer quartzites, sandstones, and limestones.

Amongst these strata, and especially in the oldest known member of the Purcell series, occur the Purcell Sills—the subject of this present article—and the Purcell Lava, the extrusive phase of the Purcell Sills also Pre-Cambrian in age. The lavas consist mainly of basalt with minor amounts of rhyolite, breccia, and tuff, with a thickness of about 300 feet. They occur higher up in the series than the sills and since they are of the same composition as the sills, therefore, the sills and lavas are believed to be representatives of the same magma.

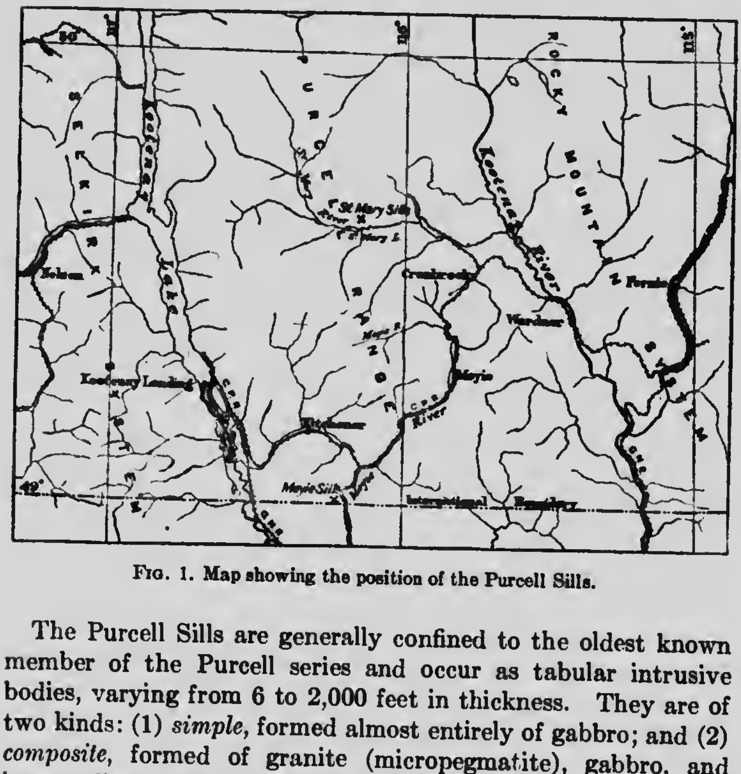

FIG. 1. Map showing the position of the Purcell Sills.

The Purcell Sills are generally confined to the oldest known member of the Purcell series and occur as tabular intrusive bodies, varying from 6 to 2,000 feet in thickness. They are of two kinds: (1) *simple*, formed almost entirely of gabbro; and (2) *composite*, formed of granite (micropegmatite), gabbro, and intermediate rock types. In the case of the composite sills, the material is stratified according to density, the granite (micropegmatite) occurring at or near the upper contact of the sill, and grading downwards into gabbro. That in the case of the composite sills, these two rock varieties have a common origin is supported by the association of the rhyolites and basalts in the Purcell Lavas, the supposed extrusive phase of the Purcell Sills.

PETROGRAPHY OF THE SILLS.

As mentioned above, the sills fall into two groups—a simple type composed almost solely of gabbro, and a composite type consisting of granite (micropegmatite), quartz diorite, and gabbro, always arranged in a stratiform fashion. These composite sills are of two types; in some cases the granite (micropegmatite), occupies the upper portion of the sill, grading downwards into gabbro (Sudbury type); while in the other type the granite (micropegmatite) is near the upper contact and grades towards each contact into gabbro (Shonkinsag type). Thus, there are three main rock types in the composite sills, and one rock type in the simple sills. Of these, gabbro is common to all types of sills.

Lithological Characters.—The rocks which constitute the Purcell Sills vary in composition from a hypersthene gabbro to a very acid granite (micropegmatite), with members intermediate between these two extreme types. The texture of the sill rock varies from fine-grained to porphyritic. The granite (micropegmatite) is always associated with gabbro and occurs at or near the upper contact of the sills. The thickness of the granite (micropegmatite), which grades downwards into a hornblende gabbro, bears no relationship to the thickness of the sill. In some cases, where the granite (micropegmatite) is not at the immediate upper contact, it grades upwards into a quartz diorite and finally into a gabbro.

Before proceeding to the general discussion as to the origin and distribution of the granite (micropegmatite) in the sills, a description of the three main rock types will be given. It must be remembered that all three types pass into each other by gradual transition.

Gabbro.—The most basic type is hypersthene gabbro and occurs in one of the St. Mary sills. It is a dark grey, crystalline rock of granitic texture, in which can be detected plagioclase and augite. The rock is quite fresh, the feldspars being clear and glassy, a feature very rare in the basic rocks of East Kootenay. Under the microscope, the essential constituents of the gabbro are seen to be labradorite and pyroxene (Plate I, fig. 1). The labradorite occurs in lath-shaped individuals, which show carlsbad, pericline, and albite twinning. Filling the interstices between the labradorite crystals occurs the pyroxene which is of two varieties, hypersthene and augite. The augite is colourless and without pleochroism. Uralitization in all stages is common in this rock; in many cases crystals of hornblende occur with a core of augite. Where the secondary hornblende is in contact with the labradorite it has the characteristic pleochroism, greenish blue parallel to **c**, strong green parallel to **b**, and pale yellowish green parallel to **a**. This is worthy of notice as nearly all the hornblende in the hornblende gabbro is of this type and it also strongly supports the theory that all the hornblende is secondary in origin.

Calkins[1], from a study of similar intrusives in Idaho, south of the International Boundary line, maintains that the hornblende of the gabbro is secondary. An extract from his report may be quoted.

"The rock now under consideration (provisionally called diorite) is, on the whole, richer in quartz than the diabase of the Coeur d'Alene district, but otherwise similar except in the absence of augite; and this may be accounted for by the probably lesser age of the latter rock, which cuts across beds as late as the Striped Peak, while the diorite sills here described were not seen in contact with rocks younger than the St. Regis. These considerations, together with the character of the hornblende, suggest that dioritic rocks of this region are uralitized diabases and gabbros, and although complete proof is wanting, I am inclined to believe that such is the case."

An occurrence of similar nature has been described by C. H. Warren[2]. The hypersthene of the Purcell Sills is about equal in amount to the augite and is characterized by a faint pink pleochroism parallel to **c**. It very frequently shows signs of alteration to hornblende.

In one instance, the hypersthene appears to have changed to a fibrous hornblende, which in turn was changed to a compact hornblende. The accessory constituents are small in amount and consist of magnetite in irregular grains, and apatite in long, colourless, idiomorphic crystals. One allotriomorphic crystal

[1]Calkins, F. C., U. S. G. S., Bull. 384, p. 49.
[2]Warren, C. H., Amer. Jour. Sci., Vol. 26, 1908, p. 469.

of quartz was present in the slide examined. The secondary minerals consist chiefly of fibrous and non-fibrous hornblende. Sericite occurs as dust-like particles in the feldspars. The structure of the rock is ophitic with the femic constituents filling the interstices of the lath-shaped labradorite crystals.

A chemical analysis of a typical specimen of hypersthene gabbro is as follows:—

SiO_2	50·36	Na_2O	2·54
TiO_2	0·90	K_2O	0·75
Al_2O_3	13·63	H_2O+	0·05
Fe_2O_3	2·22	H_2O-	0·71
FeO	8·38	P_2O_5	0·07
MnO	0·20		
MgO	8·67		99·98
CaO	11·50	S.G	2·970

(M. F. Connor analyst).

The norm calculated from this analysis is as follows:—

Orthoclase	4·44
Albite	20·96
Anorthite	23·63
Diopside	26·97
Hypersthene	9·86
Olivine	8·16
Magnetite	3·24
Ilmenite	1·67
	98·93
Water	0·76
	99·69

Hence in the quantitative classification the rock is auvergnose.

The following table shows the chemical relationship of the hypersthene gabbro to other gabbros:—

	1.	2.	3.	4.
SiO_2	50·36	49·50	49·38	51·68
TiO_2	0·90	0·84	1·19	....
Al_2O_3	13·63	18·00	18·55	13·88
Fe_2O_3	2·22	2·80	2·06	6·59
FeO	8·38	5·80	8·37	4·44
MnO	0·20	0·12	0·09	....
MgO	8·67	6·62	5·77	7·87
CaO	11·50	10·64	9·72	10·99
Na_2O	2·54	2·82	2·59	2·93
K_2O	0·75	0·98	0·68	0·81
H_2O+	0·05	....	....	0·74
H_2O-	0·71	....	....	....
P_2O_5	0·07	0·28	0·16	....
	99·98	98·40	98·56	99·93
S.G.	2·970			

1. Hypersthene gabbro of Purcell sills.
2. Average analysis of all gabbros excluding olivine gabbro.[1]
3. Average analysis of all norites.[2]
4. An analysis of Karoo dolerite (olivine diabase).[3]

Variations in the Gabbro.—The most common variation in the gabbro is the occurrence of the hornblende gabbro, which is believed to be formed from the hypersthene gabbro by metamorphism. In this gabbro, the pyroxenes are entirely absent and as a femic constituent occurs a fibrous hornblende with the characteristic pleochroism, bluish green parallel to **c**, strong green parallel to **b**, and pale yellowish green parallel to **a**. Also, these hornblendes contain inclusions of magnetite in irregular forms. This hornblende is identical with that described above as being formed from augite and hypersthene, and, hence, is considered secondary. In the hornblende gabbro, quartz is more abundant and with micropegmatite occasionally occurs as interstitial material. Epidote and calcite are present as a product of deep-seated metamorphism of the feldspars. An analysis of this variety is given by Daly,[4] who considers the hornblende as primary.

[1] R. A. Daly, Pro. Am. Acad. of Arts and Sci., vol. 45, 1900, p. 211.
[2] R. A. Daly, Pro. Am. Acad. of Arts. and Sci., vol. 45, 1900, p. 211.
[3] Hatch and Corstorphine, Geol. S. Africa, p. 232.
[4] R. A. Daly, Amer. Jour. Sci., 4th Ser., vol. 20, 1905, p. 193.

SiO_2	51·92	Na_2O	1·38
TiO_2	1·83	K_2O	0·47
Al_2O_3	14·13	H_2O+	0·10
Fe_2O_3	2·97	H_2O-	1·07
FeO	6·92	P_2O_5	0·04
MnO	0·14	CO_2	0·06
MgO	8·22		
CaO	11·53		100·78
		S.G.	3·000

The norm of the hornblende gabbro is:—

Quartz	6·78
Orthoclase	2·78
Albite	11·53
Anorthite	30·86
Diopside	21·07
Hypersthene	19·44
Ilmenite	1·52
Magnetite	4·41
Water, Carbon dioxide	1·23

Hence, in the quantitative classification, the rock is salfemic, quadrofelic, percalcic, presodic.

Towards the centre of the thick sills, there are often conspicuous streaks of light coloured material in the gabbro, which generally approximate a position parallel to the upper and lower contacts of the sill. This variation strongly resembles the banding in the gabbros of Skye, described by Harker.[1] The light coloured bands are pegmatitic in character and resemble segregation veins. There are two phases of the pegmatitic gabbro—an acid and a basic phase. The acid phase consists chiefly of quartz and the feldspars, orthoclase and oligoclase-albite. The orthoclase occurs as intergrowths with quartz forming micropegmatite. In this instance, quartz holds the feldspar, which is the reversal of the usual relations of the min-

[1]A. Harker, Mem. Geol. Sur. of the United Kingdom, 1904, pp. 90-92, 117, 121.

erals in micropegmatite, in which the feldspars contain oriented inclusions of quartz. Masses of pure quartz are very abundant and in some cases hold needles of fibrous hornblende. This acid phase strongly resembles in composition the granite (micropegmatite) described below, although it is coarser in texture, holds no biotite, and is richer in plagioclase. The similarity between the acid bands and the granite (micropegmatite) suggests that they have had the same origin.

The basic phase of the pegmatoid gabbro consists of long needles of hornblende with some interstitial quartz and feldspar. Under the microscope it is seen that the apparent order of crystallization is the reverse of that of the hypersthene gabbro which has an ophitic texture. In the pegmatoid variety, the hornblende, which is here compact and evidently primary, tends to idiomorphic outlines against the andesine, the other essential constituent. A little orthoclase and calcite are the accessory constituents, while the secondary minerals consist of epidote and calcite. The contact between the two phases of the pegmatoid gabbro is generally gradational, but has been observed to be quite sharp, like an igneous contact.

In one instance a dyke of aplite was found, which distinctly cut the basic gabbro, but was confined to the sill and apparently occurred near the upper contact of the sill. Microscopically, the essential constituents of the aplite are quartz and micropegmatite in which the quartz of the latter contains oriented inclusions of orthoclase. The latter mineral is usually clouded with a great number of sericite particles. The fibrous hornblende which is present, exhibits the pleochroism, **c**, bluish green, **b**, strong green, **a**, yellowish green, and thus resembles the secondary hornblende described above.

In the interior of the basic sills, there occurs a granitic phase in irregular masses with gradational boundaries with the surrounding gabbro. This phase consists of long needles of hornblende enclosed in a ground-mass of micropegmatite. The microscope shows that this hornblende is identical in optical and physical properties with the secondary hornblende described above, but in this case, transformation of the augite into hornblende is complete. The hornblende has a distinctly shredded appearance and minute needles of it occur throughout the other mineral constituents. The micropegmatite, which forms the ground-mass, consists of quartz containing oriented inclusions of orthoclase, minutely charged with a great number of microscopic hornblende needles. Large masses of quartz occur which are usually, but not always, free from inclusions. Apatite in long needle-like crystals, and magnetite form the accessory constituents. This phase is believed to be a variation of the acid member of the banded gabbro.

Associated with the basic sills and sometimes with the banded gabbros, are small irregular dykes of aplite, which consist almost entirely of plagioclase and quartz in varying proportions, with minor amounts of calcite. With a decrease in calcite and plagioclase these dykes pass into quartz veins which represent the extreme differentiate of the gabbro magma. Associated with all these variations occur sulphides of iron and copper.

Quartz-Diorite or Transition Rock.—With an increase in quartz and micropegmatite the gabbro gradually passes into quartz-diorite which forms the transition type between the gabbro and the granite (micropegmatite). The quartz-diorite has a light greyish-green colour and, in the hand specimen, shows quartz, feldspar, hornblende, and biotite. Under the microscope, the shredded hornblende is seen to have the same pleochroism: **c**, bluish-green, **b**, dark green, **a**, yellowish green, as the secondary hornblende described as occurring in the hypersthene gabbro, and is embedded in a ground-mass of quartz and micropegmatite. In the latter the quartz holds the feldspar, which is clouded with a great number of dust-like inclusions. Plagioclase—andesine to labradorite—is rather plentiful, while biotite, in small plates, is present sporadically throughout the rock. Chlorite and zoisite occur as secondary minerals. The following analysis is given by Daly:—[1]

[1] Daly, R. A Festschrift zum siebzigsten Geburtstage von H. Rosenbush, 1906, p. 217.

SiO_2	52·63	Na_2O	1·41
TiO_2	0·62	K_2O	2·29
Al_2O_3	16·76	H_2O+	0·12
Fe_2O_3	2·86	H_2O-	1·17
FeO	10·74	P_2O_5	0·33
MnO	0·38	CO_2	0·10
MgO	4·33		
CaO	6·17		99·91
		S.G	2·954

In the quantitive classification, this rock falls in an unnamed sodipotassic subrang of bandase.

Granite (*Micropegmatite*). The quartz diorite, with a decrease in hornblende and plagioclase and an increase in quartz and micropegmatite, gradually passes into granite (micropegmatite), which occurs at or near the upper contact of the sills; in the latter case closely resembling the distribution of the materials in the laccoliths of Shonkinsag and Square Butte[1]. The thickness of the granite (micropegmatite) bears no relation to the thickness of the sill, for cases will be cited below where sills 140 feet thick contain a large amount of granite (micropegmatite), while other sills, in the same section, 900 feet in thickness, are entirely basic. In the hand specimen the granite (micropegmatite) is a fine-grained, holocrystalline to porphyritic rock of pinkish-grey colour, in which can be identified biotite, quartz, and feldspar. Under the microscope, are seen the essential constituents, quartz, biotite, and micropegmatite, with the accessory constituents, microperthite, and plagioclase—probably andesine (Plate I, fig. 2.) The rock is very quartzose, the quartz occurring in large irregular masses associated with micropegmatite, in which the quartz holds the orthoclase. The latter is filled with dust-like inclusions and is generally scattered evenly throughout the quartz in small, round masses which extinguish simultaneously. Again, the orthoclase is only seen in the peripheral parts of the quartz, while the centre is quite free from such inclusions. Plagioclase—andesine to labradorite—is present in small amounts. Biotite is very plentiful and

[1]L. V. Pirsson, U. S. G. S. Bull. 237, p. 43.

occurs in irregular plates having an average diameter of 0·25 mm. Muscovite is present very sparingly and has a rod-like form. Magnetite, titaniferous magnetite in irregular masses, apatite in idiomorphic crystals, together with very minute crystals of garnet, complete the mineralogy of the granite (micropegmatite.) The analysis of the granite (micropegmatite) given below in column 1 is taken from Daly's paper[1]—"The Secondary Origin of Certain Granites." The analysis given in column 2 is the average analysis of granites of all periods by Osann and Clarke, given by Daly[2].

	1.	2.
SiO_2	71·69	69·92
TiO_2	0·50	0·39
Al_2O_3	13·29	14·78
Fe_2O_3	0·83	1·62
FeO	4·23	1·67
MnO	0·09	0·13
MgO	1·28	0·97
CaO	1·66	2·15
Na_2O	2·48	3·28
K_2O	2·37	4·07
H_2O+	0·14	0·78
H_2O-	1·31	....
P_2O_5	0·07	0·24
CO_2	0·13	....
	100·16	100·10
S.G	2·773	2·660

The calculation of the norm of the granite (micropegmatite) gives the following results:—

Quartz	39·90
Orthoclase	13·90
Albite	20·96
Anorthite	8·34
Corundum	4·59
Hypersthene	9·14
Magnetite	1·16
Titanite	1·22
	99·12

[1] R. A. Daly, Amer. Jour. Sci., 4th Ser. vol. 20, 1905, p. 193.
[2] R. A. Daly, Proc. Am. Ac. of Arts and Sci. vol. 45, 1910, p. 219.

Hence, in the quantitative classification, the rock is of the class persalane, order columbare, rang albachase, and subrang albachose.

Internal Relations.—The folding and faulting, to which the sills have been subject, is evidenced by the attitude and the distribution of the sills now exposed in the Purcell range. As they were intruded when the strata were flat, they have suffered all the movements which have taken place in that range, so that now they form anticlines and synclines with all angles of dip from 0 to 90 degrees. The sills often end abruptly against strata which are older or younger than those holding the sills, and in some cases the vertical displacement may be several thousands of feet. Columnar jointing, perpendicular to the upper and lower contact, is especially prominent in the thick sills and is well shown in the escarpment to the north of St. Mary lake. The cross-section of the columns is an acute angled quadrilateral.

The most striking phenomenon in the internal structure of the sills is a stratification of the material according to density. The stratification is of two kinds. In the example, studied with Daly on the International Boundary line, the distribution of material was: an upper gabbro zone 26 feet thick passing gradually downwards into a granitic phase 80 feet thick, which in turn gradually passed into a lower gabbro layer 30 feet thick. This type of differentiation is similar to that at Shonkinsag described by Pirsson.[1]

The other type was studied in the St. Mary sills and consists of an upper granitic layer 70 feet thick passing gradually downwards into a gabbro zone also 70 feet thick. All gradations exist between the granite (micropegmatite) and the gabbro, and an arbitrarily chosen type, representing the intermediate rock between the two extremes, is called the quartz-diorite. The thick basic sills also show a rough stratification in the centre of their masses, where long schlieren of acid material are elongated parallel to the contacts of the sills. The gabbro at the contacts of these basic sills is usually fine-grained, while in the centre it is coarse-grained and pegmatitic. A discussion of the

[1] Pirsson, U. S. G. S. Bull. 237, p. 43.

origin and relations of these rock types will be given below under "Rock Genesis."

The exomorphic contact effect of the sills is very small, especially where the contact rock is a fine-grained argillaceous quartzite. In one case the quartzite for an inch from the upper contact is thoroughly vitrified and charged with small needles of hornblende. Outside this narrow contact zone, the sediments are normal in character. A study of the cont. under the microscope revealed three distinct but gradational bands. The normal quartzite consists of interlocking grains of quartz, 0·5 mm. in diameter. This zone passes gradually into the vitreous variety which shows no great signs of metamorphism, except a thorough cementing of the quartz grains, whose contact with each other is very indistinct and whose individuality was only detected by their optical orientation. Hornblende with greenish-blue pleochroism parallel to c and identical with the hornblende in the gabbro, is present in this vitrified band. This zone with a gradual increase in orthoclase and plagioclase passes into micropegmatite in which the quartz holds the feldspar, the latter being filled with dust-like inclusions of sericite. Hornblende, similar to that described above, and biotite are sparingly present in this micropegmatite zone. As the hornblende and plagioclase become greater in amount, with a concomitant decrease in the quartz and orthoclase, the micropegmatite variety passes into the hornblende-gabbro proper. All three zones were seen in one slide taken from a specimen at the contact.

The exomorphic contact action, exhibited at the lower contact, was studied in two localities. In the Pyramid basin, a sill 150 feet thick is intruded into grey weathering quartzites and argillaceous quartzites. The latter, at the lower contact of the sill, is impregnated at a distance of one foot with hornblende, similar to that found in the sill itself. This hornblende is shredded in appearance and sometimes occurs in radiating groups embedded in a fine ground-mass of quartz grains. Muscovite in small, needle-shaped crystals is present in moderate amounts. A fine-grained variety of the quartzite occurred at a distance of 6 inches from the lower contact, and its metamorphism consisted only in the development of a few crystals of biotite. Under the microscope the grains of quartz, whose average size is 0·08 mm., shows a pitted structure as if acted upon by a solvent. Biotite is present in large amount. This difference in degree and kind of metamorphism between these two laminæ suggests that the texture as well as the composition had some influence on the contact metamorphism induced by the sill on the enclosing sediments. In the St. Mary sills, where a sill 140 feet in thickness was intruded into fine-grained argillaceous quartzites, the contact effects are very slight and extend for a distance of 3 feet from the upper contact. The only result. visible in the hand specimen, is a slight baking of the sediments. Under the microscope, this baking is seen to consist of a slight coalescence of the quartz grains whose average diameter is 0·09 mm. Muscovite, which, in general, is restricted to the contact metamorphosed sediments, is present in rod-like individuals. Biotite, common to all the sediments of the Aldridge formation, occurs in irregular masses 0·49 mm. in diameter.

Summary of the Contact Metamorphism.—The sharp line of demarcation between the sill and the sediments is worthy of notice, for though, as the microscopical examination showed, there is a gradational change from sediments into granophyr, yet this change takes place in a zone with a width only a small fraction of an inch. The very small amount of contact metamorphism induced by the intrusion is perhaps what might be expected, when the intruded rock is a fine-grained quartzite. It consists of a baking of the sediments for a maximum distance of 3 feet from the contact, with the formation of muscovite and the transference of femic constituents from the gabbro into the quartzites for the distance of 1 foot.

THE STRUCTURE OF SILLS.

The Moyie Sills.—One of the finest, as well as one of the most easily accessible examples of differentiated and undifferentiated sills, is exposed on the western slope of the mountain west of Kingsgate, B.C., on the International Boundary line. This section was described in some detail by Daly[1].

[1] R. A. Daly. Summary Report, Geol. Surv. Can., 1904, p. 98A.
R. A. Daly, Amer. Jour. Sci., 4th Series, vol. 20, 1905, p. 185.
R. A. Daly, Festschrift zum Siebzigsten Geburtstage von Harry Rosenbusch, 1906, p. 203.

At the time of his work in this area, through the paucity of rock outcrops, he failed to note two bands of sediment in his Moyie sill. So, instead of one sill as Daly described, there are three sills. This new field fact, which was found by the writer in 1910, materially affects the problem of petrogenesis. In 1911, the writer guided Daly to the several important exposures and the section was again carefully studied with the results given below. The exposures are not very satisfactory and other bands of sediment may be present in sill D.

The mountain to the west of Kingsgate consists of argillaceous quartzites, belonging to the oldest known member of the Purcell series, dipping 60 degrees to the east and intruded by sills of igneous material. Sections of these sills are given in Figs. 2 and 3.

Tabular section of the Moyie Sills. (Measured at a locality 1½ miles distant from section illustrated in Figs. 2 and 3.)

Sills, thicknesses in feet.	Rock zones, thicknesses in feet.	Character of rock.
	100+	Sediments.
A, 315±	50+ 100± 165±	Gabbro. Granite. Gabbro.
	100	Sediments.
B, 525	310 215	Granite. Gabbro.
	45	Sediments.
C, 30	30	Gabbro
	250	Sediments.
D, 438+	138 300+	Granite. Gabbro.

Sill "A," the highest in the series, consists of an upper gabbro phase of specific gravity, 2·96, having a thickness of 26 feet and passing gradually downwards into a granite (micropegmatite) interior whose specific gravity is 2·76. This finally gives way to a lower gabbro zone of specific gravity 2·97, about 29 feet thick. Underlying this sill occur 80 feet of argillaceous quartzites. Sill "B," of specific gravity 2·93, 30 feet in thickness, now occurs and in turn is underlain by 670 feet of quartzitic sediments. At this point sill "C" makes its appearance and has a total thickness of 910 feet, containing an upper granitic (micropegmatitic) zone, 310 feet thick, of specific gravity, 2·74, passing gradually downwards into hornblende gabbro approximately 590 feet in thickness. Intervening between sill "C"

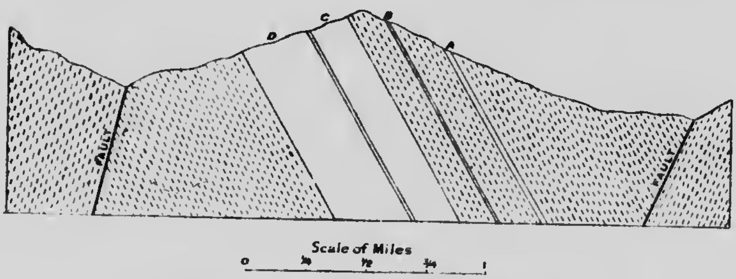

FIG. 2. Natural section of Moyie Sills. See also Figure 3.

and sill "D" occurs 75 feet of argillaceous quartzites. Sill "D" is 1500 feet thick, and was poorly exposed. It consists of hornblende gabbro of specific gravity, 2·99, no large mass of biotite granite (micropegmatite) being present in this sill. In the section at the Boundary line no further outcrops of gabbro were seen, but Daly, from his study of the region to the south, postulates another sill, "E", as the lowest sill in the Moyie group of sills. A summary description of the rock types mentioned above has been given under "lithological characters" and will not be repeated here. It will be noted in comparing Daly's columnar section of the Moyie sills with the one accompanying this paper, that there is a difference in the respective thicknesses of sills "C" and "D." Daly estimated his thickness in the field, while

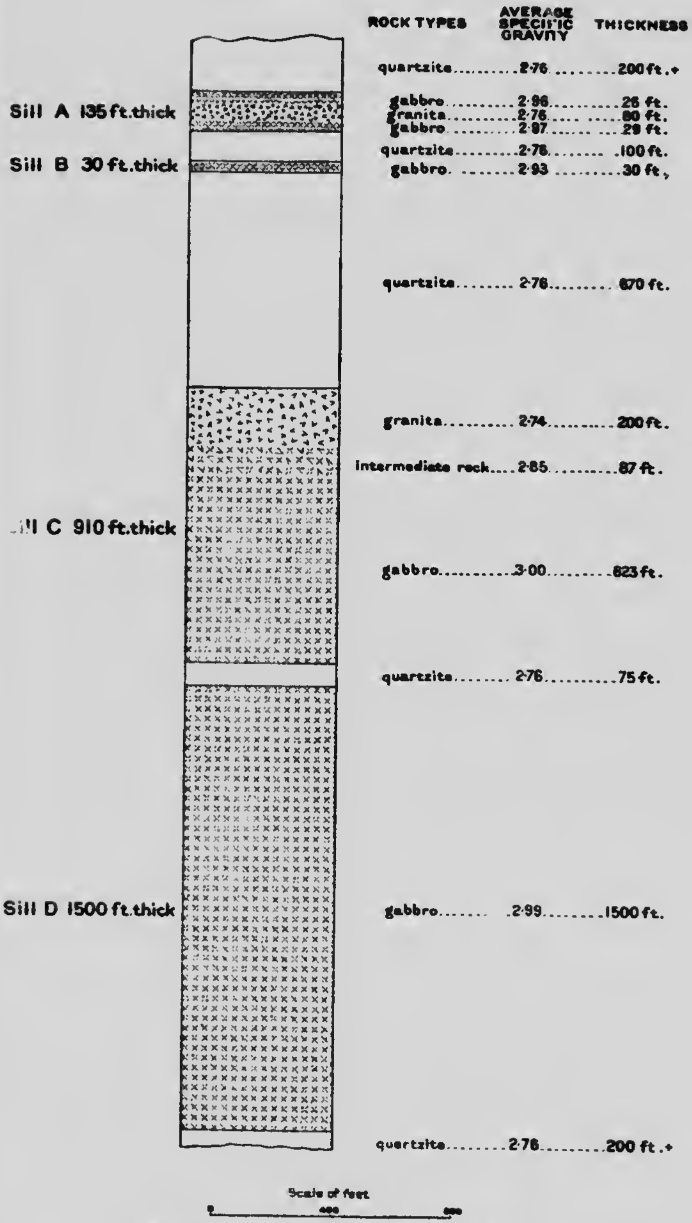

Fig. 3. Columnar section of the Moyie Sills.

the writer obtained his results by calculation, taking into consideration the slope of the hill as well as the dip and strike of the sills.

The St. Mary Sills.—Intruded into the westerly dipping Aldridge quartzites, which form the mountains rising on both sides of St. Mary lake, is a series of gabbro sills which were studied in some detail. Sill "A" (see Figure 4), which apparently represents the highest one in the series, is 140 feet thick and

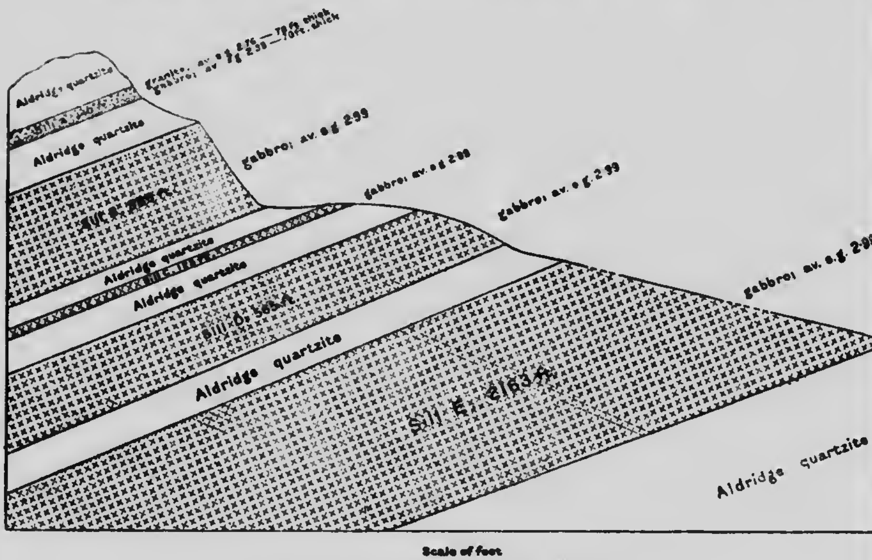

FIG. 4. Natural section of the St. Mary Sills.

contains an upper granite (micropegmatite) zone of specific gravity, 2·76, 70 feet in thickness, passing gradually downwards into a gabbro of specific gravity 3·01, also 70 feet thick. Separating sill "A" from sill "B" occurs 400 feet of argillaceous quartzites. Sill "B," which is 985 feet thick, is composed almost entirely of hornblende gabbro. It is in this sill the hypersthene gabbro occurs which shows the transformation of augite and hypersthene into hornblende. No granitic (micropegmatitic) zone is present in this sill although here and there in the centre of the sill schlieren of acid material were observed. Sill "B" is separated from the underlying sill "C" by 200 feet of argillaceous quartzite. Sill "C" is 123 feet thick and consists entirely of hornblende gabbro. The two remaining sills observed in this section were respectively 565 and 2,165 feet in thickness, but as they were not well exposed, several bands of sediment may be contained in each of the two sills. No granite (micropegmatite) was found in these sills.

ROCK GENESIS.

The facts which any theory as to the origin of the granite (micropegmatite) in the Purcell Sills must account for, are as follows:—

(*a*) The majority of the sills are entirely basic and non-stratiform.

(*b*) S[illegible] of the sills are composite.

In connexion with the composite sills, the following facts are noted:—

(1) The presence or the amount of granite (micropegmatite) in these sills bears no relation to the thickness of the sills.

(2) The composite sills are stratified according to density.

The following theories might be advanced to explain the above facts.—

(1) The simple sills may be magmatically distinct from the composite sills.

(*a*) If magmatically distinct, no special explanation is necessary for the "simple" sills. In the case of the "composite" sills any of the alternatives given in "(2)" might hold.

(2) The simple sills and the composite sills are magmatically related.

(*a*) The composite sills were injected along with a simple magma which gave rise to the granite (micropegmatite) because of:—

(1) fusion and recrystallization.
(2) assimilation.
(3) differentiation.

(b) The composite sills represent a simple magma later injected with the acid material coming either:—

(1) directly from an intercrustal reservoir;

(2) or from lower sills in which any of the things listed under 2a may have happened.

It is believed that the simple and composite sills are magmatically related, for, if they belonged to distinct intrusions, one would expect to find some evidence of this in the field. But such has not been found, though the simple and composite sills occur in the same sections and have been examined in many places over a very wide area. Also the gabbro in both types is identical in composition and all gradations occur between the gabbro and the granite (micropegmatite). The rock types are analogous to the extrusive phases—the Purcell Lava—and as both acid and basic lavas occur closely associated, it is evident that they are genetically related. Hence, it is concluded with some degree of certainty that the two varieties of sills are magmatically related.

That such an intrusion of related acid and basic magmas is possible, is supported by the relations existing between the Buttermere and Ennerdale Granophyr of England.[1] In the Buttermere and Ennerdale districts occur intrusions of dolerite and granophyr into slates and volcanics. A point of resemblance between the phenomena exhibited in the two districts arises in connexion with the dolerite which precedes the granophyr in time of intrusion and which contains towards the centre of the mass, numerous pink patches of acid material which strongly resemble the main mass of the intrusive granophyr. Rastall supposes that the pink patches in the dolerite are a *Mixture Rock* and the following extract is quoted from his paper.[2]

"According to this, the basic dolerite was first intruded, and while still hot and partly liquid in the middle, another intrusion of more acid character took place from the same reservoir and penetrated into the still unconsolidated centre of the earlier intrusion producing a hybrid rock intermediate between the granophyr and dolerite."

As already stated, Rastall has strong evidence that the two main intrusions of dolerite and granophyr are magmatically related.

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[1]R. H. Rastall, Q. J. G. S., vol. 62, 1906, p. 253.
[2]Ibid p. 263.

Another explanation of the occurrence of the pink spots in the dolerite might be given. They may represent the results of differentiation subsequent to intrusion by which the dolerite was finally freed from the granophyr and hence would be syngenetic. Many cases of such segregations are known in all parts of the world, and in general, in such cases, no granitic intrusion subsequent to the dolerite is known. In the description of the geology of the Antarctic[1] are noted numerous sills of gabbro intruded into sandstones. The interior of the sills contains patches of micropegmatite and quartz. The contact of the gabbro and the sandstone is fine grained and less acid than the interior of the sill. Here the acid patches are original, for no intrusion of granite subsequent to the gabbro is known. Holland[2] tells of augite diorites in southern India, which contain segregations of micropegmatite, and he considers that this acid material might have been separated from the augite diorite and injected as separate intrusions, similar to the phenomena and relations exhibited at Carrock Fell.[3]

Since from the above discussion, it is seen that the evidence supports the view that the simple and composite sills are magmatically related, the granite (micropegmatite) in the composite sills might be a separate intrusion of granite into simple sills. In this case, the sill would be compound. Under this supposition the second intrusion of granite (micropegmatite), since it occurs in some of the sills only and then always towards the upper margin, would be selective in character, which of itself is somewhat difficult of explanation. But there is also a complete lack of any evidence of cutting and no feeders (dykes) of acid material were observed, though basic dykes, the feeders of the basic sills, were observed. Furthermore, the contact of the gabbro and granite (micropegmatite) is in all cases gradational and the stratiform arrangement of the materials in the sill does not favour this idea.

Therefore, by the process of elimination, it may be concluded that the composite type differentiated in place and that it

[1] National Antarctic Expedition, 1901–1904, vol. 1.
[2] Holland, Q. J. G. S., vol. 51, 1895, p. 125.
[3] A. Harker, Q. J. G. S. vol. 50, 1894, p. 311.
Q. J. G. S. vol 51, 1895, p. 125.

differentiated from a magma closely related in time and origin to the magma of the simple sills.

Granting this, there may be two ways in which the granite may have originated:—

(1) The granite (micropegmatite) may represent the simple fusion of the sediments into which the gabbro was intruded. The presence of a granite (micropegmatite) zone in the interior of some of the sills at once prevents this from being a working hypothesis.

(2) The granite (micropegmatite) may represent the assimilation of blocks of the surrounding sediments which have been stoped off by the intruding gabbro. After the assimilation of the sediments, this syntectic differentiated under the action of gravity giving the mass a stratiform appearance. (Daly's assimilation-differentiation theory).

This hypothesis is based on the idea of an intrusion of a homogeneous gabbroidal magma into sills of various thickness, and as Daly has pointed out[1] demands that "a great absolute amount of thermal energy be credited to a sill in which secondary granite has been formed; that the sill must be thick. Other things being equal, granite formed by mere differentiation should be found in sills of less thickness, though here again the thickness must be considerable. True granite with relations described in this paper has never been found in any intrusive sheet 500 feet or less in thickness. The assimilation-differentiation theory readily interprets the facts as due to the relatively enormous amount of heat required for the generation of the granite-granophyr zone, namely, the amount of heat characteristic of thick intrusive sheets."

Field work by the writer subsequent to the publication of the article containing the above extract, revealed the presence of sills 140 feet thick which contained 70 feet of granite (micropegmatite) at the upper contact. Applying the hypothesis propounded by Daly, it is necessary to suppose, in such a case, that a sheet of gabbro with a thickness of about 70 feet rifted off and absorbed an equal thickness of quartzose sediments; this credits the gabbro body with an amount of thermal energy

[1] R. A. Daly, Amer. Jour. Sci., vol. 20, 1906, p. 214.

so excessive as to be almost improbable, especially when considered in the light of countless observations all tending to show the low thermal energy of sheet-like bodies of basic rocks. Apparently Daly's argument also fails in another way, since in East Kootenay it has been found, as illustrated by many cases, that the thickness of the granite (micropegmatite) in any sill bears no relation to the thickness of the sill itself, which would be absolutely necessary under the assimilation-differentiation hypothesis.

The strong emphasis placed by Daly on the chemical similarity between the granite (micropegmatite) and the enclosing quartzites (as shown by the following analyses), loses much of its force when critically examined.

	1.	2.
SiO_2	76·90	72·05
TiO_2	0·35	0·63
Al_2O_3	11·25	11·88
Fe_2O_3	0·69	0·83
FeO	3·04	4·87
MnO	0·02	0·12
MgO	1·01	0·85
CaO	0·88	2·10
SrO	....	....
Na_2O	3·28	2·20
K_2O	1·36	2·66
H_2O-	0·20	0·10
H_2O+	1·20	1·21
CO_2	tr.	0·37
P_2O_5	0·15	0·09
	100·33	99·96
S.G.	2·680	2·790

1. Represents the analysis of a type specimen of Kitchener (Aldridge) quartzite; 2 is the average analysis of acid zone, Moyie sill.

The rocks into which the sills are intruded are not all quartzites as might be concluded from Daly's description. Half of the series are very slaty and argillitic, analyses of which are not available, and, the rocks which he holds to have been assimilated, may just as well be conceived to be dominately argillitic as quartzitic. The rocks through which the magma passed before reaching its final resting place also must have affected the uprising magma. Examples of such action are described by Harvie.[1] Inclusions in dykes around Mount Royal at Montreal, show that these inclusions have risen at least 2,050 feet from their point of origin and perhaps a greater distance, for in the same dyke other zenoliths have sunk 2,000 feet from their point of origin. These zenoliths, which are great in number, often show evidences of solution by the enclosing igneous material. In the East Kootenay district one dyke was found in connexion with the Purcell Sills which was crowded with small fragments of crystalline limestone which is not represented in the Aldridge formation as far as known. Thus, the evidence of some contamination of the magma by material through which it passed is strong and if the acid material of the composite sills is indeed of extraneous origin, it would be perhaps more justifiable to assume that it was absorbed by the uprising magma before it entered the Purcell Series.

Another field fact of prime importance is that in those sills whose upper contacts were so exposed as to be traceable for long distances, the contact between the sediments and the sill was remarkably uniform and not irregular as might be expected if stoping had been very active.

A modification of this theory was discussed with Dr. R. A. Daly. It is as follows: assimilation of the blocks of sediment took place in the lower larger sills; the syntectics thus formed were drawn off in some manner and injected into a higher horizon where they differentiated under the action of gravity.

The following field facts do not support this hypothesis:—

(1) Many sections containing thick sills contain no granite (micropegmatite) in any of the sills.

(2) The upper contacts of the larger sills in sections which do contain granite (micropegmatite), where examined, show a smooth upper contact. If stoping took place to such a degree as to form large quantities of granite (micropegmatite), the upper contact would be irregular showing the effects of stoped off blocks.

[1]Harvie, R., Trans. Roy. Soc. of Can. 3rd series, vol. 3, 1909-10, p. 277.

(3) No shatter contacts were seen in any of the sills.

(4) The heat consumed in such a series of reactions, which are necessary under this hypothesis, would be very great and it is doubtful if the magma contained such a quantity of heat.

The remaining hypothesis is, that the granite (micropegmatite) in the composite sills was formed by differentiation in place.

This hypothesis is the one favoured by the author. In this case, there was an intrusion of a magma whose composition, in the case of any single sill, was the average of the whole contents of the sill in question. These sills have in some cases basic upper and lower contacts. The homogeneous magma which filled the composite sills would cool first along the contacts and hence the upper and lower contacts of the sill would be basic. Differentiation, acting on the remaining fluid portion, would cause the heavier constituents under the influence of gravity to gather in the lower part of the chamber concomitantly with the collection of the acid differentiate towards the upper part of the chamber. A similar distribution of acid and basic material in a laccolith has been described by Pirsson. A vertical section across the Shonkinsag laccolith[1] is as follows:—

Rock type.	Thickness in feet. (centre)	Thickness in feet. (outer wall)
Leucite basalt porphyry	5	10-15
Dense shonkinite	5	
Shonkinite	5-6	
Transition rock	3	
Syenite	25-30	
Transition rock	15	
Shonkinite	60-70	75
Leucite basalt porphyry	15	15
	140	100

The combined effect of convection and crystallization is used to explain the above occurrence of rock types in the laccolith. The same result could be obtained by differentiation under the

[1]Pirsson, L. V., U. S. G. S. Bull 37.

action of gravity. This latter explanation is more applicable to differentiation in sills on account of their lateral extent. In the case of the Shonkinsag laccolith, there is direct evidence that the syenitic facies is not due to assimilation in place of the surrounding Cretaceous sediments, for the composition of the laccolith is dominately alkaline, while that of the enclosing sediments is salic. Another example called the Lugar sill is described by Tyrrell.[1] This intrusive mass 140 feet thick, enclosed by sandstones and shales, differentiated according to density into the following zones:—

	Rock type.	S.G.
Upper part 35 feet thick..	Teschenite, coarse, plus analcite	2·64
	" normal	2·70
	" camptonitic	2·98
	Monchiquitic	2·99
Central part 51·5 feet thick	Picrite	3·01
Lower part 17·5 feet thick	Teschenite, camptonitic	2·81
	" normal	2·71

Tyrrell excludes assimilation in the formation of the above magma. This seems perfectly logical from the low percentage of silica and the presence of analcite in the resulting rocks.

In the Purcell sills, it is probable that assimilation of some of the enclosing quartzites took place, but assimilation of this kind is held to be a minor factor in the formation of the granite (micropegmatite) in the composite sills. Occasionally blocks of quartzites were found in the sills. When these xenoliths occur in the granite, they are charged with needles of hornblende which greatly resemble the hornblende of the gabbro. No contact aureole of micropegmatite was found around these blocks. In the gabbro the xenoliths only suffered a baking, he contact between the quartzite and the gabbro being sharp

[1]Tyrrell, G. W., Trans. Geol. Soc. of Glasgow, vol. 13, 1909, p. 298.

and no evidence of assimilation is present. The blocks may have been torn from the floor of the sill and risen to their present position. Such a phenomenon has been described by Campbell and Stenhouse.[1] Here a block of sandstone has been disrupted from the floor of a sill of teschenite and risen to the top of the sill and left trailers in its path. Thus underhand, as well as overhead, stoping is possible in a tabular intrusive body.

Bailey,[2] in his paper on the "Eruptive and Sedimentary Rocks of Pigeon Point, Minnesota," emphasizes assimilation in the following words:—

"More direct evidence of the action of the gabbro on the quartsite is found in the inclusion of the latter in the former. It will be remembered that the alteration of the fragments in the gabbro is in general similar to that of quartzitic fragments in the red rock. In the latter in certain cases the quartz fragments are surrounded by a rim of red material, which, under the microscope, presents all the appearances of the red rock, except in the presence of green flecks of chlorite. Quartzitic fragments in the gabbro are bordered by a rim exactly like the material in the red rock. At a point on the southern shore, in the eastern portion of the peninsula about ½ mile from the end of the point the rock cementing quartzite and slate fragments is similar to one of the rocks intermediate between the gabbro and the red rock, and whose formation is supposed to be due to the interfusion of these rocks. The origin of the cementing material of this breccia may be the direct solution of fragments in the gabbro. One of the fragments embedded in the intermediate rock is a large rhombohedral block of pink quartzite about 7 feet long and 4 feet wide. Surrounding this, between it and the including rock, is a bright border 2½ or 3 inches wide. The red feldspathic material has a granophyric structure in which fan-like groups of feldspar and quartz extend perpendicularly from the bounding planes of the inclusion. Since the rim is probably the result of the fusion of portions of the quartsite by the surrounding rock, and its structure and composition are identical with those of the red rock, it may fairly be concluded, in the absence of any evidence to the contrary that the red rock itself has been produced by the fusion of the quartsites by the gabbro—that it is a product of the action of the gabbro upon the slates and quartzites, melting the latter and thus producing a magma from which the red rock solidified."

In Bailey's concluding chapter on the origin of the red rock, he states that no positive determination can be made whether the gabbro is the cause of the red rock or the red rock is an original eruptive. Another solution to this problem might be given. If the intrusion is in the form of a sill, it may have been intruded as a magma of intermediate composition which later differentiated into gabbro and red rock. As the red rock contained most of the mineralizers, contact metamorphism would be greater in connexion with this phase than with the other and some assimilation of the enclosing quartzites would take place. This view is supported by the occurrence of heavy contact metamorphism only where the red rock has collected

[1]Campbell and Stenhouse, Trans. of Edin. Geol. Soc., vol. 9, 1908, p. 121.
[2]Bailey, W. S., U. S. G. S., Bull. 109, 1893.

in the irregularities of the sill roof. Where the quartzites are in contact with the gabbro, very little metamorphism has taken place.[1] This explanation also accounts for the absorption of the quartzites by the red rock. The red rims around the quartzites in the gabbro may be red rock which has frozen to the quartzite. The blocks with the red rim then sank into the gabbro zone and were caught when the sill solidified.

The composite sills, as described above, sometimes have a basic upper contact. This basic layer has a specific gravity of 2·966 and hence cannot represent the quickly chilled original magma, for in a sill which is half granite (micropegmatite), the specific gravity of the original magma after solidification and cooling would be 2·80. Hence there has been some differentiation of the basic elements to the cooler part of the magmatic chamber followed by differentiation under the action of gravity. A similar phenomenon of differentiation towards the cooler parts of a magmatic chamber has been described by Lawson.[2] In this case, the intrusive mass is a dyke 150 feet wide with the following variations in chemical composition.

	I	II
SiO_2	47·83	57·50
Fe_2O_3 FeO	4·57	5·07
Al_2O_3	30·28	23·44
CaO	6·72	[illegible]
MgO	4·32	[illegible]
K_2O	trace.	0·45
Na_2O	1·30	2·01
P_2O_5	2·19	2·02
Loss on ignition	2·05	2·25
S.G.	3·028	2·856

I. At the contact of the dyke wall.
II. At 75 feet from the contact, the middle of the dyke.

These two extreme types grade into each other and are considered as differentiates from an original homogeneous magma, differentiation being due to the difference in temperature at the

[1] Bailey, W. S., U. S. G. S., Bull., 109, p. 105.
[2] Lawson, A. C., Am. Geol., vol. 7, 1891, p. 153.

periphery and the centre of the dyke at the time of cooling and solidification. Harker[1] describes the basification of the Carrock Fell to the difference of temperature between the borders and the centre of the mass during solidification. Other interesting examples of this phenomenon are described by Pirsson.[2]

The absence of the basic upper contact zone in some of the Purcell sills is probably due to the high temperature of the intruding magma. In such cases, the initial temperature was so high that before it sank to a degree at which the basic constituents would tend to segregate towards the margin, an almost perfect separation of the granite (micropegmatite) took place. In this manner, no basic upper contact would be expected. The absence of this special layer also proves that differentiation according to gravity has played the leading role in the separation of the acid and basic material, and not differences in temperature between the contact and the interior. If such were the case, a symmetrical igneous body would result.

SUMMARY.

The Purcell sills represent intrusions from a single intercrustal reservoir of a series of magmas—acid magmas—which gave rise to composite sills whose rock types vary in the same sill, from a granite (micropegmatite) to a gabbro; and basic magmas which gave rise to simple sills of gabbro.

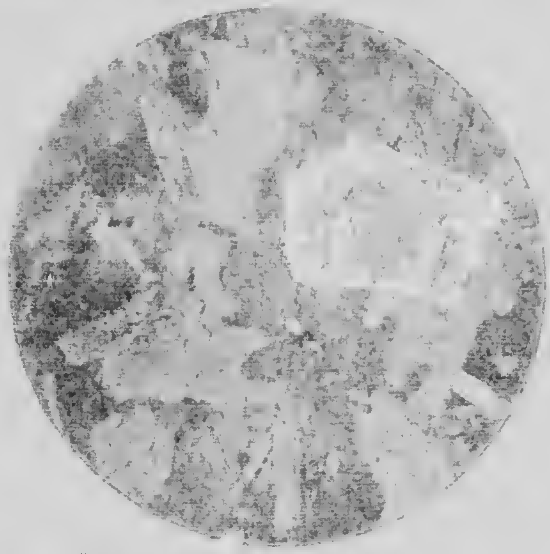
The reservoir may be assumed to have been stratified according to density, having a relatively acid portion collected in the irregularities and projections of the roof and grading downwards into more basic materials.

Crustal movements would furnish fissures which would tap this reservoir at various levels. In this way a separation of the acid and basic materials of the reservoir would occur, so that the acid and basic materials would rise through separate fissures and spread out between the strata as sills. Some exotic material was gathered up from the walls of the fissures through which they

[1] Harker, A., Q. J. G. S., vol. 50, 1894, p. 311; vol. 51, 1895, p. 125.
[2] Pirsson, L. V., 20th Ann. Rep., U. S. G. S., pt. 3, 1900, p. 563.
Pirsson, L. V., U. S. G. S. Bull. 237.
Weed and Pirsson, Amer. Jour. Sci., 4th ser., vol. 12, 1901, P. I.

passed, and in part assimilated by the rising magmas. The magmas would also probably assimilate some of the enclosing Purcell sediments but not enough to materially affect their composition.

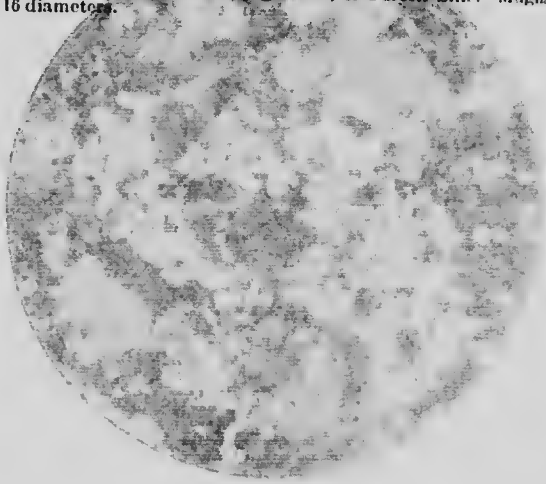
The simple sills solidified in the usual manner of such intrusives, while the acid material differentiated under the influence of gravity giving rise to composite sills.



Explanation of Plate I.

Fig. 1 Photomicrograph of hypersthene gabbro of Purcell Sills. Magnification: 16 diameters.

" 2. Photomicrograph of granite (micropegmatite) of Purcell Sills. Magnafication: 16 diameters.



passed, and in part assimilated by the rising magmas. The magmas would also probably assimilate some of the enclosing Purcell sediments but not enough to materially affect their composition.

The simple sills solidified in the [illegible] manner of such intrusives while the acid material [illegible] under the influence of gravity giving rise to [illegible].

FIG. 1.

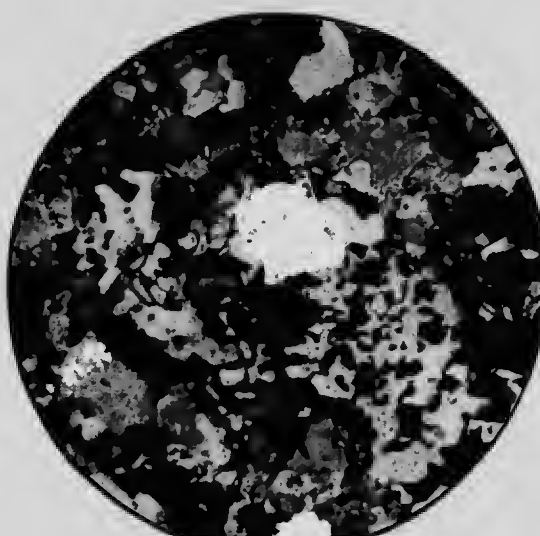


FIG. 2.

June 17th, 1914

Canada
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Museum Bulletin No. 2.

GEOLOGICAL SERIES, No. 14

II.—Columnar Structure in Limestone.

By E. M. Kindle.

Columnar structure, though very rare in sedimentary beds, is not altogether unknown in argillaceous sediments.[1] In limestones only one example of this structure has ever come under the writer's notice[2]. This occurs in a bed of Silurian limestone on Temiscouata lake in eastern Quebec. This structure is believed to be here a consequent of special conditions of sedimentation. So much remains to be learned about the factors of sedimentation involved in the formation of the various types of limestone that any deductions or inferences regarding them which may be made from physical features merit consideration as well as the structures themselves.

The pronounced columnar structure of the limestone shown in Plate II is comparable with that found in basalt, but the columns are perhaps less regular in the number and width of the sides. The columns vary rather widely in the number of faces shown, five to seven being a common number. One side of a column may have a width two or three times that of an adjacent side. The faces or sides while roughly plane show more or less irregularity of surface. The columnar limestone is a dark blue, hard, fine textured rock. It leaves a fine argillaceous and siliceous residue when dissolved in acid. The rock shows on a weathered surface

[1]Salisbury, R. D., Columnar structure in subaqueous clay, Science, new ser., vol. 5, 1885, p. 287.

[2]The structure called stylolites which is sometimes referred to as columnar structure (Geology of Canada, 1863, pp. 631-633) is unrelated to that under consideration here.

numerous, thin, paper-like lines of sedimentation—thin laminæ of argillaceous limestone alternating with less argillaceous bands; the limestone splits up freely on weathering into columns at right angles to the bedding, but it displays very little tendency to split along the bedding planes. A large number of these detached columns of limestone, with a length of from 10 inches to 24 inches, are scattered along the front of the ledge. A very thin sheet of dark argillaceous and carbonaceous matter, usually about one-fourth of an inch thick, separates the faces of adjacent columns. An approximate estimate by Mr. R. A. A. Johnston places the carbon in this material at about 3 per cent. This thin, black film is essentially free from lime, affording no reaction with hydrochloric acid, although the faces of the columns adjacent to it effervesce vigorously with acid. The laminæ of the limestone do not pass through this thin wall but stop abruptly on either side of it. The presence of this dark argillaceous partition between the faces of adjacent columns is a feature which distinguishes this structure from that characterizing the columnar structure of basalt. It distinguishes it also from joint structure, thus indicating an origin independent of the agencies which produce either joint or basaltic columnar structure. The bed of columnar limestone occurs in a region where orogenic agencies have acted vigorously. The horizontal stresses developed by these agencies have resulted locally in shortening one diameter of the columns and in changing the original vertical relations of these to the bedding by several degrees. The effects of deformation are indicated by the inclination and slight flattening of the columns shown in Plate II. In most specimens observed the columns are vertical to the bedding.

The structure described and illustrated by Plate II and Plate III, fig. 1, occurs in the lower two-thirds of a bed of limestone at the base of Mount Wissick on the shore of Temiscouata lake opposite Cabano, Quebec. The stratigraphic relations of this limestone are indicated in the following section which represents only a small portion of the Mount Wissick section.

Mount Wissick section.

	Feet.
E. Argillaceous limestone with corals and other fossils..	35
D. Bluish grey sandstone with fossils................	50±
C. Finely laminated blue limestone with columnar structure in lower two-thirds[1].....................	40±
B. Red and green shale...........................	18+
A. Green, shaly, fine textured sandstone probably in part of volcanic origin. Saucer-structure (mud-cracks) well developed..........................	50±

The beds of columnar limestone occur, as will be seen from this section, in a series in which sandstone and shale deposition alternated with limestone deposition, each in turn prevailing long enough to build 20 to 50 feet of beds. The three lower divisions of these beds, including the columnar limestone, are very sparingly fossiliferous where not entirely barren. The lowest bed exhibits a striking example of a variety of sun-cracked beds in which the margins of the irregularly rounded plates have warped upward, giving them a saucer like appearance. Littoral conditions of deposition are thus indicated for the sandy shale 20 feet below the limestone under consideration.

The limestone of bed "C" is a continuation or recurrence of the littoral conditions, indicated by the sandy shale, in the opinion of the writer. If viewed only from the surface of the strata, the columnar structure of the limestone is not evident, and the mud-crack origin of the polygonal figures appears clear. Columnar structure, however, is not ordinarily associated with mud-cracks and the reason for the association of the two which this interpretation indicates requires consideration. The factors believed to be responsible for this association of columnar structure and mud-cracks can be advantageously considered in the light of some observations made by the writer on mud-cracks on the shores of the Bay of Fundy.

[1]The columnar structure of this bed was first noted by Logan in 1863 (Geol. of Can. p. 421). It was again mentioned by Bailey and McInnes in the detailed section of Mount Wissick, published in 1889 (Geol. Surv. of Can., new ser., vol. III, pt. II, p. 31M.

At Black Rock, N.S., where these observations were made, the mud-cracks when made in the lower parts of the mud flats are obliterated by each tide owing to the heavy deposit of sediment left. In a higher zone which is under water for a shorter period, the mud-cracks are only partially masked by the sediment left by a falling tide. In a third and highest zone, mud-cracks may persist through several tides because of the shorter period of submergence and lighter deposit of sediment. The accompanying photograph of mud-cracks (Plate III, fig. 2) taken at Black Rock, is introduced here to show that mud-cracks formed on the higher portions of the littoral zone are not evanescent features requiring very special conditions for preservation as they are often assumed to be. The mud-cracks here shown lie between 3 and 8 feet below high tide and had been covered when photographed, by at least two tides. They had also been exposed to a heavy shower of rain immediately before the photograph was taken, and are cut across by resulting rills as shown in the photograph. Yet notwithstanding the deposit of sediment from two tides, the action of a strong current during ebb and flow, and the beating of rain, they remain distinctly outlined instead of being obliterated as might have been expected. A few days of cloudy weather would, of course, result in their obliteration by fresh sediment. There is no evident reason, however, why these mud-cracks which occupy the outer zone of tidal action might not, if they occurred in an arid climate, continue indefinitely to receive their daily deposits of sediment from the rising tide. So long as the mud-cracks were not obliterated by new sediment the recurrent daily shrinkage resulting from the exposure to the sun would be more likely to keep open the old cracks than to open new ones. The semi-permanent character which is assumed for the mud-cracks in an arid climate would produce the polygonal cracking of the beds which would eventually result in columnar structure being impressed upon each tidal deposit as it was laid down.

It is believed that the columnar structure of the limestone at Mount Wissick originated in this way. The shell of sediment surrounding each column strongly supports the inference that the columns are the result of mud-cracks which extended to a considerable depth and which were filled by sediment having a somewhat more argillaceous composition than the limy beds cut by the mud-cracks. The failure of the laminæ to cross this partitional material clearly indicates for it an origin later than the adjacent rock.

Explanation of Plate II.

Block of limestone showing columnar structure with two of the columns detached from the larger mass. The inclination of the columns is due to deformation and is not generally associated with the structure.

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Explanation of Plate III.

Fig. 1. Block of columnar limestone adjacent to the parent ledge. The columnar structure extends down about 20 inches in this block. Photograph by Olaf O. Nylander.

Fig. 2. Mud-cracks at Black Rock, N.S., which have been covered by two or more tides. Photograph by L. D. Burling.

Explanation of Plate III.

Fig. 1. Block of columnar limestone adjacent to the parent ledge. The columnar [illegible]ture extends down about 20 inches in this block. Photograph by [illegible]C. Nylander.

Fig. 2 [illegible]racks at Black Rock, N.S., which have been covered by two or more [illegible]s. Photograph by L. D. Burling.

FIG. 1.

FIG. 2.

June 19th, 1914.

Canada
Geological Survey
Museum Bulletin No. 2.

GEOLOGICAL SERIES, No. 15

III.—Supposed Evidences of Subsidence of the Coast of New Brunswick within Modern Time.

BY J. W. GOLDTHWAIT.

INTRODUCTION.

While engaged in 1910 in a study of the records of late Pleistocene marine submergence in Quebec and New Brunswick, I was impressed by the need for giving greater attention to the more recent of the post-Glacial movements which this region, in common with New England, has suffered. Accordingly, in July and August, 1911, during the continuance of work on the several problems of post-Glacial changes of level in southeastern Quebec and New Brunswick, I visited a number of localities where so-called evidences of modern subsidence are to be seen. Before entering upon this phase of the work, a conference was held with Professor Douglas Wilson Johnson of Harvard University, under whom an exhaustive investigation of the question of modern stability of the coasts on both sides of the North Atlantic was already in progress. A co-operative plan was arranged, between the Geological Survey, Canada, and the Shaler Memorial Investigation, which will find full expression in a later publication. The present paper merely outlines the conclusions reached by the writer during the field season of 1911.

From Professor Johnson have come many helpful suggestions, which it is a pleasure to acknowledge. Thanks are due also to Professor W. F. Ganong, of Smith College, whose published

writings on the botany, physiography, cartography, and history of New Brunswick constitute a most valuable guide in that Province for the naturalist, the antiquarian, and the traveller; and who kindly suggested to me, in personal correspondence, several localities particularly worth visiting, in my search for evidences of modern coastal subsidence.

MODERN VERSUS LATE PLEISTOCENE MOVEMENTS.

The elevated beaches, deltas, and sea-floor deposits which are found along the coast of the Maritime Provinces bear witness to a differential emergence of this region from the sea, in post-Glacial time. Judging from the strength of certain strands, especially along the north coast of Gaspe peninsula, this emergence was not steady, but consisted of two or three periods of uplift, separated by periods of stability or of subsidence. In the lower Saint Lawrence, one shore-line, in particular, which forms a wide shelf only twenty feet above the modern sea-level, and a great sea-cliff, records an interval of stability or of subsidence which must have lasted for a considerable length of time, and was followed by an uplift of approximately twenty feet.[1] Recent observations around the coast of Gaspe peninsula point to the probability that this recent upward movement of the lower Saint Lawrence region was attended by a downward movement of the more southerly coast of Gaspe and New Brunswick. It is not known whether the upward movement is still in progress along the lower Saint Lawrence, or not. From New Brunswick, however, a number of phenomena have been adduced as evidence that the more southerly coast is still subsiding. That there has been coastal subsidence, locally, if not over a wide region, since the last Glacial epoch, and presumably since the great Champlain emergence, is shown by the famous submerged forest at Fort Lawrence, Nova Scotia. The supposed evidences of a modern continuance of the subsidence, however, are open to question. On this account, it is important to discriminate

[1] J. W. Goldthwait: The twenty-foot terrace and sea-cliff of the Lower Saint Lawrence, Amer. Journ. Sci., vol. XXXII, 1911, pp. 291-317.

at the outset between modern movements and those which, so far as can be seen, may have been completed some time ago. To avoid any misunderstanding that might arise from the use of the term "recent"[1] for the period covered approximately by the twenty centuries of the Christian era, the term "modern" will here be used.

Among the supposed evidences of modern subsidence of the coast in New Brunswick, those to which attention is here invited are:—

(1) A rapid recession of the coastline now in progress;

(2) The presence of drowned valleys;

(3) The presence of barrier beaches;

(4) Recurved hooks, dipping beneath lagoons;

(5) Trees dying because of an invasion by high tides;

(6) Peat bogs whose bottoms lie below high tide mark;

(7) Old beaches on prograding shores, whose crests are lower than the crests of more modern beaches outside of them.

Such a varied list of evidences would seem to constitute a strong argument for the commonly accepted view that the New Brunswick coast is now sinking. An examination of the several lines of evidence, however, seems to show that convincing proof of modern subsidence here, is yet to be discovered; while, on the other hand, as some writers have maintained, there are some indications that the coast for several centuries has been nearly, if not perfectly stable.

SUPPOSED EVIDENCES OF SUBSIDENCE.

Recession of the Coastline.—As all who live on exposed portions of the New Brunswick coast are aware, and as Professor Ganong has pointed out in several of his physiographic and historical papers, the coast is being cut back at a rapid rate. Among the hundreds of illustrations which might be given, are the sites of the old French establishments at Fort Nipisiguit, Fort Moncton, and Little Shippigan, which have been more or less completely

[1]Which, according to the best usage, is synonymous with the "human" or "post-Glacial" period.

washed away, during the last two centuries and a half.[1] Lobster factories near Miscou point, Point Escuminac, and other places have been swept away by the recession of the cliffs, and rebuilt, farther inland, over and over again. According to Mr. Kenneth McClellan, lightkeeper at Point Escuminac, the lighthouse originally stood about 500 feet seaward from its present position, and was moved inland about eighty years ago, because of the rapid encroachment of the waves against the low cliffs of sandstone at that point. Since that time, the sea has advanced about 100 yards, and is now threatening to demolish a building where the fog horn is installed, unless the Government takes prompt measures to protect it. There is no doubt that along most of the open coast of New Brunswick, the sea is now advancing upon the land.

It does not follow, however, that because the shore-line is moving inland, the coast is sinking. In a brief note on "Evidences of sinking of the coast of New Brunswick"[2] Professor Ganong explains that the washing of the sea through the gateway of old Fort Moncton, described by Gesner,[3] must be accounted for by a washing away of the coast, rather than by an actual sinking of the ground beneath the sea. Ganong, nevertheless, argues that the rapid cliff recession thus recorded, which measures over 70 yards in a century and a half, is an evidence of subsidence. "This washing away of the upland can only be explained by a marked sinking of the coast, though the amount of the sinking is not thereby determined."[4] Were it not for the fact that this idea of a necessary connexion between cliff recession and coastal subsidence has been widely circulated, it would seem hardly worth while to point out the possibility that all this encroachment can be accounted for by the horizontal cutting of waves against the foot of cliffs, attended, as it is, by the scouring down of the inclined shelf which lies below, and without any downward movement of the coast whatsoever.

[1] W. F. Ganong: Proceedings and Transactions of the Royal Society of Canada, second series, vol. 12, 1906, p. 133, also in his translation of Nicholas Denys' History of Acadia, published by the Champlain Society, 1908, p. 202.

[2] W. F. Ganong: Evidences of the sinking of the coast of New Brunswick. Natural History Society of New Brunswick, Bull., vol. XIX, 1901, pp. 339–340.

[3] Abraham Gesner: On elevations and depressions of the earth in North America. Quarterly Journal of the Geol. Soc. London, vol. 17, 1861, pp. 381–388.

[4] Op. cit., p. 340.

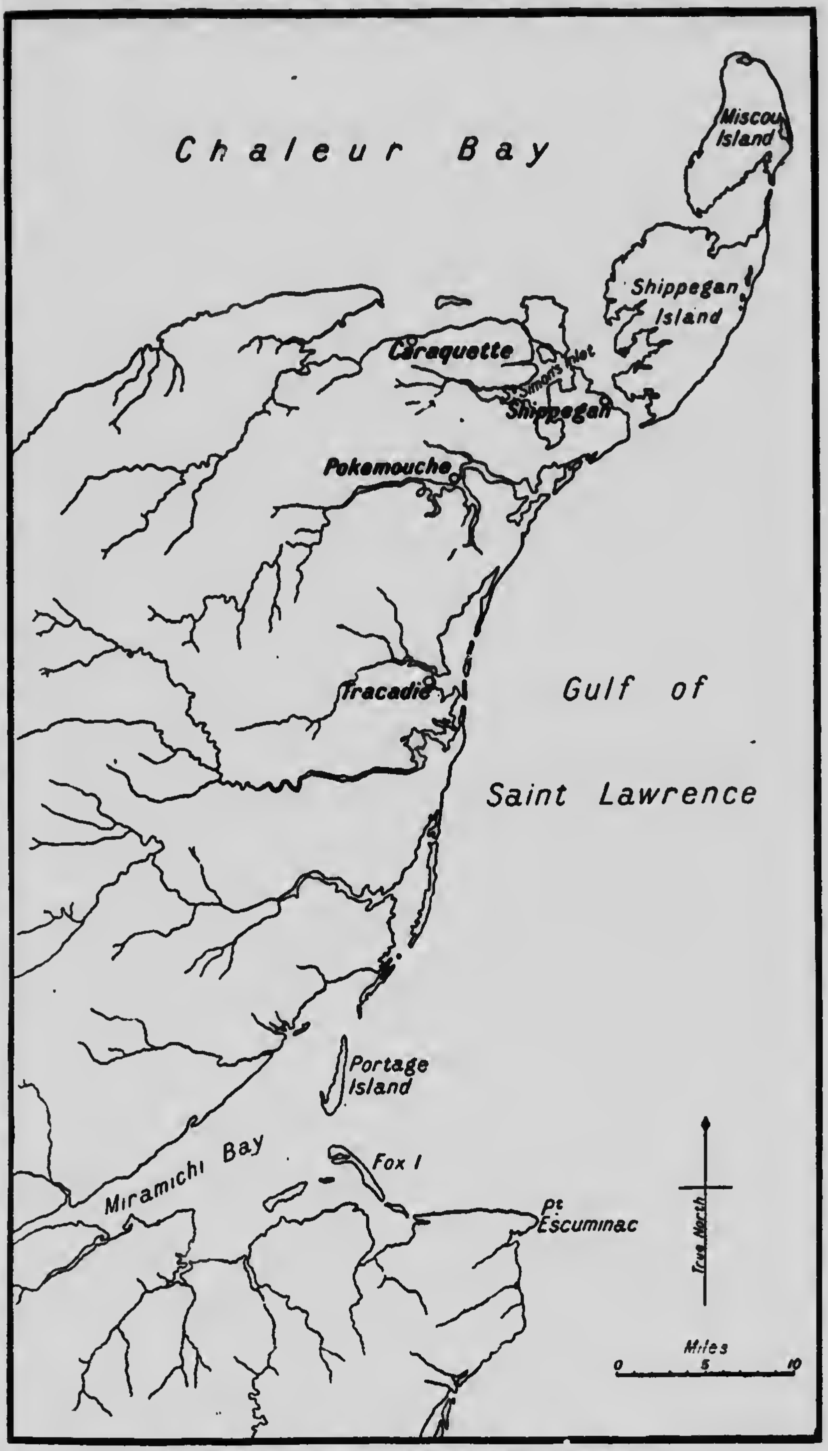

FIG 5. Map of the coast of northeastern New Brunswick.

Cliff recession is indeed accelerated by coastal subsidence; but it takes place on any fully matured shore-line, as a part of the normal sequence of changes, and even on young shore-lines where the initial slope is steep.

That rapid cliff recession does not *necessarily* indicate that subsidence is in progress is seen in the case of the west shore of Lake Michigan, between Milwaukee and Chicago. According to Dr. Edmund Andrews,[1] the average rate of recession of this cliffed coast, prior to 1870, was over five feet a year. In other words, although the cliffs along the west shore of Lake Michigan are higher than those on the northeast coast of New Brunswick, their average rate of retreat is faster. Locally, cliff recession as fast as thirty or forty feet has been observed on the Wisconsin shore.[2] This destruction of cliffs by the waves of Lake Michigan cannot be attributed to a rise in level of the water on the shore; for the surveys cover a long period of years, during which the changes of level of the lakes have been slight, and as often downward as upward.[3]

Drowned Valleys.—In a letter in Science,[4] discussing the question of modern stability of the Atlantic coast, Mr. T. L. Casey points to the well-known estuarine coast of Maryland as "positive evidence of progressive subsidence . . . in recent times." If the drowned valleys of Chesapeake bay can thus be appealed to as evidence that the coast of Maryland is now sinking, the same argument could be applied to the equally typical dendritic estuaries of Gloucester, Cumberland, and Kent counties, in New Brunswick. It seems necessary, therefore, to anticipate the use—or, more accurately, the misuse—of such evidence, by pointing out the fallacy in it. Drowned valleys simply indicate that the land once stood higher than now; they do not indicate the date of the drowning, and do not prove that

[1] Edmund Andrews: The North American Lakes considered as Chronometers of Post-glacial time. Transactions of the Chicago Academy of Sciences, vol. 2, 1870, pp. 1-23.

[2] J. W. Goldthwait: Abandoned shore-lines of eastern Wisconsin. Wisconsin Geological and Natural History Survey, Bull. No. 17, 1907, pp. 58-59.

[3] For similar testimony from the shore of Lake Huron, and information as to the fluctuations in level of the Great Lakes, see A. C. Lane: Geological report on Huron County, Michigan. Geol. Survey of Michigan, vol. 7, 1900, pp. 78-85, and Plate 5.

[4] T. L. Casey: S[illegible]idence of the Atlantic shore-line. Science, vol. 34, 1911, pp. 80-81.

the sinking of the land has continued down to present time. Indeed, in the case of New Brunswick, there is positive evidence, in the raised beaches, fossiliferous clays, and associated deposits, that at the close of the Ice Age this coast was very much farther under the sea than now; and that an elevation of from 100 to 200 feet has taken place, nearly but not quite restoring the region to its former position. Since the elevation of this coast is of later date than the stage of widespread submergence, it is more logical to conclude that the movement now in progress, if any, is upward, rather than downward. In any case, drowned valleys do not necessarily show what is the nature of the *latest* movement in a region.

Barrier Beaches.—During the past few years, there seems to have been a growing opinion, on the part of experts in plant physiology and ecology, that barrier beaches like those of New Jersey and New Brunswick are evidences of coastal subsidence. While, so far as I am aware, this opinion has been expressed in print by only one author, it is entertained by others.[1] It is hard to see the reason for this view, unless it is that barrier beaches are commonly associated with salt marsh deposits, and that these are believed, upon botanical grounds, to testify to a modern progressive subsidence. The only attempt to outline a theory for the origin of barrier beaches, based upon subsidence, so far as I have learned, appears in Professor Ganong's notes on the origin of Portage and Fox islands.[2] Referring to the long, broken barriers across the mouths of the Miramichi and neighbouring estuaries, he says: "Originally . . . they no doubt formed against the margin of the flat upland as ordinary shore beaches. But the steadily progressing subsidence carried the land beneath the sea faster than the beaches, whose rate of inward movement is determined by the erosion of the protecting headlands, could follow; hence the lagoons were formed. The coast is still sinking, and the beaches are still travelling

[1] C. A. Davis and David White, in oral discussion of the question of modern coastal subsidence, at the eleventh annual New England Intercollegiate Geological Excursion, at Tufts College, Oct. 13, 1911.

[2] W. F. Ganong: On the physical geography of the north shore sand islands. Bulletin of the Natural History Society of New Brunswick. vol. 6, 1908, pp. 6-13; and, On the physiographic characteristics of Portage and Fox islands, Miramichi. In the same volume, pp. 1-6.

inward."[1] As concrete illustrations of successive stages in this development of barrier beaches, Professor Ganong presents, among other cases, the following:—

(*a*) Three short beaches, just south of Point Escuminac, which connect headlands and which enclose very narrow lagoons. "These are of especial interest as showing the mode of origin of the greater beaches, for in the case of the first two, while they are still shore beaches, lagoons are forming inside them." Likewise, Chockpish beach, which "extends from the rocky Richibucto head in an inbowed curve south to a rocky point just north of Buctouche [illegible], encloses mostly bog and marsh, but with rudimentary lagoons. It is thus another forming beach."[2]

(*b*) The long barriers or sand reefs which shut off from the sea the wide estuaries of Pokemouche, Little Tracadie, and other rivers. According to Professor Ganong's theory, the lagoons have been broadened by progressive subsidence faster than they have been narrowed by the inland migration of the sand reefs. In other words, the vertical subsidence has been more effective, here, than the horizontal advance of the barrier towards the land—an advance which is accomplished mainly through the drifting of sand along the exposed shore and the scattering of the sand through the gulleys into the lagoons.

(*c*) The more detached fragments of sand reefs, like Portage and Fox islands, at the mouth of the Miramichi. These are conceived to have passed through the stages already described, and to have become disconnected from their original anchorage as subsidence converted the mainland border into a submerged shoal, or as the protecting ledges at the headlands were drowned and their places were taken by easily eroded cliffs of peat, whose destruction let the sea through the barrier, at points where there was no longer a supply of sand for the beach. In short, "both Portage and Fox islands . . . appear to have been formed as true beach plains against the neighbouring upland. . . . Their separation from the upland is due to subsidence of the land, admitting the sea to flow over their

[1] Op. cit., pp. 12–13.
[2] Op. cit., p. 9.

oldest and, therefore, lowest parts, while their outer parts have been more or less eroded by the advancing ocean."[1] Thus it is conceived that barrier beaches originate as true beaches at the mouths of rivers on a low coast; that as this coast sinks beneath the sea, the river mouths are drowned to form lagoons, while the beaches, being tied to headlands at either end, remain relatively fixed in position; that as soon as the subsidence allows the sea a better opportunity to cut the beach away from its supporting headlands, there is a rapid widening of gullies, and a conversion of the reef into a broken chain of sand islands.

It will be noticed, by those familiar with the commonly accepted principles of shore-line morphology[2] that the first or "rudimentary stage, as outlined above, is the final stage, according to the accepted theory. Barrier beaches along coasts like that of New Brunswick are commonly believed to owe their origin to a rapid accumulation of shore drift along the concave line of breakers between headlands, and to follow these retreating headlands in their shoreward migration, narrowing the lagoons as they go, until at last they reach the mainland, and the lagoons vanish, so that the barrier passes into a true beach. In other words, the small beaches which Professor Ganong regards as "*forming*" would be regarded by most physiographers as *disappearing* barrier beaches. It is perhaps sufficient reason for the rejection of this theory of subsidence in favour of the commonly accepted one, that long bars or barriers of this kind occur between headlands on lakes whose level has been unvarying. Moreover, since both the headlands and the beaches, on the New Brunswick coast, are known to have been rapidly retreating, during the last few centuries, at least, this horizontal shifting, alone, of the sand reefs towards the shore, is competent to account for the several stages of development noted, if the long barriers which bridge the greater re-entrants are taken as the more youthful type, and the short beaches at the mouths of streams on the most exposed headlands mark the end of the life history of the barriers. Here, as in the case of the rapid recession of sea-cliffs, we find no necessity for progressive coastal subsidence.

[1] Op. cit., p. 5.
[2] See, for instance, W. M. Davis: Physical Geography. Boston, 1899, pp. 353–354.

Re-curved, Hooked Spits, Dipping Beneath Lagoons.—In his description of Portage and Fox islands, already referred to, Professor Ganong shows that they are detached remnants of long, re-curved hooks, now being cut away at one end, and built forward at the other. "Portage island is composed of a series of approximately concentric, low dune beaches with intermediate shallow hollows, a series of sand swells or billows. . . . Near its northern end the beaches, bearing the oldest woods, are parallel with the axis of the island, and here they are being cut away, together with the covering woods, by the sea. Farther south these same beaches curve around to the westward and finally sink gradually beneath the waves of the Inner bay, their summits projecting as points, while their intermediate hollows form coves of salt marsh. These beach lines, as may be seen at many points, form only above the reach of the highest tides, and their gradual disappearance beneath the waters of the Inner bay forms one of the very best evidences we possess of progressive subsidence in this region, evidence still further strengthened by the occurrence near the north end of the island, of peat in situ on the beach below high water mark."[1]

Contrary to this statement, it may be pointed out that the hooked terminations of long sand spits are commonly inferior in height to the crestline of a main storm beach, whether the latter is covered with dune sand or not. On such a hook, the crest of the beach always descends to sea-level and extends out under water. This is due in part to the decreasing supply of sand towards the end of the hook and in part to the fact that the storm waves around the bend of the hook are weaker than on the fully exposed straight beach which faces the sea, and so do not cast beach material up so high. In this case of Portage island, therefore, there is nothing abnormal about the dipping of the extremities of the hooks beneath the surface of the sheltered lagoon. Not only is this feature seen on hooked spits of the Atlantic coast generally, but it occurs on hooked spits in such lakes as Lake Michigan, where no subsidence of the coast has taken place during the period of construction of

[1] Op. cit., p. 2.

the hooks. So far as the occurrence of the peat bed below high tide mark on the outer beach of Portage island is concerned—evidence of quite another kind—this is a common feature in retreating barrier beaches, and can be explained without appeal to coastal subsidence.[1]

Trees Killed by High Tides.—In a short paper in his "Notes on the Natural history and physiography of New Brunswick," Professor Ganong says that on the low shores of the South river, near Pokemouche, "in places the dead forest trees still standing with their roots immersed by the highest tides afford striking evidence of the rapid subsidence this coast is undergoing."[2] An examination of this estuary in 1911, with the expectation of finding convincing proof that the tides at that place rise higher than they formerly did, proved a disappointment to me. It is quite possible that I failed to find the precise place to which Professor Ganong refers, although my search for it was rather thorough. Here and there, near the creek are patches of trees whose death, like that of groves farther back on the upland, seems to have been due to fire rather than to tides. Where the road from Lower Pokemouche to Tracadie crosses the upper end of South river, a number of dead spruces and firs occur near the river bank; but they stand in a bog which is clothed with characteristic freshwater vegetation. At one point where the highway between Six Roads and Pokemouche crosses the head of a short creek, about a mile south of Upper Pokemouche, there are obscure signs of an increasing submergence by the tides. At the water's edge, where salt marsh grasses of the genus *Spartina* and meadow plants like *Daucus Carota* and *Eupatorium purpureum* are curiously mingled, are a few tall birch trees, now dead. According to farmers in this vicinity, the trees have been killed by salt water, brought up during occasional spring tides. Even if we grant that this explanation is correct, in this instance, we cannot safely argue from it that the killing of the trees registers more than the

[1] D. W. Johnson: Fixité de la Côte Atlantique de l'Amerique du Nord." Annales de Geographie, vol. 21, 1912, pp. 193-212 (particularly pp. 201-204).

[2] W. F. Ganong: On the physiographic characteristics of the Pokemouche and St. Simon rivers. Bulletin of the Natural History Society of New Brunswick, vol. 5, 1906, pp. 524-526.

injury received from an unusual succession of high tides, due, perhaps, to a series of storms of very great severity. If a downward movement of the coast is now in progress, and is so rapid as to be recorded during the short lifetime of a tree, we might reasonably expect to find, in a situation like this one, trees in all stages of destruction and of burial by the advancing salt marsh.

In one other place, of those which I visited in 1911, is there perhaps a record of forest destruction through submergence. At the head of the southeast branch of Saint Simon inlet, near the railway that runs to Shippigan, the low upland bordering the salt marsh is occupied by many stumps and dead trees. The suggestion of subsidence here in modern time is strengthened by the discovery of a number of stumps farther out on the marsh itself, entirely surrounded by *Spartina* and other halophilous plants, and of a black stratum of leaf mould or swamp deposit containing birch bark, beneath three feet of salt marsh material, near the edge of the creek, about 300 feet out from the margin of the upland. Some of the stumps are charred, as if by fire. Most of them, however, bear axe marks, as if the forest had been cut while living; for there is no apparent reason why a tide-killed forest should have been visited by the woodsman in a district where standing timber is abundant and little fuel is used. The encroachment of the salt marsh upon the forest border, therefore, must have taken place within the two centuries or so of occupation of the district by the French. A series of borings indicates that the buried stratum of leaf mould, at its greatest depth, is not more than four and a half feet below the surface of the marsh. As Professor Johnson points out, there are a number of ways to account for slight submergence without subsidence. The local high tide surface may creep up over a low upland border and bury it with a few feet of salt marsh in a district, for instance, where the widening and deepening of passageways across barrier beaches allows a constantly increasing play of the tides, or where the same result is accomplished in a single great storm, as at Marshfield, Massachusetts, in 1898.[1] On a rapidly retrograding coast like

[1] D. W. Johnson: Botanical evidence of coastal subsidence. Science, vol. 33, 1911, pp. 300–302.

that of New Brunswick, where the sea has cut back half-way to the heads of the estuaries, an increase of three or four feet in local high tide level might reasonably be expected. It does not appear, therefore, that the destruction of trees at the localities noted constitutes valid evidence of coastal subsidence.

On the other hand, as Professor Johnson suggested to me before field work was commenced, if the coast is now going down at a rate fast enough to be registered within the lifetime of trees of moderate size, the destruction of bordering forests should be seen in all parts of the area where submergence is in progress. An inspection of a number of estuaries along the drowned coast of New Brunswick, between Bathurst and Point du Chene, leads to the opinion that as a rule the forests surrounding salt creeks and marshes are not suffering from their proximity to the sea. The fringe of dead trees which we should expect to see is missing.

Forest Beds and Peat Bogs Reaching to Depths Below High Tide Level.—At a number of places along the coast of New Brunswick, peat bogs composed of fresh-water plants and containing roots of trees have been reported to extend to depths several feet below high-tide mark. Bogs of this type, composed of sphagnum and other swamp-loving plants, but generally treeless, cover vast areas on the lowlands near the coast, and are known as the "barrens." Their height is often not more than fifteen or twenty feet above sea-level. Since soundings have been known to penetrate them to a depth of over twenty feet, the impression has arisen that the bottoms of the bogs are so far below tide level as to indicate a subsidence of the coast. Among those who have studied the bogs and reported in detail upon them, the late Dr. Chalmers has published the largest amount of information. Criticism of his evidence naturally follows two lines: (*a*) Chalmers' statements of observation are so qualified as to admit of some doubt whether the peat actually does extend below sea-level; and (*b*) in case it does extend to that depth, the question arises whether it may not be explained in other ways than by supposing that the coast has gone down. In order to test both the facts and the interpretation of them as records of modern subsidence, I visited a few of the most typical barrens, including one on Miscou island, one at the head of Saint Simon inlet, and one near Point Escuminac. Natural cross sections of these bogs, cut by the sea, were inspected, and many soundings were made with a Davis peat sampler, with the expectation that the deposits would prove to extend to a considerable depth.

On Miscou island, half a mile inland from Miscou point, at a place where the surface of the barren is about ten feet above high tide mark, the sounding instrument penetrated decayed sphagnum to a depth of thirteen feet, where it struck something hard. Another group of borings 150 feet away from the first one, at the edge of a tidal "pond," gave the following section:—

Surface; typical salt marsh, with *Juncus gerardi* (?) the dominant grass; at mean high tide.
0 to 6 inches; brown, spongy peat, containing very little sediment, with many vertical fibres (salt marsh).
6 to 12 inches; brown, very compact, woody peat, without sediment; splits horizontally.
12 to 18 inches; reddish brown, very soft, fibrous peat (sphagnum).
18 to 24 inches; no core (frequently the case in boring through soft sphagnum deposits).
24 to 30 inches; same rotten, reddish brown peat.
30 to 36 inches; stiffer, rather firm, reddish-brown peat.
36 to 42 inches; brown, slippery, muddy peat in upper two inches, followed below by watery mud.
42 to 48 inches; muddy brown sand, with hard, gritty sand below, through which the sounder could not be driven.

The significant points about this section are: (*a*) that the salt marsh is merely a thin veneer over the bog peat. This agrees with the physiographic evidence that this "pond" is one of the numerous fresh-water pools on the barren, which has very recently been invaded by an advance of the sea, cutting back the cliffs into one end of it; (*b*) that the sphagnum deposit extends to a depth of only three feet and a half below mean high tide. This much submergence does not prove coastal subsidence. The bog may have grown up in a basin whose floor, although below high tide mark, was above mean tide level, and whose water, consequently, was fresh, and supported fresh-water vegetation. Later, as the sea cut its way into the pond and flooded it to high tide mark, opportunity came for a salt marsh deposit to form on top of the fresh peat, around the border of the pond.

A condition of things similar to this was found in the peat bog which lies at the head of the Saint Simon inlet, southwest of Shippigan. Here a low sea-cliff exposes the peat in cross section to a depth of not more than four feet below high tide mark, where the underlying structure, deeply decayed sandstone, is seen. Spongy brown sphagnum, in layers, alternates with tougher, blacker layers of woody peat, in which erect stumps and prostrate logs are rather abundant. The peat is exactly the sort of deposit now in process of formation on the surface of the quaking bog, where stunted spruces in scattered groups relieve the monotony of the low-bushed carpet that conceals the soft sphagnum. There seems to be a greater compactness of the basal layers of the peat, as if considerable settling of the mass had occurred. The rotten character of the moss, likewise, points to a considerable loss of volume. The very distinct stratification evidently marks recurrent cycles of wet and dry climate, in which forests encroached upon the barrens during dry periods, only to be overwhelmed by sphagnum when more humid conditions returned. The fact that the peat reaches down about to mean-tide level, but not below it, seems significant and will presently be discussed.

Of the bogs cited by Chalmers as evidence of coastal subsidence, perhaps the most notable is the one at Point Escuminac, near the mouth of the Miramichi. Ells stated, in 1880, that this bog has a maximum depth of more than thirty feet.[1] Chalmers, after mentioning the convexity of the bog, says: "From the examination made about its margin, it seems to occupy a basin . . . the central part of which is below high tide level. This gives it a thickness of twenty feet or upwards. Mr. Phillips, the lighthouse keeper at Point Escuminac, informed me that he found it twenty-four feet deep in one place."[2] Again, Chalmers remarks that "the bottom of these deposits seems to be at least ten or fifteen feet below high tide level in some places."[3]

[1] R. W. Ells: Geological Survey of Canada, Report for 1879-80, Part D, p. 43.
[2] R. M. Chalmers: Geological Survey of Canada, Annual Report, 1887, Part N, p. 24.
[3] Op. cit., p. 25.

A study of the peat exposed in receding cliffs west of the Point Escuminac lighthouse, accompanied by borings to determine the depth of the deposit, convinces me that there is little if any evidence of coastal subsidence. Behind the soft peat cliff, which rises from 5 to 15 feet above the beach, the surface of the bog ascends rapidly inland, attaining nearly 30 feet altitude in the central part. It is quite apparent that the convexity of the barren at its periphery is due mainly to loss of water near the cliffs, where the water-table descends to the level of the beach. In the first quarter mile west of the lighthouse, the freshly cut cliff shows the floor of the bog—a smooth surface of decayed sandstone, gradually descending to the high tide mark. A series of borings along the foot of the peat cliffs in the next quarter mile, taken at intervals of 200 feet, show the depth of the floor of the peat bog below high tide mark, as follows: zero; zero; 6 inches; 12 inches; zero. Half a mile from the lighthouse, where the peat cliff attains its maximum height, 13 feet, a boring through the beach reached the sandy floor of the bog at a depth of less than 24 inches below high tide mark. Since the upward slope carries the surface of the bog to an altitude of fully 26 feet (as measured by hand-level and rod) above high tide mark, it is probable that the peat here is 28 feet thick. The sounding instrument used was limited to a depth of 21 feet. The 24-foot sounding reported by Chalmers may, therefore, have been entirely above high tide mark. In the half mile between this point and Herring cove, a few borings, at wider intervals, struck sand beneath the peat at depths below high tide mark, successively, of 24, 18, and 6 inches. It appears, therefore, that the Point Escuminac peat bog occupies a rather flat basin, whose floor is close to high tide mark over a wide area, yet rarely as much as two feet below that mark. In this respect it seems to agree with the peat bogs at Miscou island and Shippigan. This I am inclined to regard as significant. If there had been a subsidence of the coast of New Brunswick in very recent times, while the bog was under construction, we should expect to find the fresh-water peat extending down to greater depths; for sphagnum would have accumulated in basins whose floors, in some places, were barely above mean tide level, and thus just above the influence of the tides; and the subsidence of several centuries would probably drown these bog floors to depths distinctly below mean tide level. If, on the other hand, there has been no vertical movement of the coast for several centuries, while peat has been accumulating in these bogs, we can see why the fresh-water structures approach, but seem in no place to exceed mean tide level.[1] The latest evidence from the peat bogs of New Brunswick, therefore, argues rather for modern stability than for modern subsidence.

Old Beaches on Prograding Shores, with Crestlines Lower than the Present Beach.—A few places on the coast of New Brunswick, where, instead of retrogression, there has been for centuries a forward construction of the beach, offer opportunity to test the hypothesis of modern subsidence by a comparison of the crestline altitudes of the older beaches with the newer.[2] Of two such localities described by Professor Ganong—Miscou Grande Plaine and Portage island, the former was selected for a visit, partly because of the interest aroused by Professor Ganong's report on the plant ecology[3] and partly because the age of the beaches on Grande Plaine can be estimated with some approach to accuracy.

As both Chalmers and Ganong have stated, Grande Plaine is a long triangular tract of sands at the northwest side of Miscou island. Hither for centuries have been swept the beach sands and gravels that drift northward along the east side of the island. Rounding Miscou point, the shore drift comes to rest on the more sheltered beach of the Grande Plaine. Each successive storm of the first magnitude causes the construction of a new beach, a little outside of the former one. Thus there has grown up a sandy terrace which is over a mile wide, and is corrugated with ridges and swales. The outer, newer ridges are very

[1] A larger amount of testimony on this point is, of course, desirable, before drawing definite conclusions. The value of this evidence depends also upon the assumption that the sphagnum deposits have had a continuous upward growth, rather than a horizontal growth out over the surface of pools, in the form of a mat, which might sink to the floor of the basin, after a time, in the manner suggested by Professor Johnson. I am unable to say how far the latter process has entered into the formation of the peat deposits here described.

[2] D. W. Johnson: The stability of the Atlantic coast. Bulletin of the Geological Society of America, vol. 23, 1912, p. 740.

[3] W. F. Ganong: The nascent forest of the Miscou Beach plain. Botanical Gazette, vol. 42, 1906, pp. 81-106.

sandy and have rather pronounced back slopes. Their crest-lines, which commonly stand four or five feet above the inter-

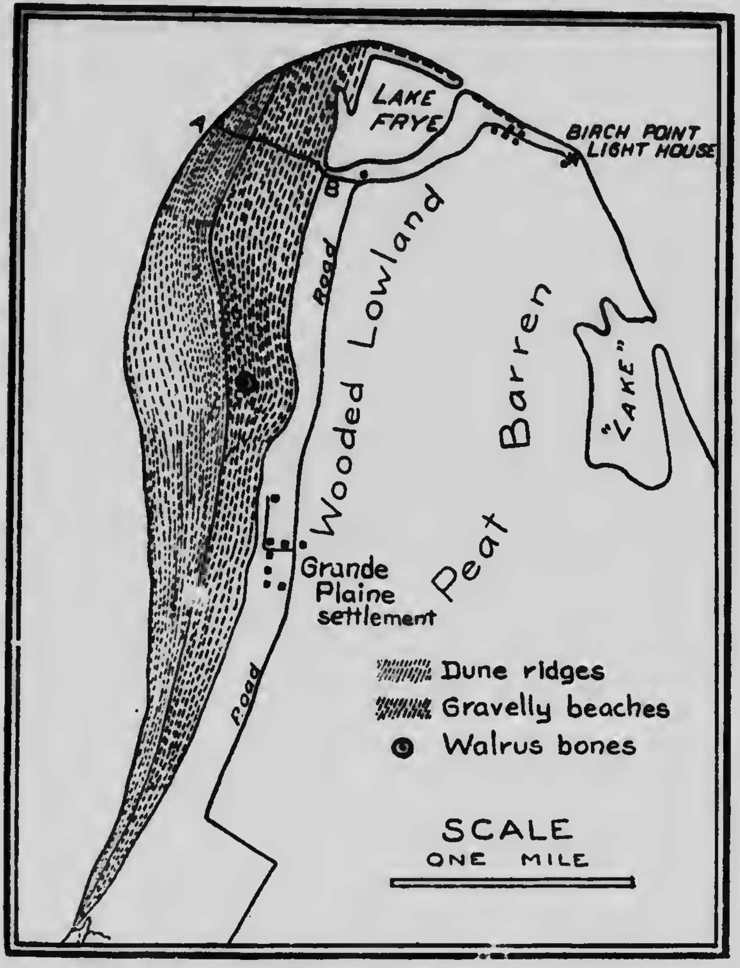

FIG. 6. Map of the northwest part of Miscou island, showing the old beaches of Grande Plaine (with slight modifications from W. F. Ganong).

vening hollows, are surprisingly uniform for dune ridges. Measurements along the crest of the outermost or newest ridge, in

August, 1911, gave altitudes of 8·37, 7·71, 8·81, 8·97, 9·77, and 10·63 feet above high tide mark. In the hollows, well within the vertical range of storm waves, gravels are common. The ridges themselves, however, so far as they exceed the altitude reached by the present storm waves (5·65 feet above the high tide mark) appear to be of æolian origin. Passing inland across this zone of dune ridges, which on the old trail to Lake Frye consists of twelve distinct members, one finds behind them a large number of flatter ridges, formerly well clothed with forest, now to a large extent laid bare by the lumberman. As Professor Ganong has pointed out,[1] the crests of these inner ridges are somewhat lower than those near the shore. Herein lies what appears to be evidence of coastal subsidence. That the inner beaches are at least a few centuries old is inferred from the presence on them of bones of walrus, which were hunted here in great numbers by the early French settlers, and exterminated shortly before the close of the eighteenth century.[2] Professor Ganong's walrus bone locality is about half a mile in from the sea, on the outer members of the inner group of beaches. From the published descriptions one would be led to suspect that enough subsidence of the coast had taken place, in the century and a half since the slaying of the walrus, to give the crests of these old beaches a perceptibly lower altitude than the crest of the present beach.

In considering first the testimony of these walrus bones with reference to the age of the beaches on which they occur, we may accept without hesitation the view that the inner beach ridges were formed prior to the close of the eighteenth century. Furthermore, the absence of such bones from the outer ridges seems to show that these have been built since the days of walrus hunting, or since the beginning of the nineteenth century. However, it is possible that the ridges which have furnished the bones are of much earlier date than the walrus hunting period, since, as Dr. John M. Clarke has pointed out to me, con-

[1] W. F. Ganong: On the physical geography of Miscou. Bulletin of the Natural History Society of New Brunswick, vol. 5, 1905, p. 459.

[2] W. F. Ganong: The walrus in New Brunswick. Bulletin of the Natural History Society of New Brunswick, vol. 5, 1903, pp. 240-241. Also, R. M. Chalmers: Geological Survey of Canada, Annual Report, 1887, Part N, p. 27.

temporary accounts of walrus hunting tell of the practice of driving the beasts from the waters or the floe ice up on to the low shore platforms and even into the woods, where they were shot at leisure. Possibly, then, some of the outer, barren beaches were already in existence when the walrus were slain in the woods close behind them, and the fossiliferous ridges are, therefore, older than we have assumed. Keeping this possibility in mind, we may say that the ridges in question date back at least to 1775. If, now, we assume that the growth of the beach plain, in the long run, has been steady, we may estimate that the age of the innermost beaches, which are as far behind the bone-bearing ridges as these are behind the modern beach, is probably not less than 300 years.

Lines of levels were run from the shore across the plain to Lake Frye, to determine what difference in height, if any, exists among the beach ridges. The measurements follow:—

Last high tide mark on the beach, on August 3, 1911, at 9 a.m.				Zero.
Cut at upper reach of storm waves				5·64 feet
Crest of first or outermost ridge, sandy				9·04 "
"	second	"	"	8·91 "
"	third	"	"	6·70 "
"	fourth	"	"	5·89 "
"	fifth	"	"	8·12 "
"	sixth	"	"	5·54 "
"	seventh	"	"	5·07 "
"	eighth	"	"	3·91 "
"	ninth	"	"	7·81 "
"	tenth	"	"	5·50 "
"	eleventh	"	"	6·09 "
"	twelfth	"	"	7·44 "
"	thirteenth	"	gravelly	4·36 "
"	fourteenth	"	"	3·70 "
"	fifteenth	"	"	3·61 "
"	sixteenth	"	"	3·56 "
"	seventeenth	"	"	4·60 "
"	eighteenth	"	"	4·64 "
"	nineteenth	"	"	3·97 "
"	twentieth	"	"	3·92 "
"	twenty-first	"	"	4·25 "
"	twenty-second	"	"	3·04 "
"	twenty-third	"	"	3·26 "
"	twenty-fourth	"	"	3·25 "
"	twenty-fifth	"	"	3·21 "
"	twenty-sixth	"	"	3·43 "
"	twenty-seventh	"	sandy	4·14 "
"	twenty-eighth	"	"	4·19 "

As the measurements show, the outer ridges, from the first to the twelfth, are on the average nearly three feet higher than the inner ridges, from the thirteenth to the twenty-eighth. This decrease in altitude, however, is by no means uniform. Indeed, there is a rather sharp distinction between an outer, higher, and more variable group, and an inner, lower, and more uniform one. Of the ridges numbered from thirteen to twenty-eight, the extreme crestline measurements are 3·04 and 4·64 feet—a difference of scarcely 18 inches among them. There is also a close approach to perfect horizontality in the crestline of any single ridge of this group. As Professor Ganong remarks, the difference between the vegetation of the outer and the inner ridges is very great.[1] There is an equally striking difference in their structure. Ridges one to twelve inclusive are dune ridges, of unusual linear uniformity and symmetry, to be sure, but built throughout of wind-swept sand. In the hollows between them, gravel frequently appears; but in no place, so far as I could see, above the altitude which is reached by storm waves on the present beach, *i.e.*, 5·64 feet above high tide mark. Ridges thirteen to twenty-six, on the other hand, are gravelly, with pebbles of good size on the very surface. Many of them are typical shingle beaches. Ridges twenty-seven and twenty-eight have a veneer of sand, perhaps a foot thick, above the gravelly foundation. As a record of the former sea-level, therefore, ridges thirteen to twenty-six are as valuable as a modern storm beach; while ridges one to twelve, being dune ridges, have relatively little significance. They are, on the average, about three feet higher than the older ridges, *not because the coast has subsided about three feet since the older ones were built, but because the wind has heaped up sands on top of the outer gravel beaches to an average depth of three feet.* Any conclusion regarding modern subsidence here must rest upon a comparison of the gravel beaches with each other and with the gravel beaches along the present shore. As already stated, the gravel ridges thirteen to twenty-six are practically equal in height; and such small differences as are brought out by the measurements are distributed unsystematically through the group. All the crests are vertically within the range of storm waves of to-day—5·64 feet above the high tide mark on the present beach. The most significant comparison is that of the old ridges with a modern

[1] W. F. Ganong: Op. cit. *Botanical Gazette*, vol. 42, 1906, p. 95.

storm beach which encloses Lake Frye at its northern end. This beach has a crestline altitude, determined by instrumental levelling, of just 4 feet above high tide—the old ridges from thirteen to twenty-six have an average crestline altitude of 3·82 feet. If the facts on Miscou Grande Plaine can be used as evidence in this disputed question, therefore, they testify that in the last three centuries or so, there has been no measurable subsidence nor elevation of the coast.

CONCLUSION.

Summing up the several lines of physiographic evidence which have been presented by earlier writers, in support of the view that subsidence is now in progress on the coast of New Brunswick, we may draw the following conclusions:—

(1) The rapid recession of cliffs and beaches along the coast at the present time proves nothing either for or against modern subsidence. If the coast had been stable for centuries, the same cliff-cutting would be expected as has been described by investigators of the cartography and history of this coast.

(2) The presence of estuaries of the drowned valley type proves that there has been submergence, and, in view of the depth of the drowning over a wide area, coastal subsidence, at some time in the past. It proves nothing about modern or very recent movements of the coast. In fact, the valleys in question seem to be products of pre-Glacial or interglacial stream erosion, drowned very deeply during the Champlain submergence, and only partially lifted out again by the subsequent upwarping of the region.

(3) Barrier beaches are not evidence of coastal subsidence. They are normal features in the simplification of a shore-line which is initially irregular, whatever the cause of that irregularity may be. It is as natural to interpret the lagoons behind them as bays, shut off by reefs which have grown up between headlands, as it is to regard them as river mouths which have been drowned since the barriers were formed. Indeed, the former explanation is the more natural one, since it involves only those processes of shore drift and deposition which can be seen actually in

progress, while the latter supposes a downward movement of the land which demands further demonstration. Inasmuch as barriers are known to have been constructed on the shores of lakes in which no relative subsidence has occurred, and the processes of shore drift, working alone, are competent to account for them, the assumption that where such barriers occur the coast has been subsiding is entirely gratuitous.

(4) The disappearance of the hooked ends of re-curved spits beneath the surface of lagoons is not an evidence of coastal subsidence. On the contrary, this is the form which hooks necessarily assume on shores where no change of level is in progress.

(5) An examination of localities where trees have been said to be dying from invasion by high tides does not afford as good evidence as one might expect. If, as one may fairly question, the dead trees at Pokemouche and Saint Simon rivers register a submergence of the low upland border by salt water, this submergence may be due to recent increase in range of tide, which in some estuaries might be considerable. On the other hand, if this coast were subsiding fast enough to kill the trees, this sort of evidence should be apparent in favourable situations throughout the region—which is distinctly not the case.

(6) The peat bogs or barrens of sphagnum and associated fresh-water plants, whose bottoms have been reported to reach ten or fifteen feet depth below high tide mark, appear to extend only two or three feet, at most, below that level. Inasmuch as these bogs seem to have grown up in enclosed inland basins before the sea encroached upon them, it is not impossible that the basin floors, originally a few feet below high tide level, but not below mean tide level, were covered with fresh water. The fact that, so far as observed, and measured, the bog deposits approximate but do not exceed the depth of mean tide level is itself reason for favouring the view that neither subsidence nor elevation has taken place during their growth.

(7) A detailed survey of the beaches on Grande Plaine, Miscou island, which seem to register a period of at least three hundred years, indicates that so far as these are true wave-built beaches they testify to coastal stability rather than coastal subsidence.

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ANTHROPOLOGICAL SERIES, No. 2

IV.—Some Aspects of Puberty Fasting Among the Ojibwa.[1]

By Paul Radin.

INTRODUCTION.

The subject of fasting among the North American Indians, although it has been touched upon frequently by a number of writers, has never been made the object of a special study as yet. In the present little essay the writer will make no attempt to study the subject of fasting in any exhaustive manner, but will merely attempt, on the basis of a number of some of the fasting experiences, to point out features that, in his opinion, seem distinctive of Ojibwa puberty fasts. He hopes to reserve a more exhaustive study of the same for his report on the ethnology of this tribe itself.

The fasting experiences will be given first and the discussion will then follow. The writer has only selected a few of the accounts he has obtained, but the five chosen seem to contain all the characteristic features of the fast, although in certain details they, of course, differ from some of the others.

It might be stated, before proceeding to give the accounts themselves, that in only two cases did the experience represent that of the informant himself, and that in the other cases they referred to relatives of the informants. I do not believe that this in any way detracts from their value, but, of course, it may have led to the omission of a detail here and there.

[1] The following article is based entirely on notes collected by the writer among the Ojibwa of eastern and southeastern Ontario during the spring and summer of 1912, for the Geological Survey of Canada.

FASTING EXPERIENCE (A).

I was about ten years old when I fasted. That is the age at which our grandparents generally desired us to fast. My parents, themselves, seemed to care very little whether I did or did not fast, and I imagine that had it not been for my grandmother, I never would have done so.

It was at about the middle of what we call the "little-bear" month that my grandmother came to visit us. When she was about to return to her home, she had me accompany her. I did not know at the time what she wanted and it was only on the morning of the next day that she told me that I was to fast. Two mornings after that I received very little to eat and drink at breakfast time. At noon I received nothing at all. For the evening meal she gave me a very small piece of bread. In addition to myself there were six other boys fasting at the same time. During the daytime we would play together, keeping a close watch on one another, lest someone try secretly to get something to eat.

We were to fast ten days, all in all. At the end of the fifth day, however, I became so hungry that after my grandparents had gone to bed, I got up and helped myself to a hearty meal. They discovered it, however, the next morning and I had to begin my fast all over again. This time I was very careful not to break my fast, for I did not want to begin over again, as on the first occasion.

At the end of the tenth day, my grandparents built me a wigwam. It was supported on four poles, about three or four feet from the ground, and I was to use it for sleeping. My little wigwam was situated at some distance from the lodge of my grandparents, directly under an oak tree. I do not know whether in olden times it was customary to build the fasting wigwam under just this tree or not. My impression is that the old people built it at some distance from their own lodge, but not too far to prevent them from watching its occupant during the day time.

My grandmother told me not to accept the blessings of every "spirit" that would appear to me in my "dreams," for there were many bad spirits around and they would doubtless try to deceive me and thus cause misfortunes. The first four nights, I slept soundly and dreamt of nothing whatsoever. The fifth night, however, I dreamt that a very large and beautiful bird came to me and promised me many great things. I had, however, made up my mind not to accept the blessing of the first spirit that appeared, so I refused all that had been offered, and as I watched the bird disappear, I saw that it turned into a chickadee. In the morning, when my grandmother came to ask me whether anyone had blessed me, I told her that a chickadee had offered me many gifts, but that I had rejected them. Then she told me that the chickadee often fooled people in this manner. For a few nights after that I again did not dream of anything, but during the eighth night another big bird came to me. I was getting tired of staying in the little wigwam so long, so I decided to accept whatever he would offer. I dreamt that this big bird took me along with him to the north, where there was only ice. There I saw many more birds just like him, some of them very old. These birds offered me long life and freedom from sickness. Indeed it was quite different from what the chickadee had promised. I accepted all that they gave me and then the bird that had brought me there took me to my wigwam again. When he left he told me to watch him before he got out of sight, and as I did, I noticed that it was a white loon. In the morning, when my grandmother came to question me about my dreams, I told her of my experience with the white loons. She was very glad to hear about it, for they had rarely been blessed by white loons. From that time they called me *Wābimą* or White-loon.

FASTING EXPERIENCE (B).

When I was a boy of eleven years old, I was told by my mother that it was about time for me to find out something concerning my future life and this I was to do by fasting. I was at first not to eat or drink anything for five days except at supper. The sixth day they built a little wigwam for me alongside of a little creek running through the woods and left me there over night. The next morning my mother came and asked me of what I had dreamt. As a matter of fact I had not slept at all that night, for I went to the creek to get a drink. However, as this was early in autumn, the nights were quite warm; she noticed my tracks near the creek and immediately suspected that I had left my wigwam. She asked me where I had been and I admitted that I had been to the creek for some water. She told me to go home, and I had to start all over again, about two weeks from that time. This time another lad fasted together with me. After four days my parents built me a wigwam in a part of the woods far away from the water. I went to this place on the evening of the fourth day. The other boy accompanied me. That same night this other boy had a bad dream, and when our mothers came to see us the next day, we told his mother that he had dreamt of being bitten by a snake, that the snake had then made him sick, and that he had finally died. After telling of this dream, he was told to go home and I remained in the wigwam all alone. My parents visited me quite frequently, about four times a day. For five days I stayed there all alone and it was only on the fifth night that I had my dream. It was as follows:—

I dreamt that I was alongside of a lake and that I had had nothing to eat for some time. As I was wandering about in search of food, I came upon a large bird (*moñ*). This bird came over to where I was and spoke to me, saying that I was lost and that a party was out searching for me, but that they desired not to rescue but to shoot me. Then the bird flew away to a lake and brought me a fish to eat. He then told me that I would have good luck in hunting and in fishing and that I would live to a good old age. He also told me that I would never be shot by a shot-gun or a rifle, for the bird of whom I dreamt belonged to a species that a man rarely finds a chance to shoot. From that time on the *moñ* was my (personal) manito.

FASTING EXPERIENCE (C).

When I was ten years old my grandmother wanted me to fast, so that I might know what blessing I was to receive. I was to start in the autumn of the year. At first I was to get just a little to eat and drink in the morning and the evening. This meagre diet was to continue all through the autumn and winter. In the spring a little wigwam was built for me on a scaffold, not very far from the ground. In this wigwam I was to stay ten days and nights, and only get a little to eat in the mornings and evenings. My grandmother told me before entering not to believe every spirit that would come to me with promises, for there are some who try to deceive people, and only to accept the blessings of that spirit who came with a great noise and power.

The first and second night I did not dream of anything, but during the third night a very rich man came to me and asked me to go along with him and said that he would give me all the riches I wanted. I went along with him but I did not accept what he offered me and returned to my wigwam. Then I looked in the direction in which the man who had appeared to me was disappearing, as he had bidden me, and I saw that he had changed into an owl and that the big lodge I had visited with him was a hollow tree with holes. The next night another rich man came to me, dressed in a suit of red material. He offered me the same things as the first man, and in addition told me that if I accepted his blessings I could change my clothes twice a year. After I refused, he told me to look in his direction as he left me, and as I did so, I saw nothing but oak trees and dry and green leaves. The next night another man came and offered me boxes of sugar. I went with him, too, but I refused his blessing, and when I turned to look at him as he left, just as I had done in the other cases, I only saw a large maple-tree.

My grandmother came twice a day to ask me about what I had dreamt and to give me something to eat. I told her about my dreams and she again told me to accept the blessing of no one but the spirit who came to me with a great noise and strength. Some night before the tenth I heard the noise of a gush of wind above me and saw a very stout and strong man. With this man I went towards the north and finally came to nine old men sitting around in a circle. In the centre sat a very old man and this was the man who blessed me. He told me that he had just been sent down from above. Then I was brought back to my little wigwam and told to look in the direction in which my guide was going. When he had gone some distance, I looked and I saw a number of large white stones in a circle and one in the centre of this circle. The next morning when my grandmother came to me to feed me and question me, I told her of what I had dreamt. That was the end of my fasting.

Some people are fooled, during their fast, by a bird called the chickadee.

FASTING EXPERIENCE (D).

When an Indian is about to fast, he gets up early in the morning, gets his charcoal ready, and marks his cheeks. In the evening, when he returns, he washes his face and eats very little. He does the same thing for two days. Then he breaks his fast for two days. After that he begins his real fast. For six days he marks his face with charcoal. After the expiration of these six days he breaks his fast again for from five to six days. After that his parents build him a little wigwam about fifty rods from their lodge and there he is supposed to remain ten days. He knows that it is here that he will see his manito and that the animal (spirit) will bless him.

While the faster is in this little wigwam, the people get a very fast runner near him. When the morning of the tenth day arrives, the fire is made and the faster gets ready to leave. As soon as he leaves his fasting lodge, he starts to run. The fast runner gets after him and soon he catches him. Then they all ask the faster what spirit had blessed him. After that they give him a little song, and then he tells them by whom he had been blessed. By a very thin man (a *pagāk* spirit) he had been blessed.[1]

FASTING EXPERIENCE (E).[2]

When a child was ten years of age, it generally started to fast. For a few days, sometimes a week, it was given nothing to eat except a little for supper. This was only preliminary to the real

[1] *Pagāk* are thin airy spirits who formerly inhabited this earth, but who became so attenuated that they ascended into the air, where they still live, flying around and making peculiar sounds. It was formerly believed that if any one heard them he would die.

[2] This is a generalized account.

fasting, which began after that. After the child has fasted for a few days, the parents or grandparents build a little wigwam in a lonely spot of the woods. In this wigwam the faster then stays and sleeps. He is not allowed to eat or take even a drop of water. Generally he keeps a small piece of lead in his mouth and swallows the saliva that gathers. Every morning the parents or grandparents visit the person who is fasting, and inquire about his dreams, and if the faster dreams that he has been in trouble, lost in the woods, or eaten up by some wild animal, then he is taken home and given something to eat for a few days, after which he must start his fast again. His first experience is regarded as bad. Thus it continues for some time. The faster generally does not get his dream until the sixth to the tenth night. Sometimes a dream obtained even then is regarded as of bad omen, and the faster must start again. He is encouraged to have patience and wait until the right spirit comes. Sometimes this takes two to three months. The dream that is to benefit him generally comes in the following form. The faster, in his dream, finds himself in great trouble or, at times, he believes he is killed, and some animal comes to his rescue. This animal, he believes, will come to his rescue in similar situations throughout his life.

DISCUSSION.

We will discuss first the contents of the preceding experiences and then the relation of the fasting experience to the faster, on the one hand, and to his cultural environment, on the other, as it is embodied especially in the person of his parents and grandparents.

Even a cursory perusal of the experiences shows that, as one would have been led to expect, all are cast in a definite mould. An animal appears to the faster in a dream, and promising him certain blessings, leads him far away to some place where he meets the one who is actually to bless him. He is then led back to his little fasting-lodge and told to watch carefully the disappearing figure of the one who has come to him. It is only when the "person" is about to pass out of sight that he takes upon himself the shape of the animal itself. This is the formula that appears over and over again, in all these dream-experiences, and is unquestionably transmitted from one generation to another. How this is transmitted would be an interesting thing to determine, but in the present state of our knowledge, I am afraid all that can be done is to offer a few hypothetical explanations. It is this that we shall in the main attempt to do.

What opportunity does a boy of say eleven years or thereabouts have of learning this dream-experience formula? That he would have the slightest opportunity of himself hearing an older person recount his dream-experience is quite unlikely, for it seems in olden times to have been customary to recount it only on one's sick bed and then to an older person. There is thus left only one means whereby he could obtain the desired information and that is through the system of instruction to which it was customary to subject all children from the age of five or six to the age of puberty and which consisted almost exclusively in directions concerning the actions necessary to take in order to ensure a happy and successful life. One of the most insistent prayers in this instruction is that without a guardian-spirit (manito) no individual could possibly surmount the crises in his life. But the main question to decide is, does the youth in this instruction obtain any detailed information about the dream-experience formula itself? I believe he does not. All that he is taught is to expect a dream-experience. The main object, I should say, is to obtain the religious thrill; the form that it assumes may be vague except for the outstanding fact that a manito has appeared to him. How then are we to account for the stability of the formal element? This, I believe, may be accounted for by two facts, first, that a minute control is exercised by the parents or grandparents, as the case may be, over the faster, and secondly, that the form in which a dream-experience is told does not represent that of the boy of eleven but that of a mature man. It is this latter fact, that we never obtain the experience of the youth, immediately after his fasting, that makes the question of the exact mechanism of transmission so difficult.

Let us return now to the nature of the control exercised by the parents over the faster. This takes two forms, a negative and a positive one. It sees to it first, that the youth observes the fast and the restrictions imposed on him during the fast, and secondly, that only certain blessings be accepted. Now if we knew exactly in what this latter positive control consisted, we would know likewise what part the individual faster and the controlling agency, the father, etc., plays. Judging from the fact that we learn from one of the experiences that the faster is directed to accept only that spirit who comes to him "with a great gust of wind," we might argue that if the spirit by whom he is to be blessed is thus limited, other details might be equally dependent upon the suggestions of those who are in control. It might, of course, be said that owing to the extreme suggestibility of a child under the conditions imposed at the time of fasting, many details might be accounted for as due to this suggestibility. This is, of course, quite true, and this is probably responsible for many of the details that distinguish one experience from another, but it has no relation at all to the dream-experience formula, for the significant fact here is that the formula is always the same. However, even if we were to credit the controlling agency with a great influence in shaping the formal aspect of the experience, this must not be overrated, for that would be practically saying that all the formal elements were given at the beginning and I hardly believe there is any evidence for this.

We thus come face to face again with the central problem in the transmission of the dream-experience formula. Did the youth obtain the entire formula during his fast, or only part of it, or indeed any of it at all? And this brings us back to the question, did the youth obtain it? As I have stated before, we do not know what the form of the dream-experience, at the time of the experience itself, is, for no youth has ever told us. However, I believe that we may safely assume that from the point of view of formalistic expression, the dream-experience as known to the mature man was different from that known to the youth. Considering the age of the boy while fasting and the nature of the instruction he received, I believe that it is justifiable to assume that the main element in the dream-experience was the religious "thrill," and that its setting was vague. It is not at all my purpose to separate the "thrill" from the setting of associations that have always clung to it in different cultural areas, but I claim that at the time of the thrill and perhaps for a considerable time afterwards in the life of the individual, these associated elements are vague and ill-defined and that they only then become clearly differentiated when the cultural environment exerts its greater influence upon the individual.

Now if we look at the dream-experience as a formal unit, we will notice that it contains a number of folkloristic elements, such as, for instance, the dreaming of a snake as an ill omen, the deceiving promises of the chickadee, etc. At the same time, the manner of obtaining the blessing, the visit to the home of the manito, etc., are all themes characteristically developed in the mythology of the people. Both these elements, folklore and mythology, begin to exercise their influence on the individual after the age of puberty. If, in addition, we allow for the increasing knowledge of the details of the dream-experience that in maturer years one is quite likely to obtain, all the conditions for the fixity of the dream-experience formula seem to be given.

Summing up, we might say that the evidence at hand seems to warrant the suggestion that a boy approaches the ordeal of fasting with definite suggestions from those who are exercising control over him at that time; that he himself is probably most intent upon the religious experience he is obtaining, and that although this religious thrill is necessarily associated with suggestions from others and from himself, these latter play a secondary part; that, finally, what I have called the dream experience formula probably does not exist at the time of fasting in any clearly defined form, but it probably represents the increasing influence of the cultural environment, and the knowledge of those details of the fast that he learns from the generation of his parents and grandparents, as he grows older.

July 3rd, 1914.

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GEOLOGICAL SERIES, No. 16

V.—The Pre-Cambrian (Beltian) Rocks of Southeastern British Columbia and Their Correlation.

By S. J. Schofield.

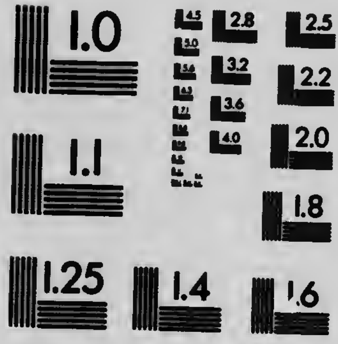
INTRODUCTION.

The Beltian rocks of the Galton range and of the Purcell range in southeastern British Columbia have been called the Galton series and the Purcell series respectively by Daly[1], in his study of a section across these ranges, along the International Boundary line. These and equivalent series in Idaho have not previously been seen in their stratigraphical relationship to the fossiliferous Palæozoic. Hence the age of these rocks, based entirely on correlation by lithologic resemblances, has been a matter of controversy; Walcott placing the whole of the Beltian in the Pre-Cambrian, and Daly on the other hand postulating that only the lower and smaller portion of the Beltian is Pre-Cambrian and the remainder or upper part is Cambrian. In 1913, the writer discovered a section near Elko (see map, Fig. 7), British Columbia, where the Pre-Cambrian-Palæozoic contact is well exposed and the interpretation of the field facts at Elko places the whole of the Beltian in the Pre-Cambrian.

[1]Daly, R. A., Geol. Sur. Can., Ann. Rept., 1904, p. 91A.
Report of Chief Astronomer of Can. Ann. Rept., 1905, p. 279.
Geol. Sur. Can., Memoir No. 38, 1913, pp. 99–139.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



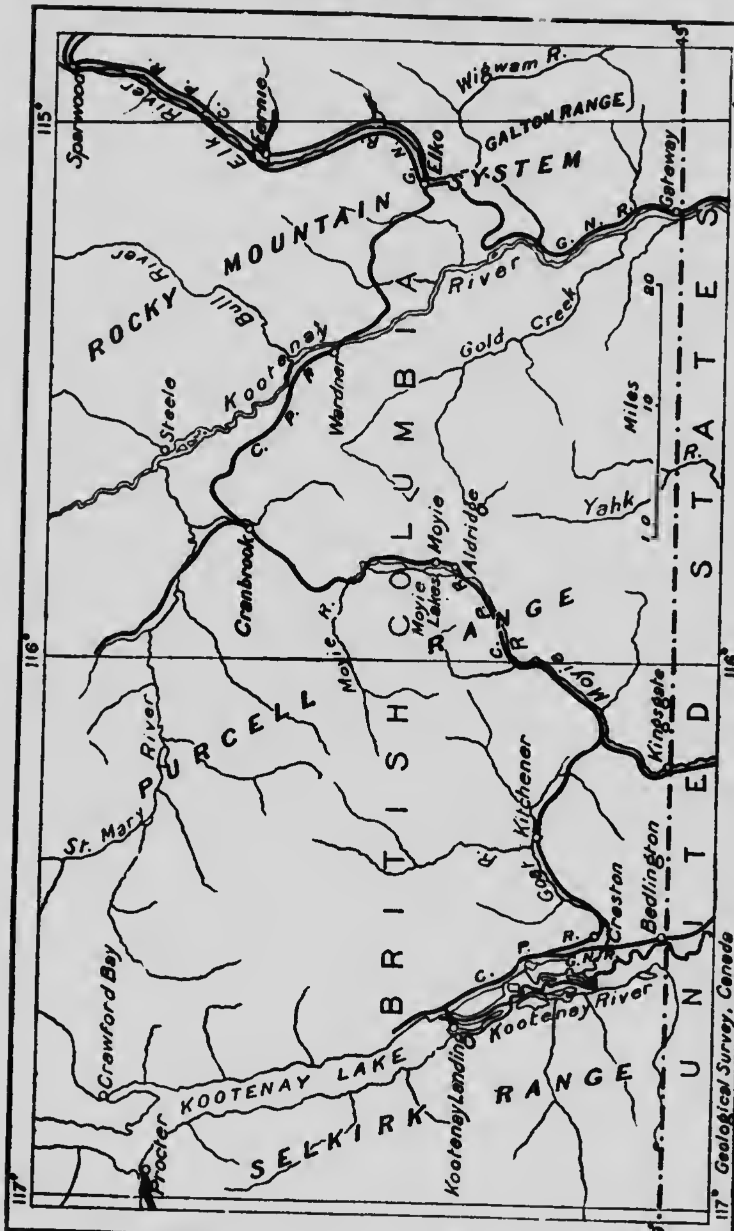


FIG. 7. Map of southeast Kootenay.

Fig. 7. Map of southeast Kootenay.

PRE-CAMBRIAN-PALÆOZOIC SECTION AT ELKO, BRITISH COLUMBIA.

The mountains to the north of the Elk River valley at Elko, form the most westerly part of the Rocky Mountain system. The structure of these mountains is of the nature of a syncline striking northwest–southeast. The eastern limb of the syncline is cut off by a northwest-southeast fault which brings the Devono-Carboniferous limestone in contact with the Roosville formation. The strata forming the western limb of the syncline and incidentally the western face of the Rocky mountains, dip, on an average, 45 degrees to the northeast.

Elko, a station on the Crowsnest branch of the Canadian Pacific railway, is situated on the western slope of the Rocky Mountain system, at the Elk River portal to the Kootenay valley or Rocky Mountain trench. The section exposed at Elko can be most easily expressed in a stratigraphical column.

		feet.
Devonian	Jefferson limestone	300+
Silurian, Ordovician, or Cambrian	Elko formation	90±
Lowest—Middle Cambrian	Burton formation	80±
	Unconformity.	
Beltian	Roosville formation	1000
	Phillips formation	500
	Gateway formation	1000+

The Gateway, Phillips, and Roosville belong to the Galton series of Daly.[1]

Gateway Formation. The lower part of the formation consists of alternating bands of massive, concretionary, siliceous dolomite and limestone weathering buff, and massive, light grey quartzites. These are succeeded by thin-bedded, sandy argillites, and greenish grey, sili[illegible]s argillites. The sandy argillites weather

[1]Daly, R. A., Geol. [illegible]. Can., Memoir 38, p. 97.

a light buff and are characterized by the presence of abundant casts of salt crystals.

Phillips Formation. The Gateway formation passes gradually into the overlying Phillips formation which consists mainly of dark purplish and red metargillites, sandy argillites, sandstones, and quartzites. At several horizons are intercalated thin laminæ of green, siliceous argillite. These rocks are exposed in a rock cut on the Great Northern railway, 1½ miles east of Elko, from which point they rise to the east in the hill to the north of the track.

Roosville Formation. The Phillips is overlain conformably by the Roosville which is composed mostly of massive, laminated, green, siliceous metargillites weathering greenish grey and rusty brown, and buff coloured sandstones. Mud cracks are abundant at all horizons. The Elk River canyon is carved in the horizontal strata of the Roosville formation. Cryptozoan forms occur at several horizons near the top of the Roosville.

Burton Formation. The Burton formation, called after Burton creek near Elko, rests with no discordance of dip on the Roosville siliceous metargillites, and consists in great part of greenish black, calcareous shales with interbedded siliceous limestone bands. A detailed section of the Burton formation at Elko is as follows.

Elko formation.	Greenish black shales with limestone interbands	60 ± feet
Burton formation.	Sandy limestone	10 "
	Greenish black shale	4 "
	Calcareous grit	3 "
	Hematite conglomerate	8 — 10 inches.

Unconformity.

Roosville formation.

The hematite conglomerate, the base of the Burton, is composed of rounded to subangular pebbles of siliceous hematite, embedded in a cement consisting of quartz and hematite. This conglomerate passes gradually into the overlying grit which is made up of angular and subangular grains of the

Roosville siliceous metargillite and a great number of milky white to glassy quartz grains in a calcareous cement. This grit contains the oldest fossils found in the Galton series. Succeeding this grit is about 4 feet of calcareous, greenish black shale which readily weathers to soft earth. It is brittle and breaks up into small rectangular shaped pieces. Above this shale comes 10 feet of sandy limestone, in beds from 1 to 2 feet in thickness, broken by vertical joints. The weathering colour of this limestone is brown. Above the limestone comes about 60 feet of greenish black, calcareous shale containing numerous bands of siliceous limestone. These interbands are especially rich in trilobite remains.

Elko Formation. The Elko formation, called after the town of Elko on the Crowsnest branch of the Canadian Pacific railway, rests upon the Burton formation. The exact contact between these two formations was not exposed in the sections studied and no structural evidence of an unconformity was present, exposures on each side of the contact being very good.

The lower 30 feet of the Elko formation is composed of massive, grey, siliceous limestone, weathering grey, containing indistinct coral-like forms. The limestone by gradual transition, passes into a massive cream coloured siliceous dolomite in massive beds averaging about 6 feet in thickness.

The Jefferson Limestone. In the Rocky Mountain system, the Devonian limestone rests conformably upon the underlying lower Palæozoic Elko formation, while in the Purcell range to the west, an apparent unconformity exists between the Devonian limestone and the Gateway formation. The staple rocks of the Devonian are a massive, dark grey limestone and dolomites weathering a whitish-grey colour. The following fossils were found in the Jefferson limestone and were identified by Dr. Kindle.

Atrypa reticularis.
Atrypa cf. missouriensis
Spirifer englemanni.
Strophostylus sp.
Stropheodonta demissa.
Schizophoria n. sp. near s. striatula

Unconformity at the Base of the Burton.

Although no structural features emphasize the presence of an unconformity at the base of the Burton, yet from other evidence such an unconformity is believed to exist.

(1). In harmony with the other sections throughout the Rocky Mountain geosynclinal, a marine Cambrian transgression is represented in the deposition of the Burton formation.

(2). The conglomerate at the base of the Burton is composed chiefly of hematite pebbles with minor quantities of pebbles of quartzite and quartz in a hematitic quartz cement. The hematite pebbles, although some have a concentric structure, probably represent the results of erosion and subsequent concentration of hematite layers which occur abundantly in the underlying Pre-Cambrian series. The quartzite (metamorphosed sandstone) pebbles are identical with the quartzite of the underlying Phillips formation. The occurrence of these pebbles already metamorphosed before the deposition of the Burton, indicates that a time interval existed between the deposition of the Roosville and Burton formations.

(3). The grit which overlies the conglomerate is characterized by an abundance of milky white quartz particles evidently derived from the erosion of quartz veins such as are known to be present in the underlying Roosville formation and other members of the Pre-Cambrian series. Green particles of the Roosville siliceous metargillites are also present and their presence supports the idea that the Roosville formation was metamorphosed before the Burton was laid down, hence the idea of a time interval between the deposition of the Roosville and Burton formations is strengthened.

(4). The difference in degree of metamorphism of the Roosville and the Burton is very striking in the field. The laminæ of the Roosville siliceous metargillites are so thoroughly cemented together that the rocks always form steep cliffs, in fact the perpendicular walls of the Elk River canyon are carved in the Roosville formation. In contrast to this the Burton formation weathers to a soft earth and is characterized by gentle slopes.

(5). Since cryptozoan forms have not been described, as far as the writer knows, from formations later than the Pre-Cambrian, the classification of the Roosville and the underlying formations as Pre-Cambrian is still more firmly established.

THE PURCELL SERIES.

The Purcell series of East Kootenay was first described by Daly in 1904,[1] and subsequently in unchanged form in 1913,[2] and is as follows:—

Erosion surface.

		feet.	
Middle Cambrian	Moyie	3400 +	
	Purcell lava	465	
	Kitchener, upper part	6000 ±	7400
Lower Cambrian	Kitchener, lower part	1400 ±	
	Creston, upper part	3000 ±	9500
Beltian	Creston, lower part	6500 ±	

Base unexposed.

In 1911, Daly identified for the writer, the Kitchener and Creston formations, in the neighbourhood of Kingsgate, B.C., (see map) where the south-flowing Moyie river crosses the International Boundary line. Subsequent work by the writer in 1912, definitely proved that the so-called Kitchener rocks near Kingsgate were older and not younger than the Creston, and the name Aldridge formation was proposed for this group of rocks. Further work on the section in the neighbourhood of the Moyie lakes (see map) showed that a group of rocks lithologically similar to those described by Daly as Kitchener, overlies the Creston and underlies the Siyeh. The name Kitchener has hence been retained for those rocks which overlie the Creston and underlie the Siyeh.

The Moyie formation was examined over a wide area. The area of Moyie rocks outlined by Daly west of Kingsgate was found to rest conformably upon the same rocks which Daly

[1] Daly, R. A., Geol. Surv. Can., Ann. Rept., 1904, p. 91A.
[2] Daly, R. A., Geol. Surv. Can., Memoir 38, 1913, p. 119.

identified as Kitchener, near Kingsgate, and which were subsequently proved to belong to the Aldridge formation. Hence, they cannot be Moyie as originally defined by Daly as lying conformably on the Kitchener. Lithologically, these so-called Moyie rocks are identical with the Aldridge and hence are classed as Aldridge. The Moyie in the vicinity of the Yahk river rests conformably on the Kitchener formation as defined by the writer, and in this region is lithologically similar to the lower part of the Siyeh formation and occupies the same stratigraphic position as the Siyeh south of Cranbrook, where it overlies the Kitchener and underlies the Purcell Lava.

The Purcell Lava is absent in the Boundary section but is present in the section south of Cranbrook (see map). Daly states that the Purcell Lava is absent between the Kitchener and Moyie on the International Boundary line, since the flow did not extend as far west as the Yahk river. The writer concludes that the lava occupied a position above the Moyie and has been removed by erosion, and that the Moyie is equivalent to the lower part of the Siyeh. Hence, the name Moyie has been dropped from the stratigraphic series of East Kootenay.

The Purcell series as defined by the writer, is as follows:—

	Erosion surface.	
Pre-Cambrian....................	Gateway	2000+
	Purcell Lava	300
	Siyeh	4000
	Kitchener	4500
	Creston	5000
	Aldridge	8000±
	Base unexposed.	

Aldridge Formation. The Aldridge formation is the oldest known sedimentary member of the Purcell series in the Purcell range. It consists of argillaceous quartzites and purer quartzites with a subsidiary amount of argillite. The beds vary in thickness from a few inches in the argillitic members to 8 feet in the pure quartzites, but the average thickness of the strata is 6 inches.

The argillaceous quartzites are grey to almost black in colour on fresh fracture. They weather to a rusty brown, and since the argillaceous quartzites are in greater abundance, they give the characteristic reddish-brown colour to the formation as a whole. The thick-bedded purer quartzites weather to a light grey colour. Shallow water features, except some conglomerates on Goat river, were not noticed in the Aldridge formation. In places, cubes of pyrite were abundant. A fact, worthy of emphasis, is that in this region the Aldridge formation is characterized by the presence of a relatively large number of thick gabbro sills called the Purcell Sills. The succeeding younger formations contain only a few gabbro sills, and these are relatively thin and unimportant.

Creston Formation. The Creston formation rests conformably upon the Aldridge formation. A transition zone 500 feet in thickness separates the Aldridge and the Creston formations. The latter consists of a well-bedded series of grey argillaceous, quartzites, purer quartzites, and sandstones with thin intercalations of argillite. The beds, averaging one foot in thickness, are often cemented together so that they form steep cliffs. In the western part of the range, in the vicinity of Goat river, the quartzites are coarser in texture, and resemble coarse sandstones in appearance, while in the eastern part they are finer-grained and more argillaceous. In general, the quartzites are grey on fresh fracture and weather to a grey colour, which is in distinct contrast to the weathering colour [illegible]idge formation. When the grey quartzites are impreg[illegible] cubes of pyrite, they weather reddish-brown.

Ripple marks were noted at sever[illegible]ns throughout the Creston formation. Intruded into the formation are a few gabbro sills reaching a thickness of 100 feet.

Kitchener Formation. Lying conformably upon the Creston formation and passing into it by gradual transition is the Kitchener formation, which is composed of calcareous argillites, calcareous quartzites, argillaceous quartzites, and limestones, in beds whose average thickness is 6 inches. The weathering colour is reddish-brown.

Siyeh Formation. Lying conformably on the Kitchene formation and passing into it by gradual transition occurs th Siyeh formation, which consists of purple and green siliceou argillites in beds from 1 inch to 2 inches in thickness. Dolo mites and limestones are present in the middle part of the forma tion. The argillites are characterized by the presence of abund ant mud-cracks and ripple marks.

Purcell Lava. The Siyeh epoch was brought to a close by the outpouring of basalt called the Purcell Lava. This lava consists almost entirely of amygdaloidal basalt with small amounts of rhyolite and breccia and is the extrusive phase of Purcell Sills.

Gateway Formation. The lower part of the formation consists of alternating bands of massive concretionary siliceous dolomite and limestone weathering buff, and massive light grey quartzites. These are succeeded by thin-bedded sand, argillites and greenish grey siliceous argillites. The sandy argillites weather a light buff and are characterized by the presence of abundant casts of salt crystals.

RELATION OF GALTON SERIES TO THE PURCELL SERIES.

The Purcell series of the Purcell range is the western or near-shore equivalent of the Galton series and the relations of these two series is expressed in the following table.

Galton series of the Galton range of Rocky Mountain system.	Purcell series of the Purcell range.
Roosville........	
Phillips........	
Gateway........	Gateway........
Purcell Lava........	Purcell Lava........
Siyeh........	Siyeh........
	Kitchener........
	Creston........
	Aldridge........

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Pre-Cambrian Sections of Northwestern Montana and Northern Idaho, by C. D. Walcott.

Belt mountains, Montana (Walcott).	Dearborn area, Montana (Walcott).	Lewis and Clark area, Montana (Walcott).	Lewis and Livingstone ranges, Montana (Willis).	Camp Creek, Mission Range section, Montana. (Walcott).	North and Northeast of Coeur d'Alene, Idaho. (Calkins).	Boundary section east from Kootenay river (Daly).
			No superjacent strata.	Cambrian. Unconformity. Camp Creek series Arenaceous-grey 1,762 feet.		
Cambrian. —Unconformity—	Cambrian.	Cambrian. —Unconformity.—	*Kintla.* *Sheppard* Quartzites. 1,200 feet.	Calcareous and arenaceous 1,500 feet.		
Marsh. 300 feet.						
Helena. Calcareous 2,400 feet.	Unconformity. Siliceous and calcareous. 945 feet.	Arenaceous 1,015 feet. Limestone, 265 feet.	Siyeh limestone. 4,000 feet.	Arenaceous mostly reddish colour 4,401 feet.		
Empire. 600+ *Spokane.* 1,500+ *Grayson.* 3,000+ Arenaceous strata 5,100 feet.	Greenish and purple, arenaceous and siliceous strata. 5,772 feet.	Arenaceous 1,210 feet. Base concealed. Total section 2,540 feet.	*Grinnell.* *Appekunny* Siliceous. 3,800 feet.	Arenaceous red and grey colours 196 feet of limestone near 700 feet from summit. 3,887 feet.	No superjacent strata. *Striped peak.* 2,000 feet.	
Newland. Calcareous 2,300+ feet.	Base concealed. Total section 6,718 feet.		*Altyn* calcareous and siliceous 700 feet.			
Chamberlain. Siliceous 1,500 feet. Neihart sandstone 700 feet.			Base concealed. Total section 9,700 feet.	*Blackfoot.* Calcareous and siliceous. 4,805 feet.	*Wallace.* Calcareous and siliceous. 5,000+feet.	No superjacent strata.
—Unconformity— *Archæan.* Total section 12,000 feet.				*Ravalli.* Siliceous and arenaceous. Purple and greenish and grey beds. 8,255 feet.	*Burke.* *Saint Regis.* Siliceous and arenaceous. Purple, greenish, and grey beds. 8,000 feet.	*Yahk.* 800 feet. *Moyie.* Argillite. 3,200 feet.
				Base concealed. Total section 24,760 feet.	*Prichard.* Banded, dark blue grey, blue black and grey. Siliceous series. 10,000 feet. Base concealed. Total section 25,000 feet.	*Kitchener.* Quartzite. 7,400 feet. *Creston.* Quartzite. 9,500+feet. Base concealed. Total section 20,000 feet.

Total thickness of section of Pre-Cambrian rocks in northwestern Montana and Northern Idaho, as now known, 37,000 feet.

ments in Montana and Idaho, by F. C. Calkins.

Probable Correlation of Principal Sections of Pre-Cambrian Sediments in Montana and Idaho, by F. C. Calkins.

Belt mountains (Walcott).[a]	Lewis and Livingston ranges (Willis).[b]	Philipsburg district (Calkins).[c]	Mission range (Walcott).[d]	Coeur d'Alene district (Calkins).[e]	Cabinet range, western and central parts (Calkins).	Forty-ninth parallel, between crossings of Kootenay river (Daly).[f]
Cambrian. ——Unconformity—— *Marsh*. Shale, red, 800 feet. *Helena*. Limestone, with some shale. 2,400 feet. *Empire*. Shales, greenish grey. 600 feet. *Spokane*. Shales, with thin beds of sandstone; deep red 1,500 feet. *Greyson*. Shales, mostly dark grey. 3,000 feet.	Top not seen. *Kintla*. Shale, maroon red; ripple marks, etc.; some quartzitic and calcareous beds. 800 feet. *Sheppard*. Quartzite yellow, ferruginous 700 feet. *Siyeh*. Limestone, dark blue or grey, weathering buff, with shale interbedded. 4,000 feet *Grinnell*. Shale, partly arenaceous; dark red; ripple-marked and sun cracked. 1,800 feet. *Appekunny*. Shale, grey black, and greenish, interbedded with white quartzite. 2,000± feet.	Cambrian. — Unconformity. — *Camp Creek*. Shale and sandstone, the latter prevailing in upper portion. Colour chiefly red. 5,000+feet to 0 feet.	Cambrian. ——Unconformity.—— *Camp Creek*. Sandstone, grey, rather thin bedded. 1,762 feet. Shales, sandstones, and limestones. 1,560 feet. Sandstones, mostly reddish. 4,491 feet Sandstones, largely shaly, colours red and grey, with 198 feet of limestone 700 feet below top. 3,887 feet.	Upper part of section eroded. *Striped Peak*. Shales and sandstone, red and green 1,000+ feet.	Shales and sandstones, medium to thin bedded; colour prevailingly greenish grey, but in part red and purple. Shales partly calcareous and weathering buff. A little white crystalline limestone, weathering yellow, at several horizons Base not seen. 10,000± feet. *Striped Peak*. Shales and shaly sandstones, prevailingly dark red; ripple marks, etc. 2,000+ feet.	Upper part of section eroded. *Yahk*. Quartzite. 500 feet.
Newland Limestone, impure, weathering buff, with interbedded shale. 2,200 feet. *Beltina danai*.	*Altyn*. Limestone, upper part thin-bedded and ferruginous; lower part greyish blue, massive, siliceous. 1,400 feet. *Beltina danai*. Base not exposed.	*Newland*. Limestone thin bedded, more or less siliceous and ferruginous, passing into shale generally buff on weathered surface 4,000 feet.	*Blackfoot*. Limestone thin bedded, more or less siliceous; siliceous layers, weathering buff, interbedded with calcareo-arenaceous shales. 4,805 feet. *Beltina danai*.	*Wallace*. Shales, more or less calcareous, interbedded with thin layers of siliceous and ferruginous limestone and calcareous sandstone. Limestones and calcareous shales weather buff. 4,000 feet.	*Newland*. Limestones, thin bedded, siliceous and ferruginous, interbedded with more or less calcareous shales. 5,000± feet.	*Moyie*. Argillite. 3,400 feet.
Chamberlain. Shale, mostly bla[illegible]k, with some san[illegible]stone, 1,500 feet.		*Ravalli*. Quartzite, grey, with some dark bluish and greenish shale. 2,000 feet.	*Ravalli*. Sandstones, quartzitic, fine grained, greyish purple and grey. 2,550 feet. Sandstones, compact grey. 1,060 feet. Sandstones, greenish grey, fine grained, in layers 4 inches to 2 feet thick. 4,645 feet. Base not seen. Total Ravalli, 8,255 feet.	*St. Regis*. Shales and sandstones, purple and green. 1,000 feet. *Revett*. White quartzite, partly sericitic. 1,200 feet. *Burke*. Indurated siliceous shales, with sandstones and quartzites, prevailingly grey-green. 2,000 feet.	*Ravalli*. Quartzites, siliceous shales, and shaly sandstones; upper par. green and purple; lower part grey mostly greenish, locally with faint purple tinge; middle part thickest bedded, and most quartzitic, consisting locally of fairly pure white quartzite. 8,000 ± feet.	*Kitchener*. Ferruginous quartzite. 7,400 feet.
Neihart. Quartzite, with some shale in upper part. 700 feet		*Prichard*. Shales, dark bluish, interbedded with sandstone; rusty brown on weathered surface. 5,000± feet. Quartzite, light coloured. Base not exposed. 1,000± feet		*Prichard*. Argillite, blue-grey to black, with distinct and regular banding, interbedded with a subordinate amount of grey sandstone. Uppermost part arenaceous and marked with shallow-water features. Base not exposed. 8,000+feet.	*Prichard formation*. Argillite, dark bluish, banded. 2,000 feet. Sandstones, grey, thick bedded to shaly, interbedded with more or less sandy bluish shales. The rocks become more argillaceous toward the south-east. 10,000± feet. Base not exposed.	*Creston*. Quartzitic sandstones, thick-platy, grey, interbedded with a subordinate amount of bluish argillaceous material. Base not exposed. 9,500+ feet.
Archæan.						

a Walcott, C. D. Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199-244.
b Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges, Montana: Bull. Geol. Soc. America, Vol. 13, 1902, pp. 305-352.
c Report in preparation.
d Walcott, C. D. Algonkian formations of northwestern Montana: Bull. Geol. Soc. America, vol. 17, 1906, pp. 1-28.
e Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.
f Daly, R. A., Summary Rept. Geol. Survey, Canada, for 1904, 1905, pp. 91-100.

Daly in his correlation of the Galton and Purcell series emphasizes the importance of the Purcell Lava in the correlation of not only these two series, but for all the equivalent series of the Rocky Mountain geosynclinal.[1] In addition, the Siyeh and Gateway formations are identical lithologically in the Galton and Purcell series.

General Correlation of Pre-Cambrian (Beltian) by Walcott.

Walcott made the first general correlation table of the Beltian of Montana, Idaho, and British Columbia, in a paper entitled the "Algonkian Formation of Northwestern Montana,[2]" and for convenience this table is here reproduced.

General Correlation of Pre-Cambrian (Beltian) by Calkins.

In 1908, Calkins[3] formulated a correlation table of the Beltian as a result of a rapid reconnaissance in Idaho and Montana and along the International Boundary line across the Purcell range. His correlation table based upon Walcott's of 1906, is identical with Walcott's except as to the position of the Purcell series. Both Walcott and Calkins place the whole of the Beltian in the Pre-Cambrian. Calkins' table of formation is here appended.

[1]Daly, R. A., Geol. Surv. Can., Memoir 38, p. 162.
[2]Walcott, C. D., Bull. G. S. A., vol. 17, 1906, p. 17.
[3]Calkins, F. C., U. S. G. S., Bulletin 384, 1908, p. 40.

General Correlation of Pre-Cambrian (Beltian) by Daly.

Daly, in 1913, from his field work along the International Boundary line, puts forward the accompanying correlation table.[1]

Correlation of Pre-Cambrian (Beltian) by Schofield.

(1) Correlation of Purcell Series with Coeur d'Alene Series. The correlation of the individual members of the Coeur d'Alene series with the Purcell series by Walcott and Calkins was based upon Daly's subdivision of the Purcell series which was found to be erroneous. The writer, in 1911, carefully examined the formations in the Coeur d'Alene district and was able to identify in that region with some degree of certainty, the formations exposed in East Kootenay. The following table shows the writer's conception of this correlation.

Coeur d'Alene Series.		*Purcell Series.*	
Striped Peak	1000+	....Siyeh (lower part)	2000+
Wallace	4000	....Kitchener	4500
St. Regis	1000		
Revett	1200	..Creston	5000
Burke	2000		
Prichard	8000+	....Aldridge	8000±

(2) General Correlation of Pre-Cambrian by Schofield. The following general correlation table is based on Walcott's original table presented on the foregoing page of this article, with additions by the writer on the results of field work in the Pre-Cambrian of Idaho and British Columbia. It will be noticed that the controversy centres around the age of the Siyeh limestone which is one of the most important horizon markers in the Beltian.

The evidence for the determination of the Siyeh limestone as Middle Cambrian by Daly on stratigraphical and lithologic bases, is given in part by these words.

[1]Daly, R. A., Geol. Surv., Can., Memoir 38, p. 178.

Correlation Table Pre

1 Summit series, Selkirk, range, 49° N. Lat.	2 Purcell series, Purcell range, 49° N. Lat.	3 Coeur D'Alene series (1).	4 Series in Cabinet range (1).	5 Series in Philipsburg district (2).	6 Series in Mission range (3).	
Conformity with upper Palæozoic?	Erosion surface.	Erosion surface.	?	Conformity with upper Palæozoic.	?	E
Lone Star, 2,000+feet.	Moyle 3,400+feet.	Striped Peak, 1,000 +feet.	Striped Peak, 2,000 + feet.	Meagher, 400 feet. Wolsey, 100-300 feet. Flathead, 50-300 feet.	Flathead. Thickness. ? Camp Creek, 11,700 (?) feet.	E P G
Beehive, 7,000 feet.	Kitchener, upper part, 6,000± feet.	Wallace, 4,000 feet. St. Regis, 1,000 feet.	Blackfoot (called Newland by Calkins) 5,000± feet.	Camp Creek, 0-5,000 feet Blackfoot, 4,000 feet.	Blackfoot, 4,805 feet	G S
Ripple, 1,650 feet. Dewdney, 2,000 feet. Wolf, upper part, 1,000± feet.	Kitchener, lower part, 1,400± feet. Creston, upper part, 3,000+feet.	Revett, 1,200 feet. Burke, 2,000 feet. Prichard, upper part, 1,500± feet.	Ravalli, upper part, 5,000± feet. Ravalli, lower part, 3,000± feet.	Ravalli, 2,000 feet. Prichard, upper part, 2,000± feet.	Ravalli, upper part, 4,550 feet.	W M H
Wolf, lower part, 1,900± feet. Monk, 5,500 feet. Irene Volcanic formation, 6,000± feet. Irene conglomerate 5,000+ feet. Total, 32,050+feet.	Creston, lower part, 6,500± feet. Base concealed. Total, 20,300+feet.	Prichard, lower part 6,500+feet. Base concealed. Total, 17,200+feet.	Prichard, 10,000± feet. Base concealed. Total, 27,000+feet.	Prichard, lower part, 3,000± feet. Neihart, 1,000± feet. Base concealed. Total, 12,550-18,000 feet.	Ravalli, lower part, 4,000+feet. Base concealed. Total, 25,055 feet.	Al Bo To
Unconformity.						
Priest River terrane.						

56815—p. 90a

(1) F. C. Calkins, Bull. 384, U. S. Geol. Survey, 1909, p. 40.
(2) F. C. Calkins, Bulls. 384 and 315, U. S. Geol. Survey, 1909 (p.
(3) C. D. Walcott, Bull. Geol. Soc. America, Vol. 17, 1906, p. 2.
(4) C. D. Walcott, Bull. Geol. Soc. America, Vol. 10, 1899, p. 201,
(5) C. D. Walcott, Smithsonian Misc. Collections, Vol. 53, No. 181

able Prepared by R. A. Daly.

Mission (3).	7 Galton series, Galton range, 49° N. Lat.	8 Lewis series, Clarke and Lewis ranges, 49° N. Lat.	9 Series in Belt mountains (4)	10 Castle Mountain Bow River series (5)	11 Series at Blacksmith Fork, Utah (5).	12 System.
	Erosion surface.	Erosion surface.	Conformity with upper Palæozoic.	Conformity with upper Palæozoic.	Conformity with upper Palæozoic.	
				Sherbrooke, 1,375 feet. Paget, 300+feet. Bosworth, 1,855+ feet.	St. Charles, 1,227 feet.	Upper Cambrian.
? . k, 11,700	Roosville, 600+feet. Phillips, 550 feet. Gateway, 1,850 feet.	Kintla, 820 feet. Sheppard, 500 feet.	Gallatin. Flathead.	Eldon, 2,728 feet.	Nounan, 1,041 feet. Bloomington, 1,320 feet.	Chiefly Middle Cambrian.
1,805 feet	Gateway, lower part, 125 feet. Siyeh, 4,000 feet.	Sheppard, lower part 100 feet. Siyeh, 4,100 feet.	Marsh, 800 feet. Helena, 2,400 feet. Empire, 600 feet.	Stephen, 640 feet. Cathedral, 1,595 feet.	Blacksmith, 570 feet. Ute, 726 feet. Spence, 30 feet. Langston, 498 feet. Brigham, upper part.	Middle. Cambrian.
per part, .	Wigwam, 1,200 feet. MacDonald, 2,350 feet. Hefty, 775 feet.	Grinnell, 1,000 feet. Appekunny, 2,600 feet.	Spokane, 1,500 feet. Greyson, 2,000± feet	Mount Whyte, 390 feet. St. Piran, 2,705 feet. Lake Louise, 105 feet. Fairview, 600+feet.	Brigham+1,232 feet.	Lower Cambrian.
ver part, t. led. 5 feet.	Altyn, 650 feet. Base concealed. Total, 12,100 feet.	Altyn, 3,500± feet. Waterton, 200+ feet. Base concealed. Total, 13,420 feet.	Greyson, 1,000± feet Newland, 2,200 feet. Chamberlain, 1,500 feet. Neihart, 700 feet. Total, 14,000± feet.	Continuation of Bow River argillites. Base concealed. Total, 12,352+ feet.	Base concealed. Total, 6,647+feet.	Beltian.
			Unconformity.			
			Cherry Creek beds			
			Unconformity.			
			"Archæan."			

r. 40.
ey, 1909 (p. 40) and 1907 (p. 33).
906, p. 2.
899, p. 201, and references therein, to Peale and Weed.
53, No. 1812, 1906.

GENERAL CORRELATION TABLE.

Clark and Lewis range 49th Parallel.	Rocky Mountains, B.C.	Purcell range, B.C.	Coeur d'Alene district, Idaho.	Cabinet range, Montana.	
R. A. Daly, G.S.C. Mem. 38, 1913, p. 97.	The correlation of these two series by the author is based on sections described by Daly (G.S.C., Memoir 38, 1913) and subsequently modified by the author.		F. C. Calkins, U. S. G. S., Prof. Paper 62, 1908, p. 25.	F. C. Calkins, U. S. G. S., Bull. 384, 1909, p. 40.	
	Lowest Middle Cambrian.				Cambrian.
	Unconformity.				
Erosion surface.	Roosville, 1,000 feet.				
	Phillips, 500 feet.	Erosion surface.		Erosion surface.	
Kintla, 800 feet. Sheppard, 600 feet.	Gateway, 2,025 feet.	Gateway, 1,000 feet.			Pre-Cambrian
Purcell Lava.	Purcell Lava.	Purcell Lava.	Erosion surface.	Shales and sandstones 10,000 feet.	(Beltian).
Siyeh, 4,100 feet.	Siyeh, 4,000 feet.	Siyeh, 4,000 feet.	Striped Peak, 1,000 feet.	Striped Peak, 2,000 feet.	
Grinnell, 1,600 feet. Appekunny, 2,600 feet.	Wigwam, 1,200 feet. MacDonald, 2,350 feet. Hefty, 775 feet.	Kitchener, 4,500 feet.	Wallace, 4,000 feet.	Blackfoot, 5,000 feet.	
Altyn, 3,500 feet.	Altyn, 650 feet.				
		Creston, 5,000 feet.	St. Regis, 1,000 feet. Revett, 1,200 feet. Burke, 2,000 feet	Ravalli, 8,000 feet.	
		Aldridge, 8,000 ± feet.	Prichard, 8,000 feet.	Prichard, 10,000 feet.	

"Walcott recognizes the Cambrian-Ordovician equivalent of McConnell's Castle Mountain group as occurring near Belton, Montana, and Nyack creek, Montana. At these localities, massive bluish and greenish limestones bearing a species of Raphistoma and Stromatoporoid form, were found in great development. As shown by Plate 6 of Walcott's paper, the field habit of these limestones is extremely similar to that of the Siyeh limestone at Mt. Siyeh, which is less than 15 miles distant from the Nyack Creek locality. It is difficult to avoid the suspicion that these Castle Mountain limestones are, in truth, identical with the Siyeh limestone in which, therefore, Middle Cambrian fossils may at some future time be discovered."[1]

The discovery of lowest Middle Cambrian fossils in the Burton formation, 3535 feet above the Siyeh formation, points out that the Siyeh limestone cannot be Middle Cambrian, and since the Siyeh formation occurs below the unconformity which exists between the Pre-Cambrian and the Cambrian in the Rocky Mountain geosynclinal, it is concluded that the Siyeh is Pre-Cambrian in age.

This conclusion is supported by Walcott in the following words.

"The series of limestones at the head of Nyack creek illustrated by Plate 6, are of Cambrian or Ordovician age, as indicated by fragments of fossils that I found in them. I do not think the Siyeh limestone is to be correlated with them nor with the Castle Mountain limestones of McConnell."[2]

[1]Daly, R. A., Geol. Surv., Can., Memoir 38, 1913, p. 183.
[2]Walcott, C. D., Geol. Surv. Amer., Bull., vol. 17, 1906, p. 19.

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VI. Early Cambrian Stratigraphy in the North American Cordillera, with Discussion of Albertella and Related Faunas.

By Lancaster D. Burling.

INTRODUCTION.

In 1913, Schofield first noticed the presence near Elko, British Columbia, of fossils immediately superjacent to a great series of rocks (the Galton) generally assigned to the Pre-Cambrian. Together with Mr. Schofield the writer visited the locality during the latter part of the same field season and secured fossils from four closely related horizons in the basal layers of the Burton formation in the immediate vicinity of the Burton mine, about 2 miles northwest of the town of Elko, British Columbia.

Schofield has called attention to this discovery in a review of the Pre-Cambrian rocks of the northern Cordillera.[1]

In adjoining areas the Galton series is mantled by the Devonian[2], and Willis[3] found the Carboniferous resting unconformably upon a similar series of rocks in northern Montana, so that the importance of the discovery at Elko depended largely upon the age of the fossils. This is particularly true for the reason that the Pre-Cambrian age of the underlying beds has been called in question.[4] That the upper and best represented of the faunas secured by Schofield and myself should happen to

[1] Geol. Surv. Can., Museum Bull. No. 2, 1914, pp. 79-91.
[2] Idem, p. 83.
[3] Bull. Geol. Soc. America, vol. 13, 1902, p. 325.
[4] Daly, R. A.: Geol. Surv., Can., Memoir No. 38, 1912, pp. 174-178.

be referable to the *Albertella* fauna, a zone which appears to occupy a debatable position between the Lower and the Middle Cambrian, is fortuitous and it will be necessary to preface the discussion of the age of the Burton formation by a general review of our present knowledge concerning the *Albertella* fauna, the Pioche formation, the relations of the basal Cambrian to the Pre-Cambrian rocks, and the boundary between the Lower and the Middle Cambrian in the Cordilleran region.

THE BASAL CAMBRIAN AND ITS RELATIONS TO THE PRE-CAMBRIAN.

The formations referred to the Pre-Cambrian in the Cordilleran region have already been described and correlated in detail.[1] In this review Schofield[2] has outlined the diastrophic criteria for the separation of the Burton formation (Cambrian) and the Roosville (Pre-Cambrian). In the following pages will be given a fairly detailed account, mainly from a palæontologic standpoint, of the beds composing the basal Cambrian in the various districts and of their relations to the Pre-Cambrian. Of the sections described the writer has visited those in British Columbia, Idaho, and Utah, with the single exception of the one at Yellowhead pass, and has drawn largely upon his unpublished field notes for the descriptions which follow.

The various districts are arranged in an order comparable with the successive stages in the advance of the Lower-Middle Cambrian sea upon the Cordilleran region, as follows: California, Nevada, Arizona, Utah, Idaho, Montana, and British Columbia.

California, Inyo County, Waucoba Springs.—The Lower Cambrian occurs east of Waucoba Springs, on the Saline Valley road, east of the Inyo range, Inyo county, California,[3] as a series of limestones, arenaceous limestones, shales, and sandstones, 5,670 feet thick, without observed upper or lower limits, and within which the genus *Olenellus* and its immediate

[1]Schofield, S. J.: Geol. Surv., Can., Museum Bull. No. 2, pp. 79-91.
[2]Idem, p. 84.
[3]Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 185-188.

allies have a range of 4,900 feet. This section and the one at Barrel Spring, Nevada, exhibit the greatest known development of fossiliferous Lower Cambrian.

Nevada, Silver Peak, Barrel Spring.—The Lower Cambrian limestones, shales, and quartzites in the vicinity of Silver Peak, Nevada, appear to have an exposed thickness of 6,250 feet,[1] without upper and lower limits, and are much like those east of Waucoba Springs, California, with the exception of the interruption of the middle of the section by a mass of andesite 750 feet thick. The genus *Olenellus* and its congeners (the Mesonacidæ) appear to have a vertical distribution in this section of about 5,300 feet. If there is no duplication in either this section or the one near Waucoba Springs, California, these vertical distributions for the Mesonacidæ of 5,300 and 4,900 feet, respectively, are of great importance and indicate clearly that, in the absence of ample diastrophic criteria, there is little justification for assigning to the Pre-Cambrian any of our basal quartzitic series, no matter how thick they may be. Such occurrences can also be interpreted as indicative of the relatively quiescent conditions which obtained in the ocean covering the southwestern portion of the continent during the time required for the general northeasterly advance of the overlapping portion of the same body of water. Traces of organic life are conspicuously absent from the major portion of the sediments resulting from this encroachment, but favourable habitats in the new sea areas appear to have shared the biota of the ocean to the southwest.

Nevada, Highland Range.—The basal quartzite series is succeeded in the Highland range of Nevada by the Pioche formation which is stated[2] to be 170 feet thick. A limestone in the section at Bennet Springs[3] carries a fauna which is to be compared directly with the fauna assigned to the Pioche at Pioche (See page 120.) As is explained on page 122, in the discussion of the Pioche formation, Mr. Walcott has called attention to the relative positions in these faunas of the *Olenellus* horizon and the horizon indicated by the other fossils, and to the fact that in the early collections from the Big Cotton-

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[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 188–189.
[2] Idem, No. 1, 1908, pp. 11–12.
[3] Walcott: Mon. U. S. Geol. Survey, vol. LI, 1912, p. 189.

wood Canyon, Highland Range, and Eureka District sections the two horizons were not separated by the field observers.[1]

The Lower Cambrian is represented by at least the lower portion of the Pioche formation (see page 121) but the relation of the underlying quartzite series, which has an exposed thickness of 350 feet,[2] to the Pre-Cambrian is unknown. Over 1,000 feet above the layers with *Olenellus* in the Highland Range section, occurs a fauna, No. 21 of the section,[3] which can be correlated with that of the Middle Cambrian portion of the "Pioche" in Big Cottonwood canyon and can be assigned to the Spence shale horizon[4] in northeastern Utah and Idaho and to the *Ogygopsis* zone of the Stephen formation in British Columbia. These faunas are discussed more fully in the section on the Pioche formation, pages 120-125.

Nevada, Pioche.—The most thorough discussion of the stratigraphy near Pioche, Nevada, is furnished by Pack[5] who gives the following section[6]:—

1. Limestone	800	feet.
2. Shale [=*Zacanthoides typicalis* zone]	75	"
3. Limestone	600	"
4. Shale [=Pioche formation]	400	"
5. Quartzite	1500	"

The town of Pioche lies in the northwestern portion of a pitching anticlinal[7] which has been considerably disturbed by faulting, but in which there is a general concentric arrangement of the shale and limestone formations about the quartzite. Both shale horizons carry well developed faunas, that of the lower (400 feet) being the one quoted on page 120, and generally ascribed to the Pioche formation.

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[1] Walcott: Bull. U. S. Geol. Survey, No. 81, 1891, p. 319.
[2] Idem, No. 30, 1886, p. 33.
[3] Idem, p. 34.
[4] The name Spence has been carried southward to the House range (Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 183) where the rocks to which the name has been applied carry a fauna more closely analogous to that in the shales forming No. 21 of the Highland Range section, but no name has as yet been applied either to these shales or to the Middle Cambrian shale outcropping near the mines in the Ely mountains near Pioche (No. 2 of the above section).
[5] School of Mines Quarterly, vol. XXVII, 1906, pp. 285-312.
[6] Idem, p. 295.
[7] Idem, pl. II, between pp. 290 and 291.

The interpretation of such a fauna as properly belonging to the Lower Cambrian has, in addition to any doubt which might be occasioned by the association itself, been clouded by the reported occurrence[1] in "the Ely mountains, just east of the Highland range", and, therefore, very near Pioche, of a Middle Cambrian shale (2 of the section, page 96) carrying several species identical with those in the "Lower Cambrian." Pioche lies on the north slope of the Ely mountains and the literature has thus come to indicate the presence near Pioche of two shales of more or less indefinite position, and with comparable faunas, the one referred to the Lower, the other to the Middle Cambrian[2].

F. J. Pack[3] was the first to point out the relationship between these two shales, their typical outcrops being given as 5 or 6 miles apart and separated by a stratigraphic interval of 1,000 feet.

The two localities may be closely defined as follows: (1) the shale which has been referred to the Lower Cambrian (4 of the section page 96) and for which the name "Pioche" was proposed[4] outcrops southeast of the town of Pioche on the road to Panaca, Nevada;[5] (2) the shale which has been referred to the Middle Cambrian outcrops in the dumps of the Abe Lincoln, Chisholm, and Half Moon mines west and northwest of Pioche.[6] The second outcrop is upon the western flank of the anticline, the first upon the east.

As thus defined the lowest shale (4 of section) represents the Pioche formation and appears to be divisible (see pages 121-123) into a basal *Olenellus gilberti* zone, and an upper portion or *Crepicephalus* zone which is believed to be Middle Cambrian in age and is in this paper (see page 127) correlated with the *Albertella* fauna in Montana and British Columbia and the Burton formation in southern British Columbia. The upper shale

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[1] Walcott: Bull. U. S. Geol. Survey, No. 30, 1886, p. 35.

[2] Cf. localities 31 and 31a, Mon. U. S. Geol. Survey, vol. LI, 1912, p. 192.

[3] School of Mines Quarterly, vol. XXVII, 1906, pp. 292 and 294-296.

[4] Walcott: Smithsonian Misc. Coll., vol. 53, No. 1, 1908, pp. 11-12.

[5] "On the east side of the anticlinal arch at Pioche:" Bull. U. S. Geol. Survey, No. 30, 1886, p. 35.
"Southeast of Pioche on the road to Panaca, Utah:" Smithsonian Misc. Coll., vol. 53, No. 1, 1908, p. 11.
"Southwest of Pioche on the Panaca Road:" Idem, No. 5, 1908, p. 184.

[6] "In the Ely Mountains just east of the Highland Range, owing to mining operations:" Bull. U. S. Geol. Survey, No. 30, 1886, p. 35.

(2 of section, page 96) carries a fauna which has been referred to the Spence (Middle Cambrian) in the House range (see page 96) and which is to be correlated directly with No. 21 of the Highland Range section. The Middle Cambrian faunas of the two shales bear more or less striking resemblances to each other. Gilbert, who was the first to describe the district,[1] appears to have had little doubt as to the unity of the different shales (2 and 4 of section, page 96), and attempted to account by faulting for their presence near the mines. Pack's description[2] of the two formations (their occurrence and their metamorphism, particularly the obliteration of bedding planes in both the quartzite and limestone, the pockety nature of the upper shale outcrops and their variation in thickness from 4 to 100 feet in distances of half a mile, the fact that many of the ores of the district occur as "bedded deposits" along fault planes in the upper shale formation, etc.) also bears internal evidence of the possibility that the two formations may be the same.

The relations between the two shale series and their correlation is further discussed in the section on the Pioche formation, pages 120-125.

Arizona, Grand Canyon.—The sediments overlying the Pre-Cambrian in the Grand Canyon region have been referred to the Tonto group and placed in the Middle Cambrian.[3] They are stated[4] to have been deposited upon an erosion surface[5] transecting at least 13,000 feet of strata and cutting deeply into the Archæan. This pre-Tonto series consists of limestones and shales remarkable for their lack of metamorphism, but the evidence of an unconformity so profound as the one by which they are separated from the Cambrian leaves little question as to the correctness of their reference to the Pre-

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[1] U. S. Geog. Surveys West 100th Meridian, vol. III, 1875, pp. 257-261.
[2] School of Mines Quarterly, Vol. XXVII, 1906, pp. 291-292 and 294-296.
[3] Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 167.
[4] Walcott: American Jour. Sci., 3d. ser., vol. XXVI, 1883, p. 440.
[5] The unconformity at the base of the Cambrian involves erosion and the line will frequently be spoken of as a plane of erosion or an erosion surface. It is to be understood, however, that the Cambrian might be in contact with several or even all of the underlying Pre-Cambrian formations through depositional or other causes without postulating a period of erosion so intense as actually to have removed the missing strata. And such an explanation is favoured by the continental origin assigned to the Pre-Cambrian by such observers as Barrell (Jour. Geol., vol. 14, 1906, pp. 553-568).

Cambrian. No Lower Cambrian fossils have been found in the Tor[illegible] lowest horizon represented being the lower portion [illegible]iddle C[illegible]mbrian.

Utah, House Range.—No Lower Cambrian fossils, with the exception of annelid trails and trilobite ? tracks (*Cruziana*), have been found in the House range in western Utah, though that section is only 100 miles distant from Pioche, Nevada, where the Lower Cambrian Pioche formation is so typically developed. The base of the section is formed of a series of unfossiliferous quartzitic sandstones and arenaceous shales 1,500 or more feet in thickness, conformably overlain by arenaceous limestones of Middle Cambrian age. In view of the proximity to Pioche there appears to be no reason for doubting the reference of the quartzitic series to the Lower Cambrian, but the Pre-Cambrian appears to be unrepresented. The horizon of the Spence shale is well represented in the House range 200 feet above the quartzitic series.

Utah, Oquirrh Range.—The first reference to the Cambrian of the Oquirrh range is by Howell[1] who mentions Primordial "shale carrying several species of trilobites and *Discina*," and it is probable that this material furnished the species for which White[2] proposed the name *Olenellus gilberti*. Emmons[3] found a fauna in 100 feet of greenish yellow clay slates immediately overlying a quartzite series which is not listed as containing *Olenellus* and which is apparently referable to a higher horizon, the *Bathyuriscus productus* zone (see page 101). Walcott[4] mentions a shale in the Oquirrh range as carrying both of these faunas (*Olenellus gilberti* and *Bathyuriscus productus*) but in 1891[5] he credits the collection to the Wheeler (100th Meridian) Survey and states that it probably represents an artificial mixing of the collections from two distinct zones similar to that described for Big Cottonwood canyon (page 101) and Pioche (page 121). The shale near Ophir City in the Oquirrh range is thus apparently the lithologic, stratigraphic, and faunal equivalent of the Pioche shale in the Big Cottonwood Canyon section.

[1] U. S. Geog. Surveys West 100th Meridian, vol. III, 1875, pp. 237-238.
[2] Idem, vol. IV, 1877, pp. 45-46.
[3] U. S. Geol. Expl. 40th Parallel, vol. II, 1877, pp. 443-444.
[4] Bull. U. S. Geol. Survey, No. 30, 1886, pp. 39-40.
[5] Idem, No. 81, 1891, pp. 319-320.

Utah, Wasatch Mountains.—The sedimentation in the different portions of the Wasatch mountains varies so greatly that the individual sections will be described in detail. The Bear River plateau or range, with the Blacksmith Fork, Utah, section upon its western flank and the Mill canyon, Idaho, section upon the east, is also to be included in the northward extension of the Wasatch mountains though it lies to the east of the Wasatch mountains proper and is separated from that range by a pronounced depression.[1] The Wasatch Canyon, Ogden Canyon, and Big Cottonwood Canyon sections occupy positions along the north-south line formed by the western escarpment of the Wasatch mountains. In the southern portion (Big Cottonwood canyon) *Olenellus* occurs in siliceous shales at the top of the quartzitic series (see below); 70 miles to the north (Wasatch canyon), and in the Bear River range immediately to the east (Blacksmith Fork and Mill canyon) conditions favouring the deposition of sandstone appear to have continued into the Middle Cambrian and the upper portion of the quartzitic series, here named the Brigham quartzite, is referable to the Middle Cambrian.[2] (See also the summary statement, pages 110-111).

Utah, Wasatch Mountains, Big Cottonwood Canyon.—An unfossiliferous quartzite 1,000 to 1,500 feet thick, conformably overlain by arenaceous shales containing *Olenellus*, itself rests with angular unconformity upon an almost similarly metamorphosed quartzite, slate, and conglomerate series approximately 10,000 feet thick, the erosion surface being so uneven that in places the upper quartzite series even rests on a much older gneiss and schist series which has been referred to the Archæan.[3] Here the weight of evidence would seem to be in favour of a Pre-Cambrian age for the quartzite, slate, and conglomerate series, and a Lower Cambrian age for the upper quartzite series.

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[1] The classic reports on the geology of the Fortieth Parallel by King, Hague, and Emmons, with their accompanying atlas, still contain the only comprehensive description and delineation of the geology of the area included within this mountain system.

[2] Middle Cambrian fossils have been found in the Brigham quartzite in Mill canyon only (see p. 102), but there as well as throughout the area the quartzite series is immediately overlain by beds similar both in lithology and faunal content, and the generalization would appear to be applicable.

[3] Blackwelder: Bull. Geol. Soc. America, vol. 21, 1910, p. 523.

The overlying shale series is the stratigraphic, lithologic, and faunal (?) equivalent of the Pioche formation in Nevada, and like that formation (see page 122) its first description[1] listed fossils collected from Lower and Middle Cambrian zones a hundred or more feet apart. This mistake was corrected in 1891[2] when the formation was divided into two zones, a lower one with *Olenellus* which for convenience of description we shall call the *Olenellus gilberti* zone of the Pioche formation, and an upper one with "*Lingulella ella, Bathyuriscus producta,*" etc., which for similar reasons will be called the *Bathyuriscus productus* zone of the Pioche formation. In Big Cottonwood canyon, therefore, this unit is lithologic and includes both Lower and Middle Cambrian horizons Indeed it includes the only Lower Cambrian forms so far discovered in the section and the placing below it of the line between the Lower and Middle Cambrian would remove from the underlying beds the very fossils upon which their age is predicated. For this reason that boundary is believed to be correctly assigned to a position above the *Olenellus gilberti* zone and it may be expected that subsequent work in the district will show this lower horizon to be properly separable as a lithologic member of the Pioche, more closely related to the underlying quartzite than to the overlying shale(see pages 124-125). Hintze[3] has proposed the term Alta shale for the strata between the quartzite and the "Ordovician" limestone to which he has applied the term Maxfield. The discovery, by Mr. F. B. Weeks and the writer,[4] of Middle Cambrian fossils in the type section of this limestone obliterates the "hiatus" at the top of the "Alta" and leaves that name so nearly the equivalent of the Pioche as hardly to warrant its adoption.

Utah, Wasatch Mountains, Ogden Canyon.—The basal quartzite in Ogden canyon, Utah, is an apparently conformable series about 1,000 feet thick, which rests on gneisses and schists referred to the Archæan and is itself overlain by shales containing fossils that have been referred to the Middle Cambrian. Black-

[1] Walcott: Bull. U. S. Geol. Survey, No. 30, 1886, p. 39.
[2] Idem, No. 81, 1891, p. 319.
[3] Annals N. Y. Acad. Sci., vol. XXIII, 1913, pp. 104, 105.
[4] Unpublished notes.

welder[1] discusses the stratigraphy and structure in the Ogden Canyon region, correlating the shales immediately above the quartzite with the "Middle Cambrian [portion of the] Pioche." The Langston limestone[2] is not present in the measured section, and while *Olenellus* was not secured from the layers immediately above the quartzite the succession appears to correspond more closely with that in the Big Cottonwood Canyon section less than 50 miles to the south than in the Bear River range to the northeast.

Utah, Wasatch Mountains, Wasatch Canyon.—At the mouth of the first small canyon south of Wasatch canyon, 5 miles north of Brigham, Utah, the Spence shale is well developed and the succession is in every way comparable with that in the Bear River range (Mill canyon) to the northeast.

Utah, Blacksmith Fork.—The basal quartzite series has an exposed thickness of 1,000 or more feet without observed unconformity, and grades upward into a series of massive limestones to which the name Langston has been applied.[2] The line between the Langston and the underlying Brignam is here drawn 500 feet down in this gradational series, while at Malade and on Mill creek in the Bear River range, Idaho, localities within 45 miles of the section in Blacksmith Fork, the Langston is very thin, sharply set off from the underlying quartzite, and crowded with fossils referable to the Middle Cambrian. In the Blacksmith Fork section no fossils were found in the Brigham quartzite, but that formation, in the Mill Canyon section, has yielded fossils upon whose basis the Brigham quartzite has been referred, at least in part, to the Middle Cambrian.[3]

Idaho, Bear River Range, Mill Canyon Section.—The sedimentation in the Mill Canyon section of the Bear River range is closely comparable with that at Blacksmith Fork in the southern portion of the same range, see above. The Middle Cambrian Brigham quartzite is clearly to be distinguished from the overlying Langston limestone, however, and the latter formation is here only 25 or more feet thick and abundantly fossiliferous. As in the Blacksmith Fork section it is conformably overlain

[1] Bull. Geol. Soc. America, vol. 21, 1910, pp. 526 and 534–539.
[2] Walcott: Smithsonian Misc. Coll., vol 53, No. 5, 1908, p. 198.
[3] Mon. U. S. Geol. Survey, vol. LI, 1912, p. 153.

by the Middle Cambrian Spence shale which is of interest in this connexion because of the similarity in lithologic position between it and the Pioche formation. The error resulting from admixture of Lower and Middle Cambrian forms in the lists of fossils credited to the Pioche formation (see pages 122-123) has been perpetuated for years and has s[illegible] further accentuated the resemblance of the Pioche to the Spence. The presence of *Olenellus* in the Pioche has been the "insurmountable" barrier to this correlation, but the division of the Pioche into two zones referable to the Lower and Middle Cambrian respectively permits the true correlation of the Spence with the upper or *Bathyuriscus productus* zone. See the discussion of the Pioche formation on pages 120-125.

Idaho, Malade.—In Two Mile canyon, southeast of Malade, Idaho, the relations of the Langston limestone to the Brigham quartzite closely approximate those in the Mill Canyon section of the Bear River range. The limestone is much thinner, however, only 5 or 6 feet, and is very fossiliferous, thirty species having been identified.[1] Of these *Oryctocephalus* is perhaps the most interesting in this connexion, because of the very limited stratigraphic distribution of this most striking form. It has been found not only in the Langston limestone and the overlying Spence shale at Malade, in the Spence in Mill canyon, Idaho, and in the Stephen formation on Mount Stephen, British Columbia, all localities which appear to be referable to one remarkably uniform though widespread Middle Cambrian horizon, but it was included in the collections which have been assigned to the "Lower Cambrian" Pioche formation. This occurrence has been used on page 124, as an argument for the correctness of the proposed division of the Pioche.

Montana, Big Belt and Little Belt Mountains.—The lowest rocks referred to the Cambrian in the Big Belt and Little Belt mountains of Montana are the Flathead sandstones which are stated[2] to carry fossils in the lowest horizons "comparable with the oldest part of the Middle Cambrian fauna as the latter occurs a short distance above the *Olenellus* horizon in Utah and Nevada."

[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 198-199.
[2] Walcott: Bull. Geol. Soc. America, vol. X, 1899, pp. 209-245.

If this correlation is correct the fauna of the Flathead would appear to be quite closely comparable to that of the shales in the Dearborn River section which are also believed to be referable to the base of the Middle Cambrian (See the discussion of the age of the *Albertella* fauna, pages 118-120). Differences of metamorphism between the Flathead and the underlying formations are marked and the two series are separated by an unconformity which brings the Cambrian Flathead into contact not only with many of the different units into which the Pre-Cambrian has been divided but with the Archæan as well. Here, as in the Grand Canyon region of Arizona, the Pre-Cambrian age of the lower series would seem to be demonstrable, though the overlying rocks can not be proven to have been deposited earlier than the Middle Cambrian.

Montana, Dearborn River Section.—An unfossiliferous sandstone 150 feet thick separates a superjacent shale carrying an assemblage of fossils to which the name *Albertella* fauna has been given, from underlying shales having apparently the same strike and dip as the base of the sandstone, but which appear, when traced on the strike, to occupy an unconformable relation. The upper shale and sandstone are referred to the Lower Cambrian by Walcott,[1] the underlying shales being referred to the Pre-Cambrian. The Pre-Cambrian age of these underlying shales seems to be well attested by sections measured by Mr. Walcott at many other points in this area of Beltian rocks. The overlying shale and sandstone, however, occupy lithologic positions exactly analogous to those of the Wolsey shale and Flathead sandstone in the Little Belt Mountains section, 100 miles to the east. There both the Wolsey and the Flathead carry well developed Middle Cambrian faunas, and while that of the Wolsey is noticeably different from the *Albertella* fauna found in the Dearborn River section, the fossils occurring in the underlying Flathead in the Little Belt Mountains are described by Mr. Walcott as comparable with the oldest part of the Middle Cambrian fauna (see page 103). This, the *Albertella* fauna is now believed to represent, see pages 116-120.

[1] Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 203.

Montana, Phillipsburg District.—The Pre-Cambrian rocks are separated from a quartzite series correlated with the Flathead by an unconformity involving angular discordance, yet[1] "difficulty will often arise in exactly defining the limit between the Flathead and the Spokane (Pre-Cambrian). A sharp boundary can be drawn only where the unconformity is visible, or where the Flathead rests on shaly Spokane strata and the contact is marked by an abrupt lithologic change." No fossils were obtained from the upper quartzite series ("Flathead") and it can not be referred with certainty either to the Lower or Middle Cambrian.

British Columbia, Elko.—The Pre-Cambrian rocks about two miles northwest of the town of Elko, British Columbia, are overlain without angular unconformity by a transitional sandstone, sandy limestone, and shale series to which the name Burton formation has been applied.[2] The formation is readily divisible into a basal sandstone member 20 feet thick, and an upper shale member about 40 feet thick, but the faunas which have been secured from these beds all appear to be referable to the early Middle Cambrian. They are correlated with the *Albertella* fauna and, more or less tentatively, with the *Crepicephalus* zone of the Pioche formation. (See page 126 and the section on the Burton formation, pages 125-128).

British Columbia and Alberta, Mount Bosworth Section and Bow River District.—The base of the section along the main line of the Canadian Pacific railway in British Columbia and Alberta is composed of a clastic series to which McConnell early[3] applied the term Bow River series or Bow River group. It is several thousand feet thick and has been recently described[4] as including 2,500 feet of Pre-Cambrian at the base. Frequent variations in the sedimentation and the presence of conglomerates at many places in the section,[5] however, complicate the proposed separation. The Cambrian rocks of the Bow River district have

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[1] Emmons and Calkins: Prof. Paper, U. S. Geol. Survey, No. 78, 1913, p. 51.
[2] Schofield: Geol. Surv. Can., Museum Bull. No. 2, 1914, p. 82.
[3] Ann. Rept. Geol. and Nat. Hist. Survey Canada for 1886, Part D, 1887, pp. 29 D-30 D.
[4] Walcott: Smithsonian Misc. Coll., vol. 53, No. 7, 1910, p. 428.
[5] McConnell: Ann. Rept. Geol. and Nat. Hist. Survey Canada for 1886, Part D, 1887, p. 30 D; and Daly: Geol. Survey Canada, Memoir No. 38, 1912, p. 176.

recently been subdivided by Walcott[1] who places the boundary between the Bow River group and the overlying Castle Mountain group[2] below a 20-foot bed of interbedded arenaceous limestones and siliceous shales (the *Olenellus canadensis* zone) forming the base of the Mount Whyte formation. The correlation of the top of this bed with the upper boundary of the Bow River group would make that group synonymous with the Lower Cambrian, at least so far as their upper limits are concerned, and would permit the relegation to the Middle Cambrian of the upper portion of the Mount Whyte in spite of the inclusion within that horizon of fragments which appear to be referable to *Olenellus*. The correctness of this reference is indicated (a) by close faunal affinities between the underlying Bow River group and the 20-foot bed in question and (b) by the presence just above that horizon of the *Albertella* fauna (see pages 116-120), a striking assemblage which is here known, in its typical expression, only from two drift blocks. One of these loose fragments weighing several tons has been thoroughly tooled by both Mr. Walcott and the writer without discovering the smallest fragment referable to *Olenellus*. The absence of this genus in strata so widespread (Montana and British Columbia, page 113) and so minutely studied, here possesses special significance since these layers appear to be interbedded between strata carrying *Olenellus* and supports the impression that the occasional appearance in the Mount Whyte of fragments referable to the latter genus is to be explained by the recurrence of a lingering type.

The discussion of the basal Cambrian sedimentation in the Mount Robson district (see below) also contains additional notes on the Mount Bosworth section.

British Columbia and Alberta, Yellowhead Pass Region, Mount Robson Section.—In 1901 McEvoy[3] described and mapped the geology in the vicinity of Yellowhead pass, dividing the basal stratigraphic succession into a "Lower Cambrian Bow River series" and an "Upper Cambrian Castle Mountain group"

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[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 204-217.
[2] McConnell: Ann. Rept. Geol. and Nat. Hist. Survey Canada for 1886, Part D, 1887, pp. 24 D-29 D.
[3] Ann. Rept. Geol. Survey Canada for 1898, vol. XI, 1901, Part D, with map.

which "may include some beds newer than the Cambrian but not distinctly separable from it."[1]

This conception of the stratigraphy and of the relations between this section and that along the main line of the Canadian Pacific railway to the south has been confirmed by the recent discovery[2] of Lower Cambrian fossils in the upper beds of the Bow River series and of drift blocks indicating the Ordovician age of the upper portion of the Robson massif, all of which was mapped by McEvoy as Castle mountain.

The Cambrian strata are divided by Walcott[2] into nine formations, see page 109, but fossil collections were only secured from general horizons in the Hota, Chetang, and Titkana. McEvoy's Bow River series is divided into a Cambrian and Pre-Cambrian sequence, but the thickness of the basal Cambrian sandstones (McNaughton) is described[3] as very uncertain since it is difficult to determine the line of demarcation between them and the unconformably underlying Miette sandstones. Here the lack of knowledge concerning the relations between the two basal sandstone series leaves some doubt as to the Pre-Cambrian age of the Miette, but the Lower Cambrian age of at least a portion of the basal clastics is certain. In this region the *Albertella* fauna is assigned[4] to a position 350 feet below the top of the 900 feet of Chetang limestones [illegible] of which is placed above the Lower-Middle Cambrian bo[illegible] While the *Albertella* fauna is thus separated by a consid[illegible] interval from what seems to be the correct position for the top of the Lower Cambrian, the actual data with regard to the distribution of the *Olenellus* fauna in the Hota formation below that boundary are very meagre.[4] On the line of section fragments assigned to the genus occur in the upper layers of this formation on Mahto mountain, a recognized species (*Olenellus canadensis*) was obtained from a horizon placed about 300 feet below the top and an undetermined species near the top of the formation, and the new subfauna with *Callavia, Wanneria, E[illegible]a?*, and *Olenellus*[5] is assigned to the 800 feet of which this formation

[1] Ann. Rept. Geol. Survey, Canada, for 1898, Vol. XI, 1901, Part D, geological notes on map.
[2] Walcott: Smithsonian Misc. Coll., vol. 57, No. 12, 1913, pp. 327–343.
[3] Idem, p. 339.
[4] Idem, p. 338.
[5] Idem, vol. 57, No. 11, 1912, pp. 309–326.

(the Hota) is composed without observation as to its relations to the upper or lower limits of that formation. Stratigraphic arrangements based solely on apparent stages in the development of the included faunas have been a source of error in the past, but this new subfauna, including *Olenellus* as it does, appears to represent a horizon high up in the Lower Cambrian, even if it may not be as young as the *Olenellus canadensis* fauna of the Mount Bosworth section to the south. If its reference to the Hota is correct it is separated by at least 550 feet of strata from the *Albertella* fauna which does not contain *Olenellus*, either here or in the Mount Bosworth region, where, as has been stated, tons of its enclosing sediment have been worked up in the minutest of detail by both Mr. Walcott and the writer.

The absence in the Mount Robson region of any fossil collections from this 550 foot interval as well as from the 250 feet immediately overlying the *Albertella* horizon, coupled with the fact that in the Mount Whyte formation of the Mount Bosworth section *Olenellus* is also absent from the beds above the position to which the *Albertella* fauna was assigned[1], would appear to lend weight to the assumption that the Chetang limestone and that portion of the Mount Whyte formation down to and including the *Albertella* horizon are to be referred to the same division of the Cambrian. As the writer has intimated in the discussion of the Mount Bosworth section, page 106, he believes the upper portion of the Mount Whyte formation to be Middle Cambrian in age. Mr. Walcott[2] has placed this formation entirely in the Lower Cambrian, but he appears to recognize its kinship with the Chetang, which also carries the *Albertella* fauna, by stating[3] that that fauna occurs at about the same horizon in both the Mount Bosworth and Mount Robson sections. In his table of formations in these two

[1]Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 212–215, gives 3 faunal horizons above the *Albertella* horizon in the "Lower Cambrian" Mount Whyte, all without *Olenellus*, the evidence for the statement (p. 203 of the same reference) that that genus "occurs so generally in the Mount Whyte formation, both above and below the *Albertella* horizon" and for the writer's discussion of the possibility of the recurrence of *Olenellus* above the Lower-Middle Cambrian boundary (page 117) being the presence in a different section (the Mount Stephen), though in an apparently similar position, of fragments assigned to *Olenellus*.

[2]Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 212. Its reference to the Middle Cambrian in No. 1 of the same volume, page 2, being a typographical error.

[3] Idem, vol. 57, No. 12, 1913, p. 338.

districts,[1] however, the Mount Whyte is correlated with the Lower Cambrian Hota formation, presumably upon the basis of the presence in each of the genus *Olenellus* and the absence from the overlying beds in each case of anything referable to that genus. This principle, to which Mr. Walcott has long subscribed, altogether ignores the stratigraphic value of so new and striking an assemblage as the *Albertella* fauna, and places that biota in the Lower Cambrian on Mount Bosworth and in the Middle Cambrian on Mount Robson. The Titkana and Eldon are correlated upon page 343 of the same paper whereas beds at least 1,000 feet above the base of the former unit are stated on page 337 to have yielded a fauna directly comparable with that of the Stephen formation. The Mount Robson Cambrian section, which is 9,200 feet thick, has yielded only seven fossil horizons and three of these are closely related zones with *Olenellus*, consequently the following table can be presumed to give only the major features of the correlation between the Mount Robson and Mount Bosworth sections:—

Correlation of Cambrian Formations in British Columbia.

	Mount Robson district.		Mount Bosworth district.	
Upper Cambrian	Lynx	2,100	Ottertail	1,725+
			Chancellor	2,500+
			Sherbrooke	1,375
			Paget	360+
			Bosworth	1,855+
Middle Cambrian	Titkana	2,200	Eldon	2,728
			Stephen	640+
	Mumm	600	Cathedral	1,595+
	Hitka	1,700		
	Tatay	800		
	Chetang	900	Mount Whyte	390
Lower Cambrian	Hota	800		
	Mahto	1,800	St. Piran	2,705
	Tah	800	Lake Louise	105
	McNaughton	500+	Fort Mountain	2,700

[1] Smithsonian Misc. Coll., vol. 57 No. 12, 1913, p. 343.

These sections differ from those of Walcott[1] in the correlations, in the substitution of the Fort Mountain for the Fairview,[2] and in the addition of the Ottertail and Chancellor formations.[3] The only correlations which can be assumed, from our present information, to have any certainty are (*a*) the equivalence of at least part of both the Hota and Chetang to the Mount Whyte and (*b*) the equivalence of the Stephen to the lower portion of the Titkana. The Mumm, Hitka, Tatay, Mahto, Tah, and McNaughton formations in the Mount Robson district have proven unfossiliferous[4] and this is also true for the Bosworth and Fort Mountain formations near Mount Bosworth.[5]

(See also the section of the *Albertella* fauna, pages 116-120).

Summary.—The data presented in the preceding pages are largely utilized in the discussion oft he boundary between the Lower and Middle Cambrian, pages 112-115, and form the basis also for the discussion of the *Albertella* fauna, the Pioche formation, and the Burton shales, but the following summary statement may be useful:—

In the Big Cottonwood Canyon, Oquirrh Range, and Pioche sections, the only localities northeast of the Highland range from which *Olenellus* has been obtained, the quartzite series is succeeded by siliceous or sandy shales; where the same series grades into limestone in the northern portion of the Wasatch mountains, both the limestone and the overlying argillaceous shale carry Middle Cambrian fossils, and at one point (Mill canyon) this fauna extends into the underlying quartzite. Diagnostic fossils were not discovered at the following localities, but if the above generalization may be applied to this portion of the Cordilleran region, Mill canyon, Idaho, and Blacksmith Fork, East Fork canyon, Geneva, Wasatch canyon, and Promontory point, Utah, all represent sections where the upper part of the quartzite series is of Middle Cambrian age; and this appears to hold for the Onaqui range, 50 miles southwest of Big Cottonwood canyon. With this exception, however, the quartzite series,

[1] Smithsonian Misc. Coll., vol. 57, No. 12, 1913, p. 343.
[2] Walcott: Mon. U. S. Geol. Survey, vol. 51, 1912, p. 131.
[3] Allan, Summary Rept. Geol. Survey Branch, Dept. Mines, Canada, for 1911, 1912, p. 178.
[4] Smithsonian Misc. Coll., vol. 57, No. 12, 1913, pp. 337-339.
[5] Walcott: Mon. U. S. Geol. Survey, vol. 51, 1912, pp. 125-131.

if present at all, is succeeded by siliceous shales and appears to be of Lower Cambrian age in all of the examined sections south and southwest of Ogden canyon, Utah, and north and east of the Highland range, Nevada. These include the Stansbury Range (Muskrat Spring), Oquirrh Range, Simpson Range, Beaver River Range (Cricket Spring), and House Range sections. The basal quartzite series is not exposed in the other sections measured in this area. In the Highland range[1] the basal quartzite series is separated from the *Olenellus gilberti* zone of the Pioche formation by 35 feet of limestone.

In the Grand Canyon, Big Cottonwood Canyon, Phillipsburg, Mount Bosworth, and Mount Robson sections, variations in the degree of metamorphism between the Cambrian and Pre-Cambrian are so slight as to make this criterion of little value. At Elko only is there a pronounced difference.

In the Grand Canyon, Big Cottonwood Canyon, and Phillipsburg sections the unconformity between the Cambrian and Pre-Cambrian involves angular discordance; in the other sections unconformity can be proven only by overlap, basal conglomerates, etc.

The Cambrian and Pre-Cambrian systems both appear to be represented in the Grand Canyon, Big Cottonwood Canyon, Dearborn River, Phillipsburg, Elko, Mount Bosworth(?), and Mount Robson (?) sections; in Ogden canyon and in the Big Belt and Little Belt mountains the Cambrian rests on the Archæan.

The Pre-Cambrian does not appear to be represented in the Highland Range, Pioche, House Range, Wasatch Canyon, Blacksmith Fork, Mill Canyon, and Malade sections.

The Lower Cambrian is not represented by fossil evidence in the Blacksmith Fork, Malade, Wasatch Canyon, Mill Canyon, Big Belt and Little Belt Mountains, Dearborn River, Phillipsburg (?), and Elko (?) sections.

The relations of the Lower Cambrian to the over- and underlying strata do not appear to have been observed in the Waucoba Springs or Silver Peak sections.

[1] Walcott: Bull. U. S. Geol Survey, No. 30, 1886, p. 33.

THE BOUNDARY BETWEEN THE LOWER AND MIDDLE CAMBRIAN.

The Lower Cambrian has, by general usage, been defined as the time interval dominated by the *Olenellus* fauna, beginning with its earliest advent and ending with its final disappearance. Such a definition for the upper limit has been called in question[1] and, as has been outlined on page 106, the Mount Bosworth and Mount Stephen sections in British Columbia appear to represent environments of so favourable a nature that *Olenellus*, or the local representative of that genus, there became temporarily immune and did not share the timely oblivion to which the other members of the group appear to have been doomed.

Chamberlin and Salisbury[2] suggest the possibility that *Olenellus* in the west may be contemporaneous with *Paradoxides* in the east, but Walcott has shown[3] the latter genus to be the probable derivative of a line of *Olenellus* ancestors including *Nevadia*, *Callavia*, *Holmia*, and *Wanneria*. Schuchert[4] would separate the two divisions and give them systemic rank, a conclusion reached from a study of the relations for the continent as a whole; Ulrich[5] would not.

Prior to 1905 the last traces of the genus *Olenellus*, the top of the quartzitic sandstone series, and the top of the Lower Cambrian were supposed, for the Cordilleran region at least, to be synonymous, indeed this condition appears to hold for Nevada and Utah as far north as Big Cottonwood canyon in the Wasatch range just south of Salt Lake City. Between this point and the Upper Columbia lakes[6] nearly 700 miles to the north in British Columbia, however, *Olenellus* is unknown, and the only palæontologic evidence for the presence of the Lower Cambrian throughout this distance is the reference to that period of the *Albertella* fauna in the Dearborn River section of central Montana. That the Lower Cambrian and a con-

[1] Ulrich: Bull. Geol. Soc. America, vol. 22, 1911, p. 619.
[2] Text book of Geology, vol. II, 1907, p. 245.
[3] Smithsonian Misc. Coll., vol. 53, No. 6, 1910, p. 249.
[4] Bull. Geol. Soc. America, vol. 20, 1910, p. 483.
[5] Idem, vol. 22, 1911, pp. 625–627.
[6] Dawson: Ann. Rept. Geol. Survey, Canada, for 1885, vol. 1, 1886, p. 156B, refers rocks at this locality to the Cambrian, but states that the included fossils were not determined even generically. They are preserved in the collections of the Victoria Memorial Museum and have been identified by the writer as *Olenellus*.

siderable portion of the Middle Cambrian seas were continuous between Nevada and British Columbia there can be little doubt. Apparently synchronous deposits occur in the Lower Cambrian of California, Nevada, Utah, British Columbia, and Alberta, though in the latter region limestone forming conditions obtained long before the actual disappearance of *Olenellus*, an event which is not believed by the writer to have been contemporaneous with the close of the Lower Cambrian (see page 112). The *Albertella* fauna crosses the interval between Gordon creek, Montana, and Mount Bosworth, British Columbia, a distance of 300 miles, with only a modicum of change; and the Spence-Stephen-Titkana fauna of the Middle Cambrian, though characterizing different lithologic facies and occupying different positions with respect to the [illegible] clastics in the areas where it has been discovered, still preserves its identity through the 1,100 miles separating the Highland range of Nevada from the Mount Robson district of British Columbia and Alberta. This broad expanse of water was bounded on the east in northern Utah, southeastern Idaho, and central Montana by land areas whose submersion was gradual and upon whose Pre-Cambrian shores the sea matured from Lower to Middle Cambrian in age before it was able to mantle the Pre-Cambrian regolith.

Without going into a discussion of the problems involved in the satisfactory solution for the continent as a whole of the true relations of the Lower to the Middle Cambrian, we may base our conclusion that the Cordilleran region offers a very close approximation to a gradual transition between these two units upon the following grounds: (*a*) the Mesonacidæ, or *Olenellus*-like genera, are everywhere represented in the uppermost layers of the Lower Cambrian by *Olenellus* (s.s.) or the latest[1] if not the highest exponent of the group for which it has long been considered typical, the importance of the apparent annihilation of this genus over so large an area being tempered by the presence of a recurrent(?) species in the Mount Stephen section of British Columbia; (*b*) in the Mount Robson region the upper portion of the rocks referred to the Lower Cambrian contains representatives of all of the genera (*Callavia*,

[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 6, 1910, p. 248.

Wanneria, and *Holmia*) that have been placed[1] upon the theoretical line of evolution between the primitive *Nevadia* and the Middle Cambrian Paradoxidæ; (*c*) there is widespread evidence of a transition fauna (the *Albertella*) between the Lower and the Middle Cambrian, a fauna distinct from its predecessors in the region and so closely united with those which follow that it has in this paper been referred to the Middle Cambrian, but whose very presence betrays a kinship between the two divisions of the Cambrian which is only emphasized by the apparent recurrence in younger strata of a surviving member of the illfated Mesonacidæ; and (*d*) nowhere have unconformable relations between the two units been observed. To be sure there is evidence of a gradual encroachment upon an eastern land mass of the waters of a great Lower-Middle Cambrian sea which appears to have been continuous from Nevada to British Columbia, but the slowness of the approach effectually barred the Mesonacidæ from participating in the march upon the promised land and reserved to their descendants the peopling of shores not 50 miles away.

In California and Nevada the Lower Cambrian arenaceous series contains large quantities of calcareous and argillaceous matter, and *Olenellus* and its congeners there yield our only record of their existence during a period long enough for the deposition of a mile or more of strata. Here the time interval necessary for the gradual spread of the Lower Cambrian sea upon the western portion of our continent was spent under conditions of more or less stable equilibrium and the deposits have yielded representatives of the Mesonacidæ ranging from the most primitive (*Nevadia*) to the most highly specialized (*Olenellus* s.s.)[2] Elsewhere in the United States portion of the Cordilleran region the members of this group appear to be confined to *Olenellus* (s.s.) and occur only in the upper thin-bedded layers of a highly arenaceous series referred to the Lower Cambrian,[3] as if the waters in or by which these sediments were deposited proved so inhospitable that the life which teemed

[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 6, 1910, p. 249.
[2] Idem.
[3] The Middle Cambrian age of a lithologic equivalent of this series has been described, p. 102.

in the contemporaneous seas of Nevada and California held back until the very last. Farther north, in British Columbia, however, the genus ranges sparingly through the upper 500 feet of a similar clastic series and then occurs in great profusion in the lower 20 feet of an overlying transitional formation.

Here the true Lower-Middle Cambrian boundary from a diastrophic standpoint would appear to lie just above this clastic series, but the profusion of Lower Cambrian forms in the overlying 20 feet[1] suggests the drawing of the boundary above that stratum, and the correctness of this interpretation appears to be attested by the occurrence, in the immediately overlying beds, of the Middle Cambrian *Albertella* fauna with its host of new types (See pages 118-119).

A similar delineation of the boundary between the Lower and Middle Cambrian has been made in Big Cottonwood canyon, Utah, in the belief that where so distinctive a Lower Cambrian form as *Olenellus* occurs just above a quartzitic series, even in transitional beds, and is neither associated with nor preceded by forms characteristic of the Middle Cambrian, we are not doing violence to the principles to which we subscribe (pages 119-120) when we suggest that the divisional boundary between the Lower and Middle Cambrian be drawn above the horizon characterized by that genus.

In our opinion the sudden and widespread introduction of so characteristic a biota as the *Albertella* fauna was an event of far more importance than the ultimate extinction of the Mesonacidæ, and the Lower-Middle Cambrian boundary has been drawn below that horizon. When the absolute disappearance of the preceding biota or of any one type is not considered a necessary corollary to the inauguration of a new period, inconsistencies which appeared to be difficult of explanation no longer vex us but give way to new problems, and the delimitation of the boundaries between the stratigraphic units becomes one of increasing complexity because of the substitution of the proper valuation of a debatable series of diastrophic and organic phenomena for a simple yes or no.

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[1] Walcott: Smithsonian Misc. Coll. vol. 53, No. 5, 1908, pp. 214-215.

THE ALBERTELLA FAUNA.

The *Albertella* fauna has had an interesting history. It was first discovered in 1905 by Mr. C. D. Walcott[1] in a shale 75 feet above a quartzitic sandstone on Gordon creek, 6 miles from the south fork of Flathead river, Ovando quadrangle (U. S. Geol. Survey), Powell county, Montana. In 1907, drift blocks up to several tons in weight were discovered on the south slope of Mount Bosworth about 500 feet northwest of the main line of the Canadian Pacific railway between Hector and Stephen, British Columbia.[2] The duplication between these drift blocks and the original locality in Montana is nearly perfect, specimens from the two localities containing at least four identical species and being almost interchangeable. At the time the drift blocks were discovered their horizon in the section could not be located and subsequent attempts have likewise proven futile. The fossiliferous shale carrying the *Albertella* fauna, an assemblage of more than a dozen species, is at least 4 feet thick, yet the only trace of its presence in the measured sections is a fragment of one specimen referred to the genus from which the fauna derives its name. On Mount Stephen, 8 miles away, the beds with which the *Albertella* fauna is correlated, and which themselves contain fragments referable to the genus, are overlain and underlain by *Olenellus*, and the *Albertella* fauna was, therefore, assigned to the Lower Cambrian.[3]

In a recent publication Walcott[4] mentions finding the *Albertella* fauna in the Mount Robson region of British Columbia, 150 miles north of the main line of the Canadian Pacific. Curiously enough the fauna was there also found in drift blocks, though their horizon was located in the measured section. It is described as occurring 550 feet above the top of the Lower Cambrian in the Chetang limestone, yet the apparently contradictory statement is made[5] that it "occurs at about the same horizon in the Mount Bosworth section" where it has been referred to the Lower Cambrian. A large part of the discussion of the basal

[1] Mon. U. S. Geol. Survey, vol. 51, Pt. I, p. 168, locality 4v.
[2] Idem, p. 197, locality 35c.
[3] Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, pp. 203 and 214
[4] Smithsonian Misc. Coll. vol. 57, No. 12, 1913, p. 338.
[5] Idem.

Cambrian sedimentation in the Mount Bosworth and Mount Robson regions of British Columbia, see pages 105-110, relates to the occurrence of this fauna. In neither of these sections is the *Albertella* fauna found below *Olenellus*, and as has been outlined on the pages just referred to the occurrence of the latter genus above an *Albertella* in the Mount Stephen section seems to argue rather for the recurrence in the basal Middle Cambrian of a surviving member of the Mesonacidæ than for the Lower Cambrian age of a fauna so distinct from its predecessors as the one in question.

The collections from China which have so recently been described[1] contain a representative of the genus *Albertella*, to which the specific name *pacifica* has been applied.[2] It is to be distinguished from the species of *Albertella* described for the Cordilleran region by the presence upon its posterior margin of four instead of two spines, but it is referred to the genus without hesitation by Mr. Walcott. It occurs 1,000 feet above a white quartzite in a low bluff on the shore of Tschang-hsing-tau island, in Liau-tung, Manchuria, and is the highest horizon from which fossils were obtained. Its resemblance to *Albertella* and its reference to a position well up in the Middle Cambrian appear to warrant its inclusion in the present discussion.

The field relations of the horizon of the *Albertella* fauna may be summarized as follows: (*a*) In the Dearborn River section of Montana and at Elko, British Columbia, it is without close relations to known faunal horizons and occurs in a shale series conformably overlying a basal sandstone; (*b*) on Mount Bosworth it was found in the drift but was referred to the Lower Cambrian because of the presence in a section 8 miles away (Mount Stephen) of *Olenellus* fragments both above and below its correlated horizon, a siliceous shale interbedded in a gradational sandstone, shale, and limestone series; (*c*) in the Mount Robson region it occurs in the section 350 feet down in a 900 foot formation described[3] as composed of "bluish grey thin

[1] Walcott: Research in China, vol. 3, 1913, pp. 1-276.
[2] Idem, p. 106, pl. 12, fig. 3.
[3] Walcott: Smithsonian Misc. Coll., vol. 57, No. 12, 1913, p. 338.

bedded limestone" and referred to the Middle Cambrian; and (*d*) in China it occurs well up in the Middle Cambrian.

The affiliations of the species constituting the *Albertella* fauna are nearly all with those of the Middle Cambrian. The fauna abounds in types not found in the Lower Cambrian, and while several of them are undescribed the following list of described species will be sufficient for the purposes of our study:—

Described Species of Albertella Fauna.

——	Mount Bosworth.	Dearborn river.
	British Columbia.	Montana.
Micromitra (Paterina) wapta Walcott	X	
Micromitra (Iphidella) pannula (White)		X
Obolus parvus Walcott	X	
Obolus (Westonia) ella (Hall and Whitfield)		X
Acrothele colleni Walcott	X	X
Acrothele panderi Walcott		X
Wimanella simplex (Walcott)	X	X
Olenopsis agnesensis Walcott	X	
Olenopsis americanus Walcott		X
Albertella bosworthi Walcott	X	
Albertella helena Walcott	X	X
Bathyuriscus productus (Hall and Whitfield)		X

Micromitra (*Iphidella*) *pannula* has been identified from forty-one Cambrian localities[1] of which ten have been referred to the lower division of that system. Three of these are from the Pioche formation and one from the *Albertella* fauna. *Micromitra* (*Paterina*) *wapta*[2] and *Obolus parvus*[3] are confined to beds to which the *Albertella* fauna has been referred in British Columbia. *Obolus* (*Westonia*) *ella*[4] has been found at 55 different localities, yet only three are referred to the Lower Cambrian and they are all referable to the "Pioche" or *Albertella* faunas. *Acrothele colleni*[5] has been found only in the Stephen formation, in the beds to which the *Albertella* fauna was referred in British Columbia, and in the upper part of the shale which carries the *Albertella*

[1]Walcott: Mon. U. S. Geol. Survey, vol. 51, 1912, pp. 363–364.
[2]Idem, p. 357.
[3]Idem, p. 408.
[4]Idem, pp. 457–458.
[5]Idem, pp. 641–642.

fauna on Dearborn river, Montana. *Acrothele panderi*[1] and *Wimanella simplex*[2] are confined to the *Albertella* fauna. *Olenopsis agnesensis*[3] and *O. americanus*[4] are the coordinate representatives in correlatable beds of a genus which has not hitherto been identified in North America but which Mr. Walcott[5] refers to the Lower Cambrian on the basis of the "Lower Cambrian" age of the *Albertella* fauna and describes as "a form intermediate between *Holmia* (restricted) and *Paradoxides*[6] or * * * descendant from the *Holmia* type of the Mesonacidæ." *Albertella bosworthi* and *A. helena* are described by Mr. Walcott[7] as representing most interesting types of the Paradoxidæ which "should first be compared with the genus *Zacanthoides* which, in the British Columbia section, is first met with in strata 2,000 feet above the beds in which *Albertella* occurs." *Bathyuriscus productus* is the representative of a genus typical of the Middle Cambrian in the Cordilleran region. It occurs in the Spence and Stephen formations and is one of the two species mentioned by Mr. Walcott[8] as characteristic of the upper or Middle Cambrian portion of the Pioche formation.

With the single exception of *Micromitra* (*Iphidella*) *pannula*, therefore, none of the twelve described species of which this fauna is composed are known to occur in rocks older than the horizon under discussion. Moreover, two of the types (*Albertella* and *Olenopsis*) seem to be derived from the old and to be prophetic of the new, and the remainder are either confined to the *Albertella* fauna or are typically to be referred to the Middle Cambrian.

The problem before us does not seem sufficiently complicated to require a discussion of the principles governing the delimitation of stratigraphic units, since, by its attitude toward both of the elementary lithologic and organic propositions (*a*) that

[1] Walcott: Mon. U. S. Geol. Survey, vol. 51, 1912, p. 652.
[2] Idem, p. 748.
[3] Walcott: Smithsonian Misc. Coll., vol. 57, No. 8, 1912, p. 242.
[4] Idem, p. 243.
[5] Idem, p. 239.
[6] The writer does not share this view of the phyletic relations of *Olenopsis*, but believes with Mr. Walcott that it is probably descendant from the Mesonacidæ.
[7] Smithsonian Misc. Coll., vol. 53, No. 2, 1908, p. 18.
[8] Bull. U. S. Geol. Survey, No. 30, 1886, p. 39.

a gradational series of beds in which the transition is from the more clastic to the less should be included with the younger, and (*b*) that the introduction of new faunas, even of new types in faunas preserving more or less of their original character, is a phenomenon attending the inception rather than the decline of stages in the earth's history, the *Albertella* fauna seems to have achieved the right to be classed with the Middle Cambrian.

THE PIOCHE FORMATION.

The Pioche formation was first described in 1908[1] when Pioche, Nevada, was cited as the type locality and it was stated to carry the Lower Cambrian *Olenellus* fauna. Later in the same year[2] it was described for the House Range section of western Utah and accompanied by a list of the fossils at Pioche, an assemblage which is compared in the following table with a list first published in 1886.[3]

Fauna of strata ("2, 3, and 4"?) resting on the quartzite at Pioche, Nevada, 1886.[4]	Fauna of the Pioche formation at Pioche, Nevada, 1908.[5]	Fauna of the Pioche formation at Pioche Nevada, 1912.[6]
Eocystites?? longidactylus	Eocystites? longidactylus	
Lingulella ella	Obolus (Westonia) ella	
Kutorgina pannula	Micromitra (Iphidella) pannula	Micromitra (Iphidella) pannula.
Acrothele subsidua	Acrothele subsidua	Acrothele subsidua.
	Acrothele subsidua hera	Acrothele subsidua hera.
	Acrothele spurri	Acrothele spurri.
Acrotreta gemma	Acrotreta primæva	Acrotreta primæva.
Orthis highlandensis	Billingsella highlandensis	Billingsella highlandensis.
Hyolithes billingsi	Hyolithes billingsi	Hyolithes billingsi.
Olenellus gilberti	Olenellus gilberti	Olenellus gilberti.
Olenoides levis	Zacanthoides levis	Zacanthoides levis.
Crepicephalus augusta	Crepicephalus augusta	Crepicephalus augusta.
Crepicephalus liliana	Crepicephalus liliana	Crepicephalus liliana.
		Olenoides sp.
		Ptychoparia sp.
		Oryctocephalus primus.

[1] Walcott: Smithsonian Misc. Coll., vol. 53, No. 1, 1908, pp. 11–12.
[2] Idem, No. 5, 1908, p. 184.
[3] Walcott: Bull. U. S. Geol. Survey, No. 30, 1886, p. 35.
[4] Idem.
[5] Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 184.
[6] Mon. U. S. Geol. Survey, vol. LI, 1912, p. 192.

The list quoted in the first column has been copied and recopied with little or no modification until 1912[1] when examination of the original material in the collections of the U. S. National Museum resulted in the withdrawal from the list of *Obolus* (*Westonia*) *ella* and *Eocystites ? longidactylus* and the insertion of *Olenoides* sp., *Ptychoparia* sp., and *Oryctocephalus primus*. Why the latter species, which was described in 1886[2], has not been included in previous lists is more or less of a mystery. Its presence is important, see page 103.

In the following discussion of the beds in question the term Pioche formation will be used though it was not so applied until 1908, see page 120. It will be shown that this formation is divisible into two zones: (1) a lower, characterized from eastern Nevada to northeastern Utah by the trilobite *Olenellus gilberti*, which will be called the *Olenellus gilberti* zone and assigned to the Lower Cambrian; and (2) an upper, which, from the collections at our disposal, appears not to belong to the same portion of the Middle Cambrian in the different sections from which the Pioche has been identified. In the Big Cottonwood Canyon and Oquirrh Range sections this upper zone will be called the *Bathyuriscus productus* zone and correlated with the Spence-Stephen-Titkana fauna; at Pioche and in the Highland range (Bennett Spring) it will be called the *Crepicephalus* zone and tentatively correlated with the *Albertella* fauna and the Burton formation.

The rocks of the Pioche formation as they were first described for the Big Cottonwood Canyon section of Utah[3] were given a thickness of 250 feet and listed as carrying the following fauna: "*Cruziana* sp., *Lingulella ella*, *Kutorgina pannula*, *Hyolithes billingsi*, *Leperditia argenta*, *Olenellus gilberti*, *Ptychoparia quadrans*, and *Bathyuriscus productus*."

The commingling of Lower and Middle Cambrian types exhibited by this fauna was first admitted by Walcott in 1891[4] and the presence of the error has been noted[5], but there appears

[1]Mon. U. S. Geol. Survey, vol. LI, 1912, p. 192.
[2]Walcott: Bull. U. S. Geol. Survey, No. 30, 1886, p. 210.
[3]Idem, pp. 38–39.
[4]Idem, No. 81, 1891, p. 319.
[5]*e.g.*: Mon. U. S. Geol. Survey, vol. LI, 1912, p. 189.

to have been no recognition of the fact that in the original reference [1] a similar condition was acknowledged to exist in the Highland Range and Eureka District sections. Indeed the writer's attention was only called to this fact after his curiosity had been aroused by noticing that the collections at the three localities (Big Cottonwood canyon, Pioche, and in the Highland range) were all made by the same field observers (C. D. Walcott and "J.E.W.") during the same field season at a time (1885) when the *Olenellus* fauna was believed by Mr. Walcott to be of Middle Cambrian age.[2]

A strong intimation of the fact that the *Olenellus* horizon was to be distinguished from that of the other fossils in both the Highland Range and Big Cottonwood Canyon sections was, however, given by Mr. Walcott five years earlier[3] when he said: "In both sections *Olenellus* comes first, and then *Lingulella ella, Bathyuriscus producta,* etc." Here Mr. Walcott does not refer specifically to the collection from Pioche but on page 35 of the same work he states that the "Pioche fauna was secured from beds 2, 3, and 4 of the section in the Highland Range," where they have a combined thickness of 131 feet[4] and four of the species occurring at Pioche are stated[5] to occur also, though they are not so listed, in corresponding beds in the Highland Range section. The applicability to the Pioche collection of the remarks concerning the adjoining Highland range is, therefore, clearly shown.

Two shale series have been identified in the vicinity of Pioche (see pages 96-98). The first collection from the lower shales, or the one to which the term Pioche formation has been applied, included two species of *Olenellus* only, and nowhere in their discussion of this fauna do either Gilbert[6] or White[7] give the slightest indication that species representing other genera were included in the collections. This only corroborates

[1] Walcott: Bull. U. S. Geol. Survey, No. 81, 1891, p. 319.
[2] Idem, No. 30, 1886.
[3] Idem, p. 39, section 76.
[4] At Pioche the thickness is given as 210 feet: Walcott, Smithsonian Misc. Coll., vol. 53, No. 1, 1908, p. 11; and 400 feet: Pack, School of Mines Quarterly, vol. XXVII, 1906, p. 295.
[5] Walcott: Bull. U. S. Geol. Survey, No. 30, 1886, p. 35.
[6] U. S. Geog. Surveys West 100th Meridian, vol. III, 1875, pp. 182-183.
[7] Idem, vol. IV, 1877, pp. 7 and 44-48.

the suggestion that the Pioche formation at Pioche includes two faunas, a lower zone with *Olenellus* discovered by the Wheeler Survey, and an upper zone with *Crepicephalus* which was mingled with the lower faunas by the subsequent collectors. Even this conclusion may be wrong, however, and we should be loth to adopt it if it had not already been forecasted by Mr. Walcott (see page 122).

At Pioche, *Olenellus gilberti* is still typical of the lower zone and that horizon may for convenience receive the same name as in the Big Cottonwood section (the *Olenellus gilberti* zone); the Middle Cambrian horizon may be called the *Crepicephalus* zone from its typical fossil. It is separated by 600 feet of limestone from what has been described as a distinct though unnamed upper shale series (see page 96) which can be definitely correlated with the *Bathyuriscus productus* zone of the Pioche formation in Big Cottonwood canyon. (See the section on the stratigraphy at Pioche and in the Highland range, pages 95-98.)

In the Highland Range and Pioche sections, therefore, the Pioche formation does not appear to include faunas so distinct as those comprised in the same formation in Big Cottonwood canyon (the Lower Cambrian and the Spence-Stephen) unless there is a duplication in the Highland Range section or the two shales at Pioche are of the same age. Locally, that is between sections 50 miles or less apart, the Spence shale exhibits marked variations in both the number and the types of species of which it is composed, differences hardly less pronounced than those (*a*) between the fauna of No. 21 of the Highland Range section and that of the Middle Cambrian portion of the "Pioche shale" in the Big Cottonwood Canyon section, or (*b*) between the two Middle Cambrian shales near Pioche—the one southeast of the town on the road to Panaca where the apparent inclusion of an underlying *Olenellus* horizon has complicated its age relationships, and the other typically exposed in the mine dumps west of Pioche in the Ely mountains. The equivalent of the Spence in the British Columbia section, the Stephen, is, however, separated by nearly 1,600 feet of strata from the Mount Whyte, to which the *Albertella* fauna is referred and with which the Pioche has been compared,[1] yet in the Big Cottonwood Canyon and Oquirrh Range sections of Utah, the original collections appear to have mingled Pioche and Spence types (see page 121). Elsewhere, if we except the House range of Utah where the reference of a shale to the Pioche[2] is not based on fossil evidence, the two shales are not represented in the same section. Interesting, therefore, as the possibility of the suggested duplication may be, and the presence of *Olenoides*, *Zacanthoides*, and *Oryctocephalus* (the latter particularly, see page 103) in the lower shale at Pioche tends still further to suggest its contemporaneity with the Spence, and, therefore, with the upper shale at Pioche, we must await the carrying out of detailed work upon these basal rocks in Nevada, contenting ourselves for the present with the suggested division of the lower shale (the Pioche) into two zones and the tentative correlation of the upper or *Crepicephalus* zone with the *Albertella* fauna and with that of the Burton formation.

Under a system of nomenclature in which formations will be referable to and comparable with lithologic or stratigraphic units, the Pioche formation, from our present knowledge, appears to be an identifiable series of interbedded shales and limestones occupying a transitional zone between true quartzite and limestone series. The two faunas into which the Pioche of the Big Cottonwood section is divisible are, however, separated: (*a*) in the Bear River Range, 100 miles to the north, by several hundred feet of quartzites and limestones; (*b*) in the Mount Bosworth section by 1,600 feet of massive limestones and 350 feet of thin-bedded limestone, sandstones, and shales carrying a new fauna (*Albertella*); (*c*) in the Mount Robson section by 4,350 feet of limestones and shales including the same new fauna; (*d*) in the House range by 205 feet of limestones; (*e*) at Pioche, if the stratigraphy has been correctly solved by 600 feet of limestone and the *Crepicephalus* zone of the Pioche formation, a horizon comparable with the *Albertella* fauna in the Mount Bosworth section; and (*f*) in the Highland range by 1,100(?) feet of limestones and shales. Such a con-

[1]Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 171.
[2]Idem, pp. 171 and 184.

dition augurs well for the probable delimitation within the Pioche of lithologic and faunal units to which member names may be applied, but this is left for the investigator who may undertake the critical study of this formation in the light of the new interpretation to which it has been subjected.

THE BURTON FORMATION.

The Burton formation has been named and described by S. J. Schofield[1], who, together with the writer, measured the following section in the slope directly back of the Burton mine about 2 miles northwest of the town of Elko, British Columbia.

Section of Burton Formation Near Elko, British Columbia.

	Section.	Feet.	Fauna.
Elko limestone (Pre-Devonian, exact age unknown).			
Burton formation (early Middle Cambrian.)	5. Greenish black shales with interbedded limestones, the limestone being in the form of lenses and stringers 1 to 3 inches in thickness and more or less continuous but making up a very small proportion of the strata.	60	In interbedded limestones within 5 feet of the base: *Micromitra* (*Paterina*), *Micromitra* (*Iphidella*) *pannula*, *Obolus* sp., *Acrothele* sp., *Acrotreta* sp., *Agraulos* sp., *Ptychoparia* sp., *Albertella* sp., *Olenoides* sp., *Bathyuriscus* sp., and *Crepicephalus* 2 species.
	4. Massive, dirty grey, sandy limestone.	10	Near top: *Micromitra* sp., *Micromitra* (*Iphidella*) *pannula*, *Agraulos* sp., Trilobite fragments 2 species.
			Near base: *Micromitra* (*Iphidella*) *pannula*, Trilobite fragments 2 species, one suggesting *Olenellus*.
	3. Green micaceous shale, badly sheared.	4	One trilobitic fragment.
	2. Rubbly weathering, calcareous grit, with annelid like borings in top layer.	3	Annelid borings, *Micromitra* (*Paterina*) sp., *Acrotreta* sp., Trilobite fragments 1 species.
	1. Hematite conglomerate........	1	
	unconformity		
Roosville siliceous metargillite (Pre-Cambrian).			

[1] Geol. Surv., Can., Museum Bull. No. 2, 1914, p. 82.

So far as the writer is aware there are only three reported occurrences of the genus *Crepicephalus* in the beds below or immediately above the line separating the Lower from the Middle Cambrian. First in the Pioche formation of Nevada (page 120), second in a limestone with *Albertella* on Mount Stephen, British Columbia[1], and third in interbedded limestones in a Middle Cambrian shale immediately overlying a quartzite on an island east of Niang-Niang-Kung, Liau-tung, Manchuria.[2] The limits of this paper will hardly permit the inclusion of any further reference to the latter occurrence or to the relations between this shale series and the horizons under discussion. The Middle Cambrian aspect of the fauna of No. 5 of the Burton formation (page 125) was evident at the time its study was undertaken, but the association in the same 1-inch layer of two species of *Crepicephalus* and a representative of the genus *Albertella* suggested the comparison of the Burton formation with the *Albertella* fauna and the Pioche formation, horizons which had both been referred to the Lower Cambrian.

Analysis of the *Albertella* fauna in the other regions from which it has been identified (see pages 118-119) revealed the lack of any necessity for the assumption that its Lower Cambrian age was infallible, and the writer turned his attention to the Pioche. This was shown (pages 121-123) to be divisible into Lower and Middle Cambrian zones respectively, and even to comprise faunas which, at the type locality of the *Albertella* fauna, are separated by 1,600 feet of limestone. At the type locality of the Pioche formation the range of faunas included in that unit does not appear to be so large and the Middle Cambrian horizon, to which the name *Crepicephalus* zone has been applied (see page 123) is to be correlated, at least tentatively, with the Burton formation. The correlation of the Burton formation with the *Albertella* fauna is based largely upon the presence in the former of an *Albertella*, a genus which, according to our present information, is confined in the Cordilleran region to this one horizon. The weight of evidence so largely opposes the Lower Cambrian age of these formations and corroborates their refer-

[1]Walcott: Smithsonian Misc. Coll., vol. 53, No. 5, 1908, p. 213.
[2]Walcott: Research in China, vol. 3, 1913, p. 26, locality 35r.

Correlation of Pioche Formation, Burton Shale, and Albertella Zone.

Pioche, Nevada.	Big Cottonwood canyon, Utah.	Elko, British Columbia.	Mount Bosworth, British Columbia
Zacanthoides typicalis zone (2 of section, page 96) = No. 21 of Highland range.	Pioche formation. *Bathyuriscus productus* zone (= Spence shale horizon in northern Utah).		Stephen formation (*Ogygopsis* zone) = Titkana formation of Mount Robson region (in part).
Pioche formation *Crepicephalus* zone	Pioche formation.	Burton formation.	Mount Whyte formation. *Albertella* zone
Pioche formation *Olenellus gilberti* zone	Pioche formation. *Olenellus gilberti* zone	Burton formation.	Mount Whyte formation. *Olenellus canadensis* zone

ence to the overlying division of the Cambrian that the Burton formation is referred with some degree of certainty to the Middle Cambrian.

It is hard to resist the impression, however, that the clastic portion of the Burton formation may represent the Lower Cambrian, and while the few species occurring in these lower layers are either unrecognizable or referable to types hitherto unknown, the suggested definition of the Burton formation will not invalidate its future division into shale and sandstone members.

The Burton formation is, therefore, interpreted as a more or less heterogeneous formational unit unconformably overlying the Pre-Cambrian, referable to the early Middle Cambrian, and easily separable into upper and lower members if such a division should be warranted by future work upon the faunas of its basal portion.

SUMMARY.

The *Albertella* fauna has been referred to the Lower Cambrian[1] and this reference has been used as an argument[2] for the systemic designation of such faunas as that containing *Olenopsis* in Sardinia. The *Albertella* fauna is shown in this paper (*a*) to occupy strata transitional between the Lower Cambrian sandstone and the Middle Cambrian limestone forming conditions of the early Cambrian, (*b*) to be unassociated with *Olenellus* though it is apparently interbedded with recurrent representatives of that genus, (*c*) to consist almost overwhelmingly of forms either typical of the Middle Cambrian or confined to the *Albertella* fauna as species of unknown or connecting affinities, and (*d*) to be referable to the Middle Cambrian.

The Pioche formation has been consistently referred to the Lower Cambrian, but it is shown in this paper (*a*) that the faunal lists with which it has been credited represent an artificial

[1]Walcott: Smithsonian Misc. Coll., vol. 53, No. 2, 1908, pp. 21-22.
Idem, No. 5, 1908, pp. 203 and 212.
Idem, vol. 57, No. 8, 1912, pp. 242 ar ' 244.
Mon. U. S. Geol. Survey, vol. LI, 1912, pp. 129-130.
Smithsonian Misc. Coll., vol. 57, No. 12, 1913, p. 343. Referred to the Middle Cambria~ on p. 338, see pages 107-109 of this paper for discussion.

[2]Walcott, Smithsonian Misc. C '' , vol. 57, No. 8, 1912, pp. 242 and 244.

mingling of Lower and Middle Cambrian forms, (*b*) that the formation is divisible in the Big Cottonwood Canyon and Oquirrh Range sections of Utah into a true Lower Cambrian horizon with *Olenellus* (the *Olenellus gilberti* zone) and a Middle Cambrian horizon which is called the *Bathyuriscus productus* zone and correlated with the Spence-Stephen-Titkana faunas, and (*c*) that it is probably divisible near Pioche, Nevada, the type locality, into a true Lower Cambrian horizon with *Olenellus* (the *Olenellus gilberti* zone) and a Middle Cambrian horizon with *Crepicephalus* (the *Crepicephalus* zone) which is tentatively correlated with the *Albertella* fauna and the Burton formation.

The Burton formation of Schofield[1] has in this paper received its first palæontologic treatment: its section near Elko, British Columbia, is given, its faunas are listed, and it is correlated with the *Albertella* fauna and referred to the early Middle Cambrian.

The Lower-Middle Cambrian boundary has heretofore been drawn above the youngest beds containing *Olenellus*, irrespective of conflicting diastrophic and organic evidence. It is in this paper redefined and drawn at the base of such horizons as the one containing the *Albertella* fauna, a suggestion which is believed to accord with the principle that the inauguration of major units in the stratigraphic series is more closely related to the phenomena attending depositional expansion and the introduction of new faunas than to the accidental and senile lingering of a decadent type.

[1]Geol. Surv., Can., Museum Bull. No. 2, 1914, p. 82.

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VII.—A Preliminary Study of the Variations of the Plications of Parastrophia hemiplicata, Hall.

BY ALICE E. WILSON.

Parastrophia hemiplicata Hall[1] is found in great abundance in certain zones of the Trenton limestone. From several of these zones a considerable number of specimens were collected, the adults of which showed a great variation in the number of plications on the valves. A few adult specimens have a simple sinus with no plications, while the majority have from one to five in the sinus with the corresponding number on the fold. A study of them was undertaken to ascertain if possible whether all of the forms really belonged to one highly variable species, and, if so, whether any reason for their great variability could be found. For the purpose of study the shells were provisionally assorted into groups according to the number of plications in the sinus. Each variation has been considered as a group—that is the no-plication group, the one-plication group, etc. These groups so merge into one another that they can hardly be regarded as separate species, and many of the individual shells of several plications in their growth pass through some of the stages of those groups which have fewer plications.

The shells used in this study come from three divisions of the Trenton limestone—the base at Indian Lorette, Quebec, the Prasopora beds in the vicinity of Ottawa and Hull, and a higher horizon represented by the specimens from Fifth

[1] Pal. N. Y. vol. I, p. 144, 1847.

avenue, Ottawa. For comparison a study was made of eleven typical specimens of ***Parastrophia reversa*** (Billings)[1] from the Lorraine formation of the Island of Anticosti. Billings later stated that this species was simply a variety of ***Parastrophia hemiplicata*** Hall.[2] The most striking differences are their size, and their greater average gibbosity, as indicated by the ratio of height and length. The mesial fold and corresponding sinus also are relatively less prominent than those of ***Parastrophia hemiplicata***, Hall.

For the majority of the specimens the writer is indebted to the kindness of Mr. J. E. Narraway of Ottawa, by whom all the Fifth Avenue specimens were loaned, as well as a large number from the Prasopora beds. The rest are in the collections of the Geological Survey of Canada.

The data taken for study are: length of shell; width of shell, measured at the widest part; height; width of sinus, measured at the anterior margin; number of plications on each side of the sinus on the pedicle valve; and the total number of plications. As stated above, the number of plications or striæ in the sinus is the basis for division into groups.

Each shell in its nepionic stage is without a plication, even the sinus not being indicated; as it grows, anteriorly, it forms the sinus and fold, later come the plications in the sinus and on the sides. Would every young shell, if undisturbed in its growth, continue to develop more and more plications until it reached the maximum number, the five-plication form? Or, does each shell start out with an inherent tendency to form one, two, three, or four plications in the sinus, as the case may be? From the specimens examined and measured it would seem that the latter alternative is the more probable.

Inherent Tendency to a Definite Number of Plications. First.—Each group of no-plications in the sinus, one, two, or three plications, etc., has adult representatives. Figure 1, Plate IV, for instance, probably represents an adult, or nearly adult specimen, with no plications in the sinus or on the sides, merely the two ridges which bound the sinus. There is no indication of

[1]Geol. Surv. of Can. Report of Progess for 1856, p. 295, 1857.
[2]Can. Jour. IV, p. 316, 1859.

another plication. It is, then, a mature specimen of that class which has no plications. In the same way figure 3, Plate IV, appears to be a mature specimen with one plication, figure 11, Plate IV, an adult of two plications, etc. That is, there are specimens which have not attained the maximum number of plications in the sinus although they have reached maturity. They, then, must have commenced growth with a tendency to form no plications, one, two, or three, as the case may be, but not the maximum number.

Second.—The adult specimens illustrated by figures 1, 3, 6, 9, 11, 20, and 30, Plate IV, appear to have reached their full development of plications and most of them have formed their maximum number while still far from reaching their present mature size, the last stages of growth being in size only. These specimens, which are quite typical, have evidently commenced growth with the inherent tendency to form a certain number of plications, and have ceased forming new ones when the required number was reached, although growth is continued. On the other hand there are a few specimens, that cannot be ignored, such as those illustrated by figures 9 and 24, Plate IV, which, though adults, are evidently in a transition stage. It is probable that each of them has reached its mature form, but the next generations might appear with three and five plications, respectively, in the sinus.

It seems, then, that each shell has commenced with an inherent tendency to form a given number of plications—whether it be one, two, three, or the maximum number—and, with a few exceptions, has ceased to form more when the required number is reached, though growth is continued.

Development of One Group from Another. First.—Considering the specimens at the stage of growth when the plications are initial, it is evident, from the illustrations given, that when a shell is of the plication-forming variety it does not usually leap at once into its adult condition of two, three, or four plications, as the case may be, but after the formation of the sinus the other plications appear, sometimes one at a time, or sometimes two, in some cases more. The initial stages of the plications show two tendencies in each group of shells. The majority of the specimens exhibit plications formed at intervals, sometimes by implantation of a later one, sometimes by the bifurcation of a plication which has already grown to some extent, the latter method of increase in number is the more frequent. In each group, however, there are some shells which form their plications simultaneously, never adding to them, though growth is continued. It seems probable that the more variable specimens give rise to the forming of new groups with more plications, while those which form their plications simultaneously have reached a constant form in that group. Figure 23, Plate IV, for instance, forms its three plications simultaneously, exhibiting no tendency to variation. It has become constant. Figure 14, Plate IV, on the other hand, shows a primary plication with two added later. Some of the descendants of this shell would probably tend to a constant form like figure 23, Plate IV, showing the final number simultaneously, others might bifurcate the primary plication and with the two added form a four-plication shell.

Owing to the worn condition of many of the shells it is not always possible to tell the origin of the plications, but, of thirty-four two-plication specimens examined, twenty-one appear to have formed the two-plications simultaneously, about three-fourths of the remaining thirteen either show faint traces of an original one-plication form with the one plication bifurcated or else they converge so as to suggest that such has been their origin. A very small minority seems to form the second plication by implantation after a period of growth of the first. Of forty-three three-plication shells studied, eleven only appear to have simultaneously formed plications, while thirty-two have produced plications at irregular intervals. Seven of these show a strong one-plication form first, with the subsequent plications introduced by implantation, one at each side, usually at different stages of growth. Four show an original strong one-plication at one side of the middle and the subsequent plications, unequal in size, introduced by implantation at one side. Twenty-one give definite evidence of having been derived from the two-plication form, eight by the implantation of a third fold and thirteen by the bifurcation of one of the two original plications. Eight four-plication specimens were examined and one only appears to have given rise to the four at the same time. Three of the other seven show an original form having one in the centre, which bifurcates, and the final two are added by implantation. Two more appear to have originated in a two-plication form, each of the two original plications being bifurcated. The sixth and seventh show that one plication at least has its origin in the bifurcation of one of the others, but the shells are too worn to show the initial form. One of the five-plication specimens has formed its plications simultaneously. Two of them form all five by implantation at irregular intervals. Two show a derivation from the three-plication form, the first by implantation of the subsequent plications, the second by a double bifurcation. A fifth shows an initial form of two plications, one of which is bifurcated, and later the implantation of two. A sixth shows no indication of bifurcation, but there are two strong primary plications. A seventh shows that the final plication is formed by bifurcation, but the initial form is worn.

Of the two-plication Anticosti specimens of *Parastrophia reversa* (Billings), four form the plications at once, one only shows a derivation from the one-plication by bifurcation. Three of the three-plication form have arisen from the two-plication form, two by bifurcation, one by the implantation of the third fold. The four-plication specimen shows one bifurcation.

That, is, then, that the one-plication form appears in the initial stages of a number of the two-, three-, and four-plication forms, but as far as the specimens examined show dies out in the five-plication form. The two-plication form, which seems the most firmly established, appears in the three-, four-, and five-plication form. The three-plication form is repeated in the initial stages of some of the four and five-plication forms. The four-plication form appears in one specimen of the five. It is worth while also to note here that the two- and three-plication shells, the most persistent forms, have a larger proportion of shells which form their plications simultaneously.

Second.—Also, though there are exceptions, the majority of shells show plications first near the middle of the sinus, where the one-plication shell has its one plication, and the additional plications, when formed by implantation, are almost always added outwardly towards the side of the sinus.

Third.—Among the Fifth Avenue specimens, which come from a higher horizon, there are none having no plications or one plication in the sinus. There are so few specimens from here, however, that perhaps it is hardly sufficient evidence to have much weight.

Hence, it seems only reasonable to infer that those groups with more plications, as groups, have their origins in the groups with fewer plications. In the stage of development of the Prasopora beds, and the Anticosti specimens, the groups with two and three plications apparently predominated, though in the former those with none and one still existed, and those with four and five had evidently made good headway.

Relationship of Horizon and Plication Development.—The 126 specimens measured and examined were collected at three different horizons. From the lowest, the base of the Trenton at Indian Lorette, there are only two specimens, both considerably worn, one having one plication in the sinus, the other two. From the Prasopora beds around Ottawa and Hull there are 96 specimens, and from Fifth avenue, Ottawa, a still higher horizon, there are 28 specimens. The Indian Lorette specimens are too few in number to furnish any grounds for comparison, but there are two interesting features shown by comparing the specimens from the Prasopora beds and those from Fifth avenue. The first has already been mentioned—the absence from the higher horizon of any specimens having no plication or one plication. The second is the much greater number of plications on the sides of the shells from Fifth avenue. Comparing similar groups of those from the Prasopora beds and those from Fifth avenue it is found that the Fifth Avenue specimens average smaller in length, width, height, etc., though the average ratio of length to height is the same, implying that in size at least they had reached their fullest development. The Anticosti species, like the Fifth avenue specimens, shows a greater number of plications upon the sides, but unlike them is in every dimension about double the size of the specimens from the Prasopora beds. The additional plications on the sides, then, must be due to the stage of development of the shells of that horizon not to the growth of the individual shell.

There seems, however, to be no definite ratio between the number of plications in the sinus and that on the sides. Many of the shells are so worn on the sides that there is frequently just the indication of a plication on the edge, its extent being obliterated. It is to be noted, however, that those plications on the sides which are nearest the sinus form first and are usually by far the strongest, as well as the earliest to appear.

COMPARATIVE TABLE OF PARASTROPHIA HEMIPLICATA HALL

No. of plications in sinus.	No. of specimens	Range of total No. of plications.	Average measurements of specimens			Largest specimen.			No. of specimens within ½mm. of average.	Index range
			Length.	Width.	Height.	Length.	Width.	Height.		
Prasopora zone.										
0	7	2	8·18	10·46	4·39	9·75	13·25	5·5	4	0·47–·68
1	5	3–5	8·45	9·85	7·15	11·25	13	7	1	0·53–·62
2	39	4–9	9·82	11·74	6·42	13	14·5	11	6	0·48–·92
3	36	5–11	10·44	12·64	6·96	14	17·75	11·75	12	0·53–·97
4	6	8–14	11·43	13·92	7·46	13	15·25	9	2	0·53–·73
5	5	7–11	10·95	13·15	7·2	11·75	14·25	7·5	3	0·63–·7
Fifth Avenue zone.										
2	3	6–8	9·42	10·67	6·5	10	12	5·75	1	0·57–0·76
3	15	5–11	10·3	12·13	6·22	14·25	15·5	9	9	0·37–0·83
4	5	10–14	10·9	13·55	7·2	12·5	15·5	9·25	2	0·4 –0·77
5	5	9–11	9·9	11·8	6·65	12	14	9·5	2	0·61–0·79
Parastrophia reversa (Billings) Anticosti.										
2	4	2–5	19·06	23·62	14·18	22·5	27	17	2	0·63–0·79
3	6	3–5	20·04	24·58	14·75	22·5	26	19·75	0	0·64–0·88
4	1	5	18	24	14·25	18	24	14·25	1	0·79

EXPLANATION OF PLATE IV.

Fig. 1. Adult specimen with no plications, from Prasopora beds, Ottawa, Ont.
" 2. Average specimen with no plications, from Prasopora beds, Ottawa, Ont.
" 3. Adult specimen with one plication, from Prasopora beds, Ottawa, Ont.
" 4. Average specimen with one plication, from Prasopora beds, Ottawa, Ont.
" 5. Specimen with one plication, from Indian Lorette, Que.
" 6 and 7. Specimens with two plications, one primary and one implanted at a later stage of growth, from Prasopora beds, Ottawa, Ont.
" 8, 9, and 10. Specimens with two plications, formed by the bifurcation of one primary one, from the Prasopora beds, Ottawa, Ont.
" 11 and 12. Specimens with two plications, formed by implantation, from the Prasopora beds, Ottawa, Ont.
" 13 and 14. Specimens with three plications, one primary, two added later by implantation, from the Prasopora beds, Ottawa Ont.
" 15. Specimen with three plications, one central primary one which is bifurcated, the third being implanted, from the Prasopora beds, Ottawa, Ont.
" 16. Specimen with three plications, two primaries, one implanted later, from the Prasopora beds, Ottawa, Ont.
" 17, 18, and 19. Specimens with three plications, two primaries one of which bifurcated, from the Prasopora beds, Ottawa, Ont.
" 20 and 21. Specimens with three plications, two primaries one of which bifurcated, from the Fifth Avenue horizon, Ottawa, Ont.
" 22. Specimen with three plications, one primary one which has apparently later divided into three, from the Prasopora beds, Ottawa, Ont.
" 23. Specimen with three plications formed simultaneously, from the Prasopora beds, Ottawa, Ont.
" 24. Specimen with three plications, one primary which has bifurcated, a third added later by implantation. The centre plication is about to bifurcate. From the Prasopora beds, Ottawa, Ont.
" 25. Specimen with three plications, strong centre plication apparently about to bifurcate, initial stages obliterated, from the Prasopora beds, Ottawa, Ont.
" 26. Specimen with numerous side plications, from the Fifth Avenue horizon, Ottawa, Ont.
" 27. Specimen with four plications, formed from two by double but not simultaneous bifurcation, from the Prasopora beds, Ottawa, Ont.
" 28. Specimen with four plications, three formed simultaneously one implanted later, from the Prasopora beds, Ottawa, Ont.
" 29. Specimen with four plications, central one bifurcated two implanted later at intervals, from the Prasopora beds, Ottawa, Ont.
" 30. Specimen with numerous side plications, from the Fifth Avenue horizon, Ottawa, Ont.
" 31. An average specimen with four plications from the Prasopora bed, Ottawa, Ont.
" 32. Specimen with five plications, formed by bifurcation and implantation, initial stages obliterated, from the Fifth Avenue horizon, Ottawa, Ont.
" 33. Specimen with five plications, two strong ones, from the Prasopora beds, Ottawa, Ont.
" 34. Specimen with numerous side plications, from the Fifth Avenue horizon, Ottawa, Ont.
" 35. Specimen of *Parastrophia reversa* (Billings) from Anticosti. Two plications formed from one by bifurcation.
" 36 Specimen of *P. reversa* (Billings) from Anticosti. Two plications formed simultaneously.
" 37. Specimen of *P. reversa* (Billings) from Anticosti. Three plications, two formed simultaneously the third implanted later.
" 38. Specimen of *P. reversa* (Billings) from Anticosti. Three plications, one being bifurcated.
" 39. Specimen of *P. reversa* (Billings) from Anticosti. Four plications formed simultaneously.

EXPLANATION OF PLATE IV.

Fig. 1. Adult specimen with no plications, from Prasopora beds, Ottawa, Ont.

" 2. Average specimen with no plications, from Prasopora beds, Ottawa, Ont.

" 3. Adult specimen with one plication, from Prasopora beds, Ottawa, Ont.

" 4. Average specimen with one plication, from Prasopora beds, Ottawa, Ont.

" 5. Specimen with one plication, from Indian Lorette, Que.

" 6 and 7. Specimens with two plications, one primary and one implanted at a later stage of growth, from Prasopora beds, Ottawa, Ont.

" 8, 9, and 10. Specimens with two plications, formed by the bifurcation of one primary one, from the Prasopora beds, Ottawa, Ont.

" 11 and 12. Specimens with two plications, formed by implantation, from the Prasopora beds, Ottawa, Ont.

" 13 and 14. Specimens with three plications, one primary, two added later by implantation, from the Prasopora beds, Ottawa Ont.

" 15. Specimen with three plications, one central primary one which is bifurcated, the third being implanted, from the Prasopora beds, Ottawa, Ont.

" 16. Specimen with three plications, two primaries, one implanted later, from the Prasopora beds, Ottawa, Ont.

" 17, 18, and 19. Specimens with three plications, two primaries one of which bifurcated, from the Prasopora beds, Ottawa, Ont.

" 20 and 21. Specimens with three plications, two primaries one of which bifurcated, from the Fifth Avenue horizon, Ottawa, Ont.

" 22. Specimen with three plications, one primary one which has apparently later divided into three, from the Prasopora beds, Ottawa, Ont.

" 23. Specimen with three plications formed simultaneously, from the Prasopora beds, Ottawa, Ont.

" 24. Specimen with three plications, one primary which had bifurcated, a third added later by implantation. The centre plication is about to bifurcate. From the Prasopora beds, Ottawa, Ont.

" 25. Specimen with three plications, strong centre plication apparently about to bifurcate, initial stages obliterated, from the Prasopora beds, Ottawa, Ont.

" 26. Specimen with numerous side plications from the Fifth Avenue horizon, Ottawa, Ont.

" 27. Specimen with four plications, formed from two by double but not simultaneous bifurcation, from the Prasopora beds, Ottawa, Ont.

" 28. Specimen with four plications, three formed simultaneously one implanted later, from the Prasopora beds, Ottawa, Ont.

" 29. Specimen with four plications, central one bifurcated two implanted later at intervals, from the Prasopora beds, Ottawa, Ont.

" 30. Specimen with numerous side plications, from the Fifth Avenue horizon, Ottawa, Ont.

" 31. An average specimen with four plications from the Prasopora bed, Ottawa, Ont.

" 32. Specimen with five plications, formed by bifurcation and implantation, initial stages obliterated, from the Fifth Avenue horizon, Ottawa, Ont.

" 33. Specimen with five plications, two strong ones, from the Prasopora beds, Ottawa, Ont.

" 34. Specimen with numerous side plications, from the Fifth Avenue horizon, Ottawa, Ont.

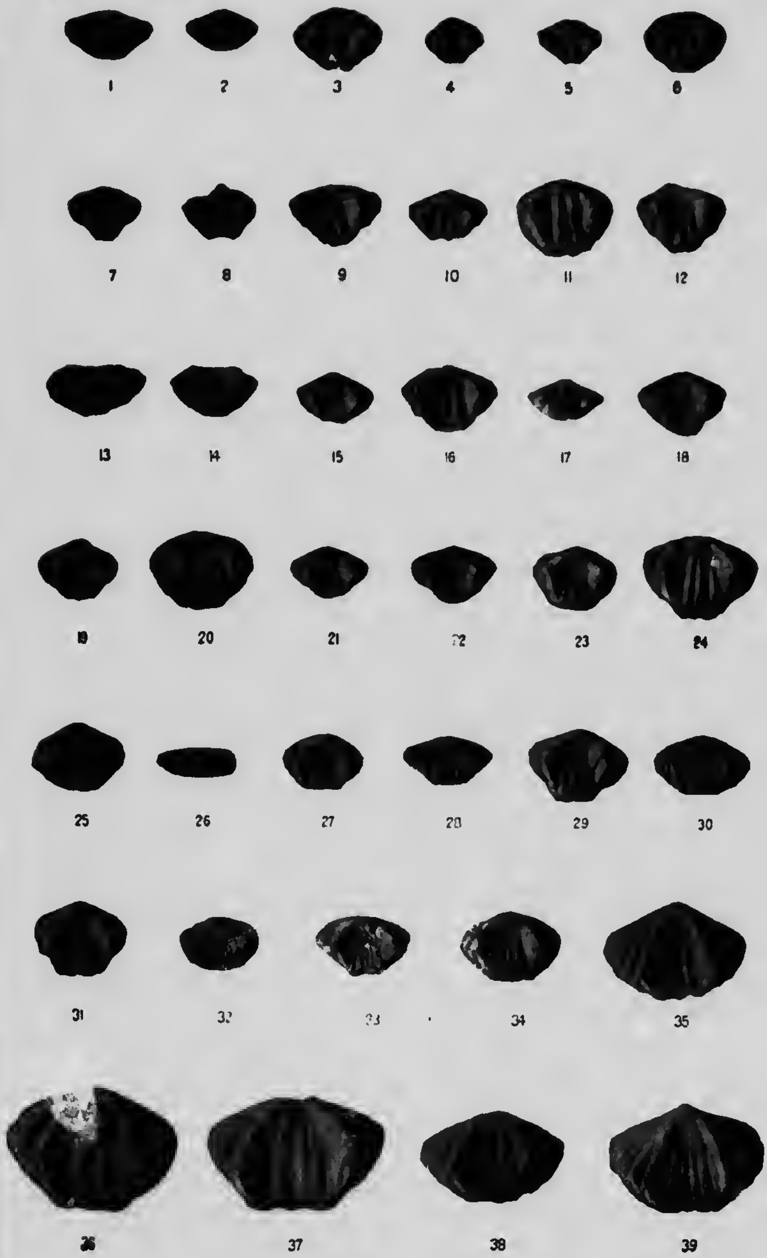
" 35. Specimen of *Parastrophia, reversa* (Billings) from Anticosti. Two plications formed from one by bifurcation.

" 36. Specimen of *P. reversa* (Billings) from Anticosti. Two plications formed simultaneously.

" 37. Specimen of *P. reversa* (Billings) from Anticosti. Three plications, two formed simultaneously the third implanted later.

" 38. Specimen of *P. reversa* (Billings) from Anticosti. Three plications, one being bifurcated.

" 39. Specimen of *P. reversa* (Billings) from Anticosti. Four plications formed simultaneously.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