Art. III.—*The Athabaska Series;* by F. J. Alcock,[1] *Geological Survey of Canada.*

In the northern interior portion of Canada are found several large and many smaller areas covered by a sandstone formation which has been described by a number of members of the Geological Survey of Canada. In two seasons work in northern Alberta and Saskatchewan the writer was able to secure some additional information regarding this interesting series.

Discovery.

In 1888 Mr. R. G. McConnell[2] made a traverse along the south shore of Lake Athabaska from the mouth of the Athabaska river as far eastward as Point William. At several places he found outcrops of a granular siliceous sandstone to which he gave the name Athabaska sandstone. No fossils were found in it, nor its contact with other formations observed, but from its general character and position he placed it in the Cambrian.

In 1892 Mr. D. B. Dowling,[3] acting as assistant to Mr. J. B. Tyrrell, made a reconnaissance survey of the south shore of Lake Athabaska and found that the sandstone extends along the whole southern coast of the lake, with a few outcrops on the shore itself, and forms an escarpment to the south. The formation was traced as far eastward as Wollaston lake. Its southern limit was not determined.

In his exploration journeys in 1893 and 1894 on the Doobaunt, Kazan and Ferguson rivers, Mr. J. B. Tyrrell[4] found many small areas of a red altered feldspathic sandstone or arkose which he correlated with the Athabaska sandstone of McConnell. In places it passes into a coarse conglomerate and in other places is represented by red arkose.

[1] With the permission of the Director of the Geological Survey of Canada.

[2] McConnell, R. G.: Report on a portion of the district of Athabaska, Geol. Surv. Canada, Part D, Ann. Rept., vol. 5, 1889-90-91, page 51.

[3] Tyrrell, J. B.: Report on the country between Athabaska Lake and Churchill River, Geol. Surv. Canada, Part D, Ann. Report, vol. 7.

[4] Tyrrell, J. B.: Report on the Doobaunt, Kazan and Ferguson Rivers, and the North-West Coast of Hudson Bay, Geol. Surv. Canada, Part F, Ann. Report, vol. 9, 1896.

Areal Distribution.

The large known areas covered by the Athabaska Series are three in number. The first and largest is that in which it was originally described and named, extending along the south shore of Lake Athabaska to Lake Wollaston, a distance of 250 miles, and with a width in a north and south direction of probably 100 miles. The second is a large V-shaped area surrounding Doobaunt lake, having a length of approximately 200 miles in a north-east direction, and with a width varying to a maximum of about 100 miles. The third region where the series is exposed is north of lake Athabaska, where it forms a number of smaller areas. The regions studied by the writer include the first and more particularly the third of these areas.

Lithological Character of the Series.

In the large area lying to the south of Lake Athabaska the dominant rock type is a sandstone consisting practically entirely of quartz. Varieties of different degrees of coarseness are found. A very common type is one consisting of well-rounded quartz grains from two to five millimeters in diameter, scattered through a finer grained matrix of rounded quartz particles with diameter varying from ·2 to ·6 millimeters. Another variety consists of a white sandstone made up entirely of these smaller grains. Still another type contains well-rounded quartz pebbles up to three inches in diameter scattered irregularly among grains of varying degrees of coarseness.

In places the sandstone is very hard, in places weak and friable. The color varies from white to yellow, weathering reddish. The beds vary in thickness from a few inches up to two feet; irregular joint-planes cause them to break into blocks some of huge size.

In the areas north of Lake Athabaska the series is dominantly red in color, although gray and yellow beds are found locally. The rock types found in these localities consist of sandstone, arkose and conglomerate, with interbedded flows and sills of diabase. The largest of these areas is north of the Beaverlodge lakes; smaller areas are found north of Spring and Maurice points, on a peninsula and some islands east of Black bay, and along the shore of Lake Athabaska between Sand and Big points.

Conglomerates are in greatest abundance towards the base of the formation, in many places resting unconformably on the truncated edges of an older quartzite series. The bowlders are well rounded and range in size up to 18 inches in diameter. They consist of quartzite, granite-gneiss, vein quartz, and a few small bowlders of iron formation. Where the series rests on quartzite, this forms the dominant type of bowlder, and where it rests on granite, the latter is the most abundant type. The conglomerates show but a limited amount of sorting, bowlders of various sizes being associated together in a sandstone matrix. East of Beaverlodge lake alternations of fine red sandstone and conglomeratic beds form the lower portion of the series.

The finer-grained portions of the series consist of sandstone and arkose. Portions of the former show incipient quartz enlargements and approach a true quartzite. In places considerable quantities of feldspar are present, and the rock becomes a true arkose. North of the Beaverlodge lake this variety becomes a red, hard, well-cemented, thick-bedded rock. A characteristic feature seen in nearly every outcrop is the presence of well-rounded, quartz pebbles averaging about an inch in diameter, which are found sparingly throughout the series. In some massive varieties of the rock they are abundant enough to mark the bedding planes. In places the rock is so well cemented that it breaks directly across these quartz pebbles.

A local outcrop referred to this series consists of a red breccia made up of angular fragments of quartzite firmly cemented by a fine-grained matrix consisting of quartz, iron ore, chalcedony and sericite. Some of the smaller quartz particles are rounded, but the majority are subangular and were clearly not transported far.

West of Beaverlodge lake, the series forms hills, which rise to a height of 200 feet above the lake. The top of these hills consist of diabase and basalt outcropping in bands parallel to the strike of the series. The coarse-grained diabase has the relationship of intrusive sheets, but two of the bands consist of amygdaloidal basalt representing surface flows. The amygdules consist of calcite and vary up to 1½ inches in diameter. In the Doobaunt area Mr. Tyrrell found dikes and masses of both acid and basic eruptives, diabases and quartz-porphyries, traversing the sandstone and conglomerate beds of this series.

Structural Features.

Bedding.—Bedding is for the most part well-marked throughout the series, the beds varying in thickness from a few inches to two feet. Locally it is marked by color banding, usually alternations of red and yellow. In places, however, the texture is so uniform that the only way of detecting the bedding planes is by the way the rock breaks into slabs. These vary in size up to those which measure ten feet across; besides those occurring with outcrops in place, many are found on the sand plains north of the lake.

Cross-bedding.—The series is extensively cross-bedded, in all the areas studied. South of Lake Athabaska the prevailing type consists of diagonal layers bounded sharply above and below by horizontal beds. The maximum length of the diagonal fore-set beds observed was three feet. At the eastern end of the lake the slope of the fore-set beds is uniformly to the south-west indicating a source of supply from the north-east.

In the areas north of Lake Athabaska, the same type of cross-bedding is dominant. In the small outcrops between Sand and Big points, however, a more irregular type is presented, showing curved and fore-set beds, irregularly truncated by other curved beds above. This type, however, is on a smaller scale, and is much less abundant than the variety first described.

Sun-cracks.—Sun-cracks are not at all common throughout the series; in some fine-grained beds north-east of Beaverlodge lake, some excellent examples were found. The outlines were polygonal, averaging about four inches in diameter, with the filling of sandstone standing up as prominent ridges. Mr. Tyrrell also mentions finding sun-cracks in certain beds of Athabaska sandstone in the Doobaunt lake area. The reason why they are not more prevalent is evidently due to the coarse clastic nature of the series which is unsuitable for their development.

Rain-prints.—Rain-prints are not common; south of Stone river one layer in some fine-grained beds afforded a few unmistakable examples, but aside from this no others were seen.

Ripple-marks.—Ripple marks were seen in fine-grained beds in several localities. Near Fair point is an outcrop where the ripple-marks were symmetrical, vary in width from two to four inches measured from east to west, and

with a height of one-half inch. Similar markings were found in the Beaverlodge area. Abundant ripple-marks were found by Mr. Tyrrell in the sandstone in Baker lake.

Clay-balls.—South of Stone river a number of round impressions filled with clay were found in the sandstone. These vary in size from one to two inches in diameter, and are very thin. Their method of occurrence was found to be the same in every case, for they were only observed in the plane between the fore-set laminæ and the top-set laminæ of the underlying stratum.

Folding.—South of Lake Athabaska the series lies horizontally, or with but very slight local dips. Its thickness here as shown by barometric measurement is over 400 feet. In the region of the Beaverlodge lakes north of Lake Athabaska, the series, however, is folded into a gentle syncline in which it was found to secure a determination of the thickness. Over 8,000 feet of interbedded conglomerates, arkoses and sandstones are exposed here. This syncline has a maximum dip on the limbs of 40° and pitches to the north at an angle of 20°. In the other areas north of Lake Athabaska the series lies practically horizontally.

Faulting.—In the outcrop of the series near Fair point excellent slickensided surfaces are preserved, which shows the existence of faulting on some scale. Friction breccias are present in an older quartzite series, but although they were developed after the metamorphism of this series it is unknown whether or not they were developed in post-Athabaskan times. Just to what extent the Athabaska series was faulted is, therefore, at present unknown.

Jointing.—Jointing is marked throughout the series, causing it to break into huge angular slabs. South of Stone river vertical jointing in an east and west direction keeps the front of the escarpment vertical while at right angles to this direction large crevasses mark a second joint system. The intersection of these two sets of planes produces blocks of sandstone ten to twenty feet across containing several hundred cubic feet of material. In places these blocks stand out as vertical pillars in front of the escarpment.

Intrusion.—The series is traversed, as has already been mentioned, by dykes and sills of diabase of contemporaneous age. At the eastern end of the lake on both the

north and south shores, moreover, are to be found intrusions of a foliated norite. Along the contact of the norite in one locality on the north shore is found a quartzite, which, if it represented Athabaska sandstone metamorphosed by contact action, shows that the latter is older than the norite intrusion. No decisive evidence was seen by the writer to establish this, however.

Age of the Series.

The age of the Athabaska series has called forth considerable discussion. Careful search in all the localities where it is found has failed to reveal any fossils in it whatever. It is, however, very probably older than the Ordovician, for nowhere has the latter in this region been found to be cut by diabase dikes or sills, such as intrude the Athabaska series. Whether it is to be referred, however, to the Cambrian or to late Pre-Cambrian has, however, been the chief grounds for debate. The greater lithological resemblance, however, to the Keweenawan sandstones of the Lake Superior region, and its association with diabase intrusives and extrusives render it probable that it is to be correlated with these rather than placed in the Cambrian.

Origin of the Series.

The structural features displayed by the series points to a continental rather than a marine origin. The features in favor of such an interpretation may briefly be summarized.

The dominant feature of the series is its clastic character throughout. Limestones are absent and shales which form the large proportion of marine sediments are at a minimum. On the other hand many deposits of known continental origin consist dominantly of clastic materials as for example the Newark Series of the eastern United States, the Siwalik beds of India, and the Old Red Sandstone of Great Britain.

The great areal extent of the Athabaska series and its great thickness also strongly point to a subaerial origin. Great areas of marine sandstones of limited thickness may be found, for currents and longshore drift will transport materials for long distances, and an advancing or retreating shore line during the period of deposition would tend to increase the areal extent, but under such conditions a great thickness of sand could not be

deposited over an extensive area. On the other hand a thick deposit of limited area might accumulate under marine conditions, as for example where streams from a mountainous region dump their load into deep water producing what might be termed a submarine alluvial fan, but such deposits must necessarily be very limited. In the formation of continental deposits a change of base-level affects all the rivers of the region and when aggradation begins in one it begins in all; as a result, subaerial deposits of practically any extent and thickness may be produced.

The character of the bedding is significant. The series is uniformly thick-bedded in contrast to the regular thin-bedded strata characteristic of marine deposits. The presence of so much conglomerate at various horizons and the alterations of sandstone and conglomerate are also much more easily explained as fluviable than as marine deposits.

The feldspathic character of portions of the formation is to be noted since it has been shown[5] that not only are feldspar fragments sorted out by rivers in their progress to the sea, but also wave action after the material has reached the sea tends further to sort out and remove the feldspar and other destructive minerals. The presence of the feldspar, therefore, not only indicates a subaerial origin, but a climate during its deposition unfavorable for decomposition.

The evidence of basic amygdaloidal and vesicular lava flows interbedded with arkose is an indication of the deposition of this portion of the series under subaerial conditions.

Many of the structural features point to the same conclusion. Rain-prints, sun-cracks and clay-balls are all more characteristic of continental rather than marine deposits. Though not abundant in the Athabaska series, their presence in beds capable of forming and preserving them is suggestive. The cross-bedding displayed is also characteristic of water-laid, torrential deposits. Local breccias are also best explained as deposits of such a character.

Conclusion.

If we assume, therefore, that the Athabaska series is of subaerial origin, then in Athabaska times, the region must have been a land area with, however, an entirely

[5] MacKie, Wm.: The Sands and Sandstones of Eastern Moray, Trans. Edinburgh Geol. Soc., vol. 7, pp. 148-172, 1897.

different type of topography from that which obtains in the region today. The great thickness of the series makes it necessary to postulate a down-warping basin or basins with adjacent country of considerable relief from which clastic material could be derived. The coarse conglomerates and local breccias suggest torrential deposits carried but a short distance; the greater part of the series, however, was certainly transported distances measured in miles. Fluviatile deposition on broad flood-plains in intermontane basins seems to best represent the conditions under which the series accumulated.

The climate prevailing at the time the formation was laid down may also be inferred. The prevailing red color is due to the oxidation of iron and indicates conditions of partial decay of granitic materials with regular periods of exposure to the atmosphere. Such a condition is met with in a semi-arid climate in which periods of rain alternate with periods of drought during which a thorough oxidation of the iron is accomplished.

The conditions of deposition may, therefore, be summarized as follows:—broad subsiding basins between mountains of considerable relief; a semi-arid climate, in which erosion and disintegration proceeded rapidly, loading up the streams to their ultimate capacity; torrential floods in which the coarser materials were spread out over the river flood-plains, followed by dry seasons in which the sediments were exposed to the air, and their iron content oxidized. The farther the materials were transported, the more would the feldspar content be sorted out, until finally the detritus would consist of practically quartz grains only. Progressive subsidence and rapid erosion would eventually give rise to a thick series with all the features characteristic of the formation.

Late Pre-Cambrian time in North America was apparently marked by wide areal extent and conditions favorable for the accumulation of subaerial deposits. Rocks similar to the Athabaska series are found on the east arm of Great Slave lake, along Coronation gulf, and the Coppermine river, on several of the Arctic islands, and in the Labrador peninsula. The subaerial character of the Keweenawan rocks of the Lake Superior region, and of the Belt formation of Montana points also to the dominance of continental sedimentation in late Pre-Cambrian time. It is probable that in no subsequent period has North America had a greater areal extent.