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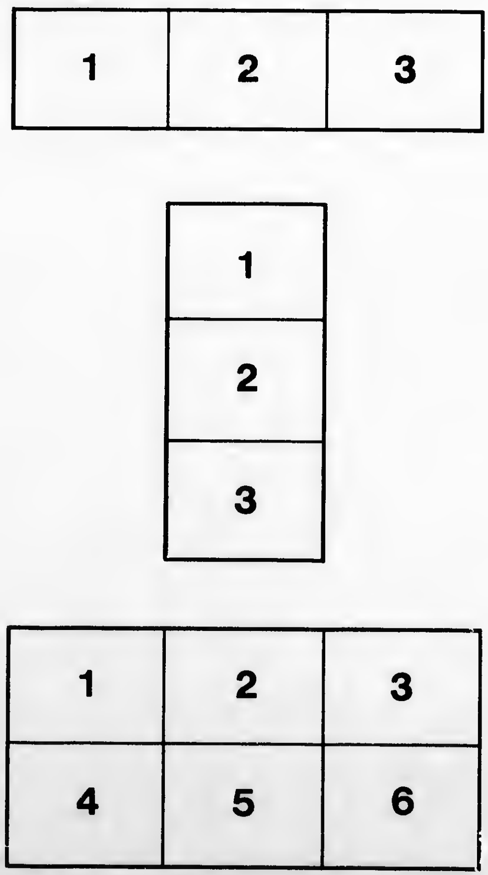

VI.—*On the Geology of the St. Clair Tunnel.*

By FRANK D. ADAMS, Lecturer in Geology, McGill University.

(Communicated by Sir William Dawson and read, May 27, 1891.)

The St. Clair Tunnel, one of the most useful and important engineering works of recent years, runs under the St. Clair River from Sarnia, Ontario, to Port Huron, Michigan, and joins the Chicago & Grand Trunk Railway in Michigan with the Great Western Branch of the Grand Trunk Railway in Canada. These points had formerly been connected by a steam car ferry, but owing to the great annual expense and the uncertainty of this means of communication, especially in winter, when the ice from Lake Huron is passing down the St. Clair, as well as to the steady increase of traffic over the line, it was decided to tunnel the river at this point, so that a continuous track might be laid.

The tunnel proper was commenced in August, 1889, and finished in August, 1890, the work being thus completed within about one year, the time being the fastest yet made in tunnel construction.

The work was begun by opening horizontal cuttings to the required depth on either side of the river, and on each of the headings thus formed a tunnel was commenced by means of Beach hydraulic shields, the tunnels finally meeting under the river and thus completing the work.

The tunnel is 6,000 feet long and 21 feet in diameter, the walls being constructed of cast iron segments bolted together.

As the tunnel passes through the heavy deposits of drift which cover this portion of the boundary of Canada and the United States, it seemed probable that an examination of the material excavated might prove of interest. Sir Joseph Hickson kindly consented, on request of Sir William Dawson, to secure specimens of the material passed through as the work proceeded, and this was arranged for through the kindness of Mr. James Hobson, the chief engineer of the tunnel; eight samples, taken from different points between the Canadian and American ends of the tunnel, being forwarded to the Peter Redpath Museum of this University and placed in the hands of the writer for examination.

GENERAL GEOLOGY OF THE DISTRICT.

Resting on the Laurentian axis, whose southern edge forms the eastern shore of the Georgian Bay, 180 miles northeast of Sarnia, there is, as is well known, a regular succession of Palæozoic strata, having a general southwesterly dip and forming an almost continuous series from the horizon of the Black River beds to that of the Chemung. These underlie what is known as the peninsula portion of the province of Ontario. Passing over the St. Clair River, into the state of Michigan, we find these highest beds succeeded

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by the sandstones, etc., of the "Waverly Group," which marks the base of the Carboniferous, and which in its turn is overlaid by the carboniferous limestone and coal measures occupying the central portion of the state.

The distribution of these formations is shown in the accompanying geological map. The entire area, however, both in Ontario and Michigan is heavily drifted, so that over long stretches of country no outcrop can be seen.

This drift in Ontario has not been as yet carefully studied. In the early years of the Canadian Geological survey it was examined in a general way, and in the 'Geology of Canada,' published in 1863, was classified as follows, in descending order:—

Recent Alluvia.
Artemesia Gravel and Algoma Sand.
Saugeen Clay and Sand.
Erie Clay.
Boulder Clay.

There is reason to believe, however, that the Saugeen clay and, perhaps, some of the other members of the series are secondary deposits whose material was derived from the underlying boulder clay.

The following extract from a report prepared by Dr. Bell, of the Canadian Geological survey, for the Royal Commission on the Mineral Resources of Ontario, gives a general description of the Saugeen and Erie clays:—

"West of the points above mentioned, south of the height of the land, the marine deposits are replaced by others which appear to be in part, at least, of fresh water origin. One of the most important of these is an extensive blue clay deposit which we have called the Erie clay, and which has as yet yielded no organic remains of any kind. It burns to white bricks, while the marine clays to the east burn red. The Erie clay is often very calcareous, and is seldom or never entirely free from pebbles and stones, more or less thickly disseminated through it. Indeed, it often seems to merge into the underlying boulder clay. It covers the whole of the southwestern part of the western peninsula, and is locally developed in many other parts of the province, as far east as the line of railway from Brockville to Ottawa. Its greatest known depth is about 200 feet, but it is found at differences of levels amounting to 500 feet. When seen in fresh sections it presents lines of stratification, and often a transversely jointed structure. In some localities its upper parts have been unevenly denuded before the deposition of the next higher formation, which consists of brownish clay yielding red bricks. This unconformable formation is well developed in the valley of the Saugeen River, and hence it has received the name of the Saugeen clay. Its thickness appears to be less than that of the Erie clay, but it is found in broken areas in all parts of the province, except the most easterly and northerly. When seen in fresh sections it is usually found to be very distinctly stratified in thin layers; sometimes with partings of fine sand between them. Beds of sand and gravel are occasionally found between the Erie and Saugeen clays, and these are of importance as affording good wells of water. Fresh water shells have been detected in a few instances in the Saugeen clay."

The "marine clays" above mentioned are those found in the valley of the St. Lawrence east of Brockville and known as the Leda clays, being probably the eastern equivalent of the Erie and Saugeen clays laid down under different conditions. This Leda clay will be referred to again later on.

Character of the Strata penetrated by the Tunnel.

Judging from the character of the deposit there is reason to believe that the St. Clair tunnel passes through boulder clay, though being in places very sandy, and having in some places a certain stratification, it partakes of the character of the Erie clay, which, as above mentioned, graduates into the boulder clay, and may really prove to be a peculiar development of it. The material obtained from the tunnel is a stiff clay, in places, as above mentioned, very sandy, and elsewhere very gravelly, while occasionally large gneiss boulders are found embedded in it.

When dry it is grey in colour, but assumes a pale reddish yellow tint on burning. Judging from the samples received it is entirely destitute of fossils.

This clay rests on a dark bituminous shale, with abundance of *Protosalvinia Huronensis*, characteristic of the so-called "Huron shale" of Chemung age, which is well exposed in Ontario at Kettle Point on Lake Huron, and is extensively developed on the Michigan peninsula. This Huron shale was struck at the bottom of a shaft which was sunk for drainage purposes close to the Canadian end of the tunnel and, as seen in the accompanying section, also occurs only a few feet below that portion of the tunnel which is beneath the river bed.

Two specimens of the rock from the bottom of this shaft were forwarded by Mr. Hobson. One consists of a thinly laminated brownish black bituminous shale holding, as above mentioned, an abundance of *Protosalvinia Huronensis*.[1] When a fragment of the shale is held in the flame of a Bunsen burner it decrepitates slightly and takes fire, being sufficiently bituminous to continue burning for some time after having been removed from the flame. The other specimen is harder and less thinly laminated as well as less bituminous than the one just described. It also contains Protosalvinia. It is, however, highly calcareous, effervescing readily when treated with dilute hydrochloric acid, while the first mentioned specimen does not effervesce at all. The Chemung beds exposed at the bottom of the shaft, therefore, consist of highly bituminous shales interstratified with coarser, less bituminous and highly calcareous strata.

As above mentioned, although some of the samples of drift received consisted of a comparatively pure clay, they generally contained a great deal of gravel or sand.

The following notes kindly sent me by Mr. Joseph Hobson, chief engineer of the tunnel, will explain their mode of occurrence:—

"Immediately over the rock there are a number of strata of quicksand and rough gravel. The thickness of these strata varies from two to three feet up to six feet.

"With regard to the sand found in the clay during the progress of the work it was usually in the shape of pockets, although occasionally the beds of clay were separated by films of sand not much thicker than a piece of coarse paper; in fact these seams were so

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[1] Sir William Dawson, "On Rhizocarps in the Erian (Devonian) Period in America" (Bull. Chicago Acad. of Science, Vol. i, 1886); also "On Sporocarps discovered by Prof. E. Orton in the Erian Shale of Columbus, Ohio" (Canadian Record of Science, 1888, p. 137).

thin, and the clay and the sand being of the same colour, it was not possible to distinguish them until the upper bed of clay slid off the lower.

"Boulders were occasionally struck, some of them containing two or three cubic yards.

"The large boulders were not numerous; perhaps there were not more than half a dozen of them. I am now speaking of boulders too large to pass through the compartments of the shields; of small boulders there were a considerable number. They were all, so far as I know, coarse granite. The workmen used to call them 'bastard granite.'

"The bed of the river consists of sand and gravel, varying in thickness from a few inches to several feet."

In order to ascertain the proportion of sand and gravel present, weighed portions of the several samples were submitted to a process of washing or elutriation, being repeatedly stirred with successive portions of water and allowed each time to settle for ten seconds; in this way only the clay and the exceedingly fine sand were removed. The gravel and the rest of the sand remaining behind were then weighed. The amount of carbonic dioxide present in the several samples was also kindly determined by Mr. A. Klock, under Dr. Harrington's supervision, in the chemical laboratory of this University. These results, together with the amount of carbonate of lime represented by the carbonic acid in each case, are given in the following table:—

Number of Specimen.	Point from which Specimen was Taken.	Percentage of Sand and Gravel.	Percentage of Carbonic Dioxide.	Percentage of Calcium Carbonate.
I.	Canadian side, 1,500 feet east of river and 70 feet below surface	11·0	6·238	14·180
II.	American side, 1,000 feet west of river and 60 feet below the surface.	12·2	6·706	15·241
III.	Various points	3·2	6·987	15·880
IV.		40·8 (Sand & Gravel)	5·225	11·875
V.		54·0 (Sand & Gravel)	5 872	13·347
VI.		64·4 (Sandy)	4·440	10·100
VII.	Canadian side, 1,643 feet in and 80 feet below the surface	81·4 (Gravelly)	5·981	13·60
VIII.	Canadian end of tunnel	73·8 (Sandy)	3·387	8·800

It may here be mentioned, however, that a certain amount of magnesia is probably present in combination with lime and carbonic acid, forming a dolomitic limestone rather than a pure carbonate of lime.

Nos. 1 and 2 when boiled with concentrated hydrochloric acid for an hour left 68·3 per cent. and 68·8 per cent. of insoluble residue respectively.

The following figures showing the amount of calcium carbonate in brick clays from other parts of Ontario may be of interest for comparison. The determinations were made by Dr. B. J. Harrington and have not hitherto been published :—

LOCALITY	Per cent. of Calcium Carbonate.
Yorkville, Ont....................	2·77
" "	26·72
Pembroke, "	·068
Glenwilliam, "	26·72
Arnprior, "	11·36
Peterboro', "	53·05

Petrographical Character of the Gravel.

The gravel in these clays is generally small, passing into sand, but in No. VII. some of it was quite coarse, the largest fragments measuring as much as two inches across. It is composed principally of worn fragments of soft brownish-black earthy looking bituminous shale. When struck with a hammer this readily splits up into thin fragments parallel to the lamination, and when held in the flame of a Bunsen burner decrepitates and takes fire, burning for a second or two and giving off a strong tarry odour.

In almost every case where a broken fragment of the shale is examined by means of a lens it is seen to be thickly strewed with the minute sporocarps of *Protosalvinia Huronensis*, characteristic of the Chemung (Huron) shales, from exposures of which the fragments were evidently derived.

In addition to the fragments of Huron shale, a number of fragments, more or less worn, of a soft fine grained, somewhat dolomitic, and micaceous sandstone, are found in the gravel, as well as some much smaller fragments of brownish or yellowish limestone, often highly magnesian. These latter are sometimes pure, and at other times contain a very large amount of siliceous and argillaceous insoluble residue. Occasionally a few rounded fragments of white or greenish quartzite are also found.

A number of fragments of the sandstone referred to above were crushed and treated with warm dilute hydrochloric acid. A slight effervescence took place, and small amounts of iron, lime and magnesia passed into solution. The dolomite being thus removed, the insoluble residue was mounted and examined with the microscope. A thin section of one fragment was also prepared. The sandstone was found to consist of the following minerals :—quartz, orthoclase, microcline, plagioclase, muscovite, biotite, hornblende (?), tourmaline, zircon, sphene (?) together with some opaque dark grains, possibly of some carbonaceous material. In the thin section, which was not treated with dilute hydrochloric acid before examination, dolomite and ferric hydrate could also be recognized. The little crystals and grains of tourmaline and sphene (?) closely resembled those which, as mentioned below, were found in the sand occurring with the clay.

One large well laminated fragment of this sandstone had a structure resembling false bedding and showed what Sir William Dawson believes to be obscure worm burrows or fucoid markings.

In all its characteristics it closely resembles the sandstones of the "Waverly Group," which, in Michigan, overlie the Huron shales. (See report of the Geological survey of Michigan, 1873-76, Vol. III, pp. 69-101.)

The limestone fragments were small and contained no fossils visible to the naked eye, or with the help of a lens. Some of the minute grains mixed in with the sand, however, when properly mounted and examined under the microscope, were found to possess an organic structure; some of them resembling fragments of crinoids, while others had a minutely punctate character and were probably fragments of brachiopod shells. There is nothing, therefore, to indicate the age of the beds from which these limestone fragments have been derived. They may have come from the thin beds of limestone interstratified with the sandstones of the "Waverly Group," or they may be from older strata of Corniferous, or even Niagara age. The very few fragments of quartzite have no distinctive characters by which their origin can be determined; some of them resemble the quartzite of the more compact beds of the Oriskany formation.

Petrographical Character of the Sand.

As will be seen by referring to the table, Nos. VI. and VIII. consist very largely of sand: No. VIII, in fact, is a nearly pure sand, but a portion of it being extremely fine was washed away during the process of elutriation. Another portion of No. VIII was carefully elutriated, and the material of various degrees of coarseness being thus separated, specimens of each were mounted in Canada balsam for microscopic examination, while others were prepared in almond oil and in water. The constituents found in this sand are the same as those found in the sands separated from the other samples, although all the minerals here mentioned were not found in every case. A brief description of this sand, therefore, will serve to indicate the character of the whole.

The coarse portions separated by the washing were found to be composed of the following minerals:—quartz, orthoclase, microcline, plagioclase, hornblende, epidote, tourmaline, garnet, calcite, pyrite, magnetite, sphene (?).

A few small pieces of the shale and sandstone before mentioned were also present.

The quartz occurs principally in partially rounded fragments, but also as angular chips, while a number of grains are perfectly rounded with a surface like ground glass. They are generally clear and colourless, but some few have the surface stained red by oxide of iron. Some of them hold the minute black hair-like bodies often seen in the quartz of the crystalline schists. Some of the quartz grains in the sand in No. I. show the peculiar crushed or broken character so often seen in the quartz of gneiss.

The orthoclase is not nearly so abundant as the quartz and occurs usually in much decomposed grains. It shows a biaxial figure in convergent light.

Microcline and plagioclase in well characterized grains occur in every slide. Hornblende occurs in green transparent anisotropic grains, often strongly pleochroic in tints of green. Generally in oblong grains with slightly inclined extinction and absorption $\mathfrak{C} > \mathfrak{a}$ Tourmaline was found in the sands of all degrees of fineness. It occurs in short, stout prisms, terminated at one extremity by a flat pyramid; the other end is sometimes similarly terminated, but is generally irregular. One of the largest of these little prisms was

found to measure ·05 × ·027 mm. They have a high index of refraction and strong double refraction, with parallel extinction, and show strong pleochroism in tints ranging from light brown, yellowish or greenish brown to deep brown or nearly black. The greatest absorption is in a direction at right angles to the length of the crystal. It is uniaxial and negative and shows no cleavage. These characters leave but little doubt that the mineral is really tourmaline.

The garnet is pink in color and isotropic with high index of refraction.

The calcite is present in considerable amount, the sand effervescing readily when treated with dilute hydrochloric acid, and occurs principally as cleavage fragments. It is uniaxial and negative, and between crossed Nicols shows the characteristic white of the higher orders. Although here referred to as calcite, as some of the grains at least are attracted by the electro-magnet showing that they contain some iron, it may really be dolomite in part.

Pyrite occurs in numerous little yellow grains with crystalline faces. Some of these are very minute but perfect octahedra. In No. IV, in addition to little rounded grains resembling minute concretions, a number of little octahedra were found often in groups. One very perfect little octahedron, showing also planes of the pentagonal dodecahedron, measured ·07 mm. in diameter. On account of the good form and sharp angles usually possessed by this pyrite it seems probable that it has crystallized in the drift.

The mineral referred to as sphene (?) occurs in small rounded grains with high index of refraction and high double refraction, and is either sphene or zircon, but I was unable to find any grain in which an axial figure could be obtained.

The fine material deposited from the first washing was found to be made up altogether of minute grains of different minerals. In addition to those already mentioned biotite and a colourless mica resembling muscovite, but probably belonging to some hydrated species, were also present. A very small amount of a fine grained aggregate, probably kaolin, was also seen in the slides.

Petrographical Character of the Clay.

A careful microscopical examination of the clay separated by washing from Nos. I. and VI. was also made. These clays were found to be almost identical in character, and may be taken as representing the clays of the whole deposit.

The material is exceedingly fine and requires a very high power for its examination. Minute fragments of calcite, orthoclase and little mica shreds can always be recognized, as well as in some cases little grains of plagioclase, hornblende and quartz. Kaolin is also present, and in No. I. occurs in large amount. Mixed with these minerals in No. I. and in No. IV., constituting a very large proportion of the clay, are dark fragments, which are opaque, except on the thinnest edges, where they are seen to be composed of a kaolin-like aggregate holding opaque grains. This is in part at least the Huron shale in a finely comminuted condition, while a portion of it seems to be a decomposition product of orthoclase.

Origin of the Drift penetrated by the Tunnel.

It is evident from the character of the drift as above described, that with the exception of the comparatively few boulders of Laurentian gneiss embedded in it, it has not been brought from the far north, but has been derived very largely, if not exclusively, from the wear and tear of the Huron shales and rocks of the "Waverly Group" which occur in the immediate vicinity. This is indicated by the character of the gravel which is present in almost every sample of the clay, sometimes constituting a large proportion of the whole.

Although the peculiar character of the sand shows that it has been derived originally from the gneisses of the Laurentian, it seems pretty certain that its proximate origin is to be found in the "Waverly" sandstones, since not only are fragments of sandstone, which, as shown above, there is every reason to believe belong to this group, scattered through the drift and occur even in these very beds of sand, but the sandstone itself contains nearly all the minerals found in the sand, and among them some of the rarer and more characteristic species. The character of the clays also points to a similar origin. Since the general movement of the drift in this district was from north to south, the material constituting the drift penetrated by the tunnel must have come from some portion of the area now occupied by Lake Huron.

This conclusion, as will be seen by consulting the accompanying geological map, is in perfect accord with that indicated by the composition of the drift itself, namely, that it is derived from the wear and tear of the Huron shales and beds of the "Waverly Group," seeing that a considerable portion of the southern half of Lake Huron lies in a depression scooped out of these formations. A great part of Lake Michigan also must be underlain by rocks of this age.

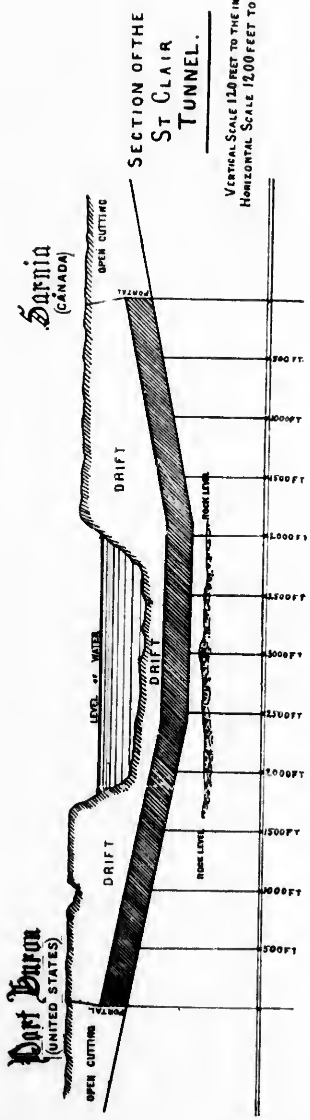
The Leda Clay.

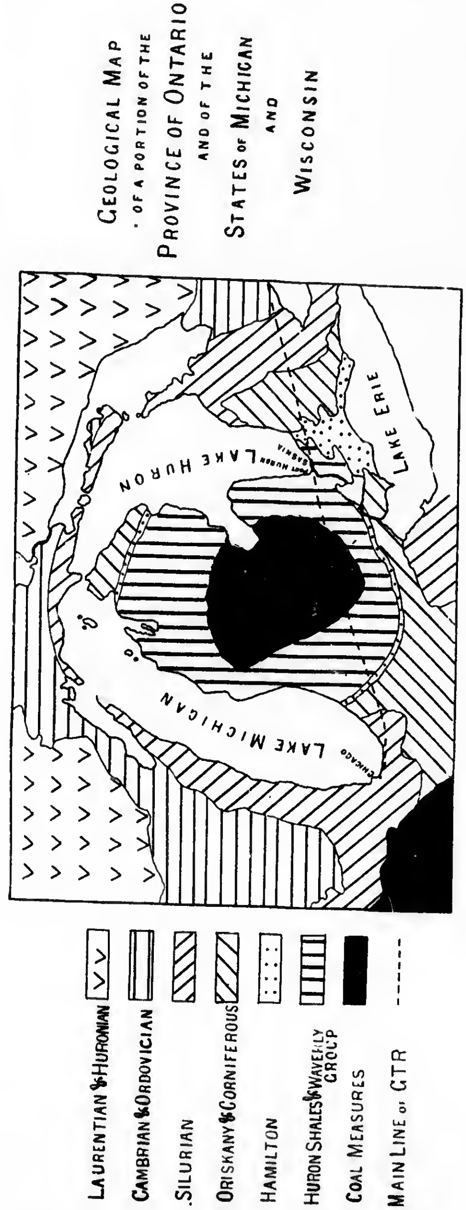
As above mentioned, the Erie and Saugeen clays do not extend down the valley of the St. Lawrence below Brockville. East of this point their place is taken by a deposit of clay quite different in character and known as the Leda clay. This clay is in places highly fossiliferous, and, as indicated by its fossils, is of truly marine origin.

For comparison with the clays above described a typical specimen of this Leda clay was examined microscopically. The sample, which was given to me by Sir William Dawson, was taken from an excavation on Sherbrooke street, in the city of Montreal. It is an impalpably fine clay with no admixture of sand and gravel. When powdered and carefully washed a minute residue remains, which, when examined under the microscope, is seen to consist of little angular fragments quite clear and fresh of the following minerals:—quartz, microcline, orthoclase, plagioclase, hornblende, garnet, calcite, apatite (?), tourmaline (?). The quartz sometimes shows the uneven extinction so often seen in gneiss. Under the microscope the rest of the clay is seen to consist of exceedingly finely divided kaolin, with here and there a few minute brilliantly polarizing fragments of one or other of the above mentioned mineral species.

This difference in the character of the Leda clay and the clays from the St. Clair tunnel is in all probability due to the fact that the Leda clay was deposited far from land in what was then a great westward extension of the Atlantic.

In closing I desire to thank the various gentlemen to whom I am indebted for assistance in carrying out this investigation. My thanks are due more especially to Sir Joseph Hickson and Mr. Joseph Hobson for having the samples carefully collected and forwarded, as well as for notes on their mode of occurrence, and to Sir William Dawson, at whose request I undertook the examination of the same, for aid more particularly in the determination of the fossils.





To illustrate Mr. F. D. Adams' Paper on the St. Clair Tunnel.