The Early Scientific Work of John Milne

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Introduction

John Milne is best-known as one of the leading seismologists of the nineteenth century. His work in this field began in 1880 and continued to his death in 1913. His contributions to seismology and his place in the history of this subject will be discussed in a further work, now nearing completion.

It is the purpose of the present work to draw attention to Milne's little-known earlier work accomplished between the years 1874 and 1886. It covers a wide field including mining geology, glaciology, mineralogy, crystallography, volcanology, archaeology and natural history.

Life and Work of J. Milne

Accounts of Milne's life and scientific career have appeared previously; this section is a synopsis of those accounts (1)-(5).

Born in Liverpool on 30th December, 1850, John Milne was the only son of Emma, daughter of James Twycross of Wokingham, and John Milne of Milnrow, Rochdale. As a boy, Milne was educated in Rochdale and subsequently at the Collegiate College, Liverpool. A striking example of his fondness for travel, his initiative and independence occurred at an early age when he used savings and a school prize of money to go to Iceland without first gaining his parents' consent. The object was to see the volcanic area of Vatna Jokul, descriptions of which had fired his imagination. This episode marked the beginning of his long-standing interest in volcanic phenomena.

On leaving school, Milne entered King's College, London, and later attended the Royal School of Mines where he studied geology under Professor Sir

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Warrington Smyth. After gaining some practical experience of mining engineering in Cornwall and Lancashire, he spent a short time at the Bergakademie, Freiburg and visited the principal mining districts of Germany. On his return to England, Milne was selected by Cyrus Field, Sir James Anderson and others to report on the mineral resources of Newfoundland and Labrador, a project accomplished during the summers of 1873 and 1874. The survey resulted in Milne making very useful contributions to existing knowledge of these resources and to the petrology of Newfoundland. Icebergs were often to be seen floating in the seas surrounding this country, coast-ice was a common feature and the rocks bore clear evidence of past glaciation of the land surface. These circumstances aroused in Milne a considerable interest in glaciology, a subject to which he also made useful contributions. While in the area, he took the opportunity to visit Funk Island where he made observations on the geology, flora and fauna and paid special attention to remains of the Great Auk. In 1874, he was appointed geologist to an expedition made under the auspices of the Royal Geographical Society and led by C.T. Beke (6) in quest of the true site of Mount Sinai in N.W. Arabia. Bake believed this mountain to be situated some 95 miles north-east of the district in which it had hitherto considered to be. Milne's geological investigations on this expedition provided material for two interesting papers.

In the following year he was appointed Professor of Geology and Mining in the Imperial College of the Public Works Department, Tokyo. The post was one of many created in response to the Emperor's wish to bring western learning and methods to Japan.

The usual method of travelling to Japan at that time was by P. and O. mail packet but it was characteristic of Milne that he chose an arduous but much more interesting route overland across Europe and Asia. His journey began at Hull on 3rd August, 1875. After crossing to Gothenburg by sea, he travelled through Norway, Sweden and Finland to Russia and thence across the Urals into Siberia. Next followed the most difficult and uncomfortable part of the journey, made by camel across Mongolia to China. For 31 days on one section of this journey there were no roads, no dwellings, bread and vegetables were lacking to augment the unpalatable food, temperatures were extremely low with snow abounding, and there was no possibility of washing or changing clothes. Shanghai was reached on

24th February, 1876, from where he subsequently travelled by sea to Japan, reaching Tokyo on 8th March, 1876.

Milne kept very full notes of his experiences and observations, even under the most arduous conditions, and they enabled him later to publish two long accounts of his journey. One account was chiefly of geological interest (7), the other was a travelogue of more general interest (8).

Milne's experience of earthquakes began on his first night in Tokyo when Yama Gouchi, the house provided for him by the Japanese Government, was shaken by a minor shock. Occurrences of this kind were frequent and could scarcely fail to arouse the interest of Milne and the other scientists and engineers who were his contemporaries at the College. It was not, however, until a semi-destructive shock took place at Yokohama in 1880 that Milne's career as a seismologist could be said to have begun.

His early years in Japan were spent in attending to his duties at the College, carrying out a little research in the laboratory, and exploring the country, with special reference to its geology, volcanoes and archaeology. As an outcome of his lectures on mining, he published in 1878 and 1879 respectively two pamphlets intended largely for the guidance of his students, works which were later to appear as part of a much more extensive textbook on the subject. His lectures on crystallography also formed the basis of a textbook, published in 1879. His investigations in the laboratory led to a publication on the elasticity of crystals.

Observations in the field, coupled with the perusal of existing collections of minerals, led to the publication in 1880 of a paper on the minerals of Japan in which he described examples of a number of minerals previously unrecognized in that country.

Milne's strong interest in glaciology led him to seek evidence for past glacial action in Japan; he presented his interesting conclusions on this hitherto-neglected topic in 1881.

While pursuing his geological interests, Milne came across examples of Stone Age artifacts which let him to undertake two archaeological studies of this period, the results of which he published in 1879 and 1881 respectively, although the erlier of these papers was not published in full until 1881.

It was in volcanology, however, where his greatest interest lay during his early years in Japan and in this field he made significant contributions especially in regard to the distribution of volcanic activity in Japan and to analysis of the shape of certain regularly-formed volcanic mountains.

An earthquake which caused widespread damage in Yokohama on 22nd February, 1880, had very important consequences for the progress of seismology. Shortly after the earthquake had occurred Milne issued a call for a public meeting, a move which met with considerable support and resulted in a crowded hall at which was formed the Seismological Society of Japan, the first to devote itself exclusively to the study of seismology and volcanology.

The Japanese Government encouraged the new wave of interest in seismology by forming an Earthquake Committee supported by an annual grant and by establishing a Chair of Seismology at the Imperial College. Milne was appointed to this post, which he held until he left Japan in 1895. This allowed him to give all his time to seismological research. His output was immense and his boundless energy and enthusiasm did much to stimulate others to carry out similar work.

Milne's work was also aided by a grant he received from the British Association. The Association appointed a Committee on the Earthquake Phenomena of Japan, with Milne as Secretary and his reports of this Committee's work and that of the Association's Committee on Earth Tremors form useful summaries of the research carried out in Japan by Milne and his colleagues. Milne's close link with the Association lasted for over 30 years, until his death in 1913.

Following his investigation of the Yokohama earthquake, the more important work carried out by Milne in Japan was the preparation of local and regional earthquake catalogues on which he based his studies of earthquake distribution in Japan, experimental investigation of the transit of elastic waves through the ground, recording and interpreting earth tremors (9), and his considerable achievement of developing a sensitive and reliable seismograph capable of recording an earthquake occurring in any part of the world. Milne also prepared a textbook on seismology, *Earthquakes and other Earth-movements* published in 1886. A companion volume, *Seismology,* was published in 1898 after he had left Japan (10).

Sometime during his residence in Japan, Milne married Tone, daughter of

Horikawa Noritsune, high priest of Hakodate, but the date of the marriage has not been recorded by his biographers.

On returning to England in 1895, Milne lived at Shide near Newport in the Isle of Wight. He quickly set up a seismological observatory at his new home where he continued to pursue his studies with the help of his Japanese assistant, Hirota. Through the medium of the British Association, Milne was successful in persuading the authorities in many countries to set up observing stations at which Milne seismographs were installed and from 1898 onwards he carried out the considerable task of interpreting and correlating alltheir records and subsequently preparing circulars for twice-yearly dispatch to the stations, providing them with full details of all the earthquakes recorded. By 1912, there were some 60 stations involved in this procedure.

With this record of achievement, it is not surprising that many honours and distinctions were conferred on Milne. He was made an Honorary Fellow of King's College, London in 1896 and was Lyell Medallist of the Geological Society in 1894. In 1887, he was elected a Fellow of the Royal Society of which he was Royal Medallist in 1908. In 1895, at the close of his career in Japan, the Emperor conferred on him the Order of the Rising Sun and granted him a pension. Milne was awarded an Honorary Doctorate in Science by the University of Oxford in 1906.

Milne's death took place on 31st July, 1913 after a short illness.

Geology and Mining

In this section, Milne's published work in mineralogy, petrology, glaciology, crystallography and mining is considered. Volcanology is considered separately in a later section. The sub-sections are arranged in approximately chronological order.

1. *The Mineral Resources of Newfoundland*

Mention has been made that Miine's first professional duties were to report on the mineral resources of Newfoundland, a task he began in the summer of 1873. His first paper, published in the following year, was an account of this survey(11). He made it clear in his opening remarks that the subject matter was largely an account of his own investigations:

"The geological characters of many of the places referred to having already been so thoroughly described by Mr. Murray in his reports on the geology of this island, or else remaining to form at some future period the subject of such reports, it is purposed (sic) in this communication to omit all that has already been written, and only to touch briefly on the remainder." (12)

After describing the principal physical features of Newfoundland and correlating them with the geology and glaciology of the island, Milne described his mineralogical findings, working round the country anti-clockwise from St. John's.

At St. Mary's Bay he found slight indications of lead and copper and on the south-east side of the harbour there was a vein of white quartz, three to four inches thick, carrying galena, iron pyrites, blende, and occasionally copper. The vein cut through slates and quartzites in a direction N.76°E. to S.76°W., with a dip of 38° (13).

Milne drew attention to the green fluor spar in which galena and blende were worked in existing and abandoned mine workings in the Placentia Bay area. Fluor spar was a comparatively rare mineral on that side of the Atlantic and its occurrence in Newfoundland ought especially to be noted (14).

He pointed out that the remaining part of the south coast as far as Cape Ray consisted, with few exceptions, of granites, syenites, mica-schists and other allied rocks of Laurentian age. The metalliferous deposits of this formation in Canada were associated with bands of limestone which were missing here; in their place were garnets, staurolite and cyanite. The garnets, almost opaque and dull red, showed rhombic dodecahedral forms and occurred scattered through mica-schist. Garnets were particularly plentiful east of Long Island and near Port au Basque (15).

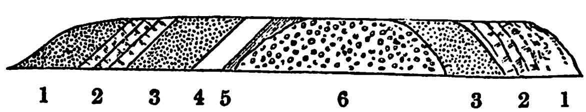
A large deposit of staurolite was discovered by Milne on the east side of Fachoux Bay, where it thickly covered upturned micaceous slates with dark brown crystals about half an inch long. Since crystals of staurolite had previously been imported from India in considerable quantities, he judged the Facheux Bay deposit to be of decided economic importance (16).

Milne also discovered, in black slates on the eastern shore on the Bay, veins of plumbago which appeared as irregularly formed dyke-like masses striking out east and west (17).

At Big Barbe Head, Bay of Despair, he described quartz veins carrying galena and specks of copper and iron pyrites and further north, serpentine rocks containing diallage and pyroselerite

Milne found at the north end of Codroy Island a small vein of siderite and on the mainland opposite this area shales which assumed the character of slates; he recommended that these might be used for supplying local requirements (18).

Between Cape Anguille and the north end of St. George's Bay, a number of rivers and streams cut the Coal-measures at right angles. Milne travelled up one of these streams for about four miles and found the general relation of the rocks to be that represented in the section shown here reproduced from his paper (19). The western (left-hand) end of the section corresponds to the south of the stream where cliffs of red sandstone dipped at an angle of about 10° downstream. This was underlain by the rocks listed in the sketch section, the series repeating itself as an anticlinal further up stream.



1. Bright red sandstone.
2. Yellowish grey limestone.
3. Bluish shale with bands of sandstone.
4. Gypsum.
5. Shales.
6. Conglomerate.

Fig. 1: Sketch Section of Coal-measures near St. George's Bay

This region where the Carboniferous rocks were predominant was one of the most important areas in Newfoundland for the occurrence of minerals of potential economic importance and led Milne to investigate in some detail the deposits of gypsum, coal, magnetite and galena which he found there (20). The exposed beds of coal in the St. George's Bay area were highly tilted at an angle of about 85° but many were too thin to be worked with advantage or were rendered unsuitable by an admixture of shales and iron pyrites. Of these deposits he concluded:

"Whether the coal improves in quality from south to north, as it would seem to do from the examples cited, and as certainly the gypsum which has been spoken of does, there is not yet a sufficient accumulation of data for satisfactory proof. It is hardly fair to judge of the value of these

> Coal-measures from the eight or nine seams or exposures which have been found cropping out upon the surface, as upon further exploration by boring and other processes seams of greater value may yet be discovered..." (21)

The magnetite deposits were too disseminated to be of economic importance but Milne drew attention to the galena deposits in the vicinity of Port-au-Prince Peninsula:

> "On the south side of this peninsula several of the small north and south dislocations hold galena; but these are merely indications and leaders up to the larger depositories in the east and west fault, where this valuable ore is apparently accumulated." (22)

The only remaining area in which economically important mineral deposits were found was at Tilt Cove in Notre-Dame Bay. These deposits had been fully described by Murray in 1868 and although further investigated by Milne, he appears to have added little to Murray's findings.

Milne concluded on an optimistic note which must have encouraged the sponsors of the investigation:

> ".....but from the numerous indications on the coast, not one half of which has yet been traversed, it might be argued that Newfoundland will in future rank high in the lists of the mining-world." (23)

2. *The Rocks of Newfoundland*

Milne's survey of the rocks of Newfoundland was carried out in part at the same time as his investigation of the island's mineral resources in the summer of 1873, but the task was not completed until 1874. An account of his survey was published in 1877 (24). It was based on visits to almost every bay and cove and treks into the interior which was then virtually unknown territory. In this way he made two complete circuits of the island and collected many specimens of rocks and fossils. Nevertheless he acknowledged that he was much indebted to previous work by Murray (25).

Near the beginning of his paper Milne provided a table of strata, including a comparison with the sequence in North America and Britain. This table is so useful in following his account of the survey that it is reproduced here.

NORTH AMERICA		GREAT BRITAIN	NEWFOUNDLAND
Lower Laurentian		Laurentian	L. Laurentian.
Upper Laurentian			U. Laurentian.
Huronian		*Cambrian ?*	Huronian.
St. John's Group		Lingula Flags	Primordial Silurian.
Paradoxides Slates			
Lower Potsdam			
Upper Potsdam		Tremadoc Slates	Potsdam.
Lower Calciferous			
Upper Calciferous			Calciferous.
Quebec Group	Levis	Llandeilo Beds	Quebec Group: Levis.
	Lauzon		Lauzon.
	Sillery		Sillery.
	Chazy		
Trenton and Bird's Eye Limestones		Caradoc Beds	Bird's Eye Lime-[stone.
Utica Slate			
Hudson River Beds			
Oneida Conglomerate		L. Llandovery Rocks	M. Silurian.
Medina Sandstone			
Clinton Group		U. Llandovery	Clinton.
Niagara Group		Wenlock.	*Niagara ?*
Onondago Group			
Lower Helderberg			
L. Devonian.	Oriskany Sandstone	L. Devonian	*Devonian ?*
	Caudagalli Grit		
	Schoharrie Grit		
	Gaspe Sandstone		Gaspe Sandstones.
Mid. Devonian or Upper Helderberg		M. Devonian	
U. Devonian, Portage Group, etc		U. Devonian	
Lower Carboniferous (Gypsiferous)		Carboniferous	L. Carboniferous.
Middle Carboniferous (good coal)			Millstone Grit.
Upper Carboniferous			

Table 1: Rock formations of Newfoundland with their British and American equivalents

Milne took the groups in order, beginning with the oldest, and described his findings in each case.

Rocks of the Laurentian series occurred abundantly in the northern, southern and central parts of the island. They consisted largely of granite, syenite and gneiss. There were many igneous dykes one of which, at Harbour Deep, had an average width of 25 yards and was investigated by Milne in some detail. The rock forming the dyke was identified as a melaphyre, the country rock being an hornblendic gneiss traversed by small veins of quartz with which was associated specks of copper pyrites. He found not only the well-known feature of variations of the constituents at different points across the breadth of the dyke but also marked variations along the length (26).

The group above the Laurentian, and roughly equivalent to the Huronian and Cambrian series, was largely made up of beds of slates which contained bands of diorite, quartzite and jasper. Milne thought it remarkable, in view of the great age of the series, that fossils were to be found embedded in the strata but Murray pointed out that the fossils were in the clay-slates quite high up in the series, immediately below sandstones and conglomerates (27).

Ascending the series, Milne noted that he had seen a fine exposure of the Primordial Silurian in the form of cliffs several hundred feet high which occurred in the Cutler's Head area of Bonavista Bay:

> "The rocks are fine-grained, chloritic and argillaceous. In many places they are coloured with red oxide of iron. Some of the rocks of this neighbourhood of an amygdaloidal character appeared to be altered diorite..... Further up the bay conglomerate and more igneous rocks of a chloritic character and rich in kaolinized felspar were observed." (28)

In the Potsdam group, consisting of dark-coloured slates and conglomerates, Milne found dykes of felsites and highly chloritic melaphyres containing quartz. In contrast, the Calciferous series, well-exposed in the west of the island, particularly on the northern side of the Port au Prince Peninsula, Milne found:

> "... definitely stratified grey limestone rich in fossils, large *orthosceri,* Corals and *Maclurea* being very noticeable."(29).

He explored two quite large caverns formed in the limestone and suggested that exploration below the bed of clay covering their floors might yield material of interest to the study of the island's fauna.

Milne was especially interested in the Quebec series, particularly the middle division known as the Lauzon, since this series was economically the most rewarding. It outcropped extensively and Milne had visited all but one of the areas concerned. A predominant feature was the presence of dark green serpentines showing traces of actinolite. Veins of chrysotile were common. There were many signs of these rocks being derived from volcanic rocks and Milne thought there was evidence of abundant volcanic activity in the country during mid-Silurian times, a view not altogether shared by Murray who put the time of maximum activity rather earlier (30).

Above the Lauzon group, but still part of the Quebec series was the Sillery, a formation composed largely of black slates and limestones. Milne had closely examined an exposure in the northern part of the island where:

> "I have observed both intrusive and embedded masses of diorite. They are generally of a dark grey or greyish green colour, and in some cases amygdaloidal, the amygdules being filled with calcite. Under the microscope, altered felspar, hornblende and grains of magnetite are generally to be seen." (31)

The Niagara and Clinton group had been recognized only at the head of White Bay; Milne described it as a series of conglomerate and slates capped with limestone. The total thickness was about 2,800 feet but the presence of faults, some with a throw of as much as 1,000 feet, made it difficult to trace the sequence of the members of this formation (32).

Milne said of the Devonian formation, found in the Cape Rouge and Fox area, that it consisted of:

> "..... a series of plant-bearing sandstones, coarse conglomerates and reddish-green slates, amounting altogether in thickness to about 3,700 feet, which have provisionally been called Devonian, and are apparently the equivalents of the Gaspe sandstones." (33)

The most recent formation found in the island was the Carboniferous. It outcropped in two localities and in both these areas rested directly on the Laurentian. Milne described the formation as consisting of red sandstones, shales, greyish limestones, gypsum and conglomerates. The gypsum occurred in great masses like cliffs of chalk and examination of surrounding rocks led to the rather unexpected conclusion that it acted as an intrusive rock, contorting and breaking the rocks in close contact with it. He found fossils of Silurian age in the limestone of the conglomerate which also contained pebbles of magnetic iron derived from the Laurentian series. There were several seems of coal, one of them 3 feet 6 inches thick and Milne thought it likely that many more would be discovered.

Above the Carboniforous formation there was a covering of alluvium which in many parts of the island showed strong evidence of glacial action by the presence of striated angular stones. In addition, the surface of the rocks on which the alluvium rested was often found to be roundly smoothed and striated. Milne believed that it was coast-ice acting on an area which was rising that caused these effects, rather than the action of glaciers (34).

3. *Glaciology*

Milne's interest in glaciology was aroused by his visit to Newfoundland in 1873, when he was greeted on arrival at St. John's by the sight of icebergs surrounded by floe-ice. His geological survey amply confirmed the conclusion reached by previous investigators that the island had been subjected in the past to an intense glacial period but he differed from then in ascribing many of the effects observed to the action of coast-ice on a steadily rising area rather than to the action of great ice-sheets. His work in Newfoundland is considered below under the headings of evidence of glacial action in Newfoundland, theories concerning icebergs, and the role of coast-ice. Milne retained his interest in the subject for a time after taking up residence in Japan, where he found evidence pointing to a limited glacial period having occurred in that country. Consideration of this evidence forms the fourth section of the present review.

(a) *Evidence of Glacial Action in Newfoundland*

Milne described his geological findings relating to the action of ice on the rock of Newfoundland in the same paper as that presenting his survey of the mineral resources of the island (35). He found that ice-scratches, usually in a north-east – south-west direction were common in some areas while roches moutonnées and heaps of drift filled with regularly striated pebbles and boulders were discovered in many parts of the island.

The presence of raised beaches and terraces indicated that the coast of Newfoundland had been rising steadily and it could be assumed that at one period, when about 1,000 feet below its present level, the land was subjected to massive ice action which gave rise to the parallelism of many natural features of the island. Milne recalled that Agassiz in 1864 had accounted for these features by the action of a great glacier 6,000 feet thick. A theory had also been put forward in terms of a polar ice flow or a polar glacier cutting its way over the island from N.E. to S.W. (36).

In either case there were anomalies to be explained, and the general tenor of Milne's comments leaves the reader with the impression that he was not satisfied with any of the explanations offered.

Milne's second published work on glaciological topics appears in 1876, by which time he had extended his observation of glacial action in Newfoundland. He now advanced theories accounting for the time of arrival of icebergs in Newfoundland waters, the manner in which the bergs floated, and the mechanism of glacial action in the island (37).

(b) *Icebergs*

Milne pointed out that icebergs usually appeared around the coast of Newfoundland on about 1st January each year. This fact called for some explanation since the bergs must presumably have been formed from their parent giacier in the far north during the previous summer and would be expected to appear during the late summer or early autumn, making due allowance for the distance travelled. He believed that the explanation lay in the observation by Artic navigators that in very high latitudes, ice was in motion much earlier than further south. Thus on 20th May the western side of Smith's Sound had been navigable, but Barrow Strait was blocked until August. Another possible factor in delaying the icebergs was the westerly winds which prevailed in the autumn; these gave way to northerly winds in the spring. The former would tend to keep the bergs at sea but the latter would aid the current bringing them to the shore (38).

Milne was also interested in the way in which icebergs floated. It was known that the mass of the submerged portion was seven to nine times greater than that above the water but he could not accept the view that the depth of the submerged part also bore this ratio to the height of the visible part. He thought that this might well be the case when the berg left its parent glacier, the shape then being a close approach to a prism. As the bergs travelled towards lower latitudes, however, encountering higher temperatures and constant battering by waves, they lost their regular shape, the greatest change being suffered by the upper portion exposed to the atmosphere.

> "As this waste goes on, the berg must rise, and the ratio of the height of the exposed portion to the depth of that which is hidden grows greater. The result of this is that the exposed portion becomes less and less in diameter than that which is protected beneath the surface of the water, which at last may be looked upon as kind of foot or pedestal." (39)

This tended to be confirmed by observations, since although icebergs were occasionally seen to ground in deep water in low latitudes, the reverse was true in most cases. In fact the grounding of icebergs was used by the fishermen of both Newfoundland and Labrador as an indication of shallows suitable for fishing.

Milne proceeded to consider the matter mathematically:

> "For example, in the accompanying figure let AB be the surface of water in which we see a piece of ice floating as indicated by the black line, the general direction of that beneath the water corresponding to that which is above. Approximating to such a figure, draw on the 'give-and-take' system a many-sided pyramid, or in the limiting case a cone approximately equal in volume to that of the supposed berg. This is shown by the dotted line."

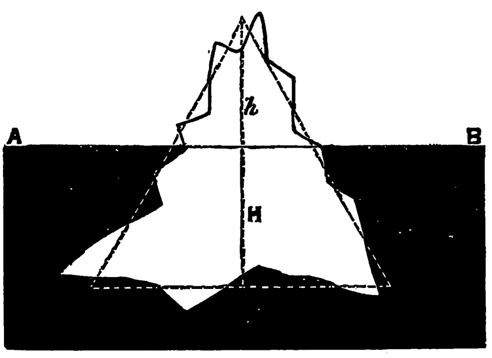


Fig. 2: Floating iceberg and equivalent cone

He then took the volume of the cone exposed above the surface to that of the solid submerged beneath it to be in the ratio of 1 : 8 and the corresponding vertical heights to be h and H. Then calling the volume of the complete cone V and that of the cone projecting above the surface v :

$$\frac{V}{v} = \frac{2}{1} = \frac{(h+H)^3}{h^3}$$

or

$$\frac{h+H}{h} = \sqrt[3]{9} = 2.08$$

giving $H = 1.08h$

Hence the depth below the surface was little greater than the height of the exposed portion (40).

Criticising this analysis in a letter which appeared in a later issue of the *Geological Magazine*, O. Fisher said that Milne had not sufficiently considered the conditions of stable equilibrium. An iceberg of the shape illustrated in Milne's paper would overturn. Fisher supported his view by some rather unconvincing experimental evidence. From a set of model crystals made of boxwood he took a tetrahedron and placed it in water, where it would float only with one of its *angles* downwards. The position of stable equilibrium depended on the shape of the floating body and on its specific gravity:

> "The specific gravity of boxwood being about 0.95, is so nearly the same as that of ice, that the positions assumed by a floating mass of either substance will be as a rule almost identical." (41)

Milne replied to this criticism in a paper published in the following year in which be discussed the stability of equilibrium of a cone of ice fioating on sea water (42). He did not accept Fisher's views and wrote of the experimental use of a tetrahedron to simulate an iceberg:

> "This I consider to be an unfair comparison, which no doubt has led many casual readers to the belief that a cone will also float with its apex downwards, and perhaps, in consequence, that my conclusions, being founded on false assumption, must also of necessity be false." (43)

Milne then proceeded to explore mathematically the conditions required for stable equilibrium, basing his analysis on the method used in Thomson and Tait's

Naural Philosophy, section 767. In the case of a cone floating in a liquid with apex downwards, he showed that the condition for stable equilibrium was:

$$r > a\sqrt{\frac{1}{\rho^{1/3}} - 1}$$

where r = radius of base of cone

α = height of cone

ρ = ratio of density of cone to that of the liquid

Then taking the specific gravity of ice to be 1.028 and that of sea water as 0.918.

$$\rho = 0.893,$$

$$r > 0.196a$$

In the case of a cone floating with its apex upwards, the condition for stability was:

$$r > a\sqrt{\frac{1}{(1-\rho)^{1/3}} - 1}$$

which reduced to r > 1.05a

In the first instance, the limiting cone would be one having only 1/25 of its depth above water and in the second case, the limiting cone would have nearly half its height above water. These limiting cones drawn to scale were represented in Milne's paper in the form reproduced here (44):

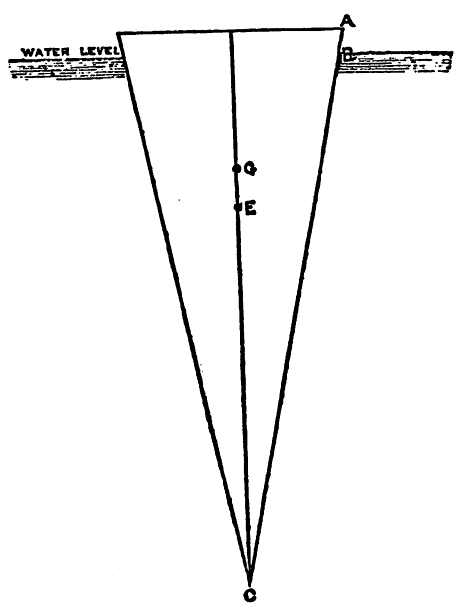
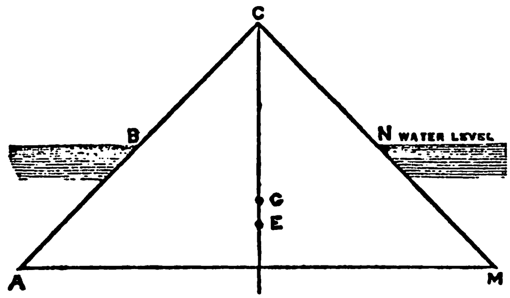


Fig. 3: Limiting cone, r = 0.196a

Fig. 4: Limiting cone, r = 1.05a



Milne pointed out that:

"The more probable form in which the generality of icebergs exist are those which have their limit represented by Case II., where we have a series of stable forms, more or less conical in their shape. Here the depth below the surface of the water never exceeds the height which is above, but is probably always less." (45)

Thus Milne saw no reason to change the views he had expressed in his earlier paper.

(c) *Coast-Ice*

Mention has been made of Milne's dissatisfaction with the theories which had been put forward to explain the abundant geological evidence of glacial action on the rocks of Newfoundland. In his paper *Ice and Ice-work in Newfoundland*, part of which has been discussed above in connection with his views of icebergs, he put forward the theory that coast-ice had played a part in the glaciation at least equal to that of glaciers and icebergs (46). He described the forms taken by coast-ice and discussed its origin. In addition to its rôle as a scratching and grooving agent, it also transported masses of material. Textbooks of geology referred to the way in which icebergs could carry rocks but it was a matter of common observation around the coasts of Newfoundland that this was a rare occurrence whereas coast-ice in the form of "balacada". barrier-ice, or ice-foot transported masses of boulders and gravel kelp.

Milne drew attention to another factor which favoured coast-ice rather than icebergs as the agent leaving a permanent record of its action on the rocks. Any grooves and scratches left by icebergs were likely to be obliterated after the ocean bed had risen to become dry land whereas coast-ice, driven backwards and forwards by the tides and advancing and retreating with the seasons, would be acting on a steadily increasing area, starting with what were now the highest points and subsequently affecting lower ground as the land mass rose.

Milne reiterated his views on the rôle of coast-ice in a paper published in 1877 in abridged form in which he pointed out that Finland too, bore evidence of a glaciological history similar to that of Newfoundland (47).

In further support of his theory, Milne drew attention to the fact that maps of northern Europe on which were indicated the general direction of ice-markings, showed the latter to be more or less at right-angles to the sea coasts. This was certainly as favourable to the view that the markings were due to coast-ice acting on a rising area as it was to the action of great ice-sheets.

He concluded:

"I will say that one thing seems to me to be certain – namely, that, even if we accept the most favourable views of large ice-caps, the appearance presented by many countries, which have hitherto been ascribed to their action, ought rather, for reasons already stated, to have been accredited to the action of coast-ice on a rising area." (48)

(d) *Evidence of a Glacial Period in Japan*

Various hypotheses were put forward in the latter part of the nineteenth century to account for the coming of the Ice Age and those which gained a firm measure of support held that the cause was not to be found locally on the earth's surface but rather in changes in the amount of solar radiation falling on the earth or in changes in the earth's orbit.

It occurred to Milne that if explanations along these lines were correct, there should be evidence of glaciation in the Eastern Hemisphere as well as the Western, but:

"... so far as I am aware it is but little that has been written about the evidences of a glacial period in the western portio of the Pacific Area, and about the evidences of this period in Japan not anything." (49)

He set out to correct this omission, his findings being published in 1881 (50). He pointed out that the most likely areas in which to seek evidence were the northern and western regions of Japn, since they were the coldest and bore accumulations of snow. Many of the highest mountains, however, were volcanic in origin and geologically recent; they were unlikely to have existed during the Ice Age. This narrowed the field considerably and among those mountains which were not of recent volcanic origin some had snowfields and even small glaciers but only one was found which appeared to provide direct evidence of a glacial period (51). This mountain was Gwassan, in the north of Japan. It was 6,000 feet high and had snowfields up to 400 yards in length when seen in July, 1879. The core might have been old volcanic rock but the flanking schists indicated great age. Here Milne found rounded rocks which he took to to be roches moutonnées. At the base of a steep slope of the mountain there was:

> "... a small tract of gently sloping country with a very singular appearance ..... The peculiarity of this country lies in its contour, which is that of a series of waves or hummocks, the average height of which may perhaps be 20 feet. The steep slopes of these in many cases were observed to point towards Gwassan.
>
> At the time I saw these undulations they were thickly covered with grass, and from this and also from the nature of the soil on which the grass grow, it was impossible for me to determine the nature of the rocks which lie beneath them. Their appearance was certainly very suggestive of glacial action, and not unlike the hummock districts we met with in Labrador and Newfoundland." (52)

Apart from this direct, but limited, evidence of former glaciation, Milne based his conclusions on indirect evidence of a somewhat speculative nature. This included the presence of terrace formations in northern Japan which he argued could have resulted from changes of cca level associated with retreat of water to the poles, the curious mixture of semi-tropical and palaearctic plants found in Japan and certain fossils found in alluvial deposits which indicated the extinction of tropical animals and the existence in southern Japan of forms of life which now existed only in the colder northern areas.

Milne concluded that a glacial period had taken place in Japan though to a much more limited extent than that associated with northern Europe; conditions were perhaps analagous to those in northern Spain at that time (53).

4. *The Beke Expedition*

This Expedition, led by C.T. Beke, took place in 1874 under the auspices of the Royal Geographical Society. Its purpose was to locate the true site of Mount

Sinai in N.W. Arabia. Milne was the Expedition's geologist and his observations led to the publication of two papers which appeared in 1874 and 1875 respectively.

Milne described the first of these papers as a note to accompany the specimens he collected in the Cairo area (54). He acknowledged that this region had already been described by several geologists and that there was little additional information to impart. It is therefore not proposed to discuss this paper in detail but merely to record that it was divided into four principal sections which described respectively the middens or rubbish heaps, the Moccattam Quarries, the Jebel Achmar hills and the approaches to the Petrified Forest.

His second paper was of greater interest (55). Observations began at Ras Sheik el Ballan, situated some 50 miles south of Suez on the coast of the Sinaitic Peninsula. Here the mountains were found to be of grey granite, consisting largely of quartz and black mica, with only a little felspar. They were cut by numerous dykes, appearing as broad red or dark-coloured bands, the red ones consisting of felsites and the others of felspathic porphyries. Milne also described unusual features in the ripple marks found in the sandy ridges running from the foot of the hills to the plains below (56).

Further south, Milne noted that the village of Tor had the very unusual feature of being built almost entirely of blocks of coral which had been obtained from large mounds of sand near-by. The fact that these mounds also contained shells in imperfect condition and arranged in an irregular manner suggested that this was the result of drift accumulation.

Investigating the area from Sherm to Ras Abou Mohammed, the most southern part of the Sinaitic Peninsula, Milne noted that the granite rocks retreated some six or seven miles back from the coast, their place being taken by low hills and cliffs of limestone and sandstone (57). East of Sherm harbour, there were cliffs of sand capped by two horizontal beds of limestone some 14 feet thick which on closer examination proved to be a breccia of shells and coral rather than a compact limestone. Beds of sand, dipping to the south at an angle of about 12°, were too friable to be termed a sandstone and in places assumed the character of a grit. Near-by, horizontal bands bends capping steep banks of sand were identified as a volcanic felspathic breccia, probably doleritic particles cemented by a triclinic felspar. With them were fragments of a coarse-grained black rock which Milne found consisted of quartz and felspar cemented by limonite (58).

At Ras Abou Mohammed the cliffs were some 90 feet high and Milne found them to consist of the same coral limestone and dip in the same direction as that capping the sand at Sherm (59).

On reaching the mouth of the Gulf of Akaba, the Expedition embarked for the town of Akaba, landings being made on the way, giving Milne opportunities to investigate the geology of the areas concerned. The first call was at Madian which he noted was situated on the boundary between two sets of lithologically different rocks. Hitherto, both sides of the Gulf were bounded by granite hills, but here they gave way to beds of sandstone and conglomerate. He investigated both formations. The surface of the granite had weathered considerably; it contained a predominance of felspar both at the surface and in the deeper, more solid, parts of the formation, but its most prominent feature was the large number of dykes by which it was traversed. The strike of the latter was generally from north to south and they dipped steeply at 80° – 85° to the east. They were of two types, consisting respectively of dark-coloured coarse-grained prophyries and pink felsites or fine-grained porphyries. On the other side of the boundary strip was brcciated conglomerate containing pebbles and even large boulders. This gave way to a mixture of sandstone, grit and conglomerate. Milne collected and described 15 specimens of rocks from this area (60).

The next landing was made at Bir el Mashiyah. Here granite predominated and Milne noted evidence suggesting that the land in this area was rising, a phenomenon he associated with the volcanic nature of the adjoining peninsula of Arabia (61). Rock specimens were again collected and described (62).

Moving on to Akaba, Milne found that the rocks of the area presented the feature, familiar by now, of granite traversed by a large number of dykes. Of greater interest was the territory to the east of Akaba towards Wady Ithm. Here he investigated the mountain wadies, narrow defiles of considerable length which wound their way between the granite hills. After describing their appearance in some detail and considering the agencies at work on the rocks, he summarized his findings as follows:

> "With regard, therefore, to the general appearance of the beds of these mountain wadies, it may be briefly stated, in conclusion, that their characters

are, in the main, rather due to a stream of sand than to water; small furrows formed in the central parts of the wady retreat towards the hills by being undermined and then falling by their weight. By this falling, boulders, often 20 feet in diameter, are rolled forward, and strewn across the plain from the hills towards a central line in which they accumulate. Whilst all this is going on, an almost continuous draft of air up or down these funnel-like defiles is in operation, carrying sand to polish the scattered debris, thus helping in the production of appearances not unlike those of some ancient river-bed, in which action it is aided by a slight trickling of water after the winter showers." (63)

While in the area Milne made further interesting, though not original, observations on the weathering effects of sand-blasting (64); he also collected and briefly described 21 rock specimens from Wady Ithm (65).

Among the granitic hills between Akaba and Petra, Beke identified to his own satisfaction Mount Baghir, or Jebel el Nûr, as the true Mount Sinai. Regarding it as a representative example of this range of hills, Milne provided a detailed description of its appearance and rocks (66). While on the summit of Mount Baghir, he noticed some flat-topped hills which, he suspected, were either not granite at all or were formed of this rock and capped by some other material. Milne confirmed this observation when he climbed one of them, Mount Atagtagheer, on the summit of which he found two large patches of sandstone, each about 100 feet thick, deposited on granite (67).

With their purpose accomplished, the members of Beke's Expedition made their way north-westwards towards Suez. Milne continued to make geological observations en route. The principal facts which emerged were that granite gave way to limestone, chalk and sandstone, with corresponding differences in topography. Some of the limestone was fossiliferous and from this Milne collected specimens of Echini, Pectines, Ostreoe and Nerinoea (68).

Milne concluded that it would not be advisable to make a definite statement about the identity of the geological horizons over which the Expedition passed because the speed of the journey had not allowed him to make sufficiently detailed observations for this purpose. However, the observations outlined above indicated that the succession was comparable with that found by Bauerman further south (69).

5. *The Minerals of Japan*

During his first three years in Japan, Milne found time among his many other activities to collect and catalogue the country's minerals. A paper based on his findings was published in 1880 (70). It included a list of 77 minerals compiled from material derived from four sources, namely specimens collected in the field during the course of extensive travels in the Japanese mainland and the Kurile Islnds, specimens in the Mining Department's collection of minerals, material exhibited at the National Exhibition of Japan of 1877, and minerals from the Kioto Exhibition of 1878. The list included 21 minerals described as rare, 11 as common and nine of doubtful identity. Of the latter group, Milne described four minerals in some detail since these were

"..... probably new varieties of old species, if not altogether new." (71)

He investigated the nature of each of these four minerals using the routine tests and methods commonly employed for the systematic examination of specimens at that time. The first specimen, tentatively labelled vermiculite, was found to consist of short six-sided prisms about 6 mm. long and 3-4 mm. broad. The prisms were laminated at right angles to the long axis. Rough measurements of the angles indicated that the crystal system was rhombic. Cleavage was parallel to the basal pinacoid. Milne was unable to find any distinguishing optical properties. The streak was yellowish-brown and the cleavage surfaces had a blackish-green to brown colour and a brilliant but slightly pearly lustre. The hardness was found to be about 1.5, the specific gravity about 2.7 and the fusibility above 5. The mineral dissolved slowly in nitric and sulphuric acids, leaving a residue of silica; it dissolved more rapidly in hydrochloric acid, with the same result. When heated strongly it broke up into metallic-looking golden scales. Deposits of the mineral were found near Tsurasee in the beds of streams running down from granite hills (72).

The properties of the other three minerals were investigated by the same methods and were tentatively labelled fluorite, var. chlorophane, hisingerite, and wollastonite respectively (73).

6. *Crystallography*

The course of lectures given by Milne at the Imperial College of Engineering included crystallography and his lecture notes on this subject were published as a short textbook in 1879 (74). The Editor, Thomas Davies of the Dritish Museum, included a Note which described the sequence of events leading to publication. He said:

> "In the latter part of 1877, Prof. J. Milne sent home from Japan lithographed copies of his *written* Lecture - Notes on Crystallography and Crystallo-Physics - to Prof. N.S. Maskelyne, F.R.S., Dr. H. Woodward, F.R.S., Prof. J. Tennant, F.G.S., to the Editor, and other friends, with a request to me to publish the same in the GEOLOGICAL MAGAZINE, or elsewhere.
>
> Owing to the absence of the Author and from other causes, a long delay has occurred in presenting them to the scientific public in their present form; and it is only due to Prof. Milne to state that these notes (*as now printed*) were completed, and lithographed by his Japanese assistant, in 1877." (75)

The book consisted of some 70 pages and was based largely on material published in existing textbooks on the subject.

In addition to this, Milne carried out one piece of experimental work on the elasticity of crystals, the results of which were published in 1879 (76). After reviewing briefly the experimental evidence on the conduction of heat and electricity, the passage of light, the dilatation, and the magnetic properties of crystals in relation to their axes of symmetry, Milne wrote in this paper:

> "..... in order to more fully appreciate the above coincidences, we should be greatly assisted if we could shew that along the directions which in any crystals exhibit different phenomena, that there was also a difference in material elasticity, which probably means difference in intermolecular space or a difference in density. The chief experiments which have a direct connection with the material elasticity of crystals, are those made by Savart, who shewed that the figures formed upon vibrating plates of crystals were directly connected with their optical axes. Lately, I have endeavoured to shew that the material elasticity in a crystal was different in different directions, and at the same time to give some idea of its relative values by bumping together spheres cut out of calcite and quartz." (77)

Milne began his experiments by placing a calcite ball of diameter about 23.7 mm. at the bottom of a cycloidal groove and allowed a quartz ball of diameter about 26.0 mm. to roll down the groove from a fixed point and strike the lower ball. This procedure was repeated, striking the calcite ball at different points on its surface each time. He said of the results:

> "Although the calcite ball was observed in consequence of being struck to roll different distances, indicating that these might be due to differences of elasticity in different directions, the experiments were too crude to be worth noting." (78).

An improved experimental method was then devized using the same quartz ball as the bob of a pendulum, the suspension consisting of a silk fibre 6 feet 5¾ inches long. When at rest this ball just touched the calcite ball, which was fixed in wood. The quartz ball was drawn back to a given distance and released, the distance of rebound being noted. The experiment was repeated with the calcite ball presenting different parts of its surface to the quartz ball. The results showed that similar distances of rebound were obtained from points diametrically opposed on the surface of the calcite ball and that the greatest rebound was obtained along the direction of no double refraction (79).

Three further series of experiments were carried out on similar lines, the principal difference being that the ball struck by the pendulum was placed on a billiard table and allowed to move after impact, the distance travelled being noted in each case. In the last experimental series, two quartz balls were used, the replacement for the calcite ball having a mean diameter of 36.8 mm. (80).

Milne concluded:

> "From the above experiments it would seem to be shewn that crystals have different material elasticities in different directions. In the case of a ball of calcite, the greatest rolling effect was obtained when it was struck parallel to the principal axis of the crystal.
>
> In a direction at right angles to this the least effect was obtained, and in intermediate directions, intermediate effects.
>
> Before endeavouring to shew what relations numbers such as those which I have obtained hold to the elasticity of a crystal, it would be better that such experiments were repeated by persons who have instruments, good materials,

and skilful workmen at their command, which I am sorry to say I have found it impossible to obtain in Japan." (81)

7. *Mining*

Milne's first published work in this field was a pamphlet, printed by the Imperial College of Engineering, for thee use of his students (82). The need for this work is seen from the opening paragraph:

"It often happens that students visiting mines omit to gather all the information which they have good opportunities of obtaining merely from the want of a proper system of enquiry and of collecting facts, a misfortune which is the more observable when the visits are short. To obviate this, the following notes have been prepared in order to indicate leading points to be observed." (83)

The pamphlet was thus on the lines of a chapter in a textbook on mining; Milne cailmed no originality for the material it contained and provided a list of sources used in its preparation (84).

A second pamphlet prepared by Milne and dealing with the ventilation of mines was also a College publication; it appeared in the following year (85). Again, it was intended to serve the same purpose as textbook.

These two pamphlets later appeared as part of a much more extensive work by Milne, *The Miner's Handbook* (86). No originality was claimed for the material it contained. The work was divided into three parts, namely, Mineral Deposits, Mining Operations, and Ore Dressing. The first part consisted of the pamphlet of 1878 while the second pamphlet was included as one of the sections into which the second part of the work was divided.

Natural History and Archaeology

There is no evidence that Milne had received formal training in the biological sciences or in archaeology; his work within these disciplines was that of a gifted amateur. It was carried out concurrently with his geological investigations and provides further examples of the considerable breadth of his interests and abilities.

1. *Relics of the Great Auk*

Reference has been made to Milne's visit to Funk Island, situated in the Atlantic Ocean some 32 miles off the coast of Newfoundland. The visit was made by schooner on 24th July in either 1873 or 1874 (87) and was described in a paper published in 1875 (88).

The island was unpopulated by man but was rich in bird life, among which Milne identified colonies of terns, puffins and guillemots. He described the rock of which it was composed as:

> "..... a highly felspathic pinkish granite, the small quantity of mica it contains being of a black colour. From its lithological resemblance to the rocks on the nearest mainland, its geological age is probably Laurentian." (89)

Apart from grass:

> "..... the most noticeable plants were the Alexander (Haloscias scoticum), and a Cochlearia (C. fenestrata), this latter occurring both as a flowering plant and a seedling. A fragment of chickweed (Stellaria media) was also discovered. In addition to these were some tufts of a plantain (Plantago maritima) and a common dock." (90)

In the grass Milne found specimens of the beetle Pterostichus (Platysma) Luczotii and the butterfly Pieris oleracca. Eggs of the birds referred to above and also of the razorbill were found almost everywhere together with a superficial layer of guano which contained many fragments of bones, some of them being relics of the Great Auk (Alca impennis), and extinct flightless bird.

Milne was fortunate in finding during the very limited time available a spot, covered by up to two feet of turf, where fragments of at least 50 of the birds were buried. He collected many pieces of bone but:

> "The remains, on the whole, are of such a fragmentary nature, that it is probable they will hardly suffice to complete a perfect skeleton. The collection which has been made, not withstanding its deficiencies, will nevertheless be sufficient to throw considerable light upon the osteology of the bird." (91)

After reviewing possible reasons for the bird becoming extinct, Milne provided a résumé of facts recorded about the Great Auk arranged chronologically for each of the following regions: North and N.E. Europe, Great Britain, The

Faroe Islands, Iceland, North America and Greenland (92). He also provided a useful bibliography of scientific works on this bird (93).

2. *The Stone Age in Japan*

Milne travelled extensively in Japan, investigating the numerous volcanoes and the geology of the country in general. In the course of his journeys he gleaned some interesting archaeological material which he presented in two papers, the first of which appeared in a highly abridged form in 1879, followed two years later by the complete version (94).

In the first paper, Milne described the artifacts of Stone Age man in Japan and gave details of a dating process based on geologically recent and rapid processes. There were three principal sources of material, namely, kitchen middens or shell heaps, tumuli, and caves, both natural and artificial.

The middens consisted of a layer of earth varying in depth from a few inches to about two feet, beneath which was a band of shells, all of them opened and many broken, this layer varying in thickness from six inches to three or four feet. Milne identified and named 15 genera of shell-fish from these pieces and found also many fragments of deer, bear, bird and fish bones (95). Of greater interest, were the numerous fragments of pottery which had apparently once formed vase-like vessels. The fragments were unglazed and only partially baked; they were about ¾ inch thick. An illustration provided in his paper showing typical fragments of this pottery and also a complete vase, is reproduced here. The impressed punctated markings shown in fragment 1 of the plate were a common feature. Incised lines, possibly made with a stick or a sharp flint were found in some pieces. They are shown arranged obliquely to form a pattern in fragment 6. Occasionally, markings in relief known as cordmarks were found as seen in fragment 8. The complete vase no. 9 in fig. 5, was found by Milne at Nemoro. It was 131 cm. high, 8.5 cm. across at the mouth and 5.5 cm. wide at the base (96).

Stone implements, in the form of arrow-heads, axes, chisels and acrapers were also found and described in detail by Milne (97). They bore a striking resemblance to those found in European countries.

Milne referred briefly to tumuli, many of which had traditional associations. He appears to have investigated only one tumulus, at Macpherson's Hill near

Yokohama. This was 20 to 30 feet high and some 50 to 60 yards in diameter. Digging uncovered a few roughly-chipped celts (98). Likewise, Milne made no significant discoveries in natural or artificial caves, but referred to finds made in

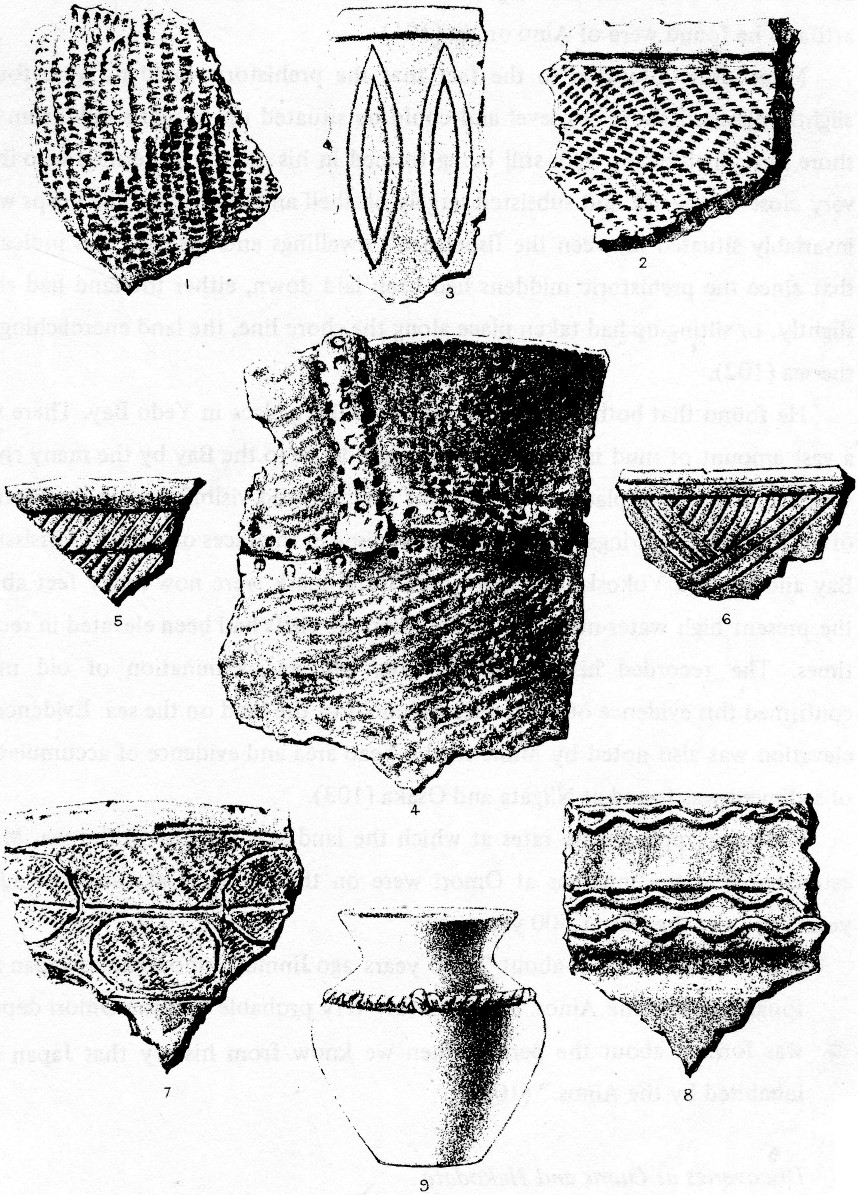


Fig. 5: Stone Age pottery from Japan

them by other investigators (99).

Comparison of markings on the fragments of pottery with those found on the modern pottery of the Ainos (100) revealed distinct resemblances and what was known of the early history of Japan tended to confirm Milne's conclusion that the artifacts he found were of Aino origin (101).

Milne drew attention to the fact that the prehistoric middens were found slightly elevated above sea level and could be situated up to half a mile from the shore line. Shell heaps were still being formed in his day by fishermen who lived very close to the sea and subsisted largely on shell and other fish. The heaps were invariably situated between the fisherman's dwellings and the sea. This indicated that since the prehistoric middens had been laid down, either the land had risen slightly, or silting-up had taken place along the shore line, the land encroaching on the sea (102).

He found that both these processes were taking place in Yedo Bay. There was a vast amount of mud in suspension brought down to the Bay by the many rivers which entered it. In places, the sediment accumulated visibly even in the lifetime of an individual. Borings made at an earlier time in the faces of cliffs at Mississippi Bay and beyond Yokoska to record high water-mark were now many feet above the present high water-mark, indicating that the cliffs had been elevated in recent times. The recorded history of the area and an examination of old maps confirmed this evidence of rapid encroachment of the land on the sea. Evidence of elevation was also noted by Milne in the Yezo area and evidence of accumulation of sediment was found at Niigata and Osaka (103).

Knowing approximate rates at which the land was gaining on the sea, Milne estimated that the middens at Omori were on the seaboard at the most 3,000 years ago or at the least 1,500 years ago.

> "History tells us that about 2,500 years ago Jinmu Tenno came to Japan and fought against the Ainos. It is therefore very probable that the Omori deposit was formed about the period when we know from history that Japan was inhabited by the Ainos." (104)

3. *Discoveries at Otaru and Hakodate*

Milne's second archaeological paper presented an account of his findings further north at Otaru and Hakodate, places situated on the west coast of the island of Hokkaido (105).

The relics at Otaru were considered under the three headings of pits, inscriptions, and middens. In his previous paper Milne had referred briefly to the traces of pit-dwellers found on the island of Nemoro. He had seen but not explored these pits and had merely offered the opinion that they might have been the habitations of Kamschadales or Alutes, people who still lived in houses partly sunk into the ground. In Otaru, the pits were roughly conical in shape, some eight feet in diameter and three feet deep. Despite the tradition associated with them of having been formerly inhabited, he concluded that the pits were merely the result of agricultural processes, possibly the removal of tree stumps (106).

Ancient inscriptions were found carved on the face of a cliff at a height of some three or four feet above the ground. The characters were about an inch broad and half an inch deep and occupied a strip of rock about eight feet long. They were not Japanese and after considering a number of possible explanations of their orgin, Milne concluded that they were likely to have been made by the Ainos (107).

Mounds and kitchen middens yielded a rich harvest of stone implements and pottery fragments. Milne provided detailed descriptions of representative examples of these artifacts which showed them to be very similar to those described in his previous paper (108). The latter had included descriptions of finds made by Milne at Hakodate but since then road-making and the laying out of public gardens had led to further discoveries of much prehistoric material, some of which he had obtained and was described in the later paper under review. Again, the material consisted of stone implements and fragments of pottery. From the comparative roughness of the latter, its glossy surface and its being unearthed at greater depth, led Milne to conclude that the Hakodate material was decidedly older than the Otaru fragments (109).

Volcanology

Milne became interested in volcanoes while still a schoolboy. Reading about them seems to have inspired his visit to Vatna Jokul in Iceland, to which reference has already been made. It is thus not surprising that soon after taking up residence in Japan he began to explore the volcanic areas of that country. His general interest soon developed into systematic study.

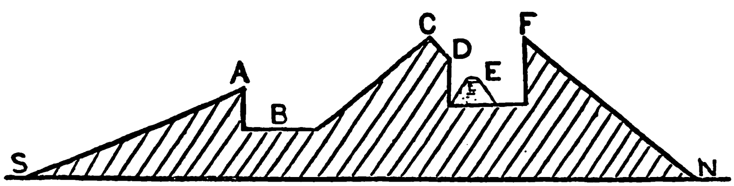
This renewal of interest can be traced to January 1877 when he observed from close quarters an impressive eruption, an event considered in the first division of this section. The second division refers to Milne's investigations of the volcanoes of the Kurile Islands. His interesting work on the shape of regularly--formed volcanic cones is described in the third division while the fourth division provides an account of his extensive catalogue of Japanese volcanoes and eruptions.

1. *The Oshima Eruption*

In 1877, Milne published an account of an eruption he had witnessed in January of that year (110). The scientific content of this paper was small and it will accordingly be discussed only briefly.

The erupting volcano was situated on the island of Oshima, some 40 miles south of the Bay of Yedo, and the most northerly member of a chain of volcanic islands stretching out into the Pacific Ocean.

The position of the volcano in relation to its immediate surroundings was such that an excellent view of the vent was provided from higher ground. The diagrammatic section shown here is reproduced from Milne's paper (111). Milne's



Approximate section of the upper portion of Oshima.
S—A, Outer slope of old crater-wall. (prehistoric ?)
B, Floor of old crater, partly filled by later eruptions.
B—C, F—N, Outer slopes of modern crater-walls.
C,D,F, Rim of modern crater.
E, New volcanic cone formed by present eruption, January, 1877.

Fig. 6 Diagrammatic section of Oshima

party approached the erupting cone E by way of the old crater wall SA, the floor of the old crater B, and the outer slope BC of a modern crater. The latter was described as:

> "..... an amphitheatre of rocks about half a mile in breadth, the walls of which, upon the opposite side, were about 300 feet in height. At the bottom of this pit, on the side nearer to us, a small cone, with an orifice of about 50 feet in diameter, was belching masses of molten lava to a height more than double that at which we were standing." (112)

His account of the visible processes of eruption was graphic and worthy of note:

> "In the intervals between the ejections the interior could be well seen, and it was observable that the sides had a slope of very nearly the same inclination as the exterior. Now and then large masses of these interior sides, which were black, would slide down towards the throat of the crater, and reveal a red-hot interior, showing that the cone itself was probably internally red hot throughout. One side of the cone had been blown away, leaving a breach, almost level with the plane from which it rose. This opening greatly facilitated our observations. Looking down on the crater from this side, molten lava, approximately level with the base of the cone, could be seen. At each explosion it rose in waves, and swayed about heavily like a huge basin of mercury, a little of it being apparently pushed forward through the breach to add to a small black-looking stream upon the outside. The explosions, which I have referred to several times as resembling outbursts of steam, might be compared to the escape of steam from a slowly-working non-condensing steam engine greatly magnified." (113)

2. *The Kurile Islands System*

The Kurile Islands form a chain stretching from Kamchatka to north-east Japan. Milne cruised among them during the summer of 1878 to observe and note the positions of the numerous volcanoes found on the islands. His findings were published in the following year (114). Altogether he provided notes on 31 named islands; between them they included 52 well-defined volcanic peaks of which he was certain that nine were active. His sketch map showing the positions of the volcanoes is reproduced here (115).

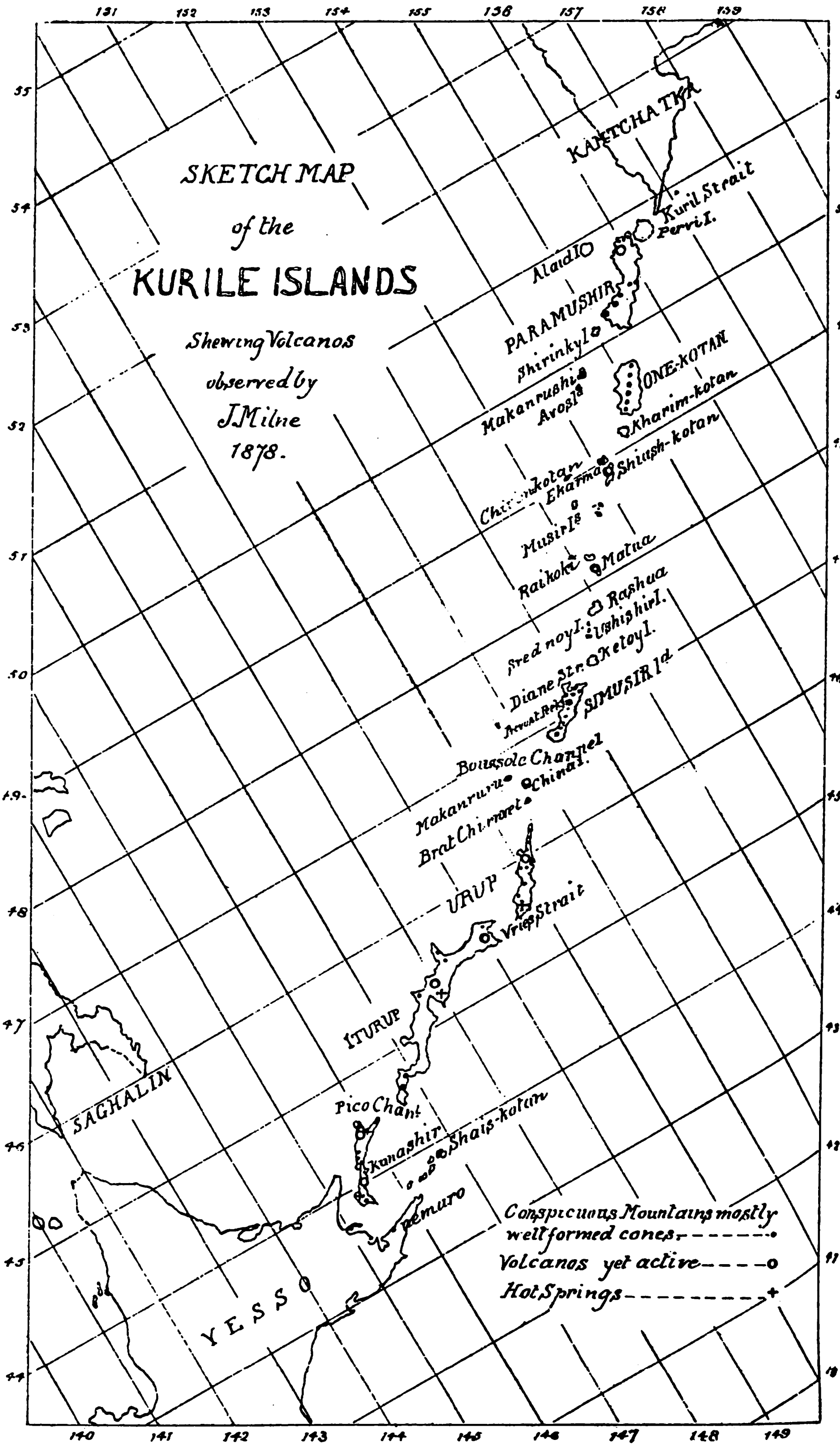


Fig. 7: Volcanoes of the Kurile Islands

Milne concluded from his investigations that the volcanic mountains of the Kurile Islands were probably of more recent date than those in Kamtschatka (116) to the north or in Japan to the south. The volcanoes of the Kuriles had suffered far less denudation than those in Japan, with the result that their sides were still covered with ashes and they had maintained their original slopes.

Specimens collected showed that the erupted rocks were augitic andesites and were characteristic of those found in the volcanic areas of Kamtschatka, Japan, Java and New Zealand. There was a striking absence of lava streams and some evidence that the activity of the Kurile chain was fast becoming spent (117).

3. *The Form of Volcanoes*

The external form and internal structure of volcanoes vary considerably but the best-known type, of which the Japanese mountain Fujiyama is a characteristic and beautiful example, is built up by the accumulation of ejected material round a central vent.

Milne became especially interested in the external form of this type of volcano and published an account of his observations and conclusions in 1878 (118). In this paper, after commenting on the ruggedness and lack of any characteristic form of volcanoes in Iceland and South America, he went on to say:

> "With other volcanos (119) which have been built up according to the formula of our text-books, that is, by the ejection and accumulation of material round a central vent, the case is different. I will endeavour to show that such mountains which, for the want of a more accurate term, have been called conical, have a particular kind of regularity which does not appear to have been hitherto noticed." (120)

As representative Japanese examples of volcanic mountains of this type Milne named Fusiyama (Fujiyama), Ganjosan, Chokaisan, Twakisan and Kamagatake, from which he selected the first and the last for study of the profiles. These mountains appeared to be sections of cones near the summits, but lower down the profile swept outwards in each case to form a much gentler curve. Before proceeding to analyse these very fine examples, it was important not to ignore less regular examples but to consider the factors which influenced regularity of form; these could be divided into seven groups, namely:

1. The position of the crater - if this was central and remained so during successive eruptions, the mountain should be regular in form.
2. Irregular or uneven eruptions - regularity in form would be lost if a paroxysmal outburst removed part of the cone or if lava erupted unevently.
3. Parasitic craters - eruptions from the sides of a mountain destroyed regularity of form.
4. Asymmetry of lapilli projection - the direction in which lapilli and similar material was flung out was sometimes more to one side than another, even in the case of a central event.
5. Wind direction - a strong wind at the time of eruption could result in the lapilli accumulating asymmetrically.
6. Nature of the erupted material - the size, specific gravity, and porosity of the material would influence the way in which it accumulated and consolidated.
7. Denudation — this process was constantly drawing material to lower levels, sculpturing and modifying the original contours. Since its action was much the same on all sides of the mountain, the process tended not so much to destroy the regularity as to alter the character of the slope.

   The tendency was to make the slope steeper nearer the top of the volcano than lower down (121).

Milne began his analysis of regular profiles by comparing the slopes of volcanoes with those of railway cuttings (122). The slopes taken up by the latter depended on the material through which they ran; it was important to note that any given material was composed of particles having much the same size. In the case of volcanoes the material consisted of particles having quite different sizes but Milne had noticed that along a given contour they were invariably uniform in size, the larger particles coming to rest near the base. He considered that the theory and rules given by Rankine in the latter's *Investigations about Earthworks* could be applied.

"As there does not appear to be any formula given in books on engineering, respecting the slope or form which would be assumed by a heap of loose dirt, an engineering friend has shown me that it follows from Rankine's theory, notwithstanding that the same is incomplete, that the surface is that which would be produced by a simple logarithmic curve revolving about an axis, - consequently such a curve would have a slope diminishing from the top to the bottom." (123)

Milne next traced profiles of Fusiyama and Kumagatake from large photographs and inserted the vertical axis of symmetry. Along this he marked points five millimetres apart and through them drew a series of parallel lines at right angles to the axis. The result is shown on the next page, reproduced from his paper (124). The curves shown are as follows:

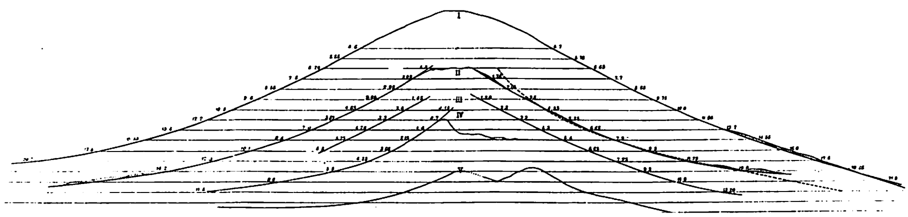


Fig. 8: Profiles of volcanoes traced from photographs

I. Upper part of Fusiyama, taken from Marayama, S.W. side.
II. Fusiyama, from near Hitoana, west side.
III. Fusiyama, from Suyama and Gotemba, S.E. side.
IV. Kumagatake, as seen from near Hakodate.
V. Monte Somma and Vesuvius.

The shaded portions show irregularities in curvature. The broken line on the right of II is a logarithmic curve drawn for comparison.

Milne made measurements from these curves of which this table represents the

Fusiyama, from near Marajama. S. W. side.

Left Side.				Right Side.			
r	R	dr	$\frac{R}{dr}$	r	R	dr	$\frac{R}{dr}$
4·60	10·15	·95	10·67	4·70	10·45	·05	20·9
5·55	11·80	·70	16·85	5·75	12·40	·90	13·7
6·25	13·75	1·25	11·00	6·65	14·35	1·05	13·6
7·50	16·05	1·05	15·28	7·70	16·35	·95	17·21
8·55	18·15	1·05	17·28	8·65	18·40	1·10	16·72
9·60	20·50	1·30	15·76	9·75	20·55	1·05	19·57
10·90	23·10	1·30	17·76	10·80	22·75	1·15	19·78
12·20	25·80	1·40	18·42	11·95	25·15	1·25	20·12
13·60	28·95	1·75	16·54	13·20	27·75	1·35	20·55
15·35	32·85	2·15	15·27	14·55	30·55	1·45	21·06
17·50	38·20	3·20	11·94	16·00	33·60	1·60	21·00
20·70				17·60	36·85	1·65	22·33
				19·25	40·25	1·75	22·00
				21·00			

Table 2: Measurements and Calculations from Profile I

results obtained from profile I; r represents the distance intersected on a horizontal line between the curve and the vertical axis. R is the sum of successive values of r, and dr is their difference (125).

Commenting on this table, Milne wrote:

"Now it is found, as will be seen by looking at the fourth column, that R/dr is equal to a number which is nearly constant, which is the peculiarity of a logarithmic curve." (126)

Similar results were obtained from profiles II, III and IV (127). Commenting on this, Milne wrote:

"That this result should agree with that obtained for the stability of a self-supporting mass of loose materials is very striking, and seems to show, notwithstanding its roughness and the observations to which it has been applied, an invariable occurrence.

This being the case, I think we are justified in regarding mountains, similar to those about which I am writing, as having a form mainly due to the simple piling up of material, and not as cones which have been subsequently modified by a number of secondary causes, such as are advocated in treatises on Physical Geology and Volcanos." (128)

Milne noted that the greatest departures from the more or less constant values for R/dr were due to variations in curvature near the summit and at the base of the volcanoes and suggested that they arose not only from external causes but also from the presence of an internal core (129).

4. *Catalogue of Japanese volcanoes and eruptions*

Milne's last published work on volcanoes appeared in 1886. It was a lengthy paper which was primarily a catalogues of the volcanoes of Japan with details of their known eruptions throughout recorded history (130). Descriptions of the volcanoes and details of their geology were based on his field work; details of past eruptions were derived from an examination of the literature, much of it in Japanese manuscripts and printed books. A bibliography was provided (131).

The scientific importance of the work lay principally in the conclusions that could be drawn from it about the geographical distribution of volcanoes in Japan and their frequency of eruption. It allowed Milne to mark on a map of Japan

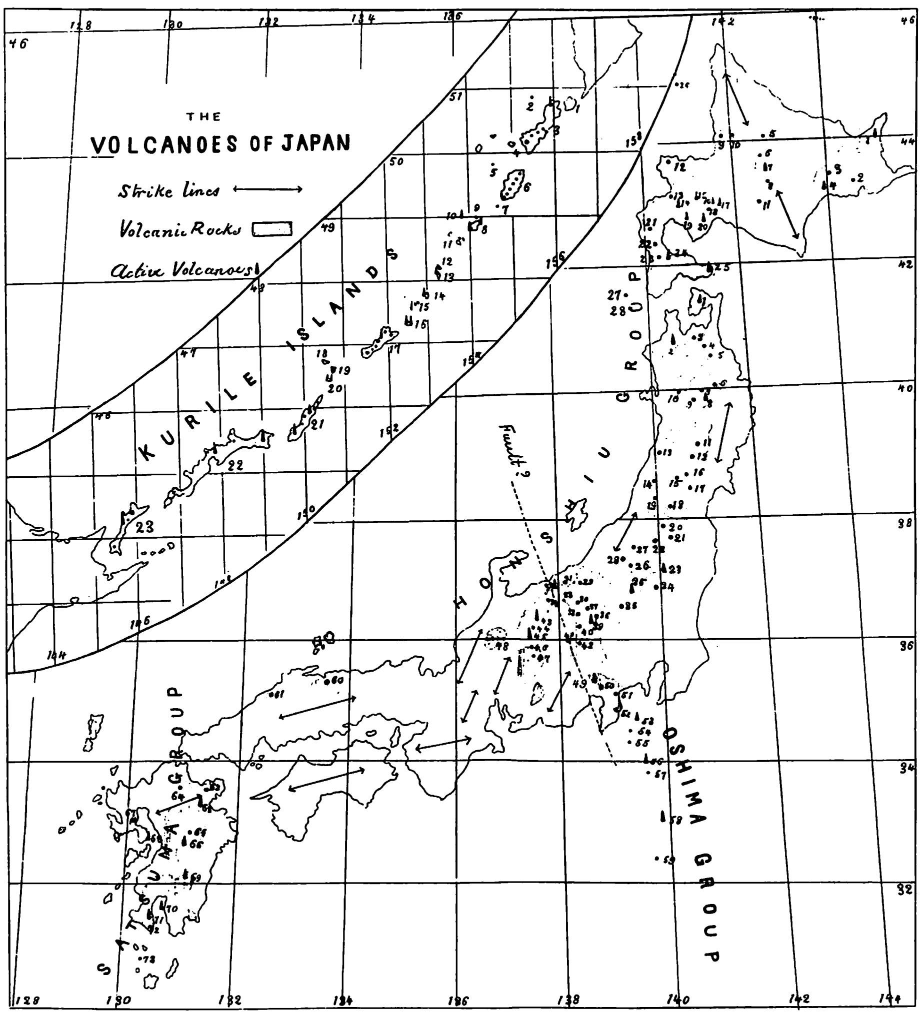


Fig. 9 The Volcanoes of Japan

those regions where volcanic rocks were found and the positions of active volcanoes. This map is reproduced here (132). A summary of the detailed information on which it was based was provided in the form of three tables listing respectively the volcanoes of the Kurile Islands, those of Yezo, and those in the regions of Honshiu and Kiushiu. In addition to giving the names of the volcanoes, the tables provided in many instances the heights of the mountains, the nature of the rocks, details of the craters and dates of the last eruptions (133).

The number of mountains which were easily recognizable as being of volcanic origin was 129, of which 51 showed traces of activity. Of the latter, 27 were situated in the northern regions of the country, the remainder being found in the central and southern regions.

Milne also tabulated eruptions in relation to the months and seasons of the year. He found that of the 233 eruptions listed, 80 occurred in the winter months, 73 in the summer months, and the remaining 80 at unknown times during the year. Eruptions took place more frequently in February and April. He attempted to explain this result thus:

> "This winter frequency may possibly be accounted for in the same manner that Dr. Knott accounted for the winter frequency of earthquakes. During the winter months the average barometric gradient across Japan is steeper than in summer. This, coupled with the piling up of snow in the northern regions, gives rise to long continued stresses, in consequence of which certain lines of weakness of the earth's crust are more prepared to give way during the winter months than they are in summer." (134)

Milne was later to refute reasoning of this kind when he considered the apparent frequency of earthquakes in relation to the months and seasons.

Looked at generally, the volcanoes of Japan formed a long chain running from N.E. to S.W. A closer examination of the distribution of the vents showed that the system could be divided into four divisions, namely, a N.E. - S.W. line running from Kamschatka through the Kuriles and northern Yezo, a curved line following the back-bone of Honschiu and terminating on the western side of the Yezo anticlinal, the N.N.W. - S.S.E. line of the Oshima group passing from Landrones to Fujisan and intersecting the line through Honschiu, and finally the Satsuma line running from the Phillipines through Sakurajima and culminating in

Mount Aso.

The most recent volcanoes were those which formed, or were situated on, the islands of the Kuriles, the Oshima group, and in the Satsuma Sea. Many of these islands had been formed during the period of recorded history (135).

The volcanic rocks were mostly andesites. Those containing augite approximated closely to basalts. Hornblende andesite was common, some containing free quartz. Quartz trachytes occurred in the north of the country. The presence of magnetite resulted in many of the lavas being magnetic, some of them markedly so (136).

Periods of more intense volcanic activity in Japan coincided with similar activity elsewhere in the world; one of the most active periods of this nature in recent times occurred in 1780-1800 (137).

Milne concluded his paper by referring to his earlier work on the logarithmic curvature of regularly-formed volcanoes and to the work of G.F. Becker who had since taken Milne's analysis a stage further (138).

Conclusion

In his first professional task of reporting on the mineral resources of Newfoundland, Milne was aided by quite comprehensive reports on the geology of the island prepared earlier by Alexander Murray. Thus Milne was in no sense a pioneer of this field. His contributions were in the nature of filling in details, rather than elucidating a geological system. Within that framework, however, his discoveries were by no means insignificant. In particular, attention should be drawn to his discovery of a large deposit of staurolite at Facheux Bay, his elucidation of the outcrop of Carboniferous rocks between Cape Anguille and St. George's Bay, and his discovery of a large deposit of galena in the Port-au-Prince Peninsula.

Milne's survey of the petrology of Newfoundland was again one which led to further knowledge being gained in matters of detail, but in this instance it is not possible to select any discoveries of special significance.

In glaciology, the position was different; this subject was comparatively new, having emerged as a separate field of study only since about 1837 due to the work of Agassiz (1807-1873). Little thought had been given to the migration of icebergs or to their stability. The explanation put forward by Milne for the time of arrival of icebergs in Newfoundland waters was based on cogent arguments, and by considering the conditions required for stable equilibrium of an iceberg, he successfully disproved the view prevailing at that time that the submerged part of an iceberg was of great depth compared with the height of the exposed part above the surface. His views on the rôle of coast-ice were original and stimulating and provided an interesting field for further study.

Milne's paper on the evidence for a glacial period in Japan contained much that was speculative but if firm conclusions based on sound evidence were lacking, his arguments served the useful purpose of opening a new field of study, since no previous work along these lines had been carried out previously in that country.

The comparatively rapid pace at which members of the Beke Expedition reached their objective precluded Milne from making thorough geological surveys of the regions through which it passed but he nevertheless amassed much information about the geology of little-known regions and was able to show that the succession was comparable with that deduced from a more detailed survey carried out further to the south by Bauerman.

The importance of Milne's study of Japanese mineralogy lay in his discovery of four minerals previously unrecognized in that country, namely, vermiculite, fluorite, hisingerite and wollastonite. His experiments on the elasticity of crystals, made at about the same time, clearly indicated anisotropy associated with the positions of the crystallographic axes. The experiments were too crude, however, to allow him to determine the elastic moduli of the materials.

Milne's contributions to mining were of a pedagogic nature, his pamphlets and text-book being written with the special needs of his Japanese students in mind.

In the field of natural history, Milne contributed to the existing knowledge of the flora and fauna of Funk Island, but in particular his observations on the relics of the Great Auk were worthy of note. His contributions to the archaeology of Stone Age Japan lay less with the nature of the material uncovered as with his ingenious dating of the Omori middens leading to the strong supposition that they were Ainu origin.

Milne's first contribution of note to volcanology was his elucidation of the distribution of volcanoes in the Kurile Islands. This was followed by his demonstration that the profiles of volcanic mountains of the type built up by the accumulation of ejected material round a central vent were logarithmic in shape and not sections of a cone. His painstaking and lengthy task of cataloguing Japanese volcanoes and their eruptions throughout recorded history led to his most impotant contribution in this field, a complete account of the distribution of volcanic areas in Japan.

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