

GEOLOGY OF THE LUMDING AREA

ASSAM, NORTHEAST INDIA

and

OIL SHALES OF WASHINGTON

by

WILLIAM THOMAS NIGHTINGALE

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INTRODUCTION

The geological work of which this thesis is a partial report, was done in Assam, India, partly in 1922 and finally in 1923. Assam is the northeast frontier province of British India. Because of its geographical location it presents a climate noted for heavy rainfall and humid atmosphere. No one unacquainted with the province can possibly form any real conception of the obstacles to be met in carrying on geological work.

Heavy jungle, growing with such rapidity that footpaths and clearings are often blotted out if unused for a single year, is the usual sort of vegetation to be encountered. As a result, roads are practically unknown in the more sparsely inhabited parts, such as the Lunding Area, and footpaths are infrequent. Because of the heavy jungle, two or three days' work may often end without a single satisfactory outcrop having been found.

LOCATION AND EXTENT OF AREA

The Lunding Area lies within a radius of 20 miles of the town of Lunding, a railroad junction of considerable importance on the Assam-Bengal Railway in the Province of Assam. (See Index Map.) The area lies chiefly within the boundaries of two different districts of Assam, the Cachar District and the Nowgong District. As shown on the Index Map, the region is located between 25 and 26 degrees of north latitude, and in the vicinity of 93 degrees of east longitude. In a north-south direction, the area extends for approximately 40 miles and in an east-west direction for about 48 miles.

Lunding Junction from which the area receives its name is intersected by 25 degrees 45 minutes of latitude.

CLIMATE

The climate of the Province of Assam is marked by extreme humidity, the natural result of the great water surface and extensive jungle over which evaporation and condensation go on, and the near proximity of the hill ranges which bound the alluvium tracts. It is on and near these hills that excessive precipitation takes place. The cloud proportion throughout the year, even in those months which in the rest of India are generally clear, is very large, dense clouds being characteristic of the cold season both north and south of the Assam Range.

The monsoon proper is generally ushered in about the beginning of June, but in some years the heavy rains of April and May, and sometimes of March, have monsoon violence. However, these earlier rains, which are characteristic of the province, are due to local causes, to storms and local evaporation. The spring rains are commonly succeeded by a break, more or less prolonged, of dry hot weather with westerly winds before the true monsoon breaks. An average of the rainfall for the entire year would show:

Brahmaputra Valley (north of Luming Area) 95 inches
Surma Valley (south of Luming Area) 125 "
North Cachar Hills (in Luming Area) 88 "

It is over the lower hills of North Cachar that the great southwest monsoon sweeps to enter the northern part of the Brahmaputra Valley. The chief obstacle to the progress of the monsoonal winds in this region is the Barail Range which extends almost due east from the southern part of the Jaintia Hills and forms the south wall of the North Cachar Hills. On the south side of this range, where the rain-bearing clouds first strike after crossing the plains to the south, the precipitation is extremely heavy. Along the hill border 150 to 190 inches is not uncommon.

An approximate chart made to show general climatic conditions in the North Cachar Hills (Luming Area) and adjacent regions would necessarily contain the following:

- November to March . . . Days warm, nights cool and very damp. Little or no rain. Excellent field working conditions.
- March to May Days warmer, nights warmer, occasional heavy storms accompanied by high winds and rain. Uncertain field working weather.
- May to June Very warm with occasional heavy storms. Poor field working weather.
- June to October Very warm, southwest monsoon breaks, extremely heavy rainfall. Field work impossible.
- October to November . . Cooler, tapering off of the monsoon, considerable rain but preliminary field work possible.

The above description of the seasons varies somewhat from year to year but will strike a very fair average.

HEALTH CONDITIONS OF AREA

With the general characteristics of the climate of Assam in mind, it will be readily understood that in its effect upon human health Assam presents the usual features of a humid, sub-tropical region. Malarial diseases, kala-azar, and cholera are the most prevalent forms of sickness, with small-pox, black water fever, and various bowel complaints quite common.

Malaria finds its chief stronghold in the broken country forming the outskirts of the Assam Range where the long low valleys are seldom disturbed by the strong winds that blow across the plains. In the open country

it is seldom so extremely severe. In the low hills such as are found in most of the Lunding Area, malaria is very common and a great nuisance. The Assam-Bengal Railway, which penetrates that part, has always paid a fever allowance to such of their employees as are required to remain there for any considerable period.

Epidemics of cholera from time to time sweep through the district causing a high mortality. Although the disease is apparently endemic in the region, it occasionally breaks out with unusual severity. However, considering the method of living of the villagers, an epidemic of any contagious disease is hardly surprising. Sanitary arrangements in the villages are nil, the rubbish usually being swept into an unused corner and allowed to rot with masses of decaying vegetation. A complete absence of sanitary arrangements makes the neighborhood of a village frequently a very unsavory place. The water supply is often bad and is drawn either from muddy streams, from shallow holes, or, in the plains, from tanks in which the villagers often wash both their clothes and their persons. In the hills the water supply is usually much better than in the plains, for running streams are more numerous and not so loaded with filth, and the population is much less dense.

In an average year, in the Lunding Area and vicinity, the total deaths per thousand, according to the Indian

Census, is about twenty-three. Of these twelve die of fever, three of cholera, and eight from bowel complaints, other diseases, attacks by tigers and elephants, snake bite, and other accidents.

POPULATION

The total population of the Luming Area, within the limits described in this report, will hardly exceed 4000 people distributed among 40 or 50 villages. This population is composed chiefly of people belonging to the Cachari, Mikir, or Kuki groups, together with the various plains people who have gathered near the railway line.

Away from the railway, the villagers are primarily small farmers. They practise what is known as the Jhum system of cultivation. In this a small area of jungle is cut on a hillside in February or March, and when dry, in April or May, is fired. The earth is then broken by the most primitive methods and the crop planted. Each household cultivates a piece of land for its own use and for barter. The principal products raised in the hills are rice, cotton, chillies, and maize.

TRANSPORTATION

So long as a party remains near the Assam-Bengal Railway, transportation problems are comparatively simple. However, once away from the railway, even for

the shortest distance, transportation assumes a different aspect. There are no roads penetrating the Lunding Area capable of supporting wheeled traffic of any sort. Even the crude native bullock carts are unable to operate in this region, and, as a result, all transportation of supplies and equipment must be accomplished either by coolies or elephants. Both methods of transportation were thoroughly tried out during the course of the work and their respective values determined.

For fast, light work over all sorts of rather rugged or very heavy jungle covered country, the hill cooly, when once acclimated and hardened to the work, is easily the more satisfactory and dependable. Elephants, if care is taken in their selection and only those obviously adapted to the work used, are very satisfactory for transporting equipment and supplies over sandy river beds or along good paths if without too much overhead jungle. When the overhead growth is heavy, far too much time is required cutting through to allow the elephant and its load to pass. For geological reconnaissance, requiring rapid trips over all sorts of country, picked coolies proved to be very satisfactory. The only paths within the Lunding Area are those made by the villagers from town to town or from the villages to the railway stations and bazaar centers. Furthermore, most of the rivers are unnavigable during the dry season when field work is

possible. This all means that the transportation of supplies and equipment is practically entirely dependent upon coolies or elephants for geological work within the Lumding Area.

COMMUNICATIONS

The only distributing post office in the Lumding Area is located in the town of Lumding. From this office mail is sent out twice weekly to the various railway stations along the line. No delivery of any sort is made by the post office away from the line of the railway; therefore, parties at work in the field must arrange for coolies to bring in mail.

The same conditions apply to the telegraph system, which in India is operated in connection with the post office system. Under such conditions, parties at work in the Lumding Area may frequently be out of touch with both post and telegraph for several days running.

FIELD WORK AND MAPS

Unfortunately no topographic survey of the region had, until 1923, been made by the Government of India since 1860-76, and the 1923 survey was not near enough completion to be of any use. The old maps, on a scale of 1 inch to 4 miles, proved to be much too inaccurate for use in any other manner than as approximate guides to the more

important stream junctions, etc. Consequently, compass traverse traverses had to be made, tying to stream junctions, railway mile posts, etc. Locations were made, and strikes and dips taken in the field with the Brunton compass.

The areal geology is indicated on the compiled map by different styles of cross-hachuring. The location of the area with respect to northeast India is shown in the Index Map.

GENERAL DESCRIPTION OF REGION

In Assam the Valley of the Brahmaputra River, on the north, is separated from the Valley of the Surma River, on the south, by the Assam Range. The Assam Range is a ridge of hills or mountains extending in a general east-west direction across the middle part of the Province of Assam. The central part of the Assam Range is occupied by the largely metamorphosed rocks of the Shillong Plateau. East of the Shillong Plateau is that portion of the Assam Range known as the North Cachar Hills, in which lies the region to which has been given the name "Lunding Area."

By far the greater part of the Lunding Area consists of Tertiary sediments exposed as alternating sandstones and shales of probable deltaic origin overlying a distinct fossiliferous Nummulitic Series. A total of nearly 30,000 feet of sediments was determined within the general confines of the region.

PHYSIOGRAPHY

The topography of the area ranges from the very low rolling hills approaching the alluvium flats of the Bara Langfer and the Dhansiri peneplain to the north and north-east respectively, to the fairly high precipitous hills of the Naga Ranges on the southeast. So far as observed there does not appear to be any structural control over the topography. Drainage is secured for the most part by an irregular network of incised streams which have kept their pre-uplift courses. In the west and northwest sections of the region, the gently rolling hills suggest plateau topography with incised streams.

In the general uplift of the Assam Range system, the North Cachar Hill section was probably the part least affected. As a result the topographic relief is here nowhere so abrupt as in the Naga Hills to the east or the Khasia and Jaintia Hills to the west.

South and southeast of the Lunding Area, the North Cachar Hills attain their greatest elevation. In the peaks that constitute the Barail Range, a maximum elevation of over 6000 feet is reached, and a probable average of about 4000 is maintained. However, proceeding north and northeast through the Lunding Area from the Barails, the elevation rapidly drops away until a minimum of 300 feet above sea level is barely retained in the valley flats of the north.

On the west the Lunding Area is drained by the Doyang River, on the east by the Dhansiri and Bara Langfer rivers, and in the center by the Lunding River. All of the streams here mentioned, except the Dhansiri, are tributary to the main Khopili River, but as their junction points are outside the area under consideration, each is considered separately.

The Lunding River is a good example of the larger stream types within the region. Starting in the higher hills along the eastern border of the area, it has rapidly cut its way to a stage approaching base level, and for the latter half of its total length pursues a very meandering course. One phase of its life history well illustrated is in the system of river terraces, now heavily forested, that are frequently seen at various elevations above the present stream banks, indicating a past period of revived energy that has again lost much of its inceptional power.

GENERAL GEOLOGY

The breaking up of the Mesozoic continent of Gondwanaland and the gradual displacement of the Tethys Sea of the north in late Cretaceous to early Tertiary time, when the orogenic movements initiating the building of the Himalaya Mountain mass were in their incipency, resulted in tremendous changes in the gulf or embayment which covered the present site of the Province of Assam. Due partly to a

silting up of the embayment and partly to the folding movements which occurred, the end of the Tertiary saw the final retreat of the seas from Assam. Since that time, through the Pleistocene and into the Recent, alluvial wash and flood plain silts have covered much of the surface of the earlier Tertiary marine sediments.

Across the center of Assam extends the Assam Range, one of the results of the Tertiary folding movements. The Lunding Area occupies a position near the east end of this hill chain. The Assam Range is characterized by a steep southern scarp and a long gentle northern slope. Along the south scarp the appearance is that of a faulted monoclinial fold. Apparently differential movement along a previous east-west belt of weakness, now marked by the escarpment, resulted in the rocks of the Assam Range being elevated some 4000 feet more than the rocks south of the scarp. However, these latter sediments were also probably somewhat elevated for the old sea had completely retreated by the end of the Tertiary.

East of Assam, in that part geographically known as Northern Burma and the North Shan States, the orogenic movements seem to have proceeded during much the same period of time as those previously mentioned, i.e., from late Cretaceous to late Tertiary. Here the great mass of the Shan Plateau was finally developed which includes the Arakon Yoma, the Patkoi Mountains, and the Naga Hill Ranges. In Burma nearly 35000 feet of Tertiary sediments are known.

The rocks of the Lunding Area consist chiefly of sandstones and shales with occasional thin beds of conglomerate, all belonging to the Tertiary system of north-east India. These are underlain conformably by Cretaceous sandstones. Below the Cretaceous occurs a profound unconformity separating great masses of igneous and metamorphic rocks of probable Gondwana age (Carboniferous to Lower Mesozoic) from the later sediments.

STRATIGRAPHY

Subdivisions of the area are made entirely upon the lithological character of the rocks together with the few fossils found. The only diagnostic fossils found above the abundant Nummulitic fauna of the Nummulitic Group were determined as belonging to about the Middle Miocene. These fossils which were determined as being PECTEN irraevadius Noetling by the Geological Survey of India, represent a common form in the Miocene of Burma. The fossils were found in beds of the Langting Series. (See following stratigraphic table.)

TABLE OF FORMATIONS

No.:	Name	Description	Age	Thick- ness, Ft.
1	<u>Fossil Wood</u> Group	Chiefly sandstone with some shale. Abundance of fossil wood near top.	Pliocene	?
2	<u>Lunding Shale</u>	Largely blue-gray shale. Lenses and thin beds of calcareous shale near base.	Pliocene	1500
. . . Unconformity . . .				
3	<u>Langting</u> Series	Groups of well bedded sandstone interbedded with dark carbonaceous shale. One conglomerate horizon. Marine Fossils <u>Pecten</u> <u>Irrevadious Noet</u> .	Middle Miocene	19,026
4	<u>North Cachar</u> Sandstone	Massive to cross bedded at the base but well bedded at the top. Highly ferruginous.	Lower Miocene	5,543
5	<u>North Cachar</u> Shale	Dark carbonaceous shales with occasional thin beds of coal and some sandstone. The latter becomes more abundant near the base.	Oligocene	1,200
6	<u>Nummulitic</u> Group	Interbedded sandstone and shale with beds of Nummulitic limestone. Marine fossils throughout.	Eocene	1,700
7	<u>Cretaceous</u> Sandstones	Hard siliceous sandstone altered to almost a quartzite.	Cretaceous	500
. . . Profound Unconformity . . .				
8	<u>Igneous and Metamorphic Rocks</u>		Gondwana	. . .

Owing to the enormous thickness of the sediments composing the Langting Series and the North Cachar Sandstone, about 24,569 feet (see Table of Formations), it was desirable to subdivide them into various individual horizons for convenience of reference. Such subdivisions were based entirely on the lithological characteristics of the various sediments therein. The following SubDivisional Table shows the divisions into which the two groups noted above have been divided. The numbers 3 and 4 refer to their respective places in the main Table of Formations.

SUBDIVISIONAL FORMATION TABLE

<u>3</u> <u>Langting Series</u>	Middle Mio- cene	19,026 ft.
a. Dhansiri Sandstone . . .	2100 ft.	
b. Interbedded Group . . .	4191 "	
c. Langting Sandstone . . .	4834 "	
d. Longren Group	5740 "	
e. Mailu Sandstone	940 "	
f. Mailu Shale	1221 "	
<u>4</u> <u>North Cachar Sandstone</u>	Lower Miocene	5,543 ft.
a. Upper Division	2079 ft.	
b. Lower Division	3469 "	

Description of Formations

Cretaceous Sandstone.- As observed along the western border of the Luding Area (see Areal Map) the Cretaceous sandstone consists of a medium grained, white to gray, even textured, siliceous sandstone with occasional argillaceous sandstone layers interbedded. Blue to buff colored shales and some conglomerates were observed at various

horizons within the sandstone. A distinguishing feature of the sandstone in the Cretaceous, especially near its base, is that it appears to be partly altered to quartzite, however, the recrystallization does not seem to have been completed. A thickness of 500 feet is assigned the Cretaceous in the Lunding Area.

Nummulitic Group.- The distinguishing feature of the Nummulitic Group is the Nummulitic limestone containing an abundance of the fossil Nummulites so characteristic of the Eocene. Besides Nummulites, Eocene members of the genera *Turritella*, *Carithium*, and *Pecten* were noted. The limestone member does not by any means constitute the entire group for a very considerable thickness of alternating sandstones and soft shales are present, mostly above the limestone. Southeast of the Lunding Area the sandstones occurring within this group are known to carry coal seams of some commercial value. An estimated thickness of 1700 feet is assigned to the Nummulitic Group within the confines of the Lunding Area.

North Cachar Shale.- The chief member of what is termed the North Cachar Shale Group is a blue-black clay shale of varying physical characteristics. It varies from a soft plastic to a hard fragmental nature. Under the influence of weathering, the shale frequently bleaches to a lighter blue and assumes a brittle splintery

character. Interbedded with the shale are numerous sandstone beds of no great thickness but often containing distinct thin coal layers of considerable value in correlation. Approaching the base of the North Cachar Shale, the sandstone layers become more numerous and a general sandy influence is noted. A thickness of 1200 feet is assigned to the North Cachar shale in the Luding Area.

North Cachar Sandstone.- (See subdivision table.)

Lower Horizon.- The lower horizon of the North Cachar sandstone is characterized by soft, massive, ferruginous sandstone with extremely complicated cross-bedding. Because of its extreme cross-bedding and massiveness, much difficulty is encountered in determining the true bedding at any particular location. In sandstone of this type every indication of bedding such as the position of cut off beds, fairly persistent shale layers, etc., require close examination. Field work approaching accuracy requires slow, painstaking observations. The Lower Horizon of the North Cachar Sandstone includes so many beds of varying texture, shade, degree of cementation, etc., that it is difficult to describe as a unit. However, the feature of ferruginosity and extreme cross-bedding apply persistently throughout and become the distinguishing characteristics of the horizon. A thickness of 3,469 feet has been assigned this Lower Horizon of the North Cachar Sandstone in the Luding Area.

Upper Horizon.- The Upper Horizon of the North Cachar Sandstone is characterized by much more regular bedding than is the case with the Lower Horizon, but the character of ferruginosity remains much the same. Some cross-bedding is discernable in the Upper as well as in the Lower Horizon, but it is neither so intricate nor so wide spread.

In general the North Cachar Sandstone may be described as a medium grained, cross-bedded, vari-colored sandstone, carrying concretionary bodies up to 5 feet in diameter in some of the more massive beds. The colors range from yellow, red, and brown to purple shades.

The North Cachar Sandstone gives every evidence of having been laid down as a shallow estuary deposit under the immediate influence of tide water. Conditions of this character can account for the complicated cross-bedding, the oxidized character of the sediments, and the variable current ripple marking frequently detected on the cross-bedded surfaces. It is quite probable that during the time of deposition of the Upper Horizon of the North Cachar Sandstone, a reversion to somewhat deeper water conditions and consequently less turbulent influences was in progress. A situation such as this is indicated by the less intensive cross-bedding and the much more regularly bedded sediments of the Upper Horizon, as well as the fact that the sandstone becomes finer grained near the top and is finally conformably

overlain by the Mailu Shale, a well sorted shale group.
(See following description under Langting Series.)

Langting Series.-

Mailu Shale.- On the Langting River, east of the village of Langting, (see Areal Map) a total of 19,026 feet of alternating sediments were determined as belonging to the Langting Series, the next group above the North Caohar Sandstone. The first member of the series lying immediately and conformably above the last mentioned sandstone was termed the Mailu Shale.

The Mailu Shale consists of gray to blue, well bedded, flagstone-like, sandy shale often almost slaty in hardness. Minute mica flakes along the bedding planes often give a lustrous sheen to the shale when freshly broken. A measured section allowed 1221 feet to be assigned the Mailu Shale.

Mailu Sandstone.- Immediately and conformably above the Mailu Shale occurred a heavy sandstone termed the Mailu Sandstone, consisting chiefly of hard, thick-bedded, rusty brown sandstone. The individual beds were cross-bedded on a small scale, and the resultant cross-bedding planes are hardened to such a degree that they protrude slightly outside the main surface of the sandstone, as exposed in vertical banks, giving a "crazy washboard" appearance. The general rusty brown appearance of the sandstone changes to a somewhat bluish shade below water level.

In general the sandstone is not very well sorted. A measured thickness of 940 feet is assigned the Mailu Sandstone in the Langting Series.

Longren Group.- Above the Mailu Sandstone occurs a mixed group consisting of shales and sandstones, pure, interbedded, and interlaminated, but showing a general shale influence over the group in rock composition. This group has been designated the Longren Group. In it occur two beds of about 30 feet in thickness separated by a massive sandstone some 50 feet thick. The lower conglomerate bed rests upon a pure shale with a slight irregular unconformity. The bottom boulders of the lower conglomerate are composed of shale similar to that which lies below, and are held in a poorly sorted fine gravel matrix. The boulders of the main beds are chiefly of well rounded, hard, fine grained sandstone and appear to be water worn concretions. Quartz pebbles up to an inch in diameter are quite common in the conglomerate. The slight angular unconformity noted is probably due only to local channeling, and the conglomerate is without doubt an integral part of the Longren Group. For the greater part of its extent, the Longren Group appears to be less resistant to the influence of weathering than the sediments both below and above it. As a result the Longren topography is low and covered with weathering products in place. The thickness of the Longren Group was determined as being 5740 feet.

Langting Sandstone.- Immediately overlying the Longren Group occurs a heavy, well-bedded, hard, even and fine grained, grayish sandstone. The sandstone stands out by forming high perpendicular cliffs resulting in a narrow gorge on the Langting River. At occasional intervals throughout the sandstone, thin layers of hard, dark, brittle shale occur. This sandstone has been termed the Langting Sandstone and its measured thickness determined at 4,834 feet.

Interbedded Group.- Above the Langting Sandstone is a rock series consisting of shales and sandy shales with occasional sandstone layers. At the bottom of the group the sediments are composed of almost pure shale, but on ascending in the series they become more and more sandy until near the top a slightly shaly sandstone predominates. For purposes of identification, this mixed group, lying conformably above the previously described Langting Sandstone, has been termed the Interbedded Group, and its thickness determined at 4,191 feet.

Dhansiri Sandstone.- Immediately overlying the Interbedded Group occurs a group of sediments which, for the sake of convenience, has been termed the Dhansiri Sandstone. As indicated by the name, the major part of the material composing this group is sandstone although badly sorted shaly horizons do occur. The sandstones are

of the reddish brown, coarse grained, and poorly sorted type and appear to have been laid down with great rapidity. Both current and wave types of cross-bedding may be encountered. In some localities the sandstone bears considerable resemblance to the North Cachar Sandstone previously described, and in others it closely resembles the Fossil Wood sandstones to be described later.

Lumding Shale Group.- The Lumding Shale Group is composed of a very mixed group of sediments. Pure shales, interlaminated shales, and sandstones, interbedded shales and sandstones, and even occasional massive sandstone beds occur. However, the group in general shows a decided shale predominance. In fact, in the northern part of the area where the Lumding Shale overlies the North Cachar Sandstone (see Areal Map, also discussion of unconformities), the shale is quite clean and well sorted with but slight sandy partings. There it is well bedded, blue-gray in color, and soft and clay like when moistened with water.

The Lumding Shale is encountered in various physical shapes. Some beds show conchoidal weathering with large spalling masses outstanding, others are thin bedded with slight sandy partings. Broken carbonaceous remains are often observed in the shale, but no specimens of diagnostic value were secured.

The Lunding Shale Group probably represents a rapid silting-up phase in a broad estuary. Certainly deposition was, for the most part, much too rapid to allow proper sorting to take place although intervening periods did occasionally permit some fine shale beds to be laid down.

The thickness of the Lunding Shale Group undoubtedly varies considerably, but, after a series of measurements, an average thickness of 1500 feet was decided to be approximately correct.

Fossil Wood Group.- The group of sediments to which the term Fossil Wood Group has been applied, is probably the top member of the Tertiary rocks of the Lunding Area. This group consists of massive, medium to coarse grained, poorly sorted, yellow to brown sandstone, containing large quantities of Fossil Wood in the upper portion of the group. Because of this, the term Fossil Wood Group has been used. Gray sandy shales occur at intervals, but they are inconsequential as compared with the sandstone mass. Owing to its massiveness and the heavy jungle which covers so much of the area, no measurements were secured as to its thickness.

Unconformities

Two major unconformities are recorded within the limits of the Lunding Area. The first is the profound

unconformity which separates the older Gondwana (Carboniferous to Lower Mesozoic) rocks from the later Cretaceous (see Table of Formations) along the western border of the Luding Area (see Areal Map). The second is the unconformity at the base of the Luding Shale. Because of it, the Luding Shale was found overlying and in contact with all of the rocks of the Area from the Langting Series down to the Igneous and Metamorphic Group (see Areal Map). The presence of local conglomerate beds at the base of the Luding Shale, together with a persistent slight change in the dip of beds above and below the unconformity, first suggested its presence. Later mapping determined accurately its field relations.

STRUCTURE

Two great thrusting movements, one from north to south and the other from east to west, have been the controlling factors in developing the structural features of northeast India.

The north-south movement left as its main effect the immense uplifted mass of the Himalaya Mountains; the east-west movement elevated the great bulk of the Shan Plateau of which the Arakon Yoma, the Patkoi Mountains, and the Naga Hills are considered a part.

Although, as described under Geology (see page 11), the physiographic features of northeast India owe their

existence to the great Tertiary movements, yet certain areas probably preceded others in the time of their elevation. Thus it would seem that the Shillong Plateau and Jaintia Hill sections of the Assam Range and the Mikir Hills of the same range were the earliest features to be raised. They then formed the northern shores of the receding sea. The sediments of the Luding Area, south of the Mikir Hills and west of the Jaintia Hills, continued to be laid down in the old embayment whose waters washed the shores formed by the above mentioned hill regions. The sediments of the old embayment are found to lap on the old shores at angles of from 5 to 7 degrees.

Along the eastern side of the old embayment a great overthrust fault has abruptly cut off the embayment sediments and obliterated the ancient shoreline. The fault, commonly referred to as the "great boundary fault," so called because it cuts off the younger Tertiary sediments of the old embayment with a wall of Cretaceous-Eocene metamorphosed rocks, extends in the shape of an arc with its convex side toward the Luding Area, for some 300 miles or more, parallel to the trend of the outer ranges of the Shan Plateau.

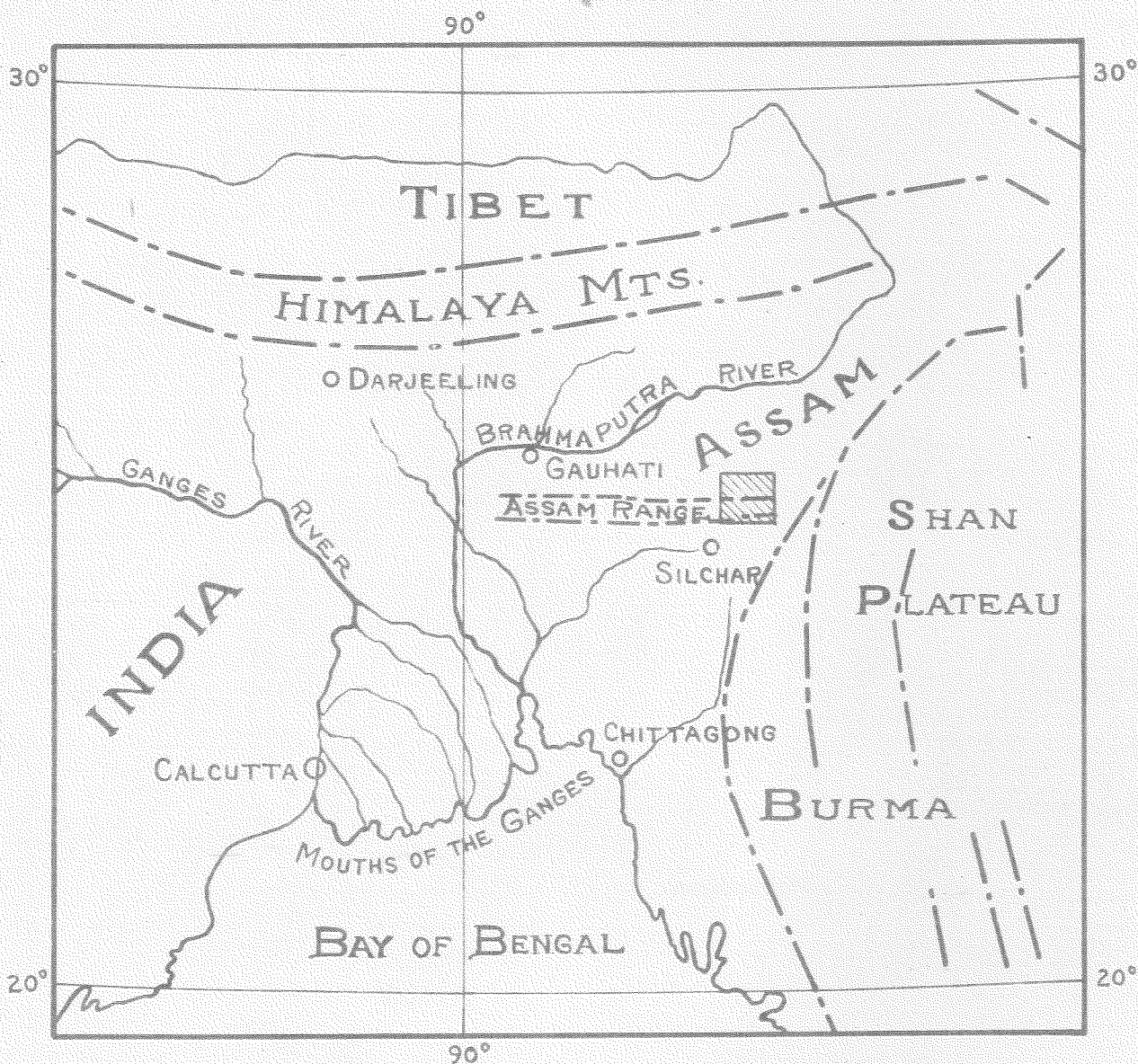
The combination of the two great compressional movements has affected the direction of the orographic feature, has in some areas aligned the structures in parallel

anticlinal and synclinal folds, and has determined the general strike of the rocks. In Upper Assam, northeast of the Lunding Area, the exposed rocks show an E.NE.-S.SW. trend in strike, and the structural and orographic features are similarly aligned. In Lower Assam, south of the Lunding Area, in the vicinity of the Boundary Fault, the strike, structure, and orographic features have been aligned in a N.NE.-S.SW. trend. Thus an orographic curvature which, as seen from the Lunding Area assumes the shape of a great convex arc, extends from the very northeast part of Assam down to the Bay of Bengal.

Perhaps the part of Assam least affected in many ways by the great compressional movements lies in the Lunding Area. Here the rock waves continuing more or less concentric with the Himalayan Mountain arc on the north and the Shal Plateau arc on the east met and neutralized each other in so far as orographic and structural alignment is concerned. The result is that the rocks of the Lunding Area have been folded into gentle domes or quaquaversals with no considerable alignment of strike, structure, or orographic features discernable. Furthermore, the absence of faulting, except occasionally on a very minor scale, indicates that the magnitude of the rock waves had decreased very considerably before reaching this area.

SUMMARY

1. That the Lunding Area has been affected structurally by both the Himalayan and the Shan compressive movements, but that neither has a marked influence on the rock structure, therefore no regular alignment was found to exist.
2. That the stratigraphy of the area has been worked out on a paleontologic and lithologic basis, and formations from the Gondwanas (Carboniferous to Lower Mesozoic) into the Pliocene designated and described.
3. That a thickness of 29,469 feet of unaltered sediments was measured above the Gondwana rocks, but that the actual total thickness is probably in excess of this figure.
4. That two unconformities were found to exist within the limits of the area:
 - a. A profound regional unconformity between the Gondwana Rocks and the Cretaceous, revealed on the western border of the area.
 - b. An unconformity that places the Lunding Shale immediately above and in contact with the Middle and Lower Miocene, Oligocene, Eocene, and Cretaceous sediments.
5. That faulting within the limits of the area is inconsequential both in magnitude and extent.



INDEX MAP
 SHOWING LOCATION OF LUMDING AREA
 IN ASSAM - N.E. INDIA

SCALE - 115 MI. = 1 INCH

- MOUNTAIN SYSTEMS
-  LUMDING AREA

OIL SHALES OF WASHINGTON

by

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OIL SHALES OF WASHINGTON

Introduction

The constantly increasing consumption of mineral oils in the various industries of the world during the past few years has become a cause of serious concern. The older oil fields are rapidly being exhausted of their mineral wealth, and the number of possible oil areas still unprospected are becoming fewer and fewer. Even at the present rate of consumption it is unlikely that our known oil reserves will last much more than 20 years, and, in the face of this, we must consider the rapidly increasing demand for petroleum products necessitated by the tremendous increase in the use of machinery. It is true that the production of crude petroleum has shown a very appreciable gain each year, chiefly through the discovery of new fields, but this gain is not nearly so large as is the increased demand for petroleum products. It is only a matter of a very few years until the curve of oil production in the United States will have reached its absolute peak, and other sources will have to be found to provide oils for our combustion engine and petroleum using industries. Already foreign interests have realized the situation and are endeavoring in every

way to augment their reserves and to block the expansion of the American oil industry in foreign lands. Because of these conditions anything which indicates a new source of petroleum should be carefully investigated. This brings us to the consideration of the oil shale subject.

The presence of oil shales in the Tertiary deposits of Colorado, Utah, Montana, and other locations in the western United States has led to an investigation of the same subject in the State of Washington. That large areas of western Washington are composed of Tertiary sediments has long been known. Whether or not these sediments contained deposits of oil shale has never been determined until recently. This paper gives the methods used and tabulates the results obtained in investigating the subject in western Washington.

History and Foreign Extent of Oil Shales

Scotland.-- Our knowledge of the extraction of oil from oil shales by destructive distillation comes largely from the successful methods of the oil shale industry in Scotland. As early as 1851 boghead coals were distilled on a commercial scale in Scotland. By 1862 these coals were more or less exhausted and the distillation of bituminous shales started.

The greater part of the bituminous shale deposits of Scotland occur in the vicinity of Edinburgh. The workable area is from 5 to 8 miles long and extends from the northern shores of the Firth of Forth to a point about 60 miles south

of the Pentland Hills. There are other small deposits, but the above mentioned one is easily the most important.

The oil yield from the Scotch shales ranges from as high as 50 gallons per ton in some seams to as low as 7 gallons in others. However, the average yield is approximately 19 gallons to the ton. The ammonium sulphate content varies from 6 to 67 pounds to the ton.

The following products* are secured through the Scotch

*Bacon and Hamor. The American Petroleum Industry, Part 2. published by McGraw-Hill Book Co., New York, 1916.

methods of conserving the by-products:

1. Permanent gases - used for fuel at the retorts.
2. Shale naphtha, gasoline, motor spirits.
3. Lamp oil.
4. Intermediate oils - used for manufacturing gas.
5. Lubricating oils - not high grade.
6. Solid paraffin.
7. Still grease.
8. Still coke - used as fuel and also as Carbon Black.
9. Ammonium sulphate - a fertilizer.
10. Fuel oils, tars, residues, etc. - used in the refineries.

France.- In France the shale oil industry is even older than in Scotland. As early as 1838 the French were distilling paraffin from shales on a commercial scale. However, the introduction of cheap American oils from the new Pennsylvania fields in 1864 seriously checked the growing shale industry in France. The French have not made the progress of the Scotch in distillation methods.

British America.- In New Brunswick, in Nova Scotia, and in Newfoundland, large areas of excellent oil shale have been discovered. In New Brunswick and Nova Scotia the shales are estimated to yield an average of 40 gallons of oil and from 30 to 69 pounds of ammonium sulphate per ton. In Newfoundland tests have shown about 35 gallons of oil and from 30 to 50 pounds of ammonium sulphate per ton. No commercial work of any importance has yet been done on these deposits.

World Outside of the United States.- Beside the locations given above, oil shale in commercial quantities is known to occur in Spain, Germany, Bulgaria, Norway and Sweden, Esthonia, Burma and Siam, South Africa, Australia, China, Tasmania, Jugo-Slavia, Bulgaria, Brazil, Argentina, Chile, and Uruguay.

History and Extent in the United States

In the United States shale oil has received comparatively little attention in the past because of the great abundance of petroleum found within our borders. However, even before

petroleum was first brought in in Pennsylvania, the Mormons had erected a shale oil still near Juab, Utah, and had attempted to distill oil from some of the shales found there. Before the discovery of oil in the great Appalachian Field, several oil companies had been organized in the United States, and some work had been done on the distillation of cannel coal and also on the Devonian black shales of the east. The discovery of crude oil in Pennsylvania made it economically impossible to continue with any distillation process, so what might have developed into a wide spread shale oil industry was ruined.

In the United States the extent of known oil shales is enormous, and their possible future influence in our industrial world is extremely great.

Utah.- In that part of the Uinta Basin lying within the State of Utah, it is estimated that there is sufficient sampled shale to produce 42,800,000,000 barrels of crude oil* and possibly 500,000,000 tons of ammonium sulphate.*

*Winchester. U.S. Geological Survey Bulletin 691-B

Colorado.- In Colorado the total shale area exceeds 2000 square miles. Assuming an average of 20 feet* of

*R. D. George. Colorado Geological Survey Bulletin 25

workable shale over this area and estimating one barrel per

ton, both of which assumptions have been shown by careful sampling to be reasonable, the total potential crude oil from the Colorado shales reaches the huge figure of 56,000,000,000 barrels. In addition to this the ammonium sulphate and other by-products are to be considered.

Nevada and Montana.^{*}- In Nevada oil shales of about the

^{*}M. J. Gavin. Oil Shale. Bureau of Mines Bulletin 210, pp.20,21.

same age as those in Colorado and Utah, are known to occur in the eastern part of the state near Elko. These shales are neither so rich nor so well adapted to mining as are those of Colorado and Utah. In Montana oil shales are known to occur at two distinct horizons, one of Permian age and the other in the Tertiary. These deposits are neither so rich nor so abundant as the ones in Colorado and Utah.

Kentucky and Indiana.- In these states the black shales of the Devonian have proved to be worthy of considerable attention. The great extent and uniformity of oil content of these shales has been proved by the Bureau of Mines. An average content[†] of 16 gallons of oil and from 30 to 50 pounds

[†] M. J. Gavin. U.S. Bureau of Mines Bulletin 210, pp.24-25

of ammonium sulphate to the ton has been shown to exist. Cheapness of mining, a nearby market, and a good grade of oil may cause these shales to be developed sooner than the more

distant but richer ones of Colorado and Utah. About 1000 square miles of Kentucky alone are believed to be underlain by oil shales.

Geology

Introduction.-- During the Eocene period^{*}, the present

* Bailey Willis. U.S. Geological Survey Tacoma Folio, No.54

site of what we know as the Puget Sound Basin was an extensive arm of the sea covering portions of the present Cascade Mountains and extending as far south as Oregon. The Cascade Mountains as a range did not exist. It is probable that the northern part of the range, within the boundaries of the state, possessed some relief, but the central and southern portions were not much above sea level. That fresh water lakes and swamps of considerable area existed on the site of our present Cascade Range is proved by the character and distribution of fossil faunas, together with the character of the sediments in which they are found. Portions of the present range were probably completely submerged, and some of the lakes and swamps undoubtedly had, at various times, connections with the estuary on the west. It is probable that parts of the San Juan Islands, and also the central portions of the Olympics, were land areas which had been lifted above sea level at the close of the Jurassic. Granites and older sedimentaries formed the land mass which bordered the great estuary.

During the Eocene period, the climate* was semi-

*Professor F. H. Knowlton, U.S. Geological Survey, Tacoma
Folio, No. 54

tropical. This condition, with its accompanying prevailing moisture, covered the land area with a dense and luxuriant flora. Probably as many as 250 different species existed, many of them since entirely extinct. In the lower part of the Eocene, ferns, gigantic palms, fig trees, and similar flora testify to a semi-tropical climate. However, the presence in the upper part of the Eocene of sumacs, birches, sycamores, etc., would indicate a gradual change in climate from semi-tropical to a sub-tropical or even an approach to present day conditions.

It is to the products of decay of the heavy vegetation accumulating in great swamps or shallow waters and then being buried under thousands of feet of sediments flowing in from the rapid weathering of the adjacent hills, that the coal beds of western Washington owe their origin. It is to the products of decay of this vegetation accumulating with the muds and fine silts which were deposited in deeper waters when the rate of subsidence proceeded more rapidly than the rate of sedimentation, that the existence of the carbonaceous shales of western Washington owe their origin.

Stratigraphy.- The Green River formation which contains the oil shales of northeastern Colorado has been determined

as belonging to the Eocene period and composed of carbonaceous materials laid down in fresh water. The sediments composing the Green River formation are mainly shales with a relatively small percentage of sandstone.

The western part of the state of Washington contains large areas of Eocene sediments of brackish and fresh water origin. Shales, sandstones, and conglomerates with all intermediate gradations compose the sedimentary formations. Lava flows, intrusive plutonic rocks, dikes and sills occur in association with the western Washington sediments.

Dr. C. E. Weaver* has made the following divisions of

*C.E. Weaver. Tertiary Formations of Western Washington.
Washington Geological Survey, Bulletin 13

the Tertiary in the western portion of Washington on the basis of fossil evidence:

	Quaternary	{ Diastrophism, volcanism, glaciation, and erosion. Development of the present Cascade Range.
	(Pliocene	{ Largely a record of Diastrophism and erosion. Igneous activity in eastern Washington. Montesano formation may belong here.
Tertiary	Miocene	{ Upper Miocene. (Montesano) { Unconformity { Lower Miocene (Wahkiakum Horizon)
	Oligocene	{ Blakely Horizon { Porter Horizon { Lincoln Horizon
	Eocene	{ Upper Eocene (Tejon formation Igneous, Lacustrine, and estuarine phases) { Lower Eocene (Martinez formation)
		Basement composed of Paleozoic and Mesozoic rocks, largely metamorphosed

Puget Group.- It is between the sandstones and shales of Eocene age that the extensive coal beds of Washington occur. To these coal bearing measures, together with their associated sandstones and shales, the name of Puget Group*

*The Puget Group of Washington Territory. American Journal of Science, Third Series, Vol. 36, 1888, pp.443-50

was given by C. A. White of the United States Geological Survey in 1888. Its age was at that time determined as Eocene on the basis of its fossil content. In Pierce County from 10,000 to 15,000 feet of the Puget Group are known to occur.

Lithology.- The Eocene shales of western Washington vary widely in their physical properties. In color, fracture, and general composition almost all extremes and their intermediate gradations are represented. In color they range from gray to blue-gray to brown and even black. Some varieties are slightly carbonaceous, and from that condition they grade into a shaly lignite. In some localities enough sand is present to permit them being designated as sandy shales whereas in others the sand constituent so predominates that they are really shaly sandstones. The presence of sandy material tends to make the shale much harder and considerably lighter in color than the more pure shales.

The shales of the Puget Group range from a fine grained and fissile to thinly bedded and laminated to massive with no appearance of stratification. Some varieties are very

tough and rubbery in character whereas others are quite brittle. The fracture varies from conchoidal to an absolute irregularity. In the immediate vicinity of igneous intrusions, the shales frequently occur in a baked or burned condition or altered to slate.

Most of the true shales of the Puget Group contain more or less carbonaceous matter. In some cases large leaves, stems, etc., are distinguishable; in others only very finely disseminated organic material is present. Sufficient iron containing minerals are present in some localities to color the shales various shades of brown upon oxidation and subsequent hydration of the iron.

Oil Shale

Definition.- According to Ziegler,* "Oil shales are

* Ziegler, Victor. Popular Oil Geology, 2d Edit. John Wiley & Sons, New York, 1920.

shales, that is, muds or clays consolidated into rocks, from which oil and gas can be produced by destructive distillation. These shales do not actually carry oil as such. They contain organic materials such as partially altered plant remains which are broken up into oil and gas when subjected to heat. That by far the greater part of the oil is not present as such is proved by the fact that even the richest shales are not greasy or oily in appearance, and that oil seeps are virtually unknown in them."

That little or no oil exists as such, even in those shales which prove richest by destructive distillation, has been proved by work in the rich shales of northwest Colorado. Here wells drilled through very rich shales with favorable geologic structures have yielded absolutely no oil.

The name of Kerogen* has been given to the complex organic

*Gavin, Hill, and Perdew. Notes on Oil Shale Industry. U.S. Bureau of Mines, Reports of Investigations, June, 1921, Serial 2254.

compounds present in the oil shales which, upon destructive distillation, decompose and yield hydrocarbon oils and permanent gases. The oil shales also contain varying quantities of nitrogenous compounds. These during the process of destructive distillation decompose into ammonia and other nitrogen bases including pyridines and pyrrols.

Origin.- A number of theories have been advanced by different investigators to account for the origin of oil shales.

At the time of his death, Davis was studying the materials that make up the Green River formation. He wrote,*

*Winchester. Oil Shale in Northwestern Colorado. U.S. Geological Survey Bulletin 641, 1917, pp.163-5

*It is clear that the structureless material of the Green River shales probably originated in a collection of plant debris which has, by decomposition and the activities of

bacteria and other microscopic organisms, passed into a jelly-like phase, which is to be found in certain kinds of peat deposits. The plant remains that have been found characterizing the shales from every locality from which they have been examined (Green River formation), are those of microscopic algae mixed in small percentage with pollen and similar parts of higher plants. Animal remains have been very rare in the material studied, and those noted were chiefly those of insects in a very fragmental state.

"It seems apparent, therefore, that the study of the microscopic structure of these shales as seen in vertical and horizontal sections, leads to the conclusion that the material was laid down originally in water, and that it passed through a series of stages of decomposition before consolidation and lithification had taken place. The remarkably well preserved state of the delicate plant structures which have been examined indicates very slight disturbance of the original material and an almost entire lack of changes produced by the action of metamorphosing agencies since lithification."

Steuart* believes from his own work and that of previous

* Steuart, D. N. Oil Shales of the Lothians, Part 3, The Chemistry of Oil Shales. Memoirs Geological Survey of Scotland, 2d Edit., 1912, pp.164-5

investigators that "oil shales may be composed of vegetable matter which has been made into pulp by maceration in water and preserved by combining with salts in solution together

with richer materials of many kinds, such as spores, which nature has provided with means of protection against decay."

Winchester* believes that the character of the original

* Winchester, D. E., Contributions to Economic Geology, 1918.
U.S. Geological Survey Bulletin 691-B, Part 2.

material is largely responsible for the transformation into oil yielding substances rather than into coal. He reports that in the Green River formation of the Uinta Basin in Utah, "invariably the shale showing the largest percentage of vegetable debris will yield the most oil and vice versa, and that shale beds occurring between beds of rich oil shale may be equally compact and fine grained and yet yield no oil on distillation."

Considering the shale deposits as a whole, the following points appear to be established, according to studies carried out by the Colorado Geological Survey:*

* George, R. D., Colorado Geological Survey, Bulletin 25,
1921, p. 24.

1. "The shales contain no hydrocarbons liquid at atmospheric temperatures.
2. "Solid hydrocarbons in minute particles and in widely differing quantities occur in the shales.
3. "There appears to be no direct relationship between the oil yield and the presence of these hydrocarbons. Shales apparently free from the hydrocarbon particles may give a high yield of oil while others in which such particles are numerous may give a low yield.

4. "The shales contain much partly bituminized vegetable matter (and possibly some animal matter), and the quantity of this and the hydrocarbons together, determines the possible oil yield.
5. "The degree of bituminization of the vegetable matter varies from place to place, and from stratum to stratum. This change in the vegetable matter is comparable to the evolution of coal from plant matter.
6. "The oil yielding materials of shales are related to lignite, or coal, on the one hand, and to true hydrocarbons on the other. The closeness of the relationship to each depends upon the nature and degree of the alteration of the vegetable matter of the shale."

In the western part of the state of Washington there is no apparent reason why shales containing oil in commercial quantities could not have been deposited. It seems likely the conditions of sedimentation in parts of western Washington were somewhat similar to those of Colorado except for the frequent brackish water phases encountered. However, where all conditions approach each other most closely between the Green River formation and the Puget Group, oil shale has been formed in the former and coal in the latter.

Mining

Shale mining approximates coal mining more nearly than that of the minerals. Where any considerable depth must be attained before mining is possible, a regular coal mining system of entries and cross cuts must be instituted. Provision must be made for supporting the roof with the usual methods of props and sets while drawing pillars.

One advantage that shale mining would have over coal mining is that there would be no objection to crushing the shale through the use of heavy explosives. Since the shale must be crushed before it is ready for the retorts, the breaking up due to mining methods would be an advantage rather than a disadvantage, as it would be in coal mining.

In many localities open pit mining would be entirely possible. Under such conditions the use of steam shovels should reduce mining costs considerably.

Retorting

Retorting is the most difficult process in the development of the shale oil industry, and on the solution of retorting problems depends to a great extent the length of time that will elapse before the industry is well established. Different types of shales present varying retorting problems. Thus the cost of producing commercial oil depends largely upon the retorting process as well as upon the general conditions that affect every commercial enterprise. The great problem of retorting appears to lie in an even distribution of all heat units through the moving mass of the shale in the retort.

Refining

The problem of refining the oil secured through retorting the oil shales has not yet been satisfactorily solved. Present refining methods have proved quite

unsatisfactory. For example, the gasoline secured from shale oil by using the ordinary fractionating process of refining is straw colored and has a very disagreeable odor. So far all attempts to eliminate the color and the odor have failed; however, it is extremely likely that these difficulties will be overcome through research and experimenting.

Distillation Tests

Apparatus.— The basic principle of the shale testing operation is to heat the oil shale until the volatile hydrocarbons vaporize, and at the same time destructively distill any other organic matter present in the shale.

The apparatus used in making the distillation tests on the Washington shales was similar in most respects to that used by Woodruff and Day in the Colorado field. It consisted of:

- 1 Pair pliers
- 1 Iron mercury retort
- 2 Ring stands
- 1 Condenser clamp
- 1 Ammonia scrubber (8 oz. wide mouth bottle
filled with crushed glass)
- 1 Balance
- 6 in. Fine iron wire
- 1 Meeker burner
- 1 Glass condenser (complete)
- 1 Iron ring
- 1 100 c.c. glass graduate
- 8 ft. Rubber tubing
- 1 Rubber cork - double hole
- 2 ft. Glass tubing
- 1 Glass separatory funnel

An ordinary iron retort equipped with a tight fitting lid and a screw clamp is used as a container for the shale.

An iron delivery tube leading from the tight fitting lid is fastened to the inner tube of the condenser by a rubberized connection which is wired to make a tight joint. The retort is fitted into the ring and held in place by it on the ring stand. The meeker burner is also set upon an adjustable ring attached to the same ring stand as is the retort.

The condenser used consists of an inner tube of hard glass three-eighths of an inch in diameter and thirty inches long. This inner tube is surrounded by a second glass tube one and one-half inches in diameter by twenty-four inches long, drawn down to provide three-fourths inch openings at each end. Through these three-fourths inch holes, the inner tube is fitted tightly with the aid of rubber gaskets. About three inches from each end, an entrance and exit is provided for the circulation of water through the outer tube to keep the inner tube cool. The condenser is so set on the condenser clamp that it will remain at an angle of about 45 degrees from the horizontal. The retort delivery tube is then bent to make a straight connection with the condenser inner tube, and at the same time leaves the retort in an upright position.

The receiver for the condensable products of the distillation consists of a 100 cc. glass graduate, provided with a two-holed rubber stopper through which are thrust two glass tubes, one to permit the liquids and permanent gases from the condenser to enter, and the other through which the

permanent gases may escape to the ammonia scrubber. These tubes should barely penetrate the rubber cork.

The ammonia scrubber consists of an 8 oz. wide mouthed bottle provided with a glass tube reaching nearly to the bottom of the bottle for the entrance of permanent gas from the receiver. The bottle is filled with either glass beads or crushed glass. This is used to provide greater surface for breaking up the gas bubbles as they rise in the bottle. A solution of 18.31% sulphuric acid by weight is used as a scrubber.

Running water for cooling the condenser is always available from any tap in the laboratory.

A balance of ordinary accuracy is needed for weighing samples of the shale.

A glass separatory funnel is used to separate the oil from the water derived from the distillation.

The pliers are used for handling the retort and for making tight joints with the iron wire.

Method Followed.- In performing the distillation tests to determine the quantity of oil and ammonia that may be secured from any sample of shale, the shale is first pulverized to pass through a one-half inch mesh. A distilling sample of eight and one-half ounces weight is then selected so as to truly represent the entire quantity. This standardized sample of eight and one-half ounces is selected because it gives the yield of oil in U.S. gallons to the short ton

as equal in number to the number of cubic centimeters of oil secured in the distillation.

The sample is placed in the retort and the cover securely fastened. In order to prevent leaks the joint between the cover and the retort bowl is well plastered with a thick paste of a fire clay mixture. This was found to be very efficient in sealing the retort cover. The delivery tube from the retort is then connected to the inner tube of the condenser and the joint made secure by wiring.

The ammonia scrubber is filled two-thirds full with a solution of 18.31% sulphuric acid, and cool water is started circulating through the condenser. The meeker burners are then lighted, with the flame turned low, and the retort is slowly heated. After from 5 to 25 minutes, condensation begins to take place and water and oil are delivered into the graduate. The permanent gases pass through the graduate and bubble up through the sulphuric acid solution in the scrubber. Here any ammonia present combines with the acid to form soluble ammonium sulphate.

As long as any oil is being delivered to the receiver, a gentle heat should be maintained; then the flame should be gradually lengthened until at the end of from three to three and one-half hours the burner will be at full blast and the shale will have ceased yielding oil, gas, or water. After a half hour of heating with no result, the flame may be extinguished and the products of distillation measured.

The water is then drawn off from the oil in the receiver with the aid of a separatory funnel and added to the liquid contained in the ammonia scrubber. The number of cubic centimeters of oil is then determined and this is taken equal to the number of gallons per short ton, if the sample used is eight and one-half ounces. The liquid in the ammonia scrubber, together with the liquid separated from the oil, is sealed and kept for further analysis.

The amount of soluble ammonium sulphate in solution in the acid liquor is determined by titrating with standardized solutions and calculating the results. A sulphuric acid solution of specific gravity 1.132, and by analysis 18.31% acid, was used in the scrubber; therefore, the number of grams of sulphuric acid present in the liquor before any gas has been introduced, is equal to .1821 times 11.32 or 2.074 grams of H_2SO_4 per 10 cc. The ammonia gas from the shale passing into the acid solution will tend to neutralize it, and the difference between the acid strength of the liquor at the beginning of the distillation and at the finish represents the amount of ammonia in solution as soluble ammonium sulphate. A solution of 0.6 normal sodium hydroxide was selected for the titration. In the first liquor tested after the permanent gases of distillation had passed in, it was found that 18 cubic centimeters of 0.6 normal sodium hydroxide were necessary to neutralize the acid solution. Since 18 cubic centimeters of 0.6 sodium Hydroxide are ~~equal to~~ 18 cubic centimeters of 0.6 normal sulphuric acid,

and since one liter of 0.6 normal sulphuric acid solution contains 29.41 grams of acid, the 18 cubic centimeters of 0.6 normal sulphuric acid solution contain $\frac{18}{1000}$ of 29.41 grams or 0.5292 grams of sulphuric acid. The first calculation gave 2.074 grams of acid in the liquor at the beginning, and the last calculation gave 0.5292 grams of acid at the conclusion of the distillation. Then the difference between these two amounts, or $2.074 - 0.529 = 1.545$ grams of acid used up by the ammonia absorbed.

The absorption of the ammonia in the sulphuric acid scrubber produces the following equation:



Then:-

$$98:34::1.545:X$$

or $X = 0.5357$ grams of ammonia in the 10 cubic centimeter sample tested. A measured quantity of 100 cubic centimeters or ten times the tested sample was used in the scrubber, therefore:

10 times 0.5357 = 5.357 grams of ammonia in the entire scrubber.

To transform to terms of ammonium sulphate, the following equation must be solved:

$$98:132::1.545:X$$

or $X = 2.081$ grams of ammonium sulphate in the 10 cubic centimeter tested sample. Then 10 times 2.081 or 20.81 grams is the amount of ammonium sulphate in the entire scrubber. Since the standard sample of 8-1/2 ounces was

used in the distillation then: *

8.8 times 20.81 = 183.12 pounds of ammonium sulphate per ton of shale.

.....

Example

Specific gravity of H₂SO₄ liquor used in scrubbing bottle = 1.132%, by weight of H₂SO₄ = 18.31%

.1831 times 11.32 = 2.074 grams of H₂SO₄ present in liquor before any ammonia is dissolved.

18 cubic centimeters of 0.6 N/l NaOH needed to neutralize the H₂SO₄ liquor left after the ammonia has been absorbed in it.

18 c.c. of 0.6 N/l NaOH = 18 c.c. of 0.6 N/l H₂SO₄

1 liter of 0.6 N/l H₂SO₄ = 29.4 grams H₂SO₄

18 c.c. of 0.6 N/l H₂SO₄ = .5292 grams H₂SO₄

.....

2.074 = grams H₂SO₄ in liquor at start.

0.529 = grams H₂SO₄ in liquor at finish

1.545 = grams used up by the NH₃ absorbed.

H₂SO₄ plus 2 NH₃ --- (NH₄)₂SO₄

{ H₂SO₄ = 2 NH₃ }
 { (98 grams = 34 grams) }

98:34::1.545:X

X = .5357 grams of NH₃ in sample tested.

Sample tested = 1/10 of total liquor, therefore,

10 x .5357 or 5.357 = total grams of NH₃ in scrubber.

.....

To transform to terms of ammonium sulphate:-

$$98:132::1.545:X$$

$X = 2.081$ grams of ammonium sulphate in tested sample.

10×2.081 grams of ammonium sulphate in the entire scrubber.

$* 8.8 \times 20.81 = 183.12$ lbs. of ammonium sulphate per ton of shale.

* Sample so taken that 8.8 times the number of grams of NH_3 equals the number of pounds per ton of ammonium sulphate in the scrubber.

Plan of Work.

The plan followed in carrying out the oil shale investigation in the state of Washington was to rapidly reconnoiter the areas in which oil shales might be found, distill the samples in the laboratory at the University of Washington, and then return to complete a more exhaustive study of the areas whose distilled samples gave favorable results. In this way but little time would be wasted in regions that were entirely barren. However, since no shales of commercial importance were located, no exhaustive investigation has been made of any particular area.

In the following pages a short account of the locations in which the various samples were taken is followed by the tables giving the results of the distillations made.

Location of Samples

Shale samples numbered from 1 to 10 inclusive were taken in the canyon of the Carbon River in Pierce County near the town of Carbonado. The actual outcrops lie in Township 18 North, Range 6 East, and Sections 4 and 5. Between 5000 and 6000 feet of sediments belonging to the Puget Series are revealed in this locality.

Shale samples number from 11 to 14 inclusive, were secured in the valley of the Cedar River, a short distance above the city of Renton in King County. The map location is in Township 23 North, Range 5 East, Section 17. The shales secured here also probably belong to the Puget Series.

Shale samples numbered from 15 to 19 inclusive, were taken from outcroppings along the beach between the Moclips River and Copalis in Grays Harbor County. These samples were secured by Mr. Charles Landes.

Shale samples numbered from 20 to 26 inclusive, were taken underground in the mines of the Carbon Hill Coal Co. at Carbonado in Pierce County. Here a considerable thickness of sediments belonging to the Puget Series and which had not been subjected to the processes of weathering were sampled. The map locations are the same as for Samples 1-10, i.e., Township 18 North, Range 6 East, and Sections 4 and 5.

Samples numbered from 27 to 32 inclusive were taken in a railroad cut made by the Northern Pacific Railway in constructing their line from Seattle to Portland. The particular cut in which the above numbered samples were secured is

located about 2 miles north of the city of Centralia in Lewis County. The map location is Township 15 North, Range 2 West, Section 34. The shales are probably of Eocene age, the same age as the Puget Series, but they differ from the latter in that they are probably of strictly marine origin.

Samples numbered from 33 to 38 inclusive were taken underground in the Mendota Coal Mine at Mendota, Lewis County, located in Township 14 North, Range 1 West, Section 3. In this region practically all of the rocks are concealed by Pleistocene and Recent alluvium, making underground sampling the only satisfactory method of getting results. It is very likely that the rocks represented by the above samples are from the Puget Series.

Shale samples numbered from 45 to 50 inclusive, were secured in the underground workings of the Bellingham Coal Mine about 2 miles north of the city of Bellingham in Whatcom County of Northwest Washington. The map location of the mine is Township 38 North, Range 2 East, Sections 13 and 14.

Shale samples numbered from 51 to 56 inclusive were taken in the underground workings of the Ladd Coal Mines at the town of Ladd, Lewis County. The map location is Township 14 North, Range 4 East, Section 12. The shales sampled here belong to the Puget Series.

Samples numbered from 57 to 62 inclusive were secured on the southwest fork of the Tilton River. Here in Township 13 North, Range 4 East, Sections 10, 11, and 13, in Lewis

County, a total thickness of nearly 9000 feet of sediments belonging to the Puget Series occurs. A considerable amount of igneous activity was observed in the region. In many places the sediments of the Puget Group were affected by small intrusives both as dikes and sills. That these intrusions were of post-Puget ages is evidenced by the baking effect noticed at some of the Puget-igneous contacts.

Sample No. 63 was a shale brought to the laboratory by Mr. Sheldon Glover of the Washington Geological Survey. It was described as a "dark brownish-black shale occurring beneath a decomposed basalt. The shale was sampled in a shallow well near the Spokane Country Club." The map location was given as Township 26 North, Range 42 East, Section 12, in Spokane County.

Shale samples numbered from 64 to 70 inclusive, were taken in the general vicinity of Kelso, Cowlitz County, in southwest Washington. Numbers 64, 65, and 66 were secured along the Coweman River east of Kelso in Section 30, Township 8 North, and Range 1 West. Numbers 67, 68, 69, and 70 were secured along the banks of Coal Creek northwest of Kelso in Sections 2 and 11 of Township 8 North, Range 3 West, and in Section 35 of Township 9 North, Range 3 West. The beds from which the samples were taken are of Eocene age and are probably of estuarine origin.

The samples numbered from 71 to 75 inclusive, were secured in northern Cowlitz County in the general vicinity of

Castle Rock. They were taken in Township 10 North, Range 2 West, and Sections 24, 7, 17, 26, and 31 respectively. The sediments of this region are also probably estuarine sediments of Eocene age.

Samples numbered from 76 to 86 inclusive, were taken from the extensive shale beds that are exposed along the Straits of San Juan, a short distance east of the camp called Twin, in Clallam County of western Washington. Numbers 76 and 77 were taken in Section 25 of Township 31 North, Range 10 West, and Numbers 78 to 86 inclusive, were taken in Section 30 of Township 31 North, Range 10 West. The sediments represented by these samples have been determined by Dr. C. E. Weaver* as belonging to the Blakely Horizon of the

*Tertiary Formations of Western Washington by C. E. Weaver, Washington Geological Survey, Bulletin 13.

Oligocene on the basis of their fossil evidence.

Samples numbered from 87 to 92 inclusive, were taken on the shales that outcrop in the Green River Canyon between the railway junction of Kanasket and the mining town of Franklin, both in King County. Nearly 8000 feet of the Puget Series are exposed outcropping in the canyon, and carbonaceous shales are numerous and of considerable thickness. Andesitic dikes and sills are of common occurrence and vary in size from a few inches to 75 feet in thickness. Samples 87 and 88 were taken in Section 10 of Township 21 North, Range 7 East. Samples 89 to 92 inclusive were taken in

Section 8 of the same township and range.

Results

The results of the distillation tests made in the laboratories of the University of Washington are given as follows:

The yield of oil varied from seven gallons per ton as a maximum, to an absolute negative result. In no case was sufficient oil secured to make the recovery of shale oil on a commercial basis a possibility.

The yield of ammonium sulphate varied from 90 pounds to the short ton to a negative result. There is no doubt but that ammonium sulphate would prove a very valuable by-product if the shales yielded a fair amount of oil, but the recovery of this useful substance for its own sake would not be a profitable undertaking even at 90 pounds to the short ton.

From the tests made this far, a negative report must be made on the occurrence of commercial oil shales in the regions tested.

The results as summarized above are tabulated in the following tables:

Sample No.	Location		County	Yield of Oil: Gals. per ton	Ammonium Sulphate: Lbs. per short ton	Notes	
	T.	R.					
1	4	18N	6E	Pierce	3.0	1.67	Sampled on outcrop in canyon
2	4	18N	6E	"	3.0	1.64	"
3	4	18N	6E	"	Trace	1.98	"
4	4	18N	6E	"	"	1.21	"
5	4	18N	6E	"	"	14.07	"
6	5	18N	6E	"	"	22.14	"
7	5	18N	6E	"	5.5	15.21	"
8	5	18N	6E	"	1.0	22.14	"
9	5	18N	6E	"	1.0	1.10	"
10	5	18N	6E	"	1.0	1.07	"
11	16	23N	5E	King	Negative	Negative	Sampled on road cut
12	16	23N	5E	"	"	9.71	"
13	16	23N	5E	"	"	6.51	"
14	16	23N	5E	"	"	9.43	"
14b	16	23N	5E	"	"	6.57	"

Sample No.	Sec.	T.	R.	Location	County	Yield of Oil: Gals. per ton	Ammonium Sulphate: Lbs. per short ton	Notes
15	5	20N	12W	Chehalis	Negative	10.40	Outcrop on beach	
16	2	20N	12W	"	Trace	6.24	"	
17	21	19N	12W	"	Negative	4.72	"	
18	21	19N	12W	"	"	Negative	"	
19	21	19N	12W	"	"	9.36	"	
20	9	18N	6E	Pierce	Trace	13.20	Sample taken underground	
21	9	18N	6E	"	Negative	3.20	"	
22	9	18N	6E	"	Trace	31.86	"	
23	9	18N	6E	"	Neg. oil	73.90	"	
24	5	18N	6E	"	1 gal.	24.60	"	
25	5	18N	6E	"	Trace	26.18	"	
26	5	18N	6E	"	1 gal.	11.86	"	
27	33	14N	2W	Lewis	Negative	30.57	Sampled in R.R. cut	
28	33	14N	2W	"	"	20.06	"	
29	33	14N	2W	"	"	12.04	"	

Sample No.	Sec.	T.	R.	Location	County	Yield of Oil: Gals. per ton	Ammonium Sulphate: Lbs. per short ton	Notes
30	33	14N	2W	Lewis		Trace	4.05	Exposed in R. N. cut
31	33	14N	2W	"		"	23.76	"
32	33	14N	2W	"		Negative	14.21	"
33	3	14N	1W	"		"	3.90	Sampled in Mendota Mine
34	3	14N	1W	"		Trace	21.80	"
35	3	14N	1W	"		Negative	2.50	"
36	3	14N	1W	"		"	2.02	"
37	3	14N	1W	"		"	4.21	"
38	3	14N	1W	"		"	5.11	"
39	21	15N	1W	Thurs- ton		Trace	10.4	Sampled in Tono Mine
40	21	15N	1W	"		Negative	11.7	"
41	21	15N	1W	"		"	19.6	"
42	21	15N	1W	"		2 gals.	Negative	"
43	21	15N	1W	"		2 "	"	Outcrop in back of mine
44	21	15N	1W	"		2 "	"	"

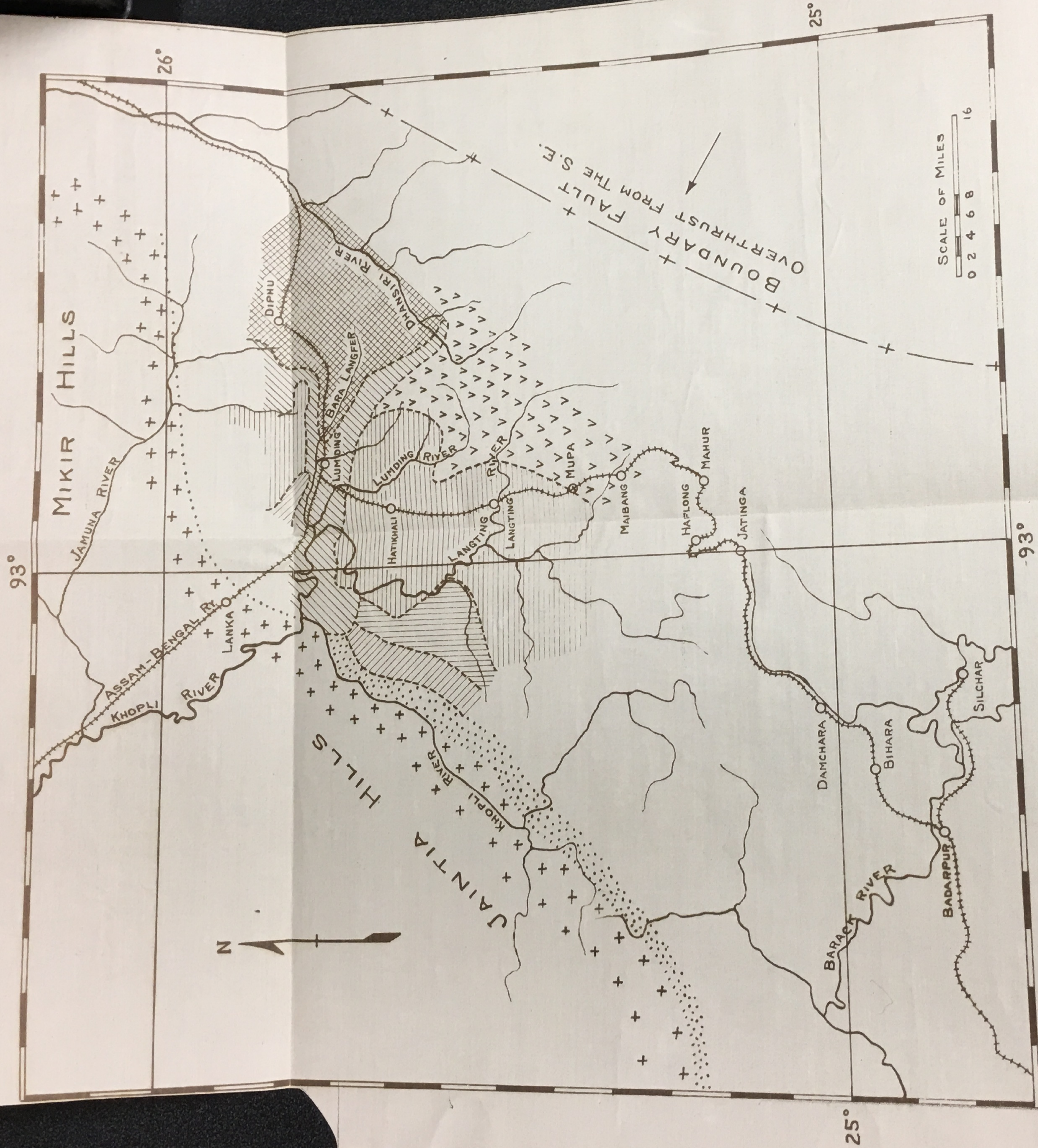
Sample No.	Sec.	T.	R.	Locetion	County	Yield of Oil: :Gals. per ton:	Ammonium Sulphate: :lbs. per short ton:	Notes
45	13	36N	2E	Whet- com:		Negative	4.05	Sampled underground
46	13	36N	2E	"		Trace	5.38	"
47	13	38N	2E	"		1 gal.	40.50	"
48	13	38N	2E	"		Trace	36.40	"
49	13	36N	2E	"		2 gals.	12.42	"
50	13	38N	2E	"		1 gal.	10.21	"
51	12	14N	4E	Lewis		Negative	12.08	" in Ledd Mine
52	12	14N	4E	"		2 gals.	7.01	"
53	12	14N	4E	"		1 gal.	12.21	"
54	12	14N	4E	"		1 "	7.04	"
55	12	14N	4E	"		1 "	9.08	"
56	12	14N	4E	"		1 "	6.82	"
57	10	13N	4E	"		Negative	90.21	Outcrop in river canyon
58	11	13N	4E	"		"	22.71	"
59	11	13N	4E	"		1 gal.	7.02	"

Sample No.	Sec.	T.	R.	Location	County	Yield of Oil: Gals. per ton	Ammonium Sulphate: Lbs. per short ton	Notes
60	11	13N	4E	Lewis	Lewis	2 gals.	12.92	Cutcrop in river canyon
61	13	13N	4E	"	"	Negative	4.71	"
62	13	13N	4E	"	"	Trace	6.22	"
63	12	26N	42E	Spo- kene	Spokane	7 gals.	14.70	Near Spokane Country Club
64	32	8N	1W	Cow- litz	Cowlitz	Negative	24.07	Exposed by spring
65	30	8N	1W	"	"	"	26.92	Cutcrop on Coweman River
66	30	8N	1W	"	"	"	24.17	"
67	11	8N	3W	"	"	"	25.52	" in Logging R.V. cut
68	11	8N	3W	"	"	"	34.58	"
69	11	8N	3W	"	"	Trace	33.97	"
70	2	6N	3W	"	"	"	19.76	Exposed in creek bed
71	24	9N	2W	"	"	"	31.84	Water in slope of old Red Ash Mine prevented entry.
72	7	9N	2W	"	"	"		
73	17	6N	2W	"	"	Negative	29.71	Exposed in county road cut
74	26	10N	2W	"	"	"	23.70	Cutcrop on river bank

Sample No.	Sec.	T.	R.	County	Location	Yield of Oil: Gals. per ton	Ammonium Sulphate: Lbs. per short ton	Notes
75	31	10N	2W	Cow- litiz	Trace		30.69	Exposed in creek bed
76	25	31N	10W	Clal- lam	Negative		32.57	Exposed in 3.7. cut
77	25	31N	10W	"	"		31.67	(Oligocene)
78	30	31N	9W	"	"		32.26	
79	30	31N	9W	"	"		33.26	
80	30	31N	9W	"	"		22.46	
81	30	31N	9W	"	"		21.18	
82	30	31N	9W	"	"		28.22	
83	30	31N	9W	"	"		24.93	
84	30	31N	9W	"	"		30.16	
85	30	31N	9W	"	"		24.73	
86	30	31N	9W	"	"		29.81	
87	10	21N	7E	King	1 gal.		33.51	Exposed in Green N. canyon
88	10	21N	7E	"	1 "		20.13	"
89	9	21N	7E	"	1 "		23.01	"

Location		County	Yield of Oil	Ammonium Sulphate	Notes
Sample No.	T. R.	Yield of Oil	Ammonium Sulphate	Notes	
		Gals. per ton	Lbs. per short ton		
90	21N: 7E	King	3 gals.	8.27	Exposed in canyon of Green River.
91	21N: 7E	"	Negative	18.07	"
92	21N: 7E	"	2 gals.	12.92	"





AREAL GEOLOGY OF THE LUMING AREA

ASSAM - NORTHEAST INDIA

LEGEND

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|--|---|
| <ul style="list-style-type: none"> FOSSIL WOOD GROUP LUMING SHALE LANGTING SERIES NORTH CACHAR SANDSTONE | <ul style="list-style-type: none"> NORTH CACHAR SHALE NUMMULITIC GROUP CRETACEOUS IGNEOUS AND METAMORPHIC |
|--|---|