THE GEOLOGY OF INDIAN COAL.

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If you look up two of the recent leading text-books on coal in general you will find that in one case it is recorded that the 'Indian Ocean' group of coalfields (including China, India, Australia and South Africa) 'are known to date from Upper Carboniferous times, although Permian coals are also known' whilst in the second text-book it is stated 'The coals of India are of earlier (Triassic) formation than the coals of Great Britain'.

In so far as India is concerned, it may be safely stated that the Gondwana coals of economic importance are all of Permian age; they are located almost wholly in the peninsula. But in addition, mainly in the mountainous tracts lying north of the peninsula, India possesses important deposits of Tertiary coal all of which belongs to the lower Tertiary (Eocene).

Past geological literature also refers to deposits of Jurassic coal in Cutch and in the Salt Range area of the Punjab. Local occurrences of lignified wood and inferior coal are certainly met with in the variegated stage of the Jurassic of these areas and the coal has, in the past, been excavated on a very small scale near Kalabagh. But the amount available is very small and analyses have shown it to be of poor quality. Mr. R. R. Simpson, in his account of the coalfields in India, published in 1913 (see *Mem. Geol. Surv. Ind.*, Vol. 41, p. 7), refers also to Cretaceous coal in Assam but more recent work by the Geological Survey of India in that area renders it probable that the latter are of lower Tertiary (Eocene) age.

The coal-bearing strata of India, within which coal of economic importance exists, may therefore be classified under two main heads—the Gondwana (Permian) measures and the Tertiary measures.

For a detailed account of the Gondwana coal measures of India, I would refer you to Dr. Fox's memoir on that subject [*Mem. Geol. Surv. Ind.*, Vol. 59, (1934)].

Briefly, these coal measures and associated strata, all of which belong to the lower part of the Gondwana system, include in the main typical fresh-water deposits which were laid down in wide river valleys and lakes that traversed the Gondwana continent during Permian and later times. The stratigraphical sequence involved includes:—

Raniganj field.	Jharia field.	Central and southern fields.
	(Panchet series)	
Raniganj coal measures		Kamthi series
Ironstone Shales	Barren measures	,, (?)
	Barakar coal measures.	
	(Talchir series.)	
	[Archaean and pre-Cambrian basement.]	

There is good reason to suppose that the whole of peninsular India and probably its extension northwards into what is now the site of the Outer Himalayas, at least for some distance east of Nepal, formed an ancient land-mass during the early and mid-Palaeozoic period. To the north and north-west an extensive sea—the Tethys—existed, and into this sea a number of large rivers, draining in a general northerly direction, carried much of the sediment derived from the Indian portion of Gondwanaland. This sediment went to form the fossiliferous marine Palaeozoic strata now met with in the inner parts of the Himalayan, Hindu Kush, and more northern ranges, and also in the Salt Range and in Baluchistan.

With the continued denudation of Gondwanaland to the south, this ancient land-mass was cut up into a series of wide valleys and lowland tracts and in these the fresh-water Gondwana strata were deposited. Climatic conditions were apparently frigid during the latter part of the Carboniferous period so that the upland regions separating the low-lying areas were of sufficient altitude to support large ice-caps—the source of the glacial and fluvio-glacial conglomerates of early Talchir times, which form the basal strata of the Gondwana system in India. With a change to a warmer climate, vegetation of the type now represented in our coal seams and in the well-known *Glossopteris* flora commenced to flourish on this ancient continent and spread rapidly with the progress of time. As a result, during the early Permian, immense volumes of decaying vegetation were incorporated in the sand, gravel and clay debris that was eroded from higher levels, and these sediments were deposited overlying the Talchir strata in a number of the valley areas of Gondwanaland. These lower Permian sediments including the accumulations of vegetation are represented in the Barakar coal measures as met with today. They comprise some 2,000 feet of felspathic sandstones, conglomerates, clays including fireclays, occasional ironstones and the majority of India's most important coal seams. In most of the areas of deposition, seams of coal were probably included but, as may be well imagined from the varying nature of the conditions under which deposition took place, the thicknesses of the individual beds varied considerably from place to place.

Regarding the conditions of formations, nowhere in India do we find definite evidence of a coal seam having been formed *in situ* as a result of the coalification of an ancient forest; on the other hand, there is plenty of evidence

pointing to the drift theory of formation and it seems probable that, in at least the great majority of cases, the coal has been formed from accumulations of drift vegetation, carried down by the rivers and deposited in wide, low-lying areas of sluggish drainage.

In the case of the greater part of the area in question, conditions suitable for the accumulation of vegetable debris, to a sufficiently large extent to give rise to coal seams of workable thickness, ceased at the end of Barakar times and the succeeding strata include only sandstones, shales and ironstones.

In the eastern part of the present Damodar valley region, however, a sequence of 'barren measures'—some 2,000 feet in thickness—was succeeded during Upper Permian times by a second series of coal-bearing strata, now represented by the Raniganj coal measures of the Raniganj and Jharia fields.

Following the deposition of higher Gondwana strata—sandstones, clays and conglomerates, including plant-remains in many places—the Gondwana deposits of the Indian peninsula were dissected by numerous faults, in most cases of the normal type, during late Mesozoic times. These faults varied in throw up to several thousand feet in a number of instances, displacements of at least 9,000 and 5,000 feet limiting the Raniganj and Jharia fields respectively on the south side. As a result of this faulting, masses of the Gondwana strata were dropped down within the older—Archaean and pre-Cambrian—rocks and were thus to a large extent preserved intact from the effects of sub-aerial erosion during the subsequent Tertiary era.

The Gondwana coalfields of India as we see them today, therefore, represent remnants of a coal-bearing sequence that was once much more widespread in its distribution.

In addition to faulting, the measures of the eastern part of the Damodar valley were intruded by a series of ultra-basic dykes and sills during the late Mesozoic. These in many instances played havoc with the coal seams, resulting in the large quantities of 'jhama' with which we are acquainted only too well today. A closely associated series of doleritic and basaltic dykes and sills were also intruded into the strata of peninsular India during late Mesozoic times. These intrusions, fortunately, had only a relatively limited effect on the coal seams.

The stage of maturity reached by the Gondwana coals varies from matured bituminous in the case of the Barakar seams of certain of the western Damodar valley areas to less matured bituminous and sub-bituminous types in other areas and in the case of the Raniganj coal measures.

The peninsular fields were apparently little affected by the intense earth-movements that gave rise to the Himalayan and related mountain ranges during late Tertiary times, but the extreme north-eastern part of the Indian portion of Gondwanaland was caught up in these movements, resulting in the sheared, coal-bearing Gondwana strata of the Daling field and adjoining areas.

As mentioned above, during a large part of the Palaeozoic and during the Mesozoic era the area north and north-west of Gondwanaland was submerged beneath a sea—named the 'Tethys'—which stretched eastwards from Europe *via* Persia and Baluchistan and continued further east into the Shan States. The southern edge of this sea, during intervals of the Triassic and Jurassic periods, lay in the vicinity of what is now the Salt Range and Trans-Indus Ranges of the western Punjab. As a result, in these regions the sediments deposited included not only marine fossiliferous strata but also sandstones and shales of estuarine origin. Among these strata are to be found lignified fossil-wood, occasional pockets of coal and definite seams of coaly shale which pass locally into bands of impure coal. But none, so far, have proved of economic significance.

Towards the end of the Mesozoic, a large part of north-western India including the western Punjab and southern Kashmir was uplifted above sea-level. This newly-formed land-area was in places eroded and, under the influence of sub-aerial weathering, a well-marked bed of bauxite and laterite was formed in a number of localities. The latter marks the time interval between the Mesozoic and Tertiary eras. Closely associated with this laterite during early Eocene (Ranikot) times, in the area west of the Indus river beyond Kalabagh, the Makarwal coal seam was formed. Immediately following these events in the early Eocene, the sea again encroached across this northern India tract resulting in the deposition of foraminiferal limestones, marls, shales and subordinate sandstones of variable thickness. Local, though in places fairly widespread, estuarine and marsh conditions once again broke into this marine sequence and resulted in the formation during late Ranikot and possibly lower Laki times, of the thin lignitic coal seam of the Salt Range and of Baluchistan and the thicker coal deposits of Jammu province, Kashmir, whilst in addition the lignites of Palana, Bikanir State, were laid down. That these coals were, in many cases, deposited in areas very close to the sea-coast (in contrast to the Gondwana coal seams) is evidenced by the close association of foraminifera-bearing shales with the carbonaceous beds.

In all these areas, during the succeeding stages of the Eocene, marine conditions prevailed during which thick limestone and shale deposits were laid down.

Late in the Eocene, the area in question was again largely uplifted above sea-level and, following a short period of erosion, the older strata were covered during middle and late Tertiary times by the vast thicknesses of lacustrine, fresh-water sandstones, clays and conglomerates of Nimadric (Murree and Siwalik) system.

Late Tertiary to sub-Recent earth-movements of organic type, culminating in the formation of the Himalayan, Sulaiman and associated ranges of northern and north-western India, together with the effects of rapid denudation, exposed the lower Tertiary and older strata as we see them today.

Turning to Assam, the geological evidence indicates that at least the western parts of that province formed a portion of Gondwanaland until Cretaceous times. During a part of the Cretaceous, the Tethys—or a branch of that sea—encroached across this north-eastern portion of the Indian Gondwana continent and marine sediments were deposited, remnants of which are seen in the southern outcrops of the Assam plateau.

As in northern India, uplift then recurred and the Mesozoic-Tertiary interval was marked by erosion and the local formation of lateritic deposits on the exposed land surface. Again, as in northern India, coal-forming conditions immediately succeeded during lower Eocene (Ranikot) times in the Garo and Khasi hill areas and resulted in the formation of several seams of lignite, two of which are of definite economic importance. It was these seams which were previously regarded as of Cretaceous age but Dr. Fox, to whom I am indebted for the recent observations here recorded regarding the Assam coal measures, is of the opinion that they are all post-Cretaceous in age.

Marine conditions followed, in south-western Assam, giving rise to the foraminiferal Sylhet limestone stage during later Eocene times. This limestone stage includes bands of sandstone with carbonaceous horizons and the latter locally thicken to a 4- to 5-foot seam of coal, now worked near Cherrapunji.

In Upper Assam, estuarine conditions prevailed during middle and upper Eocene times and gave rise to the important coal measures of the Ledo, Makum and adjoining areas. Several coal seams, lignitic and relatively high in sulphur, of an individual thickness of as much as 40 feet in places, were formed.

Following a break in sedimentation during the Oligocene, sedimentary deposition again set in during the middle and upper Tertiary resulting in an immense thickness of sandstone and shale strata.

Towards the end of the Tertiary era, the above-mentioned orogenic movements that affected the whole of northern Indian and adjoining tracts, caused the uplift, folding and faulting of the Assam area also and, combined with the effects of denudation, the coal measures were exposed along the southern and south-western parts of the plateau and in the Upper Assam region.

In most instances, these Eocene coals of India have not matured beyond the lignitic stage, but in parts of southern Kashmir, where the tectonic forces were locally more intense, semi-anthracitic coals have resulted.