FOURTEENTH
SIR ALBERT CHARLES SEWARD MEMORIAL LECTURE
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SOME RECENT ADVANCES IN THE GEOLOGICAL STUDIES OF COAL-BEARING FORMATIONS OF INDIA & COAL RESOURCES

BY

A. G. JHINGRAN
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Delhi University, Delhi
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By A. G. JHINGRAN

I FEEL very privileged to be called upon to give a lecture that has been named after the great scientist, Sir Albert Charles Seward, who attained outstanding success not only as a scientist but also as a teacher, an author and an administrator. His passion for scientific studies knew no bounds. The fields that attracted his attention included both botany and geology. Palaeobotany was his special love and he studied in detail the Mesozoic flora, his results being incorporated in a series of Catalogues of the British Museum between the years 1894 and 1904. His book entitled ' Fossil Plants ' in four volumes is classical and will continue to remain a treatise of reference for many years. Another well known book by him is the ' Plant Life Through Ages ', which is also unimitable and has won highest reputation. During the long years of his devoted career he guided many students, several of whom attained distinctions as men of science in their own turn. Perhaps the most brilliant amongst them was Dr. Birbal Sahni, who earned the reputation of being the builder of Indian Botany and Palaeobotany. Walking in the foot-steps of his teacher, Professor Sahni followed a life of selfless devotion, dedicating every ounce of his energy, every moment of his life and every bit of his resources to the one single task, advancement of knowledge. One of the fruits of his endless devotion is this Institute of Palaeobotany. It was a cruel hand of destiny that snatched away this great scholar and man, soon after the foundation of the Institute was laid. It must, however, go to the credit of the family that Sm. Savitri Sahni, wife of the Professor, took up the challenge and successfully nursed the baby Institute so well. Warding it off from the teething troubles and several critical situations, she has made it grow into a healthy blossoming institute which has already earned a reputation all over the world.

We have gathered here to pay an humble tribute to the sacred memory of the great doyen, Sir Albert Charles Seward. I take the liberty of mentioning the name of Dr. Birbal Sahni also on this occasion for it was that master-mind which conceived the idea of the Institute whose hospitality we are enjoying today. These two great doyens, Seward and Sahni, shall continue to brighten the firmament of science for all times. Their spirit of devotion shall continue to inspire the seekers of truth for generations and generations. The high standards of selfless work that they set will continue to be in the realm of envy for long ages.

INTRODUCTION

The subject I have selected for my address this evening embraces some recent advances made in our knowledge of the geology of the coal-bearing formations of India and the economic evaluation of coal resources. In this connection it may be recalled that, even though it may have been circumstantial, the pride of first place for commencement of studies in modern times in Indian Geology goes to coal. Faced with the problem of having to bring coal all the way from England even for the return voyage from India to England, the East India Company appointed a British officer who had experience of the English coal-fields, in the middle of the nineteenth century and assigned him the task of locating sources of coal in the Indian sub-continent. It was in fact that incipient beginning of geological exploration that laid the foundation of the Geological Survey of India which has grown into a large Institution, as we see it today. Pioneer work done by Williams, Oldham, Blanford, Ball, Hughes, Feistmantel, Mallet, and Medlicott and many others helped to form the solid base of our knowledge of this branch of Indian Geology. Subsequently stalwarts like Fermor, Das Gupta, Birbal Sahni, Fox, Gee and several others carried forward the studies, revised wherever necessary and collected much new data. These studies embraced various aspects such as the correlation, classification and economic evaluation of the coal seams, climatology, paleogeography and physiography, and of course the flora and fauna of those times when the coal seams were laid. The knowledge available up to the late twenties of this century was ably culled together by Sir Cyril Fox in his series of Memoirs on Indian coal-fields. A good summary of the work done upto early forties of this century is given in Bulletin No.16 of the Geological Survey of India by E. R. Gee (1945)*.

In the post-Independence period an ambitious programme of detailed investigations, including revision of geological map in many cases, coupled with extensive drilling and laboratory studies covering palynology and sedimentology has been undertaken by the Geological Survey of India. Additional teams of scientists from the recently started sister organizations like the Indian Bureau of Mines and the National Coal Development Corporation, reinforced the tempo of investigations. The purpose of this work has been primarily economic and was devoted towards the location of fresh coal resources, specially of grades suitable for production of metallurgical coke and good quality blendable coal so as to augment the coking coal potentiality of the country. Scientists working in specialised Institutions like the Fuel Research Institute and Birbal Sahni Institute of Paleobotany and Universities have carried out specialized studies. Some of these are directed towards the understanding of the fundamentals of the property of coking and whether or not the non-coking coal could be converted into the coking type, as also to determine the optimum ratio in which the various coking and non-coking coals could be blended together for use in metallurgical works.

The regional exploration carried out by the Geological Survey of India has yielded much new data. The bulk of the information so obtained still remains to be processed and analysed before the full significance is brought out. Several new ideas have, however, come up. I propose to deal with only the salient features of advancement in our knowledge about the geology of the coal-bearing formations, both from academic and commercial points of view.

LOWER AGE LIMIT OF THE GONDWANAS

An important controversial aspect of the Gondwana stratigraphy is its lower age limit, i.e. the age of the Talchirs which form the basal series of the Gondwana system and comprise of Boulder-bed at the bottom, overlain by khaki green shales

*Reprinted 1947.

and sandstones. The earliest reference to the age of these beds is that given by Feistmantel[13] who grouped them along with Damudas and Panchets as the Lower Gondwana system and assigned a Triassic age. Soon after the discovery of Lower Gondwana plants associated with marine fossils in Kashmir[35] and Salt range[51], a controversy developed regarding the age of Lower Gondwanas which continued for several years, until the eminent palaeontologists like Noetling[35], Koken[29] and others admitted a Palaeozoic age for the Talchir strata. H. B. Medlicott and W. T. Blanford[32] assigned them a Permian age, but R. D. Oldham[36] regarded them to be of Upper Carboniferous age. G. de P. Cotter[10] and C. S. Fox[14] agreed with the latter view and so did Thomas Holland[20] who discussed the problem at great length. Since then, this view has been followed in most of the literature and Text Books on Indian geology although at one stage Vredenburg[65] had opined them to be of Permian age.

The discovery of marine beds associated with the Lower Gondwanas at Umaria, Manendragarh, Bap and, very recently, Rajhara in Peninsular India and their faunal studies have thrown new light on this problem. The fauna from Umaria was originally described by Reed[50] and was later restudied by Thomas[62]. The latter has opined that it has a close affinity with the fauna from the Lyons Group of the Carnavon Basin and assigned it a Lower Permian age. Ahmad and Ahmad[4] have discussed the age of the Gondwana glaciation in detail and have also assigned a Permian age to the basal tillites on the basis of stratigraphic and palaeontologic records. Recently, Sastry and Shah[57] have studied the marine fossils from these horizons and have expressed the opinion that the Talchirs are of Permian age. Gopal Singh and Sastry[18] have discussed the bearing of palynological studies on age of Talchirs and have suggested a Permian age for the shales and sandstones overlying the boulder bed. It thus appears that the overall evidence is more in favour of the lower limit of Gondwana System being placed at Permian.

PERMIAN COAL-BEARING FORMATIONS

Karharbari Stage

The coal-bearing formations of the Permian age are well known in the Indian stratigraphy as the Damuda Series of the Lower Gondwana system, there being three principal horizons, the Karharbari, Barakar and Raniganj stages which together account for more than 90 per cent of the coal produced in the country. Of these, Karharbaris form the basal unit. Until recently this stage had been recognized only in a few fields, the most important being the Giridih which provided the type area. Quite often doubt had been expressed if there was adequate justification to recognize this stage as a separate stratigraphic unit and opinions differed considerably about its position, some authors being inclined to regard it as the uppermost part of the Talchir Series, while others were inclined to treat it as a part and parcel of the Barakar stage within the Damudas.

It may be recalled that the term Karharbari stage was originally introduced by Blanford in 1878 while mapping the Giridih coalfield, the stage being characterized by plant fossils, *Gondwanidium validum* and *Buriadia sewardi* which distinguish this stage from both Damudas as well as Talchirs. Further, the megafossil assemblage is also characterized by the abundance of two genera namely, *Gangamopteris* and *Noeggerathiopsis* a fact which was considered by the great palaeobotanist, Feistmantel, in recognizing this stage in other coalfields. His observations had suggested a closer floral affinity of these beds with the Talchirs rather than the succeeding Damudas.

Recent studies[18,31,34,41,43] have greatly added to our information on the floral contents of the Karharbari stage. It is noted that the assemblage is characteristically dominated by certain monosaccate spores, of which two genera, namely *Virkkipollenites* and *Plicatipollenites* are common; subordinate forms include pteridophytic triletes and gymonospermic bisaccate pollen grains. A comparison of the flora, both *mega* and *micro* forms of the Talchirs, Karharbaris and Barakars, brings out the following essential points:

Mega Flora

1. The genera *Gangamopteris* and *Noeggerathiopsis* are abundant in both Talchirs and Karharbaris, but decline in the Barakars.

2. Almost all the Talchir forms are present in Karharbaris, while some of the Barakar forms are absent in Karharbaris such as the following:

Phyllotheca griesbachi, Dadoxylon indicum, D. bengalense, Sphenophyllum speciousum, Pseudoctenis balli, Taeniopteris danaeoides, T. feddeni, T. mclellandi, Barakaria dichotoma, Glossopteris retifera.

Micro Flora

3. All the Talchir forms are also known from the Karharbaris, the dominant forms being *Virkkipollenites* and *Plicatipollenites*.

4. Some new forms appear for the first time in the Karharbaris; these include:

Eupunctatisporites, Parasaccites, Crucisaccites, Barakarites, Lahirites, Rhizomospora, Platysaccus, cf. Crustisporites, Tetrasaccus, Welwitschiapites, etc.

5. The monosaccate spores which are very abundant in both Talchirs and Karharbaris become extremely subordinate in the Barakars.

Thus on the basis of the floral studies there seems to be enough justification for regarding the Karharbaris as a distinct stage with greater affinity to the underlying Talchirs than the overlying Damudas and Gopal Singh and Sastry[18] as also Khan and Gopal Singh[27] have advocated the grouping of Karharbaris with the Talchirs.

In this connection however, it may be pointed out that in respect of the occurrence of coal seams, the Karharbaris show a marked similarity to Barakars than to Talchirs, the latter being devoid of coal. Since the succession from the Talchirs to Barakars through the Karharbaris is not attended to by any major break in sedimentation, and that there is a greater climatological similarity between the Karharbaris and Barakars, both being characterized by abundance of vegetation coupled with favourable conditions for formation of coal, it would be more reasonable to treat the Karharbaris as the basal bed of the Damudas. I personally strongly favour the idea that grouping of series should be determined primarily by breaks in the process of sedimentation and changes in palaeogeographic and palaeoclimatic conditions.

Mapping coupled with drilling and detailed palynological studies of the cores obtained have established the definite existence of Karharbari horizon in most of the Damodar Valley fields, the Koel valley, the Mohpani valley, the Singrauli field in Madhya Pradesh and the Talchir field in Orissa.

The quality of coal met with in the Karharbari stage has also been found to be somewhat distinctive, being characterized by low-ash and high fusain. It is also comparatively dull in appearance as compared to the coals from the Barakar stage. The associated rocks are usually arkose to sub-graywacke in character and bear heterogenous rocks fragments, somewhat resembling the Talchirs.

These studies thus reveal that the basal coal-bearing beds in many of the coalfields like Jharia, Talchir, Daltonganj, Karanpura, Hasdo-Arand, Bisrampur, Lakhanpur, etc. which were formerly considered to belong to Barakar stage are actually referable to the Karharbari stage. Keeping in view its economic importance, a thorough search for this horizon is called for in other coalfields. It is worthwhile in this connection to examine closely the basal portions of the Barakars and conduct systematic palaeobotanical studies. Examination of drill cores, wherever cases of overlap are suspected, will be very useful. Undoubtedly these wide-spread occurrences of Karharbaris have an important bearing on inter-basin correlation in the Gondwana stratigraphy all over the southern hemisphere.

Barakar Stage

The Barakar stage which succeeds the Karharbaris forms, of course the most important coal-bearing horizon in the Gondwanas. It has also a much wider geographical distribution. Accordingly this stage has attracted attention of a large number of workers. The Barakar flora comprise the Glossopteridae, Equisetales, Filicales, Sphenophyllales and Cordaitales along with a few cycads and conifers. In recent years the detailed study on the *Sporae dispersae* from this stage is indicative of the fact that the flora was much more diversified than what had been realized previously on the basis of megafossil record. The Barakar microflora is quite distinguishable from that of the underlying Karharbaris, being more diversified and having a much larger number of genera of triletes and disaccate spores, many forms being completely absent in the Karharbaris including triletes, monosaccates, disaccates, etc.[7,31]

Within the Barakar stage itself the microflora of the upper Barakars shows a greater resemblance to that of the Barren Measures than the microflora of the Lower Barakars[64].

The discovery of *Glossopteris* in Kameng division, NEFA[21] has proved the existence of undoubted fresh-water Gondwanas, in that distant north-eastern part of the sub-continent. A little further to the east in Subansiri division Sahni and Srivastava[56] established the presence of beds bearing marine fossils including *Eurydesma* and *Conularia* in close association with the fresh water Gondwanas indicating a marine transgression in the Permo-Carboniferous period.

An attempt is being made in the Geological Survey of India to utilize the palynological studies in correlation of coal seams both within a single field as also in different basins, with some success. It is expected that in course of time this may become one of the most successful methods for this kind of work.

Raniganj Stage

Raniganj, next to Barakars, is an important coal-bearing stage, and has been studied in much detail. Workable coal seams associated with this stage have been found only in the Raniganj, Jharia and Karanpura coalfields, although its presence had been proved in several other Gondwana basins. Palaeontologically this stage is of considerable importance as the Glossopteris flora attained maximum development during this period and as such largest number of genera and species are recorded from these beds. The occurrence of miospore *Gondisporites* indicates the presence of Lycopodiales, which has been hitherto unknown by megafossil record from this horizon[6].

Recent studies by A. M. Khan and Gopal Singh[26] in the Geological Survey of India have proved the existence of Raniganj horizon in the western part of the Talchir coalfield. Initially these beds in Talchir area had been taken to be a part of the Mahadevas, and later were suspected to be of Panchet age. The present study has confirmed the Raniganj age for them, which is incidentally a corroboration of an earlier assumption of Fox about the presence of Raniganj stage, southeast-wards from Chhatisgarh towards Mahanadi, in the direction of Talchir coalfield in Orissa.

Sedimentological Studies

Sedimentological studies of the Gondwana rocks have been commenced in recent years only. Ganju and Srivastava[16] studied the Talchir Boulder Beds of the Jharia coalfield with special reference to the fabric of the pebbles that constitute it. The study shows that the pebbles are preferentially oriented and exhibit an upstream imbrication. The inclination is of the same order of magnitude as determined by Cailleux for fluvial gravels. The streams that deposited these ancient gravels came from westerly and northwesterly directions, in general. The source of the debris was the moraine material left by the melting glaciers, and the debris was transported east and southeast-ward by fast flowing streams into the basin of deposition.

K. Jacob, assisted by S. K. Ramaswamy, S. R. A. Rizvi and A. Krishnamurthy[22,23,48] carried out detailed sedimentological studies on the Gondwana rocks in the Damodar Valley between 1957 and 1961. The work in the coalfields of Jharia, East and West Bokaro, part of North Karanpura, Auranga, Hutar and Daltonganj, stretching for about 300 km. from east to west, was carried out on the following lines:

1. Large scale geological mapping, where necessary.
2. Measurement of the nala sections in the coalfields with a view to compile stratigraphic sequence based on actual thickness of the sediments.
3. Classification of the sediments in the field into easily recognizable units and preparation of lithofacies maps.
4. Preparation of isopach maps based on measured thickness for interpretation of the structures in the basins.
5. Study of structural aspects especially faults and their effects on the adjoining basins.
6. Collection of specimens from different lithological units for petrological examination, mechanical and heavy mineral analyses for provenance and the nature of depositional environments.

A very large amount of data has been obtained both from the field and laboratory studies. Emphasis on economic work of higher priority has, however, prevented the completion of scrutiny of the data and their systematic studies, which is still in progress. The tentative conclusions arrived at indicate that:

(a) The total thickness of the preserved sediments increases towards east from Hutar to Jharia.

(b) The sorting coefficient of the sediments does not show any marked lateral change.

(c) Garnets are dominant, in general, in the Talchirs; zircon ratio fluctuates; tourmaline is an important constituent in the Barakars in the eastern coalfield but it becomes subordinate in the western fields. Opaque ores increase generally in the younger strata.

(d) Majority of the faults in these fields are of post-Mahadeva age, a minor set of pre-Mahadeva age is also distinguishable towards the western coalfields. All the faults are of normal gravity type. Continuation of some of the major faults in adjoining basins is common.

(e) Stratigraphical correlation and clastic ratios point that these coalfields were possibly once joined together and had a dominant westerly source for their sediments, though material from local sources was also available.

Similar studies have been carried out by Rizvi[52] in the Giridih coalfield and the area between the Giridih field and the western part of the Jainti field of Deogarh group, covering an area of 600 km. A large number of faults and fault-zones have been mapped. The study tends to indicate that the sedimentation was not bounded by any tectonic structures. The faults are normal gravity type and occurred in the post-Barakar and pre-dolerite period. Certain parts of the basin were sinking contemporaneously with the sedimentation and that the remnants of the deepest points of the basin are the original sagged spots, which were preserved by Barakar faulting.

Kar and his colleagues[24] have attempted to make detailed studies in Bokaro, Karanpura and Ramgarh coalfields, which indicate that the earlier concept of the cyclic sedimentation involving a repetition of sandstone-shale-coal sequences is not tenable in most of the cases. In fact it is found to be more of an exception than a rule in the Gondwana basins. On the basis of result obtained from drilling in Bokaro and adjacent coalfields it has become possible to classify the Barakar-Barren Measures sequence into five distinct stratigraphic sub-units as follows:

(e) Barren Measures.
(d) Upper Barakar — dominantly argillaceous.
(c) Middle Barakar — with higher shale-ratio than in the underlying horizon.
(b) Lower Barakar — mostly coarse unit with subordinate coal seams.
(a) Basal zone, barren of coal seams.

The fluviatile origin of the bulk of the Gondwana sediments has been indicated by numerous features which characterize these sediments such as cross stratification, thick to massive lenticular bedding, numerous conglomerate horizons, channel fills and poor to moderately sorted nature of the deposits. An additional evidence in this direction is the frequent presence of two contrasted types of sediments in juxtaposition with each other, there being lenses of coarse sand embedded in a matrix of fine grained sediments.

A study of heavy mineral assemblages in the sediments from East and West Bokaro, and North Karanpura coalfields has shown a very close correspondence to each other which is suggestive of the three fields having been parts of the same master basin in the Lower Gondwana times[25].

MARINE TRANSGRESSIONS

The discovery of marine beds in conjunction with the otherwise fluviatile formations of the Gondwana System at Umaria in Madhya Pradesh by K. P. Sinor[60] has been hailed as one of great significance from the point of palaeogeographic studies and marine transgressions during that period. In recent times similar beds have been located at a number of other localities including Manendragarh[17] in Madhya Pradesh, Khemgaon[56] in Sikkim and Subansiri Valley in NEFA[56], Bap[32,58] in western Rajasthan and Daltonganj[11,59] in Bihar. It is, thus apparent that a much more extensive area was covered by the sea in the Peninsular India during the Permo-Carboniferous period than had been realized in the past.

Fermor, in appreciating the value of Sinor's discovery of the Umaria marine bed, had observed that the Umaria area was possibly connected by an arm of Permian sea from the Salt Range, i.e. the Himalayan Permian sea (see Fox, 1931, p. 235). Fox himself accepted this view and postulated a marine connection between Umaria and Salt Range across the Aravallis, the Ganga-Yamuna valley and Bundelkhand[14]. Krishnan[28], however, disagreed with this suggestion, mainly because the area involved forms mostly highland and shows no trace of any rocks younger than the Vindhyans, and suggested that the connection to sea to Umaria may have been through the Narbada Valley, Kutch and Western Rajasthan.

Ahmad[1,2,3], on the other hand, is of the opinion that the marine connection was possibly from the south-east. Focussing attention to the work done by Thomas[62] and Thomas and Dickins[63] on comparison between the fauna of Umaria and that of Lyons group of N.W. basin in Western Australia, wherein they established close similarity between the two, Ahmad has suggested that the logical corrolary is the existence of a marine link between the two areas. Of particular interest in this connection is the occurrence of *Calciospongia* in Umaria, known so far only from the Australian Permian. This peculiar crinoid, is stated to provide a unique link between the Indian and Australian Permians. In coming to the conclusion Ahmad has also been guided by the geographical extent of the Umaria marine horizon, wherein he thinks there is enough field evidence to show that the Umaria marine bed did not extend either to the north or the west, there being extensive transgression by the immediately overlying fresh water beds in both these directions.

Sastry and Shah[57] have given another alternative in which it has been postulated that on the western side Umaria was connected with the main Tethyan sea either straight southwest from Salt Range or by way of Rajasthan through the Narbada valley, and that on the eastern side directly to the eastern Himalaya in Sikkim and NEFA. Through a comparative study of the fauna from these various localities they have brought out some interesting points which are summarized below:

1. The Umaria fauna is rich in Productids whereas that at Manendragarh is rich in Eurydesmids.
2. The fauna at Bap in western Rajasthan resembles that at Umaria and the Conularia beds of Salt Range.
3. The Manendragarh fauna offers greater resemblance to the fauna from the Bihar (Daltonganj) and Sikkim (Khemgaon) localities.

Since Eurydesmids indicate cold water conditions and the Productids are favoured by warmer waters, M. V. A. Sastry and S. C. Shah[57] have postulated that the incursions of sea represented by the marine beds at Umaria, and Bap on the one hand and Manendragarh, Daltonganj, Khemgaon on the other were different and not identical. On the basis of stratigraphic and faunal studies they have concluded that Umaria and Bap beds represent an Upper Talchir transgression, whereas Manendragarh, Daltonganj, and Khemgaon beds correspond to a transgression in Lower Talchir times. This proposal implies that a very narrow arm of sea penetrated into the continental massif over a distance of about 600 km. in the Lower Talchir time, at the end of which it retracted and another arm of the sea penetrated into the continent on the western side over a distance of about 800 to 1000 km. and that the narrow ledge between Umaria and Manendragarh formed a sort of buffer beyond which none of the two incursions proceeded.

The above proposition is plausible, though somewhat difficult to understand. It is not at all clear as to why the incursions of sea coming from east and west stopped at points in close proximity to each other, when the area falling between these two places also forms a part of the Gondwana basin and as such cannot be regarded to have acted as a horst block which checked the onward transgression of the sea. Furthermore, recent geophysical work by the Oil and Natural Gas Commission, confirmed by drilling in eastern Bihar has indicated that the Rajmahal basin did not extend beyond about west of Purnea district and apparently does not contain marine horizons.

As an alternative to the hypothesis of such narrow arms of sea penetrating deep into the continent, I venture to suggest that the entire area enclosed between Sastry and Shah's arms of sea was subjected to the encroachment of the Tethyan sea for at least sometime in the Permian, and that the sedimentary record left thereby has been mostly denuded away, leaving only sporadic left-outs here and there. It may be noted that it is only in recent years that marine beds have been discovered in these far flung localities. It may certainly not be the end of such finds. It is significant that the western and north-western tips of the major Gondwana basins abut against the southern margin of the postulated extension of the Tethys. The comparative cold water condition indicated by the Eurydesmids at Manendragarh and Daltonganj etc. is apparently connected with the glacial conditions that prevailed around that time. The record of corresponding beds along the western part of the postulated extension of the sea has so far not been located, but may well be expected at some place or the other. A careful search is indicated and is worth being pursued. In this connection it may also be recalled that a sequence of marine beds characterized by the Productids, the Productus shales, have long been recognized in the Garhwal and Kumaon Himalaya, which would fall within the limits of the sea suggested above. A careful and detailed study of the geographical distribution of the various horizons in Talchirs and the succeeding Damuda beds in all the Gondwana basins would be useful for better understanding of palaeogeographic conditions of Permian times. So far as the extension of the arm of the sea in the south-eastern direction is concerned, as suggested by Ahmad, I have nothing to say against it. It is not unlikely that the sea did encroach from that direction also. But I would certainly like to emphasise on the significance of the presence of marine beds bearing Productids in Kumaon Himalayas in the north and the Umaria and other associated localities in the south. The intervening areas have not provided so far any positive evidence of marine conditions during that period. But absence of evidence is really no evidence. Wait and see. Future work may establish fresh localities with marine beds in the area involved.

STUDIES IN COAL PETROLOGY

In recent years much emphasis has been laid on studies in coal petrology and considerable work has been done by several workers including Pareek, Pant, Sanyal and others. Data has been obtained with regard to the nature of the plants that have gone into the making of the coal as also on the nature of coal itself. This has been utilized successfully in seam identification and is also helpful in predicting the economic evaluation of coal.

Microstructural Details of the Coal-forming Plants

Petrological studies on the Karharbari coals[42] from North Karanpura have indicated that the vitrinized tissues have undergone considerable disintegration and appear as fragments with ill-preserved microstructural details. In the Barakar coals of the Damodar valley[42] the decay and disintegration is to a limited extent and the vitrinized tissues are seen in large masses that form lenticular sheets and show certain well preserved details. In the Barakar coals of other basins the disintegration seems to be more advanced and vitrinized tissues are not common[39,46,47]. In the Raniganj coals the vitrinized cellular tissues are common and exhibit well preserved details.

The microstructures recognized in these vitrinized tissues are mainly of secondary wood material, occasionally being of bark. The cell lumen is occupied either by yellowish resinous matter or by fine granular opaque substance similar to micrinite or even a clayey substance. The medullary rays recorded are up to twelve cells height. Fusinized tissues of wood are common in all the coals and exhibit features suggestive of their derivation from secondary wood. This data suggests that a gymnospermous flora, mostly cordaitales, existed during the Damuda period[39,42]. Some of the woody tissues and pith recorded by Pant[37] from Raniganj coal have been related to the form genus *Dadoxylon*.

Details about the nature of megaspores and microsporangia have also been obtained from the study of surface sections. They are found to vary considerably in thickness and the nature of ornamentation, and on this basis they have been classified into a number of types and sub-types[42]. The relative abundance of the different types of megaspores has been found to be a dependable criterion in fixing marker horizons[44] and thereby help in correlating coal seams.

The megaspore exines have been observed to exhibit cell structure, varying from one to three cells in thickness. In the Talchir coals, a microsporangium showing transformation of 'daughter cells' into 'mother cells' has been recorded for the first time in any Indian coal[39].

Nature of Coal

Extensive petrological studies on coals from the various coalfields indicate that, in general, there is a marked difference between the coals from the Damodar valley fields and other fields, the former being distinctly banded, bright and abounding in vitrite and clarite[42]. The coals from the Satpura basins (Pench, Kanhan and Tawa) are markedly dull, indistinctly banded and microfragemental in nature and mainly comprise 'intermediates' (Duroclarite & Clarodurite)[17]. They occasionally contain vitrinite which locally imparts a banded pattern. The Son valley coals are also dull, microlaminated and microfragmental with durite and fusite as the common microlithotypes[43]. Those from the Mahanadi[38,39] and Godavari valleys[46] are dull, nonbanded to indistinctly banded and comprise durite, fusite and 'intermediates' in variable proportions. The amount of 'intermediates' is higher in the Mahanadi valley coals.

Fusinised resins are rare in the Barakar coals of the Damodar valley coalfields, whereas they are quite conspicuous in coals from other basins[45]. Their concentration at particular horizons in the seams makes them useful for correlation.

While on this subject it may be recalled that the Damodar valley coals are also distinctive in being coking type for the most part, the best coals being confined to Jharia and Raniganj fields. It appears that the coking property is attributable to the abundance of the microlithotypes vitrite and clarite, which fuse during carbonization. The size of the vitrinized tissues also appears to influence the development of coking character, the larger sizes being found more favourable for the property. It may be noted that whereas the tissues are of considerable size in coals from Damodar valley, they are usually microfragmental in the coals from other valleys.

The coals from the Pench, Kanhan and Tawa valleys have semi-coking tendency. Detailed petrological studies by Pareek (personal communication) have indicated that:

i) There is a rise in the proportion and thickness of vitrinite from Pench valley to Kanhan valley area,

ii) which is accompanied by proportionate decrease in the fusinite content, and

iii) marked increase in vitrinite and clarite content. These factors have obviously influenced the development of semi-coking nature.

That petrographic and chemical characters are related to each other needs no emphasis.

Bright coal is useful for metallurgical coke and the dull coal finds use in boilers of the locomotives, thermo-electric plants and other industries. Coal can be improved by changing its physical composition. Petrographic studies and practical experimentation have already established that blends of non-coking coals with strongly coking coals are useful in production of metallurgical coke which would help in increasing the life of the reserves of our coking coal.

The differences in the petrologic and chemical characters of coals would obviously be indicative of the varying conditions during the times of their formation and at least broad inferences can be drawn with regard to the salient physiographic features and attendant characters of the corresponding period. The following conclusions may be drawn from the present studies:

1. The Son valley basin was not connected to the Damodar valley basin, although there is a possibility of the Son valley being connected with the Mahanadi basin. Similarity in the characters of the coals from Son and Mahanadi valleys is strongly suggestive of such a link.

2. Conditions of vegetal deposition and of coal formation were similar in the Son, Mahanadi and Godavari valley basins, as compared to those in the Pench-Kanhan and Tawa valleys. The coals from the former are non-coking, whereas those from the latter areas are of semi-coking types.

ECONOMIC EVALUATION OF THE COAL-BEARING FORMATIONS

Prior to the commencement of extensive exploratory operation during the Plan periods, a fair knowledge on the resources in all the major coalfields of India was known. With the increase in coal output both in Public as well as in Private sectors as envisaged during the Third Plan period, additional resources of coal, specially of the kinds which would be used either directly as mined or after beneficiation, for coke manufacture had to be proved and more details about the known areas had to be obtained for drawing up future exploitation programme.

Important findings in this respect are as follows:

Raniganj Coalfield, West Bengal

Exploration in Raniganj field was aimed at proving the down-dip extension of the Barakar coal seams containing metallurgical grade coal and the proving of the extension of the coalfield in the eastern and north-eastern areas below the mantle of the alluvium. Drilling operations that have been carried out by the Geological Survey of India have been successful in both these spheres. The down-dip extension of the coal seams has been proved to depths of the order of 600 m. The limits of the coalfield have also been extended sizeably by proving the presence of coal seams under the laterite-alluvium cover at depths ranging between 180 and 250 m. The most important seam met with there is the Samla (Disergarh) seam which has a thickness of about 6 metres.

Jharia Coalfield, Bihar

Jharia coalfield is of special importance being the main store house of the 'parent coking' coal in India. Accordingly it was considered very necessary to explore this field intensively and check if additional resources of coking coal could be located there. An interesting enquiry that appeared worth being pursued in that direction was to drill deep enough and test if Barakar sequence is present at depth below the Barren Measures. Accordingly some deep drilling has been undertaken and there has been singular success in the experiment. In fact the entire Barakar sequence (from seam No. I to seam No. XVIII) has been proved in a single bore-hole about 10 km. south of Kirkend. On the recommendation of Geological Survey of India, the area is under detailed investigation and exploitation by National Coal Development Corporation.

Some very valuable data has further been furnished by recent drilling in Jharia coalfield with regard to the rate in fall of the volatile contents of coal with increasing depth. It has been found that this occurs at a rate of 0·9 per cent for every 30 metres of depth in the Central Jharia area and by 0·6 per cent for every 30 m. in the eastern and western areas. This is a very important finding as it would restrict the availability of metallurgical grade coal to specific depths and help in the prediction of grade.

East Bokaro Coalfield, Bihar

East Bokaro coalfield with seams of considerable thickness as well as of good quality has provided one of the richest store-houses of medium-coking, blendable coal. In all fifteen seams in the Barakar sequence have been proved, which include the 20 to 45 m. thick famous Kargali seam. On experimental basis it has been found that 60 per cent of the washed coal from the Kargali seam can be blended with 40 per cent of the Jharia coal for use in the Steel Plants.

West Bokaro Coalfield, Bihar

Recent detailed mapping aided by exploratory drilling in West Bokaro has proved the existence of thirteen regionally correlatable coal seams, of which the seams V, VI and VII are of prime importance as they contain coal of medium coking quality for metallurgical industries. On the basis of the work by the Geological Survey of India and the Indian Bureau of Mines, a few areas, namely Taping, Pundi and Kashikhap are proposed to be developed by the National Coal Development Corporation.

South Karanpura Coalfield, Bihar

Exploration in South Karanpura coalfield has recently been completed, and the maximum development by N.C.D.C. has also been done in this coalfield. The discovery of Argada seam (51 m.) in the Jainagar area is of great economic importance. Besides, a good quality Karharbari coal seam has also been located in the Argada Block (Argada "S" and "T" seams).

North Karanpura Coalfield, Bihar

Outside Jharia coalfield, the most encouraging results have been obtained in recent years in the North Karanpura coalfield, so far as the presence of metallurgical grade coal is concerned. Till now about 30 million tonnes (with larger potentialities) of this grade of coal have been proved in the Badam Block in this coalfield, where 11 seams have been located with a maximum thickness of 25·40 m. and Caking Index (BSS) up to 25. Of these a 16·0 m. thick seam with 21 per cent ash and a Caking Index of 15-17 will yield significant reserve of blendable coal of excellent quality. Drilling, which is being extended by the Geological Survey of India in the adjoining areas of this block is also indicating encouraging results.

Ramgarh Coalfield, Bihar

Exploration of Ramgarh coalfield has also been nearly completed. Large reserves of semi-coking coal, which are of blendable type have been proved in the basal four seams in the western part of this field. Medium coking coal has been proved in VII Top and VII Bottom and VIIIA seams in the eastern part of the field. The seams VII Top and VII Bottom, first discovered by the Geological Survey of India have an aggregate thickness of about 21 m. Coals from this field will be used as a matching blend with the Jharia and Kargali coals for the Bokaro Steel Plants.

Madhya Pradesh Coalfields

Exploratory drilling operations were conducted in all the major coalfields of M.P. In a number of areas the work has been completed and in a few others it is still being continued. In the Pench Kanhan-Tawa valley coalfield, so far 333 m. tonnes of good grade, blendable coal has been proved and the Caking Index of coal from one of the seams has been found to be 22 (BSS). A Block in this coalfield has been recommended for development.

In the Singrauli coalfield the discovery of the 134 m. thick Jhingurdah Top seam with about 25 per cent as partings by the Geological Survey of India, is of great economic importance. This seam is the thickest coal seam known in India and is probably the second thickest seam in the world.

Amongst the other coalfields of M.P. superior quality coal has been located in Lakhanpur (one new seam 1·5 m. to 7·0 m. with 7·9 to 17 per cent ash), and Bisrampur (one new seam 3·5 to 4·8 m. with 10·4 per cent ash).

Karharbari formation in some minor coalfields like Daltonganj and Deogarh group has been proved to contain coals of superior quality. Some of the seams also show caking properties, indicating their suitability for utilization in the metallurgical industries.

Himalayan Belt

In the Darjeeling district of West Bengal and in Sikkim, isolated occurrences of coal are being worked. Coal in these areas, although of Gondwana age, has attained 'sub-anthracitic' rank (with very low volatile matter and high carbon content) due to tectonic disturbances. The coal is highly disturbed and crushed and, therefore, in spite of the high heating value, is not very promising.

In the Jammu area of the Western Himalaya, several small coalfields viz., Jangalgali, Kalakot, Metka, etc., contain coal of Tertiary age. The coal is highly disturbed and crushed. The erratic nature of the seams makes economic exploitation in most of the areas difficult. The coal, although high in rank, often contains a high percentage of sulphur.

The Tertiary Coals of Assam

A number of coalfields occur in Assam. But owing to communication difficulties, most of the fields have lagged in development. Only the fields in Upper Assam, particularly the Makum coalfield is well developed. There are five workable seams, of which the lower thick seam records a maximum thickness of 30 m. Tertiary coals of Assam have, by and large, a very low ash content and high Caking Index, which would have normally made them highly suitable for the production of metallurgical coke. But high percentage of sulphur in them, sometime extending up to 8 per cent poses a big obstacle for their utilization in the metallurgical industries. Attempts have, however, been made by Central Fuel Research Institute to reduce the residual percentage of sulphur in the resultant cokes produced by blending Assam coals from Makum field with low-shulphur coals of Jharia and Raniganj coalfields, in pilot plants. It has been indicated that 20-30 per cent of coal from Makum field, blended with 50-55 per cent of low-volatile, 'parent coking' coal of Jharia and 25-30 per cent of medium volatile, semi-coking coal from Raniganj coalfield, would yield metallurgical coke of acceptable quality with admissible limits of sulphur content. Final opinion on this aspect can, however, be given after tests in commercial plants. Similar quality coal is also likely to occur in the adjoining fields, namely, Namchik-Namphuk.

Thus utilization of strongly coking coals of Assam coalfields for metallurgical purposes appear feasible. The maximum utilization of Indian metallurgical coal resources, of which the Assam coals form a pretty large share, is a vital question. If sulphur poses any problem, efforts have to be made to overcome it. If these pilot experiments are successful, we will not only increase the reserves of available metallurgical coal, large areas of hitherto underdeveloped Assam will get additional opportunity for forging ahead in industrial field.

Coal Assessment and Beneficiation Work by the Central Fuel Research Institute

It would be pertinent to mention here about some very valuable work that is being carried out at the Central Fuel Research Institute, Jealgora, Dhanbad, with regard to the quality assessment of Indian coals and allied problems. The Institute has rendered considerable assistance to both, the coal producing and coal consuming industries by devicing and recommending methods by which coal that was considered unserviceable ordinarily could be made usable by appropriate treatment such as washing, blending, etc. The biggest beneficiary has of course been the iron & steel industry, but those interested in power generation, manufacture of cements and chemicals, domestic coke units, etc., have also been served by the Institute. In all the total coal reserves so far assessed by the Institute for potential use is over 10,000 million tonnes.

Substantial conservation of prime coking coal has been achieved by the beneficiation of inferior coking coals and or replacing prime coking coal by blending with non-standard and even non-coking coals. Further the Institute has innovated special techniques for preparations of batches of coal for coking purposes as a result of which it has been possible to make better quality coke from inferior coals.

A very significant advance in the utilization of non-coking coals for metallurgical purposes now appears to be in the offing through special technique invented by the Institute for carbonization of coal at medium temperature, followed by special treatment with tar/pitch and briquetting the end product into what has been termed as the 'shaped metallurgical fuel'.

The Fuel Research Institute has also been successful in producing a new type of smokeless fuel by devolatilizing coal under controlled conditions in stoker carboniser. The air feed in the different stages of the stoker run is carefully regulated so as to achieve devolatilisation up to the desired limit. A plant producing about 20 t/day of this fuel has been under successful operation since 1960.

The Institute is also engaged on many other applied problems such as the hydrogenation of coal into oil, manufacture of chemicals and fertilizers, etc. For reasons of brevity, however, I am making only a mention of them. The import of all this work on the economics of the country and on the development of coal and dependent industries is of immense value.

Aggregate Reserves of Coal

As a result of all the operations and exploration carried out during the Third Plan period, a total additional quantity of 2364·7 m. tonnes of metallurgical grade coal has been proved in the various coalfields together, taking the total to 18,448 m.

tonnes. Along with this another 864·35 m. tonnes of high grade coal has also been proved. The total quantity of coal of all grades, including the metallurgical grade now is put at 20,340·9 m. tonnes, which represents an increase of about 10 per cent above the earlier estimates.

LIGNITES IN INDIA

Lignites may be considered as immature coal of very low rank. A mention, though only briefly, of the lignite deposits of India is considered very desirable at this stage, particularly because some of the lignite deposits have shown promising commercial possibilities.

Nichahom Lignite

In the Kashmir valley lignite occurs in four beds and is associated with the Karewa formation. Important deposits occur near Nichahom, where some exploratory mining was carried out.

Neyvelli Lignite

Lignite deposit occurring in the Cuddalore sandstones of Miocene age at Neyvelli, South Arcot district, Madras, has proved to be a very successful commercial venture. After overcoming the initial hydrological difficulties, development has been well advanced. Incidentally it may be mentioned that this deposit is going to support the largest thermal-power plant in India, the present capacity being 400 MW., which is planned to be increased to 600 MW., with Russian collaboration.

Other lignite deposits, occurring in the coastal parts of South India are not of any economic importance.

Palana Lignite

The work on the Palana lignite deposit of Eocene age in the Bikaner district of Rajasthan has shown encouraging results. Rajasthan is located far away from the coal producing centres. This lignite deposit is, therefore, of special significance for the development of the state.

In conclusion it may be said that in recent years, the study of coalfield geology has made a notable progress. Studies in the academic aspects of the subject cannot be said to be complete in any way. In fact, studies about some aspects have just started and have to be continued for many more years before a picture based on regional studies can be available.

From the economic points of view, however, the first phase of achievements may be said to be partly completed. Consolidated figures of coal resources together with information regarding quality, depths and thickness of coal seams of some of the major coalfields are now available. Much work, however, still remains to be done specially in respect of the fields containing metallurgical coal, where physical and chemical characteristics of the seams at depth are yet unknown. This is all the more important as in view of the rapid expansion in iron and steel industries metallurgical coal will have to be extracted from deeper horizons in near future. Simultaneously search for new deposits of metallurgical and other superior grade coal is to be vigorously pursued specially in the out-lying and undeveloped coalfields.

Within the time available I have endeavoured to cover as much ground as possible. I owe sincere apologies for the ommissions that may have occurred inadvertently. Once again I would like to thank the authorities of the Institute for the honour they have done me. I also thank you, ladies and gentlemen for the courtesy you have extended to me this evening.

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