Himalayan coals : their nature, composition, formation and rank

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Anand-Prakash 1992. Himalayan coals : their nature, composition, formaiton and rank. *Palaeobotanist* **40** : 477-489.

The results of maceral, microlithotype and reflectance analyses, so far carried out on the Palaeozoic (Permian) and Tertiary coals of Himalaya, have been presented along with the details of geological and chemical (proximate) studies. The Permian coals, enclosed in the sediments dispersed as thrust slices in the eastern Himalaya, are characterized by their high rank and the dominance of the maceral vitrinite. In general, these coals are classified as semianthracite, except for the Bhutan coals which are of low rank and high volatile bituminous in nature. Almost all the macerals contain fairly high amount of mineral matter. Finely disseminated argillaceous matter is the most common mineral suite present in the coals followed by carbonates and iron sulphide (pyrite). In most of the cases, the mineral matter is present as infillings in numerous sets of fissures which traverses the coals. These infillings seem to have been developed during the tectonic activity and represent secondary minerals impregnated in various macerals. Often the presence of high amount of mineral matter has greatly reduced the quality of coal. Besides, the marine animal fossil-bearing mineral concretions (coal balls) have indicated that these coals were formed in a series of lagoons under the influence of marine conditions.

The Upper Tertiary coals, associated with the Tipam sediments in the eastern Himalaya, occur as small lenses, very thin impersistent seams and pockets which are characterized by the dominance of maceral vitrinite. It is generally represented by the structured variety (telinite). In general, the cellular structures indicate that these coals have been formed by the burial of wood logs in the fluvial sediments. An important feature of telinite is the presence of folded tissues which attain prominence in the coals occurring closer to the main boundary faults. The coals in this area exhibit lignito-bituminous stage in rank and are comparable to the Mesozoic coals in peninsular India. This stage in rank has been possible mainly due to the tectonic disturbances.

The Lower Tertiary coals of Jammu area are the only economically workable deposits in the Himalaya. These are associated with the beds containing marine animal remains. This indicates that coal formation took place under near-shore environment. These coals are comparable to the Permian coals of eastern Himalaya. They are also rich in maceral vitrinite and semianthracitic in rank. Such a high rank of these Tertiary coals may be attributed to the affect of tectonic movements in the Himalayan areas.

Key-words—Biopetrology, Permian coals, Tertiary coals, Composition, Palaeoenvironment.

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साराँश

हिमालयी कोयले : इनकी प्रकृति, संरचना, उत्पत्ति एवं कोटि

आनन्द-प्रकाश

हिमालय के तृतीयक एवं पुराजीवी (परमी) कोयलों के भूवैज्ञानिक एवं रासायनिक अध्ययन के साथ-साथ मेसीरल, सूक्ष्म-शैल-प्ररूप तथा परावर्तकता विश्लेषण के परिणाम प्रस्तुत किये गये हैं। परमी कोयले अपनी उच्च कोटि एवं मेसीरल विट्रीनाइट की बाहुल्यता से अभिलक्षणित हैं। भूटान के कोयलों को छोड़कर जो निम्न कोटि के तथा उच्च वाष्पशील बिटुमेनी हैं, ये कोयले सामान्यतः अर्ध एन्थ्रासाइटीय हैं। प्रायः सभी मेसीरलों में खनिज पदार्थों की अत्याधिक मात्रा विद्यमान है। अधिकतम कोयलों में दरारों में विद्यमान खनिज पदार्थ पाये जाते हैं। ये अन्तःभरण दरारें विवर्तनिक गतिविधियों के समय विकसित हुई हैं तथा विभिन्न मेसीरलों में प्रवेशित द्वितीयक खनिजों का निरूपण करती हैं। प्रायः खनिज पदार्थ की उच्च मात्रा के कारण ये कोयले कोटि की दृष्टि से निम्न हैं। इसके अतिरिक्त समुद्री जन्तु-धारक खनिज कोयला कन्दुकों से व्यक्त होता है कि ये कोयले समुद्री परिस्थितियों में लैगूनी वातावरण में बने हैं।

Four Decades of Indian Palaeobotany
Editors : B. S. Venkatachala & H P. Singh
Publisher : Birbal Sahni Institute of Palaeobotany, Lucknow

पूर्वी हिमालय में तिपम अवसादों से सहयुक्त उपरि तृतीयक कोयले पतली-पतली सीमों आदि के रूप में मिलते हैं तथा मेसीरल विट्रीनाइट से प्रभावी हैं। विट्रीनाइट सामान्यतः टेलीनाइट से अभिलक्षणित है। कोयलों से उपलब्ध कोशिकीय संरचनाओं से इंगित होता है कि ये कोयले नदीय अवसादों में लकडी के बड़े-बड़े तनों के दबने से बने हैं। टेलीनाइट की विशेषता है कि उनमें मुड़े हुए ऊतक विद्यमान हैं और ये मुख्य सीमा भ्रंश के निकट मिलते हैं। इस क्षेत्र के कोयले कोटि में लिग्निटो-बिटुमेनी अवस्था प्रदर्शित करते हैं तथा प्रायद्वीपीय भारत में मध्यजीवी कोयलों से तुलनीय हैं। कोटि की यह अवस्था मुख्यतया विवर्तनिक गतिविधियों के कारण ही सम्भव है।

हिमालय में जम्मू क्षेत्र के अधरि तृतीयक कोयले ही आर्थिक दृष्टि से महत्वपूर्ण हैं। ये समुद्री जन्तु अवशेषों से युक्त संस्तरों से सहयुक्त हैं। इससे यह प्रदर्शित होता है कि ये कोयले तटीय वातावरण में बने हैं। ये कोयले पूर्वी हिमालय के परमी कोयलों से तुलनीय हैं तथा कोटि में मेसीरल विट्रीनाइट एवं अर्ध-एन्थ्रासाइटीयों से भरपूर हैं। तृतीयक कोयलों की यह उच्च कोटि हिमालयी क्षेत्र में विवर्तनिक गतिविधियों के फलस्वरूप हो सकती है।

IN Himalaya, the coal occurs mainly associated with the Permian and Tertiary sediments. It is generally found in the form of impersistent thin seams, lenses and streaks distributed almost all along the lesser Himalayan zone from east to west. These coals attain economic importance only at a few places. Probably, due to this very reason earth scientists have not given much attention to the Himalayan coals.

The best exposures of Permian coal in the extrapeninsula have been observed in the eastern Himalaya, extending from Darjeeling to Arunachal Pradesh. A number of thin impersistent coal seams are present enclosed within the thrust slices of Permian sediments. Tindharia area (Darjeeling), Naya Bazar and Namchi areas (Sikkim), Samrang, Bangtar and Deothan areas (Bhutan) and Elephant Flat, Garu and Tatamari areas (Arunachal Pradesh) represent the important sites where coal is present at number of places, exposed in stream sections. The characteristic development of Permian coal-bearing sediments in this region led Fox (1934) to suggest a Gondwana coal basin of eastern Himalaya. In general, the coal in all these areas is highly crushed in nature and has reached semianthracitic stage. It is believed that the coals have attained this rank mainly due to the prolonged tectonic activity in the Himalaya.

The commercial coal deposit in the Himalaya occurs only in Jammu region where it is associated with the Lower Tertiary sediments. These coals are of high rank (semianthracite) and are suitable for various industrial purposes. Other coal occurrences, associated with Upper Tertiary (Tipam) sediments of eastern Himalaya, are economically not significant as they are present only in the form of small lenses and streaks. In rest of the Himalayan areas the development of these coals is virtually insignificant. The Upper Tertiary coals, unlike Lower Tertiary and Permian coals, have reached the stage of lignito-bituminous rank. The comparatively lower rank of these coals can be related to the affect of lesser tectonic activity on the Upper Tertiary sediments in the Himalaya. However, coal bodies close to the major tectonic structures, like Main Boundary Thrust, etc. show significant rise in their rank.

As early as 1854, Sir Joseph Hooker (see Fox, 1934) discovered Permian coal-bearing sediments in Darjeeling District. About two decades later, Godwin Austin (1875) reported the presence of splintery coal from Dafla Hills, Arunachal Himalaya. These discoveries of coal from eastern Himalaya were followed by geological investigation of Mallet (1875) in Darjeeling Hills, La Touche (1885) in the Aka Hills, Bose (1890) in the western Duars and Darjeeling Hills, Maclaren (1904) in the Mishmi Hills, Pilgrim (1906) in Bhutan foot-hills and Brown (1912) in Abor Hills. Subsequently, Fox (1934), Auden (1935), Gee (1945) and Ghosh (1952, 1956) contributed further on coal and coal-bearing sequences. Acharyya (1972, 1973, 1975, 1977) and Acharyya *et al.* (1975) have made significant contributions towards the advancement of knowledge of eastern Himalaya. In addition to above records, Nautial *et al.* (1964), Kumar and Singh (1974), Jain *et al.* (1974), Jain and Thakur (1975), Laskar (1979), Laskar and Roy Chowdhury (1979), Raja Rao (1981) and Pawde and Saha (1982) further enhanced the geological knowledge on various aspects. Besides, Anand-Prakash *et al.* (1988) described the presence of faunal coal-balls from the Permian coal and associated sediments of Arunachal Himalaya and suggested autochthonous formation of coal in this basin.

The only economic coal deposit in the Himalaya is of Lower Tertiary age; this is located in the Jammu area. Medlicott (1876) was the first to report its occurrence in this region. A brief account of coal in Jammu Hills was also provided by La Touche (1888). Later, Simpson (1904), Wright (1906), Middlemiss (1928, 1929), Fox (1934) and Gee (1945) made further contributions on coals from this area. Recent contributions on the Jammu area coals are very significant (Srivastava, 1972; Srivastava & Nanda, 1976).

The Upper Tertiary coal occurs as small lenses and thin streaks enclosed in the Tipam (Siwalik?) sediments of Arunachal Himalaya. In other parts of Himalaya, these coals are comparatively much less developed. They are described only as one of the constituent lithologies of Tipam sediments.

Obviously, due to this reason not much attention has been given to the study of these coal bodies.

About twentyfive years ago, the biopetrology was mainly confined to the study of various organic microconstituents of coal. Gradually, the study of coal microconstituents (macerals and microlithotypes) assumed importance mainly due to its use in the quality assessment of coal for utilization in various industries. During detailed microscopic investigation it was realized that the reflectance property of some macerals can be successfully utilized for the measurement of rank/maturity of coals. Maceral vitrinite was selected for this purpose mainly because of its sensitive nature and availability in almost all types of coal. Realizing the usefulness of maturation studies, coal petrologists analysed sedimentary rocks in order to measure chemical alteration of the dispersed organic matter. It was also demonstrated that the maturity index of dispersed organic matter can be effectively utilized in understanding the tectonic history of the sedimentary basin, estimating palaeogeothermal gradient and the degree of diagenesis or metamorphism. Therefore, in recent years the study of coal petrology is being persued as a much broader discipline of organic petrology.

In India, so far, the biopetrological investigations have been carried out mainly on the economic coal deposits from Lower Gondwana and Tertiary coalfields. Economically less significant or insignificant coals associated with the Permian and Tertiary sediments of Himalaya have remained neglected by coal petrologists. Ganju (1955, 1956), Mohan (1956) and Pareek (1970, 1983, 1988) have carried out the petrological study of Lower Tertiary coals of Jammu Himalaya. Mukerjee (1967), Mukerjee *et al.* (1973), Mukherjee *et al.* (1988) and Misra *et al.* (1987) have described the petrographic characteristics of Permian coals from Darjeeling, Sikkim, Bhutan and Arunachal Pradesh (Kameng) areas of eastern Himalaya respectively. A brief account of the petrology of Upper Tertiary coals from Tipam sediments of Kameng area, Arunachal Pradesh has been provided by Hazarika (1979) and Hazarika and Choudhury (1978). Recently, Anand-Prakash (MS) has studied the nature, composition and rank of Upper Tertiary coals from a number of sections covering Siang, Subansiri and Kameng areas of Arunachal Himalaya. Besides these aspects, Chandra and Chakraborti (1989) have briefly discussed the trends of coalification process in some coals of Himalaya. The details of maceral, microlithotype and reflectance studies carried out so far are presented in this communication to understand the nature, composition and rank of Himalayan coals. An attempt has been made to classify the coals and interpret their depositional environment. Besides, the role of intense tectonic activity on the diagenesis of organic matter has also been discussed.

GENERAL GEOLOGY

Arunachal Himalaya

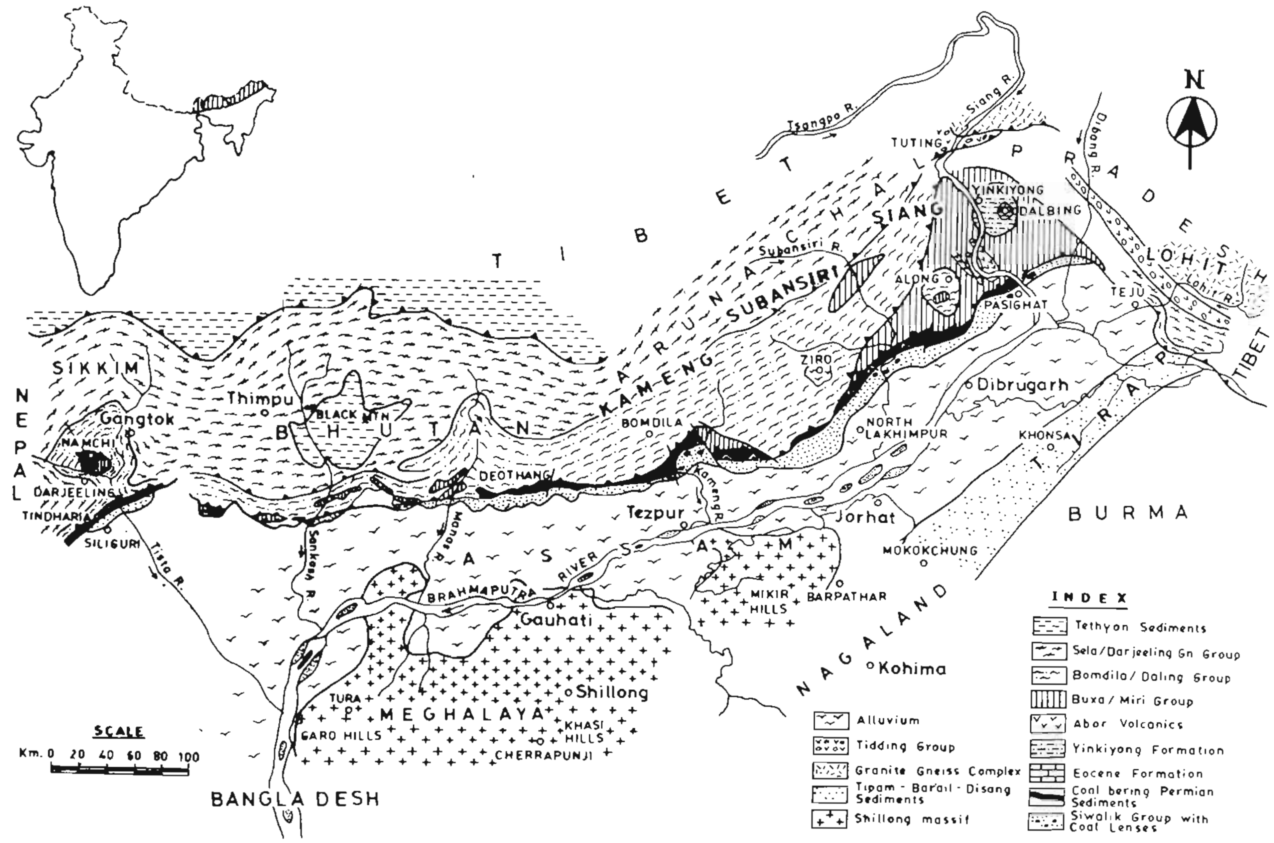
In Arunachal Himalaya, coal occurs associated with the Permian and Upper Tertiary sediments exposed almost all along the length of the lesser Himalayan region (Map 1).

Permian coal

The coal-bearing Permian sediments in Arunachal Pradesh extend from Siang District in the east to Kameng District in the west. These sediments occur as thrust slices between the Tipam sediments in south and Precambrian (Miri) rocks in north in a linear belt covering the entire stretch of Arunachal Himalaya. The geological setting in each district is described here separately:

Siang District—The coal-bearing sediments in this area form an east-west trending narrow, linear belt of low hills in between the high hills of Tipam sediments in the south and Miri rocks in the north. The maximum thickness of these sediments is recorded towards west near Tatamari and Gensi areas. The sediments thin out towards east and are cut off by a thrust near Daring. They reappear east of Daring in Renging area located on Passighat-Along Road. To further east, the coal-bearing sequence is finally cut off by the Siang River. This does not appear again. The sequence of Permian sediments in this area is given below (after Srivastava *et al.*, 1988):

Garu Formation		Predominantly carbonaceous shale, coal & sandstone. Coal balls containing marine animal fossils
Rangit Formation	Rilu Member	Olive green splintery shale, greenish siltstone and mudstone with scattered clasts
	Diamictite Member	Massive conglomeratic rocks with poorly sorted angular clasts set in dark grey or greenish argillaceous matrix. Interstratified siltstone and shale
	Thrust	
Miri Formation		Dominantly quartzite and limestone



Map 1—Geological sketch map of eastern Himalaya.

Of the Permian sediments in the Siang District, only the Garu Formation contains coal and carbonaceous beds. The formation is characterized by a succession of coal, carbonaceous shale and sandstone beds along with coal balls. The sandstone towards upper part of the sequence is ferruginous in nature and often contains pyriteous concretions.

Subansiri District—The Permian sediments in Subansiri area pinch out at several places due to over thrusting of Miri and Bomdila groups of rocks. They are exposed near Petepara in Kimin-Ziro section and before Bini in Tamen-Bini-Gogamukh section. However, in Kheel-Doimukh-Sagalee section, the thickness of these sediments is much reduced and the beds have been sandwiched between the Tipam sandstones in south and Precambrian rocks in the north. The dark grey to black carbonaceous shales, often grading into splintery coal along with coal balls and sandstone, form the dominant units of coal-bearing sequence in Subansiri area (Srivastava *et al.*, 1988).

Kameng District—The Permian sequence in this area is mainly represented by the Rangit and Bhareli formations (Acharyya *et al.*, 1975). These units are found sandwiched between the Precambrian rocks in the north and Tertiary sediments in the south. Both the contacts are marked by prominent thrusts.

The stratigraphic succession of Permian sediments is as under:

Bhareli Formation	Light-grey, white or yellowish, felspathic sandstone, impersistent carbonaceous shale and coal seams
Rangit Formation	Greenish or khaki, pebbly or gritty, frequently pyriteous lithic wackes (diamictite), splintery shales, siltstone, quartzite-wack, impure limestone

——————Thrust——————

Precambrian rocks

The various lithounits of coal-bearing Bhareli Formation are exposed near Elephant Flat area on Bhalukpung-Sessa Road and in a number of nala sections. The best exposures of the sediments of Bhareli Formation particularly of coal seams are present in Pinjuli nala and in road section between 14 km and 16 km posts. The thickness of the coal seams ranges between 0.50 to 1.50 m in this area.

Upper Tertiary coal

Small lenses, pockets and streaks of Upper Tertiary coals occur in the sandstones of Tipam Group in Arunachal Himalaya. The thickness of the coal lenses ranges between 10 cm to 1 m and their distribution is irregular in different areas. The data on coals from five road sections covering Siang, Subansiri and Kameng districts of Arunachal Pradesh have been included in the present paper. The details of these sections are given below:

Siang District

1. Passighat—Renging road section (East Siang District).
2. Likabali—Garu road section (West Siang District)

Subansiri District

1. Kimin—Ziro road section (Lower Subansiri District)
2. Doimukh-Kheel road section (Lower Subansiri District)

Kameng District

Bhalukpung-Sessa road section

The above Tipam sandstone sections contain a number of coal bodies distributed almost uniformly in all the areas studied. Generally the coal exposures are covered by thick vegetation. Good coal exposures are seen only along the fresh road cuttings.

Bhutan Himalaya

The Lower Permian coal-bearing sediments occur as thrust slices in the southeastern part of Bhutan (Map 1). They extend up to 50 km trending east-west with an average thickness between 500 to 1,500 m in a narrow belt. Mukherjee *et al.* (1988) described these sediments in Damuda Sequence, which include quartzitic sandstones, felspathic sandstones, arkosic sandstones, carbonaceous sandstones, carbonaceous shales, argillaceous shales, and lensoid coal beds. This sequence appears to be a part of the coal-bearing sediments present in Arunachal Himalaya in the east and Darjeeling and Sikkim Himalaya in the west.

In Bhutan Himalaya, coal is present generally in the form of lensoid and lenticular beds which are highly irregular in shape, size and thickness. These coal beds often grade into carbonaceous shales or terminate abruptly against the sandstones and shales. It seems that such characteristic features were developed during the initial phase of the sedimentation. The number of coal beds varies in different areas.

Sikkim Himalaya

The Permian sediments are coal-bearing in the southern part of Sikkim of the lesser Himalayan zone (Map 1). The sediments are well-exposed in the Rangit tectonic window in Rangit River Valley at Naya Bazar and near Namchi town. The Permian sediments are overridden by the Precambrian rocks of Daling and Buxa groups from all the sides. The stratigraphic sequence is given below (after Srivastava *et al.*, 1988):

Namchi Formation	Sikkip Member	Dark grey to bluish-grey sandstone, carbonaceous shale and coal
	Namchi Member	Coarse gritty grey sandstone, conglomerate and shales
Rangit Formation	Rangit Pebble Slate	Poorly sorted clasts embeded in argillaceous matrix, siltstone and thin limestone

————Thrust————

BUXA GROUP

In Sikkim Himalaya, only the sediments of Namchi Formation contain coal in the upper part represented by the Sikkip Member. This member is characterized by interbedded sandstone, slaty shale and coal. The sandstones are dark grey, hard, quartzitic, fine to coarse grained and often gritty in nature.

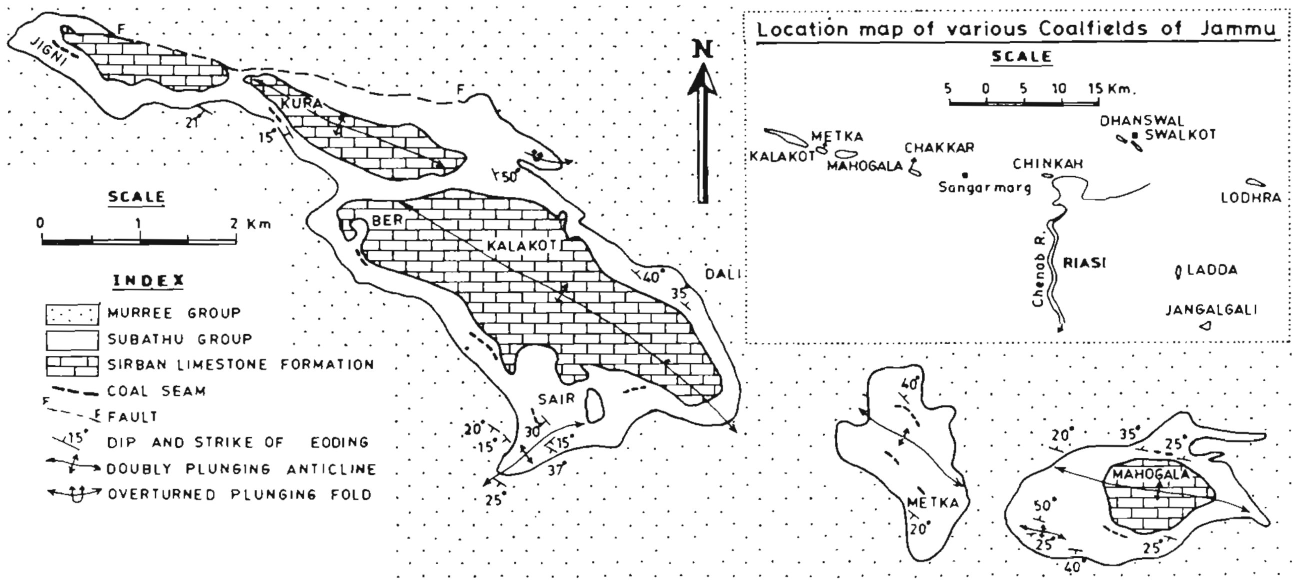
Darjeeling Himalaya

The coal-bearing Permian sediments in Darjeeling area have been broadly divided into two units: the Lower Coal Measures and the Upper Coal Measures. However, some workers prefer to keep this sequence unclassified, as the sediments occur as thrust slices at various places (Map 1) and it is difficult to correlate them on lithological characteristics alone (Pawde & Saha, 1982).

The Lower Coal Measures have a limited aerial extent and are characterized by a sequence of sandstone, shale and coal. The Lower Permian age is assigned to these sediments. The Upper Coal Measures cover a wider area and are characterized by the occurrence of sandstones and occasional coal seams. The coal seams are highly crushed and metamorphosed. An Upper Permian age has been assigned to these sediments mainly due to the similarities with the Raniganj sediments of peninsular India. The best exposures of coal measures can be seen around Tindharia and nearby areas located on Siliguri-Darjeeling Road.

Jammu Himalaya

In Jammu Himalaya, coal occurs associated with the marine Lower Tertiary (Eocene) sediments (Map 2) present in Poonch, Doda and Udhampur districts.



Map 2—Location map of various coalfields of Jammu.

The coal-bearing sediments are spread over an area of 70 km trending north west-south east. The main coal producing areas of Jammu coalfields are Ladda (Jangalgali), Chinkah, Chakkar, Gantha-Thangrote-Khabar-Bhainala, Megal, Mahogala, Metka, Kalakot, Kura, Dhandli and Dhansal-Sewaklot, Lodhra, etc. Coal measures overlie Sirban Limestone (Great Limestone) and are intensely faulted. The stratigraphic sequence of rocks in the area (after Gee, 1945) is given below:

Eocene	Numulitic limestone and shales, fossiliferous concretionary limestone.	153 m
	Upper Coal Measures, carbonaceous shale with coal seams and ironstone bands	40 m
Lower Eocene	Bauxite, Series with lower coal Measures, Bauxite, Bauxitic clays with local ironstone and coal	128 m
	Breccia-chert in siliceous or calcareous cement	69 m
....	....	....
Permo-Triassic	Great Limestone	

MEGASCOPIC CHARACTERISTICS

Permian coal (eastern Himalaya)

The coal-bearing sediments, extending from Arunachal Pradesh in the east to Darjeeling in the west, form an almost continuous narrow, linear belt in the lesser Himalayan region of this area. These beds are mostly disturbed and deformed due to the intense tectonic activity and appear mainly as thrust slices. The organic matter being more susceptible to tectonic activity is highly metamorphosed, attaining semianthracitic stage. Thus, the Permian coals from all the areas of eastern Himalaya represent a single belt and megascopically look alike with very little variation in appearance and physical behaviour.

In general, these coals are jet black in colour and fibrous, flaky and friable in nature. They also soil the fingers mainly at places where the coals are powdery due to intense structural deformation and compression. At such places, the thickness of the seam is also distinctly reduced. Occasionally, severe crushing has given rise to marked schistosity and flakyness to the coals (Mukerjee *et al.*, 1973). The effect of tectonism is also reflected in the presence of slickensides and multiple set of folds in coal and associated shale beds. The coal is almost homogeneous in nature devoid of lithotype banding. The coal and carbonaceous shales often contain lenses and pockets of pyrite.

Upper Tertiary coal (Arunachal Himalaya)

These coals are non-banded and dull in lustre, dark grey to black in colour and break with uneven to subconchoidal fracture. Occasionally, near major tectonic structures they develop a weak vitreous lustre. By and large the coals are homogeneous, hard and compact. However, in some coals woody tissues are still seen with partial deformation.

Lower Tertiary coal (Jammu Himalaya)

The coal-bearing sediments in Jammu area have been divided into a lower and an upper horizon. Both the horizons have two coal seams varying between 0.61 to 2.1 m and 0.61 to 2.3 m respectively. The coal of lower horizon is hard and compact in nature, devoid of lithotype banding and shows a uniform vitreous lustre. The upper horizon coal is similar to that of lower horizon but it is extremely fragile (Pareek, 1983).

CHEMICAL CHARACTERISTICS

Information regarding chemical properties of the Himalayan coals are available only from a few areas. However, on the basis of proximate analysis, the chemical characteristics are being described here to supplement the results of petrological and rank studies.

Permian coal (eastern Himalaya)

In general, the Permian coals of eastern Himalaya are characterized by low moisture and volatile matter and high carbon and ash contents. The volatile matter, fixed carbon and ash contents range between 4.9 to 20.5 per cent, 30.5 to 81.75 per cent and 8.5 to 50.5 per cent respectively. On the basis of volatile matter content, these coals have been classified as semianthracite (V.M. 10%) and low volatile bituminous (V.M. 20%). The high ash content of coals is related to the inclusion of a larger content of mineral matter during the deposition of vegetal matter in the basin and later at the time of metamorphism of coal (Mukerjee *et al.*, 1973).

The coals from Bhutan Himalaya, in comparison to those of Darjeeling, Sikkim and Arunachal Pradesh, are characterized by higher volatile matter (24.8 to 30.8%) and lower fixed carbon (37.4 to 43%) contents. The coals are of high volatile bituminous rank and compare closely with the Raniganj coals of Damodar Basin (Mukherjee *et al.*, 1988).

Upper Tertiary coal (Arunachal Himalaya)

This is characterized by very high amount of volatile matter (47.8 to 55.6%) and low amount of fixed carbon (23.3 to 30.8%; Hazarika & Choudhury, 1978). This indicates that these coals are of lignito-bituminous type and can be compared with the Mesozoic (Cretaceous) coals of Kutch, Gujarat. The ash content is very low and ranges between 2.8 to 6.8 per cent.

Lower Tertiary coal (Jammu Himalaya)

The Lower Tertiary coal from Jammu Himalaya is characterized by very low amount of volatile matter (9.5 to 16.3%) and high amount of fixed carbon (64.4 to 90.5%; Pareek, 1983). It indicates that the coals range from low volatile bituminous to semianthracite. The coals do not have coking property, though they have low moisture, ash and volatile contents. It seems that the coals attained this stage due to the intense tectonic activity in this part of the Himalaya.

MICROSCOPIC CHARACTERISTICS

Permian coal (eastern Himalaya)

In general, the Permian coals of eastern Himalaya are dominantly composed of vitrinite and inertinite maceral groups. The macerals of exinite group are rare and have been recorded from a few areas only except in Bhutan coals where exinite is present in a sizeable amount. It seems that the exinite content of coals have attained a level of brightness equal to that of inertinite and, therefore, could not be differentiated from various inertinite macerals. Further, the distinction between vitrinite and semifusinite macerals is also difficult due to homogenization (Misra *et al.*, 1987). In addition, these coals contain very high amount of mineral matter. A fraction of mineral matter seems to be of adventitious nature being incorporated when the coals were subjected to intense tectonic disturbance of Himalayan orogeny.

Vitrinite Group—It is mainly represented by the macerals telocollinite and desmocollinite. These macerals generally occur in the form of thin to thick microbands. Both telocollinite and desmocollinite are structureless and homogeneous in nature. Numerous fissures and cracks often infilled with secondary mineral matter are present in the vitrinites. A number of microfolds, faults and other compressional structures have also been recorded, which show the effect of intense structural deformation in the area. Such features are common in the coals located near the thrust zones. In addition, finely disseminated mineral matter is also present in considerable amount alongwith the detrital quartz grains.

Telocollinite is characterized by the shining white to yellowish white colour and strong anisotropy. Whereas, desmocollinite is greyish white to white in colour and exhibits comparatively lower reflectance and weak anisotropy. These macerals have also been described as high and low reflecting vitrinites from Darjeeling and Sikkim areas by

Mukerjee (1967) and Mukerjee *et al.* (1973). Recently, Misra *et al.* (1987) designated these types as vitrinite-A and vitrinite-B from Kameng area of Arunachal Pradesh. The vitrinite-A is of high reflecting type and closely resembles the pseudovitrinite of Benedict *et al.* (1968) in petrological behaviour. Vitrinites present in the coals of other areas of Arunachal Pradesh are also similar in nature. Unlike, the vitrinite of Darjeeling, Sikkim and Arunachal coals, the vitrinite of Bhutan coal is light to dark grey in colour and lower in reflectance. Telocollinite represents the dominant constituent of vitrinite group, followed by desmocollinite. Telinite is also present but rare in occurrence. Vitrinite particles often show crushing effect and are usually associated with more of mineral matter (Misra *et al.*, 1987). The presence of the maceral semivitrinite (Snyman, 1961; Chaudhuri & Ghose, 1978) has also been reported from this area.

Inertinite Group—This group is represented by a wide range of macerals: semifusinite, fusinite, inertodetrinite, macrinite and micrinite in decreasing order of abundance. Macerals, semifusinite and fusinite, generally occur in the form of thin to thick microbands, streaks and lenses. They also occur as finely divided shreds and pieces associated with the vitrinite fragments. These macerals often show bogen structures. Undeformed cellular structures are rarely present. The cell lumens in semifusinite and fusinite are generally filled with fine black granular argillaceous mineral matter. The infilled mineral matter seems to provide strength to the preserved cellular structures, as they have not been affected much by the shearing and cracking pressures as compared to the vitrinites. Almost all the varieties of semifusinite and fusinite, the degrado, rank and pyro are well-represented in these coals. The colour of these macerals vary from white to light yellow with reflectance ranging between 2.8 to 3.25 per cent in oil (Misra *et al.*, 1987).

The inertodetrinite is distributed in streaks and thin microbands and also as sparsely dispersed material in the vitrinites. Macrinites are present as homogeneous oval to elliptical bodies, whereas micrinite occurs as highly reflecting specks in the vitrinitic groundmass.

Exinite Group—The macerals of exinite group are present mainly in the coals from Bhutan Himalaya. Sporinite represents the most common maceral of this group. Both microsporinite and megasporinite are present in these coals alongwith cutinite and resinite (Mukherjee *et al.*, 1988). The occurrence of sporinite has also been reported from Rangit Valley coals of Sikkim Himalaya (Mukerjee *et al.*, 1973). In this area, the sporinites are very similar to the high reflecting vitrinites in optical properties, and therefore, it is difficult to recognize them under the microscope.

Mineral Matter—The mineral matter is the prominent constituent in the coals of eastern Himalaya. It has not only influenced the quality of the coal, but also reflects upon the depositional and diagenetic conditions. Argillaceous mineral matter is commonly associated with these coals. It occurs as a finely dispersed black granular material in almost all the macerals. Carbonate and sulphide minerals are also present, generally, in the form of concretions and infilled material in the cracks and fissures. The concretions sometimes contain well-preserved marine animal remains which are described as faunal coal balls (Anand-Prakash *et al.*, 1988). Siderite is also present in a few coals.

The distribution of macerals in the Permian coals of eastern Himalaya is as follows:

Areas	Vitrinite %	Inertinite %	Exinite %	Mineral matter %
Darjeeling	35-60	10-30	2.5-6.0	20-40
Sikkim	34-57	8.5-34	2.5-8.8	22-44
Bhutan	32.2-48.6	18.8-35.4	3.2-8.8	17.6-34.9
Arunachal Pradesh	11-61	15-80	—	8.5-23.8

Upper Tertiary coal (Arunachal Himalaya)

The Upper Tertiary coals of Arunachal Himalaya are mainly composed of vitrinite and inertinite maceral groups. The exinite group is rarely represented. In general, these coals are chiefly composed of vitrinite followed by the inertinite and mineral matter.

Vitrinite Group—Vitrinite group is represented mostly by the macerals telocollinite and telinite in order of abundance. Telocollinite consists of sheets of cells lacking walls. Presence of numerous uneven cracks and fissures filled with mineral matter is a characteristic feature of this maceral. Telinite is mostly characterized by the presence of cells under various stages of preservation. In some cases the cell walls are well-preserved and the lumens are empty. Whereas, in other cases the cell lumens are generally filled with fine argillaceous opaque mineral matter. The telinite is also affected by the compressional force, as in many cases the cells are seen forming tightly folded structures.

Inertinite Group—Inertinite group of macerals is not well-represented in the Upper Tertiary coals of Arunachal Himalaya. However, semifusinite and fusinite macerals form a characteristic fraction of the coal microconstituents. These macerals are composed of well-preserved tissues with marked cell wall and lumens generally filled with opaque argillaceous mineral matter. These are also characterized by the higher reflectance as compared to the vitrinite.

Exinite Group—The exinite group in the Upper Tertiary coals of Arunachal Himalaya is mainly represented by the maceral cutinite. It is associated with the macerals of vitrinite group and characterized by serrated margins. Small pieces of cutinite have also been observed at a few places.

Mineral Matter—Fine argillaceous material is the most common mineral matter present in the Upper Tertiary coals of Arunachal Himalaya. It is present in almost all the macerals in the form of bands, crack fillings and also as finely dispersed matter. The other important mineral present in these coals is pyrite which generally occurs as crystals of different sizes. However, its presence is localized and indicates reducing environment of deposition.

Maceral composition of the Upper Tertiary coals of Arunachal Himalaya indicates very high representation of vitrinite (around 70%), inertinite (around 25%) and mineral matter (around 5%).

Lower Tertiary coal (Jammu Himalaya)

The Lower Tertiary coal from Jammu Himalaya is mainly composed of vitrinite and inertinite maceral groups. It is highly metamorphosed and semianthracitic in rank. The affect of intense tectonism is visible in the crushing and fragmentation of coal. The coals are also rich in sulphur content which has greatly reduced its quality.

Vitrinite Group—The vitrinite group is mainly represented by the maceral telocollinite. It is structureless and homogeneous in nature. However, faintly recognizable cellular structures have been observed by etching the vitrinites (Pareek, 1983). A fair amount of mineral matter is always present in the vitrinites in the form of infillings in numerous fissures and cracks.

Inertinite Group—Inertinite group in Jammu coals is represented mainly by the macerals fusinite, semifusinite, micrinite and sclerotinite. Fusinite and semifusinite are generally present in the form of small fragments and lenses showing well-preserved woody structures. Fusinite is also present as ball-shaped bodies which seems to be the vascular bundles of plants (Pareek, 1983). The transitional stages between semifusinite to fusinite are also seen. Fungal spores, sclerotia and hyphae are common. The presence of such a wide range of fungal elements in these coals indicates the prevalence of oxidizing conditions in the basin during peat formation.

Mineral Matter—Finely dispersed argillaceous mineral matter, microscopic clay balls and concretions represent the common types of sedimentary mineral matter in Jammu coals. The specks, cell fillings and lumps of pyrite are seen in abundance. Siderite and ankerite are also present (Pareek, 1983).

The detailed maceral composition is not known from this area. However, on the basis of general estimates these coals are dominantly composed of vitrinite and inertinite maceral groups.

RANK

In general, the rank of coal is the stage of vegetal matter reached during the process of transformation from peat to its final product graphite. It is influenced by progressive diagenetic and coalification (organic metamorphism) processes which cause significant chemical changes, induced primarily by the quantum of geothermal energy. In the Himalayan region, large scale tectonic movements caused considerable rise in the crustal temperature which resulted into much higher rank of the coals as compared to the coals from peninsular India. A characteristic feature observed in the area is the progressive increase in the rank of coals towards the major tectonic structures, like main boundary faults, thrusts, etc.

Permian coal (eastern Himalaya)

The Permian coals from eastern Himalaya exhibit a wide range of reflectance between 0.66 to 2.4 per cent. The maximum reflectance values were recorded mainly from the coals of Arunachal Himalaya. In this area the vitrinites show reflectance range varying from 1.75-2.15 to 2.15-2.5 per cent corresponding to vitrinite-A and vitrinite-B described earlier. From Darjeeling and Sikkim areas also similar types of high and low reflecting vitrinite have been observed. However, the vitrinites from these areas show lower reflectivity as compared to that of Arunachal Pradesh. Therefore, the Permian coals of eastern Himalaya, in general, can be grouped with the semianthracite coals according to the ASTM System of classification.

As compared to Darjeeling, Sikkim and

Arunachal Pradesh, the coals from Bhutan Himalaya show much lower reflectivity (R_o max. 0.66-0.74%) characteristic of high volatile bituminous C Stage These coals are comparable to the Upper Permian coals from Raniganj Coalfield (Mukherjee *et al.*, 1988).

The trend of maturation in the Permian coals of eastern Himalaya appears to have been uniform throughout the region, except at Bhutan where the coals are much lower in rank. It indicates that the coals in Bhutan Himalaya are least affected by the tectonic activity and have retained their original nature. Thus, coal katagenesis seems to have been controlled only by the time and temperature. Whereas, in rest of the areas, intense tectonic activities have greatly increased the rank of coals mainly from the sudden supply of thermal energy generated during large scale crustal movement.

Upper Tertiary coal (Arunachal Himalaya)

The Upper Tertiary coals from eastern Himalaya have a reflectance range between 0.3 to 0.5 per cent and show a gradual rise in rank towards north. This range indicates that these coals are comparable to the lignito-bituminous coals found associated with the Mesozoic sediments of Kutch, Gujarat (Pareek, 1980; Anand-Prakash, 1985). Only the Guneri coals from Kutch are distinctly higher in rank as compared to the Upper Tertiary coals of Arunachal Himalaya. Maximum reflectance has been recorded from the coals located near the major tectonic structures, particularly the main Boundary Thrust. It shows that due to large scale movement along the thrust enough heat was generated to increase the rank of these coals, as under normal conditions the vegetal matter would have remained only at the stage of lignite.

Lower Tertiary coal (Jammu Himalaya)

The Lower Tertiary coal from Jammu has a uniform reflectance between 1.8 to 2.3 per cent, which is equivalent to semianthracite stage (Pareek, 1988; pers. commun. Dr B. K. Misra). This rank is too high for a Lower Tertiary coal in India, as the other deposits of corresponding age have reached either the stage of a lignite or high volatile bituminous C Stage (Misra, 1992). Like Permian coals of eastern Himalaya the Lower Tertiary coals of Jammu have also been affected much due to the intense tectonic activity.

DEPOSITIONAL ENVIRONMENT AND GENESIS OF COAL

An interplay of climate, landforms, existing vegetation and various geomorphic processes under favourable conditions results into the accumulation of vegetal matter in the basin. The basin may be of continental or paralic in nature. In continental basins, the plant matter is generally deposited in lakes, which are either of tectonic or fluvial origin. Most of the commercially exploitable coal deposits in the country have been formed by the accumulation of plant derived organic matter in the back swamp areas of fluvial regime. However, some important coal deposits have also been formed under deltaic and marginal conditions in coastal swamps and lagoons.

Coal formation is initiated through the process of peatification. The peat formation generally takes place under the control of sedimentary tectonics. When the basin floor sinks with the load of incoming material, a thick pile of sediments associated with the organic matter gets accumulated. This gradually increases the depth of burial of the sediments which are deposited initially under shallow fluvial environment. Consequently, the rise in geothermal temperature activates the process of diagenesis and metamorphism (coalification) resulting into the formation of coal. In Himalaya enormous amount of heat was generated during intense tectonic activities, which further accelerated these processes causing sudden rise in the rank of coal.

Permian coal (eastern Himalaya)

In general, the Permian coals of eastern Himalaya seem to have been formed by the accumulation of vegetal matter in the basins represented by a series of linear lagoons located along the sea shore. Influence of marine conditions during the formation of coal has also been indicated by the presence of coal-balls containing marine animal remains from Arunachal Pradesh (Anand-Prakash *et al.*, 1988). The flora around the lakes was chiefly composed of gymnospermous trees forming thick forest and short pteridophytic plants representing the undergrowths.

The gymnosperms were mainly represented by the genera *Glossopteris*, *Gangamopteris*, *Noeggerathiopsis*, *Walkomiella*, etc. which constituted dominantly the upland vegetation. Whereas, *Phyllotheca*, *Stellotheca*, *Schizoneura*, *Sphenophyllum*, etc. representing the pteridophytic plants occupied moist shady areas (Chandra & Chandra, 1987). The abundance of monosaccate (*Parasaccites*, *Plicatipollenites*, *Virkkipollenites*, etc.) and bisaccate (*Scheuringipollenites*, *Faunipollenites*, *Striatopodocarpites*, etc.,) pollen and trilete (*Callumispora*, *Microbaculispora*, *Cyclogranisporites*, etc.) spores also indicates the prevalence of gymnospermous and pteridophytic vegetation respectively, around the depositional basins (Srivastava & Dutta, 1977; Singh, 1979; Srivastava *et al.*, 1988). Thus, the gymnosperms and the pteridophytes mainly represent the source material for the Permian coals of eastern Himalaya.

Both during and after the accumulation of source material, the basin was subjected to frequent marine incursions across the coal-forming swamps. The repeated invasion of sea water resulted in the richness of salts which contributed towards the formation of concretions mainly composed of calcium carbonate. These concretions (coal balls) often contain marine animal remains and are found dispersed irregularly in the coal and associated beds. Some of the concretions are also composed of iron sulphide (pyrite), which seems to have been formed due to the action of sulphur bacteria during the diagenesis of the organic matter. It also indicates the prevalence of reducing environment in the basin. A critical study of the coal beds also indicates the seaward extension of peat-forming swamps which were often inundated by sea water, probably across the offshore barriers during the periods of storms and high tides. However, the sea water withdrew rapidly from the swamps and the peat formation continued almost unaffected. The presence of similar conditions during the formation of some European coals has also been suggested by Moore (1968). Besides, the basins also seem to have been fed by some channels supplying fresh water and small amount of land-derived sediments to the swampy areas; a variety of pollen and spores belonging to land plants are present associated with the coal beds. Thus, the Permian coals of eastern Himalaya have been formed by the accumulation of the vegetal matter in shallow lagoons and coastal plains largely under the influence of marine conditions. However, the conditions changed gradually from marine to fresh water towards west, which is indicated by the less and less prevalence of marine remains in the coals occurring around Darjeeling and Sikkim areas. Further, the coal seems to have been formed by the vegetation growing in and around the basin and is a result of *in situ* peat formation, unlike Gondwana coals of peninsular India, which are believed to have formed mostly from the drifted vegetal matter deposited in purely continental basins. Instead, the Permian coals of eastern Himalaya are comparable to the Carboniferous coals of Europe and America in their mode of formation.

Upper Tertiary coal (Arunachal Himalaya)

The Upper Tertiary coal of eastern Himalaya generally occurs in the form of small lenses and streaks found enclosed in massive sandstones. These sandstones are fine grained to gritty characterized by salt and pepper colour and appear to have been deposited in shallow channels and flood plains of rivers. These rivers were draining the foredeep areas developed at the base of the rising Himalaya in the north. The foredeep formed an ideal site for the accumulation of enormous amount of sediments carried by the rivers due to large scale erosion in the regions of high relief. Being the provenance this area maintained a continuous supply of sediments which were accumulated in the foredeep as the basin floor was continuously sinking due to the increasing load of the sediments under the control of sedimentary tectonics. This depositional setting provided very little chance for the accumulation and preservation of the organic matter mainly due to the absence of lacustrine conditions. Most of the organic matter seems to have been destroyed under oxidizing environment. However, a very small amount of the vegetal matter, mainly in the form of wood logs could be deposited in shallow depressions present over the wide flood plain areas. The quick burial of wood logs below the sands seems to have provided a chance for the preservation of organic matter only in the form of small bodies, streaks and lenses. The source material for the coals was mainly derived from the thick forests growing in the mountainous region of the Himalayas. The forests were mainly dominated by the families Parkeriaceae, Schizaeaceae, Pteridaceae, Lycopodiaceae, Matoniaceae, Arecaceae and Bombacaceae. The provenance had a warm and humid climate which is indicated by the profuse occurrence of pteridophytic spores and microthyriaceous fungi (Singh & Tripathi, 1990).

In general, the Upper Tertiary coals of eastern Himalaya have attained lignito-bituminous rank, which is comparable to the Cretaceous coals of Kutch, Gujarat. It indicates that the coals in the Himalayan region have attained this rank in much less time as compared to the coals from Kutch. The acceleration in the process of coalification seems to have been caused mainly by the large scale tectonic activity in this area.

Lower Tertiary coal (Jammu Himalaya)

The Lower Tertiary coal of Jammu Himalaya occurs associated with the marine sequence, characterized mainly by the nummulitic limestone, shales and fossiliferous concretionary limestone. These sediments are generally believed to have been laid down in a near-shore environment over shallow deltaic plains and lagoons. These landforms provided ideal sites for the accumulation of vegetal matter. The lacustrine conditions further helped the peat formation and preservation of organic matter in the basin. The source material was mainly derived from the forests growing in the upland areas near the coast. In general, the forests were characterized by the abundance of plants belonging to the families Lycopodiaceae, Schizaeaceae, Matoniaceae, Polypodiaceae, Parkeriaceae, Podocarpaceae, Liliaceae, Nymphaeaceae, Poaceae, Arecaceae, Oleaceae, Fagaceae, Anacardiaceae and Alangiaceae. This information is based on the palynological studies carried out by Singh and Sarkar (1989) from Subathu sediments, as no such details are known from the Lower Tertiary sediments of Jammu area.

Soon after the deposition of source material in the basin which was located in the tectonically mobile zone, the organic matter was subjected to the diagenetic and metamorphic processes which accelerated the transformation of vegetal matter into coal. These processes were further boosted up by the intense amount of heat generated during the tectonic activity and thus enhanced the rank of coal to the semianthracitic stage. It indicates that the Lower Tertiary coal in the Himalayan region has attained this rank in much less time as compared to the coals of the same age present in various parts of the peninsular India. Most of them are still in the lignitic stage.

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