MACROFRAGMENTAL FOSSILS AND THEIR COALIFIED PRODUCTS IN THE PERMIAN COALS OF INDIA

G. K. B. NAVALE

Birbal Sahni Institute of Palaeobotany, Lucknow-226007, India

ABSTRACT

The Permian coals of India have been formed from variety of macro- and microfragmental remains of fossils. The present paper deals with the types of macrofragmental fossils and their coalified products in the Permian coal formation. Some of the conspicuous macrofragmental fossil components are woody and bark tissues. They appear to have been coalified into vitrain and fusain types by the coalification processes of " vitrinization and fusinization ". A significant fact recognized for the first time from the analytical data of vitrinite and fusinite constituents is the characteristic feature of vitrinite/fusinite (V/F) ratio in the Permian coals of India, which may not only indicate certain coal properties but also help in dating and correlating the coal seams.

INTRODUCTION

PERMIAN coal is formed from the remains of former plant life. Most of the Gondwana coals were formed in widespread swamps somewhat like those found today in northern and southern parts of India, but the plants which gave rise to the coals were different from their modern counterparts. Instead, ferns, lycopods and ancestors of gymnospermous trees dominated swamp environment. Thiessen (1920) was one of the first to discover botanical remains of various plant parts, tissues, organs and excretory products in the coals. He showed that specific plant remains were essentially the same in appearance from one variety of coal to another but the proportional amounts of various constituents varied considerably. He also concluded from his study of coal and parent material that as the plant debris is collected in peat swamp, the intensity of biochemical activity and resistance of plant remains to decomposition, maceration, elimination and chemical change determine what plant organs and tissues are preserved from a particular variety of coal. The coalified products owe their origin to the coalification process. The latter is the process of conversion of peat to coal and its progressive alteration by geological processes over long duration. These concepts are true for coal from any part of the horizon but the original fossil vegetation and geological set up during the coal formation do change the composition and characteristics of the coals.

In India, majority of coals occur in the Permian age well known in Indian stratigraphy as Damuda Series of Lower Gondwana System. The principal horizons, Karharbari, Barakar and Raniganj stages, account for more than 90 per cent of the coal provided in the country. Of these, Karharbari forms the basal unit. The Barakar Stage which succeeds the Karharbari is the most important coal-bearing horizon in the Lower Gondwanas. Raniganj Stage, next to Barakar, is also an important coal-bearing horizon.

FLORAL CONTENTS OF THE MACROFRAGMENTAL ENTITIES

Permian floral contents as known (Surange, 1966) may be listed as under:

Karharbari Stage — *Gangamopteris* and *Noeggerathiopsis* formed an extensively developed genera in the Karharbari flora. Other conspicuous forms of this stage are *Gondwanidium, Buriadia* and *Rubidgea.* Some significant genera are *Euryphyllum* and many seeds, viz., *Samaropsis, Cornucarpus, Rotundocarpus* and *Cordaicarpus. Gangamopteris* is the most abundant genus. It is therefore reasonable to presume that fragments of *Gangamopteris* and *Gondwanidium* and others, chiefly contributed to macrofragmental entities in the Karharbari peat.

Barakar Stage — A characteristic feature of the plant assemblage of the Barakars is the abundance of *Glossopteris* species, the decline of *Gangamopteris* and *Noeggerathiopsis* and absence of *Gondwanidium* and *Buriadia*. It is very apparent, by and large *Glossopteris* fossils contributed to the macrofragmental constituents of Barakar coals.

Raniganj Stage — In the flora of Raniganj Stage, *Glossopteris* forms a predominant genus. Apart from this, large number of petrified woods, viz., *Dadoxylon, Kaokoxylon, Trigonomylon, Damudoxylon* and *Megaporoxylon* characterized Raniganj Stage. It is evident that the above forms chiefly contributed to the macrofragmental entities of Raniganj coals.

The floras of Karharbari, Barakar and Raniganj stages are distinguishable from one another on the basis of restricted forms (Karharbari & Raniganj stages) or in the paucity of forms (Talchir & Barren Measures) as compared to the more luxuriant floras succeeding them.

MACROFRAGMENTAL FOSSIL ENTITIES

General nature of coal and its fossil entities have already been described (Ganju, 1955; Navale, 1971, 1972; Pareek, 1967).

Bark Tissues — Bark tissues have formed an important constituent in the macrofragmental entities of Permian coals. They occur as slightly compressed non-seriate cells, thick-walled, showing more or less rectangular cells with a narrow constricted and compressed lumen (Pl. 1, fig. 3). Middle lamellae are quite conspicuous, the intercellular spaces are more or less triangular and filled with coal substance. The cells are thick-walled either due to original character or swollen during the process of coal formation. The cell cavities vary in size. The variation in size of lumen might have been due to different amount of infilling. Lamination of cell wall is very characteristic. It may be possible that certain amount of swelling of the wall took place during coal formation. They are usually small, at times larger ones are also found. The variation may be caused either by infilling or as a result of plane surface. The important feature of cell wall is lamination. Thick-walled cells are characteristic of cortical layers. At times, fine differential layers exist in the lamination. Some cells in the same tissue show effects of strain produced by compression during the process of coal formation. Some thick-walled bark tissues appear rectangular, their cavities narrow, constricted, sometimes compressed to the size of a thread. The lumens are filled with coal substance or resinuous material. An important feature of thick-walled bark cells is the presence of large number of canals. Another type of thick-walled bark tissue shows characteristic cells broken into rectangular blocks of cells (Pl. 1, fig. 4), the blocks being of similar nature though varying in size; the cells are thick-walled with small empty cavities.

Secondary Bark Tissues — These tissues are not common in the coals, when present, they occur in serially arranged thin-walled elongated rectangular cells (Pl. 1, fig. 1). Generally, it is resinous with granular matter. The nature of cell contents varies in different cells.

Woody Tissues — Woody tissues have formed a major component in the coal forming peat. The commonly observed features in the woody tissues are tracheids and medullary rays. Sometimes pith tissues with sclerotic cells have also been observed.

The tracheids of woody tissue preserved in a vitrifusinized state exhibit round to oval-shaped bordered pits, arranged in 1-2 vertical rows in radial walls (Pl. 1, fig. 5). Pits are arranged oppositely in two rows. The walls of the cells are seen unpitted indicating that the tissues might represent ray tracheids. Also the pits appear separate and alternately arranged in two vertical rows. The alternate arrangement of pits in the central tracheid is not an original feature but has resulted due to distortion of tracheid because in other tracheids, the pits are oppositely arranged. The pit aperture appears inclined, elliptical or slit-like when more compressed. The radial pits nearly occupy entire breadth of the radial walls. In broader walls, two vertical rows of pits, while in narrower ones single vertical row of pits are commonly seen. The bordered pits appear in profile view as chains of short bars along the radial walls of the tracheids. In tangentially cut woody tissue, lenticular pits in the walls of tracheids are seen. The pit chambers and the cell cavities are filled with resinous substance. Tracheids show considerable length. Woody tissue showing spiral and reticulate thickening of the walls in longitudinal section are also seen in Permian vitrains (Pl. 1, fig. 2).

In transversely cut woody tissue, cells show various states of compression. In an extremely compressed condition, cell cavities are more or less obliterated while in less compressed, cell cavities appear swollen. The medullary rays are numerous, uniseriate, and commonly 3-4 cells in height but sometimes reach up to 9 to 11 cells (Pl. 1, figs. 6, 9). Very rarely, the rays exhibit biseriate condition. The ray cells are parenchymatous. The size of the cells varies from 30 to 60 μ in length and 16 to 30 μ in width. The ray cells are thin to thick-walled, oval to elliptic. The horizontal and tangential walls of the ray cells are smooth. Pits are only found in the radial walls of the cells and are 1-3 per field, small and irregularly arranged.

Pith Tissues — Microstructure of pith in fossil *Dadoxylon* wood from Permian of India has been described by Sahni (1933), Surange and Sah (1956) and Surange and Maithy (1961). However, the preservation of pith in coal was reported by Pant (1965) for the first time. Generally, pith tissues are not preserved in coals as the cells of the pith are of cellulose and easily destroyed during coalification process. In longitudinal section of a stem (Pant, 1965, pl. 5, fig. 1) pith tissues have been recognized in the central part mainly composed of rectangular-shaped and somewhat loosely arranged sclerotic cells. On either side of the pith, a few spirally thickened tracheids of the primary xylem and medullary rays (Pl. 1, fig. 10) are visible. Pith cells depict sclerenchymatous nature. The middle lamellae appear slightly swollen. The sclerotic cells are arranged in tiers. The resinous cells are thin-walled and appear wedged in sclerotic strands at regular intervals. By and large, they appear drawn out due to compression whereas sclerotic cells have not been much affected. Pith parenchyma is also seen in a highly decomposed tissue where number of resin bodies are embedded.

COAL CONSTITUENTS DERIVED FROM MACROFRAGMENTAL ENTITIES

Coal is derived by the process of 'coalification' — a process by which vegetable substances of peat were transformed in partial absence of air and under the influence of temperature and pressure throughout geological time into lignite and subsequently into coal. The process is characterized by enrichment of carbon content. The two principal mechanisms involved in the coalification process are: (i) diagenesis including biochemical process, and (ii) metamorphism or geochemical carbonification. Diagenesis takes place under normal conditions of temperature and pressure and ends in lignite stage, whereas metamorphism occurs under the influence of temperature and pressure after burial and leads to formation of bright lignite and subsequently to hard coal, the final stage being anthracite.

The plant materials that form coal may be, in part, simply incorporated or they may be present in vitrinized or fusinized form (Schopf, 1948). The materials contributing to coal differ in their response to diagenetic and metamorphic agencies and the three essential processes of coalification are called incorporation, vitrinization and fusinization. As such, important groups of constituents or products of bituminous coals are vitrinite, exinite, fusinite, semifusinite, micrinite and resinite groups which are petrologically termed as macerals.

The macrofragmental fossil entities are coalified by vitrinization or fusinization processes. They form either vitrain or fusain types in ultimate coal.

Vitrinite (Pl. 1, fig. 7) — Microscopical evidence indicates that most vitrinite are probably derived from woody tissues (stems, branches, twigs & roots) of trees and shrubs. Vitrinite will be formed only if certain rather critical conditions of preservation of the plant remains are satisfied, in particular they must be protected from extensive biochemical attack. Because the size of the original plant debris varied so greatly, the vitrinite layers or inclusions now present in Permian coals range from fragments or sheets less than thousandth of an inch thick to layers more than an inch in thickness which may extend laterally for many feet. During the geological maturing process in which peat changes into brown coal and in turn becomes bituminous coal, the original plant tissues are chemically changed and are compressed to such an extent that a former tree trunk becomes a layer of an inch or so thick and a former twig becomes a paper-thin film of vitrinite. An extremely thin parallel-sided sheet (thin section) of vitrinite is translucent and reddish in colour when seen under transmitted light. In some layers the botanical structure is preserved in considerable detail. Vitrinite also occurs finely intermixed with other macerals and minerals. Vitrinite appears grey in polished surface sections. The exact shade depends on the degree of maturity (rank) of the coal.

Fusinite & Semifusinite (Pl. 1, figs. 8, 11) — The name derives from the French word fusain meaning charcoal while the term semifusinite is applied to material intermediate between fusinite and vitrinite. These macerals have silky black, cellular appearance of charcoal and like charcoal they also soil the hands. Under microscope they appear to have similar structure to charcoal except that in fusinite especially, the plant cell walls may have collapsed or distorted. However, many fusinite and semifusinite occurrences do exhibit well preserved botanical structures.

Since fusinite is opaque, even in very thin sections, its cellular structure is seen in silhouette by transmitted light. When polished it gives highly reflecting surface. Fusinite appears brighter than other macerals in reflected light, unlike other macerals it is equally bright whether found in brown coal, bituminous coal or anthracite. This suggests, first, that fusinite was formed at, or soon after the stage when deposition of peat occurred and secondly that fusinite is very stable. Two different interpretations, which together account for all the occurrences, have been placed upon these facts. One is that the similarities to charcoal are coincidental and that change from wood to fusinite was caused by special conditions of oxidation (biochemical changes). The close association of fusinite with sclerotinite, a similar maceral of fungal origin provides supporting evidence for this theory. The other theory is that fusinite came from charcoal produced by forest fires in and around the peat forming swamps. Fusinite, although brittle, is harder than most other macerals and therefore resistant to polishing, especially when its cavities are filled with mineral matter — calcite, ankerite etc. This process of 'mineralization' may prevent the fusinite from collapsing under pressure, as frequently happens when the lumens are empty. Crushed fusinite has a characteristic structure ('bogen-structure') consisting of tightly packed arched fragments of plant cell walls.

In many Permian coals of India, fusinite occurs in small lenticles or in impersistent layers often less than 1/4 inch thick. Most of the charcoal-like material seen in our coals is in fact semifusinite, when examined in reflected light, it varies in contrast from grey of vitrinite to the bright white of fusinite. In semifusinite, the most highly cellular material is frequently the most highly reflecting and the least translucent. Transitions sometimes occur between vitrinite and semifusinite and between semifusinites of different reflectivities, but almost never between semifusinite and fusinite. This suggests that semifusinite and fusinite may result from different geological processes. The hardness and polishing relief of semifusinite are less than those of fusinite. In general, cavities representing plant cell lumens are smaller because more of the wall tissue has been preserved. However, the same botanical structures may be preserved variously as vitrinite, semifusinite and fusinite. Semifusinite is less often mineralized than fusinite. It is also less subject to collapse. Semifusinite is a common constituent of Indian Permian coals. It usually occurs in layers, a fraction of an inch thick and up to few square inches in area, some coal is composed of great numbers of such sheets interlaminated with other macerals.

DISTRIBUTION OF VITRINITE/FUSINITE COAL PRODUCTS

The general pattern of distribution of Permian microconstituents and their composite genetic types have already been known from the works of Navale (1974, 1975), Sen *et al.* (1967) and others.

Karharbari Stage — The Karharbari coal is characterized by vitrinite and fusinite maceral groups derived from macrofragmental fossil tissues.

Vitrinite coal constituent is generally in a state of fine division. In thickness, the sheets average 0·046 to 0·188 mm. However, some individual sheets reach up to 7 mm but seldom exceed 4·00 mm. Even in the finest states of disintegration, the boundaries of vitrinite fragments appear clearly defined. More often 2 to 3% clay mineral and carbonate occur in microscopic joints of thin sheets of vitrinite. Vitrain and vitrinite proportions in micro or macrotypes vary greatly ranging from 31% to 35%, but in some areas (Giridih) it reaches up to 52% of the coal substance (Text-fig. 1).

Fusinite is quite common in which the cell cavities or lumens are filled with clay material or carbonate. Many individual sheets representing wood or bark tissues exhibit transitions between conditions of vitrinite and fusinite. Finely divided fusinite, micrinite and intermediates were disseminated throughout Karharbari coals. The fusinite proportions vary from 42% to 58% (Text-fig. 1). Increased proportions of micrinite commonly associated with fine vitrinite and increased sedimentary mineral matter mark the development of duroclarain bands.

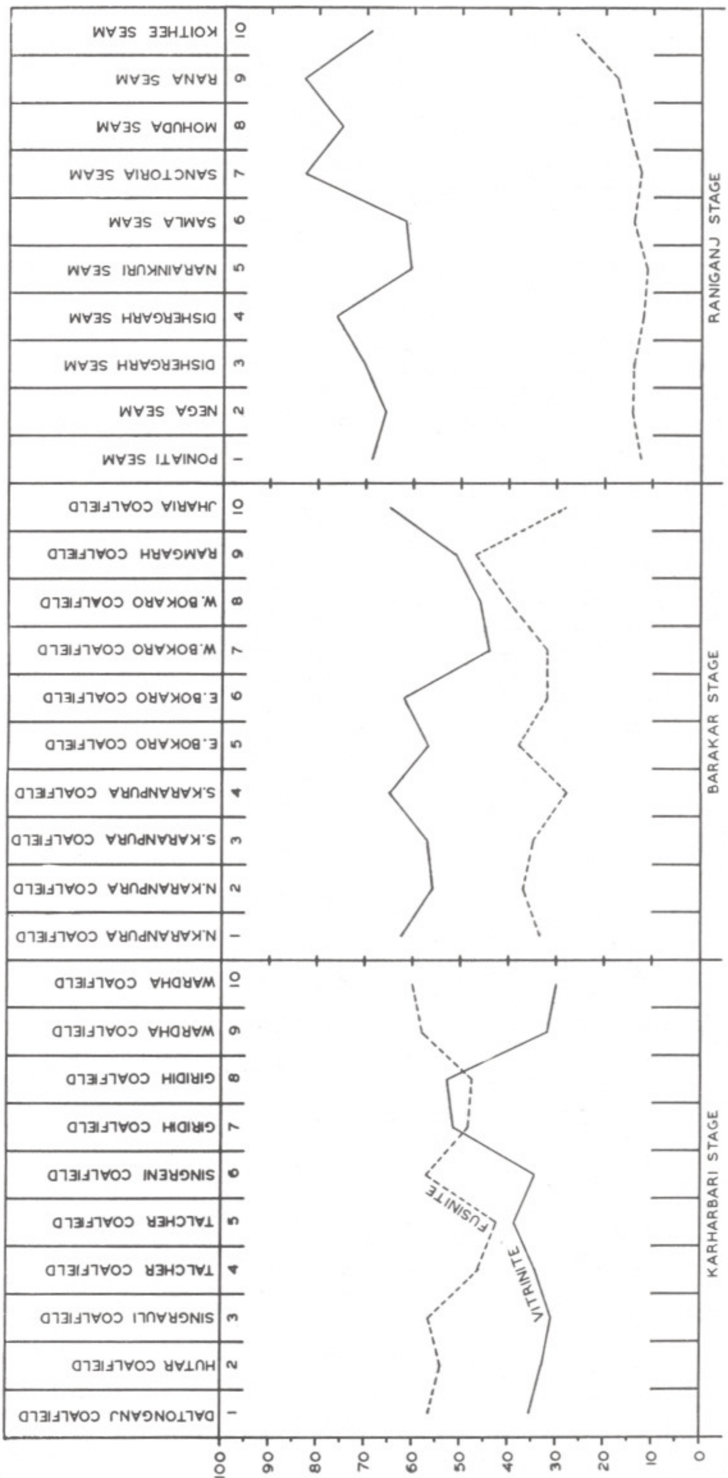
Barakar Stage — In Barakar coal, vitrinite occurs in fairly good proportions. Many vitrinitic sheets show wood and bark structures in well-preserved condition. More often, vitrinitic sheets are in finely divided condition. In thickness, the sheets range from 0·011 to 0·047 mm. Boundaries of vitrinite appear clearly marked. Clay minerals are generally seen in vitrinitic sheets. Vitrinite proportion in Barakar coals ranges from 44% to 65% (Text-fig. 1).

Fusinite occurs in coarse and fine lenticular bodies. The cell cavities or lumens are generally filled with carbonate or clay mineral. Generally, the lenticles are highly compacted with almost complete elimination of the cell cavities. Smaller masses of fusinite are particularly common. Micrinite and fusinite form a considerable proportion of the coal type ranging between 28% and 47% (Text-fig. 1). Average thickness of these constituents vary between 0·026 and 0·089 mm. In addition to the characteristic modes of preservation as represented by vitrinite and fusinite, a considerable proportion exhibit either progressive transition between the two extremes or an intermediate condition.

Raniganj Stage — Vitrinitic constituents are mainly derived from xyloidal tissues of stems constituting wood. Cortex and bark tissues of stem, which are not true wood, are not common. Well-preserved cellular structures may be compared directly with structures of known wood (Pant, 1965). The surface lustre of vitrinite substances may vary depending on the source material. The reflective property of vitrinite which is related to lustre when accurately measured with optical instruments may be used to define the degree of coalification, in other words 'rank'. Cracks are filled with mineral matter. Vitrinite forms a chief maceral group in Raniganj coal composition ranging from 61% to 83% (Text-fig. 1).

Fusinite constituents are in subordinate proportions in the coal composition. Details of cellular structure of wood tissues are often preserved as fusains. Many of the cell cavities are filled with mineral substances. Fusinite occurs as layered sheets of 0·01 to 0·08 mm or as group particles of disintegrated structure cell walls. Layered fusinites were probably formed in one place by fusinization process which results in rapid mass of conversion of cell walls into carbon rich substance. Possibly smaller particles of fusinites were transported into peat swamp from outside sources. These constituents are progressively altered like other substances. Often partly fusinised substances are seen, known as semifusinites. Many individual sheets representing bark and wood tissues exhibit transition between condition of vitrain and fusain. Fusinite group forms 11% to 27% in the total composition of Raniganj coal substance (Text-fig. 1).

It is apparent from the distribution pattern of vitrinite and fusinite constituents (Text-fig. 1) that they are closely interrelated and inversely proportional to each other in the coal composition. The fusinites form 42% to 60% in the Karharbari Stage while in Barakars they form about 28% to 47% showing decreasing tendency. In the succeeding Raniganj Stage, the fusinites form only 11% to 27% with further rapid decrease in the coal composition. Obviously, there is a decrease in tendency from Karharbari Stage to Raniganj Stage. On the contrary, the behaviour of vitrinites is opposite to fusinites. In Karharbari Stage, the proportion of vitrinite ranges from 30% to 53%, while in Barakars it ranges from 44% to 65%. In the succeeding Raniganj Stage, vitrinite constituents form 61% to 83% of the total composition. It is very apparent that there is a tendency of definite increase of vitrinization process from Karharbari to Raniganj Stage. The Text-fig. 1 illustrates the above facts and from the relative distribution of vitrinite and fusinite constituents (Text-fig. 1), it is



TEXT-FIG 1. DISTRIBUTION OF MACROFRAGMENTAL COAL PRODUCTS OF VITRINITE/FUSINITE IN PERMIAN COAL SEAMS OF INDIA possible to demarcate Karharbari, Barakar and Raniganj stages. Also from the above data, environmental conditions of coal formation during Permian sequence may also be evaluated (Navale, 1976).

IMPORTANCE OF VITRINITE/FUSINITE IN COAL UTILIZATION

Vitrinite has special importance in the utilization of bituminous coals, not only because it forms a considerable proportion of material present but also because it becomes plastic when coal is heated. This latter property is important in process of coke formation and also greatly influences the combustion behaviour of the coal. Coals containing little vitrinite do not become markedly plastic on heating and are therefore unsuitable for coke making except when blended with strongly coking coals.

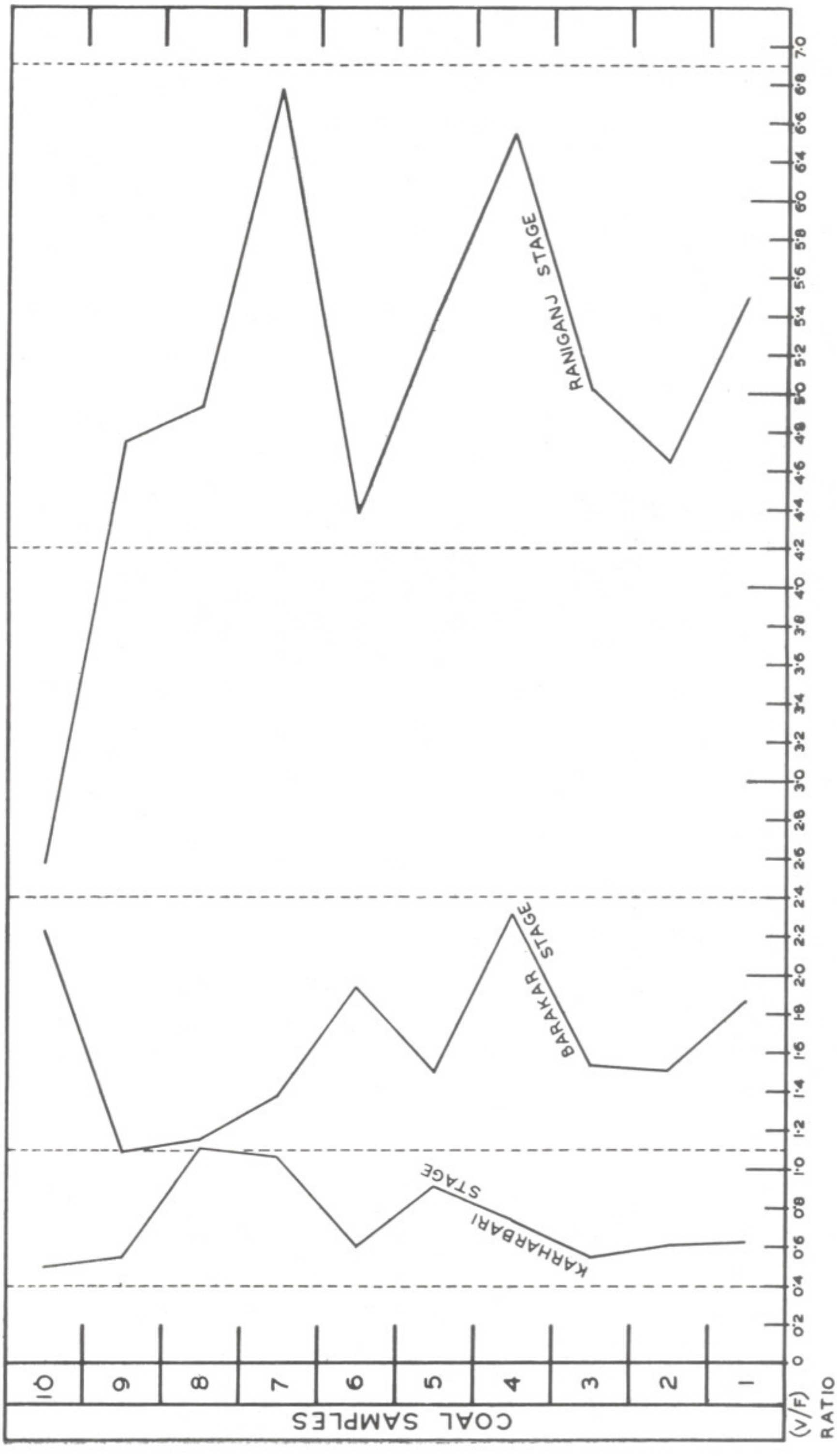
Vitrinite is readily oxidized more than any other coal macerals and this is why coking properties of a coal generally diminishes on weathering. Intrinsically, vitrinite contains little mineral matter and is often associated with low ash coal. When coal is crushed, the vitrinite tends to break into small angular fragments. Thus fine coal is richer in vitrinite than larger sizes.

Vitrinite 'concentrates' may be fairly readily prepared from most coals either by hand picking or by physical means such as specific gravity separation (the specific gravity of vitrinite is about 1·25-1·30 which is lower than for most of other coal macerals). Such concentrates may be examined microscopically for purity and subjected to chemical analysis and carbonization assays. In this way the properties of the vitrinite which alter with rank may be compared for two or more coals. Such comparisons are not possible between the heterogeneous mixtures of macerals from run-of-mine coal.

Fusinite & Semifusinite — Unlike carboniferous coals, Permian coals contain fusinite and semifusinite as common coal products alongwith micrinite and mineral matter. Fusinite has no caking property and acts as diluent. It forms 'inert' substances in carbonization process along with semifusinite, micrinite and mineral matter. The relative presence of inert substances control caking characteristic of coals. More than certain optimum, inert substances deprive caking ability of coals and ultimately cause low grade coals. As fusinite substances have all contrasting properties to that of vitrinites, it is evident that the coals having higher fusinites are poorer in rank for economic utilization. Because of its friability, fusinite despite high intrinsic hardness, concentrates in very fine particle size, some times amounting to dust hindering quality of coals. Fusinites have low yields of byproducts. By reason of its high carbon content and low hydrogen content it does not yield or lend itself to hydrogenation. Fusinite oxidizes with difficulty and therefore caking properties of coal are less shown.

Semifusinite which is more prevalent in Permian coal constituents occurs in layers of a fraction of an inch thick to few square inches in area. Some coals are composed of great number of such sheets interlaminated with other macerals. Semifusinite which has rather similar properties to vitrinites may become weakly plastic during carbonization, some of the so-called semifusinites may in fact be vitrinites. It may be mentioned here that exact evaluation of semifusinites and their nature and properties need to be determined for upgrading the coals. As these substances occur in larger grains in charges of coking coal and unless ground to minus 72 B.S. mesh, they may adversely affect quality of resulting coke.

V/F Ratio — Another important feature of Permian coals is the ratio of vitrinite and fusinite constituents as they by and large govern Permian coal composition. Any evaluation of coal either for stratigraphic correlation or utilization purposes by biopetrological methods largely depends on V/F ratio. The Text-fig. 2 showing V/F ratio curves illustrates certain aspects of Permian coals. In Karharbari coals, the range of V/F ratio is between 0·50 and 1·11 while in Barakar it ranges from 1·9 to 2·32. In the succeeding Raniganj Stage the range is between 4·38 and 6·58. Here and there exceptions are bound to exist such as one shown in Text-fig. 2. However, they are of abnormal nature of coals. It is apparent from the V/F ratio curves that delimitation of Karharbari, Barakar and Raniganj stages may be made. Also, by standardizing the V/F ratio of Permian caking coals and by comparing them with the V/F ratios of



TEXT-FIG 2. VITRINITE / FUSINITE (V/F) RATIO IN PERMIAN COALS OF INDIA unknown prospecting coal deposit, the behaviour properties and stratigraphic position of coal in question may be evaluated.

CONCLUSION

From these studies it is evident that the Indian coals have been formed from Permian vegetable swamps dominated by *Glossopteris* flora. Mainly bark and woody tissues, of the coal forming swamp, transformed into vitrinite and fusinite coal products by variable coalification process. Vitrinite derived from macrofragmental entities is of primary importance in coal utilization. The coking characteristics of the coals could be determined by degree of vitrinization of coal products. Fusinite also derived from macrofragments and a common constituent in Permian coals is 'inert' in technological process. As it is significantly associated with vitrinite, reduction of fusinized products influence the swelling characters of the coals and also the strength of the coke produced. As vitrinite and fusinite constituents are predominant and unseparable entities which govern Permian coals, it is inevitable that the V/F ratio forms the key for evaluation of coals.

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EXPLANATION OF PLATE

PLATE 1

1. Secondary bark tissue (in vitrain) showing serially arranged thin-walled elongated rectangular cells. × 600.

2. Woody tissue (in vitrain) showing fibres having spiral and reticulate thickenings in longitudinal section. × 980.

3. Bark tissue (in vitrain) showing compressed more or less rectangular thick-walled cells. × 400.

4. Bark tissue (in vitrain) showing that it is broken up into more or less rectangular blocks. × 350.

5. Woody tissue (in vitrain) showing bordered pits. × 1200.

6. Woody tissue (in vitrain) showing medullary rays in longitudinal section. × 300.

7. Woody tissue (in collinite) completely gellified. × 300.

8. Woody tissue (in fusinite) showing compressed cells. × 300.

9. Woody tissue (in vitrain) showing medullary rays in tangential section. × 300.

10. Woody tissue (in vitrain) showing pith cells and medullary rays. × 300.

11. Woody tissue (in fusinite) showing fusinized tracheids. × 300.

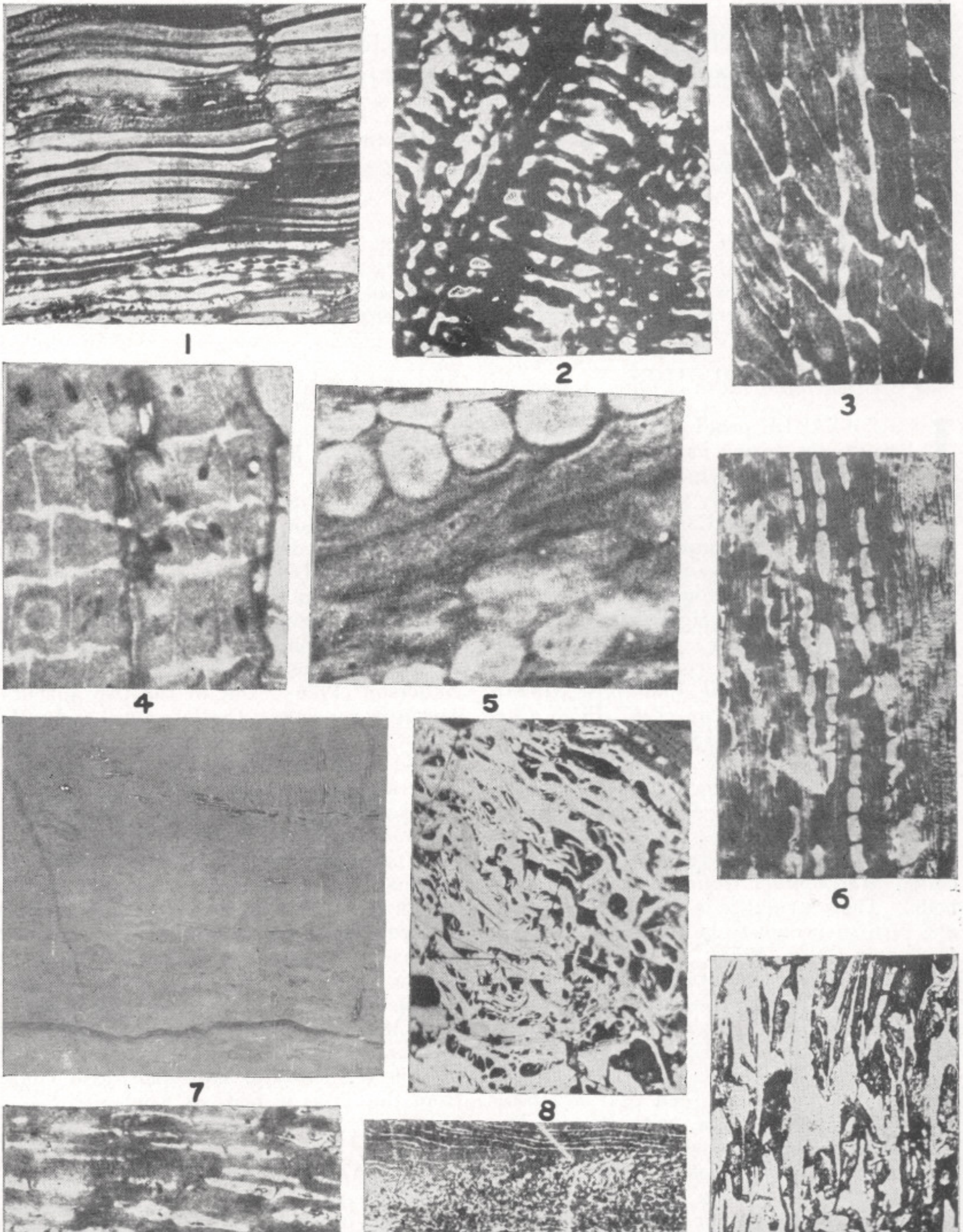

PLATE 1