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Palynofacies of Gondwana sediments of Godavari sub basin: Implications for the palaeoenvironment of continental source

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ABSTRACT

Palynofacies analysis has been carried out in borecore VEM-1 from Vemanpalli area of Chinnur Coalfield of Godavari sub-basin, south India. Palynofacies analysis indicates that the sediments are rich in amorphous organic matter and charcoal. On the basis of the quantitative composition of the sedimentary organic matter, four distinct palynofacies association (A-D) have been identified. Palynofacies-A is marked by the dominance of amorphous organic matter and the sub-dominance of charcoal. Palynofacies-B has been recognized by the dominance of amorphous organic matter along with good percentage of degraded terrestrial and charcoal. Palynofacies-C is acknowledged by the dominance of charcoal along with very less percentage of amorphous organic matter. Palynofacies-D is distinguished by the dominance of structured terrestrial alongwith good percentage of charcoal. Palynofacies A-D, reflect the depositional settings in a distal dysoxic-anoxic deep basin, dysoxic conditions in proximal settings, suboxic conditions in proximal settings and shallowest oxidizing continental shelf respectively.

Key-words: Palynofacies, palaeoenvironment, Chinnur coal belt, Godavari sub-basin.

INTRODUCTION

During the past decades, increased consideration has been paid to the extensive deviation in composition of palynofacies associated with different rock categories which has led to the rapid growth of research in other non-biostratigraphic fields. This is because of the demand in the petroleum industries which determine the source rock potential through the quantity, composition and the color of the sedimentary organic matter recovered from the rock samples. The term palynofacies was coined by Combaz (1964) which describes the total organic content of the palynological association. Further, the hydrocarbon generation relationship to the organic matter types has been approached by Staplin (1969). Palynofacies can be used as a powerful investigative tool when used in combination with geochemical and geophysical processes (Mueller et al. 2014). Consequently, determination of different organic matter types and their quantity (dominance and sub-dominance) provides evidences concerning the palaeoenvironment reconstruction and hydrocarbon potential (Zhang et al. 2015). In general, amorphous organic matter (AOM) is deliberated as oil prone, whereas, structured terrestrial organic matter is linked to gas generation (Duan 2012). For more academic implications, the palynofacies associations must be used in combination with terrestrial palaeoecology, palaeophytogeography and palaeoclimatology.

Palynofacies as a tool has been utilized to define the depositional conditions of various sediments (Batten, 1982; Singh et al. 1992; Tyson, 1995; Cazzulo et al. 2009; Götz et al. 2003; Oboh- Ikuenobe et al. 2005; Closas et al. 2005; Hermann et al. 2012) but very few reports are available from Gondwana sediments (Aggarwal et al. 2012, 2015; Jha et al. 2014; Murthy et al. 2016). In the present study, palynofacies analysis was performed on 18 samples of borecore VEM-1 from Vemanpalli area of Godavari Graben. The purpose of the present investigation is to construe the composition and distinctiveness of the various dispersed sedimentary organic matter and to reconstruct the palaeoenvironment of the Gondwana sediments on the basis of palynofacies.

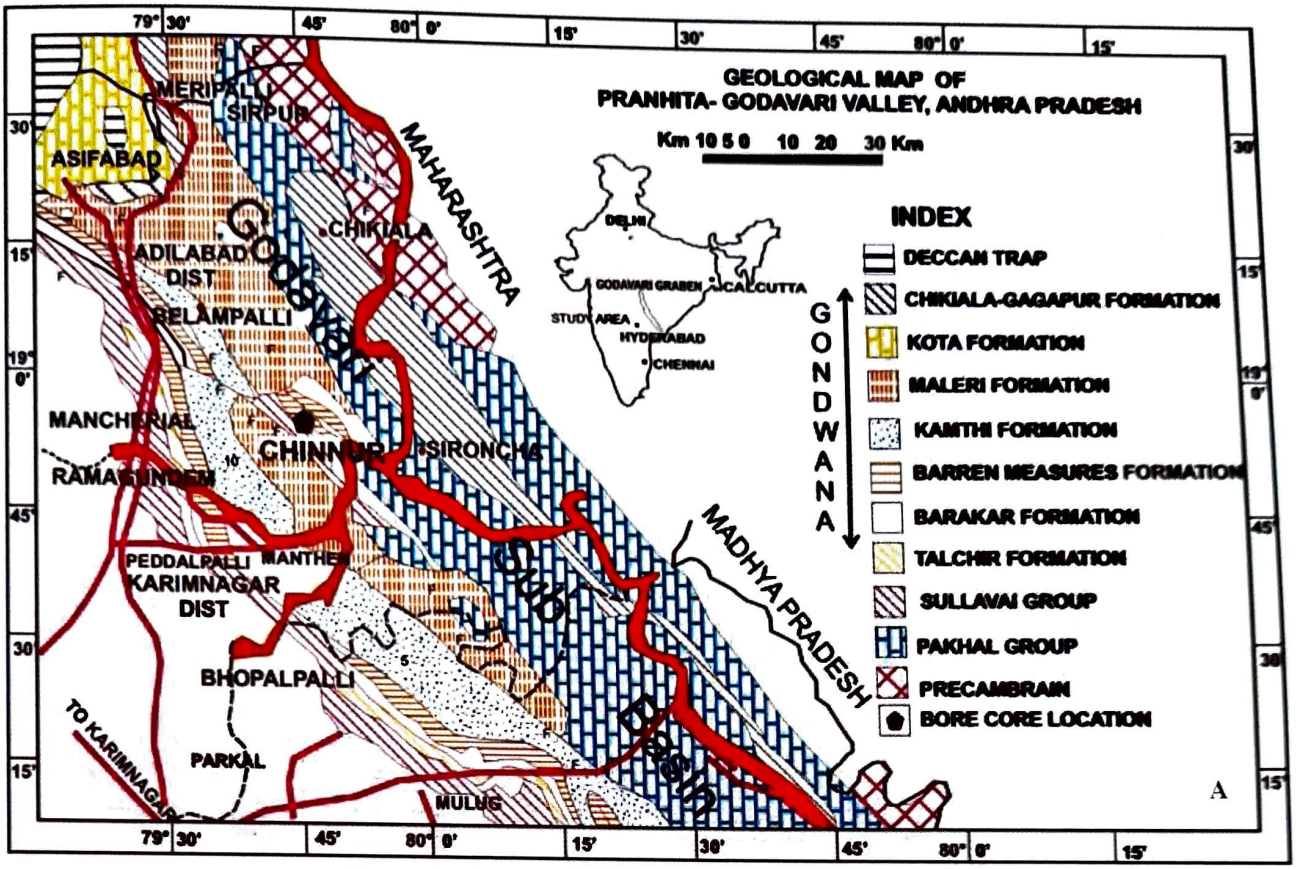
GEOLOGY OF THE STUDY AREA

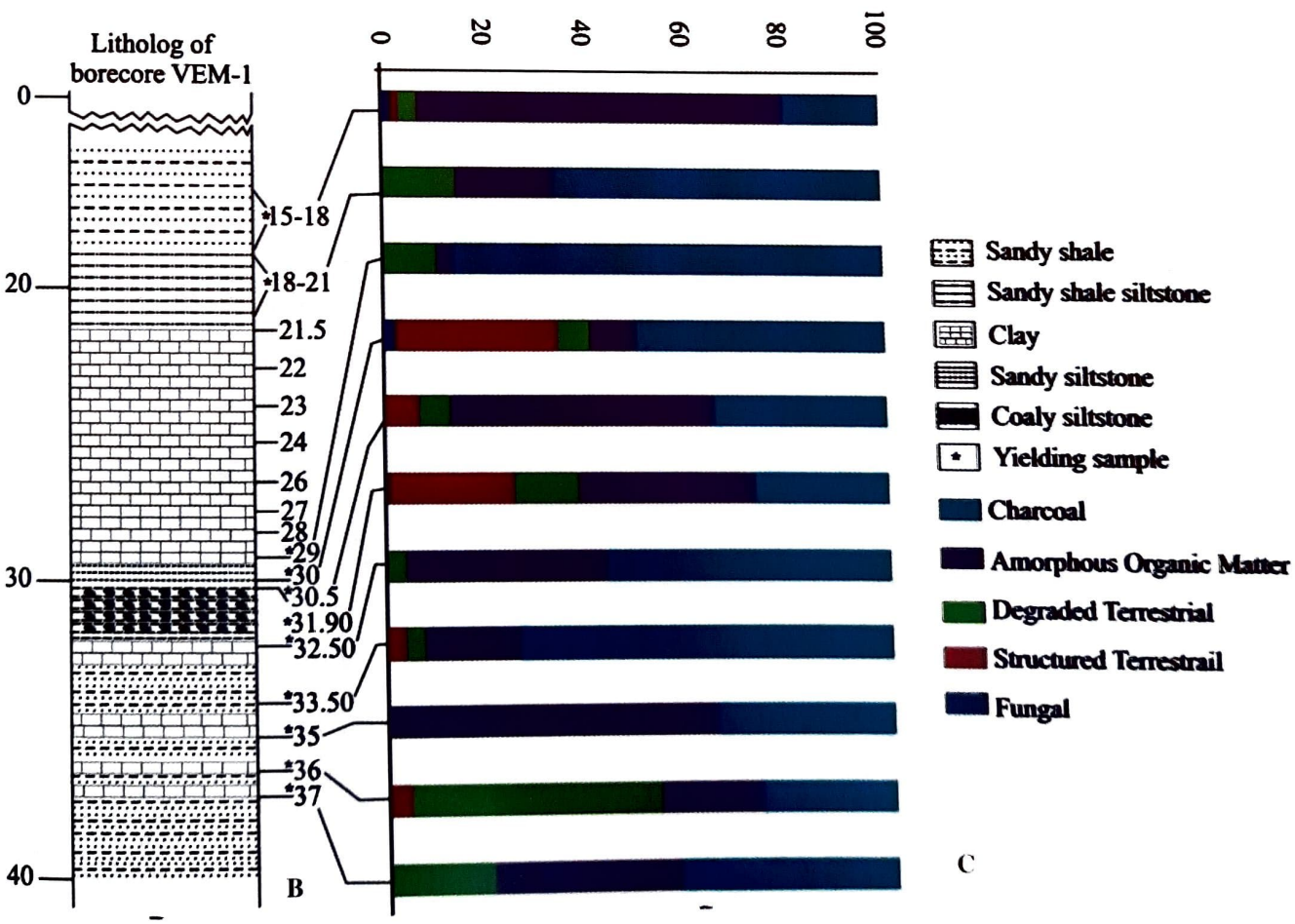
The Godavari Graben is a linear NNW-SSE trending coalbelt on Precambrian/Vindhyan platform, extending from north of Boregaon, Maharashtra in the north to Eluru in the east coast of south India. Godavari Graben holds a unique position as it has more or less a complete succession from Permian to Cretaceous sediments and the only coal producing area in southern India. The basin covers an area of about 17,000 sq km bounded by latitudes 16^0 382 and 19^0 322 and longitudes 79^0 122 and $81^0$392 with an average width of 55 km, though, there is a well defined constriction in the Paloncha-Kothagudem area, where it is only 6 km wide. The Lower Gondwana sediments are exposed along both the eastern and western margins of the Godavari Graben, while the Upper Gondwana sediments cover the central/axial portion (Raja Rao 1982). The Lower Gondwana succession is represented by Talchir, Barakar, Barren Measures and Raniganj formations, while the Upper Gondwana formations are Kamthi, Maleri, Kota and Chikiala Sandstone. Based on tectonic setting and the nature of lithic fill, the Pranhita-Godavari Graben, has been sub-divided into four structural sub basins Godavari sub-basin, Kothagudem sub-basin, Chintalapudi sub-basin and Krishna-Godavari coastal sub-basin (Raja Rao 1982).

Godavari sub-basin covers an area of 1235 sq km with a strike length of 220 km. The basin extends from Antargaon in the NW to north of Paloncha. From the southern side, this is bordered by the Proterozoic Formation in Pakhal-Sullavi trough, on the other hand a narrow outcrop of Barakar-Kamthi beds in Paloncha area links Godavari sub-basin to Kothagudem sub-basin (Text-Fig.1). The basin holds an unbroken sequence of Permian-Triassic sediments while the Jurassic-Lower Cretaceous deposits overlie the Permian-Triassic sediments with a well defined hiatus. The major coal resources of Godavari Graben are confined to Godavari sub-basin. Total fifteen coalbelts have been identified in the Godavari Graben, out of which Vemanpalli area from Chinnur coalbelt, situated in the Godavari sub-basin, has been taken for the present investigation. Chinnur coalbelt extends about a strike length of 20 km from Budharam to Enkampet. Exploration division confirmed the presence of five coal seams in this Chinnur belt, the main belt is referred to Chinnur West belt. About 350-500 m thick Barren Measures strata (devoid of any coal) has been confirmed in the Chinnur area by Ramanamurthy (1979). The coal bearing strata in Chinnur area, exposed in the axial part of the Godavari Graben, as a large fault is known as Belampalli-Chinnur fault.

MATERIAL AND METHODS

Eighteen samples were analyzed from borecore VEM-1 for palynological and palynofacies studies. Out of 18 samples only 11 samples were rich in organic matter but all the samples were devoid of spore-pollen. The samples collected from different lithologies *viz.*, clay, sandy siltstone, carbonaceous shale, gray shale, sandstone were subjected to simple maceration technique. For the removal of silica, first the material (5-10 gm) was crushed to 2mm-4mm size and subjected to hydroflouric Acid (HF) for 2-3 days. After thorough washing, the samples were treated with commercial nitric acid (HNO_3) for 3-4 days for the digestion of humic matter and later they were treated with 10% KOH to bleach the organic matter. Finally, the residue was mounted in Canada balsam with the help of Poly Vinyl Chloride (PVC). More than 300 organic matter particles were counted in each sample to obtain significant diversity of the organic matter. After calculating the percentage of each category, for each





Text figure 1: A) Location map of the borecore VEM-1, Vemanpalli area, Godavari Graben, India, B) Litholog of borecore VEM-1 and C) distribution of different palynofacies in each sample.

palynofacies association, the average of each category was calculated. Quantitative distribution of different types of the organic matter recovered in each sample from borecore VEM-1 have been shown in Text Figure1 and distribution of the different types of the palynofacies recovered through cluster analysis (CONISS) in TILIA statistical software (Hammer et al. 2001) have been shown in Text Figure 2. Different types of the sedimentary organic matter recovered have been shown in Text Figure 3. All the samples were studied using Olympus BX61 microscope and prepared slides are housed at the museum of Birbal Sahni Institute of Palaeosciences, Lucknow.

RESULTS

Characteristics of sedimentary organic matter:

In the present study, the sedimentary organic matter is of continental origin which is entirely different from marine deposits. All the samples are devoid of spore-pollen and algae and phytoplankton derived organic matter are also very scarce. The palynofacies components in this study are broadly classified as algal/ fungal, structured terrestrial, degraded terrestrial, charcoal (black debris) and amorphous organic matter (AOM). The detailed identification of palynofacies components can be referred to the previous studies (Marson and Pocock 1981; Hart 1986; Pocock et al. 1987; Darby and Hart 1994; Tyson 1995; Batten 1996).

Palynofacies analysis indicates that the sediments are rich in amorphous organic matter and charcoal. Amorphous organic matter (AOM) has been identified as granular or gelified forms. In the present study, the most common type is the granular form, while gelified forms are little bit scarce. The granular forms reveal aggregated irregular shapes by organic particles (Xiao et al. 1997). Such type of organic matter is derived either by the phytoplankton, bacterial degradation or fresh water algae that gathered in oxygen exhausted water (Pacton et al. 2011). The second type of gelified AOM is yellow to light brown, angular shaped. These particles retain the original texture of light yellow to brown smooth surfaces with fibrous margins. Such type of organic matter is derived by the microbial reworking of terrestrial fragments (Pacton et al. 2011; Tabara et al. 2015).

Structured terrestrial are plant derived fragments, including cuticles, plant tissues, tubes and filaments, etc (Ercegovac & Kostic 2006). Cuticles are translucent, light yellow to yellow and the well preserved cuticles retain the cellular surface structures. Plant tissues are infrequent as because of their softness these are very difficult to be preserved and are usually obscure to identify because of the absence of obvious characteristics. In the present study tubes and filaments and gelified particles are very scarce but very easy to identify because of their distinct morphological and optical features. Gelified particles have recently been introduced in numerous research studies (Sebag et al. 2006; Graz et al. 2010; Tabara et al. 2015). These particles are mainly derived from the leaf organs of the plants. Black opaque particles (charcoal) are characterized by their typical black colour. This category of grains is especially frequent in the palynodebris of the present study. Opaque particles are without cellular structures, mostly homogenous with elongated to rectangular shapes and sharp angular outlines.

Biodegraded structured terrestrial organic matter is characterized by their indistinct cellular structures, which is produced by the fungal and bacterial activities. In the present study fungi has been found to be the observable degrading agents, that converts the vegetal parts into different organic types with the help of biochemical reactions but it is very scant in all the studied samples. Fungi are unique in their types and morphology and are easily recognized by their hyphae, filaments and dark colour spores.

Palynofacies Assemblage

On the basis of quantitative data of the sedimentary organic matter obtained from the analyzed samples, four distinct palynofacies assemblages (A-D) have been identified (Plate 1).

Palynofacies Assemblage-A (PF-A) is distinguished by the dominance of amorphous organic matter (avg. 63.66%) and sub-dominance of black debris (avg. 29.68%). On the other hand, structured terrestrial, degraded terrestrial are 2.5% and 3.5%

Plate 1

An overview of different type of the palynofacies, BSIP slide no. 16170, N39-2 (10x). 2. Palynofacies showing structured organic matter (cuticle) and amorphous organic matter, BSIP slide no. 16170, M39-4 (20x). 3. Palynofacies showing wood part, BSIP slide no. 16171, O33 (10x). 4. Palynofacies showing structured organic matter in association with charcoal, BSIP slide no. 16172, T43-3 (20x). 5. Palynofacies showing tracheid (structured charcoal), BSIP slide no. 16172, Q60-4 (20x). 6. Palynofacies showing structured organic matter (tracheid), BSIP slide no. 16172, T57-1 (40x). 7. Palynofacies showing amorphous organic matter in association with charcoal, BSIP slide no. 16171, R48-4 (20x). 8. Palynofacies showing charcoal, BSIP slide no. 16172, N36 (10x). 9. Palynofacies showing cuticle, BSIP slide no. 16171, G46-4 (20x). 10. Palynofacies showing degraded terrestrial, BSIP slide no. 16172, T57-1 (20x).

respectively, while fungal content is very scarce (avg. 0.65%). This palynofacies has been recovered on the depth levels of 15-18 m, 30.5 m and 35 m (Text Figure 2 & Plate 1).

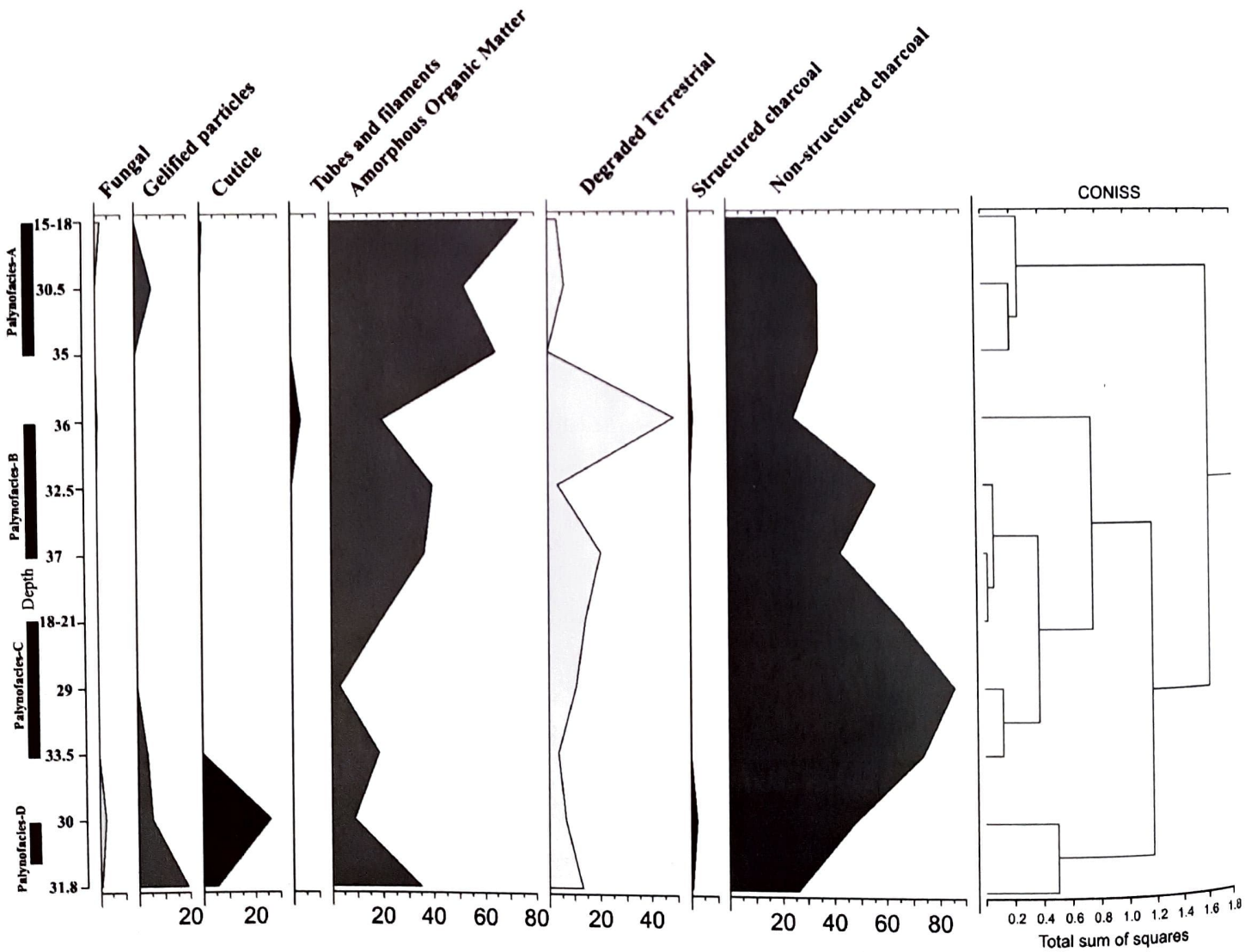
Palynofacies Assemblage-B (PF-B) has been recognized by a good percentage of degraded terrestrial (avg. 24.5%) in combination of amorphous organic matter (avg. 32.1%) and black debris (avg. 41.9%), while structured terrestrial and fungal content are average (1.24% and 0.177% respectively). This palynofacies has been recorded on the depth levels of 36 m, 37 m and 32.5 m (Text Figure 2 & Plate 1).

Palynofacies Assemblage-C (PF-C) is acknowledged by the dominance of black debris (avg. 75.2%). Amorphous organic matter, degraded terrestrial and structured terrestrial are 13.9%, 9.58% and 1.2% respectively. This palynofacies is devoid of fungal activity. This palynofacies has been recovered on the depth levels of 18-21m, 29 m and 33.5 m (Text Figure 2 & Plate 1).

Palynofacies Assemblage-D (PF-D) is characterized by a good percentage of structured terrestrial (avg. 28.18%) in combination of amorphous organic matter (avg. 21.9%) and black debris (avg. 38.47%). This palynofacies has been recovered on the depth levels of 30m and 31.8 m (Text Figure 2 & Plate 1).

DISCUSSION

The primary composition of sedimentary organic matter is represented by the palynofacies after long process of sedimentation and the organic matter composition represents the palaeoenvironment. The quantitative palynofacies assemblages reveal remarkable capability to represent the environmental evolution under diverse climatic and sedimentary settings (Sebag et al. 2006). As a result, palynofacies analysis



Text Figure 2: Classifications of palynofacies produced by cluster analysis in TILIA.

has been widely used as an important parameter for palaeoenvironment reconstruction (Buchardt and Nielsen 1991). Different types of organic matter association reflects the oxic-anoxic conditions, which estimates the lake level changes and approximate distance from the lakeshore (Sebag et al. 2006).

Palynofacies Assemblage-A (PF-A): distal anoxic-dysoxic deep basin

PF-A is represented by the dominance of Amorphous Organic Matter (AOM). High percentage of AOM is deposited in a low energy setting with a high preservation rate. Anoxic-dysoxic conditions are associated with the preservation of AOM (Tyson 1993), which is subjected to the deep and low energy aquatic environments. Aerobic microbes are the important source of granular AOM. The palynofacies assemblage is represented by the small size phytoclast particles, which point towards distal deposition (Tyson and Follows 2000). Hence, this palynofacies assemblage is considered to be deposited in a distal anoxic-dysoxic deep basin environment. The samples of this palynofacies are represented by clay and grey shale / carbonaceous shale, which are generally deposited in deep lake sediments.

Palynofacies Assemblage-B (PF-B): dysoxic shelf

PF-B is represented by the dominance of AOM along with the very good percentages of degraded terrestrial organic matter and charcoal. Degraded organic matter is derived by the oxidation of structured terrestrial matter (cuticles, plant tissues, etc.). Such type of palynofacies has been considered to be deposited in reduced flow of water (Tyson 1993; Peters et al. 2013). Phytoclasts size are relatively higher than PF-A. In addition, moderate percentages of AOM represent the dysoxic depositional settings. As the palynofacies assemblage is dominated by the AOM, alongwith the degraded biostructured and relatively larger phyoclasts, it is interpreted to represent the proximal dysoxic shelf. The samples of this palynofacies are represented by clay, which generally exists in low energy settings. Therefore, this palynofacies was most likely deposited in proximal shelf with least turbidity.

Palynofacies Assemblage-C (PF-C): Proximal suboxic shelf

PF-C is distinguished by the dominance of charcoal, which is deposited in oxidizing conditions. Additionally, the low percentages of degraded terrestrial, structured terrestrial and AOM favors the oxidizing conditions of the palynofacies deposition. Charcoal/ black debris may transport to shorter or longer distances depending on their size (Blong and Gillepse 1978). Charcoal was found to be very common in the palynological slides. Charcoal is usually rich in high energy, near shores, streams, prodelta, delta-fronts, (Pieñkowski and Waksmundzka 2009) because of its lightness and least activity towards biological/chemical degradation. Preservation of charcoal may replicate flooding actions in oxidizing conditions from the fluvio-deltaic fronts (Tyson 1989; Cincotta et al. 2015). The samples of this palynofacies are represented by shaly siltstone and sandy clay, which generally exist in near shores, streams deposits. Therefore, this palynofacies was most likely deposited in shallow settings.

Palynofacies Assemblage-D (PF-D): Proximal oxic shelf

PF-D is distinguished by the dominance of structured terrestrial matter which is originated from the terrestrial plant parts. Higher percentage of the structured terrestrial is generally to be associated with the shorter transport and tends to be deposited close to the resource (Tyson and Follows 2000). Additionally, the high percentages of charcoal content and low amount of AOM indicate oxic sedimentary settings. As the palynofacies assemblage is represented by the largest size of phytoclasts particles, it can be interpreted to be highly proximal deposits (Zhang et al. 2015). The samples of this palynofacies are represented by the sandy siltstone and coaly siltstone, which generally exist in shallow lake/delta plain deposits. Therefore, this palynofacies was most likely deposited in a shallow near shore settings.

CONCLUSION

The observation of the present study can be summarized as follows:

1) Sedimentary organic matter is mainly dominated by AOM and charcoal. Four distinct palynofacies assemblages (A-D) have been recognized. PF-A is dominated by AOM. PF-B is characterized by the dominance of AOM in combination of degraded organic matter. PF-C is distinguished by the dominance of charcoal. PF-D is very high in structured terrestrial along with charcoal.

2) Based on the palynofacies assemblages the samples of PF-A represents the distal anoxic-dysoxic deep basin, PF-B symbolizes dysoxic shelf, PF-C signifies proximal suboxic shelf and PF-D denotes proximal oxic shelf. This shows their shifting from aquatic to terrestrial (A-D) ecosystem, that is PF-A represents the deepest water system and PF-D denotes the shallowest shelf of the basin transition with large influx of terrestrial plant material.

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REFERENCES

Aggarwal N., Jha N., Joshi H. & Mishra S. 2015. Dispersed organic matter studies in Permian succession from Mamakannu block of Godavari Graben, South India. Indian Geol. Cong. 7(2): 5-15.

Aggarwal N., Jha N. & Singh A. 2012. Palynology, palynofacies and palaeoenvironmental interpretations of sedimentary sequence in core MLG-23 from Gundala area, Godavari Graben, India. Indian Geol. Cong. 4(2): 19-35.

Batten D.J. 1982. Palynofacies, paleoenvironments and petroleum. J. Micropaleontol. 1: 107-114.

Batten D.J. 1996. Palynofacies and palaeoenvironmental interpretation, in J. Jansonius and D.C. McGregor, eds., Palynology: principles and applications. Am. Assoc. Stratigra. Palynol. 3: 1011-1064.

Buchardt B. & Nielsen M.V. 1991. Comparison of organic geochemical and palynofacies methods: example from the Upper Triassic Gassum Formation in Denmark. Bull. Geol. Soc. Den. 38: 267-277.

Cazzulo-Klepzig M., Mendonça Filho J.G., Guerra-Sommer M., Menezes T.R., Simas M.W., Mendonça J.O. & Degani- Schmidt I. 2009. Effect of volcanic ash-fall on a Permian peatforming environment, on the basis of palynology, palynofacies and paleobotany (Faxinal Coalfield, Brazil). Rev. Bras. Paleontolog. 12(3): 179-194.

Cincotta A., Yans J., Godefroit P., Garcia G., Dejax J., Benammi M., Amico S. & Valentin X. 2015. Integrated paleoenvironmental reconstruction and taphonomy of a unique upper Cretaceous vertebrate-bearing locality (Velaux, Southeastern France). Plos One 10(8): 1-20.

Closas M.C., Permanyer A. &Vila M.J. 2005. Palynofacies distribution in a lacustrine basin. Geobios 38: 197-210.

Combaz A., 1964. Les palynofaciès: Rev. Micropaléontol. 7: 205–218.

Darby J.D. & Hart G.F. 1994. Organic sedimentation in a carbonate region, in Traverse, A. (ed.) Sedimentation of organic particles: Cambridge University Press, p. 177-197.

Duan Y. 2012. Geochemical characteristics of crude oil in fluvial deposits from Maling oilfield of Ordos Basin, China. Org. Geochem. 52: 35-43.

Ercegovac M. & Kostiæ A. 2006. Organic facies and palynofacies: nomenclature, classification and applicability for petroleum source rock evaluation. Int. J. Coal Geol. 68: 70-78.

Götz A.E., Török Á., Feist-Burkhardt S. & Konrád G. 2003. Palynofacies patterns of Middle Triassic ramp deposits (Mecsek Mts., S Hungary): A powerful tool for high-resolution sequence stratigraphy. Geoaustria. Mit- teilungen der Gesellschaft der Geologie und Bergbaustudenten in Öster-reich 46: 77-90.

Graz Y., Di-Giovanni C., Copard Y., Laggoun-Défarge F., Boussafir M., Lallier-Verges E., Baillif P., Perdereau L. & Simonneau A. 2010. Quantitative palynofacies analysis as a new tool to study transfers of fossil organic matter in recent terrestrial environments. Int. J. Coal Geol. 84: 49-62.

Hammer Ø., Harper D.A.T. & Ryan P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electron. 4: 1-9.

Hart G.F. 1986. Origin and classification of organic matter in clastic systems: Palynology 10: 1-23.

Hermann E.S., Kürschner W.M., Hochuli P.A., Bucher H., Ware D., Goudemand N. & Roohi G. 2012. Palynofacies analysis of the Permian-Triassic transition in the Amb section (Salt Range, Pakistan): implications for the anoxia on the South Tethyan Margin. J. Asain Earth Sci. 60: 225-234.

Jha N., Sabina P.K., Aggarwal N. & Mahesh S. 2014. Late Permian Palynology and depositional environment of Chintalapudi sub basin, Pranhita–Godavari basin, Andhra Pradesh, India. J. Asain Earth Sci. 79: 382-399.

Marson Th.C. & Pocock S.A.J. 1981. The classification of plant derived particulate organic matter in sedimentary rocks-review in organic maturation studies and fossil fuel exploration (Ed. J. Brooks). Academic Press London: 145-176.

Mueller S., Veld H., Nagy J. & Kürschner W.M. 2014. Depositional history of the Upper Triassic Kapp Toscana Group on Svalbard, Norway, inferred from palynofacies analysis and organic geochemistry. Sediment. Geol. 310: 16-29.

Murthy S., Mahesh S. & Roy J.S. 2016. Palyno-Petrographical Facet and Depositional Account of Gondwana Sediments from East Bokaro Coalfield, Jharkhand. J. Geol. Soc. India, 88(5): 549-558.

O'ɔoh-Ikuenobe F.E., Obi C.G. & Jaramillo C.A. 2005. Lithofacies, palynofacies, and sequence stratigraphy of Palaeogene strata in Southeastern Nigeria. J. African Earth Sci. 41: 79-102.

Pacton M., Gorin G.E. & Vasconcelos, C. 2011. Amorphous organic matter — experimental data on formation and the role of microbes. Rev. Palaeobot. Palynol. 166: 253-267.

Peters D.A., Agama C.I., Asiedu D.K. & Apesegah E. 2013. Palynology, palynofacies and palaeoenvironments of sedimentary organic matter from Bonyere-1 Well, Tano basin, western Ghana. Int. Lett. Nat. Sci. 5: 27-45.

Pieñkowski G. &Waksmundzka M. 2009. Palynofacies in Lower Jurassic epicontinental deposits of Poland: tool to interpret sedimentary environments. Episodes 32: 21-32.

Pocock A.A.J., Vasanthy G. & Venkatachala B.S. 1987. Introduction to the study of particulate organic materials and ecological perspectives. J. Palynol. 23-24: 167-188.

Ramanamurthy B.V. 1979. Report on occurrence of a coal seam in the Kamthi formation, from the Ramagundam area of the Godavari Valley Coalfield, and its stratigraphic significance. GSI, Misc. Pub. 45: 89-93.

Rao Raja C.S. 1982. Coalfield of India-2. Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. GSI Bull. Ser. A, 45: 9-40.

Sebag D., Copard Y., Di-Giovanni C., Durand A., Laignel B., Ogier S. & Lallier-Verges E. 2006. Palynofacies as useful tool to study origins and transfers of particulate organic matter in recent terrestrial environments: synopsis and prospect. Earth Sci. Rev. 79: 241-259.

Singh A., Mishra B.K., Singh B.D. & Navale G.K.B. 1992. The Neyveli lignite deposits (Cauvery Basin), India: Organic composition age depositional pattern. Int. J. Coal Geol. 21: 45-97.

Staplin F.L. 1969. Sedimentary organic matter, organic metamorphism, and oil and gas occurrence: Bull. Can. Petrol. 17(1): 47-66.

Tabãrã D., Pacton M., Makou M. & Chirilã G. 2015. Palynofacies and geochemical analysis of Oligo-Miocene bituminous rocks from the Moldavidian Domain (Eastern Carpathians, Romania): Implications for petroleum exploration. Rev. Palaeobot. Palynol. 216: 101-122.

Tyson R.V. & Follows B. 2000. Palynofacies prediction of distance from sediment source: a case study from the Upper Cretaceous of the Pyrenees. Geology 28: 569-571.

Tyson R.V. 1989. Late Jurassic palynofacies trends, Piper and Kimmeridge Clay Formation, UK onshore and offshore. In: Batten, D. J., and Keen, M. C. (Eds), Northwest European Micropalaeontology and palynology. British Micropalaeontol. Soc. Ser.: 135-172.

Tyson R.V. 1993. Palynofacies analysis. In: Jenkins, D.J. (Ed.), Applied Micropalaeontology. Kluwer Academic Publishers, Dordrecht: 153-191.

Tyson R.V. 1995. Sedimentary Organic Matter: Organic Facies and Palynofacies. Kluwer Academic, Dordrecht, Holland: 615.

Xiao X.M., Liu Z.F. & Shen, J.G. 1997. The fluorescence alteration patterns and origin types of immature and low-mature amorphous kerogen in terrestrial source rocks (in Chinese). Chin. Sci. Bull. 42: 1968-1971.

Zhang M., Ji L., Wu Y. & He, C. 2015. Palynofacies and geochemical analysis of the Triassic Yanchang Formation, Ordos Basin: Implications for hydrocarbon generation potential and the paleoenvironment of continental source rocks. Int. J. Coal Geol. 152: 159-176.