Hydrocarbon Potential of the Paleogene Disang Group, Manipur Region, India-A Palynological Approach

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Abstract In the present study, the rocks of the Disang Group of Manipur are evaluated for source rock potential for hydrocarbons. In these Paleogene rocks, amorphous organic matter is the most abundant component in association with other forms of organic matter. Other types of organic matters such as charcoal, partly biodegraded land plant fragments, black debris, spores and pollens are recorded as well. Rock-Eval and TOC analysis of the studied samples suggest that all the rocks have poor organic richness (TOC < 0.5 %) and poor hydrocarbon generation potential (S2 < 0.5 mgHC/g rock). The organic matter content is predominantly of Type III and Type IV. The T_{max} and Productive Index values support the results of visual kerogen analysis. Most of the kerogen is of low level of maturity inferred from light colour of amorphous organic matter in some samples. This conclusion is also supported by Low T_{max} values and low productive index obtained from these samples. TAI (Thermal Alteration Index) values above 3.5 suggest highly mature to overmature mixed palynofacies. The Disang Group of the Manipur appears poor to moderate gaseous hydrocarbons as far as hydrocarbon potential is concerned.

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1 Introduction

Manipur belongs to the north-eastern region of India which shares international border with Myanmar on the eastern and southern sides. The remaining half of this state is neighboured to the states of Nagaland, Assam and Mizoram respectively on the northern, western and south-western sides (Fig. 1). The hill-ranges of Manipur and Nagaland states of India, which form an integral part of the Indo-Myanmar Range (IMR) have accretionary prism due to subduction of the Indian plate below the Myanmar plate during the Apline-Himalayan tectogenesis (Acharyya et al. 1986). Cretaceous and Tertiary sedimentary sequences dominantly occur in the Manipur state. They are associated with minor igneous and low- to medium-grade phyllitic schist, quartzites, marble, and gneiss. The northeast and eastern part of the state is occupied by the older group of Metamorphic Complex and Ophiolite Mélange Zone. These Ophiolites are associated with exotic sedimentary blocks of chert, limestone, red and black clay/shale, sandstone and conglomerate. The central part of the Manipur state is composed of the Paleogene flysch sediments including Disang and Barail groups and that of western part mainly consist of molasses succession of Surma and Tipam groups (Fig. 1). The Paleogene rocks are well exposed in the Imphal valley and eastern part of the Manipur state and are represented by the Disang and Barail groups (Fig. 2). The Disang Group is subdivided into two formations namely, Lower Disang and Upper Disang. The Lower Disang Formation is made up of mainly sandstone and shale, while the Upper Disang Formation is represented by a rhythmic series of sandstone, siltstone and shale containing mega and microfossils and trace fossils. The Barail Group is made up of thick bedded sandstone with alternation of shale and sandstone. The overlying molassic sequence of the Surma Group consists of alternation of sandstone and shale; with more argillaceous horizons in the middle associated with minor conglomerate. The generalised stratigraphic succession is given in the Table 1.

An account on the geology of the Manipur region is given by Theobald (1871), Pascoe (1914), Evans (1932), Nandy (1980) and Acharyya et al. (1989). Chungkham and Jafar (1998), Chungkham et al. (1992), Singh et al. (2010), Sijagurumayum et al. (2011, 2014) and Singh et al. (2013) have contributed considerably towards fossil findings including planktonic foraminifera and molluscs in this region. Recently, Singh and Meera (2013) have evaluated maturation of organic matter and type of organic matter from the Lower Tertiary rocks exposed at Sora, Changamdabi and Keirak areas of Imphal valley, Manipur. They further have suggested that the middle and upper parts of the Disang Group in these areas may have potential for exploration of hydrocarbons (gas). Recently, Singh et al. 2013 firstly reported dinoflagellate cysts namely *Hystrichokolpoma rigaudiae*, *Cordosphaeridium* sp. and microforaminiferal linings such as Planispiral type III, Planispiral type IV, Biserial type II, Trochospiral type I and Trochospiral type II from the Upper Disang Formation. Rock-Eval Pyrolysis is widely used for determining the amount and type of organic matter for source rock evaluation of hydrocarbon potential (Espitalié et al. 1977, 1984). In this study we have utilised

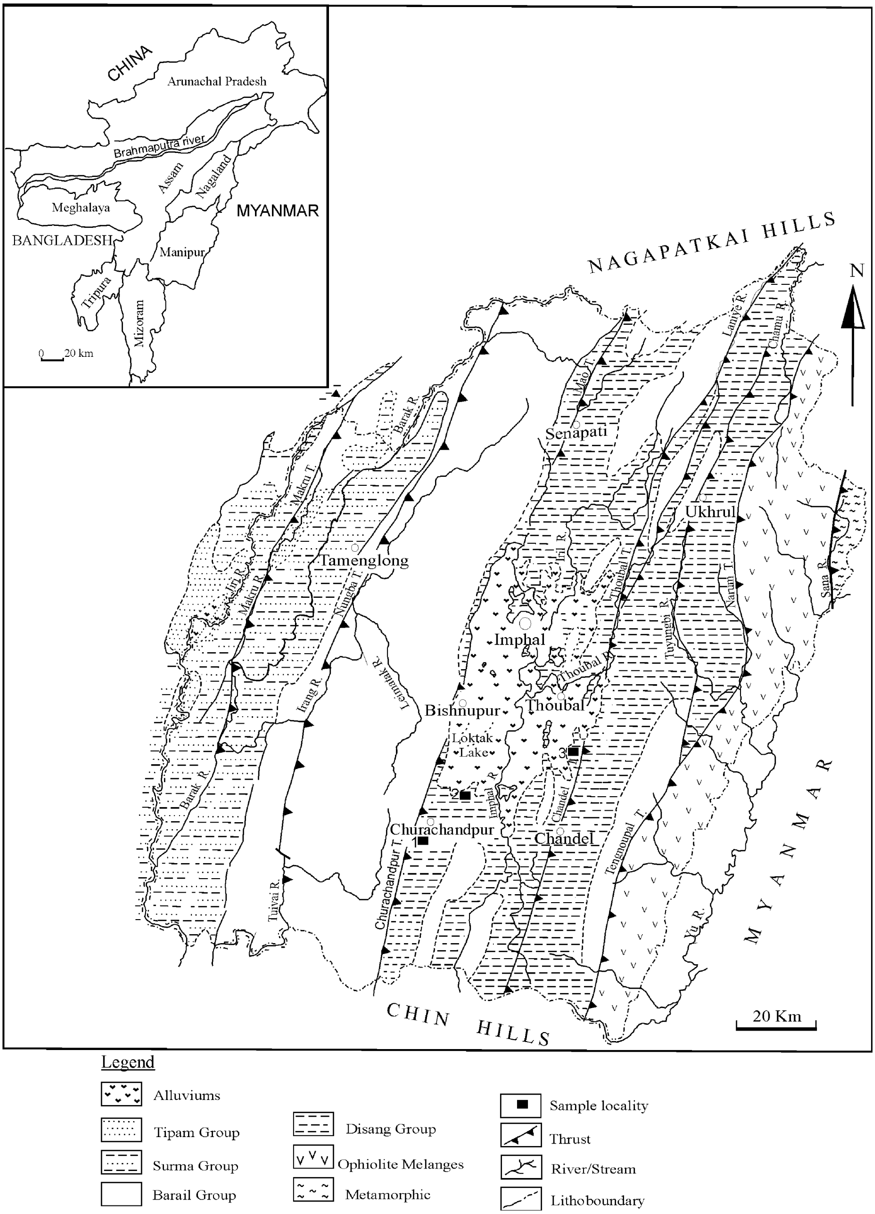

Fig. 1 Geological map of Manipur (after Singh et al. 2013) showing sample localities (*1* Gelmoul quarry, *2* Thanga Ngaram and *3* Khunutaba Ching, Kakching)

this technique for source rock evaluation for hydrocarbons from the outcrop samples of the Disang succession of Manipur region and the way of palynofacies as well. Total organic carbon (TOC) and other related parameters such as Si (free

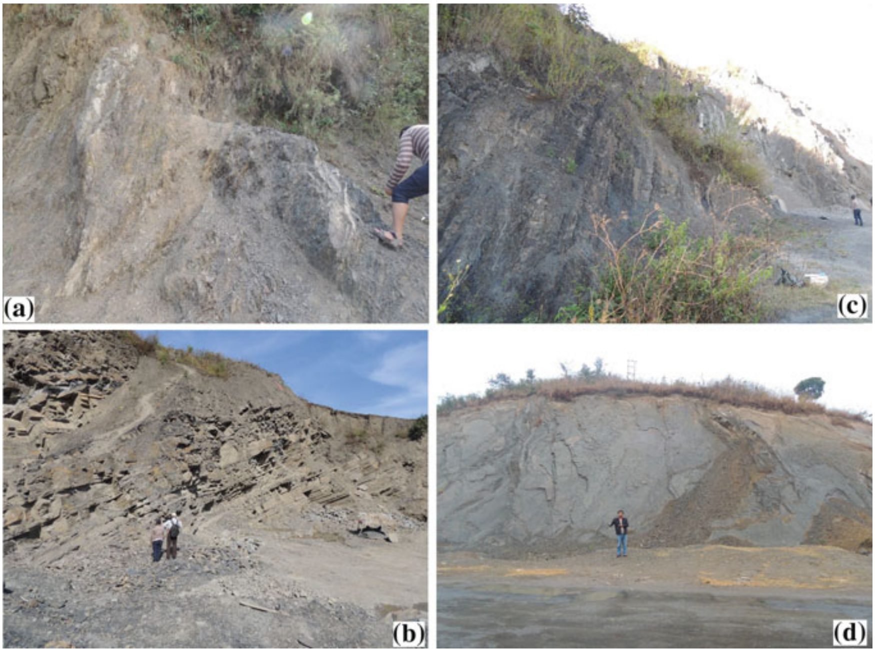

Fig. 2 **a** Splintery shale of Lower Disang at Thanga Ngaram, **b** alternation of sandstone and shale of the Upper Disang at lower part of Gelmoul quarry, Churachandpur, **c** alternation of sandstone and shale of Upper Disang at upper part of Gelmoul quarry (high of man is 1.5 m), **d** Upper Disang shale at Khunutaba Ching, Kakching

hydrocarbons present in the rock), S2 (remaining generation potential), S3 (oxidizable carbon), T_{max} (temperature maximum at peak of S2), HI (hydrogen index), OI (oxygen index), PI (production index) are being determined for the first time in this region.

2 Methodology

A total of 59 rock samples were collected from outcrops at four localities for this study. Most of them are shale and others are siltstone and sandstone (Fig. 2). Out of them, two samples, namely TNG-A and TNG-1 from the Lower Disang Formation at Thanga Ngaram (GPS: 24°31′12.1″N: 93°48′36.5″E), twelve shale samples from the Upper Disang Formation (one SO-2 from Khunutaba Ching, Kakching, GPS: 24°30′32.46″N: 94°00′50.07″E); (eleven samples from lower represented by G-1 to G-20) and (upper represented by GT-1 to GT-22) parts of Gelmoul quarry, (GPS: 24°20′40.4″N: 93°39′39.6″E).

Table 1 Generalised stratigraphic succession of Manipur (after Soibam 1998 and Anonymous of GSI 2011)

Age	Group	Formation	Description of rocks
(Quaternary-Pleistocene)	Alluvium		Dark grey to black clays, silt and sandy deposits of fluvio-lacustrine origin. Clay, sand, gravel, pebble, boulder deposits of the foothills and river terraces
Miocene	Tipam Group		Mottled clay, mottled sandy clay, sandy shale, clayey shale and sandstone Greenish to blue, moderate to coarse ferruginous sandstone with sandy shale, clay. Often brown to orange due to weathering. Molasse type of deposits
Miocene to Late Oligocene	Surma Group	Bokabil Formation	Shale, sandy shale, siltstone, ferruginous sandstone, massive to bedded ferruginous sandstone
		Bhuban Formation	Alternations of sandstone and shale with more argillaceous horizons in the middle and minor conglomerates. Transitional characters from Flysch to molasse sediments
Unconformity			
Oligocene to Late Eocene	Barail Group	Renji Formation Jenam Formation Laisong Formation	Massive to thickly bedded sandstone. Alternations of shale and sandstone with carbonaceous matters. Intercalation of bedded sandstone with shale
Middle to Late Eocene	Disang Group	Upper Disang Formation	Splintery shale and intercalation of shale, siltstone and sandstone showing occasionally rhythmite characters with fossils
Late Cretaceous to Early Eocene		Lower Disang Formation	Dark grey to black shale with minor sandstone bands
Unconformity			
Cretaceous to Early Eocene	Ophiolite Mélange Zone		Basic and ultrabasic intrusive and extrusive of peridotite, gabbro, serpentinite composition. Associated sediments are mainly pelagic, such as chert, limestone, shale etc.
Unconformity			
(Pre-Mesozoic or older)	Metamorphic complex		Low to medium grade metamorphic rocks of various composition-phyllitic schist, quartzite, micaceous quartzite, quartz-chlorite-mica-schist and marble
(?) *Unconformity*			
?Early Mesozoic rocks or Pre-Cambrian rocks	Basement complex		Unseen

TOC analysis and other parameters of the above samples have been performed by Rock Eval—VI in the Oil and Natural Gas Corporation (ONGC) at Dehra Dun, India. Palynological experiment was carried out at Department of Earth Sciences, Manipur University. Out of 59 samples, twenty six samples have been used for palynofacies analysis. Palynological preparation was made by using chemical treatment of Hydrochloric acid (35 %) and hydrofluoric acid (40 %) without any oxidation (Faegri and Iversen 1989). The organic matter residue after acid treatment was sieved using ASTM-400 before mounted on glass microscope slide in DPX. The slides were observed visually for Thermal Alteration Index (TAI) and organic content under a transmitted light microscope of Nikon E-200 (Staplin 1969). The source rock potential of the Disang Group has then discussed from the sights of TOC, the quantity and quality of organic matter, and maturation index (TAI). The visual estimation method follows that of Terry and Chilinger (1955) and a TAI value is adopted here (Staplin 1969). Classification and terminology of the dispersed organic matter follows that of Staplin (1969) and can be correlated with others, e.g. Masran and Pocock (1981), Venkatachala (1981), Tyson (1995), Batten (1981, 1996) and Ercegovac and Kostic (2006).

3 Source Rock Evaluation

Fourteen rock sample powders of the Disang Group were subjected for Rock-Eval Pyrolysis following Espitalié et al. (1977). The results are:

4 Kerogen Types and Maturity

Hydrogen and oxygen contents of the samples, measured as hydrocarbon-type compound and carbon dioxide yields, respectively, were normalized to organic carbon and displayed as hydrogen index (mgHC/g TOC) and oxygen index (mgCO_2/g TOC). They are plotted and compared to the van Krevelen-type diagram (Tissot and Welte 1984) to estimate the composition of kerogen types (Fig. 3). It can be seen from the figure that nearly all the samples fall in the area of Type IV with a few in the area of Type III, implying only a gas potential for these samples.

There are four types of kerogen such as type I-mainly algal produced, type-II-produced by spores and cuticles of plants and types III and IV-produced by the remains of the land plants. A plot of HI versus T_{max} (Fig. 4) indicates that the samples from the Disang Group are thermally immature for hydrocarbon (HC) generation (sample nos. GT- 9, GT-12, GT-14, GT-17 and GT-20) and occupy gas prone area. Sample nos. GT- 7, GT-21, GT-22 are postmature (overmature) for HC in the maturity diagram. All the studied samples suggest the presence of kerogen types III and IV. Matrix effect is most noticeable at TOCs of less than around 1.5 %, which may generate and expell considerable quantities of gas and condensate

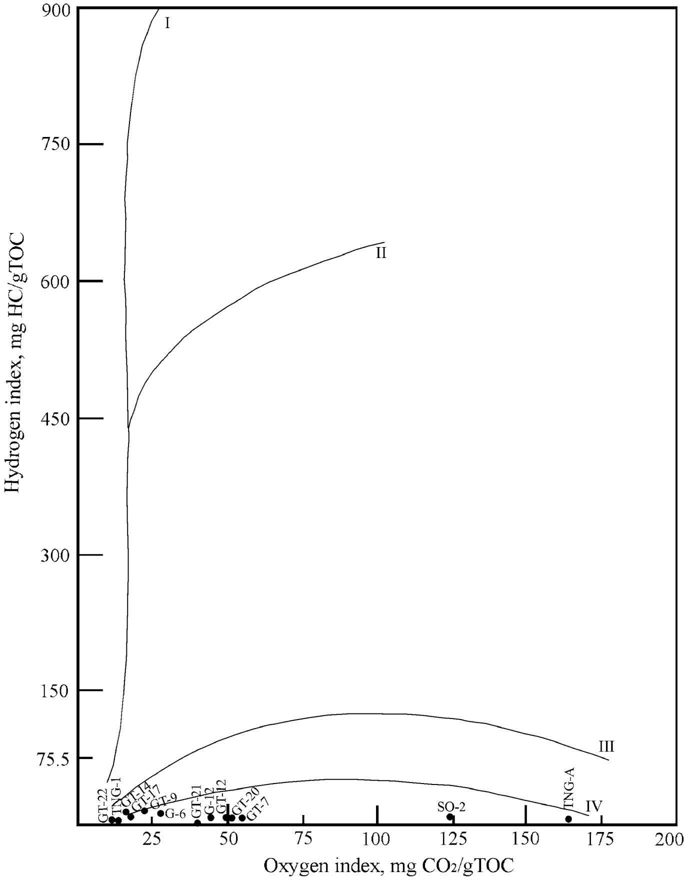

Fig. 3 Van Krevelen-type diagram for representation of type of kerogen

(Hunt 1996). The matrix effect appears likely in case of the Disang samples of the Manipur region as the TOC is <0.66 % and there is likely-hood of generation of gas.

5 Rock-Eval Pyrolysis and TOC

TOC and Rock-Eval Pyrolysis data and Rock-Eval parameters for the Disang Group are presented in Table 2. In immature sediments, organic matter dominated by marine components typically has hydrogen index values 200–400 mgHC/g TOC and the temperature at which pyrolysis yields the maximum of hydrocarbons (T_{max}) can be used as an indicator of the thermal maturity of the kerogen (Stein et al. 1989; Stein 1991). Immature organic matter has T_{max} values of less than 435 °C and

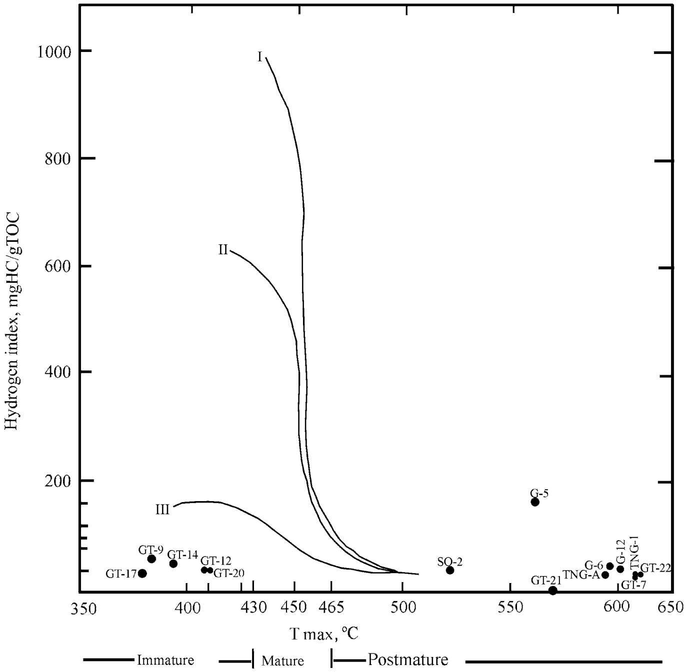

Fig. 4 A plot of HI versus T max for the Disang shale of the Gelmoul village (Upper Disang Formation; G-5, G-6, G-12, GT-7, GT-9, GT-12, GT-14, GT-17, GT-20, GT-21, GT-22); Sora (Upper Disang Formation, SO-2) and Thanga areas (Lower Disang Formation, TNG-A, TNG-1)

kerogen at the oil-generation stage generally has T_{max} values from 435 to 450 °C. High temperatures are indicative of the gas generating stage and temperature lower than 435 °C are indicative of thermal immaturity (Palmer and Zumberge 1981; Peters and Cassa 1994). In the studied samples T_{max} ranges from 381 °C (Sample GT-17) to 612 (sample GT-22). Thus GT-12 and GT-20 with T_{max} values of 409–412 °C reflect the occurrence of immature kerogen (Fig. 4). Very low T_{max} values may be indicative of some form of soluble organic matter as found in case of Upper.

Disang samples GT-9, GT-14 and GT-17 which has T_{max} values of 381–394 °C. This may represent the pyrolysis of soluble asphaltenes rather than kerogen (e.g. Clementz et al. 1979). Very high T_{max} values of 521–612 °C may be indicative of post mature/overmature stage or the occurrence of gas. Thus, samples G-6, G-12, GT-7, GT-21, GT-22, TNGA, TNG-1 and SO-2 are indicative of overmature or gas stage.

The potential source rocks are classified as Poor <0–2.5, Fair = 2.5–5, Good = 5–10, Very Good 10–20 and Excellent >20 on the basis of TOC percentage (Peters and Cassa 1994). All the studied samples are in the category of poor potential source rock (Table 2). The low values of the TOC (<0.66 %) imply a poor potential for these samples.

Table 2 Rock-eval data of sample powders from the Disang group of the Manipur region, Manipur

Formation	Sample name	TOC (%)	S1 (mgHC/g rock)	S2 (mgHC/g rock)	S3 ($mgCO_2$/g rock)	T_{max} (°C)	HI (mgHC/g TOC)	OI ($mgCO_2$/g TOC)	PI	MINC (%)	PO = S1 + S2	Richness	Hydrocarbon type S2/S3
U.D	G-5	0.02	0.01	0.03	0.28	561	150	1400	0.2	0.03	0.04	Poor	0.107
U.D	G-6	0.33	0.01	0.04	0.09	597	12	27	0.14	0.08	0.05	Poor	0.44
U.D	G-12	0.4	0.01	0.04	0.17	602	10	42	0.21	0.54	0.05	Poor	0.23
U.D	GT-7	0.27	0.01	0.02	0.15	609	7	56	0.18	0.08	0.03	Poor	0.133
U.D	GT-9	0.36	0.01	0.05	0.08	386	14	22	0.15	0.1	0.06	Poor	0.625
U.D	GT-12	0.39	0.01	0.04	0.19	409	10	49	0.19	0.09	0.05	Poor	0.21
U.D	GT-14	0.31	0.01	0.04	0.06	394	13	19	0.18	0.13	0.05	Poor	0.666
U.D	GT-17	0.44	0.01	0.04	0.09	381	9	20	0.18	0.24	0.05	Poor	0.44
U.D	GT-20	0.21	0.01	0.02	0.11	412	10	52	0.21	0.32	0.03	Poor	0.18
U.D	GT-21	0.34	0.01	0.02	0.15	570	0	44	0.57	0.15	0.03	Poor	0.13
U.D	GT-22	0.66	0.01	0.05	0.08	612	8	12	0.23	0.3	0.06	Poor	0.63
L.D	TNG-A	0.13	0.01	0.01	0.22	594	8	169	0.46	0.07	0.02	Poor	0.045
L.D	TNG-1	0.39	0.01	0.03	0.06	609	8	15	0.17	0.96	0.04	Poor	0.5
U.D	SO-2	0.21	0.01	0.02	0.26	521	10	124	0.19	0.36	0.03	Poor	0.08

U.D Upper Disang formation and *L.D* Lower Disang formation

6 Characteristics of Organic Matter

The most often encountered dispersed organic matters in the samples include amorphous organic matter, charcoal, black debris, spore and pollen and structural terrestrial organic matter (biodegraded or partly biodegraded) (Table 3). Other matters, such as fungal remains and resin, are also encountered but always rare and thus not presented in the table.

Table 3 Distribution of organic matters to the upper Disang formation at Gelmoul quarry, Manipur

Sample name	Amorphous organic matter (AOM) %	Charcoal (%)	Black debris (%)	Structural terrestrial organic matter (%)	Spores and pollen
GT-1	94	4	2	–	–
GT-2	33	40	24	3	–
GT-4	100	–	–	–	–
GT-5	96	–	4	–	–
GT-6	83	3	14	–	–
GT-7	100	–	–	–	–
GT-9	90	–	10	–	–
GT-10	32	15	47	6	–
GT-12	96	2	2	–	–
GT-13	90	10	–	–	–
GT-14	70	17	8	5	–
GT-15	72	3	12	13	–
GT-17	72	2	9	17	–
GT-19	98	–	–	2	–
GT-20	93	7	–	–	–
GT-21	44	3	41	12	–
GT-22	12	31	36	21	–
G-1	10	72	11	7	–
G-2	5	80	6	9	–
G-4	13	57	15	15	–
G-5	55	14	12	12	7
G-6	75	9	8	5	3
G-12	9	22	14	54	1
G-14	77	6	11	6	–
G-19	100	–	–	–	–
G-20	93	7	–	–	–

(a) Organic Matter Facies

All seventeen samples of the Upper Disang Formation exposed at the upper locality of Gelmoul quarry, Churachandpur i.e. GT-1, GT-2, GT-4, GT-5, GT-6, GT-7, GT-9, GT-10, GT-12, GT-13, GT-14, GT-15, GT-17, GT-19, GT-20, GT-21, GT-22 contain grey to yellow coloured amorphous organic matter. The abundance of this organic matter ranges from 12 to 100 %. The structural terrestrial matter ranges from 2 to 21 % while the charcoal is 2–40 %. The black debris ranges from 2 to 47 %. However, some samples are absent of charcoal, black debris, structural terrestrial organic matter (Table 3) except amorphous organic matter. The dinoflagellates and microforaminiferal linings have been reported after treatment of nitric acid and potassium hydroxide (Singh et al. 2013). However, the maturity of OM indicates overmaturation of organic matter to some samples according to very high T_{max} value. The rock is assessed to have potential for sourcing gaseous hydrocarbon with respect to the TOC value that ranges from 0.32 to 0.72 % (Berry et al. 1998; Mukherjee et al. 1990). Most of the samples indicate their potential as a source rock of gaseous hydrocarbon. Of them, the samples GT-2, 10, 21, 22 are of gas potential in consisting mainly of terrestrial plant debris (charcoals, black debris, structural terrestrial organic matter and pollen and spores).

Nine samples of the Upper Disang Formation collected from the same locality of lower part of Gelmoul quarry are G-1, G-2, G-4, G-5, G-6, G-12, G-14, G-19 and G-20. The organic matter of these samples are represented by amorphous organic matter (5–100 %), black debris (6–15 %), structured terrestrial organic matter (5–54 %), charcoal (6–80 %) and spores and pollen (1–7 %). However, some samples do not show the presence of charcoal, structured terrestrial, black debris and spores and pollen except amorphous organic matter. A few spores, pollen, dinoflagellates are present here. The Thermal Alteration Index (TAI) values (Fig. 5 d, h, i) recorded are above 3.5, suggesting highly mature to overmature mixed palynofacies and source potential for the gas generation.

(b) Spores Colouration

The TAI (Thermal Alteration Index) scale 1–5 is widely used in hydrocarbon exploration. Among them, the one of Staplin (1969) is considered as the simplest and the most popular for evaluating the maturity of organic matters based on changes in spores colour. This technique is conducted in the present study, too, though it can only be taken on a few samples due to the absence of spores and pollen in all the samples. Of these samples namely G-5, G-6 and G-12, the TAI values of spores recorded are greater than 3.5, suggesting a high mature to overmature nature of the organic matter and thus at a gas generation stage for Disang Group of Manipur. It also indicates that the maturity level of organic matter is at higher temperature (above 200 °C) under the metagenesis process.

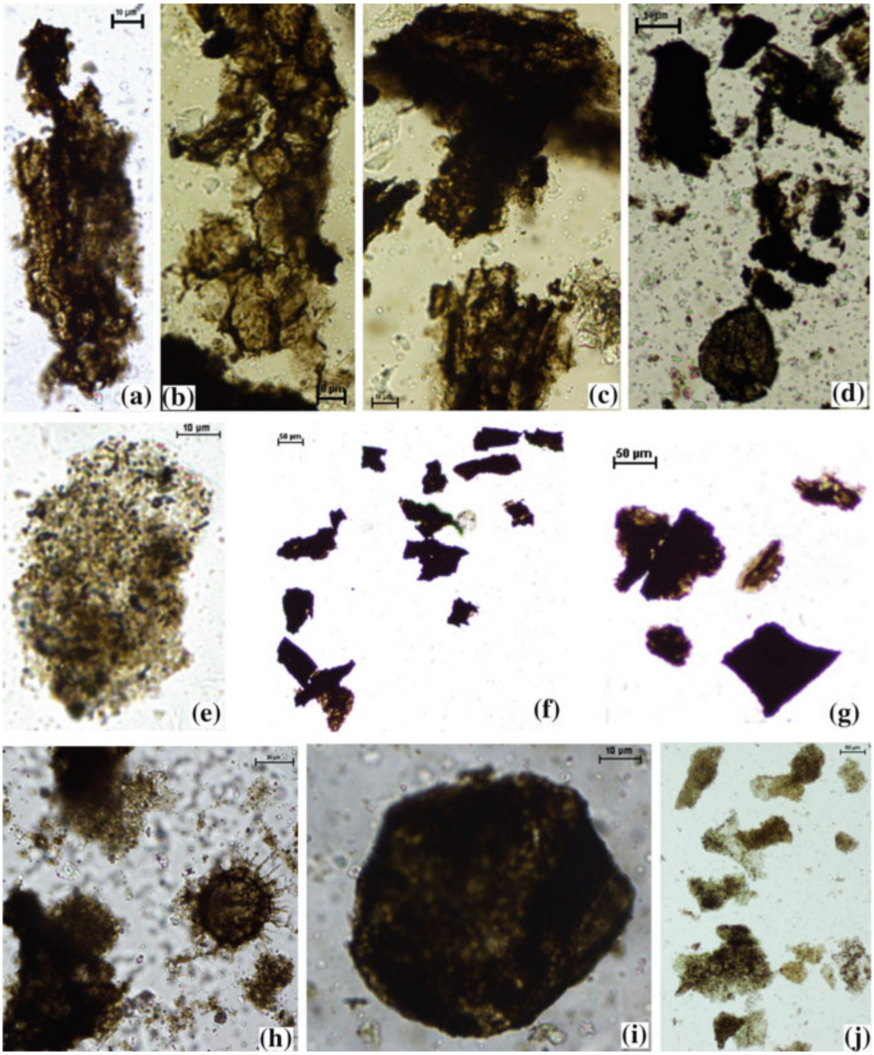

Fig. 5 **a–c** Partly biodegraded terrestrial organic matter, **d** spores with charcoal organic matter, **e** sapropelic amorphous organic matter with pyrite, **f**, **g** black debris, **h** dinocyst and associated amorphous organic matter, **i** spore showing high TAI value, **j** Sapropelic amorphous organic matter

7 Conclusions

Rock-Eval and TOC analysis of Disang rocks indicate that all the samples have poor organic richness (TOC < 0.5 %) and poor hydrocarbon generation potential (S2 < 0.5 mgHC/g rock). The organic matter content is predominantly of type III and type IV. The T_{max} and Productive index values support the findings of visual kerogen analysis. Most of the kerogens are of low level of maturity because of light colour of amorphous kerogens. Low T_{max} values and low production index obtained for these samples also confirm their low maturity. The amorphous organic matter is more abundant than other types of organic matter. The source rock potential of Disang rocks recorded the different types of organic matter such as charcoal, partly biodegraded terrestrial, amorphous, black debris, spores and pollens. TAI values suggest highly mature to overmature mixed palynofacies. The source rock potential for the Disang Group of Manipur appears poor to moderate for gaseous hydrocarbons.

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