



Vitrinite Reflectance and Palaeotemperature analysis of coals in Tikak Parbat Formation, Makum Coal basin, Assam, India

KEYWORDS

vitrinite reflectance, palaeotemperature, geothermal gradient, Makum Coal basin.

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ABSTRACT

The present study is confined only to the coal seams and associated rocks of Tikak Parbat Formation of Barail Group (Oligocene) and based on the analysis of coal petrographic data and measured depth of sections in Tikak Hills and Tirap colliery areas of Makum Coal basin.

It is observed from the palaeotemperature study that the palaeotemperature attained is 95°C to 97°C for 60ft. (18m) seam and 79°C to 88°C for 20ft. (6m) seam. Geothermal gradient (G) is found to be $\pm 38.5^\circ\text{C}/\text{Km}$ and the Tikak Hills area was under higher geothermal regime than that of Tirap colliery area but both belong to a single palaeogeothermal regime. High heat flow is a reflection of subduction-collision processes related to Indian plate against Burmese plate and the loci is Naga-Patkai geotectonic belt of which Makum Coal basin is an integral part.

INTRODUCTION:

The question of heat flow or geothermal heat supply in a particular region for tectonic reasons is automatically brought in due to the fact that sometimes coal attains a very high rank at a lower depth of subsidence (e.g. Bransche massif in N.W. Germany) whereas at a reasonable higher depth, the maturity is much less (Ammosov, 1968). Due to varying palaeogeothermal histories from region to region the effect of duration of heating also changes. Therefore, it is difficult to relate a particular degree of coalification to a precise maximum temperature as the exact value of the two variables and the functional trend, has to be assumed from indirect evidences and or field/laboratory data. Published geothermal data on Upper Assam Basin and its adjoining areas provide some interesting information. The mean heat flow and geothermal gradient are 52.16 mW.m^{-2} and $22.86 \pm 3.94^\circ\text{C}/\text{km}$ respectively for Assam Basin in particular. The geothermal gradients within the Barail group are widely scattered and do not show any linear relationship with depth. The estimated crustal temperature distribution within different depth ranges beneath the Naga-Patkai belt are 210°C at 10 km, 510°C at 25 km, and about 820°C at 45 km (Handique and Bharali, 1981; Panda, 1984; Cermak et al. 1990). Considering the above findings, the author has made an attempt to study the palaeotemperature distribution in Makum Coal basin based on measured exposed sections and vitrinite reflectance of coals in Tikak Parbat Formation of Barail Group (Oligocene).

GEOLOGICAL SET-UP:

Tectonically, the coalfield areas of Upper Assam, Arunachal Pradesh and Nagaland occur in the belt of Schuppen which is a narrow NE-SW trending linear overthrust zone on the Naga-Patkai Range. This belt is delineated on the east by Halflong – Disang thrust and on the west by Naga thrust. Makum coal basin is an isolated tectonic block of this belt where the coal bearing Barail Group of rocks were sandwiched between two thrusts namely Margherita thrust on the north and Halflong-Disang thrust on the south (Fig. 1). The litho stratigraphic succession as developed in the study area is shown in Table –1 (Sarmah, 1999). The coal bearing Barail Group is subdivided into Naogaon, Baragolai and Tikak Parbat Formation in ascending order. The upper Tikak Parbat Formation is named after the Tikak Hills ($27^\circ 15' : 95^\circ 45'$) in Makum coalfield. This formation can be subdivided into lower Argillaceous unit and upper Arenaceous unit on the basis of gross lithofacies character and association (Sarmah, 1999). The lower unit houses thick, persistent and workable coal seams. The upper unit is arenaceous in character with more of massive to well bedded, medium to fine grained sandstone interbedded with sandy shale, grey shales, sandstone, sandy clay carbona-

ceous shale with several thin coal seams.

Age	Group	Formation	Description
Recent			
Pleistocene		Alluvium and high-level terraces	Sands, Clays, Silts, Gravel beds etc.
		Unconformity	
Pliocene	DHING		Alternative pebble beds; coarse bluish green to grey feldspathic, ferruginous sandstones and greyish to brownish clays.
		Unconformity	
		Girajin Clay	Variagated clay, silty clay, bluish green and grey sandstone (+ 470m – 990m : thickness).
Miocene	TIPAM	Tipam Sandstone	Coarse, gritty and massive, bluish green to grey feldspathic and micaceous sandstone, variagated clay, sandy clay, shale, coal streaks and silicified woods. (+ 1000 m : thickness).
		SURMA (?)	Not subdivided
		Unconformity	
			Grits, thin conglomerate beds, brown, fine grained sandstone, sandy clays and shales. (approximately 400 m : thickness).
Oligocene	BARAIL		Upper Arenaceous Unit: Massive to well bedded, yellowish white to light grey, medium to fine grained sandstone interbedded with sandy shale, grey shale, siltstone, light grey claystone, mudstone, carbonaceous shale and several coal seams.
		Tikak Parbat	Lower Argillaceous Unit: Alternations of siltstone, mudstone, shale, carbonaceous shale, claystone and thick workable coal seams. Occasionally laminated shaly sandstone, sandy shale and sandy clay. (600 m : thickness)
		Baragolai	Well bedded or at places massive, hard, greyish, micaceous or ferruginous shaly sandstones alternating with bluish grey, greenish yellow clays, shale, sandy shale, siltstone, calcareous mudstone, carbonaceous shale and thin coal seams (3300 m : thickness)
		Naogaon (occurs on the southern part of the coalfield, separated by the Halflong – Disang Thrust)	Hard compact and flaggy dark grey, fine grained Sandstone and interbeds of grey splintery shales (2200 m : thickness)
Eocene	DISANG		Dark grey splintery shale with interbeds of dark grey and fine grained sandstone (over 3000 m : thickness)

TABLE 1 : LITHOSTRATIGRAPHIC SUCCESSION IN THE MAKUM COAL FIELD, UPPER ASSAM (SARMAH, 1999).

METHODOLOGY:

Coal samples from 60 ft, 7 ft, 20 ft and thin seams of Tikak Parbat Formation exposed in two sections- Tikak and Tirap were collected from Makum Coal basin. The polished coal pellets were examined under orthoplan microscope in oil media with 32x or 50x objectives and 10x or 8x ocular lens. Light source was stabilised sodium ray. For reflectance measurement a stabilised monochromatic sodium light with blue filter was imparted on the sample and the values were recorded from photovoltmeter calibrated against standard (natural glass with R_0 1.24% and Leucosapphire R_0 0.59%) following ICCP (1971) and IS 9127 (Part III) (IS 1992). The measured depth and vitrinite reflectance data are used to plot in binary diagrams and nomograms to calculate the palaeotemperature of the coal seams.

RESULTS:

Teichmuller (1970) and Doebel et al. (1974) made comparative study to show role of heat flow and trend of organic maturation.

tion in the Upper Rhine Graben (Fig.2) on which the author has also tried his own exercises. It is evident from the graph that the Tikak hills section shows lower reflectance gradient 0.099% per 100 m than that of Tirap colliery section (i.e. 0.123% per 100 m). The curve of the Tikak hill section also shows slightly steeper slope in comparison to the Tirap colliery profile indicating gradual increase of geothermal gradient towards east of the studied basin. Fig.2. indicates that the paleogeothermal condition for the Tirap colliery area is the most warmer than the Tikak hills area to the west. The depth-reflectance trend in the Tirap colliery area is almost similar to that of the Upper Rhine Graben but has comparatively warmer geothermal conditions. This variation may be due to the complex tectonic activity in the region. Bostick et al. (1979) established the relationship between vitrinite reflectance, rock temperature and burial history in number of boreholes in the region further north of California. Their results incorporated more than 5000 m of burial and supplemented the works of Hood et al. (1975). The modified nomogram presented by Bostick (*op. cit*) is considered outstanding (Fig.3 A & B) as the present observations are found to be in agreement with that of field observations and other geological information as well. Since, the rank gradient varies in different coalification ranges, any comparison should be done within the same rank range. Teichmuller (1979) illustrated relationship between vitrinite reflectance (Ro) versus depth and vitrinite reflectance (Ro) versus rock temperature for the same well. The comparison clearly demonstrated the dominant role of temperature on coalification. This is also evident from the depth versus reflectance diagram (Fig.4) using the data obtained from the present study.

Bostick (1973) gave an account on the relationship of time on coal rank and established that the rank of coal determined from vitrinite reflectance can go up to anthracite range even within a moderate temperature range of 100° - 200° C provided, the time of coalification is substantial and in the tune of millions of years. He also agreed that the time factor is not tenable for coal attaining a temperature below 50° C, since the reaction cannot be triggered off.

The influence of heating time for maturation is now accepted by most workers. Coalification studies in the Tertiary of the Upper Rhine Graben strongly suggest that a duration of heating of 2.3 m. yrs may be insufficient for the attainment of rank equilibrium (M. Teichmuller, 1979 a). Kanstler et al. (1978), Shibaoka et al. (1978) observed that in an area of extremely rapid sedimentation, a lag of reflectance increase behind temperature exists as in the case of Gippsland basin, Australia. Lopatin (1976 a,b) described that at a given depth and temperature, reflectance value decreases when the subsidence is rapid. So under continuous subsidence, required rates of subsidence are less than 10 m / m. yrs. to reach the equilibrium condition of the reflectance value.

Models suggested by Karweil (1956), Ammosov et al. (1975), Nagorny and Nagorny (1977) and Shibaoka & Bennett (1976) modified from Hood et al. (1975), Bostick et al. (1979), for determining palaeotemperature for the completed catagenesis of organic sediments from coal basins have merit of their own. Following all these procedures, the palaeotemperature values deduced in the present study by assuming maturation/soaking time to be 17 m.yrs., 25 m.yrs., 35 m.yrs., 40 m.yrs. to fit into the different geological histories suggested and prevailed in the country. Except Karweil (1956) all other procedures for determining palaeotemperature have considered oil reflectance values of vitrinite as key variable. With determined reflectance value (Rm oil) in the laboratory and assumption of effective time, maximum temperature were read from the nomogram (Fig.3 A & B) of Bostick et al. (1979), Shibaoka & Bennett (1976) respectively and incorporated systematically.

Table -2 illustrates the maximum palaeotemperature values determined by different methods in field sections at different depth level. Considering soaking time to be 17 m.yrs., 25m.yrs., 35 m.yrs., and 40 m.yrs., the values obtained from the methods of Bostick et al. (1979), Shibaoka and Bennett (1976), Karweil (1956), Ammosov et al. (1975) and Nagorny & Nagorny (1977) were compared. For the soaking time of 35 m. yrs. and the corresponding palaeotemperature values obtained from the methods of Bostick (1979), Shibaoka and Bennett (1977) and Nagorny et al. (1977) have close resemblance and matched well with the geological history and the palaeodepth of the studied coal basin when the available data pertains to Mesozoic-Cenozoic basins of India is considered to be valid (Panda, 1984). The lower soaking time of 17 m. yrs. and 25 m. yrs. resulted in comparatively higher values. The palaeotemperature values determined from the Karweil's and Ammosov et al. show much lower and higher range respectively compared to the methods already mentioned.

The plots in the diagram (Fig.5) indicate a good correlation of the methods after Bostick, Ammosov et al., and Nagorny & Nagorny. The palaeotemperatures calculated from the Bostick's method, assuming soaking time 17 m. yrs., 25 m.yrs., 35 m.yrs., and 40 m.yrs. and data available from Ammosov et al. (1975) , Nagorny & Nagorny (1977) with soaking time 50 m.yrs. against a normal scale. A good correspondence and linearity of data between Ro and palaeotemperature exist in the present case and a tendency of the plots towards the trend of Ammosov et al. (1975) near upper end. It clearly reveals a moderately higher geothermal gradient for the studied coal basin and a best fit line matches the soaking time as 35 m. yrs.

The plots in Fig.5 showing the relationship between palaeotemperature and Ro average (after Ammosov et al. 1975 and Nagorny & Nagorny, 1977) reveal that the Tikak hills area was under relatively higher geothermal regime than that of the Tirap colliery area, but both belong to a single paleogeothermal regime. The depth - reflectance trend diagrams (Fig.5.12) on the other hand do not record this observation. This deviation may possibly relate to some differential subsidence of the basin floors in response to tectonic events in the studied coal basin or to the variable depth of burial of the basement in the area.

The present indirect approach may have some direct bearing on maturation of organic matter both for coalification process and hydrocarbon generation in the sedimentary basins of Upper Assam and adjoining areas (including Makum coal basin) on a regional scale during Late Miocene and Mio-Pliocene time due to the Himalayan orogenic activity and also due to the compression forces readjusting for subduction of Indian plate against Burmese plate in the region (Nandy, 1986).

GEOTHERMAL GRADIENT (G)

The estimated values of geothermal gradient are derived systematically from the maximum palaeotemperature calculated after the methods already described when divided by the maximum paleodepth (using the paleodepth data after Bostick, 1979) and presented in the table (Table-3). Besides these another method after Middleton (1982) was applied for the determination of palaeogeothermal gradient i.e.

Geothermal Gradient (m) = (Log Rmax/Rmin)/(Max depth – Min depth) x 194.8 (constant)

Table- 3 Geothermal Gradient (G) in °C/km.

LOCALITY/COAL FIELD	COAL SEAM	ROIL MEAN (%)	PALEODEPTH (M) (AFTER BOSTICK 1979)	GEOHERMAL GRADIENT (G)		AMMOSOV et al. 1975	NAGAORNYY & NAGORNYY 1977 50 M. YRS.	MIDDLETON 1982
				BOSTICK (1979) 17 25 35 40	HOOD et al. 1975 + shibaoka & bennette (1977) 17 25 35 40			
TIKAK HILLS SECTION	20 FT.	0.58	2321	43.1 41.4 37.9 34.04	46.1 43.0 40.4 39.6	52.5	33.6	46.5
MAKUM COAL FIELD	60 FT.	0.64	2500	43.2 41.6 38.8 38.4	46.4 45.6 43.2 42.8	56.0	35.2	
TIRAP COLLIERY SECTION	20 FT.	0.54	2179	40.8 38.5 36.2 34.8	46.8 43.1 40.8 39.9	50.9	32.5	50.1
MAKUM COAL FIELD	60 FT.	0.63	2439	43.4 42.2 38.9 38.1	47.9 45.1 43.0 41.8	54.9	34.4	

By applying this method, the values obtained for the coals of Makum Coalfield show some correspondence with those of Ammosov et al. (1975) but deviate to the higher side from other determined values. According to Middleton (1982) a correspondence in geothermal gradient data from area to area can only be possible if the tectonic histories of the regions are fairly known. Thus the author has deduced the paleogeothermal data using the internationally acclaimed works in the field and the deductions made thereafter are compared with all available geological and geophysical information pertaining to the north eastern India.

CONCLUSIONS:

The foregoing account may help to arrive at broad conclusions for the ongoing work. The results clearly shows that assuming 35 m. yrs. as soaking time and accordingly geothermal gradient data calculated by following Bostick et al. (1979) and Nagornyy & Nagornyy (1977) are in good agreement with the present day geothermal gradient range. The

values after Shibaoka and Bennett (1976) indicate slightly higher order of geothermal gradient. But the values obtained from Ammosov et al. (1975) and Middleton (1982) seem to be quite high which indicate their limitation in applying the principles for the Tertiary coal basins of north eastern India.

A critical examination of the available geothermal gradient and heat flow data indicates that the Makum coal basin may not be normal to its setting with the adjoining oil - field areas of Upper Assam Basin to the further north west. The high heat flow and Moho temperature in the upper mantle beneath the mobile Naga – Patkai belt was attributed due to the subduction – collision related phenomenon in the Indian plate against the Burmese plate.

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Table-2 Comparison of Maximum Palaeotemperature Reached (determined from different methods) of Different coalmine areas in Makum Coalfield,Upper Assam

LOCALITY/COAL FIELD	COAL SEAM	PRESENT DEPTH (M)	ROIL MEAN (%)	VOLATILE MATTER (DMMF BASIS %)	PALAEOTEMPERATURE (IN ° C)					REFLECTANCE GRADIENT Ro%/ 100 M.
					BOSTIC (1979) 17 25 35 40	KARWEIL (1956) 17 25 35 40	HOOD et al. 1975 + shibaoka & bennette (1977) 17 25 35 40	AMMOSOV et al. 1975	NAAORMY & NAGORMY 1977 50 M. YRS.	
TIKAK HILLS SECTION	20 FT.	31.09	0.58	47.01	100 96 88 79	85 72 61 57	107 100 94 92	122	78	0.099
MAKUM COAL FIELD	60 FT.	91.12	0.64	50.31	108 104 97 96	51 42 33 28	116 114 108 107	140	88	
TIRAP COLLIERY SECTION	20 FT.	208.20	0.54	45.61	89 84 79 76	106 91 80 75	102 94 89 87	111	71	0.123
MAKUM COAL FIELD	60 FT.	281.22	0.63	46.69	106 103 95 93	91 75 65 61	117 110 105 102	134	84	

Fig.2

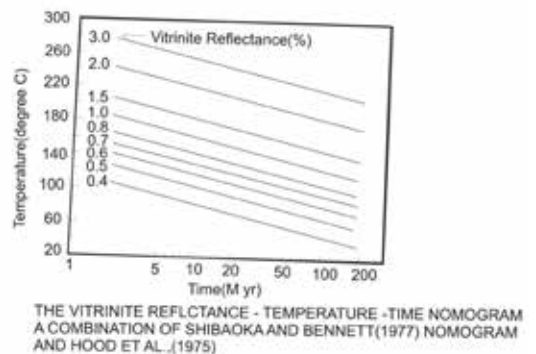
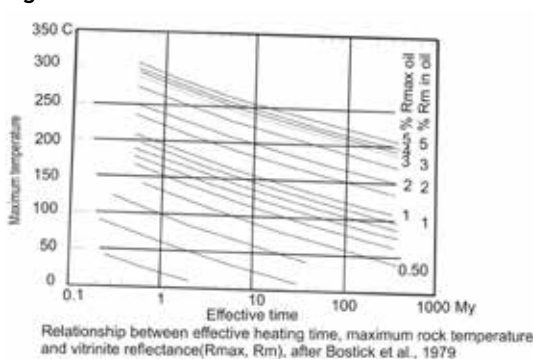


Fig.3A&B

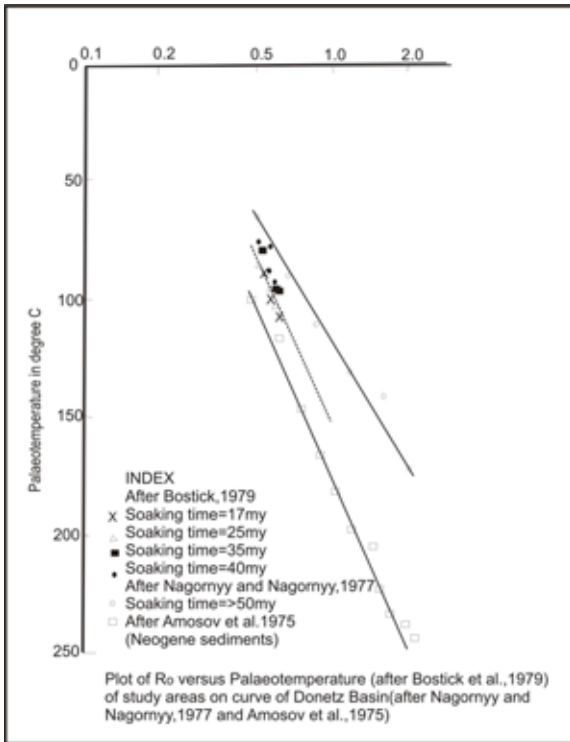


Fig.4

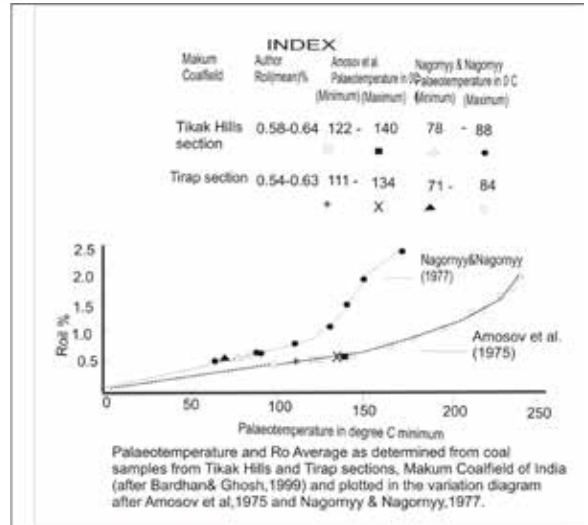


Fig.5

REFERENCE

- Amosov, I. I (1968) – Coal organic matter as a parameter of the degree of sedimentary rock lithification. 23rd Int. Geol. Congr. Proc. Sec II, Prague, pp. 23-30. | Amosov, I. I., Gorschkov, V. I., Grechnikov, N. P & Kalmikov, G. C. (1975) – Vitrinit Kak pokazatel paleotemperature, termogeneza zon nefteobrazovania. Cong. Geol. Start. Carbonifer (Moscow) 4. pp. 90-97. | Bostick, N. H. (1973) – Time as factor of thermal meta-morphism of phytoclasts (coaly particles). C.R. 7th Congr. Int. Stratigraphic Geol. Carbonifere , 2, pp. 183 – 192, Krefeld, 1971. | Bostick, N. H. (1979) - Microscopic measurement of the level of Catagenesis of solid organic matter in sedimentary rocks to aid exploration for petroleum and to determine former burial temperature – A review. SEPM Spec. Publ. No. 26, pp. 17 – 43 March. | Cermak, V., Kubik, J., Saikia, M.M. and Sitaram M.V.D., (1990) – Geothermal model of the north – eastern region of India : its possibilities and limitations. Jour. Geol. Soc. India. 36, pp. 5 – 11. | Doebel, F., Heling, D., Homann, W., Karweil, J., Teichmuller, M. and Welte, D. (1974) – Diagenesis of Tertiary clayey sediments and included dispersed organic matter in relationship to geothermics in the Upper Rhine Graben. In : ILLIES J. H. & FUCHS. K (eds) : Approaches to Taphrogenesis, Schweizerbart, Stuttgart, pp.192 – 207. | Handique, G.K. and Bharali, B. (1981) – Temperature distribution and its relation to hydrocarbon accumulation in Upper Assam Valley, India. Bull. Amer. Assoc. Pet. Geol. 65(9), pp. 1633 – 1641. | Hood, A., Gutjahr, C. C. M. and Heacock, R. L. (1975) – Organic metamorphism and the generation of petroleum. Bull. Amer. Assoc. Petrol. Geology 59, pp. 986 – 996. | Kantsler, A. J., Smith, G. C. and Cook, A. C. (1978) – Lateral and vertical rank variation implication for hydrocarbon exploration. Aust. Petrol. Explor. Assoc (APEA) J. 18, pp. 143 – 156, Sydney, NSW. | Karweil, J. (1956) – Die Metamorphose der Kohlen Vom Standpunkt der physikalischen Chemie. Z, deutsch. Geol. Ges., 107, pp. 132 – 139. | Lopatin, N. V. (1976 a) - The influence of temperature and geologic time on the catagenetic processes of coalification and petroleum and gas formation. In : Issledovaniya organicheseskogo veshchestava sovremennykh i. isKopayemykh osakdov, 361 – 366. Nauka press : Moscow (Russian). | Lopatin, N. V. (1976 b) – Historical -genetic analysis of oil formation by use of a mode of regular continuous subsidence of the source rock. Izv. Akad. Nauk SSSR. Ser. Geol. No. 8, Moscow (Russian). | Middleton, M. F. (1982) – Tectonic history from vitrinite reflectance. Geophysics. J. R. astr. Soc – 68, pp. 121 – 132. | Nagorny, V. N. and Nagorny, Yu. N. (1977) – Geothermal conditions of regional metamorphism of coals and coaly inclusions in petroliferous rocks : Geol. Geofiz. N.9. | Nandy, D. R. (1986) –Geology and tectonics of Arakan – Yoma –A reappraisal. GEOSEA V Proc. Vol.2, Geol. Soc. Malaysia, Bull. 20, pp.137 –148. | Panda, P. K. (1984) – Geothermal maps of India and their significance in resources assessments. Petrol. Asia. Jour. Dehradun, pp. 202 – 210. | Shibaoka, M. and Bennett, A. J. R. (1976) – Effects of depth of burial and tectonic activity on coalification. Nature., 259, No. 5542, pp. 385 – 386. February 05. | Shibaoka, M., Saxby, J. D. and Taylor, G. H. (1978) – Hydrocarbon generation in the Gippsland Basin, Australia – Comparison with Cooper Basin, Australia. Bull. A., Ass. Petrol. Geol., 62(7), pp. 1151 – 1158. Tulsa, Okla. | Teichmüller, M. (1970) – Bestimmung des Inkohlungsgrades von kohligem Einschlüssen in Sedimentends Oberrheingrabens; ein Hilfsmittel bei der Klärung geothermischer Fragen. Int. Upper Mantle Proj. Sci. Rep., 27, pp.124 –142. | Teichmüller, M. (1979a) – Beispiele für die Anwendung fluoreszenzmikroskopischer. Methoden bei der Erd ölprospektion Congr. Int. Geol. Strat. Carbonifere. (Moscow, 1975), 4, pp. 79 – 89. |