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Hydrocarbon potential, palynology and palynofacies of four sedimentary basins in the Benue Trough, northern Cameroon

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Organic geochemical, palynological and palynofacies analyses were carried out on 79 selected samples from four sedimentary basins (Mayo-Rey, Mayo-Oulo-Lere, Hamakoussou and Benue) in northern Cameroon. Rock-Eval pyrolysis and Total Organic Carbon results indicate that most of the samples of the studied basins are thermally immature to mature. The organic matter consists of terrestrial components (peat, lignite, bituminous coal, and anthracite) associated with organic matter of marine origin. Based on the appraisal of multiple parameters: Total Organic Carbon (TOC), maximum Temperature (T-max), Hydrogen Index (HI), Oxygen Index (OI) and Production Index (PI), some samples are organically rich both in oil and/or gas-prone kerogen Type-II, II/III and III. The source rock quality ranges from poor to very good. The source material is composed of both algae and higher plants. Samples from these basins yielded palynological residue composed of translucent and opaque phytoclasts, Amorphous Organic Matter (AOM), fungal remains, algal cysts pollen and pteridophyte spores. Abundance and diversity of the palynomorphs overall low and include *Monoporopollenites annulatus* (= *Monoporites annulatus*), indeterminate periporate pollen, indeterminate tetracolporate pollen, indeterminate tricolporate pollen, indeterminate triporate pollen, indeterminate trilete spores, *Polypodiaceoisporites* spp., *Biporipsilonites* sp., *Rhizophagites* sp., *Striadiporites* sp., *Botryococcus* sp. (colonial, freshwater green algae), and *Chomotriletes minor* (cyst of zygnematalean freshwater green algae). Age assigned confidently for all these basins the palynological data except for one sample of Hamakoussou that can be dated as Early to Mid-Cretaceous in age. *Callialasporites dampieri*, *Classopollis* spp., *Eucommiidites* spp. and *Araucariacites australis* indicate, an Aptian to Cenomanian age. The other pollen and spores recovered may indicate a Tertiary or younger age (especially *Monoporopollenites annulatus*), or have arisen from modern contamination. Geochemical data show that sediments are wackes, arkose, iron-sandstone and iron-shale. The Chemical Index of Alteration (CIA-K) is low moderate to high, suggesting a shorter exposure time and fast erosion and transport. The studied sequences cover various depositional settings ranging from wetlands to dry environment inside island arc, passive margin or active continental margin. This study reveals new data and the economic potential of this part of Cameroon.

1. Introduction

Currently hydrocarbon reservoirs in Cameroon are concentrated mainly in offshore fields within coastal areas (Rio Del Rey, Douala/

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Kribi Campo). The petroleum potential of the northern part of Cameroon, which were connected to many basins (Benue Trough, Hamakoussou Basin, Mayo-Rey Basin, Mayo-Oulo-Lere Basin, Koum Basin, Babouri Figuil Basin and Logone Birni Basin), has not yet been deeply investigated. Lithostratigraphic studies of these basins, like other intra-continental rift basins in northern Cameroon representing Cretaceous to Cenozoïc sediments, have been given little attention since the discovery of hydrocarbon hosted in younger sediments of the Coastal Atlantic basins. Hydrocarbon potential of these basins is still poorly known. Numerous authors have established a relation between the Benue Trough and the continental basins in the northern part of Cameroon (Benkhelil, 1982, 1988; Binks and Fairhead, 1992). Previous detailed studied have been carried out on these basins by Bessong (2012), Bessong et al. (2011, 2015) in the Cameroon part of the Benue Trough; Ntsama (2013) and Ntsama et al. (2014) on the Hamakoussou basin; Nolla et al. (2015) on the Mayo Rey Basin; Defretin and Boureau, 1952 (1953), Boureau (1953), Koch (1959), Maurin and Guiraud (1989, 1990), Ndjeng (1992), Brunet et al. (1988) and Ntsama (2013) on the Mayo-Oulo-Léré Basin; Ndjeng (1992) on the Babouri-Figuil Basin; and Allix et al. (1981, 1983) and Ntep et al. (2000) on the Logone Birni Basin. However very few studies focusing on biostratigraphy across all the basins have been carried out so far: Brunet et al. (1988) discovered the first Cretaceous African mammals in the Mayo-Rey Basin (or Koum Basin) and the authors showed for the first time pre-Aptian sedimentation, Barremian and even earlier in the Benue Trough based on the study of plant remains. They recorded the sporomorph *Dicheiropollis etruscus,* which is a stratigraphic indicator of the Neocomian-Barremian transition in the West Africa-South American Province; Salard-Cheboldaeff, 1990, Dupéron (1991) revealed the presence of *Metapodocarpoxylon* silicified wood in the four sedimentary basins. Therefore our present paper is focused on the study of the four sedimentary basins (Benue Trough, Mayo-Rey, Hamakoussou and Mayo-Oulo-Lere; Fig. 1) base, on a multi-proxy approach including lithostratigraphy and depositional environment. The palynofacies analysis aims to better constrain organic facies patterns in addition to organic geochemical analyses, and then provides information on the quantity, type, and thermal maturity of organic matter in a sedimentary rock (Espitalié et al., 1977; Behar et al.). The scarcity of palynological data renders the reconstruction of palaeoenvironments and dating difficult. Although these basins have been dated as Cretaceous and linked to the opening of the Atlantic Ocean, in accordance with the available biostratigraph data (Brunet et al., 1988; Dupéron, 1991) many questions remain unanswered about the age of these sedimentary rocks interbedded with Cenozoic volcanic rocks (Déruelle et al., 1987; Fitton and Dunlop, 1985). The acquired information will enable us to better constrain the age, the palynomorph assemblage, the palynofacies, the hydrocarbon potential, and the palaeoenvironment of the four sedimentary basins.

2. Materials and methods

A number of sedimentary lithofacies and facies associations were described along N-S profiles across each basin (Fig. 2: a, b, c and d). A summary of the analytical techniques is provided below. Only fresh samples with no visible signs of alteration were used.

2.1. Lithofacies analysis

The sections chosen are oriented in N-S direction, perpendicular to the general strike of the beds. The sections have been measured, described, photographed and sampled with particular emphasis on lithology, trace fossils, macrofossil and content in leaves, followed by a detailed study of the sedimentological aspects. The samples are positioned on the lithostratigraphic column along the N-S geological profiles. Trenches have been dug to obtain uncontaminated samples.

2.2. Mineralogy

Seventy-two samples were collected for quantitative mineralogy including petrography (Nixon microscope equipped with a Nixon camera), and X-Ray Diffraction. XRD was conducted on bulk rock for all the samples at the Geological Institute of the University of Lausanne, Switzerland. The samples were prepared following the procedure of Kübler (1987). Random powder of the bulk sample is used for characterization of the whole rock mineralogy. About 20 g of each rock sample was ground with a "jaw" crusher to obtain small chips (1–5 mm). Approximately 5 g were dried at 60 °C and then ground to a homogenous powder with particle sizes <40μm. 800 mg of this powder was pressed (20 bars) in a powder holder covered with a blotting paper and analyzed by XRD. Whole rock composition was determined by XRD (Xtra Diffractometer, Thermo, Ecublens, Switzerland) based on methods previously described (Adatte et al., 1996). This method used external standards for semi-quantitative analysis of the bulk rock mineralogy (obtained by XRD patterns of random powder samples).

2.3. Palynofacies analysis

Twenty-seven samples were collected from the four basins along the N-S geological profiles and qualitatively studied for palynology. The samples were previously washed to remove contaminants, dried in an oven at 150 °C for 3 h, and later crushed. Species with well-known stratigraphic ranges in other contemporaneous basins of West, Central and Northern Africa were used as key elements (index species) for interfering palynostratigraphic age (Jardiné and Magloire, 1965; Salard-Cheboldaeff, 1990). Rock samples were processed in the palynological laboratory at Geo-Techniques Research Ltd., Sunbury on Thames, UK, using standard palynological techniques. These included digestion of carbonates and silicates with concentrated HCl (32%) and HF (40%), sieving of the residue and oxidation (e.g. Wood et al., 1996). Slides were prepared from unoxidized and oxidized residues. Palynomorphs were analyzed in the slides with oxidized residue. Selected palynomorphs are illustrated on Plates 1 to 4. The studied slides are deposited at I.R.G.M in Cameroon.

2.4. Total Organic Carbon (TOC) and Rock-Eval pyrolysis

Total organic matter content was determined using Rock-Eval pyrolysis (Rock-Eval TM6, Behar et al., 2001) at the University of Lausanne in Switzerland. Values were obtained using the standard temperature cycle. Samples were calibrated with both IFP160000 and internal standard with an instrumental precision of ˂2% (Espitalié et al., 1985). Forty-five representative samples were investigated for both organic matter characterization and Rock-Eval pyrolysis. The analytical method consists of heating 100 mg of the rock in the temperature program at an increase of 25°/min under inert atmosphere (helium) to determine the type of organic matter by plotting different parameters (Espitalié et al., 1985). The resulting parameters include the following: S_1 (free hydrocarbons), S_2 (hydrocarbons yield from cracking of kerogen), S_3 (the trapped CO_2 released during pyrolysis), T-max (Rock-Eval pyrolysis oven temperature in ^{o}C at maximum S_2 generation), the Total Petroleum Potential (S_1+S_2), Hydrogen Index [HI = (S_2/TOC) x 100, mg HC/g TOC] and Oxygen Index [OI = (S_3/TOC) x 100, mg CO_2/g TOC], the Production Index [PI = (S_1/(S_1+S_2)] and the S_2/S_3 together with the HI are proportional to the amount of hydrogen in the kerogen and