BULLETIN OF CANADIAN PETROLEUM GEOLOGY
VOL. 37, NO. 3 (SEPTEMBER, 1989), P. 266-292

Organic maturation and thermal history of Phanerozoic strata in northern Yukon and northwestern District of Mackenzie

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ABSTRACT

The thermal history and levels of organic maturation of Phanerozoic sedimentary sequences in northern Yukon and northwestern District of Mackenzie have been investigated by measurement of vitrinite reflectance (%Ro; mean random reflectance in oil) and conodont alteration index (CAI). The strata are immature to overmature with respect to the oil window, and maturation increases laterally with increasing structural complexity. Coeval strata have generally lower maturity in southern Mackenzie Delta, Peel Plateau and Eagle Plain than in the Richardson and Ogilvie mountains.

In Upper Cambrian to Lower Devonian strata, CAI values vary from 3.5 to 5 whereas vitrinite reflectance ranges from 0.2 to 3.75% Ro in Middle Devonian to Upper Cretaceous strata. Time-averaged numerical modeling of measured maturation gradients (0.10 to 0.32 log %Ro/km) suggests paleogeothermal gradients on the order of 20 to 45° C/km in southern Mackenzie Delta and Peel Plateau, from 10 to 20° C/km in central Eagle Plain and from 20 to 45° C/km adjacent the Richardson and Ogilvie mountains. Higher maturity levels in mountainous areas reflect higher maturation gradients and, in the Richardson Mountains, deeper burial due to rapid subsidence caused by the foundering of grabens within the Richardson Fault Array. Anomalously high maturation values (0.92 to 1.60% Ro) measured in Lower Cretaceous strata on the Campbell Uplift are interpreted to reflect high paleoheat flow associated with basement uplift. The low paleogeothermal gradients are considered to reflect low paleoheat flow and/or rapid Late Cretaceous sedimentation and uplift. Based on interpretation of measured maturation gradients, the thickness of eroded section in the study area varies from 0.7 to 4.7 km. Such values are consistent with rates of subsidence and uplift estimated from the ages and thicknesses of preserved section in the study area.

Interpretation of burial and thermal history indicates the degree of organic maturity (DOM) required for hydrocarbon generation for Devonian strata was attained in the Late Devonian to Early Carboniferous in western Peel Plateau but not until Late Carboniferous to Permian in Eagle Plain. Devonian strata left the oil window during the Carboniferous to Early Tertiary in most parts of the study area. Carboniferous and Permian strata entered the oil window in Late Carboniferous to Early Tertiary time in most of Eagle Plain. In western Eagle Plain, the Carboniferous sequence exited the oil window during the Late Cretaceous. Carboniferous and Permian strata are immature with respect to hydrocarbon generation in central Eagle Plain. Lower and Upper Cretaceous strata in southern Mackenzie Delta, Peel Plateau and most of Eagle Plain, for the most part, have not entered the oil window, whereas, in the northwestern Eagle Plain, Lower Cretaceous strata entered the oil window in Late Cretaceous to Early Tertiary time.

RÉSUMÉ

L'évolution thermique et les niveaux de maturité de la matière organique des séquences sédimentaires Phanérozoïques dans le nord du Yukon et le nord-ouest du district du Mackenzie ont été étudiées à l'aide de la réflectance de la vitrinite et l'indice d'altération des conodontes. Les strates varient entre immatures et surmatures par rapport à la fenêtre de génération d'huile, et le niveau de maturité augmente latéralement de concert avec l'augmentation de la complexité structurale. Les strates contemporaines dans le sud du delta du Mackenzie, et dans les régions du plateau de Peel et de la plaine Eagle, ont en général un niveau de maturité moins élevé que celui des montagnes de Richardson et d'Ogilvie.

Traduit par Marc Charest

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Cretaceous strata that have never entered the oil window.

In the Richardson and Ogilvie mountains, the depth to the oil window intersects the surface, or projects above the surface.

Timing of Hydrocarbon Generation

The timing of hydrocarbon generation has been estimated using the burial and thermal history plots (Figs. 8 to 19) and the limits of the oil window (0.61% to 1.35% Ro, Waples, 1980) for Type III kerogen because potential source rocks in the study area are composed mainly of Type III kerogen (Link *et al., this volume*). Type III refers to kerogen with relatively low Hydrogen Index values (usually less than 300 mg HC/g organic carbon) and a high initial Oxygen Index value (as high as 150 mg CO_2/g organic carbon; Espitalié *et al.*, 1985) and is derived from terrestrial plants (Tissot and Welte, 1984, p. 154). In Eagle Plain, Devonian strata entered the oil window in the Late Carboniferous to Permian during deep burial (Figs. 11a to 14a and 19a). The Middle and Upper Devonian sequence exited the oil window in Permian to Late Cretaceous time in western and eastern Eagle Plain (Figs. 13a, 14a and 19a) but are presently within the oil window in northwestern Eagle Plain (Fig. 12a). Carboniferous and Permian strata in western Eagle Plain (Fig. 19a) entered the oil window in the Late Carboniferous but not until the Early Jurassic in southeastern Eagle Plain (Fig. 14a) and the Late Cretaceous to Early Tertiary in northwestern and eastern Eagle Plain (Figs. 12a and 13a). The earlier onset of hydrocarbon generation in western Eagle Plain than in other parts of Eagle Plain can be explained by deeper burial during the Carboniferous and Permian in western Eagle Plain. Most of the Carboniferous sequence exited the oil window during the Late Cretaceous in western Eagle Plain (Fig. 19a) but are presently mature in northwestern (Fig. 12a), eastern (Fig. 13a) and southeastern (Fig. 14a) Eagle Plain. Carboniferous, Permian and Lower Cretaceous strata in central Eagle Plain have not entered the oil window due to a combined effect of shallow burial depths (Figs. 15a, 16a and 17a) and low maturation gradients (0.15 to 0.18 log %Ro/km). Only in northwestern Eagle Plain (Fig. 12a) are Lower Cretaceous strata mature; here the DOM required for hydrocarbon generation was attained just after deep burial in Late Cretaceous time.

In western Peel Plateau, the onset of hydrocarbon generation in Devonian strata occurred in Late Devonian to Early Carboniferous time, but not until the Late Jurassic to Early Cretaceous in eastern Peel Plateau as a result of shallower burial depths (Figs. 9a and 10a). The Devonian succession exited the oil window in Early Permian to Late Jurassic time in western Peel Plateau whereas the strata are presently mature in eastern Peel Plateau. Lower Cretaceous strata in western Peel Plateau are immature as a result of shallow burial (Fig. 10a).

In southern Mackenzie Delta, Jurassic strata (lower part of Bug Creek Group) entered the oil window during the Late Cretaceous to Early Tertiary when they reached their maximum burial depths. Strata younger than Middle Jurassic age are immature (Fig. 8a).

Timing of Hydrocarbon Generation Relative to Structure

Because maturation values are a reflection of the stratigraphy rather than the present structural level in almost all areas of the study, maturation is considered to be pre-tectonic and thus pre-date Laramide orogeny (Late Cretaceous to mid-Tertiary; D.K. Norris, 1985; Dixon, 1986). Thus, hydrocarbons were generated and hence were available for migration prior to the formation of structural traps during Laramide orogenesis.

The timing of hydrocarbon generation must also be considered with respect to major erosional episodes, which can potentially erode and/or degrade trapped hydrocarbons. Hydrocarbons generated during Devonian to Late Carboniferous time in western Peel Plateau and western Eagle Plain, and during Jurassic to Early Cretaceous time in southeastern Eagle Plain and eastern Peel Plateau may have been eroded and/or degraded accompanying Columbian (Hauterivian) and/or mid-Cretaceous (Aptian) orogenesis.

Summary and Conclusions

The DOM of Upper Cambrian to Upper Cretaceous strata in the northern Yukon and northwestern District of Mackenzie generally reflects the stratigraphy, and maturation is considered to be pre-orogenic (pre-Laramide). The variation in DOM reflects a wide range of maturation gradients in Eagle Plain (0.10 to 0.29 log %Ro/km) and the effects of timing and magnitude of the maximum depths of burial.

Coeval strata are generally less mature in southern Mackenzie Delta, Peel Plateau and Eagle Plain than in the Richardson and Ogilvie mountains. Upper Cambrian to Middle Devonian strata have CAI values of 3.5 to 5. The DOM at the base of Middle Devonian (Givetian) strata varies from 0.79 to 3.75% Ro whereas the regional variation in DOM at the base of Upper Devonian strata ranges from 0.80 to 2.13% Ro. Reflectance values vary laterally from 0.50 to 1.69% Ro at the base of Carboniferous strata and from 0.24 to 1.39% Ro at the base of Lower Cretaceous strata. Upper Cretaceous strata have the lowest DOM with reflectance values at the base ranging laterally from 0.38 to 0.53% Ro in Eagle Plain.

Time-averaged numerical modeling of the measured maturation gradients (0.10 to 0.32 log %Ro/km) suggest paleogeothermal gradients on the order of 20 to 45° C/km in southern Mackenzie Delta and Peel Plateau and paleogeothermal gradients that increase from 10 to 20° C/km in central Eagle Plain to 20 to 45° C/km toward the Richardson and Ogilvie mountains. The higher maturity levels in mountainous areas reflect higher maturation gradients and, in the Richardson Mountains, deeper burial due to rapid subsidence caused by the foundering of grabens within the Richardson Fault Array. Anomalously high maturation values (0.92 to 1.60% Ro) measured in Lower Cretaceous strata on the Campbell Uplift are interpreted as reflecting high paleoheat flow associated with basement uplift.

The low maturation (0.10 to 0.18 log %Ro/km) and interpreted paleogeothermal (10 to 20° C/km) gradients reflect low paleoheat flow and/or rapid sedimentation and uplift in the Late Cretaceous. As a result of the low paleogeothermal gradients, a great thickness (and volume) of Carboniferous to Upper Cretacecous strata in the subsurface of the central Eagle Plain are immature (<0.61% Ro).

Time-temperature modeling shows that for Devonian strata, the DOM required for hydrocarbon generation was attained in the Late Devonian to Early Carboniferous in western Peel Plateau but not until Late Carboniferous to Permian time in Eagle Plain and Jurassic to Early Cretaceous time in eastern Peel Plateau. The Devonian sequence exited the oil window in the Carboniferous to Early Tertiary in most of the study area. Carboniferous and Permian strata entered the oil window in the Late Carboniferous to Early Tertiary in most of Eagle Plain. Most of the Carboniferous sequences left the oil window during the Late Cretaceous in western Eagle Plain but are still within the oil window in northwestern, eastern and southeastern Eagle Plain. In central Eagle Plain, Carboniferous and Permian strata are immature as a result of shallow burial depths and lower maturation (0.10 to 0.18 log %Ro/km) and thus paleogeothermal gradients (10 to 20° C/km). Lower and Upper Cretaceous strata in most of Eagle Plain have not entered the oil window due to low maturation and thus paleogeothermal gradients (10 to 20° C/km) in central Eagle Plain and shallow burial depths in north-central Eagle Plain. In Peel Plateau and southern Mackenzie Delta, Lower Cretaceous strata are immature as a result of shallow depths of burial, whereas in northwestern Eagle Plain, these strata entered the oil window in the Tertiary just after maximum burial.

In Peel Plateau, approximately 1.7 km of post-Upper Devonian section have been eroded, whereas the amount of removed post-Carboniferous overburden is on the order of 2.6 to 2.8 km in eastern Eagle Plain and up to 4.7 km in western Eagle Plain. In northwestern Eagle Plain, about 3.5 km of post mid-Cretaceous section has been eroded, which is almost three times the amount of coeval overburden removed in southern Mackenzie Delta (1.1 km), either because burial was deeper in the Eagle Plain during the Late Cretaceous to Early Tertiary, or because the calculated maturation gradient in southern Mackenzie Delta is not representative of the paleogeothermal gradient of the eroded section. Estimates of the amount of eroded Upper Cretaceous section vary significantly from central to northern Eagle Plain (0.7 to 3.4 km) and thus help define Late Cretaceous depositional patterns.

Acknowledgments

This paper is the result of research by the senior author toward the M.Sc. degree at the University of British Columbia. The project was supported financially by an NSERC grant (A7337) and EMR research contract to Bustin. The authors gratefully acknowledge the support of the Geological Survey of Canada and Shell Canada Limited. We thank Dr. M.A. Barnes and Dr. W.C. Barnes of the University of British Columbia and Dr. J. Dixon, Dr. F. Goodarzi, Dr. L. Snowdon and many other staff at the Institute of Sedimentary and Petroleum Geology for their assistance. This paper has been improved by the critical comments of the *Bulletin* reviewers with the editorial assistance of Dr. I. Hutcheon.

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