The Petroleum Geology of the Ganga Basin, Himalayan Foredeep, Northern India*

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Abstract

Basin modeling, calibrated with Acritarch age dating and integrated with petrographic studies from a new well drilled in the eastern Ganga Basin (Figure 1), has enabled the chronology of petroleum system events that affected this part of the basin to be reconstructed. New data from the Havidih-1z exploration well indicates that the Karnapur and Tilhar formations (Figure 2) comprise of low porosity, indurated pelites and crystalline limestones respectively. Achritarchs confirm a Late Precambrian to Early Cambrian age for the Karnapur Formation. The assemblage includes *Archaeodiscina umbonulata Volkova* and *Archaeodiscina umbonulata* (Figure 3), the latter being considered an important Early Cambrian zone fossil (Molyneux et al., 1996; Palmer et al., 2001; Brück and Vanguestaine, 2002).

Mineralogical and petrographic studies demonstrate conclusively that the pelites of the Karnapur Formation are characterized by low grade metamorphic type IIb polytype chlorite (clinochlore, Figure 4) which is indicative of minimum temperatures of 220^{o} C. Achritarchs recovered from the pelites also confirm these sediments have a TAI of 3.5 or higher.

Scenario modeling to investigate the implications of the inferred Tilhar Formation succession encountered in the Havidih-1z well having been heated to 220^{o} C was carried out using a commercial 1D basin model. The 1D model base case was constructed with a lamalginite Type 1 Tilhar Formation kerogen typical of late Precambrian-Early Cambrian organic material (Crick et al., 1988; Jos et al., 2001) and a heat flow model constructed from a tectonic reconstruction of the Ganga Valley Basin (Boger et al., 2001; Cawood et al., 2007 and Sarbadhikari et al., 2008) (Figure 5). An indicative Total Organic Carbon (TOC) content of 3% and a hydrogen index of 600 were used in the source rock model. In the base case heat flow model the rifting heat flow maxima is 80 MW/m^2.

The results of the base case simulation indicate that the Precambrian-Early Cambrian Karnapur Formation section underwent burial to at least 4.5 km in the Lower Palaeozoic and subsequent uplift (Figure 6). The exact timing of the uplift is unknown because the age of the inferred Mesozoic section is poorly constrained. However, the specific timing of the inversion to near surface conditions has little or no

effect on the hydrocarbon generation and maturity result. In a slightly higher heat flow scenario case (90 MW/m^2 rifting case) burial depth of >5 km was required.

For all geologically reasonable scenarios, hydrocarbon generation begins in the Early Ordovician (c. 450 Ma; Figure 7) and ceased as indicated by the Transformation Ratio (TR) of 100% in the early Devonian around 400 Ma (Figure 8). This demonstrates that the main source rock in this locality has been over-mature and exhausted of hydrocarbons for some 400 million years before present.

As a result of the Late Palaeozoic uplift the potential for successful trapping of hydrocarbons in any Palaeozoic structures is low, as breaching of structures and hydrocarbon migration to surface is very likely. The Tilhar Formation source rock has been over-mature since the early Devonian, indicating that there is no further hydrocarbon generation potential remaining in this part of the basin.

Conclusions

Havidih-1z well has brought out new information to constrain the Ganga Basin evolution. Paleo temperature inferred from mineralogy of the rock encountered in the well indicates depth-of-burial to a minimum of 5 km and subsequent uplift and erosion. This uplift and erosion might have led to destruction of any Paleozoic-Proterozoic petroleum system in the study area. In other parts of Ganga Basin, where uplift is not drastic and the Palaeozoic section is preserved, a potential hydrocarbon system is possible. Those areas could be future areas for hydrocarbon exploration. Extensive regional integration of data and new acquisition with the latest technology and improved subsurface imaging would be the key. Our search continues…

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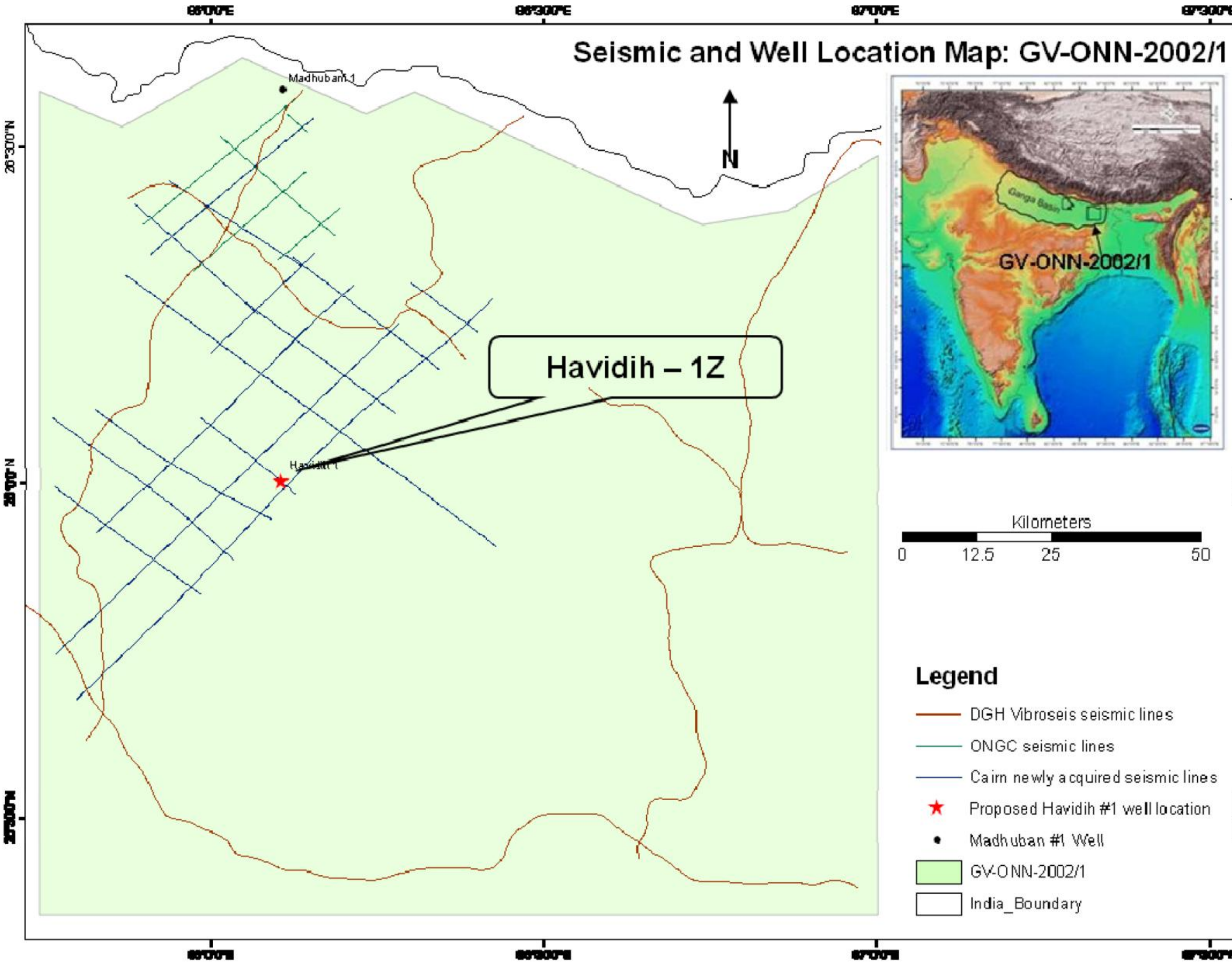

Figure 1. Location map of northeast India study area. Inset map shows Indian context.

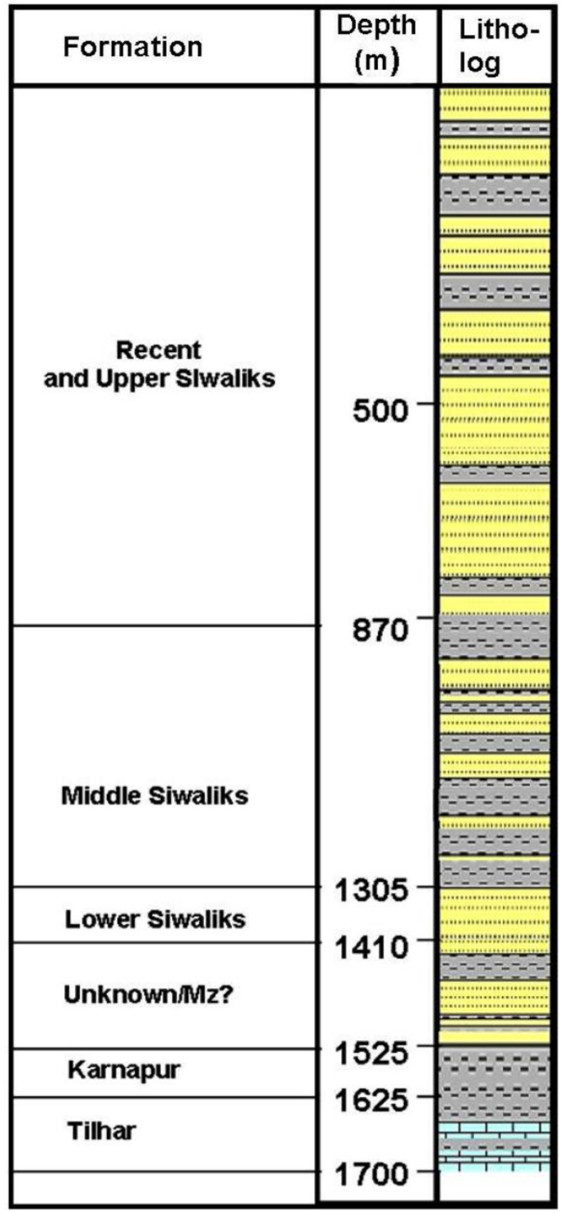

Figure 2. Summary lithostratigraphy of the section encountered in the Havidih-1z well complied from cuttings descriptions and wire line logs.

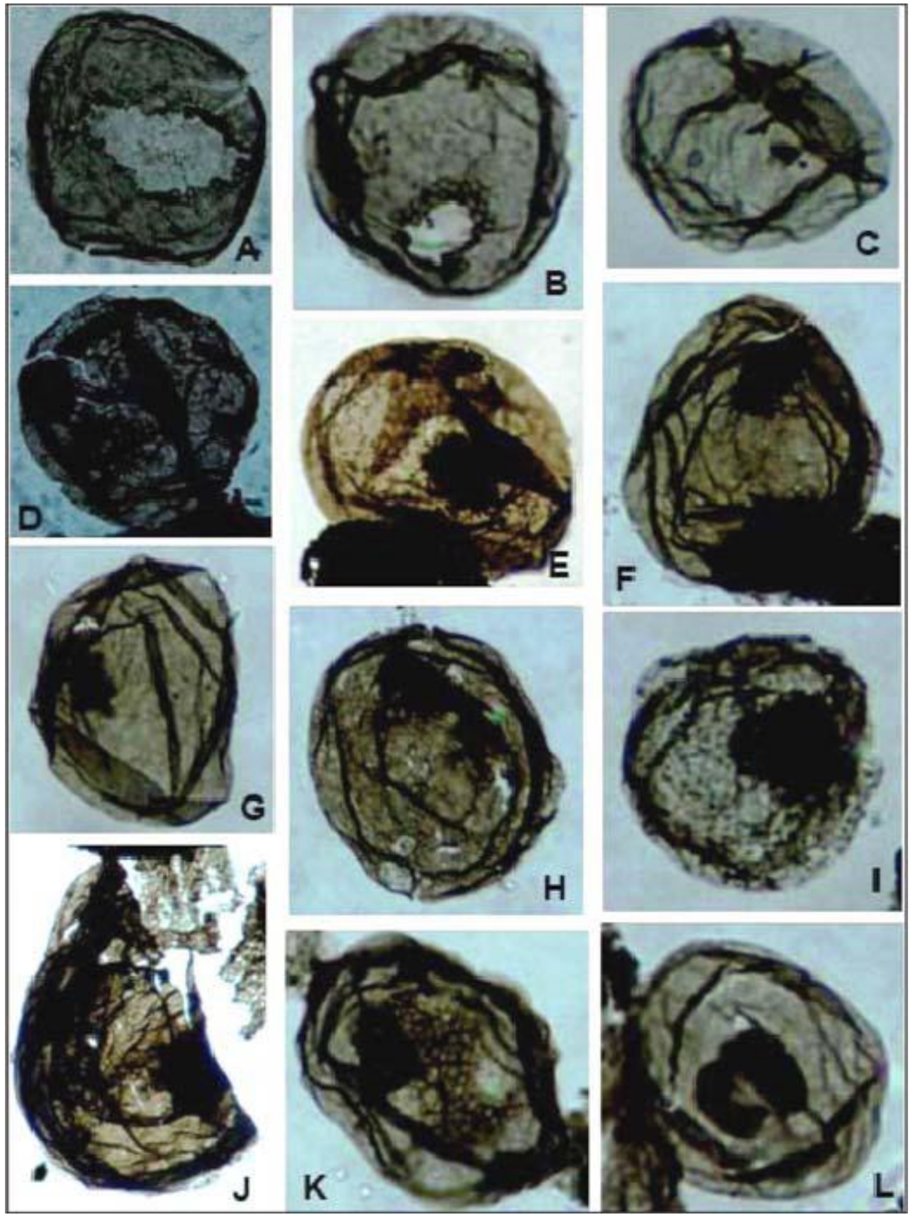

Figure 3. Plane light photomicrographs of the well preserved acritarchs recovered from the Karnapur Formation of the Havidih-1z well (1530-1587 m), including thin-walled leiospheres (A-B) and *Archaeodiscina umbonulata* (D-L).These acritarchs are present throughout the Karnapur Formation and are a consistent brown to dark brown colour indicative of a Thermal Alteration Index of 3.5.

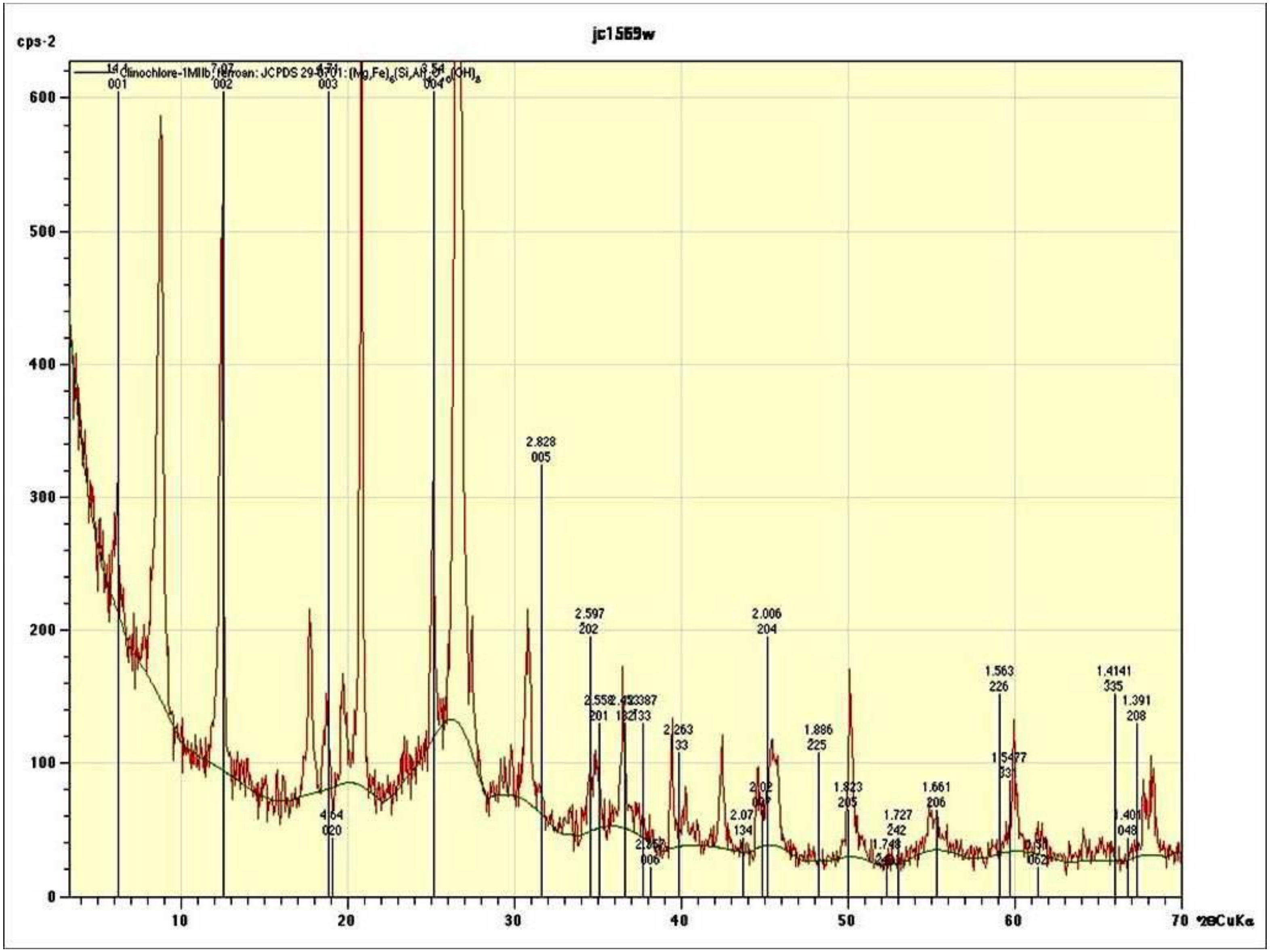

Figure 4. Annotated x-ray diffractogram of the < 2 micron clay fraction from the green pelite sample 1569 m showing the presence of type IIb clinochlore. Diffractogram scales are diffraction intensity (in counts per second, cps, y scale) and degrees 2 theta (incident-diffraction angle, for Cu K alpha radiation, x-axis). Red diffractogram trace is annotated for hkl diffractions that coincide with lattice spacing for type IIb clinochlore taken from the online WHICH mineral reference library.

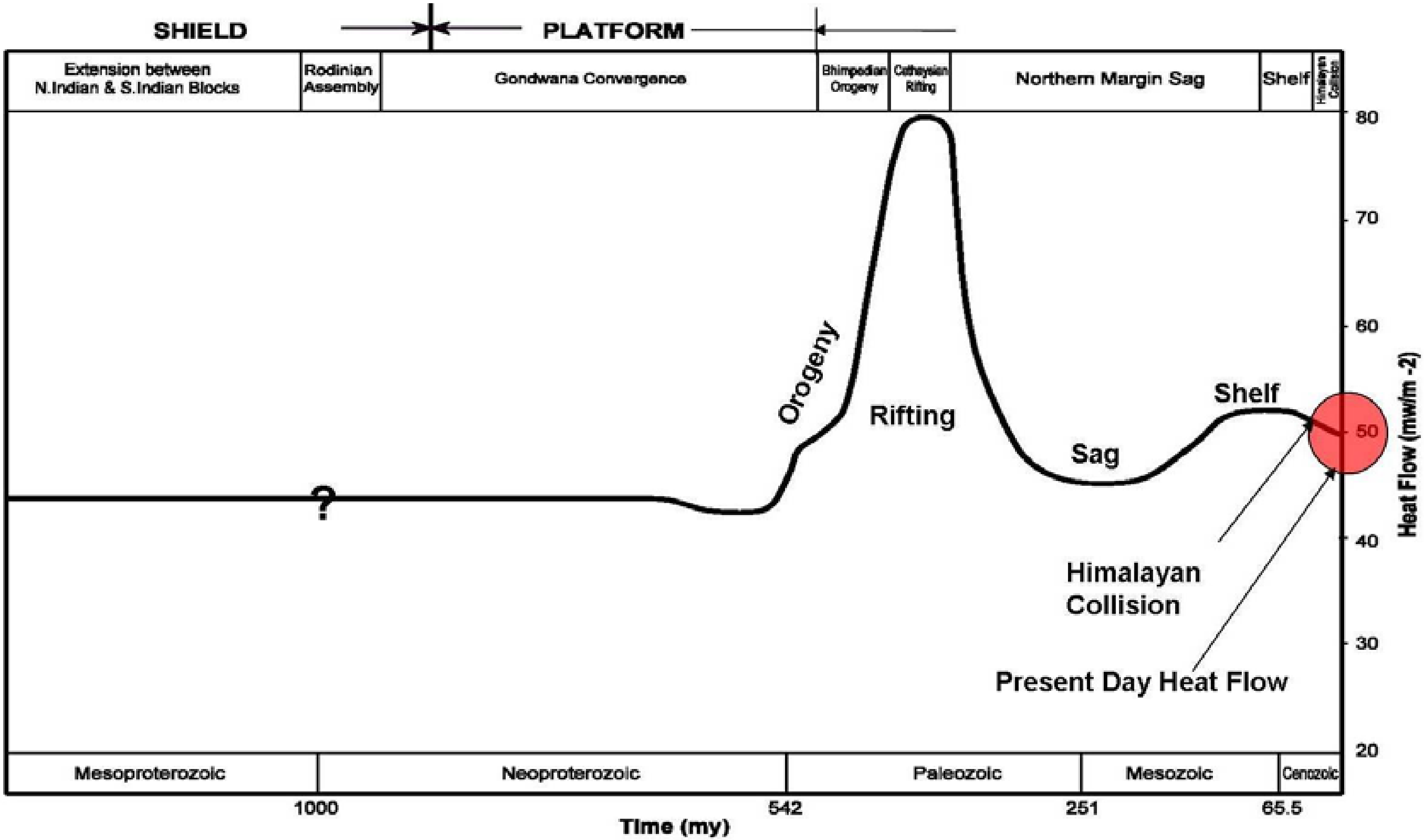

Figure 5. The heat flow model used as input in the base case 1D basin modeling simulation showing the incorporation of a rifting event during the Cathayasian in which the rifting heat flow has a maximum of 80 MW/m^2. Note the heat flow model is calibrated to present day heat flow measurements (Boger et al., 2001; Cawood et al., 2007 and Sarbadhikari et al., 2008).

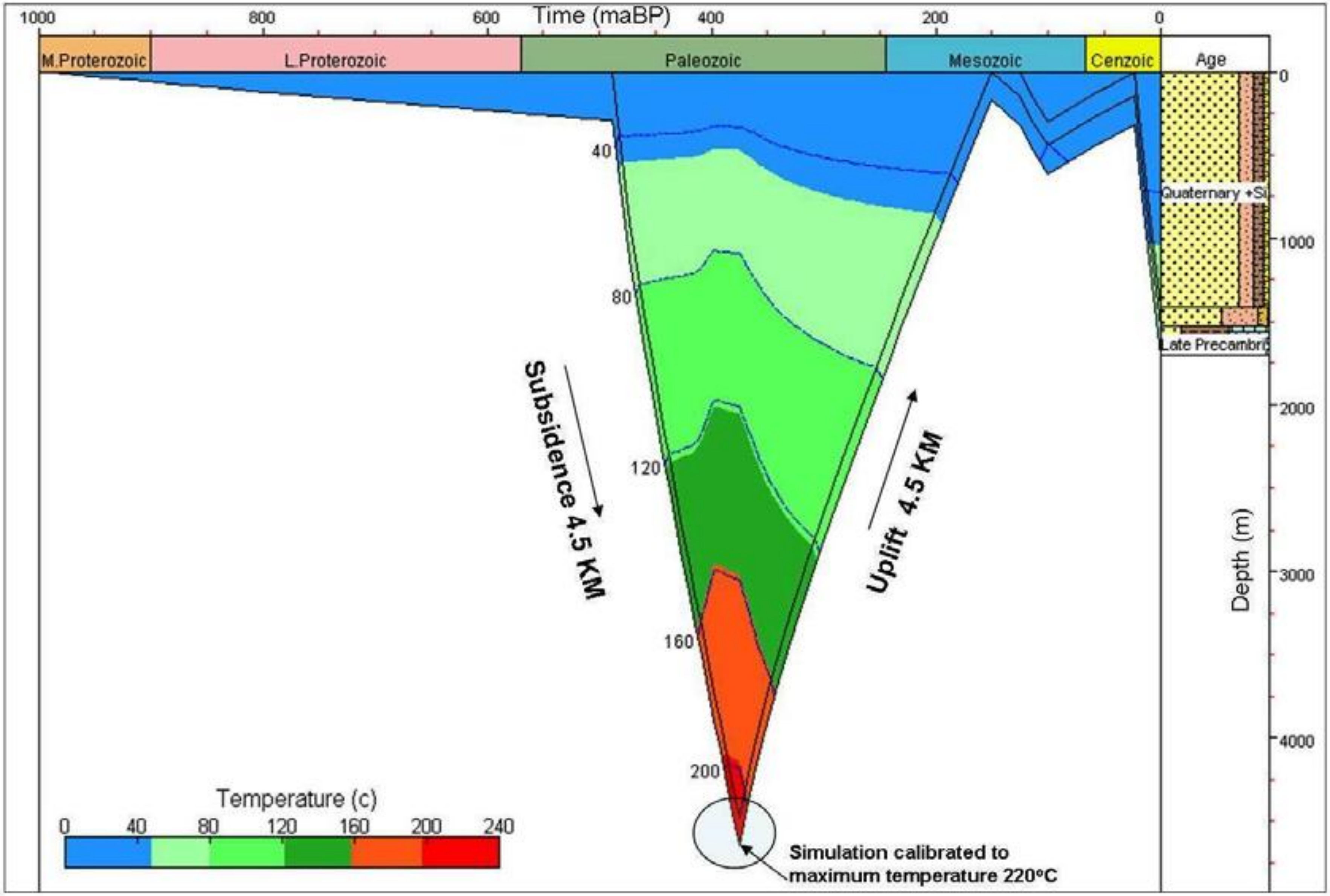

Figure 6. Base case 1-D burial model prediction resultant of minimum temperature of 220° C attained for the Karnapur Formation (indicated by the chlorite and TAI thermal indices) showing the implied 4.5 km depth of burial during the Lower Palaeozoic and subsequent uplift prior to 500 m of Mesozoic burial. Model calibrated to present day stratigraphy.

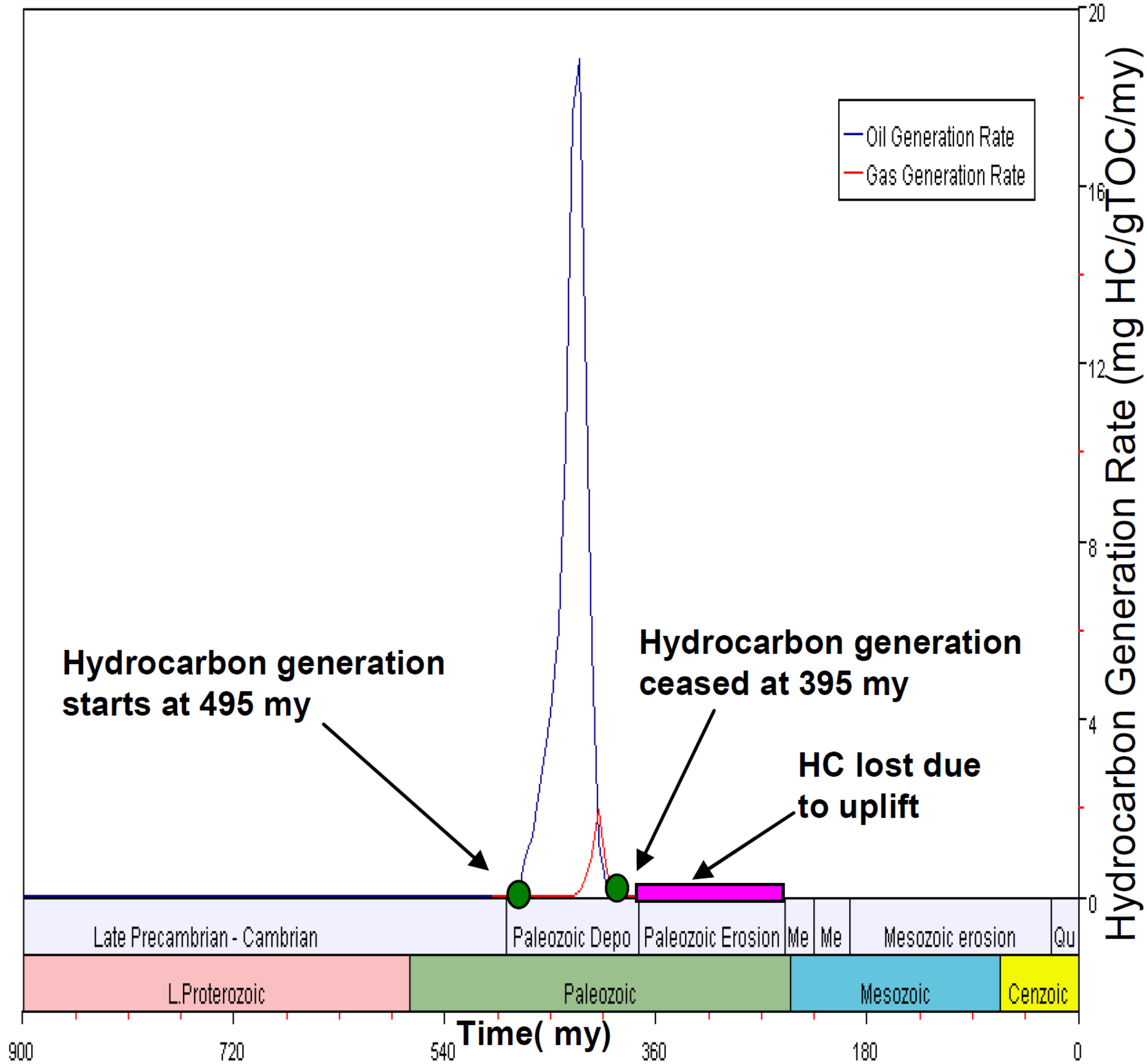

Figure 7. Base case simulation (3% type 1 algal organic matter, rifting heat flow 80MW/m^2 maxima with maximum burial temperature of 220^o C) showing timing of hydrocarbon generation. Note that hydrocarbon generation started in the early Ordovician and generation ceased at early Devonian.

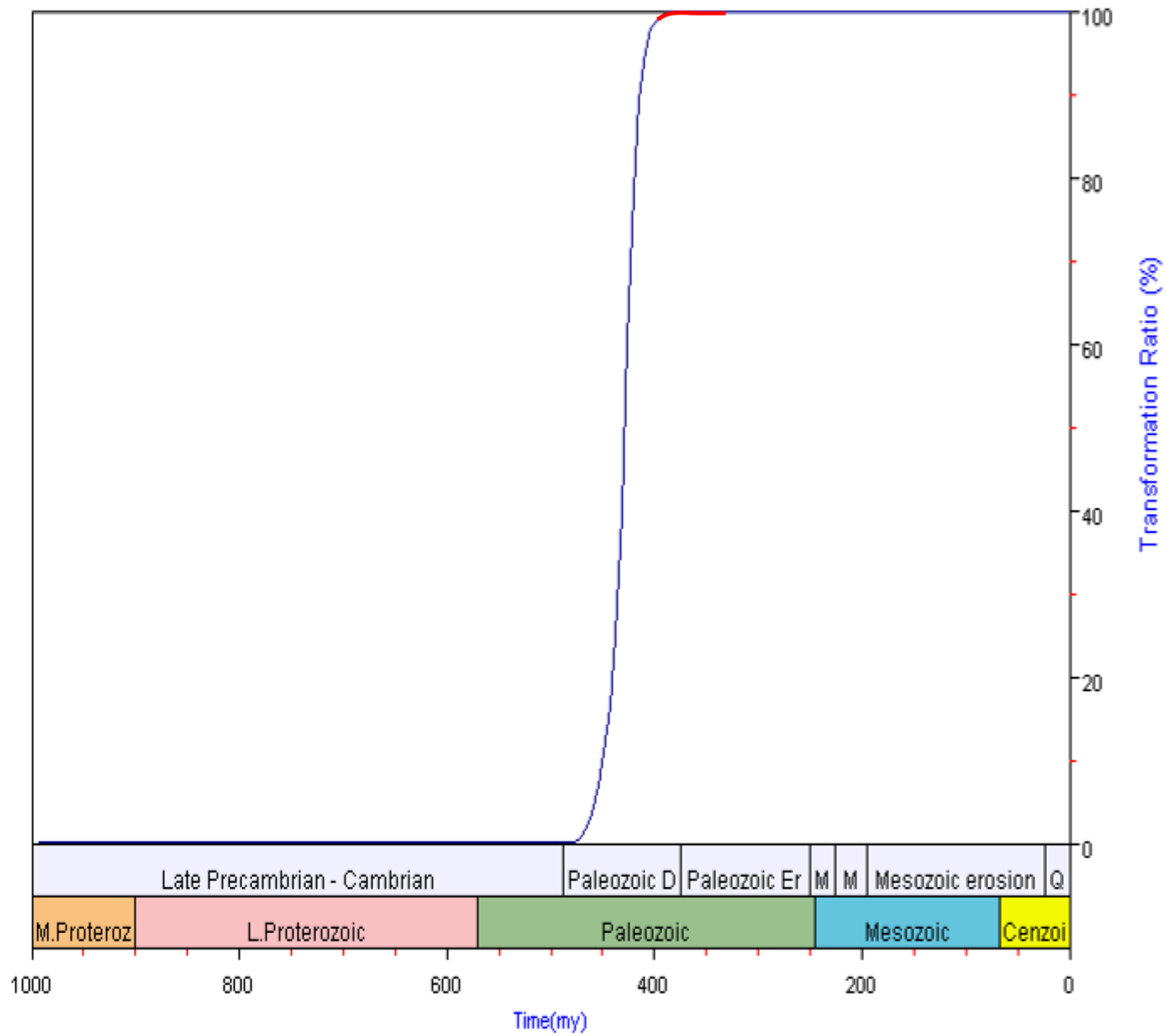

Figure 8. Transformation ration (TR) of kerogen to hydrocarbon (expressed as a percentage) for the base case simulation (3% type 1 algal organic matter in Karnapur Formation source rock, rifting heat flow 80MW/m^2 maxima with maximum burial temperature of 220^{o} C) demonstrating that by the early Devonian (400 Ma BP) the source rock was fully exhausted. There has been no further hydrocarbon generation potential since the Devonian.