



# Palynofacies and geochemical analysis of the Triassic Yanchang Formation, Ordos Basin: Implications for hydrocarbon generation potential and the paleoenvironment of continental source rocks



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## ABSTRACT

The petroliferous basins that have formed in China since the Mesozoic are characterized by non-marine organic matter input, a characteristic that is significantly different from that of marine organic sources. The Triassic Yanchang Formation in the Ordos Basin is a suite of typical intra-continental lacustrine sediments that comprise the most important source rocks for the Triassic oil reservoirs. The Yanchang Formation is divided into ten subsections from top to bottom (Chan 1 to Chan 10). Three borehole successions in the southern Ordos Basin (located in the Huachi, Zhidan and Yichuan areas) cross the Chan 4 + 5 to Chan 10 subsections and have been studied using the palynofacies method combined with organic geochemistry data. Palynofacies analysis indicates that the sediments are rich in amorphous organic matter (AOM) and phytoclasts. The AOM content in all of the samples positively correlated with the hydrogen index (HI). In contrast, the transparent ligno-cellulosic fragments (TLF) + opaque particles (OP) content are negatively correlated with the HI values. Additionally, the gelified particles (GP) content has no linear correlation with the geochemistry data. Based on the quantitative composition of the particulate organic matter, three palynofacies types are identified, reflecting depositional settings in a distal dysoxic–anoxic deep basin, a shelf-to-basin transition zone and a proximal suboxic shelf. The palynofacies, total organic carbon (TOC), and Rock-Eval data together indicate that type I and II kerogen are abundant in the D48 and W22 wells in the Zhidan and Yichuan areas, respectively. These kerogen types are uncommon in the L94 well in the Huachi area, which suggests low hydrocarbon generation potential. In detail, the Chan 7 and Chan 9 subsections of the three wells contain abundant type I and II kerogen, indicating that these layers are likely the two primary source rocks in the southern Ordos Basin.

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## 1. Introduction

The term palynofacies was defined by Powell et al. (1990) as a distinctive assemblage of specific HCl- and HF-insoluble organic matter (“palynoclasts”) whose composition reflects a specific sedimentary environment. This differs from the organic facies, defined as a body of sediment containing a distinctive assemblage of organic constituents, which can either be recognized by microscopy, or is associated with a characteristic bulk organic geochemical composition (Tyson, 1995). Thus, the use of the palynofacies method on the organic matter composition represents only a specific aspect of organic facies research. The advantage of palynofacies research is that it can quantify the various types of particulate organic matter within a source rock using transmitted light microscopy, which was described by Tyson (1995) and is widely applied, including in recent work (e.g. Roncaglia and Kuijpers, 2006; Ghasemi-Nejad et al., 2009; Graz et al., 2010; Garcia et al., 2011). This HCl- and HF-insoluble organic matter (spores, pollen grains, algae,

acritarchs, chitinozoa, foraminiferal linings, and fragments of different plant tissues) depends on primary productivity, depositional processes and biochemical degradation (Tyson, 1995; Ercegovic and Kostić, 2006). Thus, it can be used with sedimentological evidence to identify the depositional environment, such as proximal–distal changes, the time of maximal marine or terrestrial influx to a depositional area, the oxidation–reduction environment or variations in the water depth (Tyson, 1993; Tyson and Follows, 2000; Zobaa et al., 2011; Mueller et al., 2014). Consequently, the petroleum potential of a sedimentary succession can also be successfully identified from the palynofacies type (e.g. Schioler et al., 2010; El Atfy et al., 2014). In fact, palynofacies studies have been widely used to interpret paleoenvironments and to evaluate source rocks in marine sediments (Carvalho et al., 2013; El Atfy et al., 2014 and others) but have been rarely used to examine performed on continental source rocks.

The Ordos Basin is a large intracontinental sedimentary basin in China with an area of approximately  $37 \times 10^4$  km<sup>2</sup>. The crude oil reserve in the Mesozoic reservoirs was estimated to be approximately  $10 \times 10^8$  metric tons. The basin is considered to be a typical model of a non-marine oil generating sedimentary basin because the crude oils were

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mainly derived from the non-marine source rocks of the Yanchang Formation (Duan, 2012; Wang et al., 1995). The molecular and isotopic organic geochemical data suggest that the oils were generated from a source with mixed terrigenous and algal–bacterial organic matter (Wang et al., 1995; Duan, 2012). The important discovery of leiosphaerid acritarchs (*Leiosphaeridia*) and oleaginous *Botryococcus* in the Yanchang Formation by Ji et al. (2008, 2010) first demonstrated the type and character of the algae sources. Although palynofacies are an important parameter for paleoenvironment reconstruction and the evaluation of hydrocarbon generation, few studies have focused on the palynofacies of the source rocks in the Yanchang Formation.

In recent years, several major oilfields, such as the Xifeng, Huaqing and Jiyuan oilfields, have been discovered, which confirms significant hydrocarbon generation in the Yanchang Formation. The sedimentary sequence exhibits a cyclic pattern formed by alternating lake levels, which led to varying qualities of the different source rock layers in the Yanchang Formation. The different water depths, sources and depositional rates in the lake resulted from varying tectonic conditions during the same depositional interval, leading to the deposition of different source rocks in the various regions of the Ordos Basin (Li et al., 2012). Most studies have focused on reservoir research with respect to production units in the oilfields and the difficulties in obtaining drill core materials. There are few studies that involve comparisons of the source rocks in the Yanchang Formation.

In this study, palynofacies, Rock-Eval and total organic carbon (TOC) analyses are performed on source rock samples from the Yanchang Formation from three wells in different areas of the southern Ordos Basin. The objective of this research is to 1) interpret the composition and characteristics of the terrestrially derived organic matter, 2) interpret

the depositional environment of the sediments using the palynofacies, and 3) distinguish the hydrocarbon generation potential for various oil subsections in the three areas and determine the primary hydrocarbon source rocks.

## 2. Geological setting

The Ordos Basin, which contains abundant petroleum resources, is a superimposed multicycle cratonic basin located on the stable Northern China Platform. This basin experienced two main developments, Paleozoic marine deposition and Mesozoic continental deposition. Deposition in the basin was controlled by paleotopography, which can be divided into the Yishan slope, where the studied wells are located; the Yimeng uplift zone; the Weibei uplift zone; the Jinxi flexural fold zone; the Xiyuan obduction zone; and the Tianhuan depression (Fig. 1A). The strata of the Yishan slope have a gentle western tilt with an angle of approximately  $1^\circ$ . This area is presently a major area of petroleum production in the Ordos Basin. The Ordos Basin was filled by Paleozoic to Cenozoic sediments. The source rocks were mainly formed in the late Paleozoic and early to mid-Mesozoic (Fig. 1B). The Late Paleozoic stratigraphy includes the Carboniferous Jingyuan and Yanghugou Formations and the Permian Taiyuan, Shanxi, Xiashihezi, Shangshihezi and Qianfengshan Formations. The Carboniferous deposits are composed of limestone, sandstone and dark mudstone with several coal beds. The Permian succession is mainly composed of sandstone, mudstone and limestone. Although the Late Paleozoic source rocks have a high TOC (2.0–3.0%), their high maturity means that they are primarily gas source rock. The main oil-bearing sequences in the Ordos Basin are the Upper Triassic Yanchang Formation and the Lower Jurassic Yanan

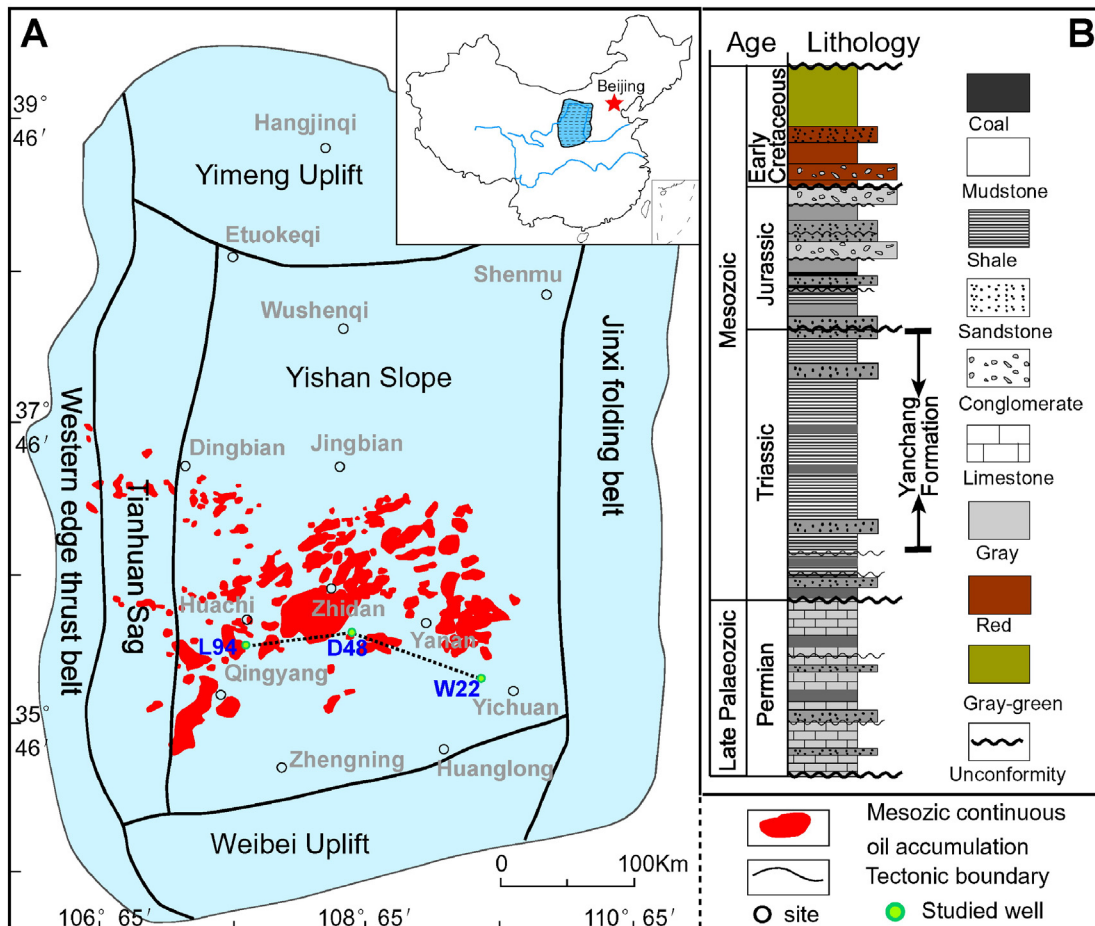


Fig. 1. A) The location of the research area and the tectonic units of the Ordos Basin; B) the generalized stratigraphic column of late Paleozoic and Mesozoic.

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