International Journal of Coal Geology 191 (2018) 37–48

Contents lists available at ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/coal

Expelled oils and their impacts on Rock-Eval data interpretation, Eocene Qianjiang Formation in Jianghan Basin, China

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ARTICLE INFO

Keywords:
Rock Eval analysis
Lacustrine shale oil
Hydrocarbon generation kinetics
Hypersaline lacustrine sediments

ABSTRACT

Source rock samples can be “contaminated” by expelled oils from nearby mature source rocks or from the organic-rich laminae within the same source rock units. The “contaminations” on the Rock-Eval samples could produce a false high S1 peak, a high Production Index (PI), a suppressed T_{max} and other anomalies. Identifying the samples affected by expelled oils, assessing and correcting the impacts are crucial in source rock study for shale oil/shale gas resource evaluation. This study analyzes the Rock-Eval 6 results of 43 core samples from two recent shale oil exploration wells of the Eocene Qianjiang Formation, a confined source rock unit embedded with salt intervals formed in a hypersaline lacustrine setting in central China. The geochemical anomalies of the affected samples are shown through the available samples in this study. Criteria for identifying the affected samples are discussed, and impacts on the conventional Rock-Eval parameters and subsequent estimation of kinetic parameters presented. This study provides insights into Rock-Eval data interpretation, particularly in source rock evaluation for estimating shale oil resources.

1. Introduction

Organic-rich shales have been traditionally regarded as the source rock in a conventional petroleum system (Tissot and Welte, 1984), and some of them are now considered as a self-sourced and self-contained, economically viable reservoir developed through long range horizontal drilling coupled with multi-stage hydraulic fracturing. Rock-Eval pyrolysis has been widely accepted by the petroleum industry as a useful tool for easy and cost effective data generation in source rock evaluation and shale oil/gas resource appraisal (Peters, 1986; Jarvie 2012a and b; Modica and Lapierre, 2012; Chen and Jiang, 2016; Chen et al. 2016a and b).

One common feature of fine-grained source rock reservoirs is the lamination or lithology alteration in vertical and lateral directions. The self-sourced and self-contained shale resource play is usually a closed petroleum system, with the crude oil and natural gas originating from the organic-rich shale and being stored in both organic and inorganic matrix pores (including natural fractures) (Loucks et al., 2009; Jarvie, 2012b; Modica and Lapierre, 2012; Chen and Jiang, 2016). In a confined and poorly drained system, expelled oils from organic-rich laminae can migrate along the kerogen network, and “contaminate” the same source rock unit by immersing into interbedded coarser grained (often silty-sandy) shales, thus leading to oil immersion of indigenous organic matter in the source rock reservoirs (Bernard et al., 2012; Jarvie 2012a and b; Loucks and Reed, 2014; Reed et al., 2014; Bernard and Horsfield, 2014; Chen and Jiang, 2016). The common pyrolysis experiment procedure was designed for normal source rock analysis. However, the heavy fraction of petroleum produces a measureable response in the 350–450 °C range by volatization in the same region where kerogen conversion to hydrocarbons occurs by thermal pyrolysis (Clementz, 1979; Espitalie et al., 1977). This “carry-over” free hydrocarbon results in a mixture with the S2 response on the low-temperature side.

“Pure Organic Matter” procedure of the Rock-Eval 6 equipment was designed to provide information relevant to quantifying a sample's source potential and thermal maturity status (Behar et al., 2001). When applied to source rock evaluation, the S2 curve is assigned to the hydrocarbon residual potential, and the S2 peak temperature (equivalent,

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https://doi.org/10.1016/j.coal.2018.03.001
Received 2 November 2017; Received in revised form 28 February 2018; Accepted 2 March 2018
Available online 18 March 2018
0166-5162/

T_{max}) to the thermal maturity. The presence of large amounts of live oils in immature and early mature source rock samples may lead to suppressed T_{max} values (Peters, 1986; Snowdon, 1995). Co-existence of indigenous organic matter and migrated hydrocarbons in source rock reservoirs may also result in false signatures due to mixing of S1 with S2 responses, causing depressed S2 peak temperature and over-stating remaining potential. This could lead to uncertainties in the estimation of thermal maturity status and hydrocarbon generation potential. In addition, inferred source rock generation kinetics may be affected due to the presence of non-authigenic organic matter. On the other hand, for liquid-rich shale reservoir evaluation, the “carrying-over” free hydrocarbons appearing in low temperature range of S2 under-estimates the free-hydrocarbons measured by S1, over-estimate generation potential, suppress T_{max}, and depress and provide unreliable Hydrogen Index (HI) value (King, 2015).

Identifying the affected samples and eliminating the impact of the migrated hydrocarbon on Rock-Eval parameter estimation are essential for restoring the true hydrocarbon generation potential and present day maturity status in resource estimation. Efforts by improved laboratory procedures have been made in removing the impact and restoring the parameters for the indigenous organic matter in recent years (King et al., 2015; Romero-Sarmiento et al., 2016). However, identifying the affected samples and assessing the impacts of the non-authugenic organic matter on Rock-Eval parameters remain elusive.

The traditional method of Rock-Eval data interpretation relies on the calculated parameters in a summary table, such as in Table 1. In fact, a large amount of information remains unused in the raw data of the analysis results, such as in the pyrograms, which can provide additional information on oil intrusions in the samples and is useful for visualizing and estimating the impacts of oil intrusion on the samples.

The objectives of this study are three fold, a) to discuss methods for identifying samples potentially mixed with migrated oils; b) to estimate the impact on Rock-Eval parameters relevant to resource potential calculations; and c) to estimate whether or not the presence of migrated oils affects T_{max} calculation. In this paper, we present the data, discuss the problems, and describe methods for identification of affected samples and assessing the impacts of non-authogenic organic matter (migrated oils) on Rock-Eval parameters through the example of salt bound organic-rich mudstones in the Eocene Qianjiang Formation in the Jianghan Basin.

2. Geological background

Core samples used in this study come from the Eocene-Oligocene Qianjiang Formation in two recently drilled shale oil study wells in the Qianjiang Depression, Jianghan Basin (Fig. 1), central China. The Qianjiang Depression is a faulted depression developed during a Cretaceous-Eocene orogenic event (Wu et al., 2013). Red clastic sediments

Table 1
Rock-Eval analysis results of core samples of Qianjiang Formation, Jianghan Basin.

Sample ID	Well	Depth (m)	S1 (mg/g)	S2 (mg/g)	PI	T_{max} (°C)	S3 (mg/g)	TOC (%)	HI	MINC (%)	OI	Marker
1,604,663	A	1746.14	4.02	16.61	0.20	427	0.81	3.36	494	1.69	24	1
1,604,664	A	1747.02	4.29	24.01	0.15	435	0.69	4.40	546	2.49	16	2
1,604,665	A	1749.26	25.02	18.86	0.57	417	0.87	4.93	383	8.23	18	3
1,604,666	A	1714.33	5.13	4.12	0.55	420	0.92	1.84	224	2.28	50	4
1,604,667	A	1710.59	9.93	9.53	0.51	425	1.11	3.50	272	3.04	32	5
1,604,668	A	1708.55	6.48	4.91	0.57	420	0.67	2.52	195	6.72	27	6
1,604,669	A	1707.29	14.34	10.05	0.59	420	1.07	3.72	270	3.97	29	7
1,604,670	A	1705.89	11.07	10.16	0.52	421	0.76	3.62	281	2.93	21	8
1,604,671	A	1704.74	5.97	3.22	0.65	407	0.26	1.43	225	0.25	18	9
1,604,672	A	1649.21	13.09	14.18	0.48	425	0.50	3.98	356	5.45	13	10
1,604,673	A	1646.49	21.11	22.57	0.48	421	0.40	5.74	393	3.37	7	11
1,604,674	A	1645.1	9.21	14.97	0.38	426	0.87	3.57	419	1.14	24	12
1,604,675	A	1633	4.09	28.71	0.12	430	0.91	5.05	569	1.48	18	13
1,604,676	A	1632.3	7.03	32.93	0.18	425	1.08	6.20	531	1.79	17	14
1,604,677	A	1309.31	8.88	60.64	0.13	431	1.26	8.22	738	7.23	15	15
1,604,678	B	1446.17	1.46	16.73	0.08	430	1.23	3.34	501	2.03	37	16
1,604,679	B	1451.59	0.50	2.87	0.15	429	0.77	0.80	359	2.14	96	17
1,604,680	B	1454.46	0.69	9.77	0.07	435	1.01	2.36	414	2.63	43	18
1,604,681	B	1463.49	3.07	27.29	0.10	426	1.24	4.64	588	1.85	27	19
1,604,682	B	1463.81	2.67	22.37	0.11	429	1.15	4.12	543	1.12	28	20
1,604,683	B	1467.79	4.06	27.68	0.13	427	1.20	4.85	571	3.85	25	21
1,604,684	B	1471.11	1.58	14.87	0.10	425	0.83	3.18	468	1.29	26	22
1,604,685	B	1475.65	3.28	40.46	0.07	427	1.13	6.75	599	1.20	17	23
1,604,686	B	1476.47	1.29	15.07	0.08	430	0.75	2.80	538	1.80	27	24
1,604,687	B	1478.1	2.18	19.26	0.10	433	1.23	3.53	546	1.36	35	25
1,604,688	B	1481.93	0.42	3.43	0.11	432	0.68	0.85	404	2.20	80	26
1,604,689	B	1485.66	2.33	11.81	0.16	432	0.49	2.33	507	3.61	21	27
1,604,690	B	1487.46	4.56	21.98	0.17	423	0.88	4.93	446	1.18	18	28
1,604,691	B	1492.24	2.56	13.89	0.16	430	0.21	2.44	569	0.88	9	29
1,604,692	B	1497.4	0.50	3.87	0.11	431	0.86	1.45	267	8.31	59	30
1,604,693	B	1500.26	1.39	20.78	0.06	432	1.25	3.71	560	1.16	34	31
1,604,694	B	1502.57	2.05	16.73	0.11	427	1.13	3.17	528	1.11	36	32
1,604,695	B	1507.08	0.41	3.31	0.11	428	0.76	1.17	283	3.28	65	33
1,604,696	B	1512.29	1.85	8.53	0.18	419	1.14	2.74	311	3.77	42	34
1,604,697	B	1513.23	1.15	8.27	0.12	426	1.17	1.97	420	1.60	59	35
1,604,698	B	1513.61	2.45	12.89	0.16	425	0.95	3.18	405	2.52	30	36
1,604,699	B	1518.82	1.88	6.29	0.23	422	1.18	2.20	286	4.70	54	37
1,604,700	B	1524.7	1.90	12.75	0.13	427	1.38	2.81	454	1.23	49	38
1,604,701	B	1528.72	6.47	13.48	0.32	423	1.04	3.12	432	1.50	33	39
1,604,702	B	1534.16	7.50	25.24	0.23	426	1.04	4.90	515	0.67	21	40
1,604,703	B	1535.23	10.07	32.08	0.24	424	1.11	6.49	494	0.74	17	41
1,604,704	B	1536.21	8.97	26.45	0.25	424	1.06	5.01	528	2.54	21	42
1,604,705	B	1537.21	7.72	17.75	0.30	427	1.50	4.15	428	2.35	36	43