IDENTIFICATION OF THERMAL MATURITY, SOURCE AND DEPOSITIONAL ENVIRONMENT FROM CORE SAMPLE OBTAINED FROM UNDERWATER GEOCHEMISTRY SURVEY IN KABAENA SUB-BASIN, BONE BASIN, SOUTHERN PART OF SULAWESI

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ABSTRACT

Bone Gulf in South Sulawesi is an area with the possibility of potential hydrocarbon deposits. This research was conducted to examine the characteristics of Hydrocarbons gotten from Core Extraction from underwater geochemistry survey in the area of study by geochemical analysis methods and compared with known geological data. Geochemical analysis was carried out on 27 seabed-core samples taken from the area around the Kabaena sub-basin to determine the maturity level and depositional environment and the source of organic material from the Hydrocarbon producing Source Rock. Determination of the maturity level and depositional environment is based on CPI and OEP value, as well as N-Alkane and Isoprenoids which obtained from Gas Chromatography (GC). Geochemical analysis for the maturity level of all the samples showed the maturity level of immature to mature. Geochemical analysis for depositional environments on all samples showed a tendency to be deposited in the transitional and the sources of organic material is Mixed Kerogen.

***Keywords**: Bone Gulf, Hydrocarbon, CPI and OEP, N-Alkane, Geochemistry Analysis, Source Rock*

INTRODUCTION

In general, oil and gas exploration activities only focus on evaluating traps and reservoirs as a place for accumulating hydrocarbons. Meanwhile, there is not much that discusses the source rock, however, source rock is the origin of the formation of oil and gas itself, therefore methods for identifying and discussing source rock further are considered important.

One method for discussing more about source rock is Geochemical Analysis. Geochemical analysis is useful for interpreting the characteristics of source rocks, depositional facies, origin of forming material, level of maturity and the factors that influence it. One of the parameters used in geochemical analysis is biomarkers. Biomarkers are complex organic compounds, composed of carbon, hydrogen, and various other elements commonly found in oil, bitumen, rocks and sediments which show little change or even do not show changes in the molecular structure of origin (Peters, et al., 1993b)

The research area is a sub-basin located in southern Sulawesi precisely located in the Gulf of Bone which is between the southern arm and southeast arm of Sulawesi. The research area is one of the sub-basins identified by (Camplin & Hall, 2014), Bone Bay is divided into 4 sub-basins namely the Padamarang sub-basin to the north, the cub-Kabaena basin to the south, Liang-liang sub-basin to the east, and the Bone sub-basin to the west, and there is one trough, the Selayar trough on the southwest. The research area is the Kabaena sub-basin

REGIONAL GEOLOGY

Sulawesi is an archipelago located in the central part of Indonesia with an area of 174,600 km². Sulawesi is the main point of the world's three major plates, namely the continental plate of India - Australia which is relatively moving to the north, the Eurasian continental plate which moves relatively south-southeast, and the Pacific and Philippine oceanic plates which are relatively westward.

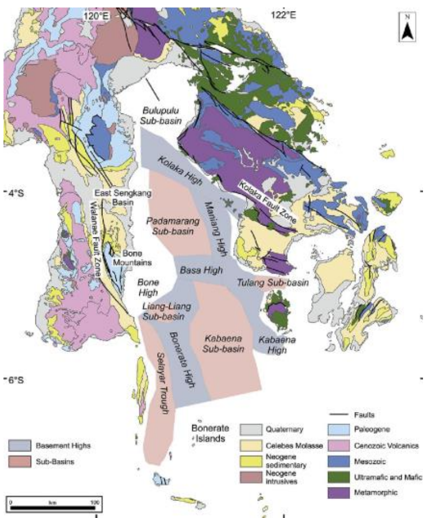

Figure 1. Geological Map of Southern Part of Sulawesi and the location of Sub-Basin and High around Bone Gulf (Camplin & Hall, 2014).

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Based on research conducted by Camplin and Hall (2013), stratigraphy was divided using seismic stratigraphy methods, namely by classifying lithology units based on the characteristics of the reflection of seismic waves. Based on the southern and southeastern arm stratigraphy of Sulawesi, it is possible to make a correlation with seismic stratigraphy in the Gulf of Bone. Stratigraphy in Gulf of Bone is divided into 7 units, namely units A, B, B1, C, D, E, and X in Table 1.

Table 1 Stratigraphy Regional in Bone Gulf

Unit	Description
E	Shallow Carbonate
D	Deep Water, Submarine-fan, Coarse Siliceous
C	Carbonate Platform
B	Shale Carbonate
B1	Like Unit A but, deposited in the same time as Unit B
A	Deltaic - Shallow Marine, Shale
X	Basement- Volcanic Rock dan Metamorphic Rock

The unit X is composed of several different lithologies. Volcanic rocks in the Bone Mountains which are of Paleogene age. In the east there are peridotites, metamorphic rocks of Paleozoic or Mesozoic age, and Triassic sandstones that undergo metamorphosis.

Unit A is interpreted as marine siliciclastic deposits containing shallow marine carbonates at the base like Early Miocene limestone and claystone limestones in the East Sengkang Basin which are known to originate from the Deltaic - Shallow Marine.

Unit B may be equivalent to claystone in the Camba Formation in the East Sengkang Basin which is Middle Miocene to Late Miocene.

Unit B1 is interpreted as part of Unit A and has an age equivalent to Unit B. This unit is likely to be a mixture of shallow marine carbonates and claystone,

Unit C is above unit B in the northern part of the Kabaena Sub-Basin. This C unit is the thin part interpreted as platform carbonate. This unit is like the limestone of the Tacipi formation in the east sengkang basin. The D unit is dominated by siliciclastic sediments originating from Central Sulawesi with sedimentary contributions from the south and southeast arms. Based on the stratigraphy in the East Sengkang Basin,

Unit D is characterized by the appearance of coarse clastic sediments, including conglomerates and limestones.

Unit E shows the character of shallow marine carbonates. E units may have experienced erosion and leverage due to leverage (Camplin & Hall, 2013).

Oil seepage was found in Kolaka High and Southwest of Bone Gulf as evidence of the presence of hydrocarbons in the Gulf Bone region (Thompson, Reminton, Purnomo, & Macgregor, 1991; Wilson, Ascaria, Coffield, & Guritno, 1997; Yulihanto, 2004). Sediment with the possibility of being a source may be deposited in the early history of the basin's evolution, which is unit A.

METHODS

Sampling Seabed Core (27) were collected from the Kabaena Sub-Basin, Bone Gulf, and surrounding areas (Figure 2), which the data is obtained from the TGS Indonesia Company.

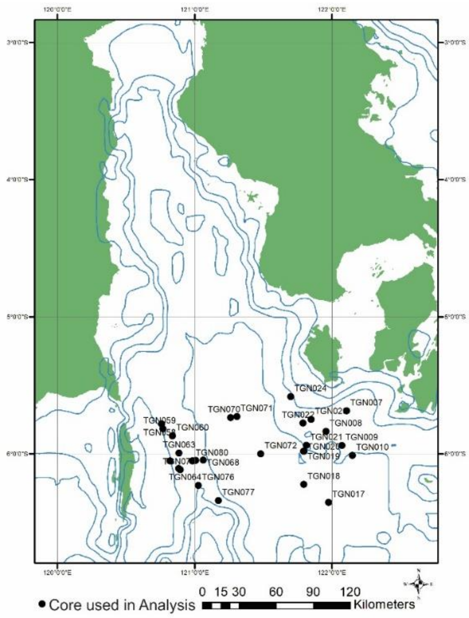

Figure 2 Location of Core Used in Analysis

In surface geochemical exploration studies, maximum core penetration and uncontaminated samples are of highest importance. Cores are obtained with a 900 kg (2000-pound) piston corer. Every effort is made to get maximum penetration. As soon as the piston core is retrieved on-deck, geochemical sample processing begins. Every effort is made to minimize the time between core retrieval, sample processing, and storage at -l5° to -20°C.

Core sections are brought back from the ship Laboratory personnel ensure that each core section bag and archive section bag is accounted for and that no discrepancies exist between the Core Reports from the ship and the labeled bags. The archive samples remain

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frozen and are stored in a walk-in freezer at -20°C.

The samples for geochemical analysis are thawed at room temperature for processing. The sediment is squeezed from each bag into labeled pre-cleaned glass jars and placed in a convection oven to dry at 40°C. Once dry, the sediment is transferred to a clean mortar and pestle, ground to a powder and placed back into the labeled glass jar to await extraction.

An automated extraction apparatus (Dionex ASE200 Accelerated Solvent Extractor) is used to extract various organic hydrocarbons from 15 g of pre-dried sediment. The extractions are performed using hexane inside stainless-steel extraction cells held at elevated temperature and solvent pressure. The extracts dissolved in the hot solvent are transferred from the heated extraction cells to glass collection vials. Pre-cleaned, activated copper is added to each collection vial in order to minimize matrix interference. Extracts are concentrated to a final volume of 8-mL using an evaporative solvent reduction apparatus (Zymark TurboVap II). Final extracts are submitted for hydrocarbon analysis Gas Chromatography Flame Ionization Detection (GC/FID).

C15+ hydrocarbon analysis refers to the determination of individual normal alkane hydrocarbons with between 15 and 34 carbons from Gas Chromatography. The analysis also includes determination of the isoprenoids pristane and phytane, and a determination of the unresolved complex mixture (UCM). The extracted sediment sample is concentrated by solvent reduction, internal standard is added for quantitation, and a portion of the extract is injected onto a capillary GC column. The analytes are separated and detected by a flame ionization detector (GC/FID). A calibration curve is established by analyzing each of 5 calibration standards and fitting the data to a straight line using the least square technique. Sample responses are then compared to the calibration curve to derive the concentrations of each analyte in each sample.

GEOCHEMISTRY FOR MATURITY

The relative abundance of odd versus even carbon-numbered n-paraffins can be used to obtain a crude estimate of thermal maturity of petroleum. These measurements are the carbon preference index (CPI; (Bray & Evans, 1961)) and the odd/even preference (OEP; (Scalan & Smith, 1970)). The values of CPI and OEP show regular variation along the profile of this study. The average CPI value is present in the top sample with a value of 2.30 and the average of OEP value show 1.33 (Table 2).

$$\mathrm{CPI(1)} = 2(C_{23} + C_{25} + C_{27} + C_{29}) / [C_{22} + 2(C_{24} + C_{26} + C_{28}) + C_{30}]$$

$$\mathrm{OEP(1)} = (C_{21} + 6C_{23} + C_{25})/(4C_{22} + 4C_{24})$$

Figure 3 CPI (Bray & Evans, 1961) & OEP (Scalan & Smith, 1970) from (Peters et al. 2005).

Table 2 Result of CPI-OEP Analysis from 27 sample in Kabaena Sub-Basin

No.	Core	CPI(1)	OEP(1)	Indication
1	**TGN007**	2.35	1.39	Immature
2	**TGN008**	2.17	1.40	Immature
3	**TGN009**	1.24	1.50	Mature
4	**TGN010**	1.83	1.06	Mature
5	**TGN017**	2.51	1.02	Immature
6	**TGN018**	2.51	1.16	Immature
7	**TGN019**	1.60	1.01	Mature
8	**TGN020**	0.93	0.70	Immature
9	**TGN021**	1.42	1.04	Mature
10	**TGN022**	2.00	1.03	Mature
11	**TGN023**	1.38	1.04	Mature
12	**TGN024**	1.23	1.13	Mature
13	**TGN058**	2.94	2.14	Immature
14	**TGN059**	2.98	2.15	Immature
15	**TGN060**	5.43	1.95	Immature
16	**TGN062**	1.80	1.70	Mature
17	**TGN063**	2.41	1.20	Immature
18	**TGN064**	1.54	1.19	Mature
19	**TGN067**	2.17	1.05	Mature
20	**TGN068**	1.89	1.33	Mature
21	**TGN070**	5.52	2.28	Immature
22	**TGN071**	3.23	1.55	Immature
23	**TGN072**	4.12	1.42	Immature
24	**TGN076**	1.12	0.93	Mature
25	**TGN077**	2.19	1.24	Mature
26	**TGN079**	1.67	1.42	Mature
27	**TGN080**	1.83	0.95	Mature

Based on the CPI and OEP values obtained from the Gas Chromatography, all the hydrocarbons from all extraction points show thermal maturity level from immature-mature.

GEOCHEMISTRY FOR SOURCE AND DEPOSITIONAL ENVIRONMENT

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The source of hydrocarbons can be determined by analysis of geochemical data, one of which is a comparison between pristane and phytane isoprenoids.

Table 3 Pr, Ph as an indicator of environment (Peters, et al., 2005)

Value	Indication
>5	Source Rock Coal, Organic Material dominated by Terrestrial
>3	Strong Influenced by Terrestrial Sediment (Higher Plant)
<2	Marine Oxic
~1-3	Lacustrine Oxic
<1	Anoxic Environment, (Hypersaline environment)

A representative sample was selected for biomarker analysis showing a bimodal n-alkane distribution. Pr/Ph value is 1.8 indicating suboxic to oxic conditions (Didyk, et al., 1978) Moreover, the relationship between Pr/n-C17 versus Ph/n-C18 can be used to determine the organic matter type Figure 4 (Peters et al., 2005).

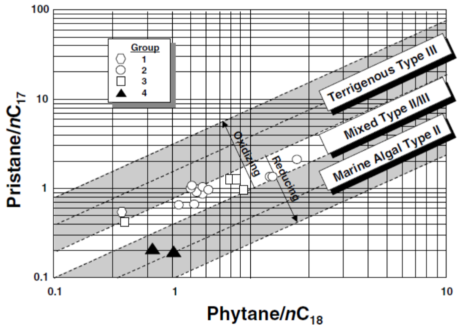

Figure 4 X-Plot Diagram Pristana/n-C17 with Phitana/n-C18 from East Indonesia Timur for knowing Oxicity and Type of Organic Material in Source Rock (Peters et al., 1993a).

Based on the value of N-alkane, almost all samples of source rock from all samples showed that the sample had originated from the environment of Lacustrine or Oceanic Sediment which indicated the depositional environment from source rock could have originated from Marine Sediment or Lacustrine.

The plotting of N-alkane values in the deposition environment graph as shown in Figure 5 shows that almost all samples from Core data belong to Mixed Kerogen types and some are in Sapropelic Kerogen.

Mixed Kerogen is classified as Kerogen types II and III where mixtures of plant origin Land, Algae are also Plankton in the transition environment. Sapropelic Kerogen is classified as type I kerogen as a producer of oil derived from algae in the environment of lacustrine and some material elements in the marine environment.

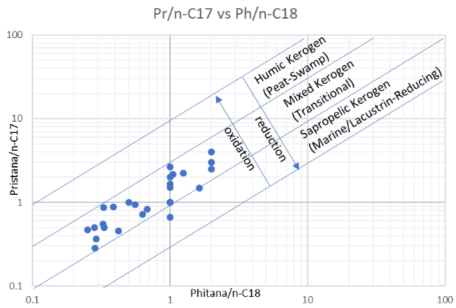

Figure 5 Depositional Environment and Source of Organic Material based on N-Alkane and Isoprenoids (Peters et al., 2005).

Based on the N-Alkane, samples show that hydrocarbon producing source rocks tend to show the characteristics of deposited in terrestrial change environments towards the marine or in transition environments. This area is a large area located in the mouth of the river with marine influences (Stride, et al., 1969) parts of the river that jut into the sea so that sediments deposited in this environment can come from land and sea (Dalrymple et al., 1992)

CONCLUSION

Maturity level of Source rocks studied from samples in the Kabaena sub-basin based on CPI and OEP parameters, generally have immature maturity levels - mature.

Based on the N-Alkane and Isoprenoid, samples in the sub-basin of Kabaena tend to show that the source rocks of Hydrocarbons are deposited in the transition environment with a kerogen type is Mixed Kerogen.

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APPENDIX

Table 1 All Parameter Used in this Research from Whole Extract Analysis C15+ from 27 sample in Kabaena Sub-Basin

Component	TGN007	TGN008	TGN009	TGN010	TGN017	TGN018	TGN019
Pristane	4	4	2	5	7	3	3
Phytane	3	2	2	2	3	1	1
n-C19	3	2	1	1	2	1	1
n-C20	2	2	1	2	3	1	1
n-C21	7	5	2	3	7	2	3
n-C22	5	6	1	3	6	2	7
n-C23	13	7	3	4	9	3	12
n-C24	10	5	3	5	11	4	11
n-C25	16	8	4	7	26	5	11
n-C26	10	7	5	7	23	4	10
n-C27	29	16	8	14	48	8	18
n-C28	15	11	12	12	38	5	21
n-C29	87	41	19	34	161	15	53
n-C30	17	16	14	14	52	8	26
n-C31	110	80	31	71	216	24	93
n-C32	11	11	12	10	39	5	20
n-C33	58	49	20	37	157	14	57
n-C34	8	8	8	6	30	3	16
Pr/n-C17	0.83	0.93	1	0.89	2.17	2.25	2.67
Ph/n-C18	0.68	0.56	1	0.39	1.06	1.25	1
Pr/Ph	1.33	2	1	2.5	2.33	3	3
CPI(1)	2.35	2.17	1.24	1.83	2.51	2.51	1.60
OEP(1)	1.39	1.40	1.50	1.06	1.02	1.16	1.01

Component	TGN020	TGN021	TGN022	TGN023	TGN024	TGN058	TGN059
Pristane	1	4	4	1	3	5	3
Phytane	1	2	2	1	2	5	3
n-C19	1	1	1	1	1	4	8
n-C20	1	1	1	1	1	1	6
n-C21	1	5	4	6	5	4	4
n-C22	2	9	7	12	9	4	5
n-C23	1	12	13	22	15	13	15
n-C24	3	11	17	36	15	6	7
n-C25	3	14	17	31	13	18	22
n-C26	5	11	11	27	11	12	11
n-C27	4	21	21	21	15	38	25
n-C28	6	16	13	19	14	23	16
n-C29	5	55	57	28	23	133	69
n-C30	6	26	19	15	18	33	23

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n-C31	6	88	96	31	33	243	131
n-C32	3	14	16	12	11	26	17
n-C33	3	51	58	23	17	122	63
n-C34	2	11	14	10	9	20	10
Pr/n-C17	1.5	2.5	4	1.67	3	0.46	0.36
Ph/n-C18	1	2	2	1	2	0.42	0.29
Pr/Ph	1	2	2	1	1.5	1	1
CPI(1)	0.93	1.42	2.00	1.38	1.23	2.94	2.98
OEP(1)	0.70	1.04	1.03	1.04	1.13	2.14	2.15

Component	TGN060	TGN061	TGN062	TGN063	TGN064	TGN067	TGN068
Pristane	4	8	3	2	1	2	1
Phytane	3	2	2	2	1	1	1
n-C19	7	6	1	2	1	2	1
n-C20	3	5	1	1	1	1	1
n-C21	3	6	3	2	1	2	1
n-C22	4	3	3	2	1	1	1
n-C23	10	14	7	3	1	1	2
n-C24	6	9	5	3	1	2	2
n-C25	14	20	8	4	2	4	3
n-C26	8	8	8	3	2	3	2
n-C27	26	32	13	8	4	9	5
n-C28	12	14	11	6	3	6	3
n-C29	98	112	32	26	7	24	8
n-C30	16	21	14	9	4	8	4
n-C31	182	295	58	55	14	53	12
n-C32	11	16	10	6	3	6	3
n-C33	87	167	49	35	8	26	15
n-C34	9	14	9	5	2	5	2
Pr/n-C17	0.5	0.47	0.55	0.29	1	0.5	0.5
Ph/n-C18	0.33	0.25	0.33	0.29	0.5	0.28	0.33
Pr/Ph	1.33	4	1.5	1	1	2	1
CPI(1)	5.43	3.25	1.80	2.41	1.54	2.17	1.89
OEP(1)	1.95	2.00	1.70	1.20	1.19	1.05	1.33

Component	TGN070	TGN071	TGN072	TGN076	TGN077	TGN079	TGN080
Pristane	5	4	8	1	2	1	1
Phytane	2	2	9	1	1	1	1
n-C19	1	2	8	1	1	1	1
n-C20	2	2	9	1	1	1	1
n-C21	6	7	11	1	3	1	1
n-C22	4	7	12	2	3	1	1
n-C23	9	9	18	3	5	2	2
n-C24	6	8	14	4	6	2	4
n-C25	13	12	31	4	9	4	6

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n-C26	8	9	18	6	9	3	4
n-C27	30	29	67	6	20	5	9
n-C28	17	12	28	8	16	4	5
n-C29	97	68	230	10	47	9	15
n-C30	25	20	48	9	21	5	8
n-C31	149	144	348	15	83	8	32
n-C32	16	16	35	7	16	3	5
n-C33	68	88	249	17	69	6	22
n-C34	10	10	28	6	13	2	4
Pr/n-C17	0.88	0.72	1.49	0.67	2	1	1
Ph/n-C18	0.33	0.63	1.64	1	1	1	1
Pr/Ph	2.5	2	0.89	1	2	1	1
CPI(1)	5.52	3.23	4.12	1.12	2.19	1.67	1.83
OEP(1)	2.28	1.55	1.42	0.93	1.24	1.42	0.95

Table 2 *Result of CPI-OEP Analysis from 27 sample in Kabaena Sub-Basin*

No.	Core	CPI(1)	OEP(1)	Indication
1	**TGN007**	2.35	1.39	Immature
2	**TGN008**	2.17	1.40	Immature
3	**TGN009**	1.24	1.50	Mature
4	**TGN010**	1.83	1.06	Mature
5	**TGN017**	2.51	1.02	Immature
6	**TGN018**	2.51	1.16	Immature
7	**TGN019**	1.60	1.01	Mature
8	**TGN020**	0.93	0.70	Immature
9	**TGN021**	1.42	1.04	Mature
10	**TGN022**	2.00	1.03	Mature
11	**TGN023**	1.38	1.04	Mature
12	**TGN024**	1.23	1.13	Mature
13	**TGN058**	2.94	2.14	Immature
14	**TGN059**	2.98	2.15	Immature
15	**TGN060**	5.43	1.95	Immature
16	**TGN062**	1.80	1.70	Mature
17	**TGN063**	2.41	1.20	Immature
18	**TGN064**	1.54	1.19	Mature
19	**TGN067**	2.17	1.05	Mature
20	**TGN068**	1.89	1.33	Mature
21	**TGN070**	5.52	2.28	Immature
22	**TGN071**	3.23	1.55	Immature
23	**TGN072**	4.12	1.42	Immature
24	**TGN076**	1.12	0.93	Mature
25	**TGN077**	2.19	1.24	Mature
26	**TGN079**	1.67	1.42	Mature
27	**TGN080**	1.83	0.95	Mature

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Table 3 Result of Geochemistry Analysis for Source and Depositional Environment to 27 sample in area surrounding kabaena sub-basin

Core	Pr/n-C17	Ph/n-C18	Pr/Ph	Environment Indication
TGN007	0.83	0.68	1.33	Lacustrine, or Oxic Marine Sediment
TGN008	0.93	0.56	2.00	Lacustrine, or Oxic Marine Sediment
TGN009	1.00	1.00	1.00	Lacustrine, or Oxic Marine Sediment
TGN010	0.89	0.39	2.50	Lacustrine, or Oxic Marine Sediment
TGN017	2.17	1.06	2.33	Lacustrine,
TGN018	2.25	1.25	3.00	Lacustrine,
TGN019	2.67	1.00	3.00	Lacustrine,
TGN020	1.50	1.00	1.00	Lacustrine, or Oxic Marine Sediment
TGN021	2.50	2.00	2.00	Lacustrine, or Oxic Marine Sediment
TGN022	4.00	2.00	2.00	Lacustrine, or Oxic Marine Sediment
TGN023	1.67	1.00	1.00	Lacustrine, or Oxic Marine Sediment
TGN024	3.00	2.00	1.50	Lacustrine, or Oxic Marine Sediment
TGN058	0.46	0.42	1.00	Lacustrine, or Oxic Marine Sediment
TGN059	0.36	0.29	1.00	Lacustrine, or Oxic Marine Sediment
TGN060	0.50	0.33	1.33	Lacustrine, or Oxic Marine Sediment
TGN062	0.55	0.33	1.50	Lacustrine, or Oxic Marine Sediment
TGN063	0.29	0.29	1.00	Lacustrine, or Oxic Marine Sediment
TGN064	1.00	0.50	1.00	Lacustrine, or Oxic Marine Sediment
TGN067	0.50	0.28	2.00	Lacustrine, or Oxic Marine Sediment
TGN068	0.50	0.33	1.00	Lacustrine, or Oxic Marine Sediment
TGN070	0.88	0.33	2.50	Lacustrine, or Oxic Marine Sediment
TGN071	0.72	0.63	2.00	Lacustrine, or Oxic Marine Sediment
TGN072	1.49	1.64	0.89	Anoxic, Hypersaline Environment
TGN076	0.67	1.00	1.00	Lacustrine, or Oxic Marine Sediment
TGN077	2.00	1.00	2.00	Lacustrine, or Oxic Marine Sediment
TGN079	1.00	1.00	1.00	Lacustrine, or Oxic Marine Sediment
TGN080	1.00	1.00	1.00	Lacustrine, or Oxic Marine Sediment

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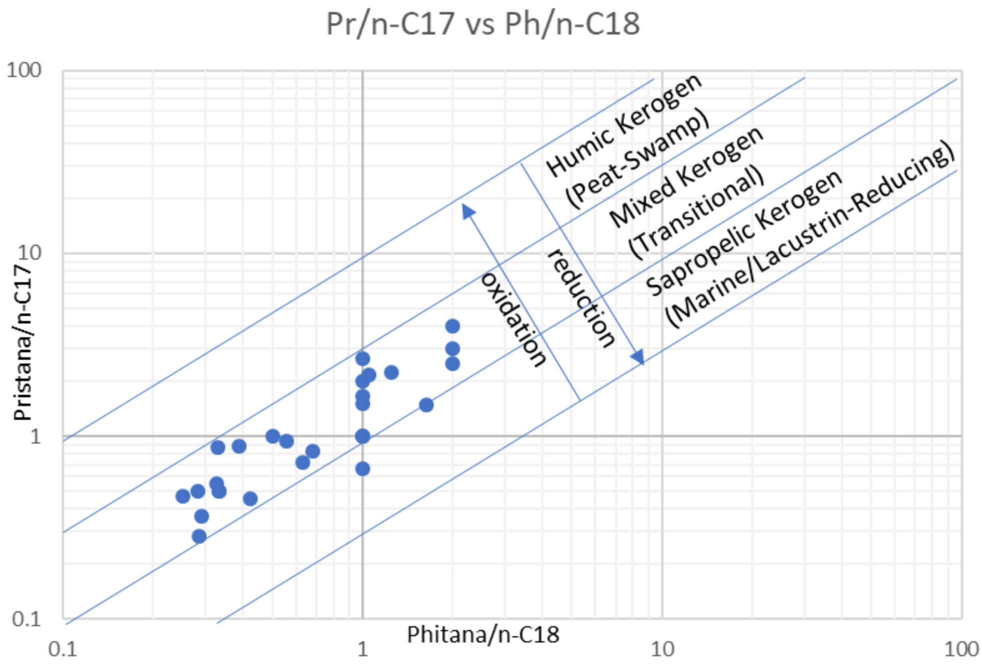

Figure 1 Depositional Environment and Source of Organic Material based on N-Alkane and Isoprenoids (Peters et al., 2005).

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