MINERALOGY OF THE MAHOGANY MARKER TUFF
OF THE GREEN RIVER FORMATION,
PICEANCE CREEK BASIN, COLORADO

by

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ABSTRACT

The Mahogany marker tuff is a chronostratigraphic marker which was deposited in Eocene Lake Uinta approximately 45-46 million years ago when the lake was at its maximum size. The Mahogany marker lies 3 to 6 meters above the Mahogany oil shale bed in the upper part of the Parachute Creek Member of the Green River Formation. The mineralogy of the marker was studied in drill cores by X-ray diffraction and hand specimen examination. The Mahogany marker consists of authigenic sodium feldspar, analcime, quartz, ankerite, dolomite, potassium, feldspar, calcite with lesser amounts of siderite, hematite, pyrite, undifferentiated clays, pyrrhotite, biotite, marcasite, and locally dawsonite. Analcime is not present in all samples and in samples which are analcime-free, K-feldspar shows a greater abundance. Dawsonite is locally present only in analcime-free samples. The presence or absence of analcime and K-feldspar is attributed to the geochemical conditions that existed in the lake at the time of deposition of the Mahogany marker. The evidence supports a stratified lake model of oil shale deposition, with extremely alkaline pH values existing in deeper central portions of Lake Uinta.

INTRODUCTION

Volcaniclastic air-fall and reworked tuffs in the Eocene lacustrine basins of Colorado, Utah, and Wyoming make excellent time correlation markers. The Mahogany marker, a tuff of approximately 10 to 15 centimeters in thickness, is correlatable throughout most of the Piceance Creek and Uinta Basins (Donnell, 1961). It maintains a position of from 3 to 6 meters above the top of the Mahogany bed in the Parachute Creek Member of the Green River Formation (figure 1). The Mahogany bed is believed to represent the maximum expansion of Lake Uinta during the deposition of the Parachute Creek Member. This event occurred between 45 to 46 million years ago on the basis of radiometric dating of biotite in tuffs by Mauger (1977).

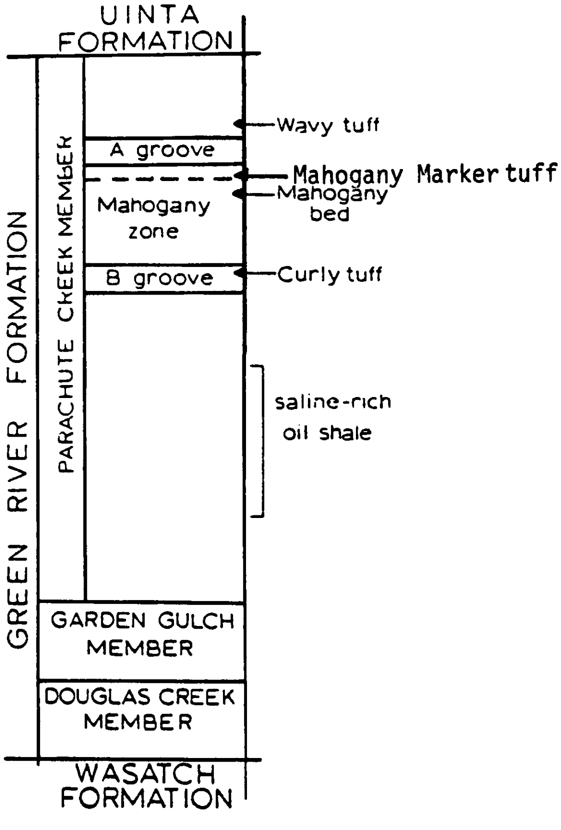

Figure 1. Stratigraphic relations of selected zones and key beds in the Parachute Creek Member, Green River Formation in the Piceance Creek Basin, Colorado.

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Since the early work of Bradley (1929) on the Green River Formation, much has been published concerning many aspects of the sequence of lacustrine strata that contain oil-extractable kerogen. Two prominent theories have emerged concerning the formation of the oil shale and minerals in the Green River Formation. The first is the stratified lake model as proposed by Bradley (1963) and supported by Smith (1969, 1974) and Desborough (1978). Basically, this model proposes a lake stratified with a lower zone of saline water and an upper zone of lesser saline water. Stratification of the lake was due to density differences of the two layers. The upper zone of less saline water could support aquatic organisms, while the lower zone would primarily sustain only sulfate reducing bacteria because of the salinity, reducing nature, and resultant pH. The second theory, proposed by Eugster and Surdam (1973), is a playa-lake model which calls for brine evolution on a playa. This model relies primarily on evidence from sedimentary structures in nearshore rocks around the margin of the Piceance Creek Basin to infer that most of the formation was deposited in a shallow lake or on a broad playa that fringed the lake.

This report shall introduce evidence that some type of stratification of Lake Uinta did occur, at least at the time of deposition of the Mahogany marker. Furthermore, this stratification occurred in the deeper, central portions of the lake and had a direct effect on the mineralogy.

EXPERIMENTAL PROCEDURE

Selection of samples was based on a megascopic and microscopic examination of cores from the LETC core library and data base. Samples represent lithologic spot samples selected specifically for mineral identifications, general mineral surveys conducted on assay samples of approximately .3 meter (one foot) lengths, and hand specimen identification. X-ray identifications were performed on a loosely packed powder pulverized to approximately -325 mesh and analyzed with Phillips diffractometers. Early identifications were made utilizing a Phillips XRG-2500, while later identifications were performed by a Phillips APD-3600/02W. Both units used CuKα radiation filtered by a diffracted-beam graphite monochronometer and scans were made at a rate of 2^{o} 2θ/min. Peak heights were measured above background in chart units for the primary reflections of the major minerals. Although quantitative data cannot be obtained without internal calibration for each sample, these techniques offer a measure of the relative amount of a mineral present. For the purpose of this report, minerals were reported in decreasing order of relative abundance.

VOLCANIC ASH FALLS

Air-fall ash deposits have been observed hundreds of kilometers from sites of volcanic eruptions. The location and shape of the fallout areas are determined by the size of the eruption and altitude of the resulting eruptive cloud, wind velocities, and direction of winds at different altitudes. Mauger (1977) published K-Ar dates of biotites from tuffs in the Green River Formation. The Absaroka volcanic area in Northwest Wyoming was probable source of ash in the Green River Formation (Mauger, 1977) (figure 2).

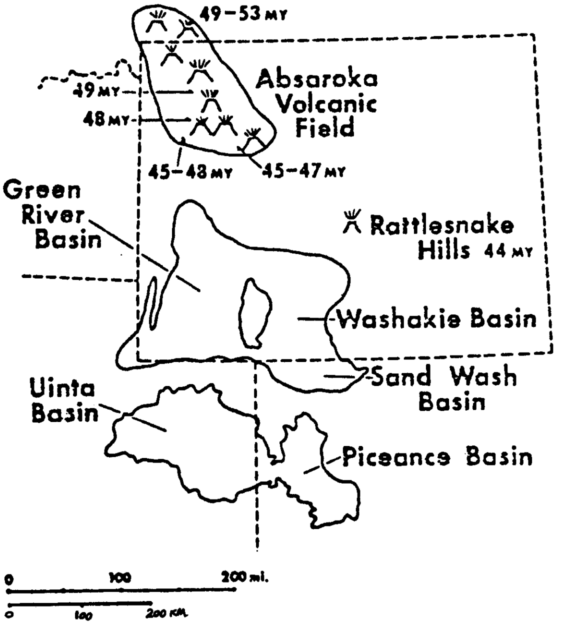

Figure 2. Index map showing Piceance Creek Basin and Absoroka volcanic area (After Mauger, 1977).

Tuffs and tuffaceous sediments compose about 2 percent of the Green River Formation (Surdam and Parker, 1972). The abundance and extensive nature of the tuffs provides time correlation markers and a source of reactive volcanic minerals throughout the Green River section. The tuffs were deposited as vitric ashes containing crystal or lithic fragments in abundances of less than twenty percent. The vitric material was altered to form one or more of the authigenic aluminosilicate minerals (Surdam and Parker, 1972). The original composition of the tuffs is unknown because of extensive alteration. Bradley (1964) supposed the composition ranged from andesite to rhyolite; however, Iijima and Hay (1968) concluded that they were in the rhyolite to rhyodacite range. Regardless of the original composition, it is certain is that the Green River tuffs have undergone extensive mineralogical and chemical alteration.

MAHOGANY MARKER

Lithology

The Mahogany marker has been lithologically described by Trudell (1966) as "buff-white to buff, slightly calcareous, possessing a very fine silty to earthy texture. Common fine to thin, medium brownish-gray to buff distorted oil shale stringers and shreds. Irregular parting and fracture." Additionally, gray colors are common and coarse textures are not uncommon (Trudell, 1983).

The Mahogany marker has been mapped in the Piceance Creek Basin in outcrops and in the subsurface by Cashion and Donnell (1974). Figure 3 shows the outcrop of the Mahogany marker and the location of sample wells used in this report.

Mineralogy

The predominant minerals identified in the Mahogany marker were: ankerite ($(CaMgFe)CO_3$), dolomite ($CaMgCO_3$), quartz (SiO_2), sodium feldspars ($NaAlSi_3O_8$),* potassium feldspars ($KAlSi_3O_8$),* analcime ($NaAlSi_2O_6 \cdot H_2O$), calcite ($CaCO_3$); with lesser amounts of pyrite (FeS_2), marcasite (FeS_2), pyrrhotite (FeS), siderite ($FeMgCO_3$), dawsonite ($NaAl(OH)_2CO_3$), mixed layer clays, hematite (Fe_2O_3), biotite ($K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$), and sanadine ($(K,Na)AlSi_3O_8$), a feldspar of volcanic origin (table 1).

Mineralogic Comparisons and Trends

Examination of the mineralogic data for the Mahogany marker tuff demonstrated the following trends: (1) the zeolite analcime is not present in all samples; (2) in samples in which analcime is absent, K-feldspar shows an increased abundance; and (3) dawsonite is present only in samples analcime-free. Analcime absences are not random, but rather are concentrated into two distinct areas (figure 3).

Tuffs of the Green River Formation, including the Mahogany marker, have been characterized by the presence of abundant analcime (Cole and Picard, 1978). The Mahogany marker represents a chronostratigraphic horizon which offers an excellent opportunity to study the geochemical conditions that existed in Lake Uinta at the "geological instant" of its deposition. Specific information about the geochemistry can be extracted by examining mineralogic trends in the Mahogany marker.

Authigenic analcime was first reported by Bradley (1928) in the Green River Formation occurring in oil shale, siltstone, sandstone, and tuffs. Analcime in oil shale and tuffs is generally believed to have formed from volcanic glass and clay minerals. Surdam and Parker (1972) listed a number of chemical reactions of analcime formation, from studying hundreds of chemical analyses of tuffs. They noted that excess silica remained as authigenic quartz. The formation of analcime in saline conditions requires a pH of at least 9 (Mariner and Surdam, 1970; Surdam and Sheppard, 1976; and Smith 1969). Surdam and Parker (1972) noted that during the extreme alteration of tuffs, K-feldspar will be formed by further reaction of analcime (figure 4). The analcime to K-feldspar reaction requires an extremely high pH. Smith (1974) hypothesized a pH of 11 could have existed in the lower zone of the stratified lake. Excess sodium generated by the analcime to K-feldspar reaction could be a possible explanation for the presence of dawsonite. Bader

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* Feldspars were generally identified only by sodic or potassic and not to specific mineral type except sanadine, due to the complexity of their diffraction patterns.

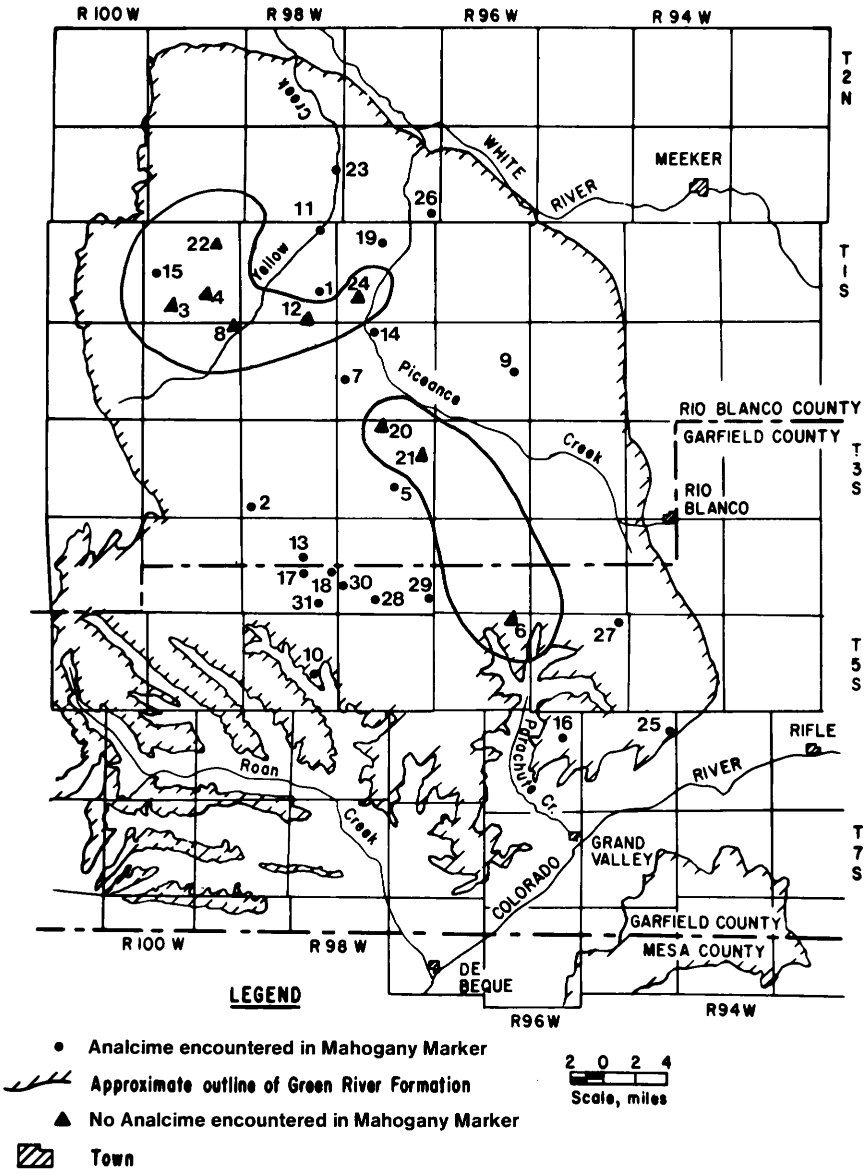

Figure 3. Map showing location of sampled wells of analcime-free Mahogany marker tuff.

TABLE 1

	Drill Hole Name	Location	Sec.	T	R	Mineralogy
1.	ARCO Skyline #1	nw¼ne¼	26	1S	98W	N, Q, A
2.	ARCO-Mobile Corehole #31-1	nw¼nw¼se¼	31	3S	98W	A, Q, K, N, P
3.	Cameron Engineers Corehole CE 707	ne¼se¼se¼	32	1S	99W	D, Q, N, C, A, K, P
4.	Cameron Engineers Corehole CE 702	nw¼se¼ne¼	34	1S	99W	D, Q, K, P, An
5.	Carter Oil Co. Upper Willow #2	nw¼ne¼	27	3S	97W	D, Q, N, K, C, A
6.	Coloney Devel. Co. Corehole 1-2	sw¼ne¼nw¼	1	5S	97W	Q, N, K, S
7.	Equity Oil Co. Boies #1	sw¼sw¼ne¼	19	2S	97W	A, Q, An, D
8.	Equity Oil Co. BX-1	se¼ne¼se¼	6	3S	98W	Q, P, N
9.	General Petroleum 11-24	nw¼nw¼nw¼	24	2S	96W	N, D, A, Q, An, P
10.	Getty Oil Co. Corehole #1	sw¼nw¼ne¼	23	5S	98W	Q, A, Cl, K, N
11.	Humble Oil Co. Yellow Creek #1	nw¼ne¼ne¼	2	1S	98W	Q, A, N, K
12.	Humble Oil Co. Ryan Ridge #1	ne¼nw¼ne¼	3	2S	98W	Q, N, K, Da
13.	Humble Oil Co. Jumps Cabin #1	nw¼sw¼sw¼	15	4S	98W	N, A, Q
14.	Marathon Oil Co. Square S #1	ne¼nw¼ne¼	4	2S	97W	A, Q, N, K
15.	Mintech Corp. Portland Corehole #1	ne¼sw¼se¼	19	1S	99W	N, Q, A
16.	Mobile Oil Co. Corehole #5	se¼nw¼ne¼	11	6S	96W	A, Q, K, N
17.	Savage Oil Shale Hunter Corehole	nw¼sw¼nw¼	23	4S	98W	An, Q, Sa, Py, S, C, K
18.	Savage Oil Shale Whiskey Corehole	se¼ne¼ne¼	24	4S	98W	N, An, A, Q, K, H, P, M
19.	Shell Oil Co. Corehole 41X-9	ne¼ne¼ne¼	9	1S	97W	D, Q, N, C, A, K, P
20.	Shell Oil Co. J. M. Greeno 1-4	sw¼ne¼ne¼	4	3S	97W	Q, D, K, N, Da
21.	TOSCO TG71-1	se¼ne¼nw¼	13	3S	97W	D, Q, N, C, K
22.	USBM Colorado Corehole #2	sw¼nw¼ne¼	14	1S	99W	Q, D, K, N
23.	USBM Colorado Corehole #1	nw¼ne¼se¼	13	1N	98W	A, K
24.	USBM Corehole 01-A	nw¼nw¼sw¼	29	1S	97W	Q, Da, S, D, K, N
25.	USBM Corehole A	nw¼ne¼sw¼	12	6S	95W	An, Q, D, A, K, C, M, B
26.	USGS Corehole CR-2	se¼ne¼	36	1N	97W	Q, A, N, K
27.	USNOSR #1 Corehole 15/16	nw¼ne¼sw¼	1	5S	95W	D, Q, A, C, N, K
28.	Wasatch Devel. Co. Carbon Corehole #1	nw¼nw¼ne¼	33	4S	97W	analcime*
29.	Wasatch Devel. Elizabeth Corehole #1	ne¼ne¼ne¼	36	4S	97W	analcime*
30.	Wasatch Devel. Washington Corehole #2	nw¼nw¼ne¼	30	4S	97W	analcime*
31.	Savage Oil Shale Camp Corehole	sw¼sw¼se¼	35	4S	98W	An, D, Q, A, K, Sa, M, B

Minerals arranged in decreasing order of relative abundances.

Mineralogy Code:

N = sodium Feldspar
D = dolomite
K = potassium feldspar
Q = quartz
An = ankerite
P = pyrite
Py = pyrrhotite
C = calcite
S = siderite
A = analcime
B = biotite
Da = dawsonite
H = hematite
Cl = undifferentiated clays
M = marcasite
Sa = sanadine

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* identified in hand specimen

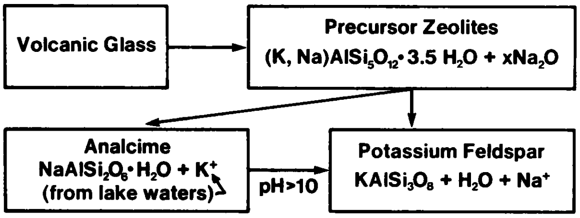


Figure 4. Chemical reaction of volcanic ash (modified from Surdam and Sheppard, 1976).

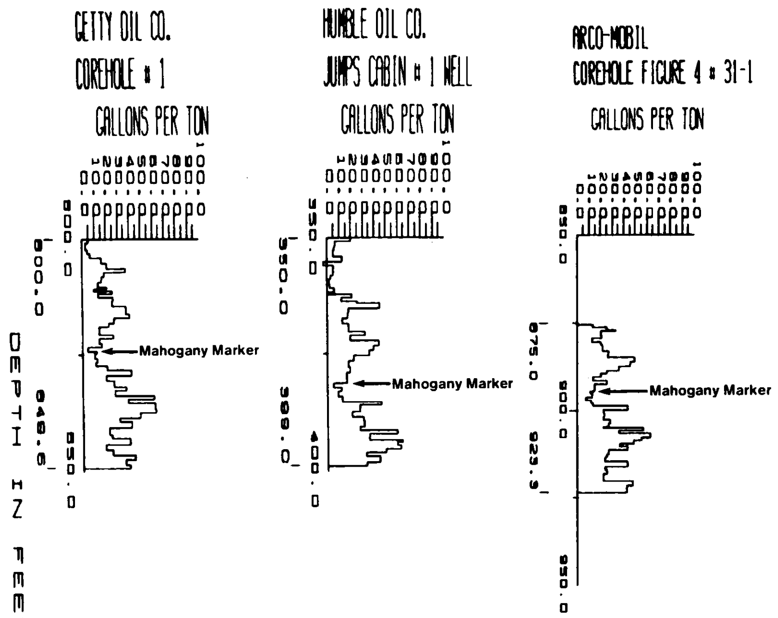
and Esch (1944) demonstrated that dawsonite forms when abundant CO_2 is present in a sodium aluminate solution at a pH of 11.

DISCUSSION AND CONCLUSIONS

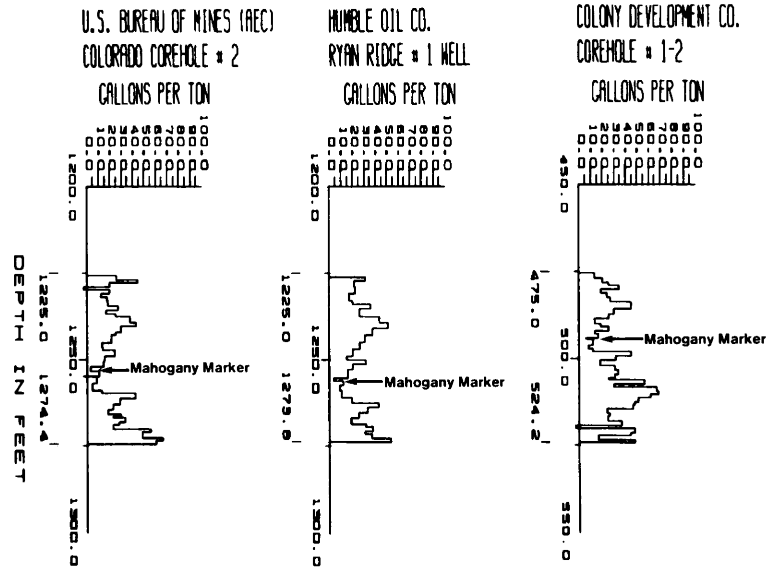
Because the Mahogany marker is a chronostratigraphic unit, it can be postulated that the chemical processes that altered the ash as it settled in the lake or surrounding playa, occurred at the same time. Surdam and Sheppard (1976) proposed that the alteration of the precursor zeolites to analcime took place on the playa and lake fringes, with the further alteration of analcime to K-feldspar occurring in the lake portion of the playa-lake complex. This explanation for the origin of analcime poses a problem in light of two key findings. First, oil shale occurs directly above and below in direct contact with the Mahogany marker whether it is analcime-rich or analcime-free (figure 5). This indicates too rapid of an environment change if analcime is formed on the playa. Secondly, the areal extent of the analcime-free portion of the Mahogany marker appears too limited. Oil shale occurrence is recognized to be more widespread than the pattern indicated by analcime-free deposition. Therefore, it can be concluded that analcime formation was not concretely related to the playa-lake boundary.

The stratified lake offers two geochemical conditions differing chiefly in pH and salinity. While both environments were extremely alkaline, one was even more basic. Differing pH values was the determining factor in the formation of analcime and its ultimate alteration to K-feldspar. Smith (1974) located the depositional centers of the Mahogany zone based on occurrence of nahcolite and dawsonite in a stratified lake. Examination and comparison of Smith's depositional centers to analcime deficient locales produce a striking similarity. Smith proposed that these depositional centers represent the deepest, least disturbed, and most strongly alkaline parts of Lake Uinta.

The mineralogic data suggests the existence of two slightly different geochemical conditions at the time of the deposition of the Mahogany marker. In one environment, the original volcanic ash is altered to form analcime. In the second environment, which depicts a deeper, calmer part of the lake achieving higher pH values, analcime was further altered to K-feldspar with sodium freed to form dawsonite.



Analcime encountered in Mahogany Marker



No Analcime encountered in Mahogany Marker

Figure 5. Sample oil yield bar graphs showing relationship of Mahogany marker with oil shale.

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