Oil Shale, 2010, Vol. 27, No. 2, pp. 179–189
doi: 10.3176/oil.2010.2.07
ISSN 0208-189X

INDEXES IN EVALUATING THE GRADE OF BOGDA MOUNTAIN OIL SHALE IN CHINA

SHU TAO[(a)*], DA-ZHEN TANG[(a)], JING-JING LI[(b)], HAO XU[(a)], SONG LI[(a)] , XIAO-ZHI CHEN[(a)]

[(a)] Key Laboratory of Marine Reservoir Evolution and Hydrocarbon Accumulation Mechanism
Ministry of Education, China;
School of Energy Resources
China University of Geosciences (Beijing)
Beijing 100083, Beijing, China
[(b)] Exploration and Production Research Institute, SINOPEC
Beijing 100083, Beijing, China

This paper aims at exploring new evaluation indicators of oil shale in order to evaluate and classify the industrial grade of oil shale and to provide the evaluation parameters for exploration and development of Bogda Mountain oil shale in China. We use organic petrology and organic geochemistry methods to make a systematic study on the relationship between petrological type, organic component content, hydrocarbon-generating potential, total organic carbon (TOC) and oil yield of the oil shale, basing on the results, the corresponding evaluation indexes are proposed. The results show that lithologic types and industrial grade of oil shales can be categorized as follows: videlicet, the content of organic component lower than 5%, between 5% and 15%, between 15% and 25%, and over 25% correspond to non-oil shale, low-quality, medium-quality, and high-quality oil shale. The total content of organic components, hydrocarbon-generating potential, TOC and oil yield correlate significantly with each other, so they can be easily used as indexes to evaluate the industrial grade of oil shale. For example, the coefficient R between organic carbon content of oil shale and oil content is 0.978, the oil yield 3.5% corresponds to the TOC 7.5%, the oil yield 5% corresponds to the TOC 9.5%, and 10% to the TOC 17.0%.

Introduction

As the overall situation of conventional oil and gas resources becomes increasingly severe, oil shale receives more and more attention. Since oil

* Corresponding author: e-mail *peach888@163.com*

shale is characterized by beneficial features and economic values and its resources are large, it is considered an important strategy and substitutional resource for the 21st century [1]. Thus, exploration and development of oil shale play an important role in solving the energy crisis. There are three important basics to evaluate the development and use of oil shale in a mine: mining fee, proved recoverable reserves and grade of oil shale, among which grade evaluation of oil shale is the most important one [2].

At present, oil content is taken as reference for evaluating mineral deposits, delineating ore bodies and estimating the amount of resources [3]. In general, oil shale is internationally referred to as mineable oil shale when it can yield 0.25 barrel shale oil (0.034 ton) per ton, or its oil yield is higher than 4% [4–5], the USGS takes the oil yield of 40 l/t (3.6%) as the cut-off value in the oil shale resource estimation. In the past, the oil shales yielding oil more than 5% were considered rich and calculated as reserves in China; oil shales yielding oil less than 5% were considered lean and neglected in calculating the reserves. Taking the economic and technological development into account, the Third National Oil and Gas Resource Assessment, which is "a new round of national oil shale resource evaluation", was carried out in 2006. This assessment takes the oil yield 3.5% as the limit cut-off value for oil shale producing rate, and oil shales can be divided into three groups, namely oil (tar) content ≥10% is referred to as high, between 10 and 5% as medium and between 5 and 3.5% as low.

Refining and combustion for generating electricity are the main patterns of oil shale application [2]. Oil content is the reference to evaluate oil shale in refining, while calorific value is the index to evaluate oil shale in burning, and the two aspects mainly depend on organic matter content and composition of oil shale. However, the testing process of oil content and calorific value is relatively complicated, the requirements on equipment specifications are also very strict and sensitive, and the test time is too long. Thus, whether we can find one or more convenient indicators based on organic matter content of oil shale, which can be considered alternative parameters to assess the quality and grade of oil shale at present, is an actual problem. This paper discusses petrological types of oil shale, total organic matter content, TOC and the correlation between hydrocarbon-generating potential ($S_1 + S_2$) and oil content, which shows a good linear relationship. Therefore, organic matter content, TOC and $S_1 + S_2$ of oil shale can be used as effective parameters (or methods) to grade oil shales.

Samples and tests

A total of 588 oil shale samples were collected from Sangonghe (west) to Ergonghe (east) eight outcrop profiles and Dahuangshan, Donggou, and Ergonghe drilling sites (Fig. 1), which are located in the northern foot of Bogda Mountain. All samples come from Lucaogou Formation in Permian,

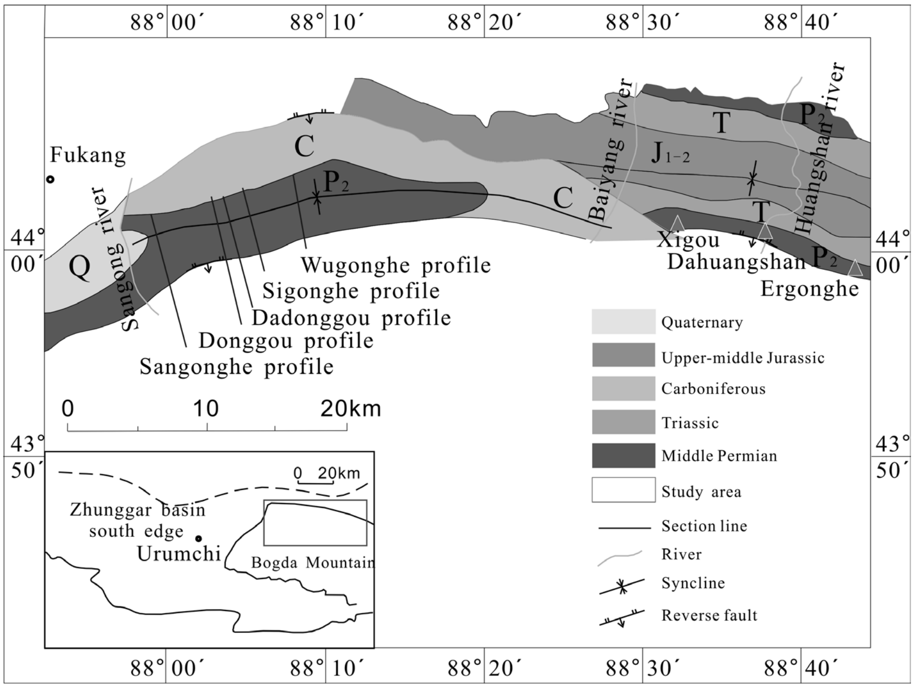

Fig. 1. Distribution map of test samples.

whose lithology is dominated by sandstone, marl, dolomite and oil shale, and the average thickness of the whole formation is about 568 meters. The profile samples were collected in accordance with the principle of the equal horizontal interval, which is 10 meters; while the drilling samples by the rule of equal vertical interval, which is 5 meters. The depth of oil shale samples changes with drilling position. No. 2 drilling of Dahuangshan ranges from 6 to 403.84 meters; No. 1 drilling of Dahuangshan ranges from 0 to 400.8 meters; No. 2 drilling of Donggou ranges from 12.36 to 169.28 meters; No. 1 drilling of Donggou ranges from 14.74 to 278.16 meters; the drilling of Ergonghe ranges from 18.76 to 289.36 meters. The thickness of oil shale in the study area ranges from 72 meters (profile 2, Donggou) to 743.23 meters (profile 1, Dahuangshan), and the average thickness of oil shale seam in the whole region is 350 meters.

The oil shale samples were studied through using quantitative identification of maceral under microscope, rock pyrolysis, TOC, Gray-King low-temperature dry distillation test. The quantitative identification of maceral under microscope was carried out by Key Laboratory of Marine Reservoir Evolution and Hydrocarbon Accumulation Mechanism, Ministry of Education, China; School of Energy Resources, China University of Geosciences (Beijing), 165 samples were tested. The applicable standard was SY/T 5162-1997. The purpose of testing was to determine the percentage of the total organic components of rocks and the proportion of sapropel component, exinite, vitrinite and inertinite in the total organic matter. Rock pyrolysis was performed by using Rock-Eval 2 plus (made in France) at oil and gas evaluation workstation (OGE-II) in China Petroleum Exploration and Development Research Institute, who tested $S_1 + S_2$. The implementation standard is GB/T 18602-2001. The TOC tests of 588 samples were made by the Petroleum Geology Research Center, China Petroleum Exploration and Development Research Institute. The implementation standard was GB/T 19145-2003. Gray–King temperature pyrolysis experiment was conducted at the Xinjiang Institute of Coal Science and Coal Testing Laboratory, 588 samples were tested, and the applicable standard was GB/T 1341-2001. Test results are summarized in Table 1.

Results and discussion

Petrological types of oil shale

According to the general principles of sedimentary rock classification, we used the major mineral components (>50%) to determine the basic name of the rock and the secondary components (especially the characteristic components) to determine the specific name of the rock. The characteristic component of oil shale in the study area is sapropel, therefore, the oil shale classification based on different percentage of sapropel components is reasonable. The classification is as follows: shale is called “black shale” when sapropel content is less than 5% [6]; and it is known as clay shale with rot when sapropel component content is between 5 ~ 25%; when sapropel content is between 25 ~ 50%, we call it rot muddy shale/sapropelic shale. In fact, oil shales whose sapropel component content is higher than 40% are very rare in nature. This classification system can be called genetic classification, during oil shale exploration and development process, however, oil shales are often divided into a variety of industrial types (or industrial level) by shale oil extraction rate under low-temperature pyrolysis: low-quality oil shale, high-quality oil shale, and so on. Due to the continuous development of processing technology, the bottom of oil productivity becomes lower and lower, therefore, the classification indicators keep changing as well. In general, oil shale petrological types can be referred to their industrial grade, as shown in Table 2. Since the clay shale with rot occurs in a wide range, clay content of 15% can be taken as the boundary to divide it into two parts, which is more convenient to contrast with the industrial grades.

Table 1. **Test data of oil shale from the northern foot of Bogda Mountain (examples)**

Project	Sample No.	Genetic type of rocks	Total organic compounds, %	TOC, %	S_1+S_2, mg g^{-1}	Oil yield, %	Organic matter types	Industrial type of oil shale
Profile 1, Dahuangshan	1-O-1	sapropel containing	13.7	9.88	88.30	4.5	I	low-quality oil shale
Profile 1, Dahuangshan	1-O-18	sapropel shale	37.7	33.87	206.91	17.0	II_1	high-quality oil shale
Profile 2, Dahuangshan	2-O-20	sapropel containing	18.2	15.11	82.68	9.6	II_1	medium-quality oil shale
Profile 2, Dahuangshan	2-O-31	sapropel shale	31.5	27.06	147.82	26.6	II_1	high-quality oil shale
Profile 3, Dahuangshan	3-O-4	sapropel shale	25.0	22.03	128.19	10.2	II_1	high-quality oil shale
Profile 3, Dahuangshan	3-O-6	sapropel shale	37.8	31.17	201.14	15.1	II_1	high-quality oil shale
Drilling 1, Dahuangshan	DZA-07	sapropel containing	13.0	10.50	73.65	5.8	I	medium-quality oil shale
Drilling 1, Dahuangshan	DZA-10	sapropel containing	5.9	4.71	14.55	3.8	III_1	low-quality oil shale
Drilling 2 ,Dahuangshan	DZB-06	sapropel containing shale	8.9	7.10	50.57	7.0	II_1	medium-quality oil shale
Drilling 2, Dahuangshan	DZB-35	sapropel containing shale	19.7	16.37	139.84	8.4	I	medium-quality oil shale
Profile 1, Xigou	XYA-13	sapropel containing shale	11.6	8.93	87.89	5.6	I	medium-quality oil shale
Profile 1, Xigou	XYA-33	sapropel shale	32.5	28.66	145.31	21.8	II_1	high-quality oil shale
Profile 1, Xigou	XYA-64	sapropel containing shale	15.8	13.35	64.21	9.6	II_1	medium-quality oil shale
Profile 2, Xigou	XYB-29	sapropel shale	28.4	25.00	202.63	23.2	I	high-quality oil shale
Profile 2, Xigou	XYB-49	sapropel containing shale	21.4	17.95	141.05	16.2	III_1	high-quality oil shale
Ergonghe profile	WTP-14	sapropel containing shale	14.0	10.90	125.24	6.6	I	medium-quality oil shale

Table 1 continued

Project	Sample No.	Genetic type of rocks	Total organic compounds, %	TOC, %	S_1+S_2, mg g^{-1}	Oil yield, %	Organic matter types	Industrial type of oil shale
Ergonghe profile	WTP-39	sapropel containing shale	13.1	9.56	61.45	5.3	II_1	medium-quality oil shale
Ergonghe drilling	WTZ-05	sapropel containing shale	16.6	14.17	118.62	9.0	I	medium-quality oil shale
Ergonghe drilling	WTZ-21	sapropel containing shale	12.9	10.03	73.36	5.4	II_1	medium-quality oil shale
Profile 1, Donggou	DGA-17	sapropel shale	20.5	16.41	127.69	11.0	II_1	high-quality oil shale
Profile 1, Donggou	DGA-56	sapropel shale	22.5	18.59	94.27	10.1	II_1	high-quality oil shale
Profile 2, Donggou	DGB-12	sapropel shale	24.1	19.00	89.69	11.6	II_1	high-quality oil shale
Profile 2, Donggou	DGB-32	sapropel containing shale	11.6	9.86	60.82	6.7	II_1	medium-quality oil shale
Drilling 1, Donggou	LCZA-12	sapropel containing shale	8.6	6.60	51.15	4.5	I	low-quality oil shale
Drilling 1, Donggou	LCZA-21	sapropel containing shale	9.3	7.53	43.27	4.7	II_1	low-quality oil shale
Drilling 2, Donggou	LCZB-04	sapropel containing shale	13.7	11.04	69.99	4.7	II_1	low-quality oil shale
Drilling 2, Donggou	LCZB-15	sapropel containing shale	20.7	17.13	127.49	6.0	I	medium-quality oil shale
South wing profile, Sangonghe	LCNO-02	sapropel containing shale	15.3	13.00	80.04	8.1	II_1	medium-quality oil shale
South wing profile, Sangonghe	LCNO-26	sapropel shale	25.3	26.20	146.12	16.2	II_1	high-quality oil shale
South wing profile, Sangonghe	LCNO-85	sapropel shale	27.2	22.10	104.66	15.3	II_1	high-quality oil shale

Table 1 continued

Project	Sample No.	Genetic type of rocks	Total organic compounds, %	TOC, %	S_1+S_2, mg g^{-1}	Oil yield, %	Organic matter types	Industrial type of oil shale
North wing profile, Sangonghe	LCBO-82	sapropel containing shale	8.0	9.95	46.63	4.2	II_2	low-quality oil shale
North wing profile, Sangonghe	LCBO-103	sapropel shale	29.2	27.3	150.07	18.6	II_1	high-quality oil shale
South wing profile, Donggou	DGJO-43	sapropel containing shale	17.2	14.6	86.76	8.2	II_1	medium-quality oil shale
South wing profile, Donggou	DGJO-92	sapropel shale	28.6	22.8	141.93	15.5	II_1	high-quality oil shale
South wing profile, Donggou	DGJO-172	sapropel containing shale	10.0	13.3	63.58	5.8	II_1	medium-quality oil shale
North wing profile, Donggou	DGBO-07	sapropel containing shale	10.5	11.00	58.82	5.8	II_1	medium-quality oil shale
North wing profile, Donggou	DGBO-39	sapropel shale	26.0	20.00	109.68	12.9	II_1	high-quality oil shale
Dadonggou profile	DDGO-25	sapropel shale	37.2	28.3	207.06	20.6	II_1	high-quality oil shale
Dadonggou profile	DDGO-73	sapropel containing shale	15.7	14.6	78.62	7.2	II_2	medium-quality oil shale
Sigonghe profile	SGJO-04	sapropel containing shale	8.8	8.45	52.24	4.6	II_1	low-quality oil shale
Sigonghe profile	SGJO-29	sapropel shale	27.0	23.4	145.11	15.1	II_1	high-quality oil shale
Wugonghe profile	WGJO-06	sapropel containing shale	13.2	11	74.42	7.6	I	low-quality oil shale

The samples listed in the table were randomly selected from each profile and drilling

Table 2. **Comparison between types of oil shale and industrial grade**

<table>
<tr><td rowspan="2">Rock type</td><td>Sapropel component content, %</td><td><5</td><td colspan="2">5–15</td><td>15–25</td><td>25–40</td></tr>
<tr><td>Rock type name</td><td>Black shale</td><td colspan="3">Sapropel containing shale</td><td>Sapropel shale</td></tr>
<tr><td rowspan="2">Industrial grade</td><td>Forecast for oil content, %</td><td><3.5</td><td>3.5–5</td><td colspan="2">5–10</td><td>>10</td></tr>
<tr><td>Industrial grade</td><td>Non-oil shale</td><td>Low-quality oil shale</td><td colspan="2">Medium-quality oil shale</td><td>High-quality oil shale</td></tr>
</table>

Correlation between organic matter and oil content

The organic matter is the basic material unit while studying hydrocarbon generation under optical microscope scale. Organic matter takes only a small or very small part of the total, but it is the key factor to decide whether this type of oil shale is good or bad.

The correlation between total organic matter content and oil content is shown in Fig. 2, the correlation coefficient R is 0.917, showing a significant correlation. The oil yield 3.5% corresponds to the total organic matter content 7.8%, and the oil yields 5% and 10% correspond to the total organic matter content 9.8% and 17.5%, respectively.

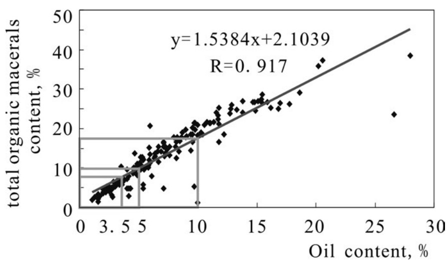

Fig. 2. Correlation between organic matter content and oil content.

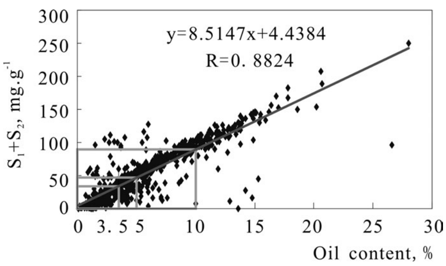

Fig. 3. Correlation between $S_1 + S_2$ and oil content.

Correlation between $S_1 + S_2$ and oil content

Hydrocarbon potential is the sum of organic matter, which undergoes degradation to oil and gas at 300 °C, and the organic matter that can produce oil and gas but is not degraded yet. $S_1 + S_2$ per unit mass of rock (source rock), characterizes the potential of oil and gas production [7-8]. The decomposable part of organic matter is equivalent to the soluble organic matter in rocks, and it volatilizes when rock sample is heated at 300 °C. The organic matter that can produce oil and gas but is not degraded yet is equivalent to the non-decomposable material of kerogen, and it equals to the number of hydrocarbons that volatilize when the insoluble kerogen is subjected to high-temperature (550 °C) cleavage. Peaks S_1 and S_2 are obtained using rock pyrolysis instrument (Rock Eval). Since the sum $S_1 + S_2$ reflects rock potential of hydrocarbon generation, there must be some correlation between it and oil content.

As shown in Fig. 3, the oil yield rate of oil shale is associated with the hydrocarbon-generating potential significantly, and their correlation coefficient R is 0.882. Oil yield 3.5% corresponds to oil-generating potential 34 mg/g, oil yield 5% corresponds to oil-generating potential 48 mg/g, and 10% corresponds to oil-generating potential 90 mg/g.

Correlation between TOC and oil content

TOC is the amount of carbon bound in organic compounds and is equal to the total carbon minus inorganic carbon. The determination of organic carbon is often made treating the sample with hydrochloric acid to remove carbonates first, and then the sample is burned in the presence of oxygen at high temperatures and converted to CO_2, to finally measure its carbon content. Since liquid hydrocarbons and gaseous hydrocarbons, which are generated during the process of thermal evolution after the original organic matter is buried, will migrate out of the source rocks, the measured values of organic carbon mean only the content of remaining organic carbon, and the evaluation of hydrocarbons present in source rock to a great extent relies on residual organic carbon content, which takes TOC as an indicator [9]. TOC is the material basis for the formation of hydrocarbon-bearing seams, so when evaluating hydrocarbon source rocks, data on its content is required first, and the quality and maturity are second requirements [8], therefore, the numerical value of oil shale TOC content is closely related to its oil ratio.

As shown in Fig. 4, organic carbon content of oil shale and oil content are in a good correlation. Correlation coefficient R is 0.978, the oil yield 3.5% corresponds to the TOC 7.5%, the oil yield 5% corresponds to the TOC 9.5%, and 10% to the TOC 17.0%.

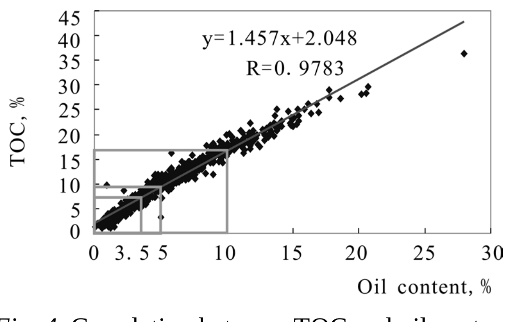

Fig. 4. Correlation between TOC and oil content.

Establishment of new indexes

In summary, the system for evaluating the industrial grade of oil shale is established as follows (Table 3).

Table 3. **New evaluation indexes**

Industrial grade	Non-oil shale	Low-quality oil shale	Medium-quality oil shale	High-quality oil shale
Oil content, %	3.5	3.5–5	5–10	10
Sapropel content, %	5	5–15	15–25	25–40
Total organic matter content, %	7.8	7.8–9.8	9.8–17.5	17.5
$S_1 + S_2$, $mg \cdot g^{-1}$	34	34–48	48–90	90
TOC, %	7.5	7.5–9.5	9.5–17.0	17.0

Conclusions

The content of organic matter in oil shale can be expressed in many different ways, such as oil content, TOC, $S_1 + S_2$, and so on. Based on the international industrial standards of oil shale grading, which is using oil yield to establish industrial grade of oil shale, this paper discusses the relationships between oil shale organic content, hydrocarbon-generating potential, TOC and oil content. We conclude that the organic component content, hydrocarbon-generating potential and TOC can also be used to classify oil shales according to industrial grade, therefore, the establishment of new evaluation indexes of oil shale is feasible. For example, coefficient R between oil shale organic carbon content and oil content is 0.978. Moreover, these parameters are easier to obtain, making evaluation more convenient and efficient.

Acknowledgements

This work was subsidized by the Key Project of the National Science & Technology (2008ZX05034), the National Natural Science Foundation of China (40730422), the National Basic Research Program of China (973) (902009CB219600), the Science & Technology Key Project of the South Branch of SINOPEC Exploration (P2004-06), and the Fundamental Research Funds for the Central Universities (2009PY19).

REFERENCES

1. *Bunger, J. W., Crawford, P. M., Johnson, H. R.* Is oil shale America's answer to peak-oil challenge? // Oil Gas J. 2004. Vol. 8. P.16–24.
2. *Hou, X. L.* Shale oil industry of China. – Petroleum Industry Press, Beijing, 1984. P. 1–28 [in Chinese].
3. *Dyni, J. R.* Geology and resources of some world oil-shale deposits // Oil Shale. 2003. Vol.20, No. 3. P. 193–252.
4. *Liu, Z. J., Meng, Q. T., Liu, R.* Characteristics and genetic types of continental oil shales in Chin // Journal of Palaeogeography. 2009. Vol.11, No.1. P. 105–114 [in Chinese].

5. Committee Office of Mineral Resources in China. Reference Manual of Mining Industry Demands. – Geology Publishing House, Beijing, 1987. P. 312–315 [in Chinese].
6. *Zhao, L., Jia, R. F., Liu, D. H.* Macerals characteristics of black argillite from Paleozoic marine-continental transitional facies and evaluation on their gas-generating potentiality // Acta Sedimentologica Sinica. 1995. Vol. 13, No. 2. P. 105–111 [in Chinese].
7. *Paist, A.* New epoch in Estonian oil shale combustion technology // Oil Shale. 2004. Vol. 21, No. 3. P. 181–182.
8. *Hao, S. S., Gao, G., Wang, F. Y., Gang, W. Z.* High-Over Matured Marine Source Rock. – Petroleum Industry Press, Beijing, 1996. P. 119 [in Chinese].
9. *Qin, J. Z., Zheng, L. J., Tenger.* Study on the restitution coefficient of original total organic carbon for high mature marine hydrocarbon source rocks // Earth Science – Journal of China University of Geosciences. 2007. Vol. 32, No. 6. P. 853–860 [in Chinese].

Presented by E. Reinsalu
Received December 17, 2009