MAOMING OIL-SHALE MINING

by Hugh J. Mitchell-Tapping
Consultant, Dallas, Texas

ABSTRACT

Oil-shale is one of the most important direct sources of hydrocarbon in southern China. The term "oil-shale" refers to organic-rich fine-grained rocks that produce oil upon distillation and has a production cut-off value, used to distinguish between oil-shale and marlstone, of greater than 12.5 litres per metric tonne. One of the largest oil-shale mining areas of China, and a major source of petroleum in southern China, is situated in Maoming Basin, Guangdong Province about 300 km southwest of Hong Kong. (figure 1) This basin is a Tertiary graben about 50 km long by about 10 km wide and is fault-bounded on its northeastern edge with the oil-shale mine located at the southwestern edge just outside of the city of Maoming. The Eocene oil-shale stretches from Yangao in eastern Dianbai county, through the towns of Xinxiu, Jintang, Dishan, Shigou and as far as Shatian in Huazhou county. Below the oil-shale there is a 0.5 m Paleocene coal bed and thin red sandstones which can be traced throughout the basin and are located unconformably on top of a Paleozoic limestone hardground. Overlying this Paleocene section there are five major sequences of Eocene dark brown compact oil-shales with tan colored fluvial sandstones each about 15 m thick, which make up the Youganwou Formation. This formation is about 65 m to 75 m thick at the exposed mine face. Although the oil-shale is soft and elastic with some fossiliferous layers consisting of paper-thin laminae, it can be firm and very difficult to fracture requiring compressed air-hammers to break up the large pieces before processing. Only the lower two sections are mined with the richest oil yield from shale immediately above the coal bed. It is in this lower section that many of the freshwater fossils are found, such as turtles and treetrunks, in a near-perfect state of preservation. The formation also includes some interbedded yellow to tan to brown mudstones and siltstones, but with no desiccation cracks and only normal microfaults, syneresic or looping structures, and mass contortion of the lamellae due to compaction during lithification, observed in the mudstones.

In the siltstones there are both cross and parallel laminations and ripple marks, which could also be interpreted as laminae with dip. The thick sandstone units, composed of sub-rounded to angular, coarse to fine-grained quartz with some feldspar, clay and organic material, usually have basal conglomerates, and flute-and-groove patterns with low-angled cross-bedded and parallel laminae. These fluvial channel sandstones are friable and iron-rich, becoming very dark brown at the top of the member. Brown to tan to dark-grey clays are dispersed or in clay balls throughout the sandstone unit and some rounded quartz pebbles, about 15 cm in diameter, occur in the lowermost sandstone member where a sharp contact with the underlying shale shows scour marks. No fish or gastropods have been discovered but woody fragments with some large tree trunks and an Eocene freshwater turtle have been unearthed. The highest unit is the Oligocene to Miocene Huangniuling Formation which can be as great as 350 m thick in the basin, but it is only about 45 m to 60 m thick at the mine face. This formation consists principally of white to yellow to red conglomerates and sandstones with some laminated and dispersed clays which become more frequent higher in the section, and is disconformable to unconformable on the Eocene Youganwou Formation.

In the basin the outcrop and near-to-surface oil-shale extends about 50 km in a northwest-southeast line. The beds at the mine dip about 5 to 10 degrees to the northeast. The present day mine face is about 5 km long and is about 75 m in height. In the immediate area around the mine there are numerous oil seeps especially in local ponds and at foundations of buildings. Mine drill-holes, to test the extent of the oil-shale, have been drilled to a depth of 1000 m and still swabbed oil from oil-shale. The mine was started in 1958 on an automated schedule using power shovels, hoppers and electric trains. Present day excavation continues at a rate of approximately 10 m per year cutback of the mine face. The clay units between the coal beds as well as between the shales are hand-mined and used in medicinal potions and for special applications in local brick manufacturing. The oil output from the oil-shale is about 100,000 metric tons per year (700,000 barrels of oil) and in 1984 it was estimated that about 1/10th of the recoverable reserves had been mined, that is about 20 MMBO. Only the two lowermost oil-shale seams are mined by four large mechanical shovels. These shovels clear the overburden and dig out the oil shale and dump it directly into hoppers which are then moved by three diesel-electric trains to the rock crushing plant. Here the shale is tipped and large pneumatic drills are used to break up large pieces so they can fall into the crusher. From the rock-crushers the particles are transported by three rubber elevators to the top of a large separator. The separator sorts out the gangue material which is shipped to dumps by small electric trains. Two large elevators then transport the crushed oil-shale to 96 vase-shaped retort heating pots, where some of the oil-shale is used as fuel in heating the pots. These pots have been specially designed for low temperature retorting by an inner heating method. The estimates of oil content of the shale average about 6.9%. After the oil is drawn off and cooled, the by-products of gas, tar, and waste pitch are separated. The
pitch is returned to the heating pot for recycling, and the residue rock is transported underground back to the separator for recycling or dumping.

A geochemical examination of the organic matter in the oil-shale showed that most of the organic matter is derived from planktonic algae, and contains abundant Pediastrum colonies. No telalginite, or alginite A, was observed and the presence of bitumen in the oil-shale may be responsible for the high hydrogen/carbon ratio of the organic content.

In samples taken from sections parallel with bedding, the lamalginite consists of Pediastrum colonies up to 0.1 mm in diameter together with structured algal colonies, of a similar size distribution but lacking processes as found on Pediastrum, and small algae, less than 0.61 mm in diameter, and fragments of algae. The Pediastrum-type lamalginite constitutes from 5% to 30% of the organic matter. All samples taken from the lower oil-shale bed above the Paleocene coal seam, the middle bed and from the uppermost bed are predominantly Type I algal-lacustrine kerogen, and although organic carbon and Rock Eval values show the samples to be extremely rich in kerogen, the Rock Eval Tmax and production index or transformation ratio data...
Figure 2. Micrograph of the oil-shale showing continuous dark organic laminae deformed by compaction. Laminae with quartz grains, clay and carbonate nodules.

indicates that the kerogen content is relatively immature, which is typical of oil-shales. The potential for liquid hydrocarbon recovery for the lowermost bed is approximately twice that of the middle bed as indicated by Rock Eval P2 data, and the large concentration of free hydrocarbons (P1) reflects the high organic content. The lowermost bed is more oil-generative and has greater maturity than the middle bed, based on higher Tmax values, but is still above the crude-oil generative window. The high hydrogen (H1) and very low oxygen (O1) indices fall into the range of Type I or I1 kerogen and gas chromatograms confirm the aliphatic nature of the shale which indicates that this oil-shale can generate a large quantity of liquids because of its high organic richness, even though the kerogen is relatively immature, and if thermally mature it would produce a low sulphur, high wax, high pour point, crude oil typical of lacustrine crude.

INTRODUCTION

Oil-shale is one of the most important direct sources of hydrocarbon in southern China. The term "oil-shale" refers to organic-rich fine-grained rocks that produce oil upon distillation. The production cut-off value, used to distinguish between oil-shale and marlstone, is that oil-shale has production greater than 12.5 litres per metric tonne (Brobst and Tucker, 1973). These oil-shales are associated with freshwater environments and large intermontane lakes.

Maoming Basin is situated in southern China in Guangdong Province about 145 km northeast of Zhanjiang and about 300 km southwest of Hong Kong. It is one of the largest oil-shale mining areas of China, and one of the major sources of petroleum in southern China. The Maoming Basin, in which the mine is located, is considered as Lower to Middle Tertiary basin. The oil-shale is considered as Eocene in age and is found lying on top of thin Paleocene coal beds. The Paleozoic carbonate beneath the coal sequence has an eroded hardground surface with large chalk pebbles imbedded in it. The mountains to the southeast of the city are composed of Paleozoic and Mesozoic igneous and sedimentary rocks. Elsewhere, other than in the immediate mine area, the Cretaceous is made up of continental tectonic sediments, such as red conglomerates and shales, together with intrusions of granite, rhyolite and trachyte. In the Maoming Basin, the shale layers stretch from Yangjiao in eastern Dianbai county, through the towns of Xinxu, Jintang, Dishan, Shigu and as far as Shatian in Huazhou county (Sinopec, 1985). Here the Paleocene coals and thin red sandstones are located unconformably on top of a Paleozoic limestones hardground. Overlying this Paleocene section there are five major Eocene oil-shale and sand sequences, each about 15 m thick, which make up the

GENERAL GEOLOGY

The Maoming Basin is an uplifted Tertiary graben about 50 km long by about 10 km wide and is fault-bounded on its northeastern edge. The oil-shale mine is located just outside of the city of Maoming at the southwestern edge of the basin. The structural and stratigraphic history of the basin is very similar to that of the Tertiary Fushun Basin of Northeast China. In the Fushun Graben there are thick Eocene coal seams up to 115 m thick which were deposited in a Tertiary lacustrine environment. On top of this coal section there is about 400 m of rich Eocene oil-shales (figure 2). During the Second World War, the Japanese open-pit mined the coal section after stripping the rich oil-shale overburden. The Chinese then developed the largest oil-shale mine in China at Fushun which has been estimated to have produced more than 20,000 BOPD. This mining experience at Fushun enabled the technological development of other oil-shale mines throughout China.

In the Maoming Basin, the shale layers stretch from Yanyang in eastern Dianbai county, through the town of Xinxia, Jinhang, Dishan, Shigu and as far as Shatian in Huazhou county (Singpec, 1986). Here the Paleocene coals and thin red sandstones are located unconformably on top of a Paleozoic limestone hardground. Overlying this Paleocene section there are five major Eocene oil-shale and sand sequences, each about 15 m thick, which make up the
Youganwou Formation. The Youganwou Formation can be described as dark brown to coffee-colored compact oil-shale with tan colored fluvial sandstones. The Formation is about 65 m to 75 m thick at the exposed mine-face. Although the oil-shale is soft and elastic, it can be firm and very difficult to fracture requiring compressed air-hammers to break up the large pieces before processing. Some shale layers consist of paper-thin laminae and are very fossiliferous. All fossil evidence (vertebrates, insects, plants) from the section suggests an Eocene age, equivalent to the Fushun oil-shales, and to the parts of the Buxin, Kongdian, Funing, Zhuhai and Lushagang Formations of other coastal and offshore basins of China. The formation also includes some interbedded yellow to tan to brown mudstones and siltstones. No desiccation cracks were observed in the mudstones but normal microfaults were common. It is thought that these microfaults were due to compaction during lithification. Syneresis or looping structures and mass contortion of the lamellae were also observed. In the siltstones within the oil-shale there are both cross and parallel laminations and the appearance of what is thought to be ripple marks but could also be interpreted as laminae with dip. The siltstone units are composed of sub-rounded to angular, coarse to fine grained quartz with some feldspar, clay and organic material. These units are thick and usually have some basal conglomerates. There are flute and groove patterns together with low-angled cross-bedded and parallel laminae. These overlying sandstones are friable and tend to be iron-rich. At the top of the member the sandstone is dark brown in colour. Throughout the units the clays are dispersed in clay balls and have a brown to tan to dark-grey color. Some rounded quartz pebbles, about 15 cm in diameter, occur in the lowermost sandstone member. A sharp contact with the underlying shale shows scour marks. These sandstone units are considered fluvial channel sands. Plant material present is mainly woody fragments but some large trunks of trees have also been found. No fish or gastropods have been discovered but an Eocene freshwater turtle has been unearthed. All the fossils observed are non-marine. This observation together with the lack of desiccation marks suggests that the environment may have been a large pond or perennial lake in a temperate climate. The lack of fish, coprolites, bioturbation, and soft-bodied animals may indicate anaerobic conditions at the sediment-water interface. The salinity of the pond was probably fresh to slightly brackish based on the presence of the turtle.

The highest unit at Maoming is the Oligocene to Miocene Huangniutu or Huangniu Formation. Elsewhere in the basin the thickness of this formation can be measured as greater than 300 m, but it is only about 45 m to 60 m thick at the mine face at the southwestern edge of the basin. This formation consists principally of white to yellow to red conglomerates and sandstones. Some laminated and dispersed clays are present in the sandstones, becoming more common higher in the section. This Oligocene-Miocene formation is disconformable to unconformable on the Eocene Youganwou Formation.

THE MINE

In the basin, the outcrop and near-to-surface oil-shale extends about 50 km in a northwest-southeast line, but only 5 km has been exploited at the present time. The beds at the mine dip about 5 to 10 degrees toward the metamorphic mountains to the northeast. The original plan was to develop and excavate three separate areas along a 30 km outcrop, but due to the political and economic situation at the time only one site at the southwestern edge of the basin has been developed. In the immediate area around the mine there are numerous oil seeps especially in local ponds and at foundations of buildings. Some water wells have been drilled but are always oil-contaminated. Mine drill-holes, to test the extent of the oil-shale, have been drilled to a depth of 1,000 m and still swabbed oil from oil-shale.

The present day mine face is about 5 km long and is about 75 m in height. At the base of the cut is a limestone hardground on top of which is about 0.5 m of coal. This coal seam can be traced throughout the basin. Atop the coal-bed there are three repeated sections of oil-shale and sandstone. Each section is about 15 m thick. The lower two sections are mined with the richest oil yield from shale immediately above the coal bed. It is in this lower section that many of the freshwater fossils are found, such as turtles and tree trunks, in a near-perfect state of preservation.

The mine was started in 1958 on an automated schedule using power-shovels, hoppers and electric trains. Present-day excavation continues at a rate of approximately 10 m cutback of the mine face each year. The clay units between the coal beds as well as between the shale in the Paleocene section are used in medicinal potions and for special applications in local brick manufacturing.

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PRODUCTION

It is estimated that 8 million tons of oil-shale are mined each year. The oil output from the oil-shale is about 100,000 metric tonnes per year; which is equivalent to 700,000 barrels of oil, or approximately 2,000 BOD since 1958. The increased overburden stripping and the cutback rate of about 10 m per year is getting greater, due to the 5 to 10 degrees of dip in the beds, but estimates consider that economically there is still enough oil-shale to last 150 years (Sinopec, 1985). In 1984 it was estimated that about 1/10th of the recoverable reserves had been mined that is about 20 MMBO. The recovery cost in 1984 was thought to be about 90 yuan (US $45) per ton, or about US $7 per barrel.

Only the two lowermost oil-shale seams are mined by four large mechanical shovels. These shovels clear the overburden and dig out the oil-shale and dump it directly into hoppers. These hoppers are then moved by three diesel-electric trains to the rock crushing plant. Here the shale is tipped into crushers and large pneumatic drills are used to break up large pieces so they can fall into the crusher. From the rock-crushers the particles are transported by three rubber elevators to the top of a large separator. The separator sorts out the gangue material which is shipped to dumps by small electric trains. Two large elevators then transport the crushed oil-shale to 96 vase-shaped retort heating pots, where it is heated by burning some of the oil-shale as fuel for the pots. These pots have been specially designed for low temperature retorting by an inner heating method. The oil is drawn off and cooled. The estimates of oil content of the shale is about 6.9% (Sinopec, 1985). The by-products are gas, tar, and waste pitch. The pitch is returned to the heating pot for recycling. The residue rock is transported underground back to the separator for recycling or dumping.

GEOCHEMISTRY

A petrological investigation of the organic matter of rock samples showed that most of the organic matter is derived from planktonic algae, and contains abundant *Pediastrum* colonies. *Pediastrum* is a planktonic colonial alga composed of two to many coenebia which form a stellate disk (Hutton, 1984). It has a widespread lacustrine distribution with reported occurrences in Tertiary sequences of Australia (Cookson, 1953), Japan (Matsuoka and Hase, 1977), India (Mathur, 1963), Indonesia (Wilson and Hoffmeister, 1953), Thailand (Gibling et al., 1985) and in the United States (Davis, 1916). It is found generally in freshwater lacustrine deposits (Cookson, 1953). Matsuoka and Hase (1977) found that *Pediastrum* was associated both with freshwater diatoms and estuarine mollusks, and inferred a river mouth environment with a minor marine influence. Singh et al. (1981) reported *Pediastrum* from late Cenozoic sediments of Lake George (Australia), and they inferred that the presence of the alga indicated water depths

![Ternary diagram](image)

Figure 3. Ternary diagram (after Tissot and Welte, 1978) showing the aromatic-asphalitic nature of the Maoming oil shales.
Figure 4. Crossplot of the Hydrogen Index versus Tmax showing the immaturity and kerogen type of the Maoming oil-shale.

Figure 5. Oxygen Index Hydrogen Index crossplot on a van Krevelyn diagram for kerogen classification.

Figure 6. Aromatization/Sterane Isomerization crossplot showing the difference in maturity of a lacustrine oil to that of the Maoming oil-shale. This crossplot reveals a possible different burial history based on the maturation rates.

Figure 7. Chemical group characterization.
to of at least 7 m for long periods of time. The occurrence of the alga in these lamosites indicates that *Pediastrum* was probably of widespread occurrence during the Tertiary. Oil shales in Tertiary deposits were termed "lamosites" by Hutton *et al.* (1980). Cook (1987) proposed a classification of oil shales based on the organic matter present. He proposed to divide the maceral alginites into two groups, telalginite and lamalginite, based on the abundance of the algal precursors *Botryococcus* or *Pediastrum* which is similar to the terminology of Hutton *et al.* (1980) that is Alginite A and Alginite B. Telalginite, or Alginite A, was not observed in the samples of Maoming. The presence of bitumen in the oil-shale may be responsible for the high hydrogen/carbon ratio of the organic content. The Maoming samples are classified in the lamosite group similar to those of the Rundle oil-shale in Australia, the oil-shales of the Green River Formation in the USA, and those found in the Mai Sot Basin of Thailand. Organic rich rocks are grouped into oil-shales, bitumen rich tar sands and carbonaceous shales according to the abundance of liptinite and bitumen. Oil shales are considered to have a limit of 10% liptinite. This classification can be used for the interpretation of depositional environments, different bed thicknesses and distribution. For example, telositic shales have thin discontinuous beds and very high oil production, but unfortunately they usually do not occur in commercial size deposits. Lamosites are geographically widespread, but are less numerous in occurrence, and are found in thick beds and have a high oil-production which is ideal for commercial enterprises. Bituminites, usually associated with marine oil-shales, have a low oil-production, usually with a high residual carbon content. Carbonate-poor oil-shales are more silicate rich with a low sulphur content, usually giving a better oil grade than carbonate-rich oil-shale.

At Maoming it was found that in samples taken from sections parallel with bedding, the lamalginite consists of *Pediastrum* colonies up to 0.1 mm in diameter together with structured algal colonies with a size distribution similar to *Pediastrum* but lacking processes as found on *Pediastrum*. Also found were small algae, less than 0.61 mm in diameter, and fragments of algae. The *Pediastrum*-type lamalginite constitutes from less than 5% to 30% of the organic matter in samples from different layers. Some samples were taken from each of the main oil-shale beds, from the lower oil-shale bed above the Paleocene coal seam (A in table 1), the middle seam (B) and from the uppermost bed (C in table 1). All samples are predominantly Type I algal-lacustine kerogen (figure 3). The organic carbon values and Rock Eval data in Table 1 show the samples to be extremely rich in kerogen. The potential for liquid hydrocarbon recovery for A is approximately twice that of B as indicated by Rock Eval P2 data. Based on Rock Eval Tmax and production index or transformation ratio data, the kerogen content is relatively immature, which is typical of oil shales (figure 4). The large concentration of free hydrocarbons (P1) reflects the high organic content in the samples. Bed A is more oil-generative than bed B, and the higher Tmax indicates a greater maturity but is still above the crude oil-generative window. The high hydrogen (HI) and very low oxygen (OI) indices fall into the range of Type I or II kerogen and gas chromatograms confirm the aliphatic nature of the shale (figure 6, 7, 8, 9, 10, and 11). This data in Table 1 indicates that a thermally mature shale of this kind would produce a low sulphur, high wax, high pour point, crude oil typical of lacustrine crude.

This oil-shale can generate a large quantity of liquids because of its high organic richness, even though the kerogen is relatively immature. However, the quality and chemistry of the generated liquid will be much different from the oil that would be produced if the shale were thermally mature.

**CONCLUSIONS**

The Tertiary Maoming Basin has been uplifted and tilted down to the northeast with a dip of 5° to 10°. The mine is situated at the southwestern edge of the uplifted basin on the crest of an anticline. The Eocene oil-shale and the Paleocene coal beds, although only exposed for 5 km at the mine face, actually extends for 30 km across the basin. The organically-rich oil-shale produces oil with plenty of light ends. The presence of *Pediastrum*, freshwater turtles, and plant material indicate that the shales were laid down in a freshwater lake in a fluvial continental environment. Geochemically the oil-shales are considered immature with a high organic content.

**REFERENCES CITED**


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**TABLE 1**

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Figure 10. Comparison of lacustrine oil to oil-shale samples A and B.

Figure 11. Cycloalkenes of samples A and B pristine/phytane ratios.