CAER -- University of Kentucky, Center for Applied Energy Research Vol.5, No.5, 1994

ENERGEIA

Organic Petrography and Oil Shales

Adrian C. Hutton
Department of Geology
University of Wollongong, Australia

During the late 1970s and early 1980s the worldwide energy crisis saw a dramatic increase in the research activities relating to oil shales. Coincidently, or perhaps not, at the same time fluorescence mode microscopy became a routine technique in organic petrography and for the first time it was possible to clearly and easily recognize the organic constituents of oil shales. Now that the oil shale bubble has well and truly burst, it is perhaps time to reflect on the those frantic activities of the 1970s and 1980s and assess whether fluorescence studies of oil shales has been useful or not.

ORGANIC PETROLOGY

Organic petrography is the study and description of organic matter in rocks and is a subset of organic petrology which includes among other things, utilization, genesis and sedimentology. Organic petrography is basically the examination of organic matter in rocks using reflected white light and fluorescence mode microscopy.

Reflected light analysis of coal was an accepted technique as early as 1913 and was used in the 1920s and early 1930s by such eminent petrographers as Stach, Thiessen and Stopes. Two major advances in organic petrography came in 1935. The first was the publication of Stach's textbook on coal petrology, which was updated 40 years later and issued as a third edition in 1982. The second advance was at the meeting of learned coal scientists at Heerlen (The Netherlands) which set out to resolve some of the many difficulties that had arisen because of the varied approaches to coal analysis adopted up to this time. Importantly, several ideas on classification had evolved and confusion had arisen over concepts and terminology. At the meeting, Mary Stopes proposed her concept of the "maceral" to designate the fundamental microscopic constituents of coal. As a consequence, the Stopes-Heerlen or International system of nomenclature slowly evolved. The maceral entities have been equated to the mineral entities in inorganic petrology. The maceral concept provided organic petrographers with a system that would permit easy communication of ideas worldwide.

In the 1950s, the International Commission for Organic Petrology, now known as the International Commission for Coal and Organic Petrology (ICCP), was formed with the aim of advancing the science of coal petrology through standardization of methodology and terminology. Under the auspices of the ICCP organic petrography is now a respected analytical technique and most researchers in coal, oil shales and petroleum source rocks are aware of its advantages and disadvantages.

OIL SHALES

The dominant organic matter in oil shales is derived from one or more of three primary sources - terrestrial plants, lacustrine algae and marine organisms (including algae, acritarchs and dinoflagellates). The abundance of organic matter in oil shales is dependent on many factors including the proximity to an available source of preservable organic matter, rate of clastic input and the degree of alteration or decay prior to, and during, diagenesis.

Organic matter sourced from lacustrine and marine organisms is normally hydrogen rich initially but may be depleted in hydrogen as a result of degradation at the time of deposition or after burial. Organic matter derived from terrestrial plants is either hydrogen-rich or hydrogen-poor depending on the chemical composition of the parent plant tissue. Woody tissues produce vitrinite and inertinite (low hydrogen macerals)

(continued, page 2)

The Role of Oil Shale in the Israeli Energy Balance

Tsevi Minster
Geological Survey of Israel, Jerusalem

HISTORY

As most of the oil shale deposits of the Holy land are located in the subsurface, their historical impact can be supposed to be marginal. However, it is accepted by most scientists that the asphalts found in the Dead Sea region are related to the oil shale sequences which frequently outcrop along the basin perimeter and are believed to underlie the region at great depths (Figure 1).

Asphalt showing in the Dead Sea area is both in surface seepages (also penetrated in boreholes) and as pure floating blocks (less dense than the salt saturated waters) found on the shores. This raw material is known to have been used by mankind for at least 10,000 years. Archaeological findings revealed its use in decoration, cult objects, cementing, waterproofing and adhesives. Roman and Medieval literature indicate other applications, e.g. agriculture, boat crafting, medicine and mummification. It was even used in the early days of photography. In 1822 Joseph Niepce took the first photograph of nature using Dead Sea asphalt,

(continued, page 4)

Organic Petrography, (continued)

whereas spores, pollen, cuticle, resins, fats, waxes and oils produce liptinite macerals (high hydrogen macerals). Liptinite is the predominant source of the oil in oil shales and this is where oil shales are related organic petrography - liptinite macerals are difficult to recognize in thin section and reflected white light but are easily recognized in fluorescence mode. An understanding of the types and abundance of liptinite in oil shales was only possible with the advent of fluorescence microscopy.

Petrographic Studies of Oil Shales

The earliest organic petrographic studies of oil shale were descriptive but were nonetheless extremely important. It was quickly realized that oil shales could be grouped into types using the liptinite macerals as the criteria for discrimination. For example, torbanite, used extensively in the Australian oil shale industry during the second half of the 19th century, and used initially in the early Scottish oil shale industry, were quite different from the Tertiary oil shales of Queensland (Australia), which were the focus of attention as a possible retort feedstock during the surges of activity in the 1980s. On the other hand, th Australian Tertiary oil shales are similar to the Lothians oil shale, which was extensively exploited well into this century.

Something perhaps even more significant was the discovery that the types of organic matter in oil shales were also present in claystones associated with the oil shales. Oil shale was thus not a geological nor geochemically distinctive rock but rather an 'economic' term. At the same time it was shown that the oil yield was more closely correlated to the volume of liptinite rather than the volume of total organic matter. This correlation is easily illustrated with the Alpha (Queensland, Australia) torbanite deposit where the torbanite lens is part of a coal seam. Within the torbanite lens the oil yields are as high as 750 litres per ton at 0% moisture (LTOM) but at the upper and lower limits of the torbanite lens the oil yield decreases to approximately 250 LTOM. Over the same interval, the abundance of vitrinite and inertinite increases proportionally. The transitional zones between torbanite and coal at the top and bottom of the torbanite lens are < 10 cm. This important result has implications for those studying the origin of torbanite deposits, but, more importantly, has significant ramifications for selective mining, selection of retort feedstocks and oil composition.

Kerogen. Since 1912, the term kerogen has been used for the insoluble component of firstly, oil shale and more recently, all sedimentary rocks, with perhaps the exception of coal. Four types of kerogen are recognized - Type I, Type II, Type III and Type IV. Type I is aliphatic kerogen with a high H/C ratio (of approximately 1.5) and low O/C ratio (approximately 0.1); it is derived from algal precursors; Type II has lower H/C and low O/C. Type III and Type IV kerogen are least aliphatic (H/C < I and O/C 0.2 to 0.3) and are derived from terrestrial plant precursors.

Most of the elemental geochemical literature on oil shale kerogen relates to bulk rock analyses and is plotted on a van Krevelen diagram. Organic petrography shows that all oil shales contain a mixture of two or more maceral groups. Thus the chemical entity referred to by geochemists is referred to by at least two, and sometimes three, entities. Each petrographic entity is known to have a fairly narrow range of chemical properties. Consequently, kerogen derived from bulk rock studies, especially Type II and generally Types I and III, is not a single kerogen entity but two components, each with relatively different chemical properties. Therefore, it must follow that any kerogen study of a bulk rock will reflect the relative abundance of each maceral group in the rock.

Realization that oil shale kerogen was composed of discrete organic matter which could be described by maceral terminology had a far-reaching effect on other areas of organic petrography. It was realized that any organic matter in any sedimentary rock, including petroleum source rocks, could be described in terms of macerals.

Petroleum Source Rocks. Source rock studies benefited greatly from organic petrography; the organic matter in source

(continued, page 3)

rocks can be described by the same terminology that is used for oil shales and which is the same as that used for coals. Vitrinite reflectance studies provided data which showed that for Australian Tertiary source rocks the lower threshold of the oil generation window was equivalent to 0.5% vitrinite reflectance and that beyond 1.1 to 1.3% vitrinite reflectance, gas was more likely to be generated than oil. Vitrinite reflectance rapidly became the standard maturation indicator and still remains so despite problems associated with rocks older than Silurian age.

Organic petrography is used to differentiate between types of source rocks and it can be shown that type of organic matter is more important than total organic carbon. Liptinite and vitrinite are recognized as sources of oil in terrestrial sequences and that, at best, inertinite is a source of gas. Detailed studies show that rocks assaying as marine oil shales are lateral equivalents of marine source rocks. The major components are alginite (liptinite derived from algal precursors) and bituminite (a liptinite probably formed through the degradation of algae) with vitrinite and inertinite as minor components.

One question that remains to be answered is the source of the oil from marine source rocks. It is generally stated that liptinite is an excellent source of oil. If this is so, the probable source of oil in marine rocks is either bituminite and/or alginite. Petrographic observations suggest that the organic matter recognized as alginite is probably not the source of oil. Most alginite has a very strong green to yellow fluorescence (an indicator that the maturity of the organic matter has not reached a sufficiently high level to have generated significant oil) and many algal bodies are well preserved and in many cases, perfectly preserved. Fine processes on acritarchs and dinoflagellates (two precursors of alginite) are preserved; processes are such small, delicate appendages that they surely would be changed if oil had been generated from this alginite. If this alginite had produced oil, it would be expected that some evidence of degradation or chemical change should exist. There is no evidence of this.

A second point suggesting alginite is not the main oil source relates to the volume of alginite; in many source rocks, alginite is such a minor component that it could not have sourced a significantly large quantity of oil to allow migration or filling of reservoir rocks.

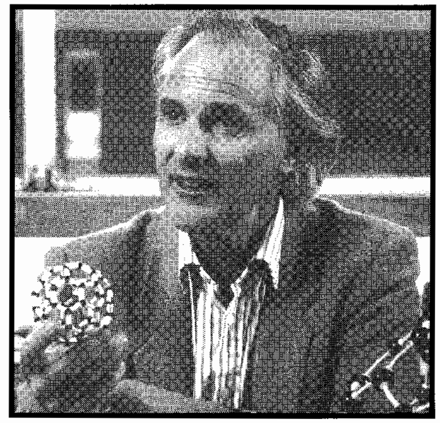
A third observation that also leads one to doubt whether alginite is a source of oil, not directly related to marine source rocks but one bearing on source rocks in general, can be found in torbanites. In Australia and South Africa, torbanites are of Permian age and occur in sequences that have reached the mid-lower to mid-upper generation zone based on vitrinite reflectance. For example, the Joadja torbanite occurs in a coal seam (vitrinite reflectance is 0.9 to 1.0, clearly well within the oil generation zone) of the Sydney Basin sequence, renowned for it lack of oil. If it is alginite, one of the liptinite macerals and supposedly one of the good sources of oil, how is it that the alginite has beautifully preserved cell structure and does not show some evidence of degradation or alteration as might be expected from organic matter that has lost a substantial proportion of its carbon and most of its hydrogen? All torbanites plot as Type I kerogen on the van Krevelen diagram if the algal constituents are high. This is inconsistent as the formation of oil would remove much of the hydrogen, leaving organic matter with high carbon-low hydrogen and that should plot as Type II or Type III. Perhaps petrographers and chemists cannot recognize evidence of oil generation!

An alternative hypothesis for the source of oil in marine rocks is bituminite. In many source rocks, bituminite is the dominant component. However, the equivocal nature of bituminite is a problem. Bituminite refers to amorphous organic matter and at least four types have been recognized. Some bituminite fluoresces quite strongly whereas other bituminite is nonfluorescing and has similar optical properties to vitrinite. Rocks containing virtually only bituminite, plot as Type II kerogen on a van Krevelen diagram. Does bituminite, a low hydrogen liptinite plotting as Type II kerogen, source oil or does bituminite represent the degraded residue of liptinite that has produced oil?

Detective Petrography

The applications of organic petrography to oil shale studies are varied. One question that is commonly asked is whether oil shales can be beneficiated or upgraded before retorting. Such a procedure, if cost efficient, would enhance the possibility of an oil shale industry becoming a reality. Petrographic studies show that the lower grade oil shale types, such as the marine oil shales and the Australian Tertiary oil shales can be beneficiated but the technical problems and associated cost are prohibitive. In Australian Tertiary oil shales the alginite, which is the major source of the oil, comprises thin lamellae generally <0.8 mm long and <0.005 mm thick. Petrography shows that when these oil shales are comminuted; the particles are elongate rather than equant. Point counts

(continued, page 4)



Organic Petrography, (continued)

show that there is a significant increase in oil yield as the particle size decreases.

For marine oil shales, the alginite has similar dimensions to that in the Australia Tertiary oil shales. Thus similar results can be expected for this maceral in beneficiation experiments. However, a much greater problem is the bituminite which is at least partly amorphous and comprises the bulk of the organic matter. The bituminite is commonly intermixed with fine-grained mineral matter and grinding is unlikely to liberate a significant amount of this organic matter.

The first commercial oil shale industry in Australia was located at Mount Kembla, a suburb of Wollongong (New South Wales, Australia). It has generally been assumed that since all other commercially-exploited oil shale deposits were torbanite, the Mount Kembla deposit was also a torbanite. However, petrographic analysis shows that the oil shale consists of a carbonaceous shale, similar in hand-specimen to torbanite, with abundant bitumen. Retorting of this rock produces oil. Alginite is not a component of the rock and therefore the Mount Kembla oil shale is not a torbanite. Mount Kembla oil shale is more akin to the Canadian tar sands than to a torbanite.

SUMMARY

Organic petrography has been one of the most useful techniques for the examination of oil shales. Oil shales are a diverse group of rocks containing a mixture of dominantly liptinite with minor vitrinite and inertinite. Thus organically, oil shales lie somewhere between coals and barren sedimentary rocks. Characterization of oil shales is not only useful for oil shale studies but has also encouraged and aided studies of other rocks such as petroleum source rocks. Indeed, the only difference between an oil shale and either coal or a petroleum source rock is the relative abundance of the macerals.

Organic petrography will continue to play an important role in studies of organic-rich rocks. New applications will be found and the diversity of applications will be as wide as researchers have the skills and initiative to push the technique.

Adrian Hutton received his Ph.D. from the University of Wollongong in 1981 and is presently a senior lecturer there.

Role of Oil Shale, (continued)

by exposing a metal plate (containing an image) covered with bitumen to sunlight. The Dead Sea asphalts are probably the 'oil' of the Bible. The commodity is thought to have had a very significant economical and political role in the days of the Nabataean Kingdom (4 - 1 centuries B.C.) and its contact with Egypt, the Greeks and the Romans.

Quarrying activity signs in the Nabi-Musa deposit, traced also in old air photos, represent some uses of in-situ oil shales in the past. Exposed material was and is still used, in limited amounts, for heating by domestic nomads and as a soft building stone. Oil shales from Ein Boqeq were successfully applied as a construction material for potash evaporation ponds in the southern part of the Dead Sea. A domestically metamorphosed derivative of the oil shale host rocks is used as an ornamental building stone, especially in terrazzo making.

TODAY'S ENERGY SCENE

Israel's 1993 total energy consumption was estimated to be around 12,500 TTOE (= x 1,000 Tons of Oil Equivalent). Most of the energy is produced from imported crude oil and coal. However, there are other domestic energy sources. One of these is solar energy which provides a significant portion of household hot water requirements (estimated to provide the country with 3-4% of the total energy needs). The country's geographical location makes solar energy a viable source (average insolation figure of some 4,500 Kcal/m2.day). Solar energy also has a limited application in industry and is a subject of two research sites in which both medium and high temperature utilization processes are tested. There is a small quantity of oil and gas production equivalent to about 1% of domestic crude oil consumption. In addition, a few small power plants based on wind, biomass and water energy were developed in the last decade.

The main revolution which has occurred in the Israeli energy market since 1980 is the diversification of electricity generation from a complete dependence on crude oil to more than 60% utilization of coal last year. This change was due to a concerted effort to secure energy resources from a host of geographical areas. The domestic energy policy of diversification is aimed at guaranteeing energy resources in the future.

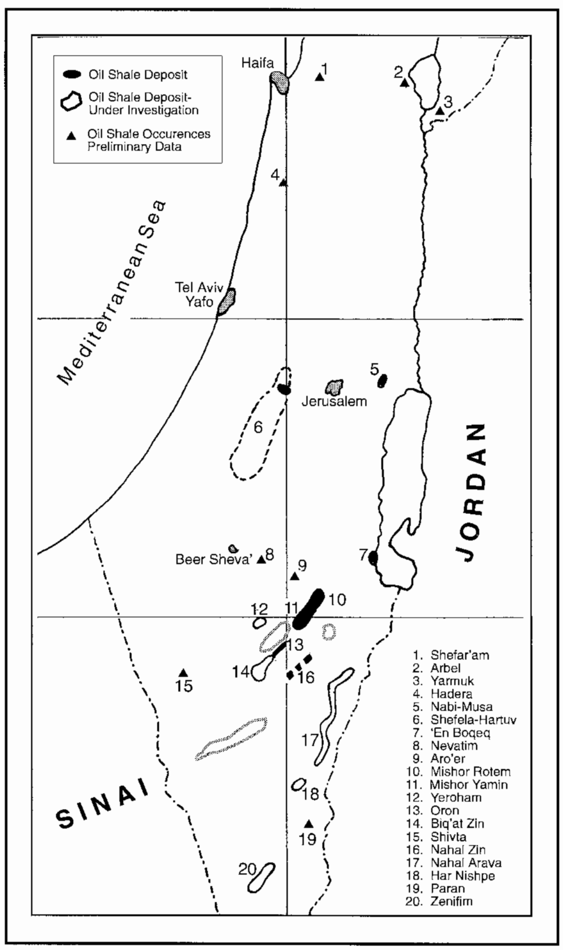


Figure 1. *Map of main oil shale occurrences in Israel*

OIL SHALE RESOURCES

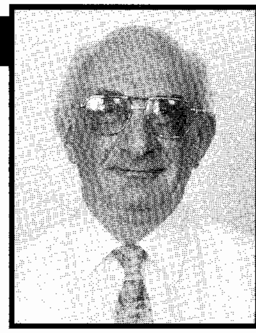
A considerable portion of the Israeli mountains in the Negev, Judea and Galilee consists of Upper Cretaceous units. It is that geological period which hosted one of the main anoxic events in the geological sequence. Only in recent years have our geologists started to realize the significance of oilshale bodies located underground. The proven and estimated reserves are very significant. The oil shale sequences may underlie 10-15% of the country's area. This equates to hundreds of billion of tons of organic-enriched material. Potential oil equivalent of these reserves may meet domestic energy requirements for many centuries. We still have to convince the policy makers about our findings and their implications.

Potentially negative properties of the domestic (or Israeli) oil shales, from an industrial point of view are - a low to medium organic carbon content (6-17%) and thus substantial amounts of ash generated; relatively high

(continued, page 5)

COMMENTARY

Where has All the Coal Gone?



Harry Marsh
Southern Illinois University
Carbondale, IL 62901-4324

Talk to students on a university campus and more than half will never have seen a piece of coal. But they will be familiar with natural gas (for cooking and central heating) and very familiar with petroleum (they all need wheels). Not so long ago, coal would have been in most homes as the fuel for domestic heating and cooking. Coal would also be brought into the local townships, to their gasworks, to provide town gas, or coal gas. The bituminous smoke from domestic chimneys and the sulfurous fumes from the gas-works left no doubt that coal was in town.

Today, all of this has gone. What is now happening is causing considerable worry to those who have to maintain the coal industry with its many facets. It is the old story of "out of sight - out of mind." There is growing, a subtle assumption that coal, by not being visible, has ceased to be important. There is a growing lack of awareness of the dominant use of coal in electricity production. The loud voice of the lobby, which advocates use of natural gas and petroleum in utilities, has drowned the coal voice. Or, is it that the coal voice is so quiet that it has become inaudible? The coal industry has never gotten itself organized in the same way that the petroleum, chemical and metallurgical industries became organized — each with its own professional societies and journals. Where, for example, is "The Institution of Coal Professionals," whose job it would be to promote the interests of coal and those who work with coal? It does not exist. Interests in coal are catered from within the Fuel Chemistry Division of the American Chemical Society, alongside the more numerous and powerful petroleum interests. This trend of ignoring or playing down the importance of coal has to be reversed. Coal is neither dead nor dirty these days.

Eight major educational points as regard coal, have to be made loud and clear, and repeated.

First, worldwide, about 5 Gt of coal are mined each year and contribute about 150 EJ (0.15 x 1018 Btu) or 30% of total energy needs. There is no possible replacement on the horizon for this level of usage.

Second, coal has emerged from its tempestuous adolescence of usage, dirt, danger and inefficiency, to become, in its mature adulthood, a clean and efficient fuel.

Third, coal as a solid fuel, with its inherent mineral matter and hetero-atom contents, must be combusted at locations some distance from centers of population in utilities of more modern and complex design with enhanced thermal efficiencies (and reduced carbon dioxide emissions). Hence, it will be out of sight, but should not be out of cognizance.

Fourth, we still do not know everything about coal, despite the last fifty years or so of its intense study. No one shouts the following statistic from the roof-tops, but in 1993, IEA, Coal Research, London, processed about 17,000 articles related to coal. The need for research and communication in the utilization of coal is clearly evident.

Fifth, coal research must continue to be funded, not only to advance the clean and efficient use of coal, but also to train the on-going supply of coal technologists who must understand coal in all its variations of rank, quality and supply. Research grants to study coal, hopefully, will do just that, but there is a spin-off, not often commented upon. It is that the research student is quite likely to continue his career with coal, so providing and maintaining the body of Coal Professionals, and so ensuring that there is a voice, loud and clear, to proclaim the indispensability of coal. In a country such as the United States, which is moving about 1 Gt (1 x 109) of coal annually, surely, there has to be someone out there who understands coal.

(continued, page 6)

Role of Oil Shale, (continued)

moisture (~20%); significant carbonate content (45-70% calcite) and a relatively high sulfur content. However, a positive and crucial point to be considered is the very low mining costs estimated for some of the deposits.

RESEARCH

The energy crisis brought about by the 1973 oil embargo served to focus attention on domestic oil shale research. Energy-related activities since then include: a producing 12 MW combustion plant; an active research center (in Mishor Rotem); an experimental oil shale retorting unit; and initiating construction on a 75 MW power station (Figure 2). It is speculated that by the year 2000, some 22% of the alternative & indigenous domestic energy production will be from oil shales. One almost certain outcome of wide-scale oil shale mining and processing will be the development and utilization of bituminous phosphorite deposits which are associated with the oil shales. In certain locales, these deposits are both high grade and extensive.

There is still a great amount of applied research which needs to be done on our oil shale resources, especially concerning their distribution, processing behavior and grade. There are indications of bituminous sequences from boreholes which were never examined for energy content, such as the recent finding in the Kineret (Sea of Galilee) basin. The many items serving as candidates for future research include the organic fractions of various beds, where the oil which was supposed to be generated in deep basins, hides the oil shale's role in the hydrological systems; and other scientific and technological aspects. Further plans for oil shale research and for utilization include: combustion, retorting, cement production, paving asphalts, light-weight construction materials, ash utilization and bituminous phosphorites beneficiation.

Remarkable reserves of oil shales are located in neighboring countries, especially Jordan and Syria. Similarities between most of those deposits and the Israeli material are indicated by correlative sequences, the pattern of organic matter distribution, and mineral matter/trace element composition, etc. On the other hand, in some deposits there are differences in the inorganic mineralogy and certain physical properties. Because of the mutual interest in the regional deposits, oil shale research could serve as a basis for improved relations and

(continued, page 6)

Commentary, (continued)

Sixth, coal is a material of ever-changing properties as mines and seams are exploited. Coal is an international traveler, but some coals do really suffer from travel sickness and do not arrive at their destination ports in good condition. These are examples of tasks for "The Institution of Coal Professionals" in order to provide agreed and unified policies and targets, for the funding of coal research, to centers of political and fiscal control within nations. The words "agreed" and "unified" are easily included in a script, but the realization, in the world out there, is another matter.

Seventh, there is a voice in the wilderness asking, even pleading, to know the necessity of cleaning flue gas emissions to the proposed extremely low levels. The voice is pointing to other health problems within the nation which exceed, by factors of tens of millions, problems, if any, created by today's best stack emission levels. Food for thought?

Eighth, optimistically, I can see "The Institution of Coal Professionals" creating working committees made up of researchers, academics, industrialists, economists, and environmentalists with the interesting possibility of political attendance. This concept deserves to be explored with professional insight and in the not too distant future, made a reality.

Role of Oil Shale, (continued)

cooperation between various nations of the region.

Tsevi Minster has held various positions at the Geological Survey of Israel since 1973.

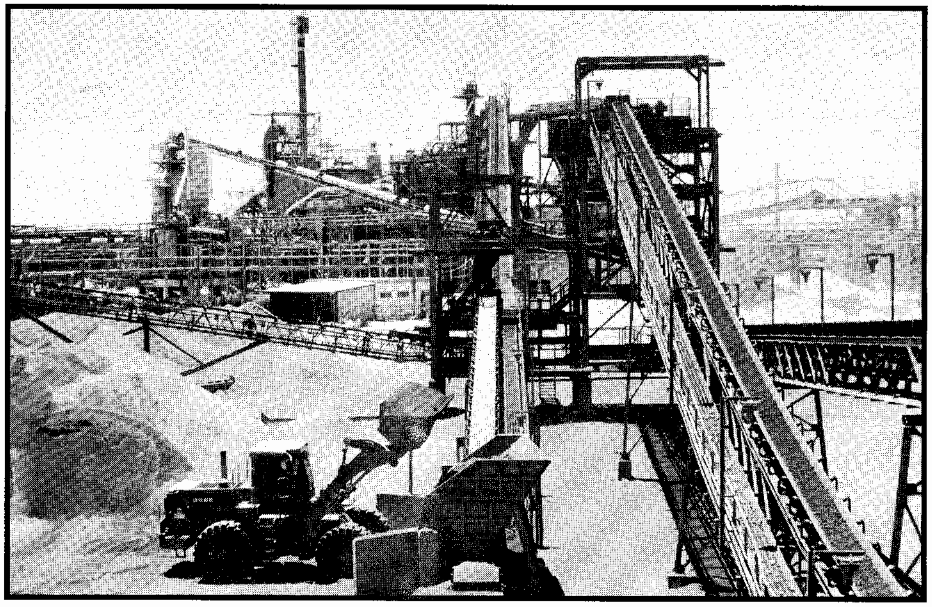


Figure 2. *12MW Demonstration Power Station*

Energeia is published six times a year by the University of Kentucky's Center for Applied Energy Research (CAER). The publication features aspects of energy resource development and environmentally related topics. Subscriptions are free and may be requested as follows: Marybeth McAlister, Editor of **Energeia,** CAER, 3572 Iron Works Pike, University of Kentucky, Lexington, KY 40511-8433, (606) 257-0224, FAX: 606-257-0302,

UK UNIVERSITY OF KENTUCKY

Center for Applied Energy Research
3572 Iron Works Pike
University of Kentucky
Lexington, Kentucky 40511-8433