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RECOMMENDATIONS FOR THE STUDY AND APPRAISAL OF OIL-SHALE DEPOSITS IN JORDAN

by

Vernon E. Swanson
U. S. Geological Survey

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RECOMMENDATIONS FOR THE STUDY AND APPRAISAL OF OIL SHALE DEPOSITS IN JORDAN[1/]

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ABSTRACT

A geologic-geochemical evaluation conducted October 5-24, 1968, both in the field area and in the laboratories has shown the Upper Cretaceous oil shale in the El Lajjun area of central Jordan to be one of Jordan's major natural mineral resources. Continued but slightly modified investigations are strongly recommended to determine the exact volume and quality of this oil shale. Further, a study to determine the most efficient processes of extraction of the oil and possible co-products should be initiated.

The economic potential of the oil shale is excellent, but the actual exploitation of this rock will depend on national economic and political factors that cannot be interpreted at this time. From a realistic point of view, regardless of these factors which inevitably change with time, systematic investigations and planning for construction of extraction plants for domestic production of fuel and/or other products from the oil shale should be completed at the earliest possible date, to assure rapid utilization of this mineral resource when necessary.

1/ Data in this report are as of 1969, when this report was prepared.

INTRODUCTION

The Natural Resources Authority (NRA) of Jordan has undertaken a program of exploration of the El Lajjun oil shale deposits in central Jordan, about 20 km east-northeast of Al Karak (fig. 1). At the invitation of the NRA, I visited Jordan from October 5 to 24, 1968, as a U. S. Geological Survey advisor, under the sponsorship of the Agency for International Development (USAID), U. S. Department of State, and the Government of Jordan, to evaluate this resource. Objectives of the study were 1) to evaluate the adequacy of the current NRA program in determining the quantity and quality of the "bituminous marl" deposits of the Karak region; 2) determine the potential economic value of these deposits; 3) specifically, provide guidance and recommendations for future field and laboratory work, and 4) advise on the need and practicality of planning a plant for oil extraction.

The speed with which knowledge of NRA's existing program was presented, and the full cooperation and stimulating discussions with key NRA personnel provided a firm basis for initiating the requested appraisal of the program. I found that a well-organized and expansive program was well underway, a program that obviously was carefully planned by deeply motivated and highly competent people, both in the NRA and in the United Nations (UN) advisory groups in Amman, Jordan. In light of current knowledge, however, aspects of the present oil shale program require certain changes and additions.

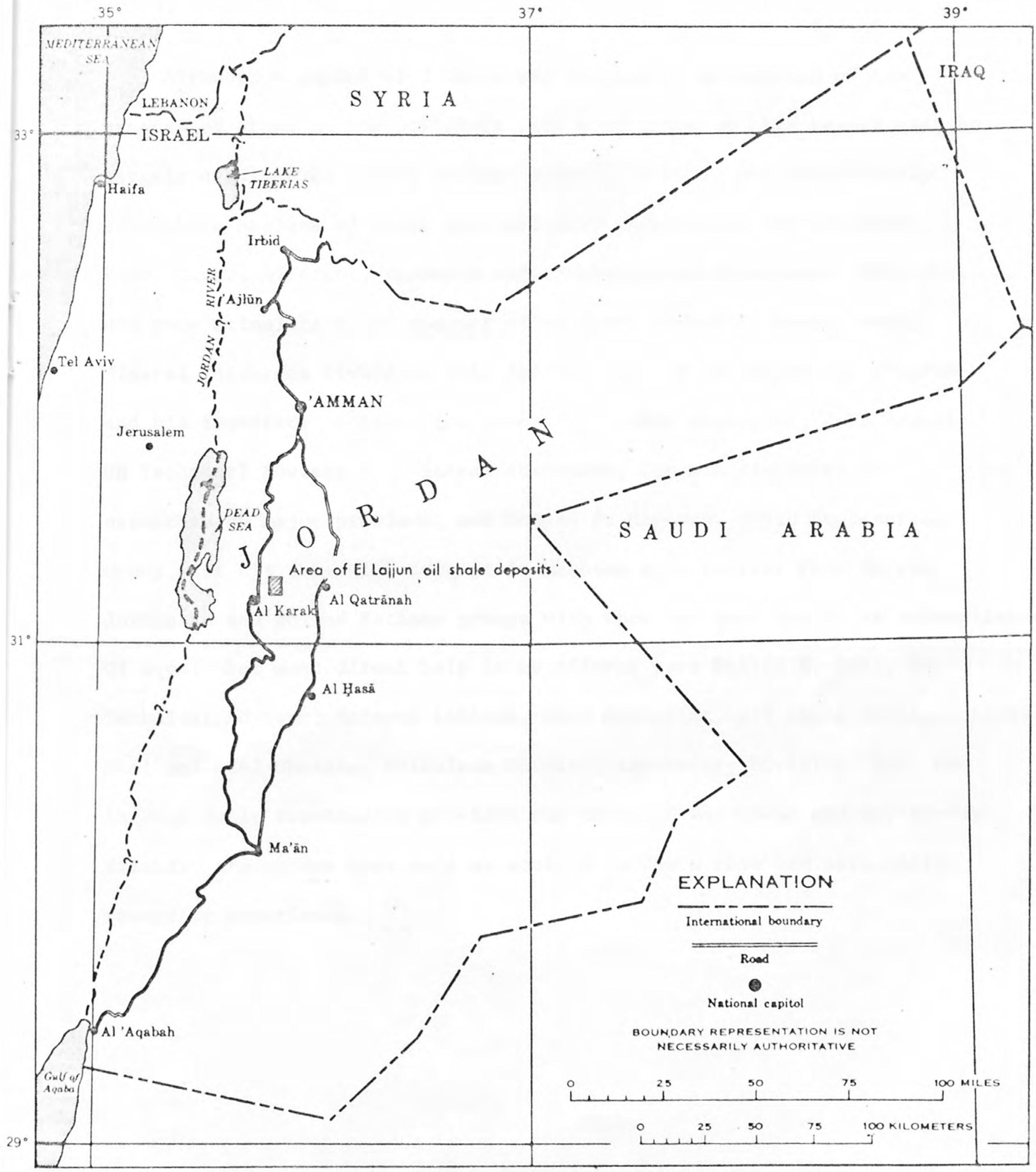

Figure 1.—Map of the Hashemite Kingdom of Jordan showing approximate position of El Lajjun oil shale deposits

Although a period of 3 weeks was devoted to evaluation of the program of study on the oil shale, any real value of this report must be largely credited to others besides myself. Several are specifically cited here because of their extraordinary cooperation and interest: Kamel Kawar, Director, Research and Investigation Department, NRA, for his rare stimulation and support of my task; Yousef F. Nimry, Head, Mineral Resources Division, NRA, for his concise review of the program and his immediate coordination to meet logistic needs; Dr. John Bennett, UN Technical Advisor for Mineral Resources, for his adeptness in focussing attention on major problems; and Howard F. Haworth, USAID Engineering Group, for his congenial support in meshing my potential role in the Jordanian and United Nations groups with whom the work was to be accomplished. Of equal but more direct help in my efforts were Philip K. Hall, UN Technical Advisor; Mahmoud Lahloub, Head Geologist, oil shale investigations, NRA; and Adel Ghashim, Petroleum Chemist, Laboratory Division, NRA, who through daily association provided the detailed knowledge and day-to-day friendly atmosphere that made my work in Jordan a rare and personally rewarding experience.

It is felt that the existing oil shale program should now be carefully reviewed and revised. The program should be revised, not only on the basis of recommendations contained in this report, but also in light of previously unanticipated rates of progress of field groups (geologists, surveyors, and drilling crews) and in the full recognition that a variety of abundant and accurate laboratory analytical information must be made available as soon as possible.

The items concerning the oil shale field operation that, in my opinion, should be incorporated into the revised program are summarized below. It should be clearly understood, however, that these are but a few specific major items, and are not intended to encompass the many minor items that should be included in the new program.

The general stratigraphic and structural setting of the Upper Cretaceous oil shale deposits is described in two reports, only one of which (Burdon, 1959) was available prior to and during my visit to Jordan. Burdon (1959) accompanies and explains Quennell's (1953) three sheets of the geologic map of Jordan east of the rift. The second report (Bender, 1968), though not available in October 1968, was prepared under the sponsorship of a Federal Republic of Germany foreign aid program. Oil shale deposits stratigraphically equivalent to those in the El Lajjun area on the west bank of the Jordan River are briefly described by Nir (1960).

GEOLOGIC INVESTIGATIONS

The work of the geology group should be modified to accomplish the necessary objectives of the oil shale program in the most efficient manner. In short, their objectives should be clearly stated to: 1) Produce geologic maps that portray the most precise data obtainable, and maps from which reliable estimates of oil shale reserves can be made. 2) Produce quantitative estimates of tons of oil shale in potential mining areas. 3) Produce factual information that unequivocably confirms the assumption that the El Lajjun area is the "best area" to begin mining. 4) Make reconnaissance geologic studies to determine other areas of oil shale that should be tested. 5) Provide clear guides--key stratigraphic and structural data--through which mining problems, and other economic problems can be resolved.

In order to attain these objectives, it is recommended that the program described below be adopted immediately.

Geologic mapping

1. Use the 1:10,000-scale topographic base map, modified and enlarged from the pre-existing topographic map. Simultaneously, use the 1:25,000-scale aerial photographs (or preferably 1:10,000 if photo negatives and enlargement facilities are available), with field stereoscopes.

2. Plot on base map the existing plane-table data, but further plane-table mapping should be temporarily recessed (see below).

3. Begin systematic geologic mapping of the El Lajjun area (24 sq km).

3. (Continued)

A. Contacts as indicated on figure 2 between "Plateau gravel" and underlying units, between the B3-B2, B2b-B2a, and the wadi alluvium should be mapped, and, wherever feasible, the contact between the B3 "chalky-marl" and "oil shale" units should be mapped. Three categories of quality of contacts should be used: 1) Precisely located; 2) location good to fair; 3) location poor, crude estimate only. These should be adopted, and consistently used, from sketching the contacts on the photographs to actual drafting the contacts on the map to be finally published. More specifically the three categories might be based on the following: 1) Contacts known to be located accurately within 1 m vertical distance should be plotted as solid lines. 2) Contacts estimated to be within 3 m of true position should be plotted as long dashed line. 3) Contacts so imprecisely located that they may be 3 m or more from their true position should be plotted as short dashes, and these dashes farther apart than in the long dashed lines.

B. Show on map by conventional symbols the strike and dip of all faults and of exposed stratigraphic units. Numerous bedding attitudes should be recorded and plotted on the "base map" by the geologist concurrently with the mapping. This not only applies most importantly to faults, but also to the seemingly minor flexures (4° to 10° dips) in the Lajjun area. These readings will: 1) Bring to light and clarify problems that can only be solved in the field; 2) be of immediate use in assisting the drilling program in spotting areas to be drilled, and reliably estimating thickness of the oil shale unit to be cored; 3) be of great use in

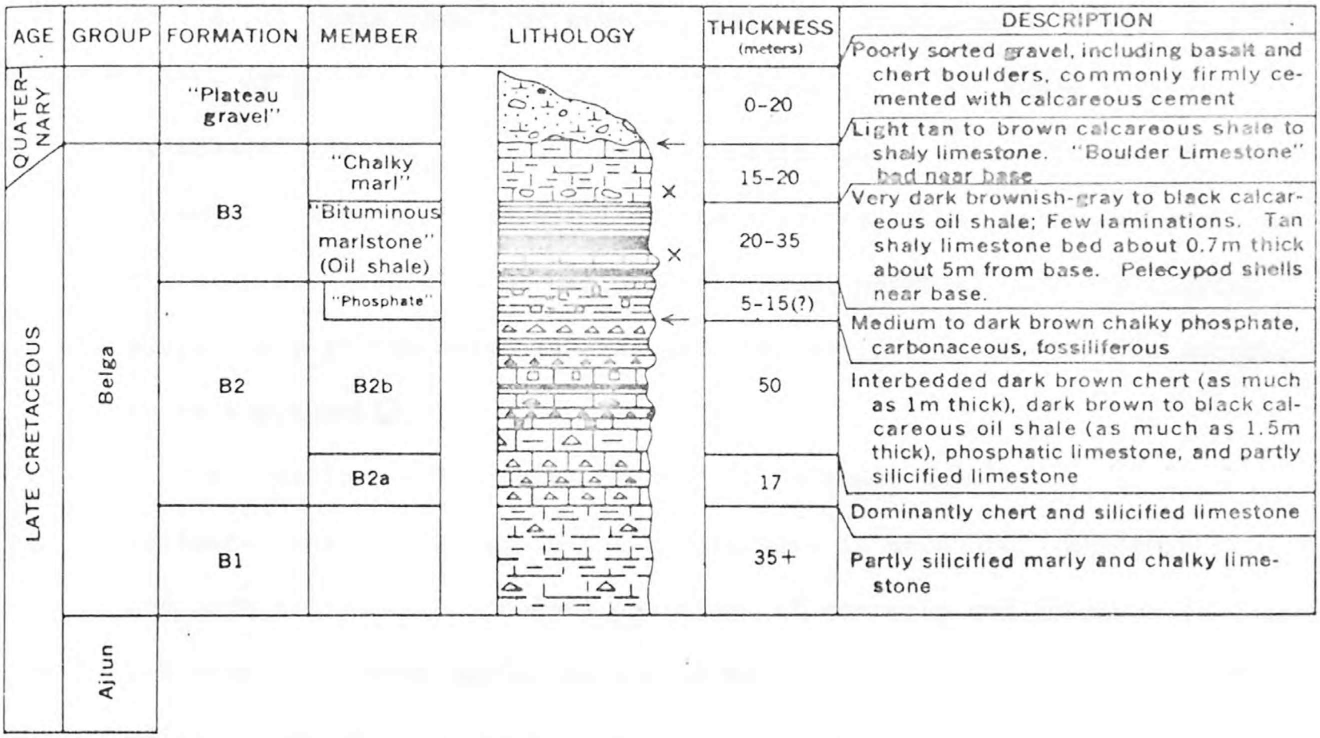

Figure 2.—Stratigraphic classification and nomenclature used in El Lajjun area. The entire B3 unit, which includes the oil shale, and the upper phosphatic unit of the B2b weather to a light yellowish tan. Arrows on right side of lithology column indicate the only generally mappable horizons in the sequence; X indicates units that can rarely be distinguished on sloping outcrop surfaces. [*Note on drilling*: "Plateau gravel" very difficult to drill, and is generally penetrated by percussion drill; "Chalky marl" penetrated using rotary bits; oil shale and upper few meters of B2b phosphate unit are cored (15 such cores, averaging 95 percent recovery, completed as of October 29, 1968); based on recommendations October 13, 1968, two holes were being drilled using alternating rotary and coring bits to penetrate entire B2 unit for general stratigraphic and oil shale data]

determining directions and geometric changes in thinning and thickening of the oil shale body (for example, thinning by non-deposition, or onlap); (4) be of greatest value when precise tonnages of oil shale reserves are calculated (for example, a dip of 4° could indicate that if the oil shale is only 10 feet thick at one locality as a result of Quaternary erosion, the oil shale could be of maximum thickness, under an opposite-dipping slope, only 1/2 km away, instead of 2 km away if the strata were assumed to be horizontal).

4. Measure thicknesses of units with Abney hand-level, or by best estimate, wherever possible and record data in notebook. Wherever possible, and especially where accurate positions of contacts are observed or where reasonably reliable estimates can be made, thicknesses of stratigraphic units should be recorded by a pinpoint on the map or photograph, and a number keyed to thickness data in the field notebook, at the same time mapping is being undertaken. This suggestion applies particularly to indicating the thickness of the Pleistocene "Plateau gravel," though thicknesses of the limestone bed down in the oil shale unit, or thickness of the interval between the upper conspicuous B2 chert bed and the base of the oil shale unit can in places be estimated with a fair degree of accuracy. These thickness data obtained either by using a simple hand level, or even by "eye-balling," will be of comparable importance, as listed above. An additional but subtle result of this close attention to thickness data is that the geologist will soon find he has become much more adept at estimating positions of contacts in areas covered with surface debris, resulting in increasing efficiency and rate of mapping.

Preparation of isopach maps

Isopach maps showing the thickness of specified units will be useful in interpreting the geology, and should be constructed as follows:

1. On copies of the topographic base map, plot "control points" and immediately begin drawing isopach maps to show thickness of "Plateau gravel" and of the B3 oil shale unit. As more data become available, bring maps up to date (during bad weather, or at least once a month).

2. Utilize the invaluable bore-hole data, and the field thickness data indicated above.

This is a relatively minor point, but I suspect that some thinning of the oil shale unit could be simply reflections of bioherms in the B2 unit that occur only a few tens of feet below the oil shale. In this connection, I confess that the bedding in these bioherms misled me in the field, where I initially assumed this bedding to indicate regional structures or flexures; thus, a word of caution to differentiate biohermic bedding from "true" bedding might be in order.

Designation of strip-mine areas

Using the geologic and isopach maps, the best strip-mine areas should be outlined; all factors, such as total volume of oil shale, least thickness of overburden, depth of weathering should be considered; oil-yield <u>and</u> quality-of-oil data should be plotted as they become available in the near future.

Strip-mine areas so designated should then be mapped in detail.

A new topographic map of each area at scale of 1:5,000 should be prepared by the surveying group.

Geologists should then plane-table in the geology in detail, following procedures outlined (for example, on mapping contacts and obtaining structural data).

Areas where strip-mining should not be attempted because of depth of weathering, excess overburden, and low oil yield, should also be clearly defined.

Reconnaissance of other large areas

Concurrently with the geologic mapping and preparation of isopach maps, about 20 percent of the geologist group's time should be devoted to searching for other large areas of possibly "better" oil-shale, particularly in known B3 areas to the east and south (20-70 km). It should be noted here that a broad V-shaped area immediately south of the present El Lajjun area was evaluated in the field on October 23, 1968, when three reconnaissance-drilling sites were approximately located.

One drill rig should be made available to test new areas. A geologist should pick the drill site, log in the cuttings, and based on his judgement, be authorized to call for coring as needed.

"Standard sample"

A very large amount of oil shale having a bituminous content slightly above average was collected from the "freshest," most unweathered part of the Wadi Arbid outcrop. It was collected from a unit exactly 1 m thick, and accurately measured stratigraphically (distance from top of oil shale, and distance above limestone bed). A sample of about 750 pounds was collected. This "standard sample" can be used in many ways; for example, as a reference to check oil-yield results, trace metal analyses, and to furnish material to send to other laboratories for their analysis (with the understanding that the analytical results they obtain be made available). Care should be taken to use proper methods of grinding, splitting, and storage. Analyses recommended are described on page 12.

LABORATORY OPERATION

Equipment and methods

The role and contribution of the laboratory operation to the oil shale investigations, like those of the field operation, have largely been circumscribed and limited by the rapid expansion of facilities and the need for obtaining personnel qualified to undertake highly specialized analyses. The major existing "bottleneck" in the entire oil shale program, however, is without doubt the lack of precise chemical analytical data. This gap, or "bottleneck," was recognized and some steps taken to overcome this major deficiency before I arrived in Jordan.

To date, the analyses of the oil shale consist of oil yields obtained by retorts of a very crude design, and of oil yields obtained by analytically precise organic-solvent extractions. Under currently known and proven methods, however, only the retort that volatilizes the fuel components on heating can be considered as equipment that can produce oil at near-economic rates. Therefore, well-designed laboratory retort equipment that will provide quantitatively reproducible oil-gas-water yields must be employed to provide the information required to judge the potential commercial value of a large volume of oil shale. In the absence of such equipment, no more analyses should be run using the old retorts, and it is also recommended that, with the exception of four samples as specified below, solvent-extraction analyses also should be terminated.

Rock analyses

Rock analyses for major compounds (e.g. SiO_2, CaO, etc.) should be made on four samples, and all subsequent analvses listed below can then be compared to these four rather lengthy and expensive analyses. The four samples should be selected in consultation with Mr. Lahloub and Mr. Hall, but should include: (1) The "standard sample" from Wadi Arbid. (2) A sample from the interval 5 to 10 feet from the top of a core which should be selected from a representative core from the Lajjun area. (3) A sample of the "limestone nodule bed," which is typically two-thirds of the distance stratigraphically from the top of the oil shale. (4) A sample from an interval 5 to 10 feet above the base of the B3 oil shale unit, from the same core indicated above from which sample 2 is to be selected.

In connection with running these "whole rock" analyses, two to five thin sections should be prepared for each sample for study of mineral-organic-chemical relations by the core geologist. The sections should be cut normal to the bedding, but one or two sections should be cut parallel to the bedding for identification of amount and type of clay minerals present.

Organic analyses of the four samples should include: (1) Percent organic carbon (percent loss on ignition, minus the percent CO_3-carbon loss by HCL treatment, equals percent organic carbon). (2) Percent bitumen removed by the single organic solvent, benzene, using Soxhlet apparatus. (3) Percent bitumen removed by the mixed-organic solvent methanol-acetone-benzene, in 50:25:25 mixture (this mixture is becoming the standard or most commonly used mixed solvent in similar organic geochemical studies). (4) "Ultimate analyses;" I understand that equipment is either ordered, or available, but the validity of the C, H, O, N, and S data obtained in this type of analysis on sediment containing more than 20 percent ash, as does the Lajjun oil shale, would be questioned not only by me, but others working in the field of organic geochemistry. The reasons why the data obtained by this method are questionable are that "bound water" or the H_2O tightly held, for example, in clay minerals, is difficult to remove entirely without volatilizing and losing organic molecules containing carbon, hydrogen, and oxygen; similarly, even small amounts of nitrite or nitrate make the nitrogen data questionable (the Kjeldahl-nitrogen method is much more reliable if organic nitrogen values are needed, which I doubt at this stage of the investigation, even though "by-product" ammonia from retorted oil shale has been cited in many early studies). A final, but possibly pertinent, statement can be made here relative to chemical separation of the organic matter prior to making an ultimate analysis--for most oils shales, the separation methods, using HC plus HF, or flotation methods using kerosene, have provided organic matter that may or <u>may not</u> have the composition of the "real" organic matter in the rock, and again data resulting from much time and effort by the chemist is of questionable value.

The analysis produced by the so-called "Modified Fischer Oil Assay" retort equipment is currently and internationally accepted to determine the exact amount of oil that can be produced from crushed oil shale.

Purchase of this equipment is imperative, and, at the earliest possible date, a "bank" of a minimum of four Fischer retorts should be installed and put into immediate use. The main reasons why the Fischer equipment is best are that it gives accurate reproducible results, the assay time is short (about 2 hours), and it is actually a laboratory bench-model of the retort which might be used in a large oil-producing plant.

A major point needs to be emphasized when the Fischer method is adopted. Though the standard procedure for the Fischer analysis should be followed when the equipment is first received (for example, mesh size and rate of temperature rise), I strongly recommend that one chemist be given time to experiment and modify the standard procedure to determine the optimum conditions that will produce the <u>most oil of the highest quality</u> from the Lajjun rock. The Lajjun rock is unique in that it yields exceptionally large amounts of "bitumen" under solvent extraction methods. Consequently, I would expect the same "bitumen" to be released at relatively low temperatures in the Fischer retort; in other words, too rapid a rise of temperature of the retort could result in formation of more complex hydrocarbon and asphaltic compounds of poorer quality. In summary, time should be allotted for experimentation with the modified Fischer method, in conjunction with the procedures described for oil analysis below, that will ultimately produce the highest percent of high-quality oil from the Lajjun oil shale; much more useful data on "Lajjun oil" will become available.

In the event that the Fischer retorts cannot be obtained and put into operation for several months, quarter-sections of several representative cores should be shipped to qualified commercial laboratories as soon as possible for modified-Fischer oil assays. Only after these assays are in hand can the potential value of the oil shale be known, and the expansion or slowing down of the oil shale program be decided.

Meanwhile, chemical investigation can and definitely should be continued while the retort and the Soxhlet extraction work is recessed. Many types of analyses on the whole rock and on the oil already extracted should be undertaken to provide, not only the data of definite importance to the chemical engineers in designing the best fuel extraction methods and equipment, but also to establish the potentially economic co-products recoverable during a commercial oil shale operation. Possible co-products may be P_2O_5, S, CaO, and even some of the transition metals, and sufficient analytical data on these materials and the form in which they occur should be obtained. This recommended interim phase of continued laboratory work in the oil shale program is as follows:

Analyses of key or potentially major commercial components of rock: (1) $CaCO_3$, which could be utilized in making of Portland-type cement after retorting of shale; thus, $CaCO_3$ or CaO content of both the whole rock, and of "spent shale" after retorting should be determined on many samples, so that the amount of $CaCO_3$ is precisely known for all the geologic sub-units of the B3 oil shale, from all the areas designated as potential mines.

(2) P_2O_5 or P analyses, which could indicate whether phosphate could be a by-product of retorting the rock for oil, with enough analyses to provide the required information indicated for $CaCO_3$. (3) S analyses, for the same reason.

Minor metal analyses

It is well known that some organic-rich rocks contain abnormally large amounts of some metals, particularly Ag, Co, Cu, Fe, Mn, Mo, Ni, Pb, V, Zn, and U, and that some black shales will be mined for several of these metals within a few decades. If any organic-rich rock is to be retorted primarily for its fuel (oil), several of these metals might be present in sufficient quantity to be valuable by-products, so a special effort is warranted at this time to determine the amounts of these "minor metals" in the Jordan oil shale. However, based on my present knowledge of the type of organic matter in this rock, I believe that only Ni and V, and possibly Cu, will be present in amounts that will be of potential economic interest (boron may be present in large amounts, but boron is not in the class of "minor metals").

This conjecture on metals in the oil shale is based primarily on the very small amount of soluble humic matter in the bituminous marlstone, less than 1 percent as determined in the laboratory, and on the relatively large amounts of "bitumen" extracted by organic solvénts by Soxhlet apparatus. At any rate, minor metal analyses should be run, as a first phase, on samples cited above, and on selected "spent shale" samples: (1) Atomic absorption analyses, for as many metals as tubes are available (purchase of additional tubes for other metals for use on the oil shale should be postponed until their purchase can be justified by the results of other analyses). (2) Emission spectrographic analyses are the most rapidly obtained for "semiquantitative" and quantitative analyses (again, purchase of this expensive instrument is not justified for use on the oil shale alone); for the present, these metal analyses can be obtained by submitting samples to other laboratories (spectrographic analyses on the samples I have collected will be sent as soon as they are completed). (3) "Wet" chemical methods or colormetric methods very likely can be run for some of the metals, utilizing equipment and reagents now available in your laboratory.

The existing retort and solvent-extraction analyses, however, should by no means be discounted as completely worthless. The retort analyses can be used as crude approximations of potential oil yield of the oil shale; first, they clearly prove that "shale oil" can be extracted from the rock, and, secondly, the values reported, if a plus-or-minus 20 or 50 percent error is assumed, do provide the basis for a semiquantitative evaluation of possible differences in oil yield from area to area or from different stratigraphic subunits within the oil shale.

The organic-solvent extraction analyses, too, are significant, particularly as the reported values indicate that a remarkably high percentage of "oil" or bitumen (ranging from 2 to as much as 13.7 percent) can be extracted by the relatively non-polar solvent, benzene. In addition, two rapid analyses were run in the laboratory October 13-16, 1968, and the amount of soluble humic organic matter in the shale was determined to be less than 1 percent. These determinations definitely suggest that the oil shale will have a high yield of the more valuable saturated and aromatic hydrocarbons. Thus, I expect that the quality of oil that can be extracted from the shale under carefully controlled temperatures will be exceptionally good. Nevertheless, the limited and very valuable core samples should not be analyzed using the presently available retorts, and ample solvent-extraction analyses are now in hand for later pertinent evaluation of the oil shale.

Analyses of the oil

This subject, and recommendations on same, could be much better discussed by a petroleum chemist or an organic chemist. However, from the organic geochemist's point of view, and in making an evaluation of the type of shale oil produced, several types of analysis should be made available.

Of basic importance, of course, are the following determinations, which I assume will be made on many samples of the retorted oil, and which will not be discussed further: 1) API gravity. 2) Abbé refractometer determination. 3) Standard distillation analyses under prescribed ASTM temperature and pressure requirements. 4) Calorimeter determinations. 5) Viscosity and pour-point data. These, and other analyses might be run on the oils extracted by organic solvents, but from point of view of producing oil by retorting, the results would be mostly of academic interest.

Under the present circumstances, four analytical procedures can be followed that will provide very useful and significant data in determining the quality of the "shale oil": 1) Silica-gel column chromatographic analysis, which can serve as a general, simple method of fractionating the oil into three major groups of "fuel" compounds, namely (a) saturated hydrocarbons (paraffinic and napthenic hydrocarbons), (b) aromatic hydrocarbons and (c) asphaltic compounds. 2) Determination of percent S in oil. 3) Determination of percent ash in oil, by ignition in pre-weighed crucible. 4) Determination of composition of ash of oil, especially of trace metals listed previously.

Except for very general information purposes, or as material to experiment with until the Fischer retorted oil becomes available, I recommend that the oil in the two large bottles now in hand not be used in the analyses listed above, as these oils represent such complex "mixtures" that the analytical results would be next to meaningless in evaluating the kind and quality of oil.

At some future date, when the demand for high-level, detailed research and precise evaluation of organic compounds warrants the high costs of the instruments, infrared analysis and gas-liquid chromatographic analysis should be undertaken. The infrared instrument is in the $3,000-$18,000 range, and the gas-liquid-chromatograph is in the $5,000-$12,000 range; both require competent, well-trained people to operate and interpret the data these instruments produce. Certainly, at this stage of the investigation of the oil shale, IR and GLC analyses can be obtained from commercial laboratories if previously outlined analyses in your laboratories show that these more sophisticated types of analytical information would be useful. I must also add that $C^{13}/C^{12}/S^{34}/S^{32}$, and other isotope analyses will be of great value to those interested in the genesis of the rock (environments of depositions, source of the main types of unidentifiable organic material, etc.), but the required mass spectrograph is in the $60,000-$100,000 range.

Sampling handling, grinding, splitting, and storage

Although the handling of the oil shale samples in your laboratory was not reviewed in detail, two basic precautions should be rigidly followed. The first is to avoid air oxidation of sample material by every means possible; for example, analysis of a sample should be made as soon as possible after receipt of sample, and ground and split samples should be kept in air-tight screw-cap glass jars or vials. Volatilization and re-complexing of organic compounds, particularly in the Lajjun rock, will be rapid, and accurate reproducible analyses will involve constant efforts to minimize these changes. The second precaution should be to avoid contamination, whether by frequent handling of cores by sweaty hands, by careless cleaning of grinding and sample-splitting equipment (high-pressure air hoses should be added as standard equipment in the grinding room), by use of filter papers of high cellulose content (glass filter papers are only slightly more expensive), or by use of dusty, nonsterile laboratory glassware and other equipment. All these should be carefully checked in the laboratory operation to avoid contamination and consequent inaccurate, nonreproducible analytical results.

POTENTIAL ECONOMIC VALUE OF THE OIL SHALE

Oil shale is at present one of the known valuable mineral resources in Jordan, phosphate and limestone construction materials also being important nonmetallics. Important deposits of potash, copper, and manganese are known in western Jordan and an area in northwest Jordan is known to contain oil shale. Thus, a complete and thorough evaluation of the oil shale resources in Jordan is clearly warranted and firmly recommended.

The present oil shale investigations are limited to the El Lajjun area of 24 sq km in central Jordan, about 20 km east-northeast of Al Karak. Geologic mapping and drilling indicate that about 7 sq km of this area is underlain by 18 to 42 m of oil shale, averaging about 30 m in thickness. The oil yield of this shale, based on the imprecise retort analyses of four cores, has an approximate range of 80 to 200 liters per metric ton of rock (or the average expected oil yield would be in the range of 30 to 40 gallons of oil per short ton of rock).

In my evaluation, the above data clearly indicate that Jordan has a major resource of fuel in oil shale. If one or two more oil shale areas of comparable size can be located and delimited within about 30 km of the El Lajjun deposit, the potential source of fuel in central Jordan would place this region in the class of some of the other major oil shale deposits of the world. Certainly, there are much larger and richer deposits in other countries, but with the probable exceptions of Manchuria and Brazil, most of these countries have sizeable reserves of petroleum that, under present economic conditions, negate their reliance on "shale oil" as a source of fuel.

The precise economic and political factors that will determine the day when Jordan (or any other country) will begin mining and exploiting her oil shale are beyond my competence to judge except in a most general way. As a geologist-geochemist, however, I will firmly state that whether that day is 2 years or 30 years hence, it behooves the government agencies responsible for mineral resources to undertake a complete program to determine exactly the tons of shale and the barrels of oil that can be derived from their country's oil shale deposits.

Also, as a geologist, I must emphasize the fact that no country should appraise its minerals potential in terms of single products (for example, only copper from a copper mine); the forward-looking country should, and will have to, appraise its deposits as multi-product resources. With rapidly improving techniques of mining, metallurgical and extractive processes, and plant construction, coupled with the rapidly expanding use of non-renewable mineral resources, a change to exploration and exploitation of multi-product resources is inevitable, and will be widely adopted within the very near future.

Consequently, it is strongly recommended that Jordan conscientiously explore all possible co-products in its possible utilization of the oil shale as fuel, for example capturing LGP (liquid-gas products) that can be piped or "bottled;" separation of high-quality hydrocarbons for gasoline and lubricant production; production of sulfur to meet the critical demand for industrial sulfuric acid and fertilizer sulfur; production of asphalt for road construction; production of phosphate (by mining the phosphatic rock immediately underlying the oil shale) and recovery of rare earth elements and uranium commonly associated with phosphate; recovery of CaO for cement manufacture; recovery of metals such as Cu, Mo, Ni, and V which, though probably present in amounts of 0.01-0.1 percent, represents thousands of tons of metals in the millions of tons of shale to process.

With these guidelines in mind, several major unfavorable factors also should be fully considered in any plan to exploit Jordan's oil shale deposits as a source of fuel. (1) The initial capital outlay required to construct a plant and its mine is extremely high--it should be reckoned in terms of 100,000,000 JD (Jordan dinar). (2) Most plants now in existence or planned in other countries, with their associated communities, require a vast supply of processing and potable water--a supply that is almost negligible in the Karak-Quatrana region. (3) If the fuel is to be used primarily for production of electrical energy, it is highly probable that a nuclear power plant would be far less costly than a "shale-oil" fired plant.

Assuming that a decision is made to proceed to exploit the oil shale, two additional ideas are submitted as worthy of study. First, if a geographically suitable low-grade source of fuel is required in central Jordan, the most significant factor will be to devise the lowest-cost production of the fuel. In its natural form, much of the oil shale can be ignited to provide heat (and much dark odorous smoke); near unweathered outcrops the Bedouins use the shale for this purpose to heat water. However, I believe that some low-cost processing method will have to be devised to greatly increase the BTU or calorific value of the oil shale. Considering that the major inorganic constituent of the oil shale is calcite ($CaCO_3$), which makes up 35 to 60 percent of the rock as indicated by meager analytical information, a process requiring minimal crushing of the rock and partial leaching with low-cost industrial-grade hydrochloric acid might reduce the "ash content" to a level where the shale could be used to fire a steam-electrical plant. (Some lignite-fired plants are known to operate competitively using 20-30 percent ash lignite). Certainly, the resulting dense smoke from the upgraded oil shale should be "scrubbed," and by using flue condensors, some of the previously cited co-products might be economically recoverable; the resulting CaO of the "ash" might also be of some value.

A second idea on possible utilization of the oil shale can be suggested, but is admittedly based on little knowledge of the industrial processes and capital investments involved. Conceivably, the complex mixture of carbon, hydrogen, oxygen, nitrogen, and sulfur which comprise the organic matter in the shale might be particularly well suited to the production of natural material which could supply the organic "building blocks" for industries that manufacture synthetic fibers, polymer plastics, synthetic rubber, with possible by-products of special lubricants, CO_2, and carbon-black. Such a complex industrial endeavor would necessarily mean contacting and creating the serious interest of one of several major companies.

In conclusion, the potential economic value of Jordan's oil shale deposits cannot be refuted. Regardless of the "when" or "how" this major mineral resource will be exploited is not of immediate nor of primary importance. Rather, now is the time that the extent and volume, and the qualitative and quantitative chemical character of the oil shale should be precisely and scientifically determined. Once these facts are made widely known, the utilization of this large and rich mineral commodity will automatically follow. Jordan's present basically solid program to obtain these facts should be vigorously continued and given every means of administrative and financial support.

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