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INVESTIGATIONS NEEDED TO STIMULATE THE DEVELOPMENT OF JORDAN'S MINERAL RESOURCES

by

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Abstract

The level of living that any society can attain is a direct function of the use it makes of all kinds of raw materials (soil, water, metals, nonmetals, etc.), all kinds of energy (both animate and inanimate), and all kinds of human ingenuity; and is an inverse function of the size of the population that must share the collective product. The relation between raw materials, energy and ingenuity is such that use of a large amount of one may offset the need for large amounts of others. The most vital raw materials are water, soil, and construction materials, for these are needed in large quantities and are hard to import. Metals, chemicals, and inanimate energy are necessary for industrialization. The more of these minerals a nation possesses, the better, but no nation can hope to be self-sufficient in all of them and therefore must trade for some essential materials.

Jordan's natural resources have been little explored. The granitic-metamorphic terrane in the southeastern part of the Kingdom could contain deposits of tungsten, rare earths, feldspar, mica, fluorite etc. and the sedimentary terrane over much of the rest of the country is favorable for the occurrence of oil. Even if none of these minerals are found, however, Jordan's other mineral resources, if fully explored and developed in the light of modern technology, will support a far higher level of living than her people now enjoy. Very likely she can increase her rainfall by about

1/ Report prepared in 1959.

10 percent by cloud seeding, and she has undeveloped supplies of both surface and ground water that are sufficient to nearly double her usable water supply. Even if she does not have oil or have it in large quantities, she can buy it cheaply from neighboring countries, and in addition has undeveloped sources of hydroelectric power, large reserves of bituminous limestone, large reserves of nuclear power as uranium in phosphate rock, and can use solar and wind power for special purposes. Her large supplies of construction, fertilizer, and other chemical raw materials will not only satisfy her own needs, but will yield both raw materials and some manufactured products for export. And she has valuable resources of touristic interest in the form of incomparable scenery, antiquities, and holy places, which, if properly advertised, could well become her largest single source of foreign currency. Revenue obtained from this source and from the export of agricultural products, nonmetallic minerals, and mineral products should support foreign purchase of oil, machinery, and other products not mined or produced internally.

Full development of Jordan's economic potential will take years to achieve and involves many complex activities. One of the most essential is one that can be pressed in the early years, namely the gathering of facts and basic data concerning the character, extent, and distribution of her resources, and the uses that can be made of them. Without such fundamental data or the understanding of their meaning or the ways to use and apply them, costly developmental projects and similar efforts to raise the level of living are likely to have limited success at best.

Basic data on mineral resources are best gathered and published by permanent government agencies, for private organizations and individuals cannot afford to take the risks involved in gathering data that may not have an immediate economic return; and even if private parties do collect such data they are not likely to make them generally available.

Of the activities needed in the field of mineral resources, some are already underway as the established function of government agencies. No bureau however, seems to have responsibility for making geologic maps and for gathering data on such things as stream flow, composition and properties of minerals and rocks, or for investigating the uses to which Jordan's minerals might be put. To satisfy these needs, a Geological Survey and a Bureau of Mineral Industries should be formed and placed in operation as quickly as possible.

The task of collecting and interpreting basic data or mineral resources must be done largely by Jordanians, for only in this way will Jordan acquire the technical competence needed to use the information. Few Jordanians have enough training or experience to work independently in these fields now, however, so help from outside technicians would be necessary over an initial training period of several years. But the number of outside technicians should never exceed the number of Jordanian technicians, and for this reason, neither organization could have a staff of more than a few people during the early years of operation.

Introduction

As a part of the International Cooperation Administration's technical assistance to the Hashemite Kingdom of Jordan (HKJ), the United States Operations Mission in Jordan (USOM/J) proposed in May 1958 to aid the development of Jordan's phosphate industry by exploring and mapping some of the more promising of the known deposits, and searching for additional deposits in the southern part of the Kingdom. Before embarking on this program, the International Cooperation Administration in Washington (ICA/W) asked the U. S. Geological Survey to review data already available on the phosphate deposits of Jordan, to examine the deposits in the field, and to make recommendations as to the work needed to develop the phosphate and other minerals. I was asked to make this examination and did so during the months of October and November 1958.

Although the initial emphasis was on phosphate, it became apparent early in the assignment that attention should be given also to other minerals as well. With the approval and encouragement of Mr. Ralph H. Workinger, Deputy Director, USOM/J, and Mr. Frank S. Wilson, Chief of its Industry and Commerce Division, the study was broadened to an analysis of the work needed to help stimulate development of other minerals as well as phosphate. The time available in the field was not long enough to undertake any original investigations, but it was sufficient to become familiar with each of the major kinds of geologic terranes, and to examine and discuss in the field the problems related to the development of the important mineral resources with those people most acquainted with them. Thus, I travelled by car more than 3,000 miles within the Kingdom; was able to examine all the known phosphate deposits, some of the bituminous limestones, and the Wadi Dana manganese deposit; had opportunity to review the geologic background of groundwater problems at Azraq, Irbid, the Jordan Valley, and many other areas on both the West Bank and the East Bank, including the western part of the eastern desert; and was able to see the important structures and some of the facies relations that bear on the search for petroleum in the northern and western parts of the Kingdom (fig. 1).

A draft of this report, summarizing the main conclusions and recommendations, was prepared and distributed to officials of the government of Jordan and the United States Operations Mission at the close of my stay in Jordan. This is expanded here to include a review of some of the principles of economic development, particularly as applied to Jordan; a description of the minerals that find use in an industrial society; and a fuller review of Jordan's mineral resources and the possibilities they offer for development. The approach taken to these matters perhaps deserves some advance explanation.

The principles of economic development are described in many publications, and no attempt is made to reiterate them in full here[1/]. Most accounts of the subject, however, do not discuss in much detail the part minerals play in an economy, the importance of developing

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1/One of the best analyses of the problem is that of George Hakim and others, 1951.

mineral resources for domestic use rather than for export, or the work needed to bring this about. These subjects are among the chief ones treated in this report, and some of the principles of economic development are outlined to show how and why it is important for a country to increase its consumption of mineral resources. It would be a mistake, however, to create the impression that resource development is the only measure a nation need take to raise its level of living. The other necessary measures are not discussed much in this report, but some of them are mentioned to place the main subject in proper perspective.

The approach taken to the evaluation of Jordan's potential resources is not the one practiced by most geologists and engineers representing industrial firms, for they are mainly interested, and rightly so, in minerals that can be exported at a profit, and that can be mined and processed by the methods used to treat high-grade ores. Admittedly Jordan's exportable resources are few--in fact, the Mission organized by the International Bank for Reconstruction and Development probably expressed a widely held view when it said (1957, p. 69) that "even with foreign aid, Jordan's resources cannot be developed to the point where they will provide a living even for all the present population and their children, much less for the future population as it will grow over the years." Nevertheless, if Jordan is to achieve her expressed aims of raising her level of living and reducing her financial dependence on external sources (IBRD, 1957, p. 65), she must vastly increase her consumption of raw materials and inanimate energy. This requires, in turn, that she develop her own resources to the maximum degree that modern technology permits; the criterion of interest in the development of many minerals, then, is not whether the substance can be produced for profitable export by old fashioned methods, but whether it can be produced for Jordan's use, by any known method, as cheaply as it can be obtained from foreign sources. Jordan's resource potential, therefore, is viewed here in the light of the maximum development permitted by modern technology.

This supposes, of course, that Jordan will develop advanced technical skills and acquire knowledge that she does not have now, which in turn means that it will be many years before she reaches the goals to which she aspires. Such goals cannot be attained in any other way, however, and these conditions must be accepted as prerequisites. Accepting them as such, however, and viewing Jordan's resource potential in the light of the maximum permitted by modern technology (and, with the currently rising rates of consumption everywhere, it will not be many years before the development of resources in most other areas will have to be approached in this fashion also), I believe Jordan's resources will support a moderately high level of living for a population of the present size. The reasons for this belief are discussed in the section on Jordan's mineral resource potential.

Acknowledgements

Many people gave generously of their time and knowledge in acquainting me with the geology and mineral resources of Jordan and the problems related to their development, and aided in my work in other ways. I am indebted for enlightening discussions and helpful advice to His Excellency, Sam'an Daoud, Minister of National Economy of the Hashemite Kingdom of Jordan, Dr. Hazem Nuseibeh, Under-Secretary of the Ministry of National Economy, Dr. Najm-Eddin Dajani of the HKJ Development Board, and Mr. Farid Azar, Chief, Technical Surveys Section of the Department of Lands and Surveys. Special thanks are due to Mr. Isam Khairy, geologist and Chief of the HKJ Section of Mines; Mr. Maurice Khoury, General Manager, Mr. Djordje Kolcov, mining engineer and Technical Director, and Mr. Ali Rashad Ezzeer, geologist, of the Jordan Phosphate Mines Company; Mr. Ralph Freeman and Mr. Munib Masri, petroleum geologists of the Phillips Petroleum Company; Mr. David Wozab, ground-water geologist of the FAO; Mr. Kamel Kawar, ground-water geologist of the HKJ Development Board; Mr. Leslie Riggins, ground-water geologist of the Baker-Harza Company; and Mr. J. B. Howard, sanitary engineer, and Dr. J. J. F. Rogier, Chief, Health and Sanitation Division of USOM/J, all of whom guided me on visits to one or another part of Jordan to inspect mineral deposits or problems related to them.

This study was undertaken at the instigation and under the general direction of Mr. Ralph H. Workinger, Deputy Director of the United States Operations Mission to Jordan, and Mr. Frank S. Wilson, Chief of its Industry and Commerce Division, both of whom, along with many other members of the staff of USOM/J and the United States Embassy in Amman, facilitated my efforts by providing working facilities and helpful advice and suggestions. Mr. George Nowak, Financial Advisor of USOM/J working on the Jordan Phosphate Mines Company's application for a loan from the Development Loan Fund, was expecially helpful in supplying much information concerning the costs and problems of mining and marketing phosphate in Jordan.

The final compilation of this report has benefited greatly from the constructive advice of many of my colleagues on the Geological Survey, particularly T. M. Cheney, T. E. Eakin, J. H. Feth, D. M. Lemmon, A. M. Piper, T. W. Robinson, G. L. Schoechle, H. E. Thomas, and M. E. Wing.

The relation of natural resources to level of living

If we think of level of living as the amount of goods and services we consume, this level is plainly low if the average individual has to exert much time and great physical effort to satisfy his minimum needs for food, clothing, warmth, and shelter; and the level is high if he can obtain luxuries as well as necessities at the expenditure of little time and effort. This means that the more raw materials (e.g. food, water, fibres, fuel, and materials for making tools and dwellings) easily available, the higher the level of living. It takes work, however, to gather and use these materials effectively, and over the millenia man has found many ways of getting this work done for him, and thus reducing the effort required to satisfy his needs and wants. Animate energy--slaves and domesticated animals--was captured first for this purpose, but the greatest gains have come from discovery of means to capture inanimate energy--i.e. power from wind, water, and especially fossil fuel. The most efficient way found to use inanimate energy to save labor is to use it to run a machine that will perform a service in a more exact and often faster way than a person can do it.

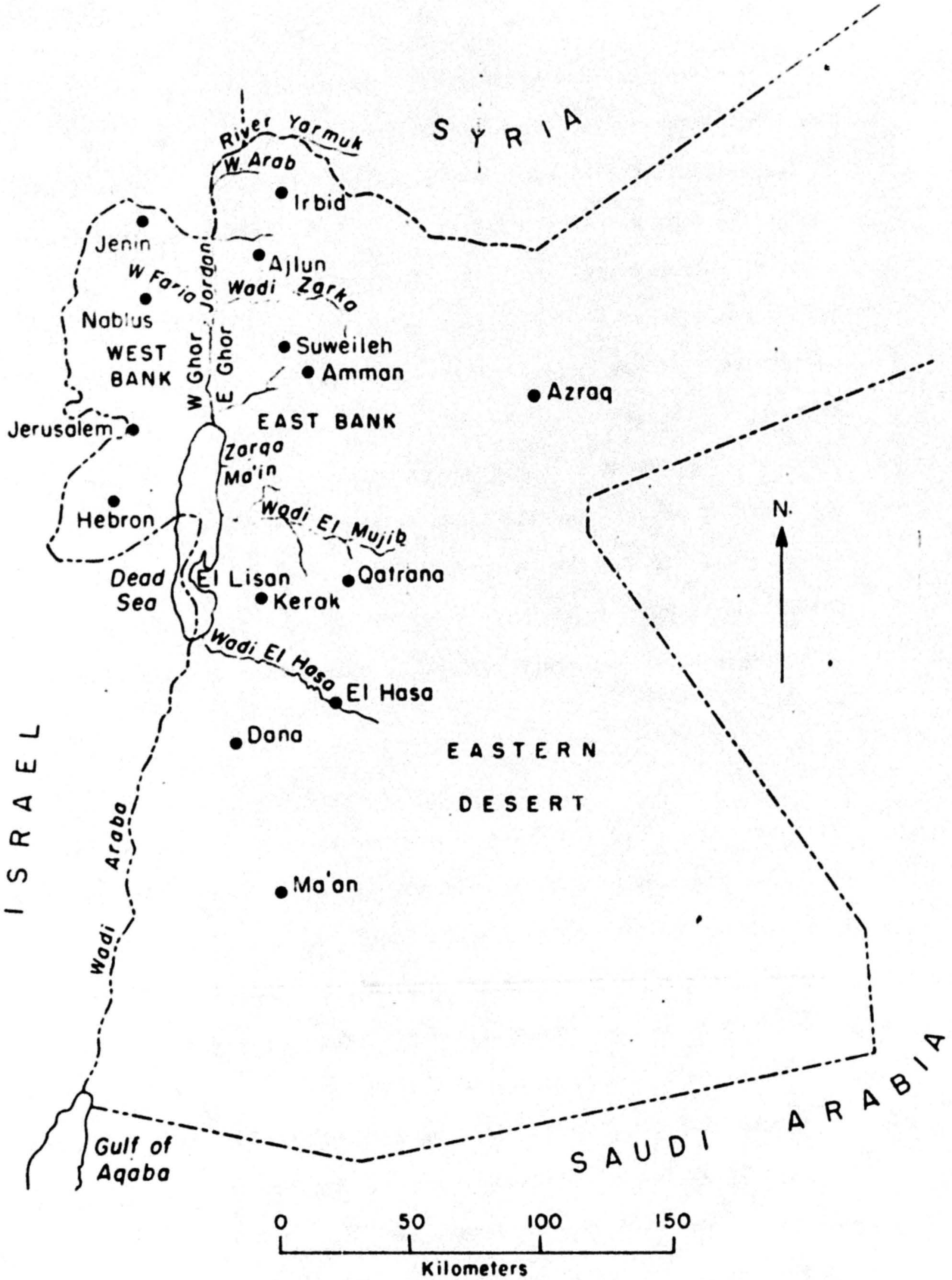

FIGURE 1.— Index map of Jordan.

The widespread use of inanimate energy and machines is, of course, the tangible basis for the high level of living--i.e. the consumption of large quantities of goods and services without much physical effort--enjoyed by many western societies today. The essence of this wealth, however, is something less tangible, namely human ingenuity, defined in the broad sense of the collective ability of a group to obtain, distribute, and use raw materials and energy efficiently. Summing all this up, we can say that a group's total consumption of goods and services is a function of the use it makes of all kinds of raw materials, all kinds of energy, and all kinds of ingenuity (McKelvey, 1959). The amount available for the individual, of course, decreases roughly with the number of people that must share the total. Expressed in the form of a simple equation, the relationship among these factors is approximately:

$$L = \frac{R \times E \times I}{P},$$

where L is the level of living of the average person, R is the total useful consumption of all kinds of raw materials by the society, E the total useful consumption of energy, I the total useful consumption of ingenuity, and P the total number of people who must share the society's product. This is an oversimplified statement, but it serves to show the general relation among the most essential factors, and it brings out another important point: the elements of wealth (i.e. R, E, and I) bear a multiplicative relation to one another, for if any of them is zero, the level of living is zero also. This means that the use of a large amount of one of these elements will offset the use or availability of only small quantities of the others. For example, we usually think of a wealthy nation as one that possesses and uses large amounts of metals and energy; Switzerland, however, has scant resources of metals and only moderate resources of energy, yet achieves an extremely high level of living through manufacturing, banking, and trade; and Ireland, which also has scant resources of metals and fuels, achieves a relatively high level of living by making full use of her soil in agriculture, and by keeping her population to a rather low level, mainly through the practice of late marriage.

Although the elements of wealth are those broadly described in the above equation, it is worth examining briefly the most effective ways of bringing them together to produce a high level of living for the average person. To increase its total wealth, a society must find and use more raw materials and energy, as we have said. The average person, however, cannot do the multitude of things necessary to provide a comfortable living for himself, and he has no way of forcing all the people in the society to the effort required to increase greatly the availability of goods and services if the others are satisfied with what they already have. Even an absolute dictator is severely limited in what he can get other people to accomplish. For one thing he cannot force reluctant workers to their maximum effort (particularly in mental endeavors), and, to the extent that he controls their labors and assigns jobs to them, he uses only his own knowledge and ideas and loses the benefit of the knowledge and ideas that might come from others if they had a chance to use their own initiative. For these reasons, maximum benefit to the society as a whole and to its individual members comes from a socioeconomic and political system that not only permits but stimulates personal gain of all kinds--social and intellectual, as well as economic; and that allows and encourages freedom of thought and expression--not merely in the political sense but in all matters, for if people are not free to question (and abandon if necessary) dogma of all types, progress or even change of any kind is impossible. Such a system produces a free society that grows economically and intellectually by reason of its own internal ferment. Even though it is self-stimulating and to a large extent self-regulating, one can single out two extremely important phenomena that serve to keep it growing: one is distribution of the wealth; and the other is creation of wants. The distribution of wealth, whether it is brought about by collecting taxes for public works, raising wages, or any other means that do not severely curtail the individual's desire to accumulate it in the first place, helps raise the level of living of the bulk of the people, and, even more important to the growth of the ecomony, it produces purchasing power. This creates demand, not just for the few expensive items that only the wealthy can afford, but for the myriad of things that the small consumer can buy if he has a little surplus; this in turn stimulates manufacturing, sales, creates new jobs--and so the economy grows. The creation of new wants pries out of the individual some of his economic surplus (or makes him work harder to accumulate a little surplus), creates demand for more goods or service, and hence also stimulates manufacturing, makes more jobs, and so forth. Both these phenomena contribute in a major way to making the society as a whole recover from nature and from its people the raw materials, energy, ideas, and skills that are the elements of wealth and a high level of living.

Another requisite to the growth of an economy is the accumulation of wealth or, better, capital (one might distinguish between these two concepts on the basis that wealth merely implies an accumulation of goods, property, or money, whereas capital implies that this accumulation is available for the constructive purpose of investment). This is partly because the individual must be permitted to accumulate wealth or his incentive to work will be much reduced. More importantly, however, the accumulation of capital is necessary to finance endeavors that will ultimately benefit a large portion of the population, but are too large for small investors to undertake independently, at least without some organizing influence. But, for the reasons already indicated, the accumulation of all wealth in the hands of a few reduces purchasing power, so there must be a fine balance between the accumulation of wealth and its distribution.

In speaking of capital, it may be well to place in perspective another essential element of an economy whose real significance is widely misunderstood--namely money. Money is merely a medium of exchange--a symbol of wealth that can be exchanged for goods and services. In spite of the fact that gold, which is used mainly as money, can be dug up and immediately changed into money, money itself has no inherent value. As already indicated, real wealth consists of property, goods, services, and ideas. Such a medium of exchange is extremely important, of course, for it eliminates the need for a trade based wholly on the cumbersome physical exchange of tangibles. The important thing to recognize, however, is that while at any given time there is some definite amount of money in the world or in a given society and some rather indefinite amount of wealth that it represents, new wealth can be created--not just by discovering more gold or silver[1], but by recovering from the earth and its people more raw materials, energy, and ideas. When this happens, more money is created to symbolize it.

In summary, wealth consists essentially of natural and human resources, recovered and used to man's advantage. The mere existence of these things is nothing except a potential; to be of benefit to the level of living or to be translated to wealth they must be found and used. This is accomplished best in a free society in which personal effort is stimulated by the hope of personal gain, and in which people are free to question dogma and modify old ways of doing things where such will increase the efficiency of methods of discovering and utilizing raw materials and inanimate energy. The growth of an economy is aided in an important way by the growth of purchasing power resulting from the distribution of wealth, by the creation of new wants, and by the

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1/Silver has important real value because of its properties as a metal, but not many important uses have been found for gold except for ornaments and jewelry. If, therefore, some tremendous bonanza of gold were discovered, or if the alchemists' dream of making gold cheaply were to suddenly come true so that gold could be as abundant as, say, iron or even lead, gold would cease to have any value as money, and the "bonanza" would be of little or no benefit to the discoverer.

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accumulation or concentration of sufficient capital to finance large and complex enterprises. New wealth is created not by discovering gold or coining money but by finding and utilizing more raw materials, energy, and ideas.

A self-stimulating, growing society is not only aggressive in finding and utilizing raw materials and energy to satisfy its wants, but it is, through the initiative and imagination of its members, continually finding new uses for raw materials, new ways to recover less accessible ones, and so on. For this reason, resources must not be regarded as fixed or unchanging in total amount. For example, wealth was achieved by the earliest agrarian societies only when they had access to soils that were continually renewed by flooding of large rivers, and to easily manageable sources of water. Except for solar energy, which they took advantage of but could not control, they depended mainly on animate sources for energy; in fact, the wealth of many individuals and groups was achieved mainly through the use of slaves. As metal craft developed, the ancients were restricted to the use of extremely high grade and easily workable deposits of metalliferous minerals. With modern technology, however, we can use poor soils and rehabilitate worn out ones; and we can use sources of water, energy, and other raw materials that were completely unknown or unavailable to the ancients. Modern transportation systems, of course, often make it far cheaper and hence more desirable to import a given raw material than to try to extract it from a very low grade source, even though the latter might be feasible technologically. It is true, nevertheless, that modern technology can create usable resources where none existed before.

Usable natural resources

Common popular concepts of natural resources tend to overemphasize the importance of valuable minerals like gold, gems, and oil, and to overlook the fundamental importance of more prosaic resources such as soil, water, and construction materials. It may be instructive, therefore, to examine briefly the raw materials that are actually utilized by an industrial society and to consider the use and importance of different types. Because of the availability of data, it is convenient to use the United States as an example of such a society; this is a fairly good choice for other reasons also, for the economy of the United States has an extremely broad and diversified base, and thus provides a good cross section of the raw materials used in the modern world. It should be understood, however, that the pattern of use of raw materials in the United States is not the only one, or even the best, that will support a high-level of living.

The relative value of various raw materials consumed by the United States is shown in Table 1. These data show clearly that the value of products derived from the soil--food, fibres, lumber, and other agricultural and forest products--far exceeds that of all other materials, even in an industrial society. Next in value are the mineral fuels. Metals and nonmetals are nearly equal in value.

Table 1.--Per capita consumption of raw materials in the United States in 1900 and 1950[1]

	1900		1950	
	Value[2]	Percent of total	Value[2]	Percent of total
Agricultural materials		70.4		63.0
Foods	$59.3		$68.0	
Non foods	13.0		14.6	
Fishery and wildlife products	1.6	1.6	1.9	1.5
Forest products		15.7		6.2
Saw logs	6.4		3.7	
Pulpwood	0.2		1.6	
Other forest products	9.6		2.8	
(Subtotal)	(90.1)	(87.7)	(92.6)	(70.7)
Minerals		12.3		29.3
Iron and ferro alloys	1.3		2.7	
Other metals except gold	1.2		3.9	
Mineral fuels	8.6		25.8	
Construction materials	1.1		3.7	
Other nonmetallics	0.5		2.2	
Total, except gold	102.8	100.0	130.9	100.0

1/Presidents Materials Policy Commission, 1952, vol. 2, p. 184.

2/In constant 1935-1939 dollars. In this and subsequent tables, raw materials are considered to be essentially untreated products obtained from the earth, and the value stated is generally based on the price at which they were sold by the producer. The actual amount of treatment they have received at this stage varies from product to product. A few are sold as extracted, but most are cleaned, purified, or graded in some way, and some, such as lime and cement, have been altered chemically or physically.

The value of several other natural resources--chiefly solar radiation, certain atmospheric gases, water, and scenery--are not shown in this compilation. The value of most of these is impossible to estimate, but we can gain some idea, at least, of the value of water from the data and assumptions shown in table 2. The annual rainfall of the United States averages nearly 30 inches a year. Not all of this is used, of course, and, on the other hand, some of it is used several times (this is brought out in table 2 by the fact that the amount of water "used" in the manufacture of hydroelectric power exceeds the total runoff). Only a part of what is used, moreover, is sold directly--the value of rainfall used in agriculture is represented in the price and rent of land, cost of food, etc. but is not ordinarily valued separately. The average cost of water used for several purposes has been estimated recently by Gilliland (1955), however, and by applying these costs to the quantities shown in table 2, and making other conservative assumptions we find that the water used for crops, forests, and livestock and withdrawn for personal, industrial, and irrigation purposes has a value of about 6 billion. This neglects the recreational value of water and other uses such as waste disposal, but it is enough to show that the actual monetary value of water consumed is greater than that of any other mineral except petroleum, and is greater than the value of all metallic and nonmetallic minerals produced in the country (compare table 2 with tables 3 and 4).

Table 2.--Approximate volume and value of water used in the United States in 1955[1]

		Approximate volume (millions of cubic meters[2] per year)	Approximate value[3] (billions of dollars)
Total precipitation[4] (average 30 inches per year)		6,000,000	
Total runoff (av. 8.6 inches per year)	1,700,000		
Total evapo-transpiration (av. 21.4 inches)	4,300,000		
Mined water[5]		7,500	
Total received and mined		6,000,000	
Evapotranspiration from nonirrigated crops[6]		1,200,000	1.00
Evapotranspiration from forests[7]		1,700,000	0.48
Evapotranspiration from grazing land and pasture[8]		960,000	0.78
Irrigation[9]		150,000	0.40
Generation of fuel electric power		100,000	0.66
Other self-supplied industrial use		52,000	0.34
Generation of water power		2,100,000	0.42
Public supplies		23,000	1.90
Rural use		3,400	0.22
Total			6.20

1/All estimates, including those from original sources and totals, are rounded to two significant figures.

2/1 million cubic meters (MCM) = 810.7 acre-feet.

3/The costs of waters commonly sold are those reported by Gilliland (1955, p. 2413), as follows: averge household, $97.77 per acre-foot; average industrial, $8.13 per acre-foot; average irrigation, $3.25 per acre-foot. Water used for other purposes is ordinarily not sold directly, but its value is taken into account in the price of the land or the value of the product. The costs assumed here are: evapotranspiration from crops and pasture, $1.00 per acre foot; evapotranspiration from forests $0.35 per acre foot; water used for hydroelectric power, $0.25 per acre foot; water for rural use, $8.00 per acre foot. All of these are rough estimates, arrived at in the following ways: the cost of water for rural use is assumed to be the maximum cost of agricultural water reported by Gilliland. The other estimates reflect the value of the product. For example, the value of crops produced on irrigated land in 1954 was about $6.2 billion; at $3.25 per acre foot, the cost of the water used was therefore about 8 percent of the total value of the product. It was assumed that water represented a similar proportionate cost of the value of nonirrigated crops and pasture land products. Water was taken to be 15 percent of the value of forest products, and about 25 percent of the value of hydroelectric power.

4/Langbein and others, 1949, p. 5

5/Ackerman and Löf, 1959, p. 51

6/Crop land assumed to be 450 million acres (Anderson, 1958, p. 58). Evapotranspiration assumed to be 2.2 feet per acre per year, as is reported by the Kansas Water Resources Fact Finding and Research Committee (1955, p. 42) to be the case on the crop land in Kansas; this is taken to be representative of the whole country because the rainfall there (29.26 inches) is nearly the national average.

7/Assumed to be 2.2 feet over 620 million acres (Anderson, 1958, p. 58) per year.

8/Assumed to average 1.2 feet over 640 million acres (Anderson, 1958, p. 58) per year. Evapotranspiration from remaining land (190 million acres, used for urban areas, highways, or composed of wasteland) is assumed to be 420,000 MCM (1.78 feet or 21.4 inches per year) but to have no value.

9/Irrigated land is about 30 million acres. Estimates of volume used for irrigation and other withdrawal uses are from MacKichan (1957).

The water costs on which the estimates in table 2 are based give some indication as to the value water has for different purposes, for these costs reflect the price that the user can afford to pay and still make a "profit" in an economy influenced mainly by supply and demand. For example, most farmers could not pay as much for water as does the householder and still make a profit on their produce; and a lumber company could not afford to irrigate a forest if it had to pay as much for water as the farmer does for irrigation water. Viewed in this way, the "value" of water for different purposes increases in the following order: hydroelectric power[1/], forests, pasture land, rain-fed crops, irrigated crops, industrial uses, and domestic uses. This is merely another way of saying that, as an economy develops, forest land is converted to cultivated land, and cultivated land to industrial and urban use.

1/The value of a unit of water used for this and some other purposes is perhaps misrepresented for the comparison here, for the water is not consumed but can be reused, perhaps several times.

Focusing more closely now in the mineral raw materials consumed in the United States, the data on tables 3 and 4 bring out several important points. Table 3 shows the apparent consumption of the major groups of minerals compared to production, and table 4 lists separately the value of raw materials or groups of raw materials that make up at least 0.01 percent of the total value of the production. The fact that there are about 40 such materials shows the diversity of minerals that find important use in an industrial society. The full list of usable minerals is between 150 and 200 (depending on how they are classified), and it includes a large number of things that have only come into use in recent years. Tables 3 and 4 also show that even a country noted for its diversity of mineral resources does not have within its own confines all the mineral raw materials it needs, but is dependent on trade with other countries for many essential commodities, particularly metals.

Table 3.--Production and apparent consumption of minerals

in the United States in 1955

(in millions of dollars)[1/]

	Production	Imports	Exports	Apparent consumption
Fuels	10,744	674	540	10,988
Nonmetallics	2,959	459	178	3,240
Metallics	2,114	1,896	367	3,643
				17,873

1/U. S. Bureau of Mines Minerals Yearbook. Imports and exports include manufactured and semimanufactured products. Data on the value of uranium ore produced in 1955 are not available, but an estimate of $70 million (the value of the 1956 production) is included in the figure for metallic minerals. Imports and exports of uranium have not been estimated.

Table 4.--United States apparent consumption of minerals whose value was 0.1 percent or more of the total in 1955 (millions of dollars)

Mineral fuels	
Coal	1,810
Natural gas and natural gas liquids	1,582
Petroleum (crude)	7,494
Nonmetallic minerals except fuels	
Asbestos	65[1/]
Boron	19
Bromine	38
Cement	892
Clays	132
Diamonds	217[1/]
Fluorspar and cryolite	24[1/]
Gems	24[1/]
Gypsum	40
Lime	126
Magnesium salts	23
Nitrogen compounds	30
Phosphate rock	58
Potassium salts	80
Salt	121
Sand and gravel	527
Stone and slate[2/]	597
Sulfur and pyrite	134
Metallic minerals	
Aluminum	139[1/]
Chromium	49[1/]
Cobalt	40[1/]
Columbium and tantalum	24
Copper	1,118[1/]
Gold	155[1/]
Iron	768
Lead	204[1/]
Manganese	107[1/]
Molybdenum	51
Nickel	167[1/]
Platinum	46[1/]

Table 4.--United States apparent consumption of minerals whose value was 0.1 percent or more of the total in 1955 (millions of dollars)--Continued

Silver	100 1/
Tin	175 1/
Titanium	22 1/
Tungsten	118 1/
Uranium	70
Zinc	202 1/

1/More than 25 percent of the commodity has been imported.

2/The value of stone stated in Table 2 of the Minerals Yearbook for 1955 apparently includes some duplication (see footnote 14, p. 57 of that volume); the difference between the total stated in table 2 of the Yearbook for nonmetallic production, and the total of the values listed for individual commodities therefore has been subtracted from the value reported for stone in the Minerals Yearbook.

It is important to observe in tables 1 and 4 that the value of construction materials--common materials (such as cement, lime, gypsum, stone, sand, and gravel) that many people don't even think of as mineral resources--are more valuable than iron and the ferro-alloy metals, and far more valuable than the precious metals. This brings us to consider the part that minerals play in an industrial society. Soil, water, and construction materials, of course, are the most essential raw materials, for they are the source of the basic necessities of food, clothing, and shelter. Water, construction materials, and other nonmetallics also play essential and increasingly important roles in industrial activities; this is is well shown by the quantity and value of water now used for non-agricultural purposes (table 2), and by the growth in consumption of construction materials and other nonmetallics from 1900 to 1950 (table 1). The increasing use of construction materials has come about as a consequence of the development of the transportation system as well as the construction of more and larger factories and homes. Most of the other nonmetals are used as chemicals and they have multitudinous uses in the processing of ores, food, and fibres; the manufacture of paints, explosives, rubber; and so on through the full range of almost every group of products. One group of chemicals deserves special notice--namely those used as fertilizers, soil amendments, and insecticides. The discovery of the value of animal fertilizers is relatively recent. Their development has made it possible to rehabilitate worn out soils, and their use--together with insecticides, mechanized equipment, and improved strains of plants--has led to attainments in agricultural production that few would have thought possible even a decade or two ago.

Important as these things are even in an industrial society, there is no doubt that the key resources in industrialization are metals and fuels, used for machines powered by inanimate energy. The significance of the use of inanimate energy may be illustrated by comparing the cost of the physical work it will do to that which can be done by human efforts. For example, a gallon of gasoline burned in a conventional gasoline engine produces about 8 horsepower hours, which is as much energy as can be produced by 25 laborers working an eight hour shift on a food intake of 3,500 calories per day. Omitting capital and other costs, the fuel cost alone, at a gasoline price of $0.25 (90 fils) per gallon is equivalent to buying labor at about 1 cent (3.6 fils) per man day (Slichter, 1959, p. 368). Defining a high level of living as the condition in which man's needs and wants for shelter, warmth, food, clothing, transportation and so on are fulfilled with little expenditure of energy on his part, it is easy to see that the high level of living of industrial societies is founded more on the use of large quantities of inanimate energy than anything save technological ingenuity itself[1/].

1/The grand works of architecture of most ancient civilizations were accomplished by the lavish use of slave power, and surely the abundant use of slaves or servants will do wonders to fill the needs and wants of the master. In the industrial society this help is provided by inanimate energy and machines. A touch of the switch in the ordinary home makes available about 2 kw per hour and brings to almost anyone's command about 14,000 kg cal per eight-hour day--the equivalent of the physical energy product of about 70 well-nourished servants--at a cost of 65 cents (234 fils) or less per day, exclusive of capital and related costs.

Although the focus here is on the use of natural resources, it would be misleading to leave the subject of the United States economy without pointing out the essential role that ingenuity and education have played in its development. During the period from 1900 to 1950 the per capita income in the United States increased from 325 to 864 constant dollars--2.68 times. Increase in the consumption of raw materials, especially fuels, contributed to this, as is shown in table 1, but the overall per capita increase in raw materials consumption was only 1.26 times. The difference reflects the contribution of what was broadly referred to in a previous section as ingenuity. This is impossible to quantitize, but the trend can be demonstrated by many statistics. For example, between 1910 and 1950 the proportion of professional persons in the total labor force increased from about 4.4 to 8.8 percent, and the unskilled workers decreased from about 36 to 19 percent of the total labor force.

In summary, a wide variety of resources finds use in an industrial economy. The most essential ones for a nation to have within its own confines are usable soils, water, and construction materials, for not only are their uses fundamental, but, as low cost items used in large volume, they are expensive to import. Metals, fuels, and chemicals are essential to an industrial nation, but no nation is or can hope to be self-sufficient with respect to all of these materials. The fewer a nation has to import, the better, of course, but even if she has to import many of them she can do so with ultimate profit. This is because raw materials are sold at prices that reflect supply, demand,

and the effort and materials required to obtain them, rather than the function they will perform. Viewed in terms of the work produced by a machine powered by inanimate energy, both metals and fuels are now sold at bargain prices, and their intelligent use yields a margin of profit that more than pays for the cost of the raw materials involved.

Jordan's current economic status

With this background of understanding of the factors that influence the growth and development of an economy, it is worth while now to examine Jordan's current economic and technologic status. Shown in table 5 are some statistics on a group of countries selected to cover the range of economic development over the world today. Ideally it would be desirable to list all the things referred to in the level of living equation previously discussed. This is not possible, of course, simply because many of the essential ingredients cannot be measured quantitatively. Instead, several statistics have been selected that are indicative of fundamental relations and trends. The level of living of each country is indicated by the per capita income, a value obtained by dividing the total national income by the size of the population; this is not as reliable a figure as we would like (apart from the difficulty of measuring the national income, we have no way of knowing how fairly the per capita average represents the level of living of the bulk of the population), but it is the best available measure. The degree to which the population is urbanized and engaged in specialized activities, including manufacturing, is suggested by data on the proportion of the labor force engaged in agriculture; this may also be considered a measure of the extent to which the population as a whole is engaged directly in obtaining basic necessities, as opposed to activities that may produce a further economic surplus, and hence is also indicative of the level of living. The population density with respect to agricultural and forest land is a crude means of appraising the availability of soil and the extent to which the country's population is straining its capacity to supply food and other essential agricultural products. Data on the per capita production and consumption of iron, steel, and energy provide clues to the extent to which a country is using the kinds of raw materials and forms of energy that increase the efficiency of human operations and permit the accumulation of an economic surplus. The use of ingenuity is difficult to judge, of course, but the indices shown in table 5 give some indication of the extent to which the population has a chance to acquire new information and is prepared to apply it.

The data in table 5 provide general confirmation of some of the principles already discussed. They emphasize again that the complexion of the economies of all countries, even those with comparable levels of living, is not the same, and show that the same result can be achieved in different ways. They show, however, that in a general way the per capita income tends to increase with decreasing employment in agriculture and decreasing population density; with increasing consumption of metals, energy, and newsprint (which is a crude measure of the extent to which knowledge is distributed); and with increasing literacy, educational advantages, and so forth.

It is important to note that the correlation between per capita income and production of iron and energy is not as good as that between income and consumption of these things. This emphasizes the fact that the fundamental value of raw materials is in their use, not their sale. Countries deficient in essential resources must obtain them through trade with those that have a surplus, of course. But mere export of raw materials does not bring about a high level of living, especially for the bulk of the population, and a country that aspires to a high level of living must plan not only to increase its ability to find natural resources but also and especially to use them for its own purposes.

It will come as no surprise to find from table 5 that Jordan does not have a very favorable balance between the size of her population and extent of her agricultural land, that she consumes relatively small amounts of steel and inanimate energy, or that her educational budget is low, for these things are well known, at least qualitatively. The comparison of data on Jordan with other countries, however, shows that these phenomena are interrelated, and that they bear a causal relation to level of living. The data indicate plainly that if Jordan is to raise her level of living appreciably she must obtain and use more raw materials and more inanimate energy; she must vastly increase the dissemination of knowledge among her people and develop and use their skills to the utmost; and she must bring about a better balance between the size of her population and the resources on which she has to draw for their support. Only the problem of the development and use of mineral resources receives further attention in this report, but the others are of equal if not greater importance.

Geology of Jordan

The general geology of Jordan is described by Blake (in Ionides, 1939), Quennell (1951), and Burdon (in press), and those interested mainly in the geology of Jordan should consult their reports. The review here is intended mainly to acquaint the reader with the names and stratigraphic position of the formations in Jordan (table 6), to which frequent reference will be made in the following sections, and to outline the general structure of the country (fig. 2).

Jordan is underlain by five main groups of rocks: 1) Precambrian igneous and metamorphic rocks; these are exposed only in the southern part of the Kingdom, but they underlie the rest of it at depths that generally increase northwestward. 2) Marine limestones, dolomites, marls, cherts and other sedimentary rocks that range in age from Cambrian to Eocene. The Upper Cretaceous and Eocene rocks are found over all but the southern part of the Kingdom, but the pre-Upper Cretaceous marine rocks are largely restricted to the northwestern part of the Kingdom. A few thin tongues extend southeastward into the Nubian sandstone facies. 3) The Nubian sandstones are terrestrial rocks of the same general age as the marine rocks just described and they intertongue with them. They overlie the Precambrian crystalline rocks and crop out mainly in the south. 4) Tertiary basalts intrude all of these older rocks and are found as dikes, remnants of volcanic necks, and flows, especially along the edge of the plateau east of the Dead Sea Valley, and in the northeastern part of the country. And 5) late Tertiary and Quaternary lake beds and alluvial deposits are found in most of the main valleys and depressions.

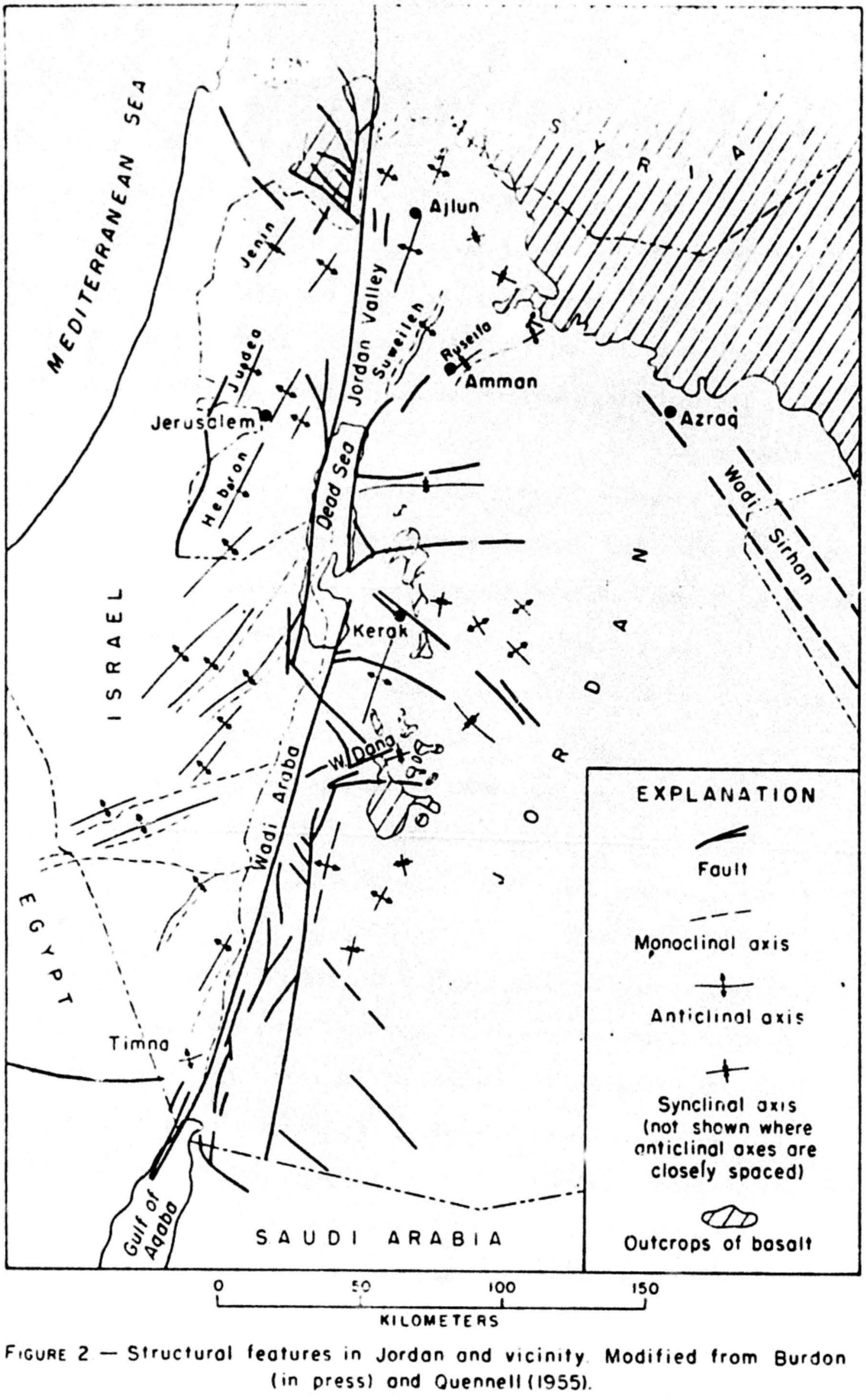

FIGURE 2 — Structural features in Jordan and vicinity. Modified from Burdon (in press) and Quennell (1955).

Table 6.--Stratigraphy of Jordan[1/]

ERA	PERIOD	EPOCH	SERIES		DESCRIPTION	
CENOZOIC	QUATERNARY (or Diluvium)	RECENT	RECENT		Gravel and sand	Basalt flows and dikes
		PLEISTOCENE	LISAN SERIES		Marl, gypsum.	
	TERTIARY	PLIOCENE MIOCENE	NEOGENE UNDIFFERENTIATED		Limestone, sandstone, conglomerate	
		OLIGOCENE				
		EOCENE PALEOCENE	BELQA SERIES		Chert, limestone, chalk, marl, phosphate rock, bituminous limestone and shale, 400 m.	
MESOZOIC	CRETACEOUS	DANIAN				
		SENONIAN: MAESTRICHTIAN CAMPANIAN SANTONIAN CONIACIAN				
		TURONIAN CENOMANIAN	AJLUN SERIES		Limestone, dolomite, marl, sandstone, 125-450m-thick	
		ALBIAN APTIAN BARREMANIAN HAUTERVIAN VALANCIAN	KURNUB SANDSTONE	Nubian facies in S. Jordan	Multicolored sandstone and shale, 150-200 m. thick	
	JURASSIC	PORTLANDIAN KIMMERIDGIAN LUSITANIAN OXFORDIAN				
		CALLOVIAN BATHONIAN BAJOCIAN	UM SAHM SANDSTONE		Sandstone and shale, 50-300 m. thick. In northwestern Jordan passes into marine Triassic and Jurassic dolomite, sandstone and gypsum.	
		LIAS				
	TRIASSIC	KEUPER MUSCHELKALK BUNTSANDSTEIN				
PALEOZOIC	PERMIAN CARBONIFEROUS DEVONIAN SILURIAN ORDOVICIAN		RAM SANDSTONE		Grey, white, and buff sandstone, 100-250 m. thick.	
	CAMBRIAN	UPPER CAMBRIAN MIDDLE CAMBRIAN LOWER CAMBRIAN	QUWEIRA SERIES		Sandstone, shale, cong., 300-500 m. thick; Burj marine ls. in middle.	
PRE-CAMBRIAN			SARAMUJ SERIES		Basic intrusives Arkose conglomerate	
			AQABA GRANITE COMPLEX		Dolerite, felsite, quartz-porphyry dikes. Granite, granodiorite. Schist, gneiss, quartzite.	

1/Modified from Quennell (1951) and Burdon (in press).

The geologic structure of Jordan shows the effects of two main periods of deformation. The first took place in late Mesozoic and early Tertiary time; it consisted of gentle warping and folding of the rocks, and resulted in the formation of several gentle folds and arches, most of which strike northeast and plunge gently northward. This general northward plunge, incidentally, accounts for the exposure of Precambrian rocks in the southern part of the country. Some of these folds began forming in Late Cretaceous time, while much of Jordan was submerged, and, as ridges on the sea bottom, they caused local variations in the thickness and lithology of sediments deposited contemporaneously.

Superimposed on and disrupting these simple folds are the faults associated with the Jordan-Dead Sea-Araba rift valley. These faults originated in mid-Tertiary and Pleistocene time, and, although their origin and relative displacement are not fully understood, they consist essentially of 1) the great north-trending faults along which the rift valley has developed; 2) related faults, most of which strike northwest; and 3) sharp monoclinal flexures, most of which strike northeast. The basalt intrusives are closely associated with all three of these structures, and this accounts for their frequency along the margin of the Dead Sea-Jordan Valley.

Both the stratigraphy and structure have striking influence on the topography. The deep and relatively narrow rift valley divides the area into eastern and western highlands, sometimes called the East and West Banks, which are locally incised by deep gorges that extend to the rift valley. The eastern highland has three fairly distinct parts: 1) the northwestern hill country, underlain largely by resistant limestones and interbedded marls of the Ajlun formation; 2) the eastern desert, mainly a rolling surface underlain by soft chalk, marl, and limestone of the Belqa formation; and 3) the southern desert, a rugged, precipitous topography formed by the Nubian sandstone and Precambrian rocks. The West Bank is similar to the hill country of the eastern plateau and like it is underlain mainly by the Ajlun formation. The lava flows, especially in the northern part of the country, often form a barren, rocky wasteland.

Jordan's mineral resource potential

Jordan's mineral resources are inadequately known and poorly developed. At the present time she is making only partial use of her water supply; is producing for internal use only construction materials, and a little salt; and is exporting only phosphate rock. Almost certainly she does not have a great variety of minerals suitable for export, but, as already emphasized, the important question is: what resources does Jordan have that she can use herself? No doubt more exports would benefit the economy, and like any other country Jordan will find it necessary to barter for materials she needs but doesn't have. But her main need is for resources suitable for her own use.

Examined in this light and also in the light of modern technology, Jordan appears much better off than is generally recognized. As is shown in the following pages, she can increase her usable water supply substantially, has several sources of inanimate energy that could be exploited economically now, and has the ingredients for important fertilizer, chemical and construction materials industries.

The review that follows is uneven, mostly because more information is available on some minerals than others, but partly also because I have studied some of them (phosphate in particular) in more detail than others.

Water

Jordan's most critical mineral resource is water, and it is the one that has received the most study. The most comprehensive of the factual reports are those of Ionides (1939), Blake and Goldschmidt (1947), Baker-Harza (1955, 1958), and Burdon (in press); although these reports are based on meager data, they serve as a basis for evaluating Jordan's potential water resources.

Full appreciation of the problems, limitations, and possibilities of expanding Jordan's water supplies depends on an understanding of the principles that govern the dissipation of water within a given basin. It is desirable to begin, therefore, with a brief review o. these principles as they apply to the Dead Sea basin.

The hydrologic cycle in the Dead Sea basin

Because the Dead Sea basin has no outlet to the sea, all the water it receives as rain is eventually returned to the atmosphere by evaporation, but in doing so it may follow one of several paths: a) some evaporates almost immediately after it falls; b) some runs off the surface, collects in streams and flows to the Dead Sea shortly after the storms that bring it (this is called direct runoff or storm runoff); and c), some sinks into the ground.

Of the water that sinks into the ground, a large part may be used shortly by plants and returned to the atmosphere by transpiration, and some may evaporate slowly through the soil pores. Depending on the intensity and duration of the rainfall and the permeability of the soil, some water seeps further into the ground. Although many rocks are dense and impervious, others have pores or cracks that will hold water and some have pores large enough to allow it to filter through; water that sinks into permeable ground is gradually channeled into pervious beds or underground water courses, along which it flows by gravity just as it does at the surface. Because some of these pervious rocks (aquifers) are surrounded at all lower levels by less pervious or even impervious beds, they act as sealed reservoirs that accumulate or store water until they are saturated to the point at which water enters from the surface; after this condition of saturation is reached (and in the Dead Sea basin it may be assumed to have been reached long ago), all water that does not leak through the underground dam flows past the entrance to the aquifer, and drains through another, generally more shallow, underground channel, until it eventually reaches the surface or flows underground to the Dead Sea or other depression. The part that reaches the surface comes out as seeps or springs. Most of the water from the smaller of these (called effluent seepage) is returned to the atmosphere almost immediately via evaporation or transpiration; that issuing from the larger springs forms the permanent streams (this discharge is called the dry weather or base stream flow). It is important to note that, depending on the local structure of the rocks through which the water flows underground, some of the water derived from rain within the Dead Sea topographic basin issues as springs in other watersheds and does not flow to the Dead Sea at all. For example, some of the water rising in the springs at Azraq may be derived from the hills near Ajlun. Conversely, some springs within the basin may have their source in rain that falls in other watersheds.

Some of the flowing ground water doesn't reach the land surface but collects in the alluvium in wadi bottoms and flows beneath the surface. When the underflow, as it is called, is within a few feet of the surface, it is tapped by phreatophytes--ground water-loving plants like oleander, willow, salt bush, tamarisk, and poplar. Dense stands of several of these common shrubs consume and discharge to the atmosphere through transpiration more water than will evaporate from a water surface of the same area; a large part of the underflow, therefore, returns to the atmosphere by transpiration and only a small part actually reaches the Dead Sea.

Water now received and used

With this background, we can now examine the potential water supply in Jordan.

Neglecting an unknown quantity of water carried in or out of the Kingdom by underground structures, the annual water supply is roughly 12,000 MCM, as shown in table 7.

Much of the rainfall is returned to the atmosphere by transpiration and evaporation, and of the 12,000 MCM total supply, only about 1,900 MCM per year is concentrated in surface streams or springs (table 8; fig. 1). Of this, a little more than 1,200 MCM is base flow--relatively steady the year round and therefore relatively easily managed; the rest is storm runoff, not easily managed or recovered unless storage facilities are developed.

Table 7.--Jordan's annual water supply[1]

	MCM per year
Rainfall within the Transjordan part of the Dead Sea basin (22,000 km^2)	4,500[2]
Rainfall on the West Bank (5,600 km^2)	2,500[3]
Rainfall in remainder of Jordan (ca 69,000 km^2)	4,000[3]
Surface inflow from the River Yarmuk	470[4]
Surface inflow from the River Jordan	540[5]
Total (rounded)	12,000

1/ All estimates, including those from other sources, rounded to two significant figures.

2/ Ionides, 1939, p. 133.

3/ Estimated from maps showing mean annual rainfall (e.g., IBRD, 1957, p. 42).

4/ Baker-Harza, 1955, vol. V, p. 26.

5/ Ionides, 1939, p. 194.

Table 8.--Surface discharge within Jordan[1]

	MCM per year
Yarmuk River[2]	
Base flow	250
Storm flow	220
Jordan River at outlet of Lake Tiberias[3]	540
East Bank Wadis	
Base flow[4]	200
Storm flow[5]	300
West Bank wadis[6]	
Base flow	160
Storm flow	170
Small springs on the East Bank[4]	80
Azraq springs[7]	10
Total (rounded)	1,900

1/ All estimates rounded to two significant figures.

2/ Baker and Harza, 1955, vol. V, p. 26; vol. VA, pt., 2, table 23.

3/ Ionides, 1939, p. 194.

4/ Idem, p. 190.

5/ Idem, p. 200, 205.

6/ Calculated by assuming that the base flow and storm runoff are 6.3 and 6.7 percent respectively, of the rainfall--the proportions Ionides used in the Transjordan Basin (idem, p. 200). Baker-Harza (1955, vol. V, p. 17) estimate that the average flów of the West Bank wadis and springs entering the Jordan Valley is 58 MCM.

7/ IBRD, 1957, p. 77.

It is difficult to estimate how much water is currently used in Jordan, but the estimates presented in table 9 are based on what seem to be reasonable assumptions and are probably of the right order of magnitude. They suggest that about 3,500 MCM per year are being used now for rain-fed crops, irrigation, and domestic use. We may ask now, how much more water can be obtained for these same and related purposes?

Potential water supply from replenishable sources

A rough answer is given to this question via the estimates of table 10. None of these estimates are firm, except that of Baker-Harza (1955) for the Jordan Valley irrigation project, but again they are based on reasonable assumptions and show what can be expected. The total potential recoverable supply from replishable sources is seen from this table to be of the order of 6,000 MCM per year; as most of the estimates are generous, this is probably close to the maximum expectable from economic sources. The basis for the estimates is shown in the footnotes, but some of them deserve further explanation and comment.

Table 9.--Water currently used in Jordan (excluding rain on forest and grazing land)

	MCM per year
Irrigation 1/	225
Rain fed crops 2/	3,200
Public consumption 3/	15
Total (rounded)	3,500

1/ Assuming that the 322,000 dunums of land irrigated during 1952-1954 (IBRD, 1957, p. 80) receive 790 cubic meters of water per year per dunum--the amount Ionides (1939, p. 191) found representative. The chief sources of this water are, in probable order of importance, the East and West Bank wadis, hill springs, and ground water in the Jordan Valley.

A dunum is 0.001 km^2 or about ¼ acre.

2/ The area of rain-fed field and fruit crops, including fallow land, in 1952-1954 was about 8,300,000 dunums (IBRD, 1957, p. 80); this is about twice the area Ionides (1939, p. 236) estimated for the Transjordan part of the Dead Sea basin alone, and I assume the larger area receives the same average rainfall, or about twice the total precipitation Ionides estimated is received by rain-fed crop land in the Transjordan Basin.

3/ Estimated on the assumption that the per capita consumption is about 28 liters per day; this is probably twice the actual consumption for the bulk of the population. Industrial consumption is not estimated, but is probably not enough to affect the total.

Table 10.--Potential usable water supply in Jordan from replenishable sources (excluding rain on forest and grazing land)[1/]

	MCM per year
Rain on arable land[2/]	4,200
Jordan Valley irrigation[3/]	760
Base flow from other wadis and springs in the Transjordan Basin[4/]	160
Base flow from other wadis and springs on the West Bank[4/]	100
Azraq springs	10
Storm runoff, not included above, captured directly or indirectly through water spreading or similar techniques[5/]	70
Underflow and ground water discharge[6/]	250
Total (rounded) from ordinary sources	5,500
Artificially induced rainfall[7/]	480
Total (rounded) from all economic, replenishable sources	6,000

1/All estimates rounded to two significant figures.

2/Assumes that 2,500,000 dunums of new land will be brought into use for hill fruit (IBRD, 1957, p. 87), and that it will receive the same annual rainfall as land now cultivated (see table 9).

3/As proposed in the Jordan Valley master plan. This would use 467 MCM per year from the Yarmuk, 92 from the Zarqa, 121 from other East Ghor wadis, 58 from West Ghor wadis and springs, and 155 from the Jordan--a total of 893 MCM; of this 69 MCM is committed to Syria and the Yarmuk triangle and 64 MCM is expected to be lost in the flow from unregulated wadis (Baker-Harza, 1955, vol. V, p. 27).

4/Total base flow in the area, less that to be utilized in the Jordan Valley irrigation project.

5/Assumes that about 25 percent of total storm flow (exclusive of that from wadis draining into the Jordan Valley) could be recovered.

6/Baker-Harza (1955, vol. VA, p. A113) assumed that of the total rainfall in the watersheds tributary to the Jordan Valley, 25 percent sinks into the ground for recharge. Of this, some (about 13.8 percent of the total rainfall in their calculation) reappears as base and spring flow and seepage. Of the remaining ground water, they assume that only 20 percent could be found and recovered. This calculation places effluent seepage (the amount of which is hard to estimate anyway) in the wrong category, for it is part of the ground water one could hope to recover. In the calculation here, it is assumed that 25 percent of the total rain falling in areas receiving more than 200 mm per year (3,295 MCM in the Transjordan basin, according to Ionides, p. 235, plus 2,500 MCM on the West Bank) sinks into the ground. The total base and spring flow is subtracted from this, and it is assumed that the remainder (1,010 MCM) drains off in wadi underflow and other underground drainage channels. It is assumed that 25 percent of this could be recovered, either directly by pumping, or indirectly by planting useful phreatophytic vegetation in the water courses or in seepage areas. This is probably a maximum, but it does not include stored ground water that might be mined faster than it is recharged annually.

7/Assumes a 10 percent increase in water obtained from all sources except the Yarmuk and Jordan.

The estimate of the amount of rain that could be used in the cultivation of crops and fruit assumes that about 2,500,000 dunums of presently uncultivated land will be brought into use for hill fruits, as IBRD (1957, p. 87) estimated could be done. This would make effective use of nearly 1,000 MCM per year, and it is the largest single "source" of additional water in Jordan. It will require the least capital to develop, it may have the greatest economic yield, it does not involve the solution of complex international problems, and much of the work can be done by individual families (see IBRD discussion, p. 86-90, of this program).

The use of water on forest and grazing land has not been considered in tables 9 and 10, but it is worth mentioning here that the total rainfall in areas receiving more than 200 mm a year (the approximate minimum required for dry farming) is about 5,800 MCM per year, so that about 1,600 MCM is assumed to fall on non-cultivatable areas. This is not to imply that Jordan should convert every space into cultivated land, but the amount of water falling on non-cultivatable areas emphasizes the need to introduce useful vegetation (defined here as vegetation that not only prevents soil erosion but also yields some kind of harvest) wherever possible.

The Jordan Valley irrigation project would make available nearly three times the water now used for irrigation, but its completion requires large sums of capital as well as the solution of complex international problems. A smaller project--the East Ghor Canal--that will use some of the Yarmuk flow is now underway. The advantages and problems of full use of the Yarmuk-Jordan water are well known and require no elaboration here. Suffice it to say that the potential exists, that it will provide the largest source of irrigation water, and that neither economic nor engineering obstacles prevent its realization.

Not much of the base flow listed in table 10 represents a new supply--most of the wadis and springs that yield it are already tapped for irrigation or potable water, though not always as efficiently as possible.

The Azraq area has recently been investigated by Baker-Harza (1958), but its maximum possible yield is not yet known. The water is probably derived from some distant source--perhaps the Ajlun anticline or Mt. Hermon in Syria; additional water has been found by drilling, but until the source and amount of recharge is established, the total sustainable yield cannot be estimated.

Very little of the direct runoff within the basin is used now. Ionides considered the capture of floodwater too expensive, except where the construction of a small dam and reservoir could be paid for by the labor of the family or village that would benefit from it, and this probably is still true today. Another use for flood water--water spreading--deserves consideration, however. In this technique, already tried successfully in parts of Jordan (e.g., IBRD, 1957, p. 74), flood waters are diverted by low cost structures, either onto tillable ground, where they are used directly, or onto pervious ground, where they sink in and are recovered down dip by pumping.1/ How much of the roughly 700 MCM of storm runoff could be captured in this cannot be estimated without more

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1/ They can also be used to flush out soluble salts from soil or, under favorable circumstances, from underground reservoirs.

knowledge of the intensity and duration of wadi discharge and of the distribution and character of receptive aquifers The estimate in table 10, therefore, is merely a guess, but it serves to indicate the order of magnitude of water obtainable from this source.

The concealed ground water discharge is difficult to estimate, and the amount that is recoverable is even harder to predict. As previously indicated, we are concerned with essentially two different types of water here: a) underflow along the water courses, and b) water draining through underground aquifers whose distribution may not be related to the present topography. The underflow that escapes into the Dead Sea has been estimated by Neumann (1958) to be of the order of a few tens of MCM and probably not more than 50 MCM per year.[1] Added to this is water consumed by phreatophytes along the water courses. Without more data it is not possible to estimate the transpiration loss via these useless plants, but the amount probably is large. For example, phreatophytes of the type that grow profusely on the Zor (the floodplains of the Jordan River) consume 1.5-2 meters of water per unit of area per year; the transpiration loss in that area alone could be 60-80 MCM per year. A significant part of this water could be recovered in two ways--directly

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1/ Dead Sea evaporation — rain falling on the Dead Sea — total inflow of surface water to Dead Sea = underflow to the Dead Sea. Neumann estimates that the evaporation from the Dead Sea is about 155 cm per year and other recent estimates place it between 153 and 160 cm. Rainfall on the Dead Sea averages about 80 MCM per year; the inflow from the Jordan at the Allenby Bridge during years when the Dead Sea level has been stable averages 1,250 MCM per year; and the base inflow to the Dead Sea from other sources south of the bridge has been estimated, from sparse data, as about 150 MCM per year. Because of uncertainties as to the exact amount of evaporation and storm flow, the underflow to the Dead Sea cannot be gaged precisely; but Neumann's estimate is surely of the right order of magnitude.

by drilling and pumping, or indirectly by growing useful phreatophytes (like alfalfa or date palms) on the flood plains. One technique, suggested to me by T. W. Robinson, that may be worth trying in some of the smaller wadis is to create underground dams by grouting clay into the alluvium; such subsurface dams may be just as effective in trapping small or dispersed underflow as ordinary dams are in the conservation of surface flow.

Two other types of geologic environments within Jordan are most promising for ground water development: 1) the alluvial fans that border the Jordan Valley, and 2) bedrock aquifers--mostly synclines like that west of Suweileh but also basalt flows and fault traps (fig. 2). The alluvial fans are already yielding some production and they deserve further exploration and study (water in their lower parts is often saline as a result of contact with old lake beds; as these beds are mainly composed of carbonates and sulfates, their salt content is not high, and it is possible that the salt could be flushed out by water spreading). Although some wildcat drilling has been attempted in search of ground water, the geologic mapping required to guide such exploration effectively has not been done in most areas. Nevertheless, enough is known to say that water-bearing beds and structures exist and can be developed through appropriate geologic studies and exploration. Most of the formations of Jordan yield some water locally, but the most important aquifers seem to be in the Quweira, Kurnub, Ajlun, and Belqa series (table 6).[1] The Suweileh syncline and the Azraq area have already been mentioned as important water-bearing structures and in addition to these, the Ruseifa Valley syncline is known to be water-bearing. The Jenin syncline, the flanks of the Judea and Hebron anticlines, and several small synclines in northern Jordan (fig. 2) also offer opportunity for recovering ground water. Although the geology of the eastern desert is poorly known, much of the area appears to be underlain by a broad syncline, locally undulating and possibly broken by faults. This structure is favorable for the accumulation of ground water, for its recharge area, at least on the west, is in the belt of higher rainfall along the margin of the Dead Sea rift valley. Most of the known desert oases or wells derive their water from this structure and the springs that are found in Wadi Hasa, Wadi Mujib, etc., are also derived from this syncline on its western flank.

Still another source of ground water deserves consideration--water trapped in relatively impervious beds, or aquicludes as they are sometimes called. Although the volume of this water is large, it cannot be extracted by drilling, simply because it does not seep into a small bore hole rapidly enough to make pumping worthwhile. Some of it can be extracted, however, by infiltration galleries, or kahrezes--large tunnels or shafts of the type dug in Jordan by the Romans and others in ancient times. Some of these kahrezes have been rehabilitated, others could be, and new ones could be dug; they will not yield a volume of water comparable to that from the other sources discussed here, but they will produce supplies for village use and garden irrigation.

Because all of the sources discussed above are dependent directly or indirectly on annual rainfall, it is reasonable to assume that the total usable supply would be increased if the rainfall were increased. This appears to be feasible, for in recent years considerable success has been achieved in artificially inducing rain by cloud seeding. Even though this technique is in its infancy, Ackerman and Löf (1959,

p. 356-383) report, from a review of the extensive tests made thus far, that in areas of orographic rainfall the method yields an increase of about 10 percent (30 percent is claimed for some tests in Australia) in the precipitation at a cost of 1 to 5 cents per acre (0.7 to 3.5 fils per dunum). Fortunately, most of Jordan's rainfall is of the orographic type--"that is to say, the rain-bearing wind is driven upwards by the hills, producing a drop in temperature which causes the rain to form" (Ionides, 1939, p. 26)--and it seems likely that this technique could be applied successfully, especially in the northern part of the Kingdom. Although the cost is low when done by commercial firms, it would be reduced still further if the cloud seeding could be taken over as a routine function of the air force. Certainly the technique deserves serious consideration, for it would be by far the cheapest source of additional moisture.

Except for the possible local development of bedrock aquifers already mentioned, little hope can be held for greatly increasing the desert water supply. The rainfall in much of the eastern and southern desert is less than 50 mm per year and it does not average much more than that over the whole area. Because the area is large, the total rainfall is probably 3,000-4,000 MCM per year, but a much larger percentage of this is lost through evaporation and direct runoff than in the other areas; in fact, in areas of such low rainfall it is generally agreed that, except under the most favorable circumstances (when most of the rain that does fall is moderately intense but not torrential), only a small percentage of the rain ends up as ground water. Although desert wadis do contain some underflow and may also yield enough direct runoff to be usable locally by water spreading techniques, these sources cannot be expected to increase greatly the desert water supply. The success of water spreading at one locality in the eastern desert, where it supported the growth of 4,000 dunums of wheat in 1955, is a notable example of one type of development possible in favorable years (IBRD, 1955, p. 74). One other type of development that deserves consideration is the growth of desert plants, useful for their chemical or therapeutic properties (e.g., Duisberg, 1953).

Stored ground water

The world's ground water reserve in the upper 2,500 feet of the crust is equivalent to a layer of water nearly 31 meters thick over all the land areas (Nace, 1958). As explained previously, this water is held in different ways. Some saturates beds so impervious that it is virtually locked within them; some is tightly held by capillary forces; some has accumulated soluble salts and is saline; but some is stored in pervious rocks from which it can be removed by pumping or similar means.

Since the total amount of this water is only one or two hundred times the annual rainfall in many areas, we may assume that over the thousands, perhaps millions of years that the storage beds in question have been exposed to recharge, they will have become saturated. In most areas, then, the current rainfall either bypasses these beds to flow through shallower water courses or recharges them to an extent equal to the annual drainage through them.

The rocks that underlie Jordan are as favorable for the storage of water as are the general average, and even though Jordan is an arid country it is reasonable to assume that she contains a proportionate amount of this stored water, or about 3,000,000 MCM. For the reasons mentioned above, most of this water is not recoverable; we cannot estimate how much is recoverable, but we may be sure that it is large--at least several and perhaps many times the annual supply.

Stored water occurs in the kinds of rocks and structures described in the preceding section, and it can be found by geologic studies followed by exploration. In desert areas, however, or where the source of the water in the aquifer cannot be traced to current recharge, stored water must be cautiously developed, or used in the light of the certainty that continued withdrawal will mine out the supply.

Special circumstances, of course, may make the withdrawal of stored water advisable, at least as a temporary expedient. Moreover, if storage beds are completely saturated, withdrawal of water may allow them to accept as recharge water that otherwise would be lost as storm runoff. Even in relatively dry areas, therefore, some stored waters can be used without fear of exhausting the aquifer, provided water is not withdrawn faster than it is replaced. As already indicated, Jordan's eastern desert probably has considerable ground water in storage, and careful studies may show that enough of it can be withdrawn to support small irrigation projects or other settlements.

Sources not yet economic

Experiments involving the direct use of saline waters in irrigation are in progress in adjacent countries and they show considerable promise for use with salt-tolerant crops. The prospects for increasing Jordan's water supplies by this approach are not as promising as some of the others discussed, but research in this field should be watched for possible applications in Jordan, not only in the Dead Sea rift valley but also at Azraq, where saline as well as fresh water occurs. The possibilities of using brackish or saline water in industrial processes that do not require fresh water should be investigated also.

Research on the demineralization of sea water is also in progress in many parts of the world. Indeed, several processes are already in commercial operation in several areas where the use for the water permits a higher cost. Costs have nowhere been reduced to the extent that demineralized water can be used for irrigation, and it may be years before this happens. Jordan is not yet in a position to contribute much to the advance of research on these problems, but she should keep abreast of new developments.

Summary

Although the data on which to base a firm estimate of Jordan's water supplies are not available, we may summarize what seem to be the order-of-magnitude values as follows: neglecting underground waters received from or lost to adjacent countries, the total supply received from rain and from inflowing rivers is of the order of 12,000 MCM per year. Of this, about 3,500 MCM per year are already being used for rain-fed crops, irrigation, and domestic purposes. Full development of arable land within the area of high rainfall and maximum use of potential sources of both surface and ground water discharge may yield about 2,000 MCM more, and artificially induced rainfall probably will add another 500 MCM. A large reserve of ground water probably is stored beneath the surface in Jordan, and it may be possible to withdraw some of it without seriously reducing the reserve. All told, Jordan's usable supply can probably be increased to about 6,000 MCM per year or slightly more.

Although we can thus see ways to substantially increase Jordan's water supply, this optimism is tempered by viewing the facts in relation to both present and future needs. Assuming that the present population is about 1.5 million, the potential usable supply is about 4 thousand cubic meters (TCM) per capita per year, and the total received is only about 8 TCM per capita per year. From an analysis of water requirements in other similar areas, Ionides (1939, p. 235) concluded that a minimum of 9 TCM per capita per year was required to support a population engaged in agriculture, and his assumptions suggest that this amount would not produce much of a surplus for an auxilliary population. From this study, Ionides calculated that the Transjordan part of the Dead Sea basin would support only about 280,000 people in agriculture--a number only slightly more than were then engaged in agriculture in that area. Applying his per capita requirement to the potential usable supply indicated above, the maximum agricultural population sustainable in the whole of Jordan would be about 660,000.

Since Ionides made his analysis, technologic advances have much increased agricultural productivity, so that the minimum water requirement now is considerably less. How much less is difficult to say; the data shown in table 2 indicate that in the United States about 8.2 TCM per capita are used for rain fed and irrigated crops and 1.1 TCM for other purposes exclusive of water power and forest and grazing land. Much of this is not used effectively and what is used produces an agricultural surplus. In view of this, the disparity between 4 TCM per capita Jordan can hope to have and the 9 TCM the United States is apparently using now is by no means staggering--in fact, the gap probably could be closed by the full application of modern technology, especially if the latter continues to develop, as we can expect it to do. But the comparison indicates that Jordan's problem is not an easy one to solve, and the data indicate clearly that Jordan will have to use modern agricultural and conservational practices to the maximum if she is to achieve a high level of living with a population of the present size.

Jordan's possible future needs are still more sobering, however, for whereas the maximum potential supply may conceivably meet the needs of the present population, we cannot hope that they will support at a high level of living a vastly larger population. If Jordan's population continues to grow at the present rate (which will cause it to double in about 25 years), the per capita gain will be short lived, if it is realized at all.

The estimates of the potential water supply point up a problem concerning plans for its use. In contemplating the development of Jordan's water supplies, one is inclined to think mainly in terms of irrigation, water spreading, recovery of underflow, and similar techniques of value mainly for agricultural purposes. Yet, as previously indicated, substantial industrial development is essential to a high level of living even in a country devoted mainly to agriculture, and water is a vital raw material for most industries. It is important, therefore, that considerable thought be given to the best use that can be made of Jordan's water supply before it is fully committed to any given purpose. This requires that good information on the distribution of available supplies of water and the other raw materials of industry be obtained in the near future.

Energy supplies

The per capita consumption of inanimate energy in Jordan in 1955 was about 0.1 ton of coal equivalent, compared to about 8 tons in Canada and the United States; nearly all of it was imported as oil. Although there is a tendency in Jordan now to avoid the use of labor-saving inanimate energy and machinery in order to give employment to the largest number of people, the general level of living will rise most in the long run by obtaining physical energy from cheap inanimate sources and by reserving human efforts for activities that require thought and skill. Clearly it is important for Jordan to much increase its consumption of inanimate energy.

The low cost of oil compared to its value measured by the work it will do makes it a bargain purchase at present prices, and it would pay Jordan to buy far more oil from neighboring countries than now contemplated, if this were the only available source of additional energy[1]. There are, however, several probable sources of usable energy in Jordan that she can hope to develop 1) oil, 2) oil shale, 3) water power, 4) nuclear power, 5) solar energy, and 6) wind power.

1/Plans for the construction of a petroleum refinery have recently been laid and are being carried forward now. This will use crude oil carried through Jordan by the Trans-Arabian Pipeline Company's line and I believe it will have a capacity of 1,000 tons of crude oil a day (= about 0.2 tons of coal equivalent per capita). This is perhaps slightly more than can be utilized effectively now (IBRD, 1957, p. 224), but as Jordan approaches a more advanced stage of industrialization her per capita requirements for energy will increase several times.

That Jordan's climate favors the recovery of solar and wind power requires no elaboration and these sources will not be discussed further. Methods are already available for using both sources for special purposes, and profitable use could be made of them now.

Oil

The oil possibilities in Jordan were reviewed by Gardner (1954), who considered them favorable because: a) the area contains a fairly thick section of marine sedimentary rocks, favorable for the formation and accumulation of oil; b) surface indications of oil in the form of oil seeps, asphalt springs, and bitumen deposits are found in the Dead Sea area; and c) geologic structures suitable as traps for oil are present in several parts of Jordan. As a result of Gardner's favorable report, oil exploration concessions were taken up by the Pauley (later transferred to the Phillips Petroleum Company) and Ismiri companies. The Phillips' Company drilled five holes, all of which were dry, and relinquished their concession early in 1959.

The experience of the Phillips Company is discouraging, of course, but five holes in an area of this size are not enough to rule out the possibility that Jordan contains oil. In addition to the evidence presented by Gardner, three points favor the occurrence of petroleum in Jordan. 1) As Gardner mentioned, the bituminous rocks of the Belqa are favorable source beds, but we may go considerably beyond this and say that marine phosphorite formations in general are good indications of the occurrence of petroleum, for nearly all of the marine phosphorite formations of the world have important oil fields associated with them. The reason for this association is that the phosphate-rich marine waters that produce the phosphorites also produce the tremendous growths of phytoplankton that eventually yield large accumulations of petroleum (McKelvey, 1959). 2) The environments of deposition of phosphorites and associated rocks are typically laterally zoned, with the result that rocks of one lithology change laterally into rocks of another lithology or facies. Such facies form important stratigraphic traps for petroleum that may not be evident from the structures observable at the surface, and we may be sure that such traps are present in Jordan. And 3) the anticlinal arch that lies along the western edge of the eastern plateau (fig. 2) appears to have formed contemporaneously with deposition of late Mesozoic sediments on and around it. This is suggested by the fact that the Belqa series on the arch contains much more chert and little or no phosphorite and bituminous shale than is the case to the east; hence the arch probably existed as a submarine ridge during the deposition of the Belqa. A similar situation has been found in the Negev by Bentor (1953). An arch of this type is especially favorable for the occurrence of petroleum, because it combines stratigraphic traps (both facies changes and pinch-outs) with a structural one. Much of this particular arch is not very favorable for the occurrence of petroleum now, for it has been breached to the core by later erosion in several areas, but parts of it appear favorable and similar structures probably occur in the relatively unexplored eastern desert.

Four of the Phillips' holes were drilled in pre-Belqa rocks on anticlines in northwestern Jordan[1/]; whether or not they were sufficient

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1/The fifth was a shallow hole in the Jordan Valley.

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in number to test these structures may be debatable, but it is certain that many more holes would be necessary to explore and test stratigraphic traps in the same general area. Beyond this, several other as yet untested areas appear highly promising. Especially so are the Dead Sea rift valley, particularly the El Lisan Peninsula (which may be a salt dome), and the Wadi Sirhan depression, for both these areas probably contain concealed bituminous source beds in the Belqa as well as favorable structural and stratigraphic traps. The probable presence of the same features in parts of the eastern desert makes it a generally favorable area also.

Although it is reasonable to believe that petroleum occurs in Jordan, it may not be found for some time and may never be found in large quantities. If either should prove to be the case, it is worth emphasizing again that it would be desirable for Jordan to buy more oil from neighboring countries. The profit obtained through its use in manufacturing, agriculture, and transportation will more than justify its cost.

Oil shale

The Belqa series contains important deposits of bituminous limestone and shale in the Yarmuk River-Wadi Arab area of northern Jordan, and in the Nebi Musa and other areas on the east flank of the West Bank. Blake (1930, p. 17) briefly investigated these deposits and had a few samples analyzed. These indicated that unweathered rock contains about 20 percent total organic matter, including about 28 gallons per ton of oil and some gas. The total calorific value of the rock is about 6¼ million Btu per ton compared to 28 million Btu per ton of good quality bituminous coal.

The amount of bituminous limestone cannot be estimated from available data except in an extremely rough way. Blake estimated that the northern part of the Nebi Musa area, where the bituminous limestone is 5 to 10 meters thick, contains about 25 million tons minable by stripping; and that the southern part contains more than 100 million tons minable by underground methods. Although he pointed to one strippable deposit in the Yarmuk area containing 1 or 2 million tons, Blake did not estimate the reserves over the region as a whole. As the bituminous limestone is about 100 meters thick in the Yarmuk area, each square kilometer underlain by th.. formation contains roughly 225 million tons of bituminous limestone. Although this formation almost surely underlies many scores, perhaps even a few hundred square kilometers in northern Jordan, it is not known now how much lies at depths shallow enough for low cost mining. Nevertheless, it is reasonable to expect that the amount of such rock is of the order of many billions of tons.

Blake considered three possible uses for the bituminous limestone: 1) direct fuel; 2) recovery of oil by distillation; and 3) manufacture of quicklime with by-product recovery of oil. The first use did not appear promising to Blake and does not now, merely because the low calorific value of the rock makes it a poor fuel to handle, ship, and burn. At the time of Blake's work, the recovery of oil by distillation was being practiced in a few areas but costs were high and the Belqa rock appeared to be very close and perhaps below the quality that could be used profitably for this purpose. Since then, the technology of distillation has improved markedly, and it seems likely that oil could be recovered from the Belqa at a reasonable cost if supplies were not available elsewhere. Lying as close to rich oil fields as Jordan does, however, it would not seem advisable to undertake large-scale treatment of the bituminous limestone for its oil alone. The third possibility discussed by Blake is of a different character, for it involves recovery of oil as a by-product of another useful operation. According to Blake, 100,000 tons of rock would yield 40,000 tons of quicklime and 8,500 tons of crude oil beyond that required to burn the lime. Data from which to estimate how much quicklime could be marketed are not available to me, but at the time (1930) Blake wrote his report, the consumption in Palestine was 50,000 tons. If a similar amount could be marketed in Jordan today, the by-product oil would be about 9,400 tons. This is an equivalent to about 12,000 tons of coal, and its importance to Jordan now is shown by the fact that the total inanimate energy consumed in 1955 was equal to 145,000 tons of coal. Because quicklime has a wide variety of uses and because the Belqa self-burning limestone should yield lime at a low cost, an important industry probably could be developed here. It is possible also that bituminous limestone could be used in the manufacture of cement. Certainly these possibilities deserve thorough investigation.

The bituminous limestone also contains some sulfur. The possibilities of recovering this as a by-product are discussed in a later section.

Water power

Jordan is not now recovering hydro-power, but she has potential resources on several rivers in the northern part of the country. The estimates shown in table 11 are the result of investigations of these sources by Baker-Harza (1955, vol. VI, p. 71).

The power from the Jordan would not be available if the latter is used for irrigation, as seems advisable, and the availability of the Yarmuk power is not only contingent upon the solution of difficult international problems, but would require an extremely high capital cost. For these reasons, Baker-Harza and IBRD (1957, p. 358) both recommend that plans for the development of power from these sources be laid cautiously.

The firm power available from the other rivers is estimated by Baker-Harza to be 6,450 kw, which compares to an estimated 7,000 kw available from all sources in 1955 (IBRD, 1957, p. 349). The amount of power potentially available from these undeveloped sources is therefore large. Although IBRD recommended that consideration be given to developing power from the Zarka River in the event that the future needs in the Amman-Ruseifa area prove larger than expected, they recommended that the immediate needs be supplied by expanding thermo-electric facilities. The reason for this recommendation is obscure, for "on the average the cost of electricity supplied today by hydroplants is substantially below the cost of electric energy from thermal plants" (President's Mat. Policy Comm., 1952, vol. III, p. 36). These sources

Table 11.--Estimate of Gross Power and Energy Available from Hydroelectric Resources (after Baker-Harza, 1955, vol. VI, p. 71)

Streams	Firm power	Annual firm energy	Average annual secondary energy	Average annual total energy
	(kw.)	(Million kwh.)	(Million kwh.)	(Million kwh.)
Yarmuk[1/] (Min.)....	2,340	20.5	45.4	65.9
(Max.)....	19,100	167.0	27.0	194.0
Jordan............	8,000	70.0	--	70.0
Zarka.............	4,350	38.1	22.9	61.0
Arab..............	1,260	11.0	--	11.0
Ziglab............	570	5.0	--	5.0
Jurum.............	270	2.4	--	2.4
Total (Min.)	16,790	147.0	68.3	215.3
(Max.)	33,550	293.5	49.9	343.4

1/Minimum and maximum according to location and height of the dam, and operating conditions.

would not supply all of Jordan's electric energy needs, which IBRD (p. 354) estimates will be 22,715 kw in 1960 and 29,950 in 1965, but they would supply a substantial part. The possibility of developing hydroelectric power from these rivers therefore should be scrutinized closely.

Nuclear power

Methods for manufacturing power from nuclear fission are still very much in the research and experimental stage, but even so, the cost of power obtained from this source is only about 1 to 5 times that from conventional sources and "it will undoubtedly become competitive" (Starr, 1959, p. 489). Jordan has no high-grade sources of uranium but she does have a potential by-product source in phosphorite. Available analyses suggest that these rocks contain about 0.01 percent uranium, which is roughly the same as that found in the Florida phosphorite. Uranium from the latter is currently recovered as a by-product of the manufacture of triple-super phosphate at a cost about the same as that of uranium derived from high grade uranium ores. As is discussed in a later section, the known phosphorite reserves in the Ruseifa area total about 30 million tons, and potential reserves in the adjacent area are of the order of 100 to 175 million tons. Not enough samples of this rock have been analyzed for uranium to be sure that all of it contains the amount indicated above, but very likely much of it does. The significance of this as a source of energy for the future may be appreciated by this comparison: one pound of uranium is the potential power equivalent of 1,200 tons of coal, so the 0.2 pound of uranium in a ton of phosphorite is the potential power equivalent of 250 tons of coal. Therefore, if the Ruseifa phosphorite reserve contains 0.01 percent U, as appears to be the case, it is the potential power equivalent of 7.5 billion tons of coal. Not all of the uranium in phosphorite is recoverable, of course, and an additional loss of power equivalent takes place in the conversion of nuclear energy to usable power; nevertheless, an enormous potential supply of usable energy is contained in these uraniferous phosphorites.

Summary

Although Jordan now recovers no inanimate energy, she has several sources that would permit a vast increase in her consumption of energy. She has good prospects of finding oil, and in any case can buy it cheaply from neighboring countries. Available technology would permit the immediate recovery of hydroelectric power, and, for special purposes, wind power, and solar power. Development of industries utilizing her large deposits of bituminous limestone would not only yield useful chemical and building materials, but a crude oil by-product as well--large enough perhaps to support other chemical industries. And for the future, Jordan has large supplies of uranium for use in the manufacture of nuclear power.

All of these sources will yield power at present costs, but, with the exception of oil and gas, if they should be discovered in large quantities, none of them will yield very cheap power, and all of them will require the full application of modern technology to develop and use efficiently. Therefore, Jordan's consumption of inanimate power will increase slowly. The point is, however, that her own resources will support a tremendous increase ultimately, and that these sources can be developed about as fast as the industries that will use it.

Metalliferous minerals

Jordan is currently not mining any metalliferous minerals, and all of her known deposits are either small or difficult to exploit for other reasons. Some prospects deserve further investigation, however, as indicated in the following pages.

Iron

On the north slope of Wadi Zarqa, 12 km south of Ajlun, high-grade hematite and limonite ore occurs in poorly explored lenses in limestone. According to Blake (1930, p. 36) and Krauskopf (1955), samples contain more than 50 percent Fe and less than 0.05 P. Exposures are too poor to judge the extent of the ore. Blake thinks it doubtful that the deposit contains more than 200,000 tons of high-grade and 200,000 tons of low-grade ore; both he and Krauskopf, however, think that the ore solutions probably came from depth and they recognize that replacement of the limestone might have taken place on a more extensive scale than can be judged from available exposures. The exploration necessary to determine this would be rather costly, and it is unlikely that it would define a deposit large enough to support a local steel industry, particularly in view of the shortage of suitable fuel. On the other hand, a number of small (i.e. a million tons or so) but high-grade deposits of iron in the United States have been mined in recent years and ore from some in the Rocky Mountain States has been shipped to Japan. Perhaps such an enterprise would be profitable here, or perhaps, as Quennell (1951, p. 114) suggests, it might be possible to mine some of the ore as a source of pigment. These possibilities deserve investigation, not because they would immediately aid Jordan's economy, but because they would at least open up the deposit and permit a better appraisal of its full potential than could be obtained without costly physical exploration.

Blake (1930, p. 26) mentions oolitic iron minerals in the Ajlun formation in Wadi Faria, east of Nablus, and Picard (1955) thinks this is the same horizon that has recently been investigated as a source of iron in Israel. The iron-bearing beds in Israel are 2-3 meters thick and appear to have great lateral extent, but because they contain only 26-28 percent Fe, they would have to be beneficiated. Even if the deposit near Nablus proved to be similar in extent it would be many years before it would be an economic source of iron for Jordan.

Copper and manganese

Both Blake (in Ionides, 1939, p. 114) and Quennell (1951, p. 114) mention indications of copper in an intrusive igneous rock, but do not give its location. Aside from this doubtful occurrence, the known copper deposits are in the vicinity of Wadi Araba. In Wadi Dana, most of the copper occurs in a manganese ore that lies in lenticular, relatively tabular bodies along or close to the contact between the top of the Cambrian Burj dolomite and near the base of the overlying sandstone. The Dana deposits have been sampled by Mackay and Schnellmann in shallow trenches and briefly studied by Krauskopf and others. Krauskopf estimates the reserves to be about 200,000 tons containing about 45 percent Mn and 2 percent Cu. Because copper has been regarded as a deleterious constituent of manganese ore, and attempts to recover the copper separately have not been successful (Thompson, 1956, p. 10), the ore has not been mined. Other, perhaps more fundamental drawbacks are that the deposit is now relatively inaccessible, and the known reserves are too small to justify the expense of building a road or arrangements for a special treatment or market. The one problem discourages work on the other, and so investigation of the Wadi Dana ore is at a standstill.

For reasons that will be explained below, the prospects of finding important manganese or copper deposits in the Wadi Dana area seem reasonably good, good enough at least to warrant further exploration if the ore were more accessible and could be processed and marketed easily. Such exploration would be expensive, however, so it would be advisable to delay it until availability of a suitable process or market is assured. For example, because of the increased use of scrap in steel manufacture over the years, the copper content of many steels is higher than it used to be, and some manufacturers might not consider copper the deleterious constituent they once thought it to be. In fact, the Dana ore might bring a premium price for use in making the copper-bearing rust-resistant steel recently developed. It is possible also that a means is now available for recovering the copper as a co-product.

In essence, periodic review of the question of marketability of the ore would seek an affirmative answer to a question such as: could this ore be processed and sold if its reserves were, say, a million tons? If such assurance were received, search for additional reserves would be justified. Even if such exploration is successful, however, actual mining should be postponed until a road is built up Wadi Araba for other purposes, for the expense of a road would be prohibitive if it had to be borne by the mine alone.

The reason for thinking that additional reserves may be found in the Wadi Dana area is that two other closely similar occurrences in the general region have important reserves; they are better known than the Wadi Dana deposit, and provide a better basis for appraising its potential than can be gained at this stage from Wadi Dana alone.

The best known of the other occurrences is the Um Bogma manganese oxide district on the Sinai peninsula of Egypt (Attia, 1956). The ore there contains only a few hundredths of a percent of copper, and it contains iron in amounts ranging from less than 1 percent to 35 percent or more. Some ore is found in faults or fissures, but most of it occurs in irregularly shaped tabular bodies that range from less than 1 meter to 8 meters in thickness and from a few meters to several hundred meters in diameter. These bodies generally occur in sandstone, sandy shale, or shale at the base of a dolomite of Carboniferous age, or within the lower part of the dolomite itself. The host rocks are a part of the Nubian sandstone facies. Most of the ore bodies at Um Bogma are grouped along fault lines; they tend to be elongated along them; and their grade and thickness diminish away from the faults. In spite of the fact that they are present at a single stratigraphic horizon, the ore bodies are clearly metasomatic replacements associated with late Tertiary faulting and basaltic igneous activity. Manganese ore, mostly in veins in the underlying basement rocks, also occurs at several other localities in the Sinai; all of them are probably of the same age and origin as those at Um Bogma.

The Um Bogma district produced about 3.5 million tons of ore prior to 1955; proved reserves at that time were 2 million tons, and, according to Attia, scores of millions of tons probably will be found on additional exploration.

The other manganese oxide district in the general region is at Timna in the Negev of Israel (Bentor, 1956; Picard, 1955; Dor, 1955). The manganese ore there contains about 1 percent copper, and copper, mostly as chrysocolla, occurs in the same stratigraphic unit over a wider area. Both the manganese and copper ore are in lenticular tabular bodies in sandstone and shale at the top of a Cambrian or Ordovician dolomite. According to Bentor (1956, p. 171), the copper is more abundant where the underlying dolomite was eroded prior to deposition of the sandstone, and hence where the sandstone is thickest; manganese is most abundant where the dolomite is preserved in its maximum thickness. Faults are present, but no pronounced relation has been observed between them and the distribution of the ore. According to Bentor, no igneous intrusions are known in the area, and he considers both the copper and the manganese to be sedimentary in origin. This interpretation will be discussed later, but the important things to recognize here are that a qualitatively similar assemblage of minerals occur in "bedded" deposits associated with a dolomite in the Nubian sandstone facies in both the Negev and the Sinai.

The Timna deposit is estimated to contain 560,000 tons of high grade concretionary manganese ore in a zone generally less than 1 meter thick, and about 10 million tons of low grade disseminated ore. Possible reserves of copper ore are estimated to be about 60 million tons, the average grade of which is about 1.5 percent Cu, and the average thickness about 6.25 m (Dor, 1955). The manganese ore is too thin or too low grade to be of commercial value now, and current plans are focused on the copper alone.

As previously mentioned, the Wadi Dana deposits are also tabular lenticular deposits that occur along the contact between a dolomite and shale or sandstone within the Nubian sandstone facies. Their extent and geologic relations are poorly known, for they are not well exposed naturally and have been cut only in shallow trenches. There is a suggestion, however, that their distribution is related to faults, one of which is followed by Wadi Dani itself; its displacement is such that beds on the south side of the canyon are about 200 meters higher than their equivalents on the north side (Krauskopf). Most of the known deposits occur along the north canyon rim and are found sporadically over a distance of about 3 km. One deposit occurs on the south side of the canyon about 2 km east of the other group of deposits. An igneous intrusion, thought to be the neck of a volcanic vent, occurs at the head of Wadi Dana about 10 km to the east.

Remains of an ancient copper smelter are found at Feinan near the mouth of Wadi Dana. Although Mackay and Schnellmann conclude that the ore for this operation was the cupriferous manganese ore now known in Wadi Dana, several other occurrences of copper minerals in sandstones of about the same age are known at other localities within a few kilometers to the north and south of Feinan. References are made both by Glueck (1940) and Blake (1930, p. 35) to specimens of copper sulfides in the vicinity of old slag piles, and this suggests that ancient workings somewhere in the area may have penetrated unoxidized deposits. Although most of the copper known in the Wadi Dana area is in the manganese ore, or is intimately associated with it, the other showings of copper in Wadi Araba indicate that copper also occurs separately, as it does at Timna.

The Um Bogma, Timna, and Wadi Dana deposits are not identical. The Um Bogma ore contains more iron and less copper than the others; the Wadi Dana manganese ore is more cupriferous than the Timna ore and no extensive non-manganiferous ore is known; and at Um Bogma, the main ore horizon is the lower rather than the upper contact of the dolomite. But the similarities are even more striking, and the Timna and Um Bogma occurrences suggest that large deposits of either copper or manganese or both could occur in Wadi Dana or its vicinity.

Analysis of available data on the Wadi Dana and other deposits in the region provides some information that may guide further prospecting, when and if other developments warrant it. Knowledge of the origin of the deposits is especially helpful in early stages of exploration, and we may consider this problem first. The difficulty of determining the origin of deposits such as these is shown by the fact that each of the deposits in question have been assigned a different origin by those most familiar with them. The Um Bogma ore is considered to have been derived from hydrothermal solutions arising along late faults; the Timna deposits to have formed in Early Paleozoic time by deposition in a shallow sea;

and the Wadi Dana deposits to have formed from descending solutions that may have concentrated manganese previously dispersed in the overlying sandstones. Under each of these hypotheses, it is possible for ore to form in tabular bodies that are roughly conformable with other layers in a sedimentary sequence and that occur at one sedimentary horizon. There are, however, differences in the deposits formed in each of these ways that are economically important: sedimentary ores generally have greater lateral continuity than the others, and their distribution is not related to later structures, such as faults, or to the present topography. The distribution of epigenetic ores in sedimentary rocks may be controlled by primary sedimentary features--chemical composition or permeability--that influence the migration of ore forming solutions and precipitation of their constituents, but they are likely to show some relation also to later structures. The distribution of some deposits that are formed by descending solutions, particularly those within the zone of weathering, is related to the topography of the land surface.

Following a suggestion offered by D. F. Hewett, I undertook, as one approach to the problem, to compile and examine many chemical analyses of vein deposits, of manganese deposits associated with modern hot springs, and of manganese deposits forming on the present sea bottom. These analyses suggest that more than 1 percent BaO, 0.2 PbO, 0.1 As, and any amount of WO_3 indicates a hydrothermal source; whereas more than 0.2 percent NiO, and 0.2 TiO_2, and less than 1 percent BaO indicates a sedimentary origin. Judged by these criteria, the three deposits in question are hydrothermal, for all are high in barium and low in titanium and nickel. The lead content of the Um Bogma ore is low-only 0.07 and 0.14 percent in the analyses reported by Attia--and that of the Dana ore has not been reported; in the Timna analyses, however the PbO content is 0.22 and 0.93 percent. The presence of manganese in tufa deposits now being formed by the Zarqa Ma'in hot spring adds some support to this conclusion; even though the manganese there is of no economic value and occurs about 100 km north of the Dana deposit, it shows that manganese-bearing hydrothermal waters are associated with late igneous activity in the region. All of the evidence together suggests that the origin of the deposits is essentially that described by Attia (1956) for the Um Bogma deposits--precipitation from hydrothermal solutions arising along late Tertiary faults. As on the Sinai peninsula, we may expect to find, therefore, some veins in the older basement rocks as well as tabular bodies in the Nubian facies in close proximity to faults.

In the Wadi Dana area, therefore, further prospecting might focus especially on deposits that appear to be close to major faults. In this connection, the reason most of the ore is on the north side of the canyon may be because the mineralized horizon on the south side of the main Wadi Dana fault is at such a high elevation in that part of the valley that the part close enough to the fault to be mineralized has been stripped away by erosion. The one occurrence of ore on the south side of the fault is closer to the head of the canyon, where erosion has not cut so deeply or widely. If the ore in Wadi Dana is related to the main fault, it would be worth testing the ore horizon on both sides of the fault in the upper reaches of the canyon (where it has not been exposed by erosion) by diamond drilling. This, incidentally, is one of the few areas within Wadi Dana where diamond drilling would be feasible, and even there it would be difficult because of the rugged nature of the gorge. Exploration elsewhere in the area probably will be done best by driving adits into the more promising deposits (judged both by surface showings as well as relation to structure), and perhaps augmenting them by cross-cuts and short drill holes from within the workings.

Discovery of a Timna-like deposit would be extremely important to Jordan, for it would form the basis for an internal copper industry and provide revenue from export as well, but the copper-bearing manganese deposits are the bird in the hand. It seems best, therefore, to concentrate on the exploration of the manganese deposits first. Exploration for copper in the same general area would follow naturally, and could be carried out more wisely than would be possible now.

In summary, the known occurrences of cupriferous manganese ore and copper minerals in Wadi Dana, together with information on other better known deposits in the same general region, suggest that the area could contain sizable deposits of manganese or copper or both. Exploration to test this possibility should be postponed until a suitable process and market for the ore is assured, and mining should not be attempted until a road is built up Wadi Araba for other purposes besides access to the mine area alone.

Other metalliferous deposits

High-alumina clays have been found in the Kurnub formation of Lower Cretaceous age in the Negev, and, according to Picard (1955, p. 32), they also occur in the same formation in Jordan. Very likely their greatest use will be as a source of clay, but if any deposits of the quality mentioned by Picard (60 percent Al_2O_3) are found to be extensive they may also have promise as a source of aluminum.

The Dead Sea brine is extremely rich in magnesium salts, in fact more so than most other brines from which magnesium salts and metal are currently being produced[1/]. Perhaps the greatest value of this is not as a source of metal (which requires cheap power to make), but for other magnesium compounds. Nevertheless, magnesium metal is coming into greater use, and it may be practical eventually to produce it from the Dead Sea brine.

No other metalliferous deposits are known in Jordan, and inasmuch as the area has been occupied for several millenia it is safe to assume that important surface outcrops of minerals with a metallic luster or bright color (such as many metalliferous minerals have) would have been found already if they existed. Nevertheless, Jordan has a granitic-metamorphic terrane in the southern part of the Kingdom that could contain

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1/"The average magnesium content of sea water is 0.13 percent. Sea-water bitterns--the liquor residue from extraction of sodium chloride (salt)--contains 6.0 to 8.7 percent magnesium chloride ($MgCl_2$) and 4.2 to 6.1 percent magnesium sulfate ($MgSO_4$). Michigan well brines contain about 10 percent magnesium chloride." (U. S. Bur. Mines Bull. 556, p. 484). The Dead Sea Brine, below depths of about 300 feet, contains about 12.8 percent of $MgCl_2$ and 0.5 percent $MgBr_2$.

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deposits of metalliferous minerals of two general types: 1) poorly exposed or concealed deposits that were not found by the ancients even though they may have been familiar with the type of mineral involved; 2) deposits of minerals with a nonmetallic luster, such as rare earth- and tungsten-bearing minerals, that had no value in ancient times and have never been prospected for. For example, Blake (in Ionides, 1939, p. 62) mentions an intrusion of augite-nepheline syenite in southern Jordan. Alkalic rocks of this type often have associated deposits of rare-earth minerals, apatite, ilmenite, and magnetite, and such rocks may be the source of the black sands reported in southern Jordan and Israel (Dor, 1955). The association of these minerals with alkalic rocks is not an invariant one, and no great hope can be held now for their discovery; nevertheless, the possibility justifies geologic mapping, as will be discussed more fully later.

Phosphate

Previous investigations

The phosphate deposits of Jordan were discovered in cuts made near Ruseifa and El Hasa during the construction of the Hejaz railroad in the early part of the century. G. S. Blake (1928; 1930; in Ionides, 1939) made observations concerning the distribution, thickness, and quality of exposed deposits in the course of his geological reconnaissance of Palestine and Transjordan, and he acquired most of the data--still meager--available on the regional stratigraphy of the Belqa series, in which the phosphate deposits occur. Lucien Cayeux (1939) studied the composition, mineralogy, and petrography of specimens of phosphorite from Jordan and adjacent areas furnished by Blake and others. A. M. Quennell (1951, 1956) made a reconnaissance geological map (scale 1:250,000) of the western part of former Transjordan, which shows the approximate distribution of the Belqa series. W. T. Benson (1954), K. B. Krauskopf (1955), James Barr (IBRD, 1957), and D. J. Burdon (in press)--consultants employed by ICA, the World Bank, and the United Nations--briefly examined the more important deposits and made recommendations concerning their exploration or development. Pierre Delaitre (1956), a geologist attached to the United Nations Technical Assistance Administration (UNTAA), gave advice to the Jordan Phosphate Mines Co. and the Ministry of Nationa Economy concerning the mining operations at Ruseifa, and he refers to previous reports, which I did not see, by Hawari, Hencock, and Deflandre (presumably all consulting geologists or engineers employed by the Kawar family, which first developed the Ruseifa deposits, or the phosphate company) in 1936, 1938, and 1955 respectively. Isam Khairy of the HKJ Ministry of National Economy collected samples and measured sections in the El Hasa area. Otto Nottmeyer, a mining engineer of UNTAA assigned as an advisor to the Ministry of National Economy, has examined some of the deposits and made some recommendations to the Jordan government concerning their development.

Most of the exploration of the phosphate deposits has been done by Mackay and Schnellmann (British consulting geologists) under contract with the Jordan government, and by Jugometal, which is, by a trade agreement, responsible to Jordan Phosphate Mines for technical supervision of mining and exploration. The Mackay and Schnellmann work consisted of test pitting at intervals of scores or hundreds of meters, sampling, simple beneficiation tests, and some mapping in both the Ruseifa and El Hasa districts. They also made a reconnaissance search for phosphate in the vicinity of Qatrana, Ras en Naqb and perhaps intermediate areas. The results of these investigations are summarized in reports dated July 1954, March 1955, and July 1957.

The recent exploratory work of Jugometal and JPM is analogous in character and scope to that of Mackay and Schnellmann, and it too has been concentrated in the vicinity of Ruseifa and El Hasa. The results are summarized in an application to the Development Loan Fund for a loan to finance a proposed expansion in the Ruseifa area.

Geology of the phosphorite-bearing formation

Age and vertical succession

The phosphate deposits of Jordan are of Maestrictian (Upper Cretaceous) age. They are a part of the Belqa series, a marine formation that includes rocks ranging in age from Upper Cretaceous (Coniacian) to Eocene. The vertical succession of the rocks composing the Belqa is as follows: the lower part consists of interbedded nonresistant limestone and chalk or marl beds, locally bituminous, 35-235 meters thick, overlain by relatively resistant, often contorted chert limestone beds, 5-300 meters thick; these beds are overlain by the phosphorite-bearing unit--5-35 meters of interbedded nonresistant phosphorite, marl, bituminous limestone, and chert. The upper part of the Belqa consists of nonresistant chalk (including some cherty layers), marl, and limestone beds, locally bituminous; in some areas, as in an exposure 7 kilometers west of Ma'an, chert and thin beds of phosphorite are present also. The thickness of the upper Belqa is poorly known, for it is covered in many areas and partly stripped away by erosion in many others, but the remnants measured by Blake are 30-120 meters thick.

Extent and areal variations

The Belqa series probably once extended over all but the extreme southeastern part of Jordan but since its deposition it has been stripped away by erosion from the crests of anticlines on the West Bank, and along the margin of the plateau east of the Dead Sea rift and near the southern border of Jordan, and covered by younger deposits in parts of the Dead Sea rift valley and the eastern desert.

The Belqa is poorly exposed in most places, and not many sections have been measured. The scattered observations on its thickness and lithology, summarized in table 12, are sufficient, however, to show some important areal variations. Some of these variations are due to the effects of weathering or metamorphism. For example, dark bituminous rocks have been observed only near the eastern margin of the West Bank, in the vicinity of the Yarmuk River, and Wadi Qatrana. These are deeply dissected areas and it is probable that relatively unweathered rocks are exposed in them; very likely the chalks, marls, and phosphorites on the eastern plateau were also rich in carbonaceous matter at the time of their deposition.

Table 12.--Lithology and thickness of the Belqa series at various localities[1]

West Bank

Nablus[2]	Jenin[2]	Jerusalem[2]	Safed, Israel (north of Jenin)[3]
Red and yellow chalk, 30-90 m.			Bituminous limestone and chalk, 185 m.; chert bed about 60 m. above base
Chert, 5 m.	Chert absent	Chert	

Bethlehem[3]	Nebi Musa (12 km S. of Jericho)[2]	Dead Sea Valley[2]
Black phosphorite	Gypseous limestone, 65 m.	Phosphatic limestone, bituminous limestone, flinty limestone 150 m.
Older rocks not described	Black gypseous shale, 30 m.	Cherty limestone, 30-90 m.
	Brown phosphatic limestone, 6 m. Black bituminous limestone with thin chert beds, 18 m. (thin out to west)[3] Phosphorite with thin chert beds, 15 m. Limestone, some phosphorite, 45 m.	Chalk with some hard limestone, 90 m.

1/The information is incomplete at many localities but whatever is available is reported here for the light it may cast on areal variations in lithology and thickness.
2/Blake, 1928, p. 17-18.
3/Blake, 1930, p. 30.

Table 12.--Lithology and thickness of the Belqa series at various localities--Continued

East Bank		
Irbid-Yarmuk River 4/	**Salt**	**Amman-Ruseifa**
Red chalk	Metamorphosed phosphorite and limestone	White marl and chalk, 15 m.
Chert, 75 m.	Phosphorite and limestones	Red and green chalk, 25-30 m.
Bituminous limestones, 90-150 m.	Chert	Phosphorite, chalk, and marl, 15-20 m.
	Limestone	Chert with few limestone layers, 30-70 m.
		Limestone and chalk, 235 m.
Kerak-Qatrana 4/	**10 km E. of Qatrana 4/**	**El Hasa 4/**
Phosphorite, limestone, and chalk	Phosphorite	Chalk and chert
Chert, 150-170 m.	Angular unconformity Brecciated chert	Limestone phosphorite and chalk 40-50 m.
Bituminous limestone, 45 m.		Chert and limestone
Aqabah Naqeb (S. of Petra) 4/	**Ain Musa (near Petra) 4/**	**Ma'an-Ras en Naqb 4/**
Chert, 130 m.	Quartzitic sandstone, chert, silicified phosphorite, 180 m.	Cherty limestone, 20 m.
Cherty limestone, 15 m.		Nummulitic limestone, 10 m.
	Chert, 300 m.	Gypseous marl, 10 m.
	Dolomite, 50 m.	Red chalk, 15 m.
		Phosphatic, cherty limestone, 30 m.
		Massive chert, clay partings, 30 m.

4/ Blake, in Ionides 1939, p. 84, 87-90.

The phosphorites and associated rocks in the vicinity of Salt are metamorphosed and have a slaty or phyllitic texture. The origin of this metamorphism isn't clear; the rocks are tightly folded, but because intense physical deformation of such rocks in other parts of the world has not produced such metamorphism, it seems probable that it must result from some igneous intrusion, not exposed.

The observations in table 12 indicate that the lower chalk-marl section thins out westward along the western edge of the plateau south of Kerak, that the chert is thicker in this area, and that phosphorites are thin or absent in the same area. Quennell (1951, p. 101) also mentions that in the thick sections of the Belqa exposed in the Edh Dhira monocline west of Kerak, the Wadi el Bustan northeast of Shaubak, and along the Sadaqa-Gharandal road between Petra and Ras en Naqb both the bituminous chalk and phosphorite members are missing. Phosphorite is present at a number of localities on the West Bank between Bethlehem and the Dead Sea Valley, and on the East Bank between Amman and Ma'an (fig. 3). Of the known deposits, those in the Salt-Amman-Ruseifa area are thickest and richest; other minable but somewhat lower grade deposits known are in the vicinity of El Hasa; all the other known deposits are too thin and/or low grade to be minable now.

Bentor (1953) has shown that in the Negev of southern Israel the phosphate rocks (there of Campanian age, supposedly equivalent to the chert-limestone unit of the Belqa series in Jordan) are best developed in synclines, are thin and of poor quality on the flanks of adjacent anticlines, and pass into cherts on the anticlinal crests; this and other evidence he interprets to mean that the anticlines began to develop while the sea still covered the area, and that the very shallow water environment created along the crests of these rising anticlines was unfavorable to the deposition of phosphorite. We have found a similar depth-facies relation in the rocks of the Phosphoria formation in western United States and find Bentor's interpretation wholly credible.

The structural history of Jordan is not easy to interpret because of the complex rift faulting that is superimposed on earlier structures, but it appears from Quennell's maps and from Burdon's structure sections that the western margin of the plateau is the flank of an arch (perhaps a southward continuation of the Ajlun anticline) whose axis, prior to rift faulting, lay near the eastern edge of the Dead Sea rift, and plunged gently north-northeastward. It seems likely, therefore, that the absence of phosphorite in the area along the edge of the plateau south of Kerak is due to nondeposition in an unfavorable environment created by tectonic elevation of the sea bottom during the deposition of the Belqa series. If this is true, and if (as found in the Phosphoria and other phosphorite formations) the zone of phosphorite deposition on the sea bottom corresponded to some favorable depth zone, it is possible that some pattern may be found to what might otherwise seem to be an irregular or erratic distribution of phosphorites. Favorable environments presumably would be the basins (synclines) between submarine ridges (anticlines but if the sea bottom (both ridges and basins) had a regional slope, only some part of the basins would fall within the favorable zone, and, on the other hand, phosphorites might also be deposited on ridge tops where they pass into deeper water. Enough data are not available now on the location of folds that formed prior to or during the deposition of the Belqa or on the distribution of phosphate deposits either to adequately test this hypothesis or to accurately guide further prospecting. About all that can be said now is that the distribution of known structures and phosphorite deposits suggests that the richest and thickest phosphorites occur on

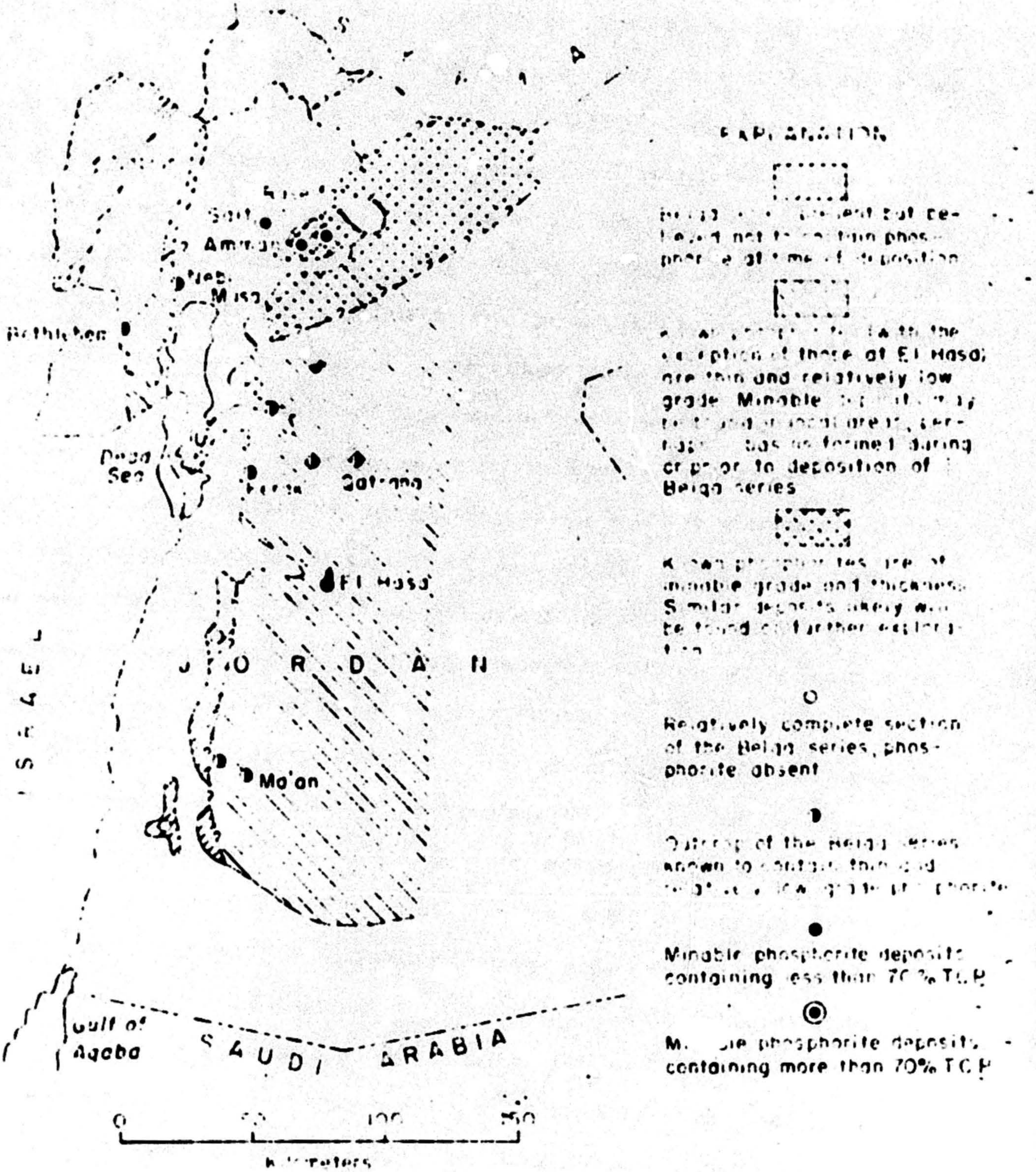

Figure 3. Probable distribution of phosphorites in Belga series, Jordan. Boundaries shown between various areas are speculative and are shown only to bring out what available information suggests are regional trends.

the plateau north of El Hasa and east of Kerak (fig. 3). Minable deposits may be found considerably east and north of those now known; and inasmuch as local concentrations of phosphate are sometimes found in fringe areas (as in the Phosphoria formation in parts of Montana) it is possible that minable deposits will be found between El Hasa and Ma'an.

Phosphate deposits

Ruseifa-Amman area

Geology.--The phosphate deposits in the Ruseifa-Amman area lie in a broad syncline that plunges gently northeastward. This syncline is occupied by the upper reaches of the Zarqa River, and, except in the deep valley adjacent to the river itself and in some of the tributaries, the rocks are covered by older alluvial deposits formed when the river was at a higher elevation. The chert unit underlying the phosphorite zone crops out along the margins of some of the deeper valleys, and exposures of all the rocks are found in artificial cuts in and near Amman. Over much of the area, however, exposures of the phosphate beds are limited to test pits dug by Mackay and Schnellmann or JPM.

The phosphorites are of two main types. The type mined is light gray or yellowish gray, soft, and contains 70-74 percent tricalcium phosphate (T.C.P.). The other type is not mined at present; it is also light colored but is relatively hard, calcareous, and generally contains less than 68 percent T.C.P. The soft phosphorite goes under the name of "soft phosphate" in the trade. It is recognized by a special name not only because it is soft, but because it has somewhat different (and better) acidulation characteristics than hard or pebble phosphate. Both hard and soft types are composed of the same phosphate mineral, carbonate fluorapatite.

Four beds of phosphorite are of minable thickness in the Ruseifa area and a fifth is believed to be present in the southern part of the area. A representative section of the phosphatic portion of the Belqa in the vicinity of the mine, compiled for me by JPM geologist Mr. Ali Rashad Azzeer, is shown in table 13.

Table 13.--Stratigraphic section of the phosphatic part of the Belqa series in the vicinity of Ruseifa

	Thickness (in meters)	T.C.P. (percent)
Upper marl-chert series	50	
Phosphorite (BED IV)		
Soft phosphorite	1.4	71-72
Hard phosphorite	0.4	52-53
Soft phosphorite with a few thin bands of clay at base	1.1	71-72
Chert	0.1	
Rosy limestone	0.6	
Soft marl	1.75	
Chert	0.05	
Phosphatic marl, chert, and limestone	1.7	
Phosphorite (BED III)		
Soft phosphorite	0.4	68-69
Marl with thin clay layer in center	0.15	
Soft phosphorite	0.6	68-69
Chert	0.1	
Soft phosphorite	0.2	70
Rosy limestone, thin layer of marl at base	0.8	
Phosphorite (BED II)		
Soft phosphorite	1.15	72
Hard phosphorite	0.2	52-53
Soft phosphorite	0.3	72

Table 13.--Stratigraphic section of the phosphatic part of the Belqa series in the vicinity of Ruseifa--Continued

	Thickness (in meters)	T.C.P. (percent)
Lenticular limestone and soft phospherite	0.15	
Soft phosphorite, marly near top	0.5	72
Phosphatic clay and marl, thin layers of limestone near top	0.75	
Limestone, marl, and soft phosphorite, interbedded	0.85	
Limestone, some marl and clay in middle	0.9	
Hard phosphorite, limestone, and phosphatic chert	0.35	
Phosphorite (BED I)		
Soft phosphorite	0.65	73-74
Hard phosphorite	0.45	52-53
Soft phosphorite	0.9	73-74
Dark chert, thin limestone layer at top	0.35	
Soft phosphorite, thin clay layer at top	0.25	
Hard phosphorite and limestone	0.3	
Phosphatic marl and clay; limestone concretions near base	0.9	
Hard phosphorite	0.35	
Limestone and chert interbedded; thin layer of soft phosphorite near base	1.3	

Table 13.--Stratigraphic section of the phosphatic part of the Belqa series in the vicinity of Ruseifa--Continued

	Thickness (in meters)	T.C.P. (percent)
Soft phosphorite (BED 0)	0.7	76-77
Chert, marl, and phosphorite, interbedded	1.6	

The average thickness and T.C.P. content used by JPM in its calculation of reserves in its application to DLF are as follows:

Table 14.--<u>Average thickness and T.C.P. content of phosphorite beds in the vicinity of Ruseifa</u>

Bed No.	Thickness (meters)		T.C.P. (percent)	
	North area	South area	North area	South area
IV	1.83	1.52	73.73	70.8[illegible]
III	0.73	0.97	64.97	69.69
II	1.50	1.00	72.05	71.03
I	0.94	1.66	72.70	73.98
0	--	0.81	--	76.5

The individual layers described in these sections, as well as thinner ones not recognized separately, have great lateral continuity, although they vary somewhat in thickness and composition. Part of the variation in grade and thickness may be primary, part may be due to folding (the beds are locally tightly folded), and part is due to the differential effects of weathering and redeposition of calcium carbonate and perhaps gypsum. The light color, exceptionally high phosphate content, and the presence of secondary uranium minerals are indications of deep oxidation, sufficient to remove the carbonaceous matter almost surely present at the time of deposition. Nearly all of the soft phosphorites become harder and slightly lower grade as they approach the surface; this is apparently due to a caliche-like secondary deposition of calcium carbonate.

The three soft phosphorites each contain a central hard and lower grade layer, which, along with hard lenses and concretions, is screened out or otherwise separated during mining or crushing.

Reserves.--The reserves of phosphorite in the area in which JPM holds or has applied for a lease are stated in their DLF application to be as follows:

Table 15.--Reserves of phosphorite in the vicinity of Ruseifa

Bed No.	Total area (square meters)	Total tonnage (metric tons)	Average T.C.P. (percent)
IV	1,425,000	5,108,246	72.0
III	2,173,400	4,320,888	68.5
II	2,592,600	6,397,160	71.8
I	3,028,000	9,947,872	74.0
0	3,056,400	5,446,505	76.5
Total (rounded)		31,200,000	
Total excluding III		26,900,000	

The area in which these reserves lie is roughly 4 x 4 kilometers in size. It lies within a larger area, about 3 kilometers wide and 15 kilometers long, in the Ruseifa Valley, sampled by Mackay and Schnellmann by test pits on a grid of about 400 meters. Mackay and Schnellmann estimated that this larger area contains 16,480,000 square meters underlain by Bed I, and that recoverable reserves in this bed total about 29,500,000 metric tons. They made no separate calculations of the reserves in the other beds because they felt these were too irregular in grade and thickness, but estimated that they contained a gross tonnage of 9-1/4 million tons containing 65 percent T.C.P.

By either estimate, the reserves within the explored area are large and represent, at the minimum, a 30-year supply at the rate the company hopes to produce in the future. The difference between the two estimates, however, is conspicuous--Mackay and Schnellmann's estimate of the tonnage in the upper beds in the larger area is about three-fifths that of JPM for the smaller area; and whereas Mackay and Schnellman estimate that the 16.48 million square meters underlain by Bed I in the larger area will yield 29.5 million tons, JPM estimates that in the mine area 3.03 million square meters will yield 9.9 million tons from the same bed. Very likely the difference between these estimates reflects the stage of exploration at which they were made. At the time Mackay and Schnellmann made their estimates not much was known about the continuity of individual layers beyond the small area then exposed by mining, and the results of widely spaced test pits could only be interpreted cautiously. JPM's present estimates are based on many more test pits and on much more knowledge of the continuity and characteristics of individual layers gained through additional mining; they probably give a more reliable picture, therefore, than did the early, more conservative estimates.

According to Mr. Khairy, JPM now estimates the reserves in the remainder of the area explored by Mackay and Schnellmann at about 50 million tons rather than the approximately 20 million tons that might be deduced from Mackay and Schnellmann's figures. These figures do not seem unreasonable, for if the 16.48 million square meters Mackay and Schnellmann consider to be the area of Bed I in the broader area yields phosphorite in the same proportion as JPM estimates for the 3.03 million square meters in the mine area, the reserve in this bed alone in the remainder of the area would be 54 -9.9 = about 44 million tons. Resampling and relogging would be required to establish which estimate is the more reliable. Because JPM does not have additional pits in the broader area, its basis for revising the other estimate is less sound than in the mine area; the more intensively sampled mine area may be regarded as a random sample of the whole, however, so the JPM estimate is not without foundation. Regardless of which estimate is correct, the reserves in the remainder of the explored area are large.

In addition to the area explored by Mackay and Schnellmann in the Ruseifa Valley, phosphorite of minable thickness and quality is exposed in natural or artificial cuts in and near Amman and Zarqa, and the area that could be underlain by phosphorite of the same general thickness and quality as that in the explored area is more than twice as large as the explored area[1/]. What proportion of this area will be found to contain minable phosphorite on exploration is unknown, of course, but it could be large. Phosphate resources in the greater Amman-Ruseifa-Zarqa area, including the explored area, could well be of the order of 150-200 million tons.

Mining and marketing.--Nearly all of the mining thus far has been underground, and because of the dip of the beds and the extent of the cover, this is the method the company will continue to use on the north side of the Ruseifa Valley. Plans for mining in the south area sensibly call for stripping. Bed III is not mined at present because of its lower grade and local hardness, and JPM does not plan to mine it in the immediate future[2/].

1/The ground underlain by phosphorite is gradually being pre-empted by the growth of the towns of Amman, Ruseifa, and Zarqa and by the construction of various plants in the Ruseifa Valley. The government of Jordan should take steps to channel such expansion onto lands underlain by older rocks. To be done best, this would require geologic mapping of the Amman-Ruseifa-Zarqa area, but effective action during the near future could be based on information already available, supplemented locally by field reconnaissance.

2/As Barr (IBRD, 1957, p. 189) points out, hard-rock phosphate draws a premium price in Europe because of its superior value for electric furnace use. It would seem advisable, therefore, to investigate this potential market, and perhaps to stockpile rock from Bed III as it is mined in stripping for eventual sale or use.

Mine production during 1957 totaled 261,000 tons, of which 35,000 tons was shipped by both rail and truck to Beirut, and 179,000 tons was shipped by rail and truck to Aqaba. Transportation by either rail or truck to Beirut costs JD 1.990 ($5.57) a ton. The railroad extends south only to Ras en Naqb, which is about 280 kilometers from Amman and 82 km from Aqaba; rail shipment to Ras en Naqb costs JD 1.200 ($3.36) a ton and the truck haul on to Aqaba costs JD 0.550 ($1.54), including a cost of JD 0.060 representing a loss in weight in transhipment. Direct truck transport to Aqaba costs JD 1.500 to 1.750 ($4.20 to $4.90) per ton. Considering the miserable state of the desert track over which most of the truck haul is made, the truck costs are incredibly low, but it is JPM's belief that a long term truck contract could be made for about JD 1.500 a ton.

Just before my departure, Dr. Nuseibeh, Undersecretary of the Ministry of National Economy, proposed that the railroad form a trucking company for the Ras en Naqb-Aqaba haul, or that a trucking company join forces with the railroad company in some way that would insure the railroad enough volume to reduce its costs to the comparative low that rail transportation should yield. Along this line, it would be worth considering the possibility of the kind of piggy-back containers that are being used successfully now in this country for combined rail and truck haul. Properly designed boxes would not only eliminate much of the cost of transhipment at Ras en Naqb, but would also eliminate the dust loss that occurs there and along the entire route.

Present sales prices FOB vessel are now JD 4.100 ($11.48) and JD 4.4 ($12.32) in Aqaba and Beirut, respectively--a price sufficient to yield a profit of about $0.85 a ton at Aqaba and $1.27 a ton at Beirut. JPM hopes to triple the profit at Aqaba when improvements in transhipment facilities at Aqaba and Ras en Naqb are completed.

Of the 214,000 tons shipped in 1957, 35,000 went to India, 104,000 to Yugoslavia, 62,000 to Czechoslovakia, 11,000 to Italy, and 2,000 to Spain. The company expects its largest markets in the future to be Yugoslavia and India, and according to James Barr (IBRD, 1957) Jordan phosphorite can be sold at an advantage over that of its competitors in these general areas.

Salt area

The metamorphosed phosphorites in the vicinity of Salt (about 20 km west of Amman) are extremely high grade. Barr (IBRD, 1957, p. 188) reports that a bed 1½-2 meters thick contains about 82 percent T.C.P.; this approximate quality was found by JPM in their analysis of a hand specimen collected during my visit, and has been reported also by Blake (1930, p. 40). The bed has not been sampled extensively and there is no sound basis for estimating its reserves. The beds dip steeply and would have to be mined by underground methods. Unless an attractive outlet can be found for rock of this hardness and quality, the deposit could not be mined competitively with those at Ruseifa.

El Hasa

The phosphorite deposits at El Hasa lie along the Hejaz railroad and are divided into a northern and southern area by Wadi Hasa. An area of about 3 square kilometers in the north and about 4 square kilometers in the south has been explored by trenching and test pitting on 100-200 meter centers by Mackay and Schnellmann, with some check sampling by Jugometal and JPM.

The section in the north area consists of the chert-limestone unit at the base, overlain successively by 10-12 meters of marl and phosphate, 1-5 meters of an oyster-bearing limestone, and a few meters of marl. The upper marl contains at least one and perhaps two thin (less than 1 meter thick) phosphorite beds. The lower marl-phosphate sequence contains several phosphorites, the principal one of which is at the base. It varies from less than 1 to about 3.5 meters in thickness, and contains only 60-65 percent T.C.P. It can be upgraded by screening out less pure, silicified parts, and Mackay and Schnellmann calculate proved and indicated reserves to be 1,785,000 tons that average 63-69 percent T.C.P.; JPM estimate that the areas most favorable for strip mining contain about 820,000 tons, which, when mined and screened, will average about 69 percent T.C.P.

In the southern part of the area the upper marl series contains a phosphorite bed 1-3 meters thick near its base and attention in exploration has focused wholly on this bed[1]. Mackay and Schnellmann's estimate proved and indicated reserves in this bed to be about 3,760,000 tons averaging about 65 percent T.C.P. and JPM consider that about 2,340,000 tons of this can be mined by stripping.

The El Hasa area plainly contains additional reserves as yet untested (the lower bed in the southern area has not been explored at all). There is no sound basis for estimating their extent, however, and it is risky to extrapolate grades and thicknesses of beds far outside the explored area, for, unlike the situation at Ruseifa, the beds in the El Hasa area are plainly lenticular and variable in grade and thickness.

JPM has proposed to mine the El Hasa deposits at the rate of 150,000 tons a year, but they will probably accept the good advice given by USOM/J to wait until the expansion of Ruseifa has been completed.

1/The oyster bed is much thicker in the southern area than in the northern and there has been some speculation as to whether or not it is the same bed and hence as to whether or not the phosphorite above it is the same or a different bed from that explored in the northern area. Mr. Khairy and I examined this problem critically in the field and concluded that the oyster bed is at the same horizon in both areas. The evidence for this is: 1) the oyster bed shows the same sequence in both areas--giant oysters in the lower part, chert and impure phosphorite in the middle, and smaller oysters in the upper part; 2) one test pit that penetrated the oyster bed in the southern area shows phosphorite beneath at roughly the same horizon as the phosphorite unit in the northern area; and 3) a few test pits in the northern area show phosphorite beds above the oyster bed; even though these are thinner and lower grade than the main phosphorite above the oyster bed in the southern area, they plainly belong to the same horizon.

Other deposits and prospects

Phosphorite has been observed at several other localities (fig. 3), but minable beds are not known at any of them. The regional facies relations--particularly the westward decrease in phosphate toward the margin of the plateau and its southward decrease (reflected not only in the fewer number of minable beds at El Hasa, but also in their lower T.C.P. content)--suggest that the area most favorable for the occurrence of minable deposits lies north of El Hasa and east of Kerak. Mr. Kawar, the man who opened up the Ruseifa deposits, is reported to know of a minable deposit in the Ma'an--Ras en Naqb area, the location of which he refuses to disclose unless he is guaranteed some personal royalty. His claim cannot be verified or be refuted on the basis of present knowledge. The deposits I saw in this area were too thin and probably too lean to be minable, but it is possible that isolated deposits of minable quality do occur in the general area, just as they do in the fringe area of the western phosphate field in the United States. The lenticular nature of the phosphorite beds at El Hasa suggests that the deposit is itself an isolated occurrence, and hence an example of the kind that might be found in the southern area--a lense a few kilometers square and probably somewhat lower in quality than the phosphorites in the Ruseifa area. Most of the area underlain by the Belqa in the area north of Ma'an is covered by desert pavement or younger surficial deposits and outcrops are sparse. Field mapping, supplemented by interpretation of aerial photos, probably would make it possible to block out favorable areas, but any exploration would have to be done by deep test pitting or drilling.

Although the known phosphorites west and south of Jericho are not of minable thickness or quality, it is possible that further exploration may reveal workable beds in this area; the prospects do not appear promising, however. Exposures in the deeply dissected flank of the West Bank are good enough to show the position of the phosphorite horizon and samples in many areas could be obtained by trenching.

Conclusions

The known reserves and potential resources of phosphorite in Jordan are large and rich, and they constitute an extremely valuable resource. Very likely an aggresive marketing campaign would considerably enlarge the foreign market and add significantly to Jordan's foreign exchange. This is important, but an even more important goal is the development of a fertilizer industry within Jordan, partly to permit export of a higher-priced product, but mainly to make possible increased use of fertilizer on Jordan's own soils. The construction of sulfuric acid and superphosphate plants was strongly urged by Barr (IBRD, 1957, p. 195), who "conservatively estimated" a local need for 60,000 tons a year of superphosphate in 1960, and a private company is said to be laying plans for such an operation now. Barr recommended that a plant to make triple superphosphate (which contains 42-48 percent P_2O_5 instead of 16-20 percent as does single super) be considered in the future and this is also urged here. Not only is triple super a better product for export, but the process lends itself to the recovery of uranium and similar by-products. Other possibilities that invite investigation are the manufacture of elemental phosphorous, ammonium phosphate, and the recovery of fluorine or fluosilicates. These processes, some of which depend on cheap power, may not be economic now, but it is through processes such as these that Jordan will obtain maximum benefit from this tremendously valuable resource, for it will yield the greatest return in the export and internal use of high-cost fertilisers and chemicals.

Saline minerals

Dead Sea salts

The Dead Sea contains about 2 billion tons of potassium chloride, 1 billion tons of magnesium bromide, and 22 billion tons of magnesium chloride (Blake, 1930, p. 7); it is one of the world's large reserves of these valuable materials. Potash and several by-products were recovered at the north end of the Dead Sea between 1930 and 1948, when the plant was destroyed. Plans have been laid to build a pilot plant to guide the development of a better process, and work is going ahead.

The importance of extracting potash from the Dead Sea is well recognized, but two points deserve emphasis. One is that in addition to marketing potash abroad, Jordan should plan on producing enough to satisfy local needs for fertilizer. Canada and the United States use 0.005-0.01 tons of K_2O per capita per year as fertilizer, and as Jordan's need is surely no less she should use something like 10,000-15,000 tons a year to increase the productivity of her soils. The other point is that full attention should be given to the recovery of all possible by-products, and, as Jordan's technologic skill increases, to the manufacture of refined chemicals for both internal use and export. Prior to the Palestinian war, the potash works not only produced potash but also bromine, magnesium chloride for various types of cement, dehydrated carnallite, salt, and brines for road-sprays and refrigerators (Block, 1955). All of these products and others too should be produced in the future. As Barr, (IBRD, p. 182) points out, part of the potash could be prepared for shipment as potassium sulfate--a much higher priced product than the muriate; caustic soda should be recovered at least for local use; and several magnesium compounds probably could be marketed abroad and used locally. In other words, the Dead Sea is an enormous source of valuable chemicals, and its full potential should be utilized in both Jordan's foreign trade and domestic chemical and fertilizer industry.

Other sources

The Dead Sea is a remnant of a much larger lake that once extended much further north and south. Lake Tiberias and the Dead Sea are isolated remnants of this lake, and the Dead Sea itself is nearly divided into two separate lakes by the El Lisan Peninsula. M. E. Wing of the U. S. Geological Survey has suggested that other remnants of the larger lake may have been isolated at some time in the past, and have been evaporated completely. The large salt deposit at Jebel Usdum near the southwestern shore of the Dead Sea may be such a deposit, although it now appears to be a fault slice of an older deposit of Miocene-Oligocene age (Picard, 1955, p. 28). The structural dome that composes the El Lisan peninsula may be caused by a salt plug (Gardner, 1954). Prospecting by drilling there or in the rift valley south of the Dead Sea may disclose the presence of rock salt of one of these origins and perhaps other salines that are commonly associated with it.

Salt is currently recovered in small quantities from seepages near Azraq, but it is unlikely that this source will yield as cheap a product as that obtainable as a by-product of Dead Sea potash production.

Large deposits of high-grade gypsum, probably of Triassic age, are known in the general vicinity of Kerak (Blake, in Ionides, 1939, p. 118). These would have to be mined underground, but, according to Blake, the rock could be trammed by gravity to the Dead Sea. Gypsum may eventually prove to be an economical source of sulfur (IBRD, p. 200), but its most important uses now are in the manufacture of plaster, gypsum lath and wallboard, cement, and as a soil conditioner (especially on alkaline soils). Gypsum could be used now for all of these purposes in Jordan, and there seems to be no good reason why a local gypsum industry could not be started, using gypsum derived either from the Dead Sea or from Kerak. Eventually, it might be used for the manufacture of ammonium and potassium sulfate (IBRD, p. 182, 200).

Sulfur

Sulfur is a vital commodity to chemical industries as a source of sulfuric acid, and it would pay to import it now for the manufacture of superphosphate (IBRD, p. 196) if for no other purpose. Such a development should not be postponed pending the development of a domestic source but, in addition to gypsum, Jordan has several possible sources of sulfur. 1) If the El Lisan dome is a salt dome, it may contain sulfur as do many other similar structures. This possibility is enhanced by the occurrence of sulfur as float in the Dead Sea, in the Lisan gypseous marls, and in association with the asphalt along the Dead Sea; in other words, the conditions necessary for the formation of native sulfur from gypsum appear to have prevailed in this area, at least on a small scale. 2) The bituminous limestone of the Belqa contains about 2 percent sulfur (Blake, 1930, p. 19), and it is possible that this might be recovered as a by-product of one of the operations already described. Sweden recovers sulfur from her oil shale, enough, it is said, to supply about one quarter of her requirements. 3) Depending on the process used in the oil refinery to be constructed in Jordan and its size it may be economical to recover sulfuric acid as a by-product. And 4), the previously mentioned occurrence of a sulfide copper mineral in the vicinity of Feinan suggests the possibility that this is the form of the copper mineral at depth. If minable deposits of copper are found in that area, they might yield sulfur as a by-product of smelting.

Cement and lime

Jordan has unlimited raw materials for the manufacture of cement, and a plant has been erected recently near Amman that produces high quality cement from the Ajlun formation. At the time of my visit, however, demand had apparently outstripped the capacity of this plant, for imported cement was seen on several occasions. Inevitably Jordan's demand for cement will increase in the future, and it is desirable that cement-making capacity be progressively enlarged. The bituminous rocks of the Belqa should be investigated carefully for this purpose, for their use would not only save fuel but might yield a petroleum by-product as well.

The possibility of producing lime at low cost from the bituminous limestone of the Belqa was discussed in the section on energy sources. Although this is a most appealing source, numerous other limestones also are available for lime if special requirements warrant. Lime has a multitude of uses in the chemical and building industries and in agriculture, and it would be surprising if a sizeable internal market for various lime products does not already exist.

Clay

Jordan has abundant deposits of clay, but they are poorly known and little used at present. The clay is of several types--ball clay, fire clay, flint clay, white kaolin, swelling clay, and perhaps others. One of the best sources of fire clay, flint clay, and other kaolinite clays is the Kurnub formation of Jurassic-Cretaceous age. The Ajlun formation also contains usable clays, and they may be expected also in many of the other formations in Jordan, including alluvial and lacustrine deposits (Quennell, 1951, p. 111; Picard, 1955).

The Jordan Clay Works Company, a recently formed enterprise in Amman, manufactures heavy clay products such as clay pipe and tile (IBRD, p. 225); the Palestine Pottery Company in Jerusalem makes ornamental pottery for the tourist trade; and several small village enterprises make pottery for local uses (Thompson, 1956, p. 14). A swelling clay in the Azraq area is mined for use in well drilling by the Phillips Petroleum Company, and a poorly-formed adobe is used as a building material in many villages. These are relatively minor uses, however, and a much larger and more diverse clay-product industry probably could be developed in the near future. Aside from pottery for the tourist trade, initial expansion might be aimed wholly at goods for internal consumption--dishes, stone-ware, and similar types of pottery, as well as brick and tile. Construction materials deserve special emphasis, for better housing is one of Jordan's foremost needs. Although fine building stone is available for this purpose, it is too expensive (in terms of labor) to use for inexpensive homes. Wood, of course, is not available for this purpose either, and the best and least expensive materials are artificial clay or cement products.

Barr (IBRD, p. 199) points out that if a paper clay could be found it might be beneficiated locally and exported as a premium product. Kaolin is the clay commonly used as a filler in paper and it would be worth examining the kaolin clays of Jordan to see if any of them are suitable for this purpose.

Glass sand

Abundant glass sand is available in the Kurnub sandstone near Amman and elsewhere and in the Ram sandstone of Cambrian age near Aqaba (Quennell, 1951, p. 112), and flint for flint glass is abundant in the Belqa formation. A small quantity of glass is now made at Hebron, but without doubt Jordan's resources and needs would support a much larger glass industry. Certainly internal needs for bottle glass and other commonly used types could be met more inexpensively by domestic production than from imports, and it seems likely that a glass industry specializing in containers for local products, such as olive oil, or in ornamental glass, both catering to the tourist trade, would prosper also.

Building stones

Jordan has a wealth of fine building stone (Blake, in Ionides, p. 123), as is amply attested to by the beautiful ancient and modern buildings in Jerusalem, Amman, Jerash, and other towns. One of the popular stones--the rosy limestone--is a bed within the Belqa formation, and it will soon be produced in quantity as a by-product of the stripping operations in the phosphate mine at Ruseifa. Other fine-quality limestones are found in the lower part of the Belqa formation and the Ajlun formation. Sandstone suitable for building stone is found in the pre-Cretaceous formations. Fine-quality marble is found within the Belqa series at several localities, and granites and porphyries near Aqaba are also of fine quality (Quennell, p. 111; S.S., 1955, p. 88).

At the present time most of the fine homes and public buildings in Jordan are built with native stone worked largely by hand. This doubtless will continue for some time, but introduction of mechanical methods might extend the use of this stone and facilitate the growth of the industry. In addition, it would be well to explore the possibility of exporting granite or other crystalline rocks that lie close to the port of Aqaba.

Road metal and aggregate

Road metal and materials suitable for concrete aggregate and fill are abundant throughout Jordan, and require no special comment here (see Baker Harza, 1955, vol. VI-B, for a description of construction materials examined and considered for use in the projects that were proposed in the Yarmuk -Jordan Valley Master Plan). One material that may be useful in the construction of secondary roads in Jordan is calcium chloride, which probably will be one of the co-products of the Dead Sea Potash operation. This compound reduces dust and helps establish a hard surface on unpaved roads. It might reduce the cost of road construction and maintenance, especially in the arid parts of the country.

Other nonmetallic minerals

High-quality white barite has been found near Bethlehem (IBRD, p. 198), but its extent has not been reported. Feldspar, mica, barite, quartz, and fluorite are known to occur in pegmatites in the Aqaba granite complex (Picard, 1955, p. 33; Braunfeld, 1955); they have not been explored, but we may be confident that minable deposits of feldspar and perhaps of some of the other pegmatite minerals too, can be found. Garnet in metamorphic rocks near Aqaba might be suitable for abrasives. Quartz sand and chalk are other abundant materials suitable for various kinds of abrasives.

Diatomaceous earth--also useful as a fine abrasive, as well as a filler, a filtration medium, an absorbent, and an insulation material--occurs in the Belqa formation near Kerak and very likely at many other localities also. Onyx, alabaster, hematites, and other semi-precious stones suitable for costume jewelry and ornamental objects are also known in Jordan.

Scenery

Although it is not found among mineral statistics, scenery is a natural resource of great economic value, and was so recognized by some of the early geologic explorers of western United States. The desert-canyon scenery of Jordan is incomparably beautiful, and added to it as a tourist attraction are the antiquities and holy places. Although Jordan is well known as the Holy Land, its reputation abroad does not go much beyond this; most foreigners picture it as a desolate, rocky wasteland, and are only vaguely aware of the marvels of Jerash and Petra and the breathtaking grandeur of Wadi Dana and Wadi Yutum. If these and other features of touristic interest were publicized, and if more hotels and rest houses were built, Jordan could expect to increase her tourist trade several fold. In fact, of all of Jordan's natural resources and potential industries, tourism is the one that could be developed most quickly, and, for a time at least, it would probably be the largest source of foreign exchange. Many other industries will be more important eventually, but their development depends on the relatively slow processes of accumulating facts and technical knowledge, the education and training of people, the growth of trade, and other things that take time. A trained or easily trainable labor force for the tourist industry already exists, however, and most of the necessary access roads are already built. Essentially all that is needed is the construction of more accommodations and more publicity.

Summary

Jordan's known or traditionally used resources of many vital materials are small. The rainfall is slight to moderate; perennial streams are few in number and relatively small in total flow; areas of easily tillable, naturally fertile soil form only a small percentage of the kingdom; and minable deposits of metals and fuels are unknown. One would be safe in saying that if Jordan had to depend on its traditionally used resources it would not be possible to achieve a level of living as high as that attained by ancient Egypt, merely because Jordan does not have a river like the Nile.

While we must not underestimate the difficulty of the problem, it would be a grave mistake to conclude from this that Jordan's resources will not support a much higher level of living in the modern world, partly because her resources are little explored but mainly because modern technology permits the profitable use of materials that were unknown to the ancients. Viewed in the light of modern technology, Jordan's resource potential takes on an entirely different aspect. Her usable water supplies, even her rainfall, can be much increased. Almost certainly she has oil, but even if she does not she can buy it relatively cheaply from neighboring countries; in addition, she can develop some hydroelectric power, has vast stores of energy in the form of bituminous shale and nuclear energy, and can also capture solar and wind power. Like many other countries, she probably will have to import iron and other metals, but she has some prospects of finding minable deposits of iron, copper, manganese, and perhaps a few other alloy

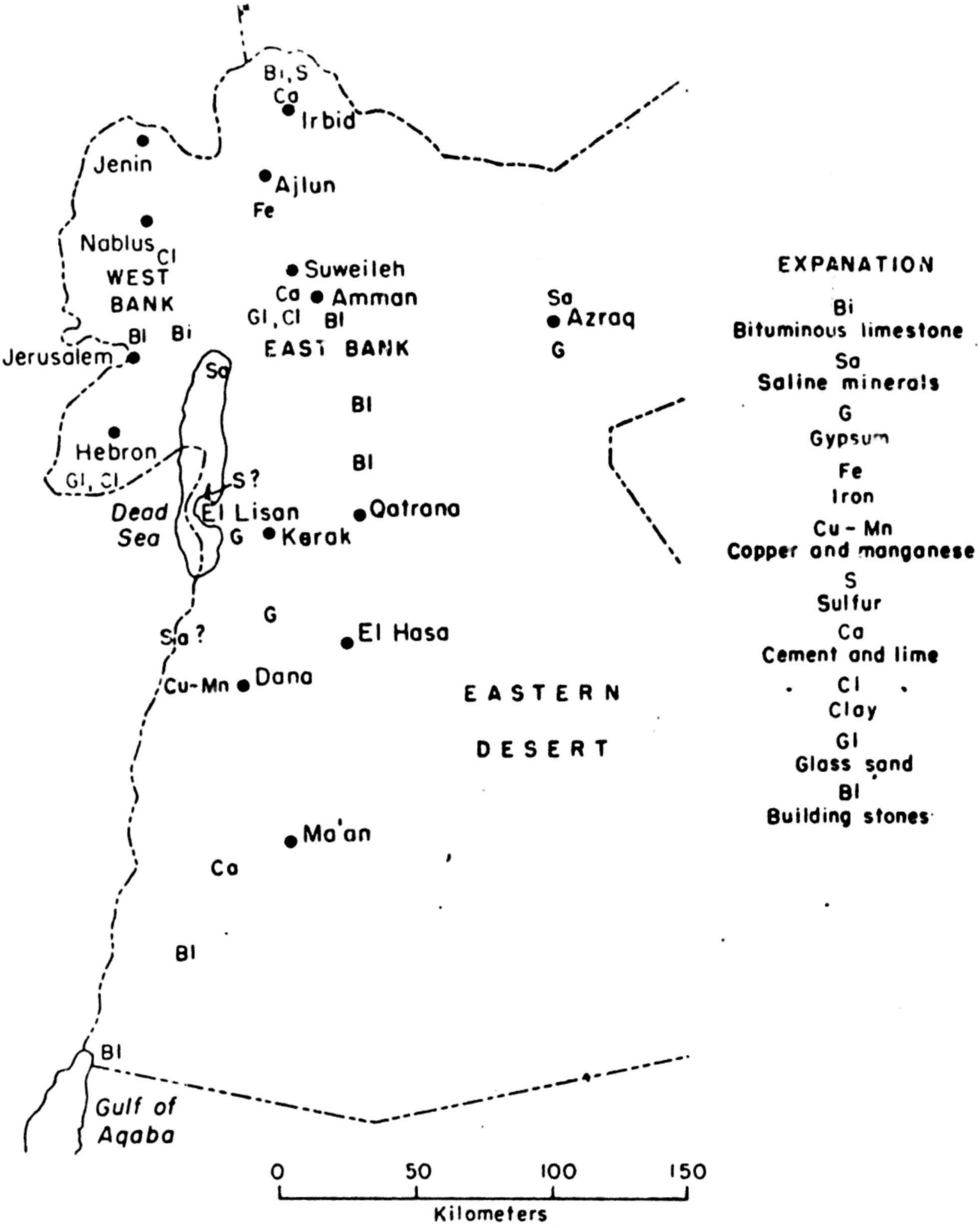

Figure 4. Distribution of usable minerals (excluding phosphates and road metals) in Jordan. Only a few of the many deposits of cement, lime, clay, glass sand, and building stones are shown.

metals; in the more distant future she can probably produce alumina from high-alumina clay and magnesium from the Dead Sea brine. And when it comes to materials essential to the chemical, fertilizer, and construction industries, she is better off than most countries (fig. 4).

Returning to the concept, then, that a high level of living is attained through the intelligent consumption of raw materials and energy, it is plain that Jordan has potential supplies adequate to support a high-level of living--provided she can soon strike a favorable resource/population balance.

Table 16. Summary of Jordan's mineral resource potential

Material	Occurrence or extent	Recommendations and possibilities for development
Water	Currently usable supply is about 3,500 MCM per yr.	Usable supply could be increased to about 6,000 MCM per yr. by artificially inducing more rainfall, expanding acreage of hill fruit, making full use of Yarmik-Jordan water, practicing water spreading, and capturing more of the ground water discharge.
Sources of Energy	Billions of tons of bituminous limestone; billions of tons of coal-equivalent from uranium in phosphorite; 6,500 kw potential hydroelectric power; large potential in solar and wind power; good possibility of finding oil.	Bituminous limestone probably would support a lime or cement industry with oil as by-product. Hydroelectric power could be developed, and solar and wind power should be used for special purposes. Oil exploration should be resumed.
Iron	Hematite deposit near Ajlun contains 400,000 tons of ore, probably more.	Might be sold to Japan or exploited on a small scale for pigment. Either would be desirable as a cheap means of opening up and exploring the deposit.
Copper and manganese	Wadi Dana contains about 200,000 tons of cupriferous manganese ore; might contain much more.	If a market and process are found that permit separate recovery of copper, deposit should be further explored. Mining should be delayed until road is built up Wadi Araba for another purpose.

Table 16. Summary of Jordan's mineral resource potential (Continued)

Aluminum	High alumina clay may occur in Kurnub formation.	Probably best use is in ceramics rather than source of aluminum, but should be investigated.
Magnesium	Dead Sea Brine	One of world's large and rich sources. Manufacture of metal requires cheap power, but may be possible in Jordan eventually. Magnesium salts for other uses should be recovered now.
Other metals	Tungsten, rare earths, and similar metals could occur in granitic-metamorphic terrane.	Favorable region should be geologically mapped and prospected.
Phosphate	30 million tons known at Ruseifa, scores of millions of tons may be inferred there and elsewhere.	Plants should be constructed to supply fertilizers for Jordan's use and for export. By-product recovery of fluorine chemicals, uranium and other elements should be considered.
Saline minerals	Dead Sea brine contains one of world's largest reserves of potash, bromine, and magnesium. Ancient Dead Sea salts may be buried in Wadi Araba. Triassic rocks contain high quality gypsum near Kerak. Salt now recovered on a small scale from Azraq brines.	Brine should yield variety of salts for export and for internal chemical industry. Gypsum should be produced for soil conditioner, wall board, and other purposes.

Table 16. Summary of Jordan's mineral resource potential (Continued)

Sulfur	Possible sources are El Lisan salt dome(?), bituminous limestone, gypsum, by-product of oil refinery, and sulfide minerals.	All should be investigated. Sulfuric acid plant should be started soon, even if it must depend on foreign sources of sulfur.
Cement and lime	Abundant source materials. Bituminous limestone especially promising.	Cement industry should be expanded; lime should be produced for a soil conditioner and many other uses.
Clay	Kurnub, Ajlun, Belqa, and other formations contain variety of kaolinite and other clays.	Clay products industry should be much expanded and diversified. Possibility of exporting paper clay should be investigated.
Glass sand	Kurnub and Ram sandstones are good sources of glass sand; chert of Belqa and Ajlun available for flint glass.	Glass industry should be developed.
Building stones	Wide variety of excellent building stones.	Stone cutting should be gradually mechanized. Possibility of exporting granite and other rocks from Aqaba area should be investigated.
Road metal and aggregate	Abundant sources.	More testing and mapping needed to use most efficiently.
Other nonmetallic minerals	Quartz sand, diatomite, barite, ocher, feldspar semi-precious stones. Perhaps also fluorspar, garnet, and mica.	Occurrences and possible markets need to be investigated. Diatomite, quartz sand, feldspar, and garnet could form the basis for a domestic abrasives industry.

Jordan's potential resources and the possibilities they offer for development are summarized in table 16. As indicated there, several mineral industries could be started or expanded, at least in a modest way, in the near future. For example, the cement and clay industries could be enlarged, and lime, gypsum, glass, abrasive, fertilizer, and perhaps lapidary, granite export, and sulfuric acid industries could be started soon.

By and large, however, the development of Jordan's resources will be slow, and we cannot hope that she will achieve wealth overnight or even in a few years. Nevertheless, some of the activities essential to development can be started now and pursued vigorously. Those dealing rather directly with mineral resources are discussed in the remainder of this report.

It is worth emphasizing again that while technical activities of the kind recommended in subsequent pages are vital to the advancement of Jordan's economy, they are not the only steps or even the most important ones to be taken. Nothing even closely approaches the fundamental importance of advancing the general education of the Jordan people, of stimulating their wish to improve their economic status through their own efforts, and of encouraging them to take the initiative in finding better ways to fully use the resources available to them. But because this involves the population as a whole, progress toward this goal is inevitably slow. The accumulation of facts and the investigation of processes and other work similar to that described in subsequent pages involves a much fewer number of people. Therefore, it is not only an essential prerequisite to resource development, but is one that can be pressed in early stages.

Work required to develop Jordan's mineral resources

Of the work that must be done to fully realize Jordan's resource potential, most prominent in the public's mind are large public and private developmental projects--the construction of irrigation systems, dams, and roads; reclamation of soil; construction of manufacturing plants; development of mines and oil fields; and so on. But essential as these projects are, they must be preceded by other more fundamental activities, namely 1) the acquisition of facts concerning the character, size, and distribution of the resources to be developed or exploited; 2) investigation of processes and markets for the treatment and sale of raw materials; and 3) development and administration of laws that encourage private initiative in prospecting and mining (table 17).

It is not possible, or at least involves great risk or uncertainty, to build a successful irrigation system without adequate knowledge of the supplies of surface or underground water or of the volume of water required per unit of land to raise specific crops under local conditions of soil, temperature, and evaporation; to find oil or valuable mineral deposits without mapping the distribution and structure of the rocks and studying regional variations in their composition; or to build a plant without knowing the extent and distribution of the raw materials it will use. It is, in other words, necessary to acquire factual data concerning the nature and extent of a country's resources before they can be adequately developed and utilized.

By the very nature of the task, the job of fact-finding is almost a never-ending one. The reason for this is partly that the job is large --it simply takes time to map large areas adequately, for example--and partly that the concept of the information required necessarily changes or enlarges as technology develops.

The nature of the work to be done also requires that much of it be done by government. Even in an industrially advanced free enterprise society, private parties cannot afford to make the investment of time and money required to accumulate basic data that offer no promise of immediate exploitation; and whatever data are accumulated in the course of private activities are generally not published or made available to others who may put them to unanticipated uses. For these reasons, it is essential that fact-finding activities in the field of natural resources be established as the main functions of permanent government agencies that will publish their findings and thus make them available to private industry.

Table 17.--Public functions in the

field of mineral resources

I. Collecting and publishing basic data.

A. Aerial and topographic surveys

1. Triangulation and levelling to establish horizontal and vertical control.

2. Aerial photography.

3. Construction and publication of topographic maps and photo mosaics.

B. Geological surveys

1. Geologic mapping, petrologic and stratigraphic studies, geophysical and geochemical surveys, and reconnaissance sampling leading to information on distribution and rough appraisal of resources of ground water, fuels, metallic, and nonmetallic deposits.

2. Appraisal and perhaps limited exploration of promising deposits.

C. Mineral statistics

1. Collection and publication of statistics on annual production of minerals and on new developments in or affecting the mineral industry.

D. Hydrologic surveys

1. Collection of data on quality and quantity of spring and stream flow.

2. Collection of data on rainfall and other climatologic phenomena.

E. Mineralogic and geochemical services and research

1. Determination of mineral, and, where warranted, chemical composition of samples of ores, rocks, soils and waters submitted by public agencies and private parties.

II. Administering mining laws and regulations

A. Acting on applications for mineral leases.

Table 17.--Public functions in the field of mineral resources--Continued

B. Broad supervision of mining on the public lands, particularly with reference to the enforcement of feasible conservation practices and accepted health and safety regulations

C. Research, or at least investigation of work done elsewhere, on mining methods and equipment suitable for local use; and advice to private parties on mining methods and equipment

III. Developing processes, markets, and mineral industries

A. Research on methods of beneficiation and treatment of minerals

B. Investigation of uses and markets for Jordanian mineral products

C. Contact with and initial aid to private parties potentially capable of operating mineral product companies, particularly in new fields

IV. Applying basic data to the development of natural resources

A. Irrigation and reclamation projects

B. Municipal water supplies

C. Dam construction

D. Highway and airfield construction (including problems having to do with foundations, drainage, and sources of road metal)

E. Construction of public buildings and other large public works

One might question the advisability of including promotional activities as a public function in the field of natural resources, and it is true that as free enterprise develops it probably will suffice merely to publish the facts--private capital will take it from there. At the present time, however, private initiative in the field of mineral industries is in its infancy in Jordan; it may be necessary therefore, for the government to stimulate activity by exploring a mineral deposit, developing a process, or perhaps finding or even helping promote a market during certain stages of the development of an industry. The government should do no more of this, however, than is absolutely essential to help the company or industry get started; moreover, wherever possible, the aid should be given via advice or subsidy rather than as government participation in the work itself. This is necessary not only because the company will learn best by doing but also because it would be easy to dissipate all of the government's resources in this fashion, leaving no capacity to attack problems that the companies cannot be expected to solve.

Status of work in the mineral resource field

Some of these activities are already underway as continuous public functions, some are partly underway, and some have not been started. My relatively short stay in Jordan did not permit an accurate appraisal of work going on in these various fields, but the status of work seems to be as follows:

1. The Department of Lands and Surveys is responsible for aerial and topographic mapping and plans to complete, by an ICA supported contract, topographic mapping of most of the Kingdom, on scales of 1:25,000 and 1:50,000 in the near future.

2. A reconnaissance geologic map (scale 1:250,000) of the western part of former Transjordan was prepared during the latter years of the Mandate by A. M. Quennell of the Department of Lands and Surveys and published by the same Department in 1956; certain deposits of phosphate, manganese-copper, and iron have been sampled rather intensively and partly mapped by a private firm under contract with the Ministry of National Ecomony; concessions have been issued to the Phillips and Ismiri petroleum companies to search for oil and the Phillips company has drilled five holes; some exploratory drilling has been done for water by the office of Water Resources Development and other organizations, and these groups as well as the Food and Agriculture Organization of UN have prepared numerous reports (for the most part unpublished) on the ground water resources or problems of small areas. The geologic mapping (on scales of 1:50,000 or larger) and other fact-finding studies required for search and appraisal of mineral resources, including water, have not been begun at all.

In recent months the Section of Mines of the Ministry of National Economy, acting in part on the advice of the United Nations Technical Assistance Advisor on mining, has proposed that geologic maps (scale 1:25,000) be prepared of Jordan on a contract calling for their completion in three years; that areas and deposits deserving more detailed investigation be selected, mapped (1:5,000), and explored; and that a Department of Mineral Resources and Geological Research be established in the Ministry of National Economy to carry on or supervise mineral leasing, mining, geologic and topographic mapping, and related studies. The IBRD mission previously recommended that a Bureau of Mines and Minerals be established and that a systematic geological survey and mineral exploration program be carried out on a contractual basis.

3. Mineral statistics are being compiled and published by the Department of Statistics in the Ministry of Economy.

4. Meteorological data are currently collected at a few stations by the Department of Irrigation and published by the Department of Statistics. A few data on stream and spring flow have been collected and some published, but such observations are not being made systematically or continuously by any existing agency.

5. The Government Laboratory in the Ministry of Public Health makes chemical analyses and some types of physical analyses of rocks and minerals as requested by other agencies, and the Division of Highways in the Ministry of Public Works may establish a laboratory to test construction materials, etc. No organization is equipped to perform mineralogic or geochemical services or research.

6. The Section of Mines is responsible for the review of applications for mineral and oil leases, enforcement of mining laws, etc., and these activities are, in fact, its principal ones now.

7. No government agency has specific responsibility for developing processes, markets, and industries in the minerals field, although the broad responsibilities of the Development Board encompass this function. At the present time, no such work is underway.

8. The responsibility for various developmental activities is already allocated to several government agencies and the Development Board has been established to plan, stimulate, and initiate the kind of projects that are needed to develop Jordan's natural resources. None of these organizations, however, are carrying on the geologic mapping or similar fact-finding activities necessary to place such development projects on a firm footing or to insure their success at the lowest cost.

From this review of needs versus current activities we may conclude that responsibility for the preparation of topographic maps, collection of mineral statistics, and supervision of mining laws is already assigned. But geologic mapping and related studies needed to provide a basis for search and appraisal of mineral resources, collection of data on streamflow, and the investigation of minerals processes and markets are activities that not only are not underway but do not seem to be established functions of existing agencies at the present time.

Recommendations for the formation of permanent government agencies in the field of mineral resources

For the reasons indicated above, it seems advisable for the Government of Jordan to form certain new, permanent agencies to perform continuing functions in the broad field of mineral resources. Neither the availability of funds or trained technicians will permit the initiation of these activities on a large scale, but even though the groups formed are small, their contributions will be apparent within a few years if they have continuing responsibility and purpose.

The work that needs to be started in the field of mineral resources could be carried on most effectively by two organizations 1) a Geological Survey and 2) a Bureau of Mineral Industries. Before discussing the functions, size, and initial programs of these organizations, let me stress something that applies to both. At the present time, only a few Jordanians have university training in geology, mining and related fields; none appear to have had the experience necessary to plan and direct continuing investigations in these fields, and few the experience necessary to work independently. It is essential, therefore, that foreign technicians participate in and direct the work during a training period (possibly five years or more). The number of foreign technicians should never exceed the number of Jordanians, and it would be preferable to have several times as many Jordanians in order to develop within the country a trained group of people who can interpret and use the data collected. Although the work might be done faster at the beginning if a large number of foreigners were employed or if large segments of the work were contracted to foreign firms, the ultimate usefulness of the information obtained will depend upon the technical knowledge of Jordanians. The development of a skilled body of Jordanian technicians should be an objective of the Geological Survey of Jordan and of the Bureau of Mineral Industries. Elsewhere in the world, government technical organizations have served to train technicians who later worked in private industry. In the United States, for example, many geologists have worked for the U. S. Geological Survey for a period of years, and then transferred to industry or to teaching with experience not only in the collection of facts but also in their interpretation and application. Such training of geologists has long been recognized as an important function of the U. S. Geological Survey.

Functions and initial program

of the Geological Survey

The functions of the Geological Survey should be to make geological maps that show the structure and distribution of rocks and mineral deposits, differentiated as to composition and age; to study and interpret regional variations in the composition, thickness and other characteristics of rocks; to search for and appraise, by reconnaissance sampling and other techniques, sources of usable supplies of metallic and nonmetallic minerals and water; and to publish maps and reports that not only present factual data, but interpret their significance in economic and practical problems.

If the Geological Survey is a distinct organization, as I recommend it be, it may not matter in what Ministry it be placed. It seems to me, however, that it would be more appropriately a part of the Department of Lands and Surveys than the Ministry of National Economy. This is partly because an important part of its work has to do with the making of maps and the Department of Lands and Surveys is at present the chief map-making agency; it is also because the Survey's objectives--fact-finding of long range importance--are more similar to those of the Department of Lands and Surveys than to the short-range strictly economic objectives of the Ministry of Economy.

Along the same line, it should be clear that it is not necessary that all geological work required by the Jordan Government be done by the Geological Survey. Developmental or engineering agencies almost certainly will require geological information or advice in conjunction with construction of irrigation systems, highways and dams, and the exploration and development of groundwater systems. This work generally focuses on a specific problem in a small area and it is thus of a different character from most of the broad scale, long range work of the Geological Survey. Moreover, it is usually urgent that it be done at a certain time, so as not to delay the construction schedule. For this reason, the engineering agency involved needs to have the kind of direct control over the work that is possible only when the work is done by its own employees; and on the other hand, if the Geological Survey has major responsibility for engineering geological work it is likely to consume most of its energy and funds meeting these urgent demands from other agencies and will have little time to devote to its own basic objectives. Although the Survey must expect to do some consulting to other agencies, and should have at least one engineering geologist available for such work, any other agency that needs a geologist full time should have him on its own staff.

A word of elaboration is perhaps desirable on the search and appraisal function of the Geological Survey; except during the early stages of the development of an industry, it is generally not appropriate for the Geological Survey to do detailed sampling or exploration of mineral deposits of the type required for their exploitation by a company, nor to search for water or oil by drilling. Such work should be done by private companies or, in the case of water by municipalities, by the Office of Water Resources Development or companies. It is appropriate for the Survey to acquire background data on the extent and character of rocks and structures that may contain water or influence its quality.

to indicate areas broadly favorable for its occurrence, and to help estimate the water-producing capacity of important aquifers; similarly, it is appropriate for the Survey to provide enough data on the occurence, quality, and extent of unexplored ore deposits to encourage private organizations to explore them further, and to give the government an idea of the extent of the Kingdom's resources. In the initial stages of the development of new industries this may require the Survey to do some prospecting and physical exploration, but the aim should be to interest private parties in taking over as quickly as possible.

Because the Geological Survey would be a small organization at the outset, no special consideration need be given to a table of organization now; it should have a chief, of course, but his administrative duties would be relatively small and should permit him to carry on a field project just like the members of his staff (this is good practice even in a large organization, for it permits the chief to continue his professional growth, and to keep a fresh, constructive viewpoint). The staff should include men competent in the several fields of specialization important in Jordan: at least one ground-water geologist; a geologist competent in the field of igneous and metamorphic rocks and associated mineral deposits; one competent in the field of sedimentary rocks and associated deposits; an engineering geologist; a stratigraphic paleontologist; a mineralogist-geochemist; a surface water hydrologist; and a librarian or a clerk sufficiently well trained in library science to organize and maintain a library and archives. Because it is unlikely that all of these specialists could be recruited at the outset and matched by Jordanian trainees, the initial professional staff likely would be only half as large. Eventually, however, the staff should be increased beyond the numbers indicated above; the work in sight in ground-water geology, for example, would make it desirable to have several geologists in that field alone, if they were available.

Except for mineralogical, geochemical, and paleontologic studies, which would be largely of a service or topical character, most of the Survey's work would consist of geologic mapping. Areas to be mapped by various individuals would be assigned on the basis of the most important mineral deposits in the area. For example, mapping in the Jordan Valley would be assigned to a ground-water geologist; although his map and report would treat all the various kinds of rocks and minerals in the area, the chief emphasis would be on ground-water geology. Similarly, mapping in the Wadi Yutum area would be assigned to a geologist thoroughly competent in igneous and metamorphic geology and in hydrothermal ore deposits. As indicated previously, during the early years of the Survey's work, each field party should consist of an outside geologist and at least one Jordanian trainee who already has had university training.

Attention is called to the fact that photogeologic mapping per se (i.e. maps prepared in the office from the interpretation of aerial photographs, with no field work or even with the field checking and reconnaissance sometimes done as a part of photogeologic mapping) is specifically not recommended in Jordan. Even under the most favorable circumstances (in areas of simple structures and little or no cover) such maps yield incomplete information at most; i.e. they yield good information on structure but very poor information on the composition of rocks and facies changes. Added to this is the fact that in Jordan the rocks in many areas are poorly exposed; wide areas are covered by desert pavement, and the outcrops in many other areas are covered or obscured by soil, rock walls, and terraces. Photogeologic methods should be used where applicable, of course, in individual areas in conjunction with field work; that is, the geologist mapping in a given area will use photographs in his regular work and he may occasionally find it possible to map small or even large areas from the photos.

Many of the supporting services required by the Geological Survey would be the same as those of other organizations and need not be discussed. Two deserve special mention however: (1) the Survey will require many chemical analyses of rocks, minerals, and waters, and special analyses of a variety of types. The need for this work probably would not be great at first, and it probably would be best for the Government Laboratory to continue to be responsible for all of it the first year or so, and for decreasing parts of it during the next few years. As the Survey's need for analyses grows, however, it should have its own laboratory facilities. (2) Because the Geological Survey would be mainly a mapping agency, it will need draftsmen, at least one editorial clerk, and facilities for publishing maps and reports; for the foreseeable future it is not necessary that it have its own printing facilities, but care should be taken to provide the capacity and funds in the appropriate agency for prompt publication of its maps and reports.

Several projects that ought to be attacked in the near future are described in the following pages. Although they are listed roughly in the order of priority, all of them are important, and the qualifications of available personnel and like criteria should determine which projects are started first. In spite of the fact that the job to be done is large, the staff will necessarily be small at first because not many Jordanian geologists are available. Two to four outside geologists and a similar number of Jordanian counterparts would be enough to get the work underway, and during the early years of the Survey (until Jordanian geologists acquire enough field experience to train additional recruits themselves) the total technical staff probably should not be larger than 10 or 12.

Completion of the 1:250,000 geological map of Jordan

The West Bank was mapped during the Mandate by Blake and Shaw and published as part of geologic maps of Palestine; these maps are out of print and only one or two copies of them are available in Jordan. It would be highly desirable to recompile these maps, incorporating if possible newer information obtained by the Phillips Petroleum Company as well as the results of reconnaissance that might be done in certain areas, and to publish the results at a scale of 1:250,000 in sheets that would adjoin Quennell's maps of the western part of former Transjordan.

The eastern desert has never been mapped at all and it would be desirable to map this area also at a scale of 1:250,000. This would be largely a field reconnaissance project that would make the maximum possible use of aerial photographs. These maps probably would require 2-3 geologist man years to complete, depending partly on the experience of the Jordanian assistant and the availability of helicopter support (the desert reconnaissance would be speeded up tremendously if the army could furnish a helicopter for use in the more remote areas). The 1:250,000 maps will not suffice all the needs for geologic information in these areas, no more than have Quennell's maps; but they will supply general information on the distribution and structure of the rocks that will aid, as have Quennell's maps, in defining areas favorable for the occurrence of oil, ground water, and other minerals.

Geologic mapping of the Jordan Valley

According to local ground-water geologists, the ground-water resources of the Jordan Valley are only 3-5 per cent developed in most areas. On the other hand, it is possible that within the near future, too many wells will be drilled in local areas; if this happens, the water-producing and even the water-bearing capacity of the aquifers (which are mostly unconsolidated sands and gravels) in the Jordan Valley may be permanently reduced. Geologic mapping of the Jordan Valley, coupled with observations made on existing wells, would permit wise development of the Jordan Valley ground-water resources, define recharge areas that might be taken advantage of in water spreading, and indicate the location of clays and other nonmetallic minerals that might be used as construction and ceramic materials. The area and species of phreatophytes should be mapped as a part of this investigation as a first step in the recovery of underflow for construction use. Probably 4-5 geologist man years would be required for this project.

Geologic mapping of the Azraq area

The Azraq area contains one of Jordan's largest undeveloped concentrated water supplies--a supply that could be used to irrigate new land and furnish a source of livelihood to hundreds, perhaps thousands of now unemployed families. Just how many people could be so supported, or how best the supply could be used will not be known until the water-producing capacity of the Azraq area is determined.

The work recently completed at Azraq by the Baker-Harza Company shows that large areas contain soils suitable for irrigation, and the springs alone produce enough water to irrigate about 17,000 dunums*. Several exploratory wells suggest that enough ground water is available to irrigate an additional 10,000 dunums. Geologic mapping and other

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* 1 dunum = 0.247 acre

studies that would determine the source of the ground water tapped by these wells have not been undertaken, however, and until they are done, it will not be known whether production from these wells will reduce the spring flow. Although available information is sufficient on which to base a modest irrigation project, geologic studies and eventually more drilling are needed to determine Azraq's full potential. As in other areas, such studies will also aid in the location of nonmetallic mineral deposits. Probably 3-5 geologist man years would be required for the geological studies.

Reconnaissance investigation of nonmetallic minerals

Little information is available on most of Jordan's nonmetallic minerals, even those known to occur in abundance. Some of them will be mapped, sampled, and appraised as a part of other mapping projects, but some information is needed soon on the others to define their potential and to stimulate the development of the most promising ones. For example, reconnaissance examination of the bituminous limestones in the Irbid area, if supplemented by laboratory tests, would quickly yield enough information to define several possible sites for a cement or lime plant. Similar examinations of clay, glass sand, gypsum, building stone, and other nonmetallics might suffice to define sources of raw materials suitable for several industries, and they will at least help to define the location of deposits that deserve further study. Probably 4-5 geologist man years would suffice to acquire enough information for a preliminary report on the nonmetallic minerals of Jordan, and such a project is strongly recommended.

Stream gaging

If surface run-off in Jordan is to be utilized fully and wisely, much more information is needed on stream and wadi discharge. Accordingly, I recommend that an outside hydrologist and Jordanian counterpart be assigned to the job of setting up gaging stations on the permanent streams, and to acquire information also on the volume and peak discharge of ephemeral drainage in the major wadis.

Reconnaissance geologic mapping and sampling of phosphate-bearing areas

The Belqa series contains phosphate beds over a wide area in Jordan but only the deposits in the vicinity of Ruseifa and El Hasa have been extensively prospected. Because the known deposits in the Ruseifa area are clearly sufficient to support production for many years, and because the Jordan Phosphate Mines Company has shown itself willing and able to do the test-pitting and sampling required in advance of mining known deposits, it is not necessary for the Jordan government to undertake more exploitation sampling in the El Hasa or Ruseifa areas. Inasmuch as the Ruseifa deposits are already being mined and marketed at a profit, more exploitation of any kind is not urgent. Nevertheless, discovery of a minable deposit closer to Aqaba would yield some savings in freight costs that might enable Jordan phosphate to compete more successfully in far distant markets, such as Japan; moreover, better knowledge of the distribution and extent of Jordon's phosphate resources would permit wiser and more profitable development in the long run than would be possible otherwise; and better knowledge of the stratigraphy and facies relations of the Belqa series would assist in the search for oil in Jordan. For these reasons, I recommend further investigation of the Belqa series and its phosphate rocks, particularly in the area between Zarqa and Ma'an, along the following lines:

1. Test pitting, trenching, or drilling at intervals of 5-15 kilometers (probably 100-150 localities). The purpose of this sampling is not to appraise specific deposits--any promising ones discovered can be further explored by private enterprise--but rather to disclose areas that contain or could contain minable deposits. Attention should focus not merely on the phosphate beds themselves but also on the rocks with which they are associated; all of the rocks of the Belqa should be measured and carefully described, and all of the beds in the phosphorite-marl units should be sampled. This will permit analysis of facies relations that will provide clues to the location of the best deposits. The means by which the samples are to be obtained, and the areal spacing of sampling locations should be determined experimentally[1/].

1/Samples are now obtained by sinking deep test pits by hand. Although this technique yields the best exposures for stratigraphic studies, it works best where the pits need not be more than 15 or 20 meters in depth. Air drills are now used successfully for both sampling and stratigraphic purposes (particilarly where good knowledge of the rock assemblage has been gained from other exposures) in similar areas, and may well prove to be the cheapest and most efficient means of sampling in Jordan as well.

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2. Ideally the sampling and stratigraphic work should be preceded by quadrangle geologic mapping on a scale of, say, 1:50,000, to delineate the areas underlain by favorable horizons, to facilitate the selection of sites for sampling, and to aid in the interpretation of the relation of areal variations in facies to structural features, particularly those that may have formed during or prior to the deposition of the phosphorite and that therefore may have influenced its distribution. This mapping is recommended also for its general value in the search for water and other minerals (see next project). It seems probable, however, that the phosphate work should be begun before this mapping could be completed, and I believe that field reconnaissance mapping would be adequate to guide the sampling and stratigraphic studies outlined, at least during its initial stages.

Although the time required for this work is difficult to estimate it probably would take a two-geologist team, assisted part of the time by laborers and samplers, about six years to complete.

Geologic mapping of the Qatrana-El Hasa-Ma'an area

The Qatrana-El Hasa-Ma'an area not only contains phosphate deposits, but also important supplies of ground water. It lies on the western fringe of the eastern desert, and most of it receives less than 200 mm of rain a year. This supports a few permanent springs, wells, and kahrezes at Ma'an, El Hasa, Qatrana, and at a few other localities water has been found in bedrock as well as alluvial aquifers. As indicated earlier, we cannot hope to greatly increase the usable, replenishable supply of water in the eastern desert, and bedrock aquifers must be developed cautiously until the source and extent of their recharge is determined. But the wells already located and the phreatophytes growing in wadi bottoms are indications that more water can be found, especially in the western part. In fact, the development of ground water coupled with water spreading and the replacement of useless phreatophytes with useful ones might support thousands of additional families in this area. Again, just how many could be supported, or how the water could be used most efficiently can not be determined until the geology of the area is better known. Therefore, the first step in the further development of this area is geologic mapping. This will not only aid in the development of ground water in the area but it will yield information helpful in the location of other nonmetallic minerals, including oil. Inasmuch as much of this area is close to the railroad and the southern part of it is close to Aqaba, usable minerals could be gotten to their markets more cheaply than from most other parts of Jordan. The geologic studies needed may take several years to complete but good progress could be made at the rate of two geologist man years of work per year.

Geologic mapping in the Wadi Yutum-Wadi Araba area

As previously mentioned, the granitic-metamorphic terrane in the southwestern part of Jordan could contain vein and replacement deposits of rare-earths, tungsten, fluorspar, and feldspar, and they contain granite and other building stones that might be suitable for export. In addition, Wadi Araba and some of the tributary wadis probably contain significant supplies of ground water as underflow in alluvium. Aqaba is Jordan's only seaport, and in developing the volume of Jordan's export serious attention should be given to a) the development of closely adjacent raw materials (e.g. fine building stone) suitable for export; and b) the location of manufacturing industries at Aqaba. For example, if sulfur is imported for the manufacture of triple super phosphate or potassium sulfate for export it would be logical that the plants be at Aqaba. Developments such as these will require both water and building materials. For these several reasons, geologic mapping and related studies ought to be started soon. Because the area is large and the country extremely rugged, this job will require many years for completion, but it should be attacked at the rate of at least 2 geologist man years per year.

Study of regional facies relationships of post-Paleozoic rocks

As previously mentioned, the full staff of the Geological Survey should include at least one stratigraphic paleontologist, who would identify fossils and make age determinations for other field parties as needed. Very likely this work would not require more than half his time and inasmuch as there is considerable need for information on regional changes in the thickness and composition of the post-Paleozoic rocks in Jordan, it would be advisable to begin a program of measuring sections, collating the results on lithofacies maps, and analyzing their significance. This information would be of tremendous value in the search for oil, and for other minerals, including phosphate and water, as well. Several years would be required for the completion of this work, but good progress could be made on it by one outside geologist and his Jordanian counterpart working half time on the problem.

Publication of reports already completed and of data already collected

A large number of reports have already been completed on various aspects--mostly local problems concerned with water supplies--of the geology of Jordan. Many of these are suitable for publication, or could be made so with slight revision, and they ought to be published so that the information they contain will be more widely available and usable. It might be argued that a report on the ground water possibilities in the vicinity of a small village, for example, has no general significance and hence doesn't need to be published. One can never predict, however, when and in what way some of the observations reported in a small area or on a narrow problem will be utilized in a wholly unforseen way by a later worker, dealing perhaps with a completely different problem. It is the accumulation and spread of such data by publication that nourishes free enterprise in the minerals industry, and the Jordan Government can perform its greatest service over the long run by disseminating such information. Accordingly, I strongly urge that the geologists assigned to the Geological Survey spend part of their time reviewing earlier reports and preparing them for publication.

It would also be highly desirable to compile in report form many of the scattered data already in the files of various agencies on such things as the quality of water, well and spring flow, etc. These data in their present form are of little value even to the Government; compiled and published they would serve many purposes beyond those for which they were collected.

Formation of a library

At the present time, previous publications on the geology of Jordan are not housed in any library where they are readily available, and it is unlikely that all of them are even present in Jordan. In addition, geologists working in Jordan need access to information on the geology of other countries of the Middle East and adjacent areas in order to understand and learn of regional geologic trends that bear on Jordan's problems. And they also need access to other literature that deals with scientific principles, regardless of where they were first observed. For these reasons, a good library in the general field of earth sciences should be established in Jordan. Eventually it might have 25,000 - 50,000 volumes, but its early goal could be much less. The cost to Jordan of acquiring this library probably would not be large, for I believe other countries would cooperate in furnishing previous publications. If Jordan begins a publication series of her own Geological Survey, she can get publications of other Geological Surveys and scientific societies all over the world by agreeing to exchange her publications as they are issued with theirs. This is a well established procedure, and there are at present several hundred organizations throughout the world that function on this basis.

Bureau of Mineral Industries

The functions of the Bureau of Mineral Industries would be to review and take action on applications for mineral and oil leases; enforce conservation, health and safety regulations; prepare advice as needed on revision of the mining laws; collaborate with other government agencies in deciding on the use to be made of public lands that contain mineral deposits but are suitable for other uses; investigate or keep abreast of mining practices and equipment so as to be able to advise small companies or individuals on such matters; and investigate uses that can be made of Jordan's minerals as well as possible markets for mineral products. Because its objectives are closely tied to industrial development it is logical that the Bureau of Mineral Industries be in the Ministry of National Economy, where the Section of Mines is now located.

As with the Geological Survey, the Bureau of Mineral Industries need not be large, especially in the foreseeable future, nor its organization complex. Its essential members should be a geological engineer to take action on lease applications and investigate land classification and related problems; a mining engineer to supervise mining on the public land, enforce health and safety regulations in operating mines and quarries, and give advice to operators to help develop safe and efficient mining practices; and a chemical or mineral products engineer, experienced in the commercial uses that can be made of minerals, to investigate the properties, uses, and possible markets for Jordan's known mineral deposits, and in this way to stimulate the growth of new mineral industries in Jordan. If petroleum is found in Jordan, the staff should also include a petroleum engineer to supervise regulations governing the extraction of oil. The Bureau should have a solicitor to advise on legal matters, although it probably does not need one as a fulltime member of its staff.

Revision of the mining laws is needed to stimulate greater activity in the mineral industry, particularly in prospecting. This step has been recommended by every one who has studied Jordan's mineral resource situation, and it must be taken if Jordan is to enlist the aid of private prospectors in the search for mineral deposits. The Government could provide additional stimulus for prospecting by offering short courses in schools or in adult education classes. A possible fruitful and fairly simple way to create interest in looking for minerals would be for a member of the Bureau of Mineral Industries or the Geological Survey to give talks, possibly monthly, in Aqaba, Ma'an and perhaps occasionally other places, to give information on the appearance and properties of minerals of commercial interest. If such talks were well illustrated with specimens and pictures, they might attract considerable interest and spark the imagination and zeal of at least a few people who roam the hills.

A chemical or mineral products engineer is needed to stimulate the growth of new industries in Jordan. He should know the uses for various raw materials, particularly nonmetallics like clay, sand, and limestone, and be able to determine the suitability of various materials for industrial purposes. Beginning with information already on hand

and augmented by the geologic work to be done concurrently, he would attempt to find answers to questions such as: what kinds of products can be made and marketed from the clays in Jordan, the high silica sands, the limestones? What process is best suited to the manufacture of lime or cement from the bituminous limestone? Is there a market for gypsum products that could be made in Jordan? Would the local and foreign market justify the manufacture of phosphate fertilizers and chemicals in Jordan? Answers to questions such as these might do much to aid the development of Jordan's mineral industry.

I recommend that the present Section of Mines in the Ministry of National Economy be expanded to a Bureau of Mineral Industries as soon as possible, and that its staff be increased to include an outside mining engineer, experienced in mineral leasing, mining law, and mine safety and to include also an outside chemical or mineral products engineer and Jordanian counterpart; both outside engineers should be on two year assignments. Plans for further expansion of the Bureau should be postponed until recommendations are received from its own staff; very likely growth of the mine leasing phase of the work will be slow, but the mineral products investigations may well bear early expansion.

Conclusion

The foregoing analysis of Jordan's mineral resource potential shows that she can greatly increase her consumption of raw materials and energy in the years to come by a combination of domestic production and trade. A wide variety of activities and changes are necessary before the general level of living can be raised significantly, and some of them cannot take place for many years. For example, Jordan can eventually develop a strong and prosperous chemical industry--an industry that would not only supply important products for internal use but that would be one of its main bases for trade--but before this can happen a skilled labor force must be trained, sources of power must be developed, markets must be developed, and so on.

Fortunately two of the essential prerequisites for economic development are ones that can be pressed during early stages, for they involve a relatively small number of people. These are 1) collection of basic data on the distribution, extent, and quality of Jordan's mineral resources, and 2) investigation of uses and markets (internal as well as external) for the minerals with which Jordan is well endowed. To an important extent, both of these activities are appropriate functions of government, and it would be advisable for the government of Jordan to establish two permanent agencies, namely a Geological Survey and Bureau of Mineral Industries, to collect and publish data in these fields.

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Table 5.--Indices of income, production, consumption, and education in selected countries in 1955

(Based on data reported in the United Nations Statistical Yearbook for 1956)

	Income, employment, and population density				Production		Consumption				
	Per capita income (dollars per year)	Employment in agriculture (percent of labor force)	Population density (people per sq. mile)	Population density per sq. mile of agric. and forest land	Iron ore (kg of Fe per capita per year)	Energy (equiv. tons coal per capita per year)	Food (calories per capita per day)	Steel (kg per capita per year)	Energy (equiv. tons coal per capita per year)	Newsprint (kg per capita per year)	Education budget (dollars per capita per year)
United States	1,963	12.1	55	60	327	7.9	3,100	620	8.2	35.2	30.67
Canada	1,335	19.0	4	8	555	5.2	2,885	322	7.6	27.5	----
Sweden	1,135	20.3	43	68	1,438	1.8	3,030	102	4.1	22.0[1]	28.27
New Zealand	1,109	18.3	20	26	neg	1.9	3,375[1]	446	2.8	18.4[1]	25.47
Venezuela	510	41.3	16	17	933	26.5	2,280[3]	109	2.0	2.8	8.43
Eire	442	39.6	107	151	neg	.14	3,480[1]	53	1.4	11.0	11.66
Lebanon	288[1]	----	356	---	neg	.09	-----	118	0.5	----	3.85
Japan	229	48.2	636	737	10	.82	2,220	82	1.0	5.1	-----
Turkey	217[1]	----	80	90	23	.27	2,670	19	0.3	0.7[1]	6.30
Colombia	175	----	29	33	neg	.79	2,370[4]	27	0.5	1.7	1.12
Jordan	132	----	36	306	neg	neg	-----	19	0.1	----	0.70
Ceylon	126	52.9	339	390	neg	.009	1,980[1]	6	0.1	1.0	3.50
Egypt	106	51.0	59	2,540	neg	.13	2,450	14	0.2	0.9	3.26
Brazil	96	----	18	26	43[2]	.14	2,340[5]	25	0.4	2.8[1]	-----
Pakistan	65[2]	76.7	229	650	neg	.014	2,030	4	0.1	0.2	-----
India	59	70.6	300	506	7	.11	1,850	7	0.1	0.2	-----

1/1954

2/1953

3/1951

4/1949

5/1952

79-1869

Education and culture

Illiteracy (percent of pop. 10 and over)	High School and technical students (per 1,000 of population) total	High School and technical students (per 1,000 of population) Female	Students in teacher training and higher schools (total per 1,000 of population) total
Ca 3	45[2]	23	14[2]
Ca 3	---	--	---
Ca 3	29	13	4
Ca 3	38[1]	19[1]	7[1]
51	7	3	2
Ca 3	27[1]	14	4
----	---	--	3
----	86[1]	42[1]	6
65	6	1	2
----	9[1]	4[1]	2
----	25	4	0.2
42	---	--	1[1]
74	21	4	3
----	12	6	2
----	14	2	1
82	17[2]	--	2