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POTASH AND OTHER EVAPORITE RESOURCES OF AFGHANISTAN

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CONTENTS (cont.)

CONTENTS

POTASH AND OTHER EVAPORITE RESOURCES OF AFGHANISTAN

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ILLUSTRATIONS

TABLES

APPENDICES

POTASH AND OTHER EVAPORITE RESOURCES OF AFGHANISTAN

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SUMMARY

On the basis of earlier work and geologic settings, seven areas in Afghanistan were identified as being favorable for evaporite deposits other than halite. Five were known or suspected to contain continental brines or evaporites; two are diapirs composed of deformed marine evaporites. They were visited, sampled, and are here evaluated.

Brines from Daste Nawar are considered a possible source of sodium carbonate (soda ash). The largest uncertainty lies in the amount of brine that can be extracted from the impervious muds in the basin.

Brines in Namaksar Andkhoi, Namaksar Tashqurghan, and Namaksar Herat are considered possible sources of magnesium minerals (magnesia) but nearby markets for magnesia are few. Namaksar Tashqurghan and Namaksar Herat contain brines that represent marginal sources of potassium minerals (potash), but only the latter site has adjacent areas suitable for solar evaporating ponds.

Test drilling is recommended for Daste Nawar and Namaksar Herat; the other basins are considered too shallow to contain deeply buried deposits.

The brines in the Gawdezereh have no economic potential. The marine salt being mined from diapirs at Taqca Khana and Kalafgan does not contain detectable traces of potassium minerals or other components of value.

INTRODUCTION

The present study of the evaporite deposits of Afghanistan was an outgrowth of a 1969 investigation by C. W. Sweetwood. Several of his analyses indicated potassium concentrations that are comparable to those in brines being exploited in other parts of the world. The possibility that these could be exploited, and that better or additional evaporite deposits might also exist, made it advisable to study the area in more detail. In late 1971, I was requested to spend four to eight weeks in Afghanistan to do so. The work described here was undertaken in cooperation with the Ministry of Mines and Industries (MMI) under the auspices of the Government of Afghanistan (GOA) and the Agency for International Development, U. S. Department of State (USAID).

This report is based on visits to seven evaporite deposits or closed basins that appeared to be possible sites for such deposits. Four of these were selected because they appeared to be the most promising of the eleven sites sampled by Sweetwood; one was selected because verbal descriptions of it by Afghan geologists suggested the possibility of potassium mineralization, and two were selected because study of geologic and topographic maps showed that the areas had favorable settings.

I would like to thank the following for their roles in promoting and expediting my study. Eng. Sayyed Hashim Mirzad, former President of the Survey and Geological Department, MMI, has been most helpful in advising and supporting my work during this project. I was accompanied either by Eng. Abdul Rahman Kazikhani, Dr. Eng. Anayattullah Inea, or Eng. Mohammed Kabir, on three of the four field trips, and I greatly appreciate their contributions to my field efforts. Eng. Badruddin Sharifi, President of the Petroleum Exploration Department (Mazari-i-Sharif) and Dr. Eng. Subat, Acting Director of the Geological Survey of Afghanistan (GSA) made my work much more productive by furnishing sound advice and discussions of geological problems. Dr. Eng. Mozafuruddin Yaqubi, President of the Cartographic Institute, was most helpful during my collection of maps and aerial photographs needed for field work. Many members of USAID/Kabul have contributed to this project, for which I thank them. Mr. W. A. Stiles and Mr. H. A. Springer of the Engineering Department sponsored and supported my work throughout. Mr. Abdul Rouf drove my truck throughout the study without either accidents or serious incidents--not an easy record to achieve.

SUMMARY OF EVAPORITE TECHNOLOGY

The term "evaporite" is one used by geologists for any concentration of minerals that resulted from the evaporation of natural waters. The largest and most valuable deposits in the world are marine evaporites that resulted from the concentration of salts[1/] in sea water. Deposits of this

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[1/] "Salt" is a general term used by chemists to refer to inorganic compounds dissolved in water. The same term is used in the industrial-mineral industries as a synonym for halite (NaCl). In this report, the usage of chemists is generally followed; where industrial mineral terminology seems necessary, the limited meaning is indicated by adding "(NaCl)" if not clear from the context.

type were formed during every geologic period and are found on every continent. The principal products recovered from these deposits as solids are gypsum ($CaSO_4 \cdot 2H_2O$), salt (NaCl), and potash (K_2O[2/]); the interstitial or related brines are often sources of magnesium (Mg), bromine (Br), and iodine (I). Because halite and potash minerals are quite soluble in water, they are not exposed as outcrops except in very arid regions, and most deposits of them have been discovered accidentally during drilling carried out in the course of petroleum or natural gas exploration. Annual production of salts from marine evaporite deposits in the United States is valued at approximately $400 million.

Smaller--but also very valuable--deposits of evaporites resulted from the evaporation of inland lakes that contain dissolved salts. These are called continental evaporites. Most are of Cenozoic age, but some were formed in closed basins that are geologically so old that they ar no longer reflected by the present topography, whereas others formed

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[2/] Technically, "potash" refers to K_2O, but most potassium is sold for agricultural purposes as KCl ("muriate") or K_2SO_4 ("sulfate").

in basins that had virtually the same size and shape as they do now. Products mined as solids from continental evaporite deposits in the United States and elsewhere are salt (NaCl), salt cake ($NaSO_4$), soda ash or soda (Na_2CO_3), and borax ($Na_2B_4O_7 \cdot 10H_2O$); brines associated with these deposits provide extractable salt cake, soda ash, borax, potash (K_2O), lithium (Li), phosphate (PO_4), bromine (Br), calcium chloride ($CaCl_2$), and magnesia (MgO) or magnesium metal (Mg). The value of annual production from deposits of this type in the United States is currently about $130 million.

Geologic setting of evaporite deposits

The basic requirements for the formation of evaporite deposits are (1) the availability of large quantities of water that contain dissolved solids, and (2) a depression or basin that receives these waters at a rate that is equal to, or less than, the amount lost by evaporation. This allows the concentration of solutes to increase, usually to a point where solids are crystallized. As a general rule, the greater the degree of concentration, the higher grade the deposit.

Marine evaporite salts mostly formed where large bays, lagoons, or inland seas had narrow or intermittent connections with the open sea. Some of the bodies of water were quite shallow, others apparently were deep; all had in common an evaporation rate that equaled or exceeded the inflow of sea water. Because the composition of sea water has apparently remained stable throughout geologic time, the sequence of crystallized salts and the species of minerals originally formed in marine evaporite deposits is quite predictable and consistent. Many deposits have undergone postdepositional changes in their mineralogy or in the physical distribution of the concentrated elements because burial under thick sections of younger sediments brings about changes in the temperatures and pressures acting on the layers of crystallized salts and any interstitial brines. Compared to continental evaporites, though, the mineralogy and chemical composition of marine deposits varies only within narrow limits.

Rocks surrounding marine evaporite bodies are most commonly limestone or dolomite on the seaward side, and poorly sorted reddish sandstones and siltstones on the landward side. Among the minerals crystallized from evaporated sea water, gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) are the most abundant and usually extend over the largest areas. Deposits of halite ($NaCl$) form from much more concentrated sea water; occurrences are therefore less common, but the mineral may form larger volumes of rock, because NaCl constitutes a higher percentage of the dissolved salts in sea water than $CaSO_4$. Deposits of potassium as sylvite (KCl), carnallite ($KCl \cdot MgCl \cdot 6H_2O$), langbeinite ($K_2SO_4 \cdot MgSO_4$), or kainite ($MgSO_4 \cdot KCl \cdot 3H_2O$) indicate even higher concentrations of salts in water, and therefore are found even more rarely.

These minerals commonly occur in crudely concentric zones, with gypsum or anhydrite in an outer zone that encloses a halite zone that encloses a potash zone. In theory, therefore, exploration needs only to determine the direction toward the center of the concentric area to determine which areas are most likely to contain potassium minerals.

In actual practice, the potassium-rich zones--if any--may be located asymmetrically in the basin or be discontinuous, but the basic pattern and exploration approach remain the same.

Continental evaporites formed where inland closed basins received mineral-rich waters which evaporated to a concentrated brine or a mixture of brine and salt. The composition of natural waters varies enormously, so the types of minerals and the components remaining in evaporated brine are less predictable than those of marine evaporites. In Afghanistan, however, only two types of continental evaporites and brines are found; these are referred to as being of the calcium-sodium-sulfate-chloride type and the sodium-carbonate-sulfate-chloride type.

In other parts of the world that have been studied more extensively, calcium-sodium-sulfate-chloride waters commonly occur in areas that receive drainage from marine rocks (limestone, dolomite, shale, sandstone), plutonic rocks (granite), or metamorphic rocks (slate, gneiss, schist, etc.). On evaporation, they commonly form gypsum and halite. The remaining ions in solution are normally dominated by sodium, calcium, magnesium, bicarbonate, sulfate, and chloride, but may also contain significant amounts of potassium, lithium, or bromine. Their pH is near 7.

Studies elsewhere have also shown that sodium-carbonate-sulfate-chloride type waters are generally the product of drainage from geologically young volcanic rocks and from areas containing alkaline hot springs. The minerals formed on evaporation are usually mixtures of halite ($NaCl$), thenardite (Na_2SO_4), mirabilite ($Na_2SO_4 \cdot 10H_2O$), trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), natron ($Na_2CO_3 \cdot 10H_2O$), or nahcolite ($NaHCO_3$). Interstitial brines, if present, normally contain sodium, carbonate, sulfate, and chloride, and may contain significant amounts of potassium, borate, lithium, bromine, and phosphate. Their pH is normally between 9 and 11.

To the extent that could be determined from geologic maps and literature, and from conversations with geologists familiar with the geology of Afghanistan, the chemistry of the waters draining into the basins that were sampled follow these generalizations.

Besides the chemical composition of the water draining into a closed basin and the relation between inflow and evaporation, three other factors can be important in determining the composition and economic favorability of a continental evaporite. One is that if there is a high percentage of suspended silt and clay in the inflow, the material deposited in the center of the basin may consist of salts or brines with such a high concentration of impurities that the salt concentrations are not recognized. Even if recognized, the valuable components in the salts or associated brines may not be recoverable as brines because of the low porosity caused by the high clay content. Another important factor is season in which rainfall is at a minimum, because this controls the season during which maximum concentration of brines and crystallization from them takes place. Low (winter) temperatures at the time of crystallization will promote higher percentages of some valuable minerals, and high (summer) temperatures will promote higher percentages of others. Which season is preferable depends on the elements being extracted, on the process being used, and on the ratio of ions in the water. A third important factor is the amount of bacterial decomposition occurring on the bottom of a saline lake. This greatly influences the amount of carbon dioxide in the brine, and this affects the amount of carbonate in the solution and controls the species of carbonate mineral being crystallized.

The above considerations can be applied chiefly to continental evaporite deposits that have recently formed--or, in some instances, are still being formed--in present basins. Geologically older evaporite deposits were controlled by the same factors, but prospecting for them is much more difficult. This is because the location, extent, and shape of the basin in which they were formed is not evident, and the chemical nature of the water that drained into the area cannot be evaluated because the rocks that characterized the drainage area are unknown. Also, the brine which remained after the solids formed is generally lost, and in many instances, it was the brine that contained the most valuable components. The compensating fact, though, is that older rocks being searched for deposits span a very much greater time, so the chance for the existence of larger and more valuable deposits is much greater.

Exploitation techniques and limiting factors

The technology of extracting chemicals from evaporite deposits is complex, and many existing processes are adaptable only to one deposit. For this report, I am assuming that the exploitation of any of the deposits visited in Afghanistan would be largely or totally by solar evaporation techniques. This assumption is supported by several considerations as applied to the current situation in Afghanistan:

(1) Solar evaporation processes work best in areas of high evaporation (high temperature, low humidity, and low rainfall). (2) Construction of solar evaporation ponds can be done by hand labor with little prior experience by the supervisors and none by the labor force. (3) The expense of constructing ponds by this manner in areas having low labor costs is reasonable. (4) The cost of removing the evaporated salts (known as "harvesting") from the floor of the ponds by hand labor is also low. (5) Most alternative processes require complex industrial plants; these need to be custom designed, require the importing of high-priced equipment, and are relatively (to extremely) sophisticated operations.

Almost all solar evaporation processes require a series of evaporating ponds arranged so that brines can be pumped or drained from one into the other when solar evaporation has concentrated the brine to a certain point. In most systems, one or more salts crystallize in each pond before the remaining brine is transferred to the next pond in the series. For brines being processed to extract sodium carbonate or sodium sulfate, the desired product is commonly crystallized in the first pond, the unwanted components being removed in the solution containing them to the next pond. For brines being processed to extract potash, lithium, or magnesium, the unwanted components would be removed as crystals in the first ponds with the desired components remaining in solution until later stages. Extraction of some of these components could be achieved by crystallization; others would reach high concentrations in the final brines but other techniques would have to be used for final extraction and purification. Most processes would allow extraction of edible table salt as a byproduct.

Should further studies of areas described in this report seem warranted, preliminary evaluation and generalized processes can be suggested on the basis of the existing chemical analyses. Detailed recommendations, however, would be premature until more drilling and/or trenching has been completed to allow estimates of the quantities of salts that could be extracted and collection of samples that more assuredly represent the gross composition of the salt or brine. After that step, detailed recommendations of exact techniques may be warranted. Such recommendations, however, are outside my field of competence.

A problem that is commonly overlooked in evaluations of this type made here is the availability of good sites for evaporation ponds. The best sites are large areas of flat surfaces that are not subject to flooding during the wet season, and that are underlain by silt or clay layers that are virtually water tight. Cracks, sand wedges, or a large amount of windblown sand mixed with the clay commonly cause excessive leakage of evaporating ponds. Preliminary evaluations are presented here, but more careful studies should also precede development.

For extraction of high-magnesium brines to make magnesia (MgO), a nearby source of dolomite or limestone is required. I have made no study of the proximity of these rocks to the high-magnesium brine sites. For calcining to the final product, temperatures varying from 1,000°C to 1,850°C are required, and natural gas or other high-energy fuel is required.

Transportation and marketing considerations

A major consideration in evaluating whether an evaporite deposit can become an economically practical source of chemicals is the cost of transportation to market. The most abundant chemicals in such deposits are relatively low in value, and the cost of transportation commonly becomes the biggest part of their final cost at the point of use. The following list illustrates typical prices of compounds extracted from evaporite deposits in the U. S., before transportation costs are added:

	Dollars per metric ton (1,000 kg)
Salt ($NaCl$)	$ 6
Potash (K_2O)	16
Soda ash (Na_2CO_3)	35
Salt cake (Na_2SO_4)	31
Borax (decahydrate) ($Na_2B_4O_7 \cdot 5H_2O$)	55
Magnesia (MgO)	70
Lithium (as $LiCO_3$)	900
Bromine (Br)	380
Iodine (I)	2,500

Freight rates to a port or the point of consumption in the U. S. generally add $5 to $30 per metric ton to these costs. The final price, of course, is the sum of the two costs.

In Afghanistan, the cost of transporting a substance on poor roads from the point of production to another point within the country is relatively high; on good roads, it is similar to cost of railroad transportation in the United States. The estimates that follow are based on the cost of transporting salt by truck from Kalafgan, Namaksar Andkhoi, and Namaksar Herat to its destination. The prices quoted to me by the mine managers are converted (85 Afs = $1.00) and extrapolated to give the cost in U. S. dollars of transporting a metric ton for a distance of 1,000 km. Over poor roads:

Using the prevailing rate between Kalafgan and Badakhsahn	$28
Between Namaksar Andkhoi and Sheberghan	18
Between Namaksar Herat and Herat	27

Over good roads:

Using the prevailing rate between Herat and Kabul	10

In 1969, the cost of transporting 1,000 kg for a distance of 1,000 km in the United States by rail averaged about $9.25 on long hauls.

To evaluate the possibility of using air freight for a valuable product, an official of Ariana made a very approximate calculation (verbal commun. to James Hawley, III, U. S. Embassy, Kabul, October, 1971) that a DC-6 containing 12 short tons, could fly from Kabul to and from the nearest port (Karachi, Pakistan) for $2,730. Recalculated, this amounts to $250 per 1,000 kg (or about $120 per 1,000 km). If the return trip carried enough load to pay half the cost of transportation, transportation to the port would cost only $125. In either case, though, it means that of the products that might be extracted from an evaporite deposit, only lithium, bromine, and iodine have values sufficiently high to make this means of transportation to a port a reasonable possibility.

Marketing of products from evaporite deposits is too complex to consider in any detail at this stage. The price of products sold within the country would be subject to the outcome of interaction between the producing agency, the government, and the consumers. The prices of products sold outside of the country--in all probability, one of the higher-priced chemicals--would be subject to the same controls, plus those resulting from import duties or pre-existing long-term contracts between consumers and present-day producers. In many instances, the majority of markets for industrial chemical products are virtual captives of present producers, and the best way for Afghanistan to enter an especially competitive field might be via an agreement with one of the existing producers from another country.

EARLIER STUDIES OF EVAPORITES IN AFGHANISTAN

Only two earlier studies have been made, to my knowledge, of the economic potential of evaporites in Afghanistan. Both are unpublished. In the early 1940's, at the request of the Government of Afghanistan, a study of the salt (NaCl) resources of the country was made by E. R. Gee, of the Geological Survey of India, and T. C. Seth, of the Central Excises and Salt Department, N. W. India. The 100-page typewritten report contains descriptions of four "rock salt" deposits (marine evaporite diapirs) and four "brine salt" deposits (continental salt lakes), as well as recommendations for improved methods of exploitation, administration, and transportation. The geologic settings of some deposits were misinterpreted, but descriptions of the salt deposits themselves are accurate. Chemical analyses of salt from one rock salt deposit, and of salt and brine from four brine salt deposits are included in their report. The brine analyses must be regarded with caution because even today, accurate analyses of such brines are difficult to make. All potassium percentages in their analyses are reported as "trace," and several of the minor elements of interest to this study (for example, boron, lithium, and bromine) were either not sought or not analyzed with sufficiently sensitive techniques to determine small amounts. Nevertheless, a large amount of useful information is available in their report, and many of the suggested improvements in technology of mining or extraction could be of use today.

The second study was made in September 1969, by Charles W. Sweetwood, Regional Minerals and Petroleum Attache, U. S. Embassy, New Delhi. He visited and sampled the major salt-producing areas of Afghanistan as well as several other areas that he thought might provide guides to deposits of valuable components. His main concern was the country's potential for domestic supplies of evaporites containing potassium, but other elements were sought. The results of his study were not published, but the analyses of brine and salts are included in the present report for the record. Those analyses were made by chemists working at the facilities of the GOA Ministry of Mines and Industries, Kabul, and by chemists at the University of Kabul under the direction of Dr. James N. Holsen.

Papers concerning the geology of the areas of rock salt deposits have been published (Hinze, 1964; Weippert and Wittekindt, 1964), but none appraise the mineralogy or economic potential of these salt bodies. After my field study was completed, study of closed lakes in Afghanistan was published by Förstner (1973). It included sediment and/or water chemistry analyses of Daste Nawar, Band-i-Amir, Ab-i-Estada, and Hamun-i-Puzak, and its conclusions concerned the clastic sedimentation and limestone and dolomite deposits but not salines. A study by Huntington (1905) of older Pleistocene lake deposits exposed on the Iranian side of the Helmand Basin (and elsewhere in that country) provides a clear record of closed basin sedimentation far back into Pleistocene time. A more recent study of playas in Iran by Krinsley (1970) includes many photographs of closed basins similar to those visited in Afghanistan, data on the surface evaporite mineralogy of selected playas (mostly halite and gypsum), and the subsurface stratigraphy of Pleistocene salt deposits in Qom playa which lies in a closed depression 150 km south of Tehran.

DESCRIPTION OF PRESENT STUDY

Nine areas were visited during this study. On the basis of data from the previous studies, seven areas were considered to have potential for evaporite deposits; two were visited in an attempt to find boron-rich waters which, on geologic grounds, were expected to be present and would have encouraged future prospecting for borate deposits.

Four field excursions that required 21 days and 4,400 miles of travel by 4-wheel-drive truck were necessary to visit and study these localities; a slightly longer period of time was required to obtain maps and supplies and make arrangements for these trips.

Samples of salts and/or brines were collected at all sites. Field geochemical tests (Appendix A) were made on the brines for pH, and carbonate, sulfate, chloride, potassium, and boron ions, and the brine type approximated in the field from the results. Similar tests on solutions made by dissolving salts in water gave data to supplement visual identifications of the salt minerals. The results were used as a guide to other observations that needed to be made at the site. Duplicate samples of brines were collected to allow analyses by both the laboratories of the GOA MMI and of the U.S. Geological Survey (USGS). Mineral identifications were made by X-ray diffraction in USGS facilities.

One area, Daste Nawar (fig. 1)[3/], contains brine that might become a source of soda ash (Na_2CO_3) if enough brine can be extracted from the tight muds in the lake. This area is recommended for first priority for further study.

[3/] All place names in this report use the spelling given on the 1960 series of topographic maps of Afghanistan.

A second area, Namaksar Tashqurghan, has brines characterized by moderately high magnesium contents and lies near the Sheberghan gas field, combinations that might lead to the practical manufacture of magnesia (MgO). Problems lie in the relatively unfavorable nature of the areas for construction of evaporation ponds, and in the fact that markets for magnesia are mostly in industrial areas which would require costly transportation. Brines from Namaksar Tashqurghan also have the highest lithium concentration of any brines sampled in Afghanistan and should be evaluated further for the practicality of extracting it. Brines from this area and from Namaksar Herat have the highest potassium contents among those sampled, although they are only about half the grade of the lowest grade brines now in production elsewhere in the world; Namaskar Herat has large areas suitable for evaporating ponds.

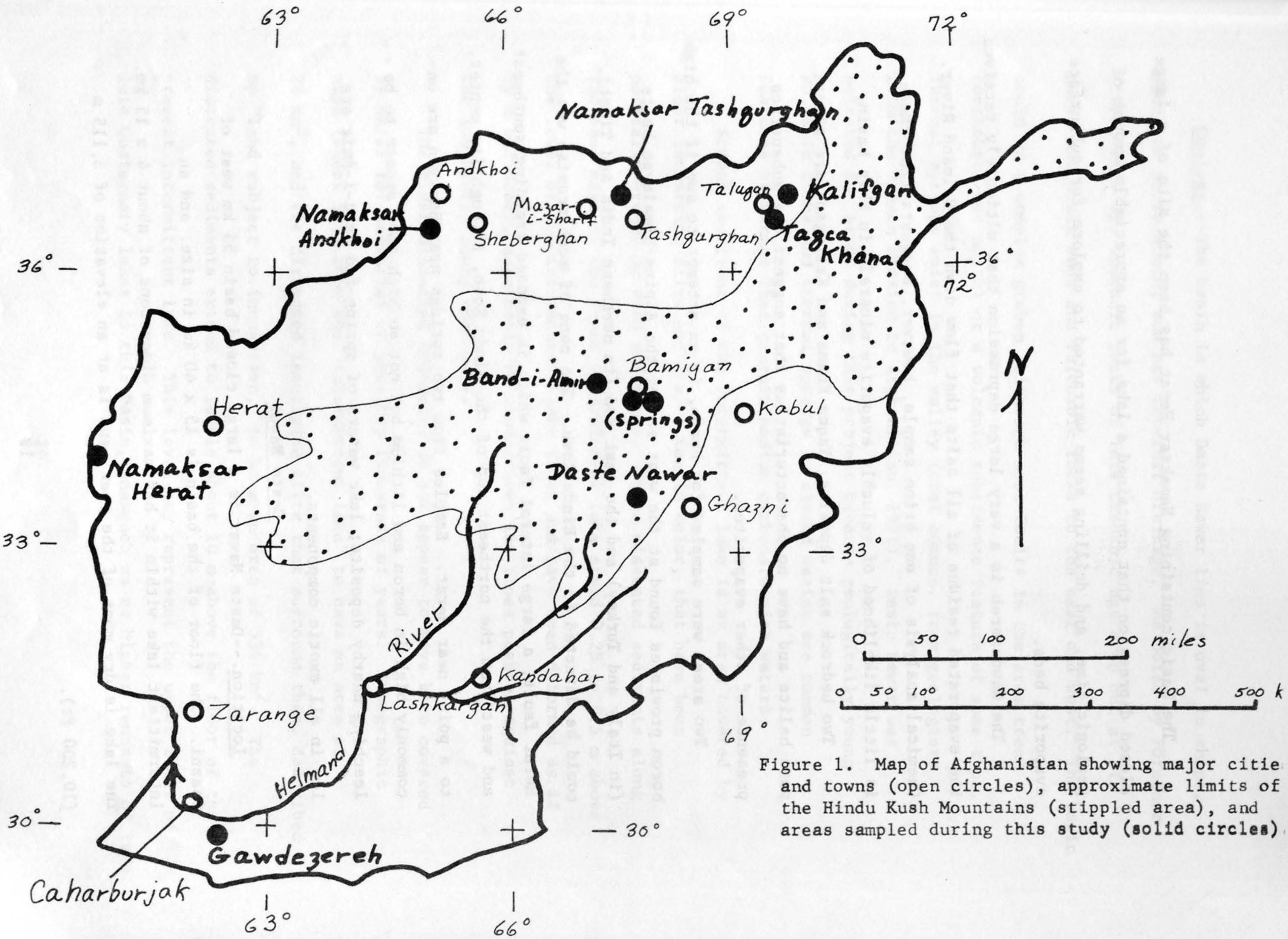

Figure 1. Map of Afghanistan showing major citie and towns (open circles), approximate limits of the Hindu Kush Mountains (stippled area), and areas sampled during this study (solid circles).

The basin containing Namaksar Herat has been the site of a large closed depression that contained a lake for an appreciable amount of geologic time, and drilling seems warranted to explore for subsurface evaporite beds.

The Gawdezereh is a very large depression that ultimately receives the evaporated residue of all salts that flow down the Helmand River. Chemical analysis of one brine sample, however, suggests that there is little likelihood of valuable evaporite minerals in this basin.

Two bedrock salt deposits, Taqca Khana and Kalifgan, are almost pure halite and have no characteristics that suggest the subsurface presence of other evaporites.

Two areas were sampled for boron, in an attempt to see if the high boron provinces found at the west end of the Alpine-Himalayan belts (in Italy and Turkey) and the east end (in northern India and Tibet), could be detected in the Hindu Kush. The zone of most promise was the Herat fault, a large lateral fault which is exposed trending southwest and west from the northeast end of the Hindu Kush, through its center, to a point near Herat. Samples from two springs near Bamiyan are uncommonly high in boron and lithium but not so high they appear to be leaching nearby deposits; lake waters of spring-fed Band-i-Amir are low in all exotic components.

Daste Nawar

Location.--Daste Nawar is a large closed basin 55 km west of Ghazni. The floor of the basin is 15 x 40 km in size, and an intermittent lake within it has maximum dimensions of about 4 x 15 km. The lake is dry most of the year, and is at an elevation of 3,115 m (10,200 ft).

Geology.--The basin in which Daste Nawar lies is oval in shape, elongate north-south, and has internal drainage. As noted by Förstner (1973, fig. 2), volcanic rocks of late Cenozoic age crop out at its north and south ends and Paleozoic rocks to the east and west. The basin could be a complex graben (although most faults in the area trend northeast, not north) or a volcanic subsidence feature of some type. Thermal springs exist in the valley (oral commun. from geologists from the French Mission to Afghanistan, 1971). Daste Nawar was selected for study during this project because geologically young volcanic rocks and thermal springs in closed basins are common features of basins that contain sodium carbonate-rich waters.

Around the floor of the intermittent lake is an area covered by older lacustrine silts and clays, tan in color, that have been partially eroded by wind and water. These dissected sediments along the east edge of the inner intermittent lake stand 0.25 to 0.5 m above the level of the intermittent lake floor and have been deformed as if by a bulldozer, apparently by wind-driven ice floes pushing against the low bluffs along that edge.

The older dissected sediments do not appear to have been covered by water for centuries or possibly thousands of years. Topographic maps (sheet 514) show the "intermittent lake" to have an area of 28 km^2, and the dissected lacustrine silts that surround them, described as "land subject to innudation," to have an area of 334 km^2. The dissected sediments extend to levels about 10 m above the floor of the present intermittent lake. This level may represent the upper limit of late Quaternary lakes in this basin, inasmuch as no higher remnants of lake deposits or shorelines were seen. Fresh water issues from springs along the west edge of the valley floor where downward-moving ground water from surrounding alluvial gravel meets the silt and clay.

The dry surface of the present-day intermittent lake in the central area is composed of undissected clay and silt. The surface of the lake at the time of sampling (Oct. 4, 1971) was entirely dry, and covered by a 1-3 mm layer of unconsolidated silt on a more resistant crust. Light gray efflorescent areas as much as 1 m in maximum dimension covered about 5 percent of the surface. The mud was moist below 5 cm depth, but standing water was not found at a depth of 50 cm.

Analyses and economic potential.--The light-gray efflorescent material was sampled for analysis. Efflorescent crusts provide a crude sample of the dissolved solids in the interstitial brine that was drawn to the surface by capillary action; their compositions can be seriously in error, though, because minerals that crystallize as fine powder tend to blow away more quickly than minerals that form crusts. Laboratory tests on the powdered minerals by X-ray diffraction methods showed major amounts of thenardite (Na_2SO_4), lesser amounts of halite (NaCl), dolomite ($CaMg(CO_3)_2$), calcite ($CaCO_3$), and clastic minerals such as quartz and feldspar. Field tests (a pH near 10 for the water-soluble fraction, and taste) on a sample of this efflorescent material strongly suggested that sodium carbonate minerals were also present, but a chemical analysis (table 1) shows that their percentages are near the limit of sensitivity for X-ray diffraction techniques; in the water-soluble fraction of the efflorescence, 1.05 percent CO_3 and 2.14 percent HCO_3 indicate sodium carbonate mineral percentages

Table 1.--Analysis of efflorecence, Daste Nawar

[Concentrations in weight percent of total sample; n.d. means not determined; USGS laboratory no. W-177092; analysis by Marian Schnepfe [1]]

	Water soluble fraction	Acid soluble fraction [2]
Ca	0.0034	n.d.
Mg	0.15	2.9
Na	12.23	n.d.
K	1.46	n.d.
CO_3	1.05	n.d.
HCO_3	2.14	n.d.
CO_2	n.d.	16.8 [3]
SO_4	16.9	n.d.
Cl	4.2	n.d.
B	0.018	n.d.
PO_4	0.0043	n.d.
Total (calculated)	38.15	--
Total (measured)	40.0	69.0
pH	10.2	--

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[1] See table 2 for techniques used for analysis of each component.

[2] Dissolved in 0.5N HCl, values include water soluble plus acid soluble ingredients.

[3] Value determined by gas chromatography; value obtained by titration was 15.2.

that total about 5 percent, probably a mixture of trona ($NaHCO_3 . NA_2CO_3 . 2H_2O$) and nahcolite ($NaHCO_3$). This is the percentage in the total sample, which was only 40 percent water soluble, so the implied sodium carbonate content of the pure efflorescence is more than twice this amount. These data suggest that the interstitial brine is dominated by sodium sulfate and carbonate, with some sodium chloride. After my study was completed, however, four analyses of porewater were published by Förstner (1973, table 2). They show that the interstitial brines at their maximum concentration in October 1969 contained more carbonate than sulfate or chloride, and that dissolved solids in those analyzed brines totalled about 1.25 percent. Förstner's sample site is not indicated but presumably was near the middle of the lake within the area shown on his figure 4D as containing less than 1.5 percent dissolved solids; brines from the south end of the lake are shown in that figure to contain 2.3 percent solids.

One can make a crude estimate of the volume of brine that might be extracted for processing. If the brine level stands at a depth of 1 m (Förstner, 1973, fig. 4A), and if the sediments contain 30 percent interstitial brine, and if trenches covering about half the lake (15 km^2) were 3 m deep and able to collect half of the brine down to the depth, then one could extract from the muds about 4.5 million m^3 of brine. If it had a salinity of 2 percent and a density of 1.02, this brine would weigh about 4.6 million metric tons (1 mt = 1,000 kg). Using the ionic ratios in Förstner's (1973, table 2) October analysis, this brine would contain about 45,000 tons of sodium carbonate, 15,000 tons of sodium sulfate, and 30,000 tons of sodium chloride. The greatest uncertainty in this calculation is the amount and grade of brine that could be extracted from the mud. Tests would determine this figure more closely.

The floor of Daste Nawar is apparently favorable for an evaporating pan operation. The muds that make up the present floor of the lake appear quite tight, although much fibrous plant material is mixed with them. Sandy beds and sand-filled cracks were not seen. Evaporating pans constructed on the slightly higher dissected silt that surrounds the present lake would probably be more porous unless dug ½ to 1 m below the present surface which is eroded, desiccated, and locally sandy. Pans in that location, however, would have the advantage of not being subject to floods and possible damage during the wet season, and would allow brine to be pumped into them for evaporating during any part of the year.

Climatic data for the valley are not available. During the dry season (June to October) Ghazni, 55 km east and 875 m lower, has mean monthly temperatures that range from 11° C to 26° C. Assuming a mean lapse rate of 7° C/1000 m, mean monthly temperatures in Daste Nawar for this period would range from about 5° C to 20° C. The rate of brine evaporation from pans at these temperatures might be between 0.5 to 1 m during the dry season. From a saturated brine, this would allow 15 to 30 cm of crystallized salts to accumulate in the bottom of an evaporating pan.

If the compositions of the average pore waters in Daste Nawar are close to the samples analyzed by Förstner (1973, table 2), an estimate of the feasibility of producing sodium carbonate is possible. Analyses suggest that salts of Na, CO_3, SO_4, and Cl are the major components and solids that would be produced by evaporation of brine can be inferred from phase diagrams. Representative diagrams are shown in figure 2. Crystallization at 20° C of a brine having the composition of Förstner's October brine, shown as a solid circle in figure 2a, would result in the crystallization of natron causing the brine to change its composition along a path like that shown by the line and arrow. If crystallization occurred at 20° C, the brine would change composition until burkeite also precipitated. Crystallization of this phase is undesirable; it would deplete the Na_2CO_3 content of the brine and prevent one-stage crystallization of a Na_2CO_3 product. Fortunately, burkeite is not stable below 14° C in this system, and if evaporation was carried out at lower temperatures, the crystallizing phases would be restricted to Na_2CO_3, Na_2SO_4, and NaCl minerals.

Figure 2b shows the two-component system and disregards NaCl. The important point is that up to the base of the burkeite field, the natron field expands with increasing temperature. In the three-component field, the natron field probably expands at about the same rate, but if the NaCl content of the average brine is as much or more than it is in the analyzed brine, the second phase to precipitate would be halite rather than mirabilite. Production of sodium carbonate could be carried out as shown in figure 2b. The initial evaporation should be carried out during a season when average daily temperatures are between 10° and 20° C. A crop of natron crystals would crystallize, and the brine composition would shift from its initial composition to a point at which natron would coprecipitate with halite or mirabilite. Brines should be moved to another pond prior to this change so that the sodium carbonate minerals in the first pond would remain pure.

Normally, a hydrated product of crystallization is calcined to

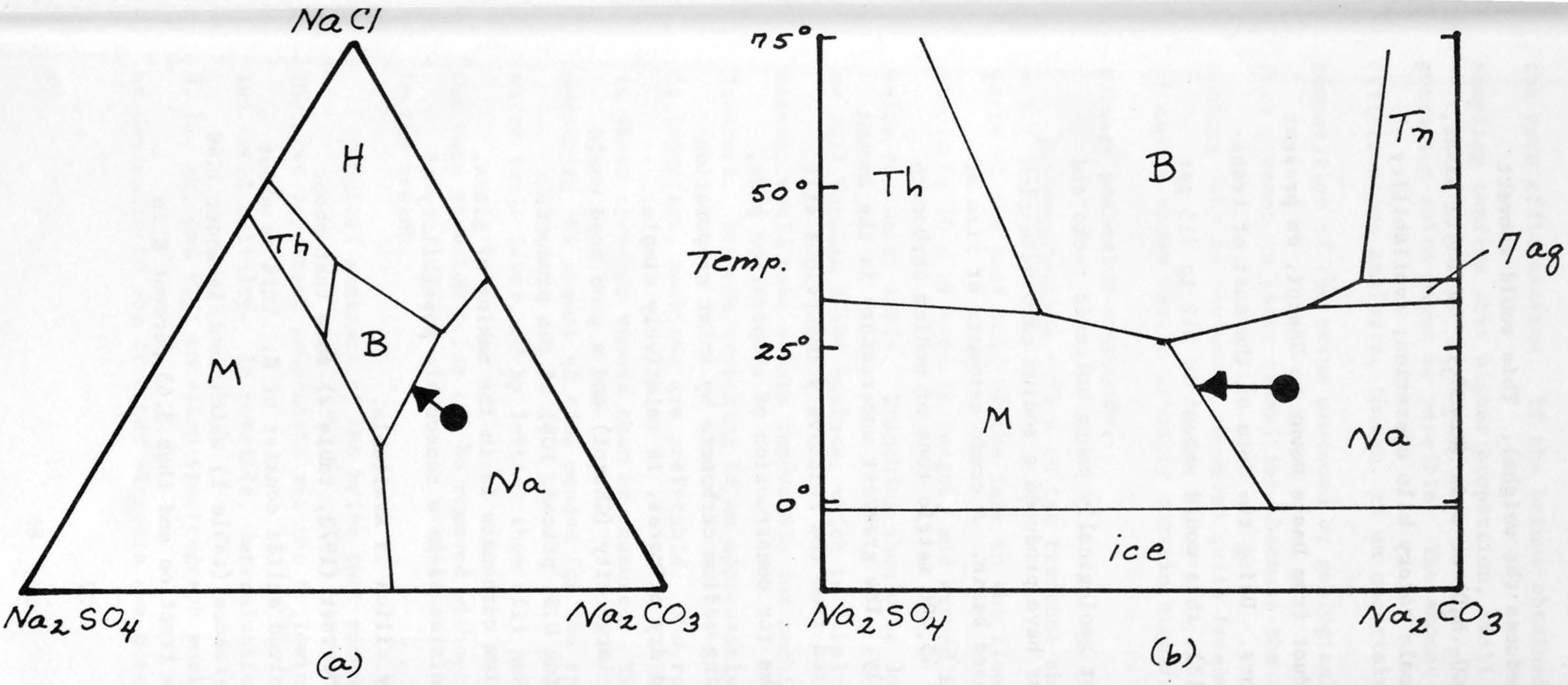

Figure 2. Phase diagrams applicable to Daste Nawar brines; data from Makarov and Blidin (1940, figs. 5 and 7). Phases abbreviated as follows:

M, mirabilite ($Na_2SO_4 . 10H_2O$)
Na, natron ($Na_2CO_3 . 10H_2O$)
Th, thenardite (Na_2SO_4)
7aq, unnamed mineral ($Na_2CO_3 . 7H_2O$)
B, burkeite ($Na_2CO_3 . 2Na_2SO_4$)
H, halite (NaCl)
ice, Ice (H_2O)

(a). System Na_2SO_4-Na_2CO_3-NaCl at 20° C showing the composition of the inferred brine in Daste Nawar (solid circle) and the compositional path followed by the brine as natron is crystallized from solution (arrow).

(b). System Na_2SO_4-Na_2CO_3 at temperatures between -10° C and 75° C showing effect of temperature on phase boundaries and the compositional path followed by Daste Nawar brine as natron crystallizes at 20° C.

drive off the water (which reduces the weight). This would convert natron to thermonatrite ($Na_2CO_3.H_2O$) or soda (Na_2CO_3). At Daste Nawar, this might require a small-scale rotary kiln operation; availability of fuel would be a problem.

Transportation of a product from Daste Nawar to Ghazni, on present roads, would take about 4 hours. Using the data on the cost of transporting salt to markets (p. 13), this would amount to $12 to $15 per metric ton.

Summary.--It appears that geologically young volcanic rocks and thermal springs in Daste Nawar have produced a sodium carbonate-rich water in the floor of the closed basin. A crude estimate of size of the brine body indicates that 45,000 metric tons of sodium carbonate might be available semiannually. The greatest uncertainty is the amount of brine that could be extracted from the relatively impervious silt. The area offers excellent sites for construction of evaporation pans, and the technology of extracting sodium carbonate by solar evaporation techniques, especially in cold dry climates, is relatively simple. Transportation to the nearest large city (Ghazni) and a good road would cost about half the value (using U.S. prices, FOB) of the product.

The principal use of sodium carbonate is in the making of glass, and a small industry in Afghanistan seems a reasonable possibility if a nearby source of high-purity silica is available.

The brines analyzed by Förstner (1973, table 2) show that about 1.7 percent of the total dissolved solids consist of K. This is about half as much as in the efflorescence (table 1) which contain about 1.46 percent K in the water-soluble fraction and thus 3.65 percent K in the pure efflorescence. If the brines obtained from more extensive sampling confirm this higher proportion, small scale production of potassium salts might be possible. The amount of K reported in efflorescence analysis, though, is an uncertain measure of the composition of the brine produced by geological processes--and therefore present in large quantities--because the area surrounding the central lake is obviously occupied quite frequently by large numbers of camels whose wastes probably contain significant percentages of soluble potassium compounds.

Recommendations.--Five to ten trenches should be dug in scattered parts of the east half of the lake in the floor of Daste Nawar. They should be 10 m or more in length, and extend in depth at least 1 m below the water table. Trenching should be done during late summer or fall because a wet surface, which is likely during the winter wet season, would make access impossible for machinery and difficult for laborers. Because trenching to an appreciable depth below water is important, machines are preferable. The rate at which brine accumulates in these trenches should then be measured. This can be done either by measuring the amount of time needed for the trenches to fill to the water table level, or by letting them fill and then experimenting with the rate at which brine can be removed without changing the residual level in the trench.

Chemical analyses of the brine that accumulates should be made. The most important components are the following: Na, K, CO_3, SO_4, Cl, and total salinity. If possible, determinations should also be made for B, Li, Br, and PO_4; emission-spectrograph analyses of dried samples would be desirable to see if other elements are present in abnormal amounts.

In addition to the trenches recommended above, it would be advisable to drill a core hole to a depth of at least 100 m, and preferably 250 m, to test for deep layers of salts or porous zones containing brine. A possibility to guard against is fresh artesian water; casing and a means of sealing it off under pressure should be installed when the drilling has reached a depth of 10 or 20 m. If salts are found, they should be sampled and identified, and the interstitial brine should be sampled and analyzed. Other core holes would then be needed to find the extent of these zones.

Namaksar Andkhoi (Khwaja Mod)

Location.--Namaksar Andkhoi is a salt lake about 38 km south of Andkhoi and 60 km west-southwest of Sheberghan. On some topographic maps (sheet 124C), the lake is called Khwaja Mod. Its elevation is 257 m. Table salt is mined from the lake.

Geology.--The salt lake known as Namaksar Andkhoi lies in a large closed depression that is a result of deflation by wind from the northwest. The axis of the trough is at right angles to this direction and is gently crescentic, with the concave side toward the wind. The rim lies 150 m to 250 m above the floor of the lake and is asymmetrical. On the downwind (SE) side, the rim is a steep bluff that consists of a series of steep, smooth, cirquelike re-entrants that are concave toward the northwest. On the northwest side, the rim is a gentle undulating slope. The floor of the basin consists of six broad depressions, elongated parallel to the strong wind directions, that contain lakes during the wet season. They are divided by swampy areas or positive areas a meter or so high. Salt of appreciable thickness has accumulated in the middle depressions whose floors are lower, and little or no salt forms on the floor of the less deeply eroded northeastern and southwestern depressions.

The depression containing Namaksar Andkhoi is excavated in loess[4], and 250 m of this material is exposed in one place on the southeast side of the basin. There is no obvious reason why a wind excavation of this size should occur at this place. It is suggested elsewhere (Smith, in press) that there may be significance in the fact that both the Namaksar Andkhoi depression and the Gawdezereh depression (which is also wind-excavated) are about 60 km upwind from the flanks of large mountain ranges that deflect the wind. It is possible that abnormal turbulence occurs at about this distance upwind from the deflecting mountain, and that such turbulence might enhance the ability of wind to excavate a depression and transport sediment away from it.

The geologic origin of the depression in which Namaksar Andkhoi lies is important because it provides the basis for suspecting that there are no deep salts in the basin. In a wind-excavated basin, the water table limits the depth of excavation of dry material, and the degree of aridity controls the level of the water table. In most parts of the northern hemisphere where paleoclimates have been extensively

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[4] Loess is a semiconsolidated windblown silt.

studied, the climate of the last 10,000 years is found to be about as arid, or more so, as any of the other interglacial and interpluvial periods within the last 100,000 to 150,000 years. This means that more arid periods that would allow deeper excavation by wind probably have not occurred within that period. The depression may have been partly excavated prior to 150,000 years, but several episodes of intense glacial and pluvial events have occurred since, and these have dissolved any older salts and filled the depression with loess.

When visited, the surface of the salt in the area being mined (1/3 km north-northwest of salt mine office) was dry, flat, light tan, and cracked into polygonal patterns 1/2 to 1 m in diameter. Minable salt covered an area estimated to be 5 km^2. The firm salt crust that is being mined is 15 to 20 cm thick, composed of four distinct units (from the surface down):

10 cm salt, clean, slightly pink; crystals 1-2 mm diameter
1 cm salt, tan to light gray
4 cm salt, like that above tan zone
4 cm salt, pink in upper half, crystals smaller than above.

The foreman of the salt mining operation reported that other beds of salt lie below the bed being mined, but no pits were available for study. Gee and Seth (unpub. data) report test pits to a depth of 4 feet, and salt and mud layers down to depths as great as 3 feet. The salt being mined rested on tan mud. The tan color and lack of H_2S odor probably means that the sediment is periodically exposed to air or oxygenated water. This results, most likely, from a complete solution of the 15-20 cm salt crust each year, allowing oxygenated water to be in contact with the underlying mud. A sample of the mud was collected and analyzed by X-ray diffraction. The major minerals are gypsum ($CaSO_4 \cdot 2H_2O$), bassanite ($2CaSO_4 \cdot H_2O$), and halite (NaCl), with smaller amounts of calcite ($CaCO_3$) and clastic minerals such as feldspar and quartz.

Analyses and economic potential.--The salt crust was not sampled but appears to be pure halite. A sample of the interstitial brine was collected; when collected (noon) its temperature was 26°C, and its level was 15 cm below the surface. An analysis of that sample (table 2) shows that it is dominated by Na and Cl, but that more than 2.5 percent SO_4 and 1 percent Mg also are present. Other components, including potassium, are minor.

Besides salt, the only component of possible value appears to be magnesium. A concentration of 10,800 mg/l Mg is equivalent in this brine (density about 1.20) to about 0.9 weight percent Mg. Sea water, from which magnesium and magnesia are produced commercially in large volumes by complex processes, contains about 0.13 percent Mg which, when concentrated to a NaCl-saturated solution, is increased to about 1 percent. However, in producing magnesium or magnesia from brines, it is the volume of brine available and the ratio of other ions in solutions, as well as the absolute percentage of Mg, that determines the difficulties that would be encountered. To extract magnesia, concentrated brine must be processed in a plant that uses dolomite or limestone, and the final product must be calcined. Probably some sodium sulfate (mirabilite, or Glauber's salt) would be produced in the evaporation pans as a byproduct.

Table 2.—*Analyses of brines*

[All concentrations in milligrams per liter; n.d. means not determined because of inadequate sample size. Analyses for K, Na, and Li by Roberta Barnes, for remaining components by Marian Schnepfe, both of U.S. Geological Survey]

Location (and field no.)	USGS Lab. No. (W-)	pH[1/] (field)	pH[1/] (lab)	Ca[2/]	Mg[2/]	Na[2/]	K[2/]	Li[2/]	CO_3[3/]	HCO_3[3/]	Total CO_2[4/]	SO_4[5/]	Cl[6/]	B[7/]	PO_4[8/]	Total dissolved solids[9/] (meas.)	Total dissolved solids[9/] (calc.)	Solic crystallized from 2 ml prior to analysis (mg
Namaksar Andkhoi (Andkhoi B)	177086	6.5	7.45	292	10,800	108,000	800	1.9	0.0	376	212	25,700	188,000	28	0.18	401,000	333,735	0
Namaksar Tashqurghan (Tash B)	177085	n.d.	7.45	236	23,000	82,200	2,650	8.4	0.0	568	286	39,200	180,000	3.4	0.45	365,000	327,942	12,500
Namaksar Herat (NH-A)	177087	6.5	7.65	320	15,000	105,000	2,000	9.0	0.0	616	290	33,200	190,000	76	0.072	374,000	346,221	731
Gawdezereh (GZ-C)	177088	6.5	7.65	2,280	1,900	43,800	352	2.4	0.0	96	41	3,480	73,000	13	0.0	138,000	124,923	494
Hot spring near Bamiyan (along Hajikak pass road)	177089	9.0	8.55	10	108	1,280	268	8.4	9.7	565	688	484	1,600	74	0.20	4,700	4,407	355
Cold spring near Bamiyan ("Dragon")	177090	8.0	8.55	12	94	670	48	7.7	9.8	520	636	26	860	14	0.01	2,300	2,262	873
Band-i-Amir lake	177091	6.0	8.00	35	79	24	3	0.16	0.0	202	125	n.d.	n.d.	0.65	0.053	240[11/]	n.d.	0

[1/] pH values measured in laboratory (lab) with meter, on samples that had been previously opened allowing some loss or gain of CO_2; in field, values determined with pH-sensitive paper.

[2/] Values determined by atomic absorbtion methods.

[3/] Values determined by fitration of sample alkalinity to CO_3 and HCO_3 end points when received in laboratory; alkalinity expressed as CO_3^{-2} and HCO_3^- but concentrations of these ions probably actually lower because alkalinity also reflects concentrations of other titratable components such as OH^-, PO_4^{-3}, HPO_4^{-2}, HBO_3^- and $H_3SiO_4^-$.

[4/] Values determined by gas chromatography and includes CO_2 from carbonate ions plus $CO_{2(g)}$ dissolved in brine.

[5/] Values determined gravimetrically as $BaSO_4$.

[6/] Values determined titritimetrically by precipitation with $AgNO_3$ using chromate as indicator.

[7/] Values determined spectrophotometrically using 1,1-dianthramide.

[8/] Values determined spectrophotometrically using molybdate.

[9/] Values measured (meas.) in laboratory by evaporation of filtered sample and drying at 110°C; calculated (calc.) from sum of analyzed ions (excluding CO_2).

[10/] Solids crystallized in some bottles because the samples were not diluted or acidified at time of collection. Analyses are of filtered brine remaining after this crystallization.

[11/] Value very approximate because of inadequate sample size.

Construction of high-quality evaporating ponds on the surface of Namaksar Andkhoi might be difficult. Large flat areas are available, but the surface is flooded parts of most years, and protective dikes would need to be constructed. Another problem might be the porosity of the silt that underlies the salt. Tests were not made, but the silt resembles material in the United States that has proven to be permeable.

The cost of removing sodium sulfate crystallized out on the bottom of evaporating pans would be approximated by the cost of removing annually crystallized salt (NaCl) from the floor of Namaksar Andkhoi and carrying it to the truck-loading area. Data given to me by the manager show that the wage plus local overhead costs (but not managerial costs) are approximately $1 per metric ton.

Transportation of an evaporite product would cost about $3.40 per metric ton to Sheberghan. Better roads, in the opinion of the salt mine manager, might reduce this figure by half.

<u>Summary</u>.--Namaksar Andkhoi consists of more than 5 sq km of salt crusts that are likely to be no more than a few meters thick. The salt is fairly pure. The brine contains quantities of magnesium that have marginal potential. The percentages are similar to brines being processed elsewhere, but several problems exist: the volumes of brine are relatively small, the final extraction processes involves calcining which requires fairly large amounts of fuel, and major markets for magnesia (mostly refractory brick for metal production) are remote. The quantities of sodium and sulfate are large enough to allow winter crystallization of a mirabilite crop from evaporating pans, but markets

appear scant. Potassium, lithium, and boron percentages are too low to encourage further consideration. The outlook for evaporating pond processing is only fair because of the likelihood of leakage problems.

Recommendations.--If any nearby use of magnesia is developed or conceived, 10 or 20 trenches, like those described in previous sections, should be dug to a depth of 1 to 1½ m. They sould be in different parts of the several lakes in the basin so that any variations in brine composition would be noted. One pit should be dug as deep as possible to explore for deeper salt layers. A core hole is not warranted because the top of the eroded Pleistocene loess is probably within a few meters of the surface.

In the test trenches, the rate of brine percolation should be measured, and samples of brine should be collected and analyzed for Mg and other components important to the production process. Test evaporation ponds should be constructed and flooded to a depth of at least 1/2 m. Their tendency to gain or lose brine should then be evaluated; this is best done by keeping accurate measurements of the changes in brine levels and comparing them with an adjacent pan containing the same depth of brine which is constructed of metal or some other water-tight material.

Namaksar Tashqurghan (Sar-i-Namak)

Location.--Namaksar Tashqurghan, shown on some topographic maps as Sar-i-Namak, is 20 km north of the road connecting Tashqurghan and Mazar-i-Sharif, and an estimated 5 to 10 km east of a new road (not shown on topographic maps) that leads north to Termez, U.S.S.R. The elevation of Namaksar Tashqurghan is about 310 m. Salt for consumption by sheep is mined from the lake.

Geology.--Most of the area between the road connecting Tashqurghan with Mazar-i-Sharif and the salt deposit is composed of flat-lying Pleistocene(?) deposits that are being eroded by wind and water. Along the road to the salt deposit, remnants of eroded sediments are preserved as gravel-capped mesas that show that at least 2 m of sediment has been removed over much of the area. Larger mesas observed a few kilometers from the road may be remnants of as much as 10 or 20 m of sediments. Sediments that have been removed include conformable beds of loess, tan gypsiferous lacustrine silt, aeolian sand, and fluvial(?) deposits including or entirely composed of well-rounded pebbles. About 2 km south of the salt deposit, a 2 m thick remnant of pre-existing layers is preserved. In it, two gypsiferous fossil soil horizons are exposed, one above the other, most likely representing successive Pleistocene or Holocene episodes of soil formation. X-ray diffraction confirms the gypsiferous character of the soil, but shows that half or more has been altered to bassanite ($2CaSO_4 \cdot H_2O$). These sediments suggest that during Pleistocene(?) time, this area received fluvial, aeolian, and lacustrine sediments deposited in a lake rich in Ca and SO_4. Sedimentation was apparently discontinuous, as indicated by the superimposed fossil soil horizons. Erosion seems to be a result of a slight postdepositional lowering of local base level.

The shallow closed depression containing the nearly dry lake and the salt deposit is the result of wind erosion that removed sediments almost down to the water table. The area surrounding the lake has an uneven surface with relief of 0.5 to 1 m. The lake bed has a more even surface and its length and width are estimated to be 1,700 m by 700 m. Salt is produced by digging pits 3 to 10 m in diameter (larger pits accumulate too much windblown sand) and allowing ground water to flow in. When visited (Oct. 9, 1971), the ground water was about 60 cm below the level of the dry lake surface; brine is reported to be closer to the surface in winter and spring. The material removed from the artificial pits--a sample of the subsurface stratigraphy--was a mixture of windblown sand, gypsiferous black mud, and salt. X-ray diffraction of one sample of black mud showed it to consist mostly of gypsum ($CaSO_4 \cdot 2H_2O$), bassanite ($2CaSO_4 \cdot H_2O$), and halite (NaCl) with some windblown(?) quartz.

Production of salt was reported to be 1,100 metric tons per year. Most of the salt is fed to sheep rather than humans, apparently because there is a high content of epsomite ($MgSO_4 \cdot 7H_2O$) and related salts; these salts help control the concentration of intestinal parasites in sheep but do not improve its taste or popularity with nearby villagers.

Analyses and economic potential.--A sample of brine was collected (at 25°C) from a pond that had evaporated to form a 2 cm layer of salt on 10 cm of brine; the analysis is listed in table 2. The dominant ions are Na and Cl, but 39,200 g/ml (3.9 g/100 g or about 3.2 weight percent) of SO_4 and 23,000 g/ml (2.3 g/100 g or about 1.9 weight percent) of Mg are also present. These are the highest percentages of these components found in Afghanistan brines.

The amount of Cl present exceeds the amount that could form halite with the Na present in this solution, so phases involving Mg, Cl, and SO_4 would form upon continued crystallization of this brine. Simple predictions cannot be made of the phases that would form during evaporation because the stability relations between minerals change with temperature. Persons familiar with the chemical engineering aspects of brines and solar evaporating processes would have to evaluate the potential of these brines as practical sources of magnesia or sodium sulfate. Discussions and diagrams of the pertinent phase relations are presented by D'Ans (1933, table 19) and Braitsch (1971, p. 58-64).

The other ions in Tashqurghan brines are present in concentrations too low to be of interest. The quantities of K are highest of any brines sampled in Afghanistan, but they are about half the values in the lowest grade brines being processed by solar evaporation processes in the U. S. or elsewhere. The percentages of Li are among the highest found in brines in Afghanistan but are about a quarter of the concentration in Searles Lake, Calif., brines that allow production of Li, and about 3 percent of the concentration in Silver Peak, Nevada, brines. These low grades, plus the unfavorable aspects of the area for solar evaporation ponds, means that their potential as a source of potash and lithium is low.

Older analyses of salts and brines from this deposit are listed in Appendix C.

As a site for evaporating ponds, Namaksar Tashqurghan is poor. The natural surface is uneven, and the exposed and near-surface deposits include many porous sandy layers. If a project were started, though, some of the very fine lacustrine silt and clay noted in the exposed section would make a satisfactory water-tight lining material for ponds.

The climate at Namaksar Tashqurghan is similar to that of Mazar-i-Sharif where the mean monthly temperatures during the dry season (April to October) range from 9.1°C to 25.5°C. Potential annual evaporation at that place is reported to be 2.2 m; a salt-saturated brine with a high percentage of Mg might have an evaporation rate of about 1 m. This could allow production of modest amounts of brine having a very high concentration of Mg. If production were to be undertaken, a plant would have to be constructed that reacts calcined dolomite or calcite with the brine to form a brucite ($Mg(OH)_2$) slurry which would be washed, filtered, dried, and calcined to form magnesia (MgO). High temperatures are needed for both calcining processes.

Transportation of a product to the nearby black-top road would probably cost less than $1 per metric ton. If magnesia were to be produced, it is possible that calcining using natural gas from the Sheberghan gas field would be practical. Transportation to that area by truck would add an estimated $1.50 to costs. Most magnesia production is consumed by industrial nations and shipping costs to those areas might be substantial; however, for a product whose price in the United States prior to transportation is about $70 per metric ton, it is possible that a product could be manufactured and delivered at a competitive price.

Summary.--Namaksar Tashqurghan contains brine that appears to contain enough magnesium to serve as a source of magnesia. Construction of evaporating ponds that are suitable would be very difficult, and this factor may eliminate the deposit from further serious consideration. Should production be started, though, a small plant that utilizes dolomite or limestone would have to be constructed, and the resulting product would have to be calcined. Nearby sources of natural gas would facilitate calcining.

Recommendations.--If preliminary chemical engineering studies based on the brine analysis in table 2 support the possibility of producing magnesia or sodium sulfate by evaporation pond extraction techniques, the following studies are recommended.

Trenches, 10 to 50 m long and at least 1 m deep, should be dug in three or four parts of the deposit. The rate at which brine accumulates should be measured. Samples of this brine should be taken for complete analysis to see if variations in composition occur, and to see if the sample collected during this study is representative.

At the same time, test evaporation ponds should be constructed. Preferably, they should be 10 m to 100 m on a side, but the rate at which windblown sand accumulates may preclude the use of ponds of this size in an actual operation. The rate of leakage should be measured. Various techniques of lining the ponds with clay should be tried.

Namaksar Herat (Kol-i-Namaksar)

Location.--Namaksar Herat (shown on some topographic maps as "Kol-i-Namaksar") lies about 150 km west-southwest of Herat, 156 km by poor road. It is a large dry lake, about half of which is in Afghanistan and half is in Iran. The lowest part, where brine and salt accumulate, is in Afghanistan. The east-west dimension of the lake is about 40 km, its north-south dimension (on the Iran side) about 30 km, and its elevation 558 m. Table salt is mined from the lake surface.

Geology.--The closed basin that contains Namaksar Herat is several times the size of the lake, with about three-fourths of it in Iran. Several lines of evidence suggest that the geologic cause of the depression is tectonic warping and faulting, not wind erosion. One of the strongest indications is that the basin has contained at least two large lakes during previous geologic episodes. The youngest lacustrine deposits, observed 5 to 10 km east of the present salt lake but probably well preserved elsewhere because also noted by Huntington (1905, p. 243), are tan silt. They are tectonically undisturbed, as much as 10 m thick, and overlain and underlain by gravel. The overlying gravel forms dark terraces that are graded to levels 10 to 15 m above the present drainage. Both north and south of the east arm of the dry lake, features are visible on aerial photographs that are interpreted as east-trending gravel bars resting on these terrace gravels. The bars are 2 to 4 km away from the present edge of the dry lake, and their degree of preservation is about the same as gravel bars preserved in basins in the United States that contained Pleistocene lakes of Wisconsin (Würm) age.

Older lacustrine deposits in the area have been uplifted and folded, and commonly dip between 5° and 25°. They consist of gypsiferous silt interbedded with sand, gravel, tuffaceous(?) silt, and volcanic(?) breccia.

The surface of the present day salt lake is mostly tan silt. The area covered by salt when the lake is dry is estimated from aerial photographs to be about 30 sq km. During most years, according to the salt mine manager, water floods this part of the lake to a depth of 1 m during winter and evaporates by midsummer. When visited (Oct. 13, 1971), the lake was entirely dry, and the salt crust had cracked into polygonal forms; ridges 1 to 5 cm high developed along the polygon edges. The surface was light tan, a mixture of salt and silt. Slabs of salt about 15 cm thick were being mined from the surface. The brine level was at a depth of 15 cm; layers of softer salt and soft black mud lie below this level to a depth of a least 60 cm. The mine manager reported a similar sequence down to 5 m, the deepest pit ever excavated.

Analyses and economic potential.--Samples of salt and brine were collected. X-ray diffraction analysis indicates the salt to be virtually pure halite (NaCl) contaminated by a trace of silt. A brine sample was collected about 300 m northwest of the company office for analysis (table 2). The brine is dominated by Na and Cl ions, and the Mg and SO_4 percentages are intermediate between those of brines from Namaksar Andkhoi and Namaksar Tashqurghan. Although the potassium percentages are almost as high as at Namaksar Tashqurghan, they are nevertheless only about half the concentration in the lowest-grade brine being processed commercially today. Because of the relatively high K values, though, some preliminary study should be made of the commercial feasibility of extracting K from these brines, which are present in moderately large quantities. Areas suitable for evaporating ponds apparently exist north of the salt production area; those surfaces were not carefully examined but appear from a distance and on aerial photographs to be flat, smooth, and possibly impermeable. The Li and B values are also higher than in any of the other lake brines, but not nearly high enough to be commercially attractive. Quantities of other components are too low for further consideration.

Older analyses of salts and brines from this area are given in Appendix D.

The rate of annual evaporation clearly exceeds 1 m inasmuch as this much natural inflow evaporates each year. Between 1941 and 1948, during the April to October dry season, Herat monthly mean temperatures ranged from 17°C to 29°C; Namaksar Herat is 365 m lower than Herat, and monthly means would be about 2°C higher. Perhaps 1 to 1.5 m per year of evaporation from ponds can be expected.

Transportation to Herat by poor roads, a distance of 156 km, now costs about $4.20 per metric ton. Additional costs would obviously depend on the product and the location of its market.

Summary.--Namaksar Herat is a very large deposit of salt, covering an area estimated to be 30 km^2. The known thickness of salt (interbedded with mud) is 5 m and may be very much thicker inasmuch as salt lakes appear to have existed in this basin during much of late Cenozoic time. Besides NaCl, which is now mined from the solids, the brines contain moderately large quantities of Mg, SO_4, and K. Chemical engineering studies of the possibility of a small-scale solar evaporation industry to extract one or more of these substances should be made. A survey of possible markets should accompany such a study.

Large areas suitable for evaporating ponds are present if engineering studies show that some constituents could be extracted. Harvesting a solid salt from an evaporating pond would cost about $1 per metric ton; transportation to the nearest good road would cost an additional $4 per metric ton.

Recommendations.--The brine in the interstices of the salt at Namaksar Andkhoi is a marginal to submarginal source of MgO, Na_2SO_4, and KCl. The presence of large areas that appear suitable for evaporating ponds, the low cost of labor, and the countries' need for exportable or consumable chemicals, make it advisable to seek advice from competent chemical engineers familiar with solar evaporation techniques as to the feasibility of production of one or more of these substances. The analysis in table 2 should serve as an adequate basis for a first appraisal.

In addition to the above, it is advisable to drill a test hole 250 to 500 m deep in Namaksar Herat. Because it appears to be a tectonic depression, the thickness of evaporites that could have accumulated is great. Past evaporites may not be the same composition as those now on the surface (although they probably are), and any deposit of value that is found would be large.

Gawdezereh

Location.--The Gawdezereh lies near the southwest corner of Afghanistan. Some maps use the Iranian name Sora-i-Hamun. It is a closed depression 100 km long and 10-20 km wide, containing a large dry lake. The depression is arcuate in shape, concave toward the north-northwest, and is the lowest point in the Helmand River drainage, although water from that river reaches the basin only once every few decades. Its floor is at an elevation of 450 meters, which is 150 to 200 m below the level of the high flat desert pavement surfaces to the north. The nearest village is Caharburjak, 40 km to the north by the shortest route.

Geology.--The Gawdezereh is a depression that was excavated by wind out of Cenozoic age lake deposits that are capped by 5 to 10 m of pebble to cobble gravel (Smith, in press). The small-scale morphology of the present walls of the basin indicate erosion by intermittent streams. The large-scale shape of the south side, however, consists of three or four broad north-facing wind-excavated cusps; the north side consists of an irregular series of ridges and valleys parallel to the prevailing wind. Inasmuch as the depression was formed by wind erosion, the geologic reasoning described in the section on Namaksar Andkhoi applies here, and the thickness of lacustrine deposits is considered small.

The part of the Gawezereh sampled was near Zyrate Sultan Weskarni, at the easternmost and lowest end. This is an area about 6 m lower than the central and western parts of the dry lake surface, and would have contained any surface salt crust that exists in the basin. The surface in this area, however, is composed of loose silt that contains scattered clumps of crystals which X-ray diffraction shows are mostly bassanite ($2CaSO_4 \cdot H_2O$) pseudomorphous after gypsum ($CaSO_4 \cdot 2H_2O$) which still makes up part of the crystals. The loose silt is underlain by a 5 cm-thick zone of gypsum-cemented silt, which X-ray diffraction shows also contains halite (NaCl), and possibly some phillipsite $[KCa(Al_3Si_5O_{16})6H_2O]$ and calcite ($CaCO_3$). At 30 cm is a 2 cm-thick band of light gray gypsiferous sand. The remaining material down to a depth of 2 m is tan windblown sand and silt. The sand was moist from a depth of about 20 cm, and water was found at 177 cm.

Analyses and economic potential.--At the time of sampling (2 PM, Oct. 18, 1971), ground temperatures, which are responsible for the dehydration of gypsum to bassanite, were:

1 cm below surface	39°C	
5 cm below surface	31°	
10 cm below surface	28°	
175 cm below surface	25°	(same as brine)

The lowermost temperature may approximate mean annual temperature; if so, it is about 3°C warmer than Zarange and 5°C warmer than Lashkargah.

A sample of brine from this test pit was analyzed and is listed in table 2. Its total dissolved solids are less than half the concentration of brines in contact with halite or other common salts of inland lakes. Most of the dissolved solids are Na and Cl; percentages of Mg, SO_4, K, and other ions of potentially extractable components are proportionately lower than in other lake brine samples.

The lack of a concentration of salts in this terminus of the Helmand River probably means that there is either underground migration of salts in solution to another area, or large-scale loss of efflorescent salts as a result of wind. It is possible that the rate at which windblown silt fills the basin is greater than the rate at which evaporation can concentrate the brine, but this seems an unlikely explanation to apply to a depression whose origin is attributed to removal of sediments by wind.

Summary.--Gawdezereh contains no significant amount of salts at or near the surface.

Recommendations.--No steps toward further exploration seem warranted. Drilling a test hole is not justified because the lacustrine fill is inferred to be thin.

Taqca Khana and Kalafgan

Locations.--The salt mine known as Taqca Khana is 4 km south-southeast of the village of that name, about 25 km southeast of Talaqan, and an elevation of about 1,300 m. The salt mine known as Kalafgan is 13 km southwest of the village, 32 km east of Talaqan, and at an elevation of about 1,600 m. Both currently produce table salt.

Geology.--The Taqca Khana and Kalafgan salt deposits are apparently extensions of the same marine salt body and are described together. According to Hinze (1964), they lie along the northwest side of a low-angle normal fault, and are considered (p. 41) to be salt intrusions or diapirs. Hinze considers the salt to be of marine origin and Early Lower Cretaceous age. However, on the basis of data obtained from petroleum exploration drilling, Eng. Badruddin Sharifi, President of the Petroleum Exploration Department, GOA Ministry of Mines and Industries, Mazar-i-Sharif (oral commun., Oct. 1971) considers salt deposits north of the Hindu Kush more likely to be of Jurassic age. He reports, for example, a thick salt bed underlying well-dated Cretaceous rocks at a depth of 3,000 m in the vicinity of Andkhoi.

The salt mined at both Taqca Khana and Kalafgan is nearly pure NaCl, although one sample of salt revealed a trace of anhydrite on X-ray diffraction charts, and the other revealed a trace of dolomite. Salt crystals average 1-2 mm, although a few from Kalafgan were as much as 15 mm in diameter. Laminae of gypsum and anhydrite, common in many marine salt deposits, were not seen in either area of mining. In the Taqca Khana deposit, bedding appeared to be flat, whereas in the Kalafgan mine it was contorted, as would be expected in a diapiric structure. Red coloration of the salt at Kalafgan is cause by reddish silt which is both disseminated and in pods.

Analyses.--Analyses of salt from these deposits were not made during this study because visual observation, taste, and geochemical tests on solutions made from them suggested that they were virtually pure NaCl. An analysis of the salt from the Taqca Khana deposit is included in the unpublished report by Gee and Seth (p. 15) (the deposit is described in their report by the name "Namakab, Kataghan Province...in the vicinity of Sar-e-Kan village") as follows:

Element	Wt. percent
Ca	0.05
Mg	.02
Na	38.03
K	trace
HCO_3 as CO_3	trace
SO_4	.41
Cl	58.56
$Fe_2O_3+Al_2O_3$	trace
H_2O	.26
Insoluble matter	2.70

Analyses of 31 samples collected from Taqca Khana by C. W. Sweetwood during his study were analyzed for K_2O by the laboratories of the GOA MMI; percentages ranged from 0 to 0.31 and averaged 0.10.

Summary.--The salt at Taqca Khana and Kalafgan consists of halite with a small amount of silt and clay; no potassium or other valuable minerals were seen or detected by field tests or X-ray diffraction.

Recommendations.--The lack of brine or any evaporite minerals other than halite make Taqca Khana and Kalafgan (and Cal, a nearby deposit, presumably of similar origin and mineralogy) unpromising areas for exploration for potassium or other compounds. However, cores or cuttings from the buried marine salt beds, when encountered during petroleum exploration, should be tested for potassium minerals. In addition, gamma ray logs and neutron absorbtion logs should be made of these zones, and favorable signs of potassium minerals (high gamma ray activity due to K^{40}, and high neutron absorbtion due to H in hydrated minerals such as carnallite) should be further investigated.

Other salt areas

A sample of salt being sold by a vendor along the road leading north from the village of Darwesan (southwest of Lashkargah, on the Helmand River) was collected. Its taste was exceptionally bitter. The vendor reported that it came from a small salt deposit about 5 km southwest of the road, but northwest of the river, and that salt formed beds there that are 5 to 10 cm thick. X-ray diffraction of the sample showed halite plus several of the hydrates of magnesium sulfate, apparently including epsomite ($MgSO_4 \cdot 7H_2O$), hexahydrite ($MgSO_4 \cdot H_2O$), and possibly others. Brine samples were not available, but the brine may be exceptionally high in Mg. It should be sampled and analyzed.

A salt efflorescence along the bank of the Helmand River at Chaharburjak was, according to X-ray diffraction, mostly halite (NaCl) plus a small amount of gypsum ($CaSO_4 \cdot 2H_2O$).

Boron investigations

Two other areas were visited during this study to collect samples that might identify provinces characterized by boron-rich waters. For several geologic reasons, such waters were expected in Afghanistan. Delineating such provinces is helpful to economic geology studies because borate deposits can be very large and valuable, and to agricultural studies because even small amounts of boron in waters (e.g., 1 part per million) can be toxic to plants.

The areas visited were in or near the Herat fault zone which is a large strike-slip fault that trends west-southwest through the crest of the Hindu Kush. Two springs near Bamiyan were sampled, as were the spring-fed lakes at Band-i-Amir. Analyses are listed in table 2. A thermal spring that flows into a concrete tank along the Kalo River, 30 km southeast of Bamiyan and along the Hajigak Pass road was sampled. It had a temperature of 37°C, and issued from the side of a canyon in an area of much fault gouge. The water was yellowish and turbid. Another thermal spring, 1/2 km downstream, was not sampled, but had a temperature of 31°C and a field pH of 9. A cold spring, about 2 km southwest of Bamiyan known as "the Dragon," was also sampled. It had a temperature of 15°C, and has formed a large travertine ridge indicating a high percentage of Ca and HCO_3. The waters in Band-i-Amir lakes are apparently from subsurface springs. Large amounts of $CaCO_3$ as travertine and as fine white crystal material are deposited on the bottom and form natural dams around the edges of the water bodies; these indicate saturated or supersaturated solutions of Ca and HCO_3. X-ray diffraction shows the $CaCO_3$ to be calcite.

Analyses (table 2) show that waters from the hot spring contained 74 mg/l of B in 4,700 mg/l total solids. The cold spring contained 14 mg/l of B in 2,300 mg/l total solids. Both are far above normal for springs. The waters of Band-i-Amir lake, in the same geologic setting and apparently representative of large quantities of water draining from this area, contain 0.65 mg/l B and about 240 mg/l total solids. This too is far above normal for waters of this salinity.

Although the results are not indicative of borate deposits in the immediate vicinity, they do show that the crest of the Hindu Kush is indeed a boron-rich province, and Cenozoic deposits formed in closed basins that received waters from this area should be considered potentially favorable for boron-bearing evaporite deposits.

Samples of salts and brines from several other areas visited by C. W. Sweetwood were analyzed by the GOA MMI. They were not visited as part of this study because the results reported by Sweetwood appear unpromising. Selected analyses are summarized in Appendix E.

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APPENDIX A

Chemical reagents and reactions used in the field to approximate brine composition were as follows:

Ion Sought		Test Reagent		Identifiable product and color		Balance of Reaction
$CO_3^=$	+	2HCl	=	$CO_2\uparrow$ (gas)	+	H_2O+2Cl^-
$CO_3^=$	+	$SrCl_2$(aq)	=	$SrCO_3\downarrow$ (white)	+	$2Cl^-$
$SO_4^=$	+	$SrCl_2$(aq)	=	$SrSO_4$ (white)	+	$2Cl^-$
Cl^-	+	$AgNO_3$(aq)	=	$AgCl\downarrow$ (white, turning brown in sunlight)	+	NO_3^-
$3K^+$	+	$NaCo(NO_2)_6$(aq)	=	$K_3Co(NO_2)_6\downarrow$ (yellow)	+	$3Na^+$
B^{+++}	+	HCl + tumeric paper	=	blue coloration of paper		

The pH tests were made using chemically treated paper that changes color according to pH from reds to greens to blues over a range of pH 2 to 11.

APPENDIX B

Older unpublished analyses of salts and brines from Namaksar Andkhoi are reproduced below to make them part of a permanent record. The report by Gee and Seth gave the following analyses (p. 50):

	SALT (wt. percent)			BRINE (g/100 ml)	
	1[1/]	2[2/]	3[3/]	4[4/]	5[5/]
Ca	0.10	0.15	0.10	0.042	0.020
Mg	0.16	0.22	0.22	.352	.897
Na	37.76	38.14	38.00	12.392	11.76
K	Trace	Trace	Trace	Trace	Trace
Cl	58.21	59.27	58.56	18.83	18.56
SO_4	0.86	0.61	1.15	1.86	2.958
HCO_3 as CO_3	Trace	Trace	Trace	.006	.007
$Fe_2O_3+Al_2O_3$	Trace	Trace	Trace	.007	Trace
H_2O	2.30	1.34	1.74	--	--
Insoluble	0.40	0.40	0.30	.017	.040
Density of brine	--	--	--	1.20[6/]	1.20[6/]
Sum soluble ions	99.79	100.13	100.07	33.487	34.202

[1/] "Red brine salt, Maimena Lake," first lake south of office building.

[2/] "White brine salt, Maimena Lake."

[3/] "Brine salt, Andkhoi Lake," northernmost lake in depression.

[4/] "Brine from Maimena Lake."

[5/] "Brine from Andkhoi Lake."

[6/] Estimate of brine density by present author.

One analysis of brine from Namaksar Andkhoi was made by the GOA, Petroleum Exploration Department, Mazar-i-Sharif:

	Brine (wt. percent)
Ca	0.0456
Mg	0.333
Na+K	12.23
Cl	18.73
SO_4	1.586
HCO_3	0.0128
Total solids	32.93
pH	5.0

Samples of solids and brines from Namaksar Andkhoi were collected by C. W. Sweetwood in 1969. They were analyzed for potassium by the GOA, Ministry of Mines and Industries with the following results:

Sample No.	Description	K (wt. percent)
A-1	"Mud brine," 30 cm depth	3.14
A-4	Brine from "lake bed spring"	1.09
A-6	Mud from 15 cm below lake bed surface	2.73
A-7	Salt, pink, from surface	0.05
A-8	Brine, muddy, depth 30 cm	0.68

APPENDIX C

Older analyses of salts and brines from Namaksar Tashqurghan are given below for the record. Analyses of brine and salt were reported in the unpublished study by Gee and Seth as follows (p. 79):

	Salt (weight percent)	Brine (g/100 ml)
Ca	0.15	.085
Mg	0.82	.598
Na	36.34	9.640
K	trace	trace
Cl	57.85	15.693
SO_4	1.11	1.427
HCO_3 as CO_3	trace	.006
$Fe_2O_3+Al_2O_3$	trace	.002
H_2O	3.50	--
Insoluble	0.60	.005
Brine density	--	1.18
Sum	100.37	27.451

Ten samples were samples were collected for analysis during C. W. Sweetwood's study. Analyses for potassium are as follows (analyses by MMI, GOA):

Sample No.	Description	K (wt. percent)
Tash 2	Salt from salt production area, below brine	0.91
3	Salt, as mined from same area	.16
4	Mud, below salt	1.55
5	Brine, 100 m W of Tash 2	.85
7	Salt, as mined near Tash 5	.05
8	Salt, as mined 100 m W of Tash 5	.11
9	Brine, from area of Tash 8	1.01
10	Salt, as mined from 100 m E of Tash 2	.11

APPENDIX D

The unpublished report by Gee and Seth included the following analyses of salt and brine from Namaksar Herat (p. 64):

	Salt (wt percent)	Brine (g/100 ml)
Ca	0.20	.058
Mg	0.15	.270
Na	37.77	12.426
K	trace	trace
Cl	58.21	19.150
SO_4	1.09	1.229
HCO_3 as CO_3	trace	.004
$Fe_2O_3+Al_2O_3$	trace	trace
H_2O	1.60	--
Density of brine	--	1.21 (est. by present author)
Sum	100.02	33.137

Analyses of salts, muds, and brines from this area were made on samples collected by C. W. Sweetwood in 1969. Most analyses were made by the GOA MMI, but some duplicate analyses for potassium were made by Dr. J. Holsen, University of Kabul. The GOA values are listed first (some are averages of two determinations); Holsen's values follow in parenthesis:

Sample No.		K (wt. percent)
NH 1	Mud, black, 15 cm below lake surface, mining area	0.33 (.10)
NH 2	Brine, same area	.26 (.14)
NH 3	Salt, from soft layer below mined salt	.09 (.05)
NH 4	Salt, as mined	.16 (.03)
NH 5	Mud, 15 cm below surface, 100 m W of NH-1	.18 (.14)
NH 6	Salt, 30 cm below surface, same area as NH-5	.04 (.01)
NH 7	Brine, from same area as NH-5	.18 (.14)

Complete analyses of samples of NH-1 (mud), NH-4 (salt) and NH-5 (mud), made by the GOA laboratories, are listed below. Values are in weight percent.

Analysis of mud, salt, and sand[1]

	NH-1	NH-4	NH-5
Acid insoluble	58.26	2.58	71.50
Ca	4.70	0.54	1.66
Mg	0.20	0.23	0.03
Al	0.79	0.05	0.68
K	0.30	0.17	0.17
Na	6.91	37.50	6.94
SO_4	13.23	2.59	6.71
Cl	11.95	56.50	10.70
CO_2	3.34	0.00	5.80
H_2O	2.00	0.37	1.22
Fe	1.15	0.11	1.24
Sum	100.89	100.48	94.73

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[1] There are inconsistencies in the way the analyses were reported to me, and the above may misrepresent the actual results obtained by the chemists. All were analyzed in duplicate, and I have used the results of the second analyses because the sums are better in two of the three examples.

Appendix E

Four areas were sampled by C. W. Sweetwood but not visited during this study because considered unfavorable. The analyses, by GOA Ministry of Mines and Industries, are listed below for the record.

Ab-i-Estada (lake, 130 km south-southwest of Ghazni, samples from northeast corner of lake)

Brine samples: 0.05 to 0.18 percent K_2O [1/]

Solid samples: 0.14 to 0.19 percent K_2O.

AE-2 (sample of black mud, below water level in stagnant pond above lake water level)

	Weight percent
Ca	5.42
Mg	1.79
Na	.78
K	.15
CO_2	5.64
SO_4	.82
Cl	.87
H_2O	.63
Fe	2.30
Al	1.62
Acid insoluble	67.80

[1/] Four analyses of water from Ab-i-Estada are listed by Főrstner (1973, table 4).

Daghal-i-Bashtu (small brackish lake 5 km south of Farah):

Solid crust: 0.00 percent K_2O

Average of two brines: 0.04 percent K_2O

Hamum-i-Puzak (large shallow lake 50 km north of Zarange northeast corner)

Salty salt on old lake above terraces, 300 m north of edge of lake.

	Weight percent
Ca	0.78
Mg	.02
Na	21.64
K	.17
CO_2	3.52
SO_4	6.93
Cl	32.75
H_2O	.59
Acid insoluble	37.50

Brine sample reported as 0.00 percent K_2O.

Hamun-i-Sabari (large shallow lake 75 km northwest of Zarange, sample near northeast corner)

Average of three solid samples: 0.18 percent K_2O

Sample of lake water: 0.00 percent K_2O